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ENERGY EFFICIENCY IN DOMESTIC APPLIANCES AND LIGHTING

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16-18 June, Berlin, Germany

VOLUME 3

Editors: Paolo BERTOLDI, Rita WERLE

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EEDAL'09 Proceedings
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Heating/Water Heating and CHP

Energy Services for Domestic Heating – Special Aspects of the Domestic Heating Oil Market

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Abstract

Domestic heating is key to achieving the European Union's commitment towards 20% energy savings by 2020. Liquid fuels, such as domestic heating oil, kerosene or bioliquids, currently provide energy for heating and domestic hot water for almost 20% of European households [1], [2].

The directive on energy end-use efficiency and energy services (2006/32/EC) [3], an important piece of EU legislation which could contribute up to 9.8% of energy savings by 2020[1], obliges energy distributors to offer energy services to their customers. The domestic heating oil market has some important differences, when compared to pipeline- or grid-bound energies, such as gas or electricity. One such difference is the high percentage of the heating oil market which is covered by small distributors, or those entities which may be defined by the term "small retail energy sales company", according to the directive[2].

Another important difference in the domestic heating oil market is the fact that normally there is no information available to the oil distributor on individuals' actual energy consumption figures. The consumer is free to change his or her domestic heating oil supplier as often as he or she wishes to do so. In addition, there is no direct correlation between sales and consumption, because the energy is stored at each consumer's home.

In spite of these difficulties, heating oil sales companies - together with the oil industry - have already successfully implemented several different measures to increase efficiency in the oil heating sector in a number of European countries.

The Challenge

Liquid fuels are expected to play an important role in Europe's future energy mix, in both the heating and transport sectors. A major user of energy, heating provides a very high potential for savings through better efficiency. Liquid fuels, such as domestic heating oil, kerosene or bioliquids, currently provide energy for heating and domestic hot water for almost 20% of European households, and comprise some of the most important alternative energy sources to gas, for domestic heating in Europe [1] [2]. As well as providing this crucial energy security aspect, the liquid heating fuels sector is also meeting the challenges of providing more sustainable solutions via further limiting greenhouse gas emissions, and making the required energy savings.

With the recently adopted 20-20-20 targets by EU Member States, achieving emissions reductions, increasing the share of renewable energies and accelerating energy savings are the three pillars of the current EU-wide policy framework in which Eurofuel[3] and its members have to operate. Considering the current state of the existing housing "parc" in Europe, the modernisation and improvement of heating installations in existing buildings represent some of the most effective ways of achieving energy savings.

Figure 1 (below) shows that a high share of the market is in existing buildings[4], where typically neither the building standard nor the heating equipment fulfils current energy efficiency standards. The oil heating market therefore has a high potential to reduce energy consumption and emissions, especially in existing buildings with very often a relatively large energy demand. The main market for heating oil

[1] European Commission Communication on "Energy Efficiency, Delivering the 20% Target" (COM(2008)772), 13 November 2008.
[2] Directive 2006/32/EC, Article 3 (r).
[3] „Eurofuel" is the abbreviated name of The European Heating Oil Association (see www.eurofuel.eu)
[4] Also see Reference [1], which (at p 6) estimates that the replacement market accounts for around 60% of boiler sales

in domestic heating is the single-family house sector, which can facilitate the undertaking of necessary heating system renovations.

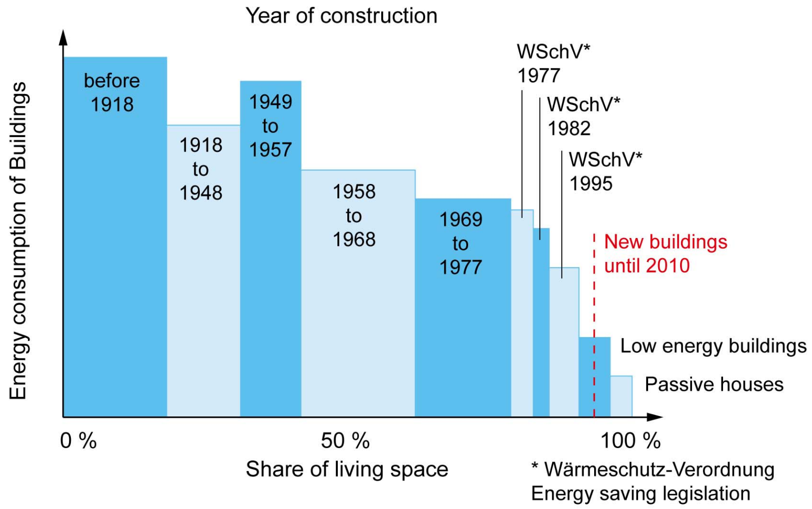


Fig. 1: Share of Living Space in Germany by Construction Date and Energy Standard of Building

Source: [4]

There are several different possibilities of reducing the primary energy demand of existing buildings (Fig. 2). Reducing energy demand by better insulation and/ or efficient heating technologies - including the integration of solar thermal energy - automatically results in an increase in the overall energy efficiency of the building, and lower energy costs for the consumer. Other possibilities for reducing the demand of fossil fuel (primary energy) include, inter alia, improving the efficiency of electricity generation, and reducing subsequent electricity distribution losses, or switching fuels; however, such measures do not automatically imply a reduction in energy costs, or an increase in the energy efficiency of a particular building.

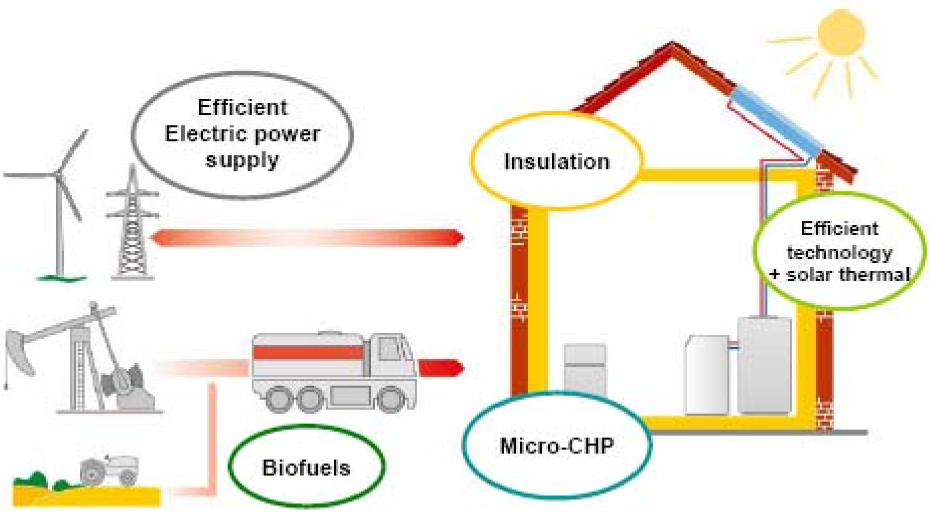


Fig. 2: Options for Reducing the Primary Energy Demand of Buildings (on a "Well to Chimney" Basis).

Graphic: IWO Germany

Theoretically, it is possible to reduce the energy demand of many existing buildings by some 50% to 70%, if the complete building is insulated to modern standards, and where modern efficient heating technologies are installed (e.g., condensing boilers, preferably with the integration of solar thermal equipment). Projects in many European countries have shown that the building's overall energy demand can be reduced to that of a new building. However, a major problem is the amount of investment which is needed to turn an outdated existing building into a new one (in energetic terms), [5].

For a single-family house the above building and heating system renovation costs can easily add up to between €50,000 and €100,000. Usually, modernising the heating system requires investments of between €5,000 and €20,000; a far higher percentage of the investment is often needed to improve the energy performance of the building envelope (walls, roof, windows, etc) [6].

Although the standard of new buildings can only be reached if both heating technology and insulation are improved, the installation of modern efficient heating equipment alone allows significant reductions in energy demand. Depending on the type of old boiler to be replaced, energy savings can reach around 30% to 50%. The latter higher figure is possible if a condensing boiler is installed with integration of solar thermal technology, for domestic hot water and domestic heating (Fig. 3).

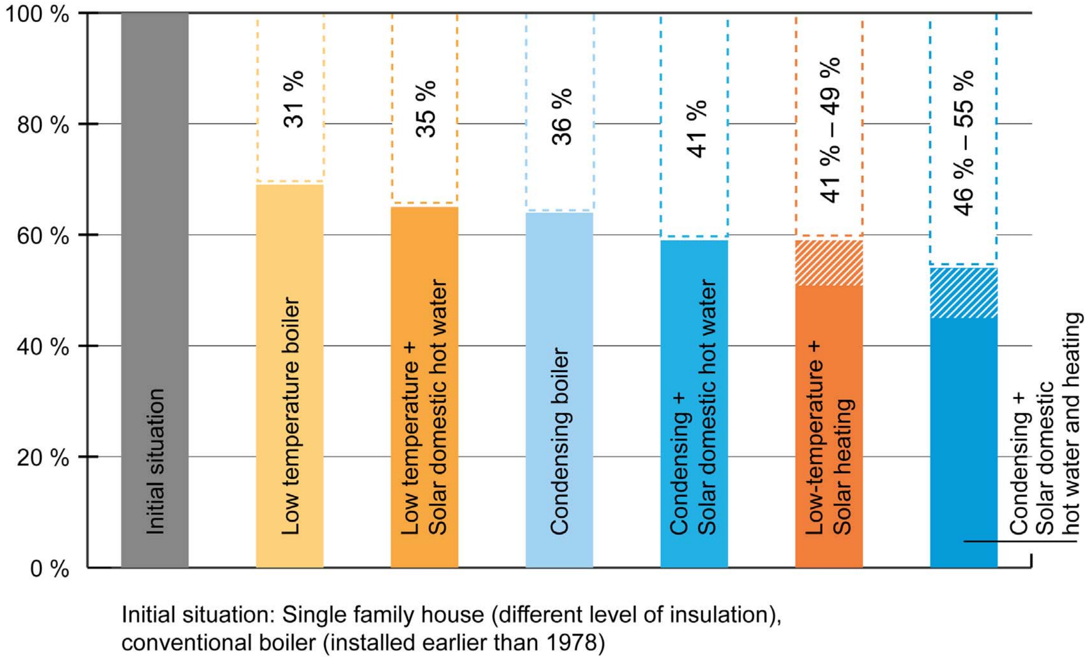


Fig. 3: Energy Savings Possible via Installation of Modern Heating Equipment (in accordance with DIN V 4701-12)

Source: [7]

The above arguments explain why oil companies, oil distributors, heating equipment manufacturers, trade associations and other stakeholders started initiatives in many European countries, with the aim of improving the energy efficiency of existing heating systems. The motivation behind these initiatives was to take advantage of the recognition that implementing and installing improved boiler technologies was relatively cost-effective, compared to other measures.

Energy Services in the Domestic Heating Oil Market

According to the directive on energy end-use efficiency and energy services (2006/32/EC) [3], energy distributors are obliged to offer energy services to their customers. The aim of the directive is to reduce energy end-use in the European Union by approximately nine percent by 2016, in comparison to the average consumption between the years 2001-2005. According to an estimate [*op cit,* footnote 1] from the European Commission, a thorough implementation of this directive could translate into 9.8% of energy savings by 2020, which is a substantial part of the overall 20% energy savings commitment made by the EU.

The characteristics of the EU's domestic heating oil (DHO) market (gasoil, kerosene and bioliquids) imply that there are some obstacles to overcome, in order to successfully implement the directive in this sector. The DHO market differs from grid-bound energies like gas or electricity, because a high percentage of the DHO market is covered by small distributors, or "small retail energy sales companies", according to Article 3 (r) of the directive. Another difference is the fact that normally the oil distributor cannot control the client's actual energy consumption. The consumer is free to change his or her supplier as often as s/he wishes to. Another complication of the DHO market, from the perspective of directive 2006/32/EC, is that there is no direct correlation between sales and consumption, because the energy (the volume of DHO in the oil tank) is stored at the consumer's property. Thus, it would be almost impossible for the individual oil distributor to detect the effect of the energy services which he has provided to the client.

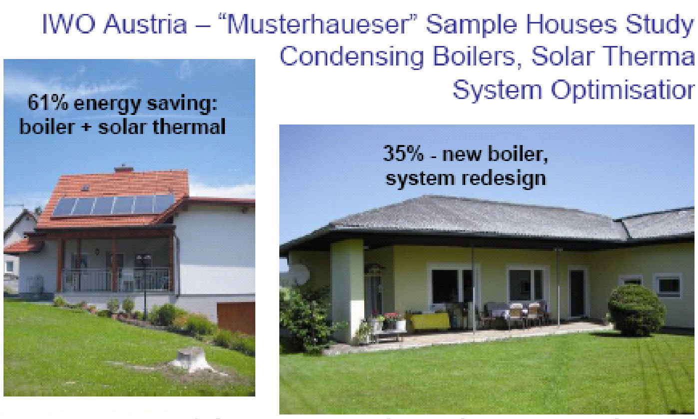
In spite of these difficulties, oil companies and their associations have successfully carried out information campaigns, and in some cases they have allocated funds from which incentives could be paid for, to promote the installation of higher efficiency heating equipment. These activities were, in many cases, carried out before the discussion began at EU level on the energy end-use efficiency and energy services directive. Such measures could therefore be regarded as "early actions", according to the detailed implementing measures for Member States, with respect to the directive.

Examples of Successful Energy Services in the Heating Oil Sector

Austria:

In Austria the situation is as follows: some 922,000 households utilise oil for heating, using approximately 750,000 oil boilers. In 2007, around 35% of all oil boilers had been in operation for more than 20 years. Only 2% of all oil boilers installed were condensing-type boilers, with the highest efficiency [8].

Although it is possible to realise significant energy savings with modern condensing boiler technology, consumers hesitate to modernise their outdated heating system. The Institute for Economic Oil Heating Austria (IWO-Austria) realised that the benefit of this technique was not sufficiently well known. Hence, IWO-Austria launched a long-term "sample houses" study to document the potential energy savings which could be realised via changing from an old boiler to a modern condensing boiler. In some houses involved in the study, other energy-saving measures, such as the installation of solar thermal systems, were carried out at the same time.



	Boiler Type		
Old: oil-fired, conventional	40 kW	29 kW	17 kW
New: oil-fired condensing	15.5 - 23.3 kW	16.8 kW	14 kW
	Annual DHO use		
Old system	4,500 l	2,500 l	2,970 l
New system	2,400 l	1,130 l	1,160 l
	Annual DHO & CO2 savings		
Domestic Heating Oil (DHO) reduction	2,100 l	1,370 l	1,810 l
CO_2 reduction	5.7 t	3.7 t	4.9 t
Energy saving	47%	55%	61%

Fig. 4: Results of the IWO-Austria Project "Musterhäuser" (Sample Houses)

Source: [8]

The consumption of heating oil in the houses monitored during the above "sample houses" study decreased by between 20% and 61%, after installation of the new heating equipment (see Fig. 4 examples). However, despite these very encouraging results, oil boiler sales have declined significantly in recent years in Austria. Consequently, the Austrian Oil Industry Association (Fachverband Mineralölindustrie), the Association of Oil Traders (Fachverband Energiehandel) and the Austrian Institute for Economic Oil Heating (IWO-Austria) have put measures in place to commence a substantial subsidy programme to facilitate the installation of modern oil condensing boilers in 2009.

Finland: "HÖYLÄ III"

In Finland the so-called HÖYLÄ voluntary agreement recently entered its third phase [9]. HÖYLÄ is an energy efficiency agreement, concerning the distribution of liquid heating and transport fuels, and has been entered into by the oil industry - represented by the Finnish Oil and Gas Federation - and Finnish national administrative bodies. The activities of HÖYLÄ are financed by the Finnish oil companies, and are also partly subsidised by the national government.

The objectives for the oil heating sector are:

- To promote energy efficiency measures
- To encourage the use of biofuels/ bioliquids/ renewables
- To support implementation of relevant EU directives.

The measures should affect at least 80% of the sector, and by these means, they are supposed to contribute substantially to the mandated 9% energy savings during the 2008-2016 period. Buildings and especially oil heating systems should be maintained in an optimal condition by the promotion of regular inspections. The training and certification of technicians, in cooperation with the Finnish Oil and Gas Heating Association, comprises part of the programme.

The replacement of 10,000 boilers per year by modern systems will be promoted. In 2016, 20% of the boilers replaced should be combined with solar thermal systems. From 2009 on, bioliquids will be gradually introduced - via blending – into domestic heating oil (from a 2% [B2] blend in 2009, to a 10% [B10] blend in 2016) [9].

Information resources for consumers are being set up, addressing energy saving possibilities. These will comprise a dedicated magazine, together with internet-based resources. Most of the activities will be fulfilled by the Oil Industry Service Centre, a company which is owned by the Finnish Oil and Gas Federation.

France: "Ecofioul"

The association "Ecofioul" was created in 2006 by the oil industry, in conjunction with several related trade and professional associations. "Ecofioul" is legally based on French national energy-saving obligation (La loi d'orientation de la politique énergétique, du 13 juillet 2005), i.e., predating the implementation requirements of the directive on energy end-use services. French heating oil distributors become members of this association via a subscription fee. Approximately 90 % of the subscription money is used to promote energy-saving measures [10].

If a domestic heating client wishes to realise one of the accepted energy-saving measures, the oil distributor can give his client a subsidy. In this way, the oil heating industry and associated stakeholders achieved the renewal of 62,000 boilers up to the end of 2008 [10]. In the first two and a half years of the Ecofioul association's operation (01/07/2006 – 31/12/2008), 84% of the kWh saved resulted from boiler renewals, 10% from optimisation of controls, and the remainder came from insulation, and via the hybrid integration of renewable energies. The Ecofioul project has already fulfilled 80% of the national energy saving obligation allocated to domestic heating oil [10].

The Ecofioul programme is partly supported by the French government, which presently gives tax reductions of 25% for the installation of a condensing boiler, and 50% tax reductions for the additional costs when integrating solar thermal technology [10].

Germany:

Already in 1995 the associations of the German oil industry declared that they were going to carry out many projects to reduce oil consumption in the domestic heating sector [11]. This voluntary agreement has comprised an important part of the German industry's climate protection programme. The objective of the German voluntary agreement is to increase the average annual efficiency of all oil heating systems installed from 68% in 1990, to 86%-88 % in 2012 [11].

In 2007 this programme was enhanced by a joint memorandum of understanding between the German Federal Government and the oil industry, which covered energy conservation and reduction of CO_2 emissions, via the widespread market introduction of low sulphur (50 ppm S) domestic heating oil, a fuel which facilitates the uptake of oil-fired condensing boiler technology. [12]

From 2008 onwards, a widespread, demand-based supply of low sulphur heating oil was guaranteed by German oil dealers, via the above agreement. Today, more than 1,000 oil dealers offer low sulphur domestic heating oil to their customers [13].

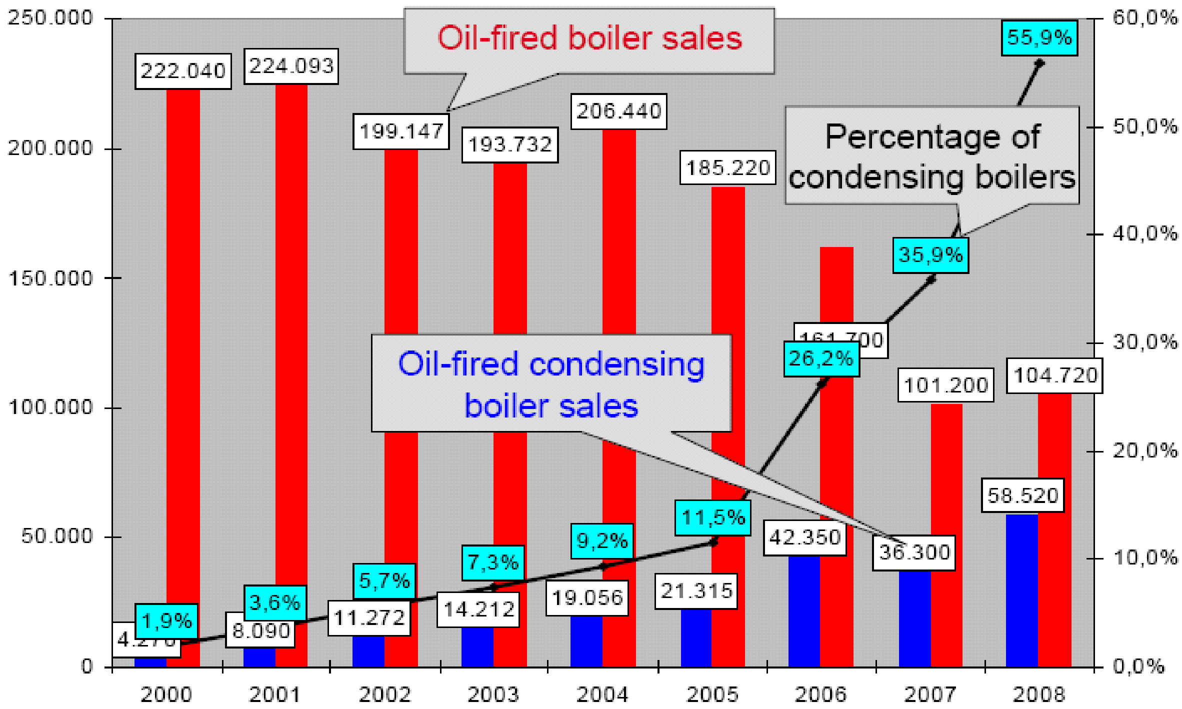


Fig. 5: Development of Oil-fired Condensing Boiler Sales in Germany, 2000-2008

Source: [14]

The introduction of low sulphur domestic heating oil helped to convert the modernisation market to condensing technology. In 2008 the market share of oil-fired condensing boilers exceeded 50% of new oil-fired boiler sales, developing from less than 10% of new oil-fired equipment sales in 2004 (Fig. 5).

This tendency to opt for more efficient boilers was supported by the widespread installation of solar thermal collectors, in conjunction with boiler renewal. In 2008, approximately 50% of oil boilers installed were combined with solar thermal technology [14].

The organisation responsible for co-ordinating the oil industry's measures in support of best practice, oil-fired condensing boiler technology, in combination with solar thermal installations, has been the Institute for Economic Oil Heating (IWO), especially with regard to:

- direct consumer communication, and information about the energy-saving potential of modern oil-fired, condensing technology and the additional use of solar thermal energy
- strengthening of information provision, and motivating market partners (e.g., the heating industry, heating installers, etc) toward taking advantage within their customer base of the modernisation potential of old heating systems, through the installation of condensing technology.

All these activities have led to an increase in annual efficiency, which has fulfilled the self-commitment of the German oil industry since 2001 (Fig. 6).

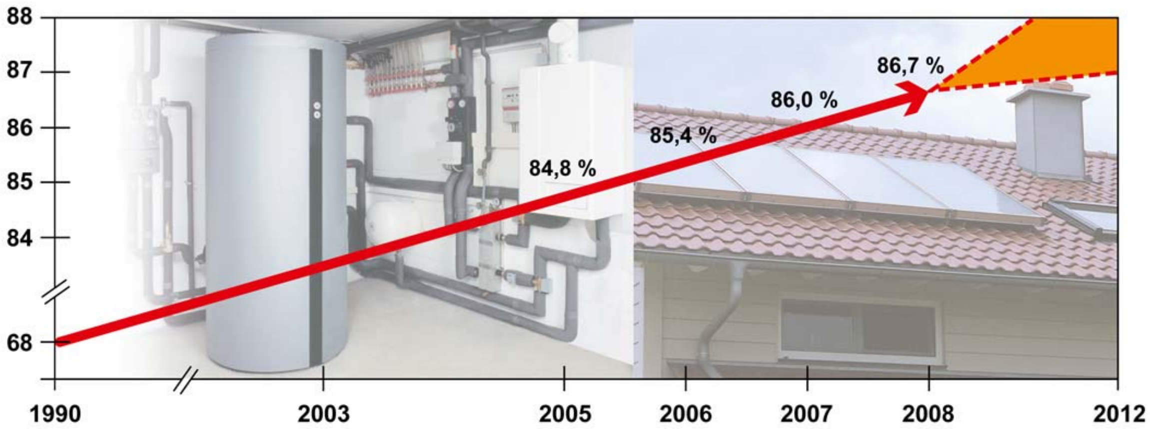


Fig. 6: Increase of Average Calculated Annual Efficiency of Oil Heating Equipment in Germany

Source: [15]

Summary and Outlook

Although the situation for the domestic heating oil market differs significantly from grid-bound energies, oil associations and oil dealers have already succeeded in commencing information and promotion programmes to increase the efficiency of oil heating in many European countries.

In most cases the activities and campaigns concentrate on boiler renewal, preferably with condensing boilers, and in an increasing manner on the additional installation of solar thermal collectors. A cost-effective combination of highly-efficient heating technology based on conventional fuels, mixed with renewable energies and improved insulation of buildings, will be necessary to fulfil future requirements in the buildings sector.

Bioliquids will play an important role over the long term, as bioliquids can be stored – just as with conventional heating oil. This is an important feature, especially in the domestic heating market, where there is a peak demand in winter time. Fig. 7 illustrates an overview of the role of bioliquids and other renewable energy sources, in combination with increased energy efficiency measures.

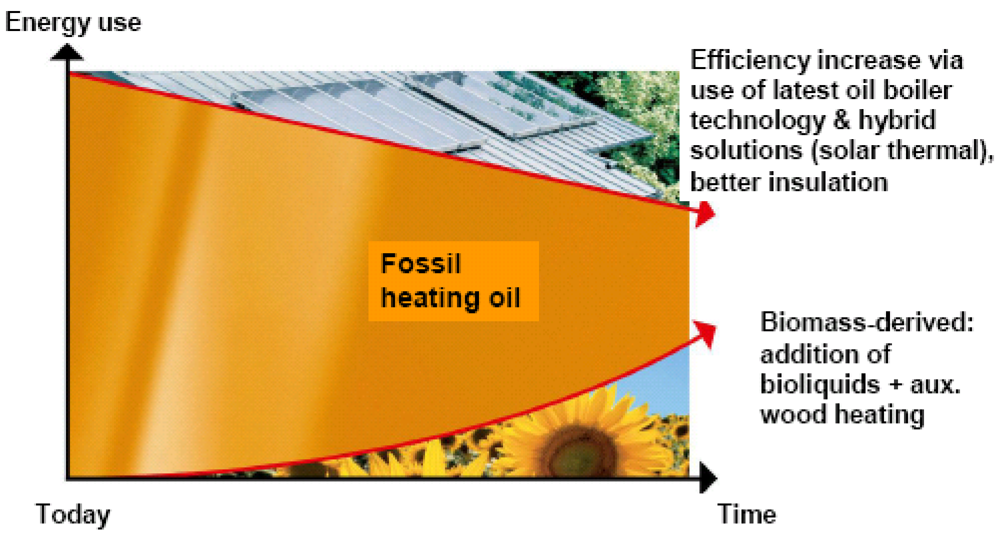


Fig. 7: Reduction of Fossil Heating Oil Demand via Energy Efficiency and Hybrid Combinations of Renewables, including Bioliquids

Source: Adapted from [16]

A very promising system for the combination of fossil and renewable heating energies is the so-called “Hybrid Heating System”, comprising a combination of an oil condensing boiler, solar thermal technology and a wood-burning fireplace with a heat exchanging device. This system enables the connection of highly efficient conventional heating technology with three kinds of renewable energies. Several distinguished heating manufacturers presented such systems this year at the world's leading trade fair for building, energy, air-conditioning technology and renewable energies, the ISH in Frankfurt, Germany (Fig. 8).

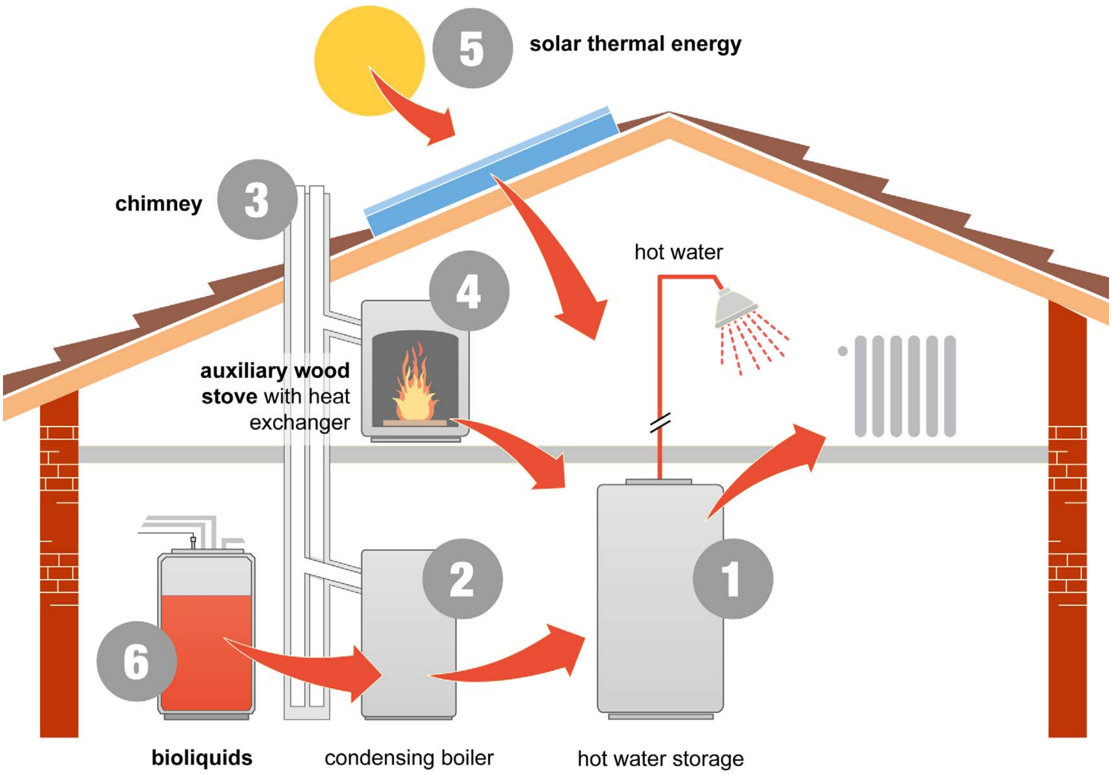


Fig. 8: Hybrid Heating Systems, with Three Types of Renewable Energy.

Graphic: IWO Germany

The core of the hybrid heating system is a well-insulated hot water tank, which stores the heat from the different heating appliances. During the summer months the hot water requirement can be almost completely satisfied by the solar thermal system alone. Throughout the colder seasons the wood-burning fireplace supports the heating of the whole building. The fireplace should be equipped with a heat exchanging device, whereby the heat of the log fire can be fed into the hot water store. It is only when the solar heating and fireplace systems fail to deliver enough warmth that the oil-fired condensing boiler automatically activates itself, and starts to produce additional heat.

An option to additionally integrate a third renewable energy together with solar and wood is to operate the condensing boiler with a bioliquid/ mineral oil blend. Sustainably-produced bioliquids can help to reduce the primary energy demand of the overall heating system, as well as CO_2 emissions, and are another means of assisting the conservation of valuable fossil energy resources.

References

[1] BRG Consult. *The Boiler and Heating System Markets in the European Union.* Study to prepare a revision of Directive 92/42/EEC on Efficiency Requirements and Energy Performance Labelling for New Hot-Water Boilers, presented to DG TREN (Tender No. TREN/D1/31-2005), Final Report, November 2006. Available from DG TREN, Directorate D.

[2] VHK. *Preparatory Study on Eco-design of Boilers. Task 2 (FINAL), Market Analysis, September 2007.* Available at: http://www.ecoboiler.org/public/ecoboiler_task2_final.pdf

[3] European Commission. Commission Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC, Official Journal L114, 27.04.2006, pp.64-85. Can be downloaded at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0064:0085:EN:PDF

[4] Dr. Burkhard Schulze Darup. *Energetische Gebäudesanierung mit Faktor 10 (Energetic Building-Refurbishment with Coefficient 10),* Guest contribution at homepage of energy agency of North Rhine-Westphalia. Available at: http://www.ea-nrw.de/_database/_data/datainfopool/darup_gebaeudesanierung.pdf

[5] Deutsche Energie-Agentur GmbH (dena) – the German Energy Agency. *dena-Modellvorhaben: Niedrigenergiehaus im Bestand („Pilot Project: Efficient Homes"), 2005.* Available at: http://www.zukunft-haus.info/de/projekte/niedrigenergiehaus-im-bestand.html

[6] IWO Germany (Institut für wirtschaftliche Oelheizung). *Aktion Energie-Gewinner (Campaign „Energy-Winners), 2008.* Average costs for refurbishment to energetic standard of new buildings, calculated within energy consulting work performed for "Energy-Winners".

[7] IWO Germany calculation using Software *Hottgenroth Energieberater,* based upon German standards DIN V 4701-10 and DIN V 4701-12.

[8] IWO Austria (Institut fuer Wirtschaftliche Oelheizung). *Musteranlagen: Grosse Einsparungen durch Oel-Brenwerttechnik ("Large Savings via Oil-Fired Condensing Technology"), 2008.* Available at: http://www.iwo-austria.com/fileadmin/user_upload/pdf_2008/IWO-Musterhausstudie_Folder.pdf

[9] Ministry of Trade and Industry (now Ministry of Labour and the Economy), Ministry of the Environment, Finnish Oil and Gas Federation, Finnish Oil and Gas Heating Association, Finnish Petrol and Traffic Service Retailers Organisation SBL, and participating Companies. *Höylä III – Energy-Efficiency Agreement on the Distribution of Liquid Heating and Transport Fuels,* DNo 22/804/2007 MoTI, December 2007, Helsinki, Finland.

Finnish original citation: Kauppa- ja teollisuusministeriö (nyk. Työ- ja elinkeinoministeriö), Ympäristöministeriö, Öljy- ja Kaasualan Keskusliitto, Öljy ja Kaasulämmitys Yhdistys, Suomen Bensiinikauppiaitten ja Liikennepalvelualojen Liitto SBL sekä lämmitys- ja liikennepolttonesteitä toimittavat yhtiöt: *Lämmitys- ja liikennepolttonesteiden jakelutoiminnan energiatehokkuussopimus – HÖYLÄ III,* Helsinki 4.12.2007 Dnro 22/804/2007 KTM.

[10] Pierrick Rabillon, Président, Chauffage Fioul: *private communication, April 2009*. Update on Ecofioul's progress in France.

[11] Mineralölwirtschaftverband e.V. (MWV, German Mineral Oil Trade Association), Institut für wirtschaftliche Oelheizung e.V. (IWO, German Institute for Economic Oil-Heating), Gesamtverband des Deutschen Brennstoff- und Mineralölhandels e.V. (gdbm, German Association of Fuel and Mineral Oil Trade), Außenhandelsverband für Mineralöl und Energie e.V. (AFM + E, German External Trade Association for Mineral Oil and Energy). *Zweite Klimaschutzerklärung der Mineralölwirtschaft für den Wärmemarkt (Second Declaration for Climate Protection of the Mineral Oil Industry for the German Domestic Heating Market)*, September 2001, Hamburg/Berlin, Germany.
Available at: http://www.iwo.de/outputFileData/67790/kse_waermemarkt.pdf

[12] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (German Ministry for Environment, Nature Conservation and Reactor Security), Mineralölwirtschaftverband e.V. (MWV, German Mineral Oil Trade Association), Interessengemeinschaft mittelständischer Mineralölverbände e.V. (German Joint Venture of Medium-Sized Mineral Oil Associations), Gesamtverband des Deutschen Brennstoff- und Mineralölhandels e.V. (gdbm, German Association of Fuel and Mineral Oil Trade), Institut für wirtschaftliche Oelheizung e.V. (IWO, German Institute for Economic Oil-Heating). *Gemeinsame Erklärung von Bundesregierung und Mineralölwirtschaft „Energieeinsparung und CO2-Minderung durch breite Markteinführung von schwefelarmem Heizöl und Öl-Brennwerttechnik" (Common Declaration of German Government and Mineral Oil Industry „Energy Conservation and CO2 Decrease by Widespread Market Penetration of Low Sulphur Heating Oil and Oil Condensing Boiler Technology"),* January 2007, Berlin, Germany.
Available at: http://www.iwo.de/outputFileData/85150/701-15-Erkl%C3%A4rung-Endg.doc.pdf

[13] Expert Database, available at: http://www.schwefelarmes-heizoel.de

[14] Bundesindustrieverband Deutschland Haus- Energie- und Umwelttechnik e.V. (BDH, German Industry Association for Building, Energy and Environmental Technology). *BDH Sales Statistics 2008.*

[15] IWO-Calculation for *Second Declaration for Climate Protection of the Mineral Oil Industry for the German Domestic Heating Market,* based upon data regarding properties of oil heating systems from the Zentralinnungsverband des Schornsteinfegerhandwerks (ZIV, German Association of Chimney Sweeps), sales statistics of the Bundesindustrieverband Deutschland Haus- Energie- und Umwelttechnik e.V. (BDH, German Industry Association for Building, Energy and Environmental Technology), statistics about new buildings from the Statistisches Bundesamt Deutschland (German Federal Office of Statistics), heating system census of Dr. Spence International, and sales statistics of the Bundesverband der Solarwirtschaft (BSW, German Solar Industry Association).

[16] http://www.eurofuel.eu/eng/eurofuel_brochure.pdf

The use of heat pumps in the renovation of buildings

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Abstract

The use of heat pumps for room heating and the heating of tap water can contribute significantly to the reduction of CO_2 emissions and primary energy consumption. According to the German standard DIN 4701-10 air to water heat pumps save 18 % and ground source heat pumps save 36 % of primary energy in comparison to condensing boilers, if the heat is transferred to the room by a floor heating system.

The efficiency of heat pumps depends strongly on the flow temperature of the heating water. The lower the flow temperature is, the higher is the efficiency and subsequently the seasonal performance factor. The measures that can be taken to ensure low flow temperatures in the renovation of buildings are the reduction of the heat losses of the building and the increase of heating surfaces. For the energy efficient use of heat pumps the maximum flow temperature should be 55°C or less.

A tendency in R&D activities is to increase the flow temperatures that can be reached, mainly to allow the preparation of domestic hot water at higher temperatures. A possibility to allow flow temperatures of approximately 65°C with the refrigerant R407C is the intermediate vapour injection into the compressor during the compression process. With a two stage compression with an intermediate inter-cooling even flow temperatures of up to 75°C can be reached.

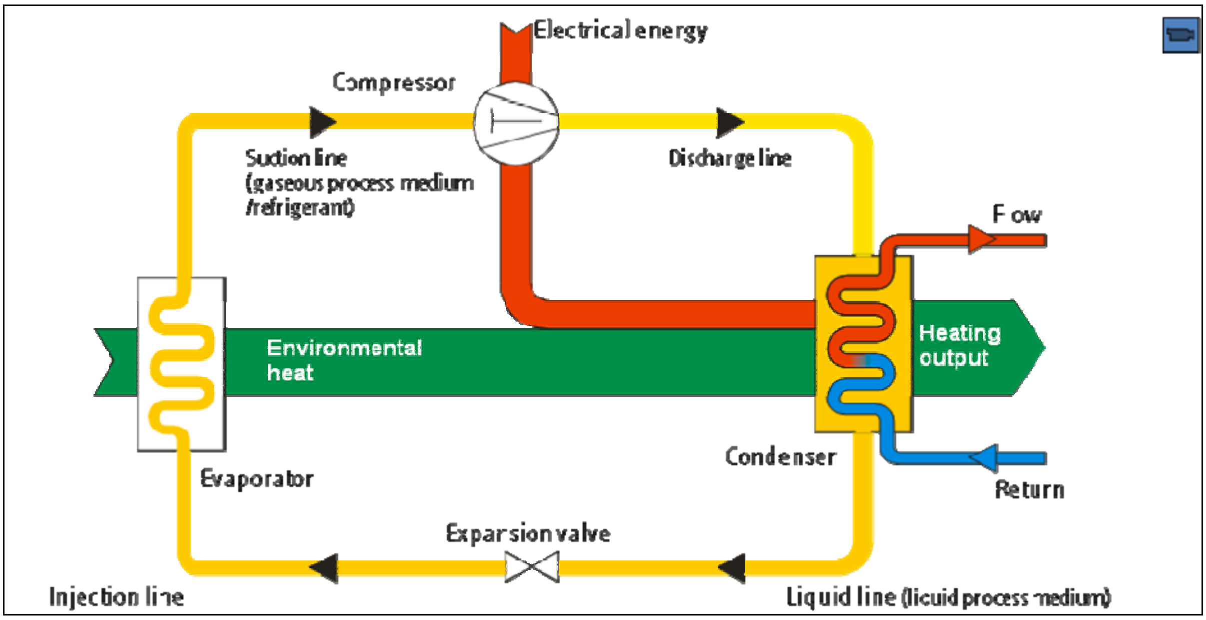
The continuous control of the heating capacity of heat pumps with inverters allows the adjustment of the heating capacity of the heat pump to the momentary heating demand of the building.

Because of the increase of energy costs during the last years the use of heat pumps in renovated buildings is today economical.

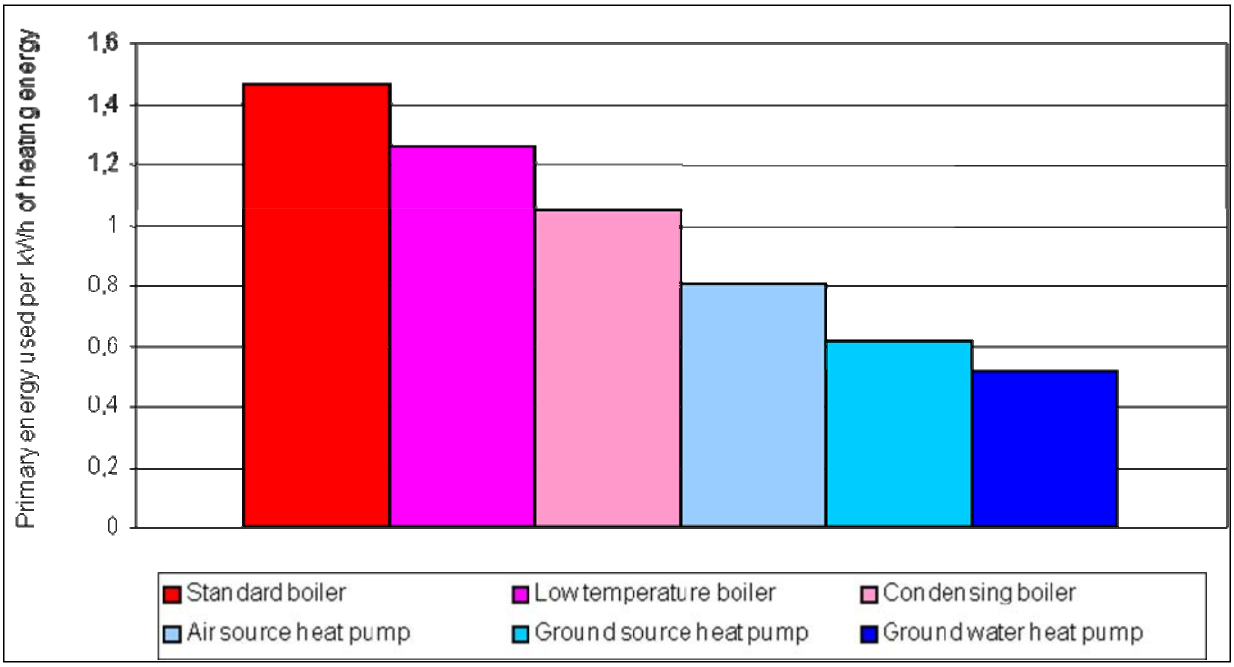
Benefits for the environment

The use of heat pumps for room heating and the heating of tap water can contribute significantly to the reduction of CO_2 emissions and primary energy consumption.

Heat pumps allow the use of geothermal or aero thermal energy for the purpose of space heating or domestic hot water production by lifting the energy from the environment to a useful temperature level. The evaporating refrigerant in the evaporator of the heat pump extracts heat from the geothermal or aero thermal heat source. The compressor of the heat pump compresses the refrigerant to a higher pressure and temperature level. In the condenser the refrigerant rejects the heat from the environmental heat source plus the energy that is necessary to drive the compressor to the heat sink, for example the heating water, while being liquefied. The refrigerant cycle is closed by throttling the refrigerant to the pressure in the evaporator via an expansion device. Typically a heat pump uses 2 to 4 parts of geothermal or aero thermal heat plus one part of electrical energy to drive the compressor to produce 3 to 5 parts of heating energy.



Working principle of a heat pump



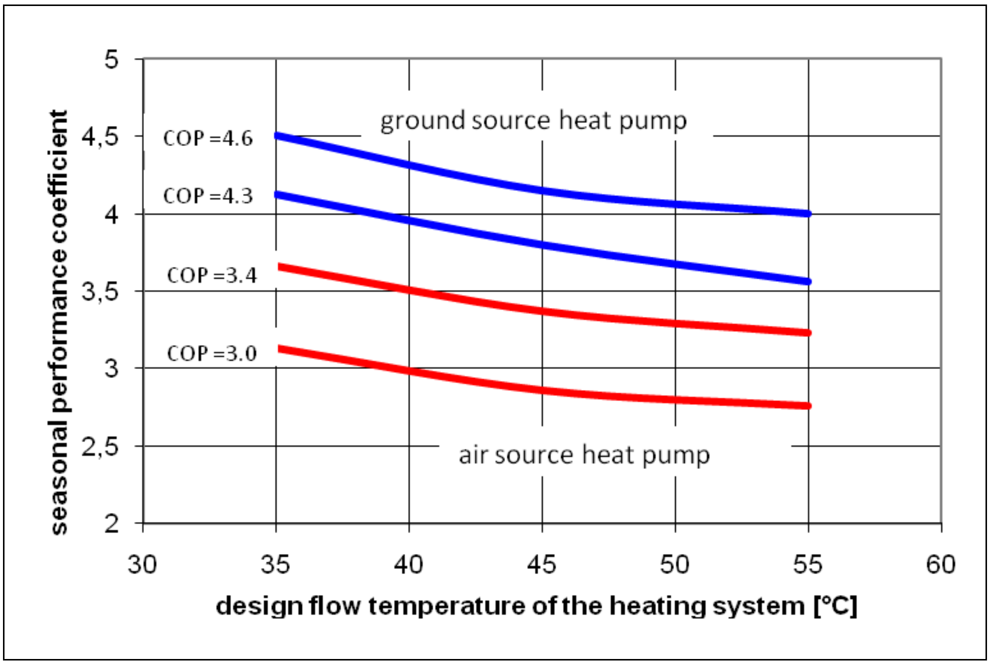
Primary energy needed for the production of heat

According to the German standard DIN 4701-10 [1] air source heat pumps save 18 % and ground source heat pumps save 36 % of primary energy in comparison to condensing boilers, if the heat is transferred to the room by a floor heating system. Thus the use of heat pumps in new built houses is by now very common in northern European countries. The market share of heat pumps in the sector of new detached houses is somewhere between 90 % in Sweden and 20 % in Germany.

In the renovation business up to now heat pumps are far less common. Nevertheless, because of the high energy demand of old buildings, the potential savings of energy and CO_2 in the renovation of buildings are even bigger than in the sector of new built houses.

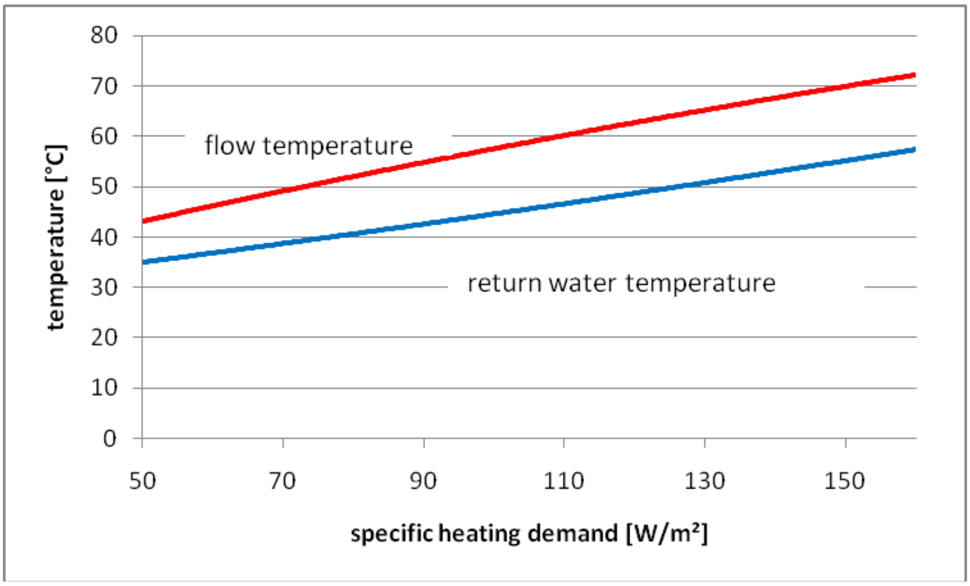
Boundary conditions for the use of heat pumps in renovated buildings

The efficiency of heat pumps depends strongly on the flow temperature of the heating water. The lower the flow temperature is, the higher is the efficiency and subsequently the seasonal performance factor of the heat pump. The measures that can be taken to ensure low flow temperatures in the renovation of buildings are the reduction of the heat losses of the building and the increase of heating surfaces. For the energy efficient use of heat pumps the maximum flow temperature should be 55°C or less.



Dependency of the seasonal performance coefficient of heat pumps from the flow temperature of the heating system

The reduction of the heat losses is something that should be done anyhow to improve the quality of the building and the comfort of living. Appropriate ways to achieve it are: The insulation of the roof, the ground plate and the outside walls and the replacement of the windows by modern 2- or 3-glazing windows. Apart from the reduction of the necessary flow temperature the reduction of heat losses also results in a reduced heating demand and thus diminishes the necessary investment for the heat pump and the heat source.



Dependency of the flow and return temperature of a heating system from the specific heating demand of a building

The increase of the heating surface area may be necessary especially if radiators are used for the rejection of the heat. To reduce the flow temperature from 70°C to 55°C roughly twice the heating surface is needed.

The system for warm tap water currently used in the house that is to be renovated has to be checked. A decentralised electrical heating of the tap water in many cases need not be changed because it results in acceptable energy efficiency due to the reduction of storage, distribution and circulation losses that compensate the poor energy efficiency of the direct electrical heating of the tap water. If a central heating of the tap water is applied in the house in the majority of cases the indirectly heated tank will have to be replaced by a tank with a bigger heat exchanger if a heat pump shall be used in the renovation.

The selection of the size of a heat pump can be done calculating the heating demand of the building according to EN 12831 [2] and adding 0.2 kW per person for the production of domestic hot water. If the electricity of the heat pump can be cut out by the utility company, as it is done in Germany to allow lower fees for the use of the electrical grid, than the necessary heating capacity of the heat pump should be multiplied by a factor of 1.2.

If only the oil or gas consumption of the building that shall be renovated are known the necessary heating capacity of the heat pump can roughly be calculated as

$$\Phi_{HL} = \frac{oil\,consumption\left[{}^{l}\!/_{a}\right]}{230\ {}^{l}\!/_{(a \cdot kW)}}\,in\,[kW] \qquad \text{equation 1}$$

$$\Phi_{HL} = \frac{gas\,consumption\left[{}^{m^3}\!/_{a}\right]}{230\,{}^{m^3}\!/_{(a \cdot kW)}}\,in\,[kW] \qquad \text{equation 2}$$

Future development of heat pumps

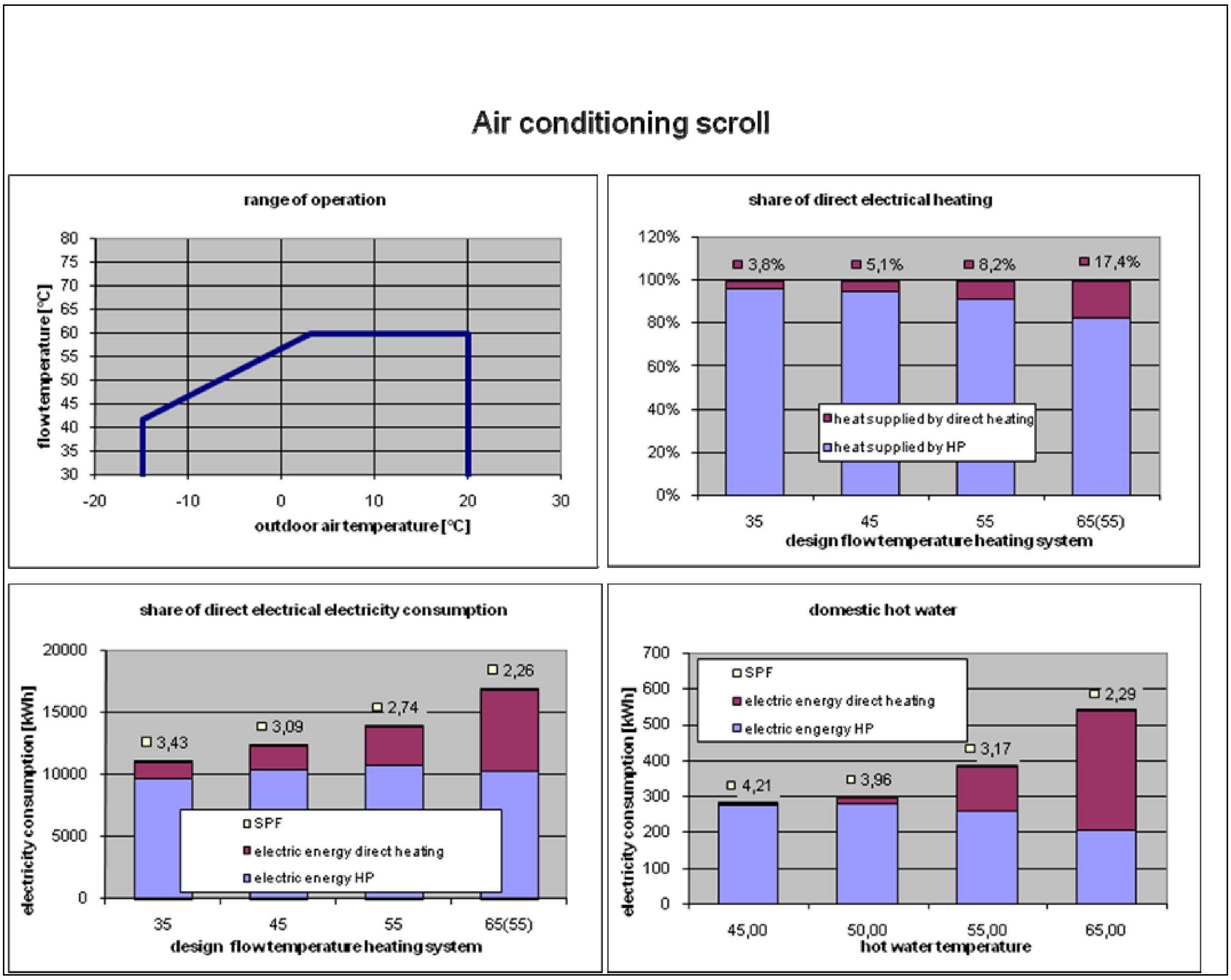
The importance of the renovation market has been understood by the majority of heat pump producers. Because of the high heating demands of renovation buildings bigger heat pumps have been developed and are rapidly gaining market share. Air to water heat pumps have become very popular for the renovation of buildings because the overall investment is significantly lower than for a ground source heat pump including the heat source and because the installation of air to water heat pumps is quite easy because there is no need for a costly and space consuming heat source installation. Nevertheless, air source heat pumps have two significant disadvantages:

1. The possible flow temperature of the heating water is limited, especially at low outdoor air temperatures, when it is needed and

2. The lower the outdoor air temperature is, the lower are the heating capacity and the COP of the heat pump.

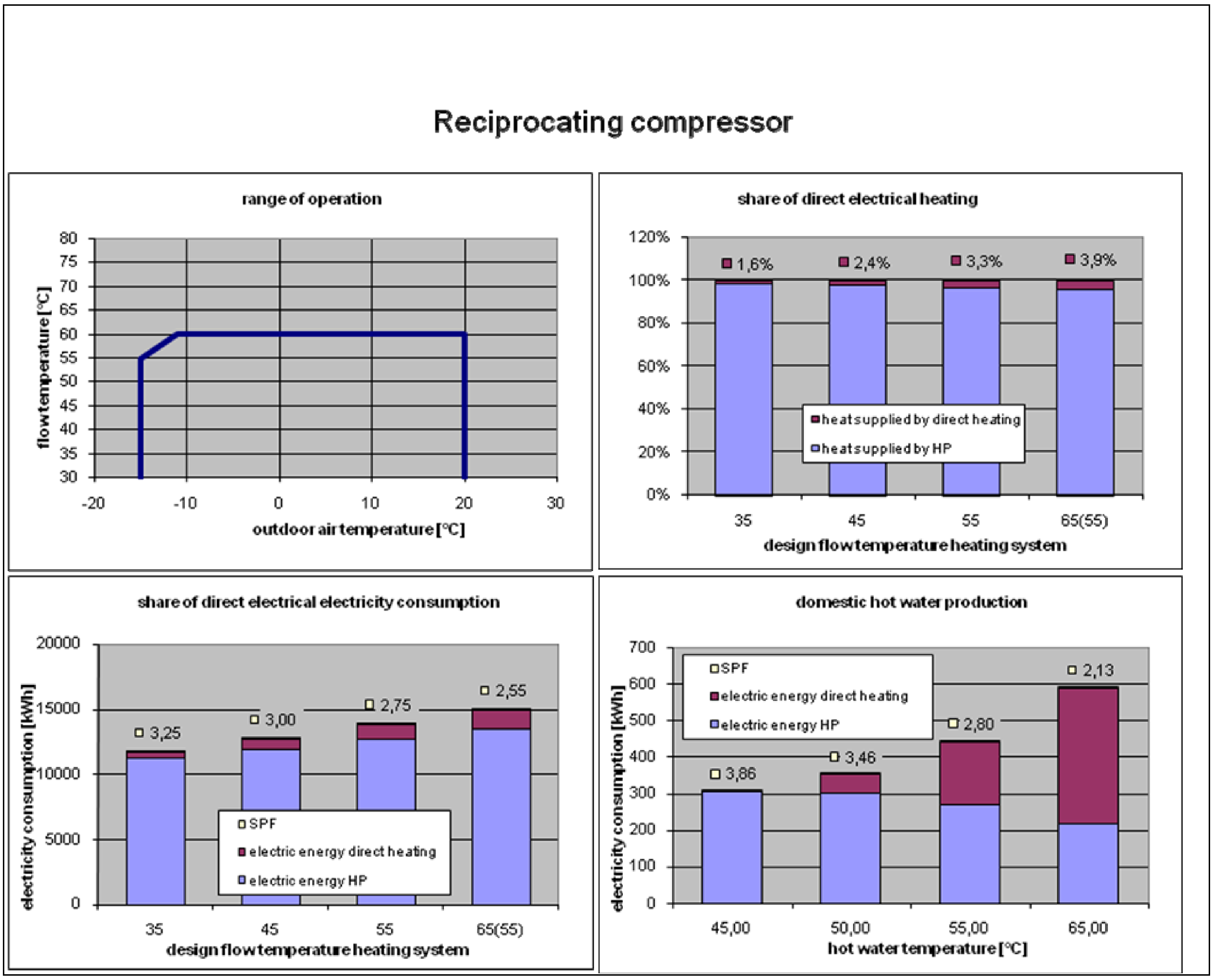
Thus a lot of R&D effort is currently directed towards the improvement of the characteristic of the heating capacity and the efficiency of air source heat pumps. The use of CO_2 as refrigerant allows reaching flow temperatures of 75°C or even more. Using counter flow heat exchangers for the preparation of domestic hot water high water temperatures can be reached with a good COP, because the COP of CO_2 heat pumps depends mainly on a low return water temperature while it is not very sensitive as far as the flow temperature is concerned. Unfortunately the heating-COP of CO_2 heat pumps up to now is around 20 % below the COP of HFC heat pumps under comparable conditions. Thus the use of CO_2 heat pumps is currently restricted to new built houses where the energy demand for the domestic hot water production is in the same range as the heating demand. In these houses CO_2 heat pumps are a good solution with a high seasonal performance coefficient and additional advantages as being very compact and having a low noise emission.

Air source heat pumps for the renovation market can be improved by optimizing the compression of the HFC refrigerant. Air conditioning scroll compressors, that are widely used for air source heat pumps have quite a high heating capacity at low outdoor air temperatures but can only reach very limited flow temperatures when the outdoor air temperature is low. In renovated buildings with radiators as a heating system that results in a poor seasonal performance coefficient because the heat pump has to be switched off at low outdoor air temperatures and the heat must be supplied by a second heating system, for example an electric boiler. This type of heat pump operation is called bivalent alternative, because either the heat pump or the second boiler is operating.



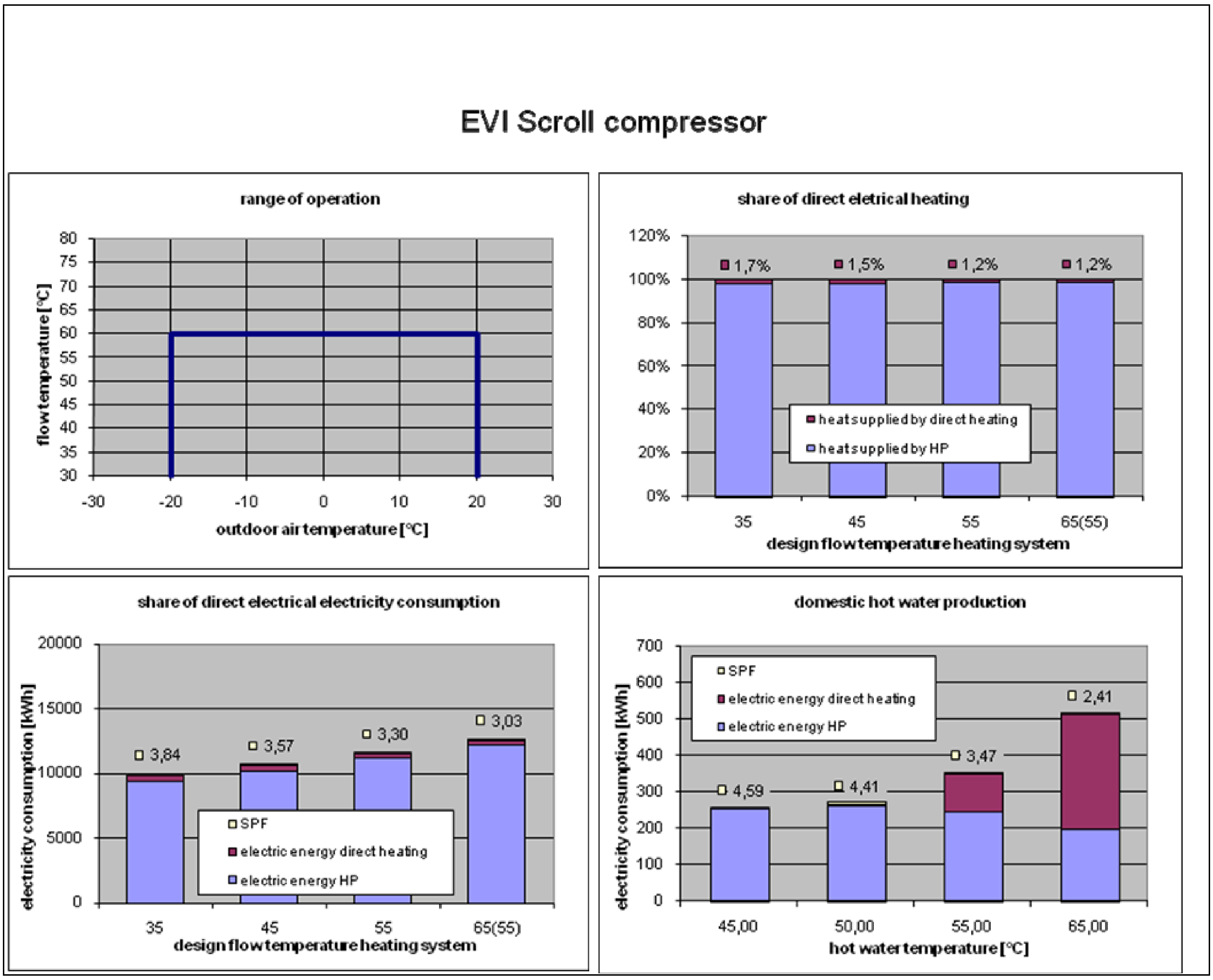
Characteristic data air conditioning scroll compressor

Reciprocating compressors allow higher flow temperatures at low outdoor air temperatures than air conditioning scroll compressors. But they have a low heating capacity if the outdoor air temperature is low, so that a second heating system, for example an electric boiler, is needed to supply part of the heat needed by the building. This type of heat pump operation is called bivalent parallel, because the heat pump continues running together with the second heating system.



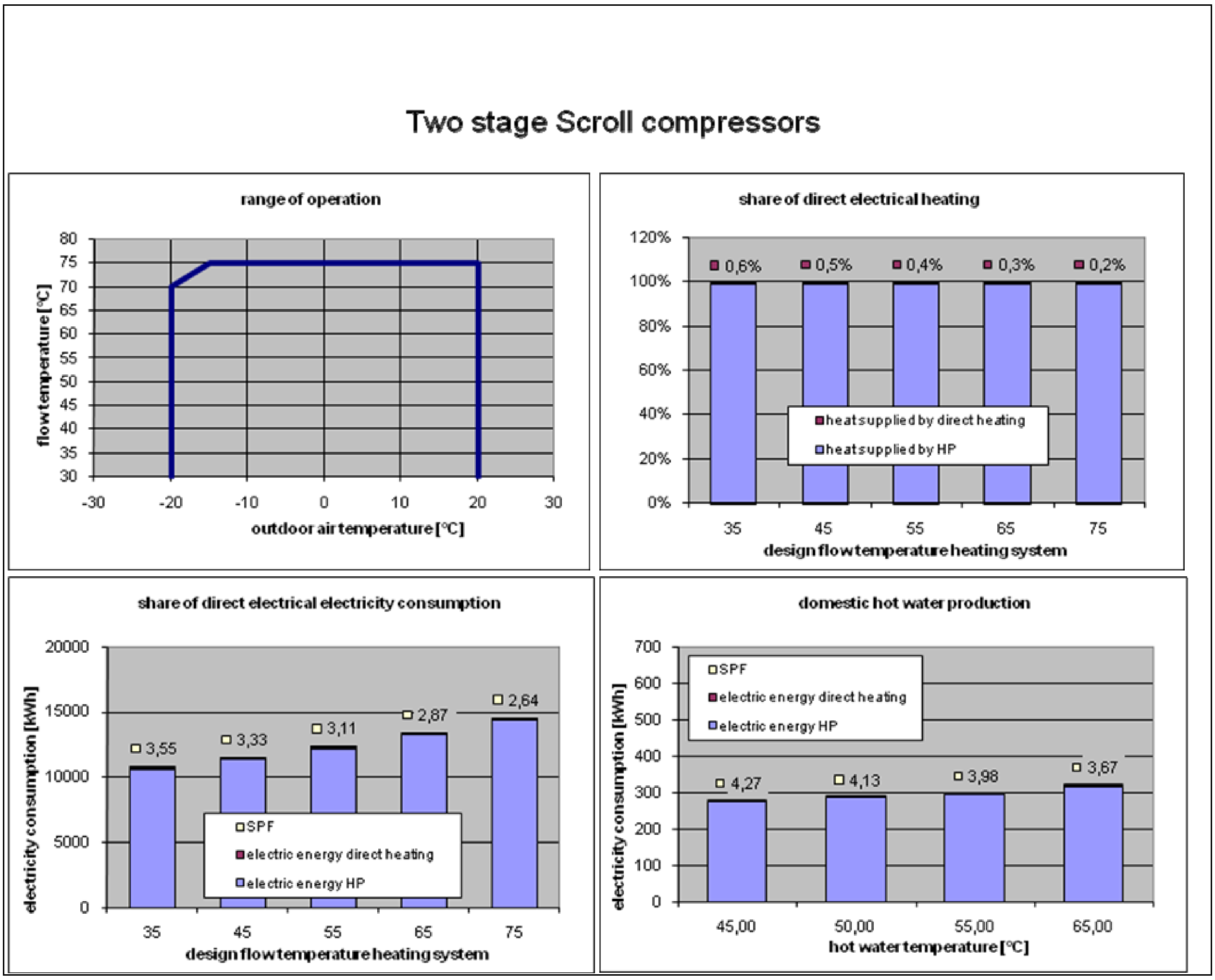
Characteristic data reciprocating compressor

Scroll compressors with an intermediate vapor injection (known as EVI compressors) can reach quite a high flow temperature and a high heating capacity at low outdoor air temperatures. They can be used for most heating systems with radiators and allow a high seasonal performance coefficient. Only if very high flow temperatures are necessary they need an additional electrical boiler. Air source heat pumps with a scroll compressor with intermediate vapor injection are state of the art renovation heat pumps. The air source heat pump in the comparison of different heating systems further down in this paper uses an EVI scroll compressor.



Characteristic data EVI scroll compressor

All the needs of radiator heating systems can be fulfilled by using a two stage compression process with an intermediate cooling of the compressed vapor between the two compression stages by injecting vapor. A heat pump with a two stage compression cycle using the refrigerant R407C can reach flow temperatures up to 75°C. Thus domestic hot water temperatures of 65°C can be reached with the heat pump. Moreover a two stage compression air source heat pump can operate as a monovalent heat pump without any backup heater, which improves the seasonal performance coefficient in comparison to other air source heat pumps especially if high flow temperatures are necessary for the heating system.



Characteristic data two stage scroll compressors

Another tendency in R&D activities is the increasing use of inverter driven compressors resulting in modulating heat pumps. Obviously the combination of a refrigeration cycle with two stage scroll compressors and inverter driven compressors results in a nearly perfect renovation air source heat pump, because the heating capacity of such a heat pump can match the heating demand of a building exactly under most conditions. Apart from saving the installation space needed for a buffer tank for on/off heat pumps such a modulating heat pump has a SPF that is approximately 0.4 higher than that of conventional heat pumps because the heat losses from the buffer, the mixing of temperatures within the buffer, the energy input for an additional circulation pump and the losses due to flow temperature fluctuations are avoided.

Economical aspects of the use of heat pumps in the renovation business

In the renovation of buildings heat pumps are often competing against oil or gas boilers. The most common heat pump solutions for the renovation of buildings are either ground source heat pumps with buffer and domestic hot water tank or air source heat pumps with buffer and domestic hot water tank. The energy costs, the overall costs, the demand of end energy and the demand of primary energy have been calculated for a detached house with an area of 152 m² built in 1981 that has gone through some renovation so that the heating demand has been reduced to 103 kWh/(m² a).

requirements					
radiator heating flow/return [°C]					55/45
norm heat demand in kW					14,5
annual specific heat demand in kWh/m²a					103
	oil	natur. gas	pellet		electricity
PE-factor	1,1	1,1	0,2		2,7
CO_2-factor	0,315	0,230	0,031		0,613

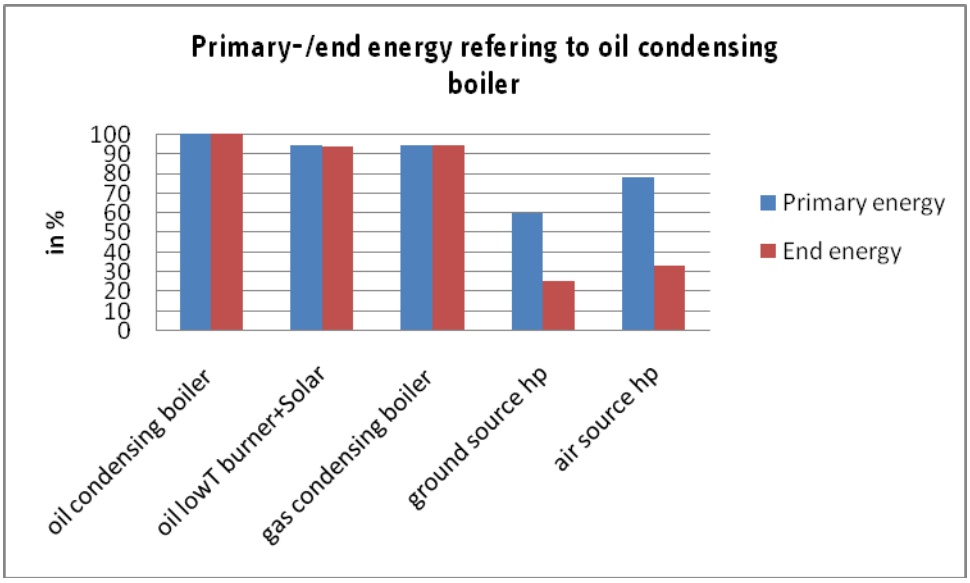
energy price	
electricity tarif household	18,06 Ct/kWh
electricity heat pump mix tarif	12,00 Ct/kWh
oil	7,00 Ct/kWh
natural gas	6,50 Ct/kWh
pellet	4,50 Ct/kWh

house details/interests	detached house
active surface A_N [m²]	152
time	20 years
interests	4,00 %
price increase	2,00 %
price increase II	5,00 %
Annuität	0,0736
DHW reff. to EnEV	12,5 kWh/m²a

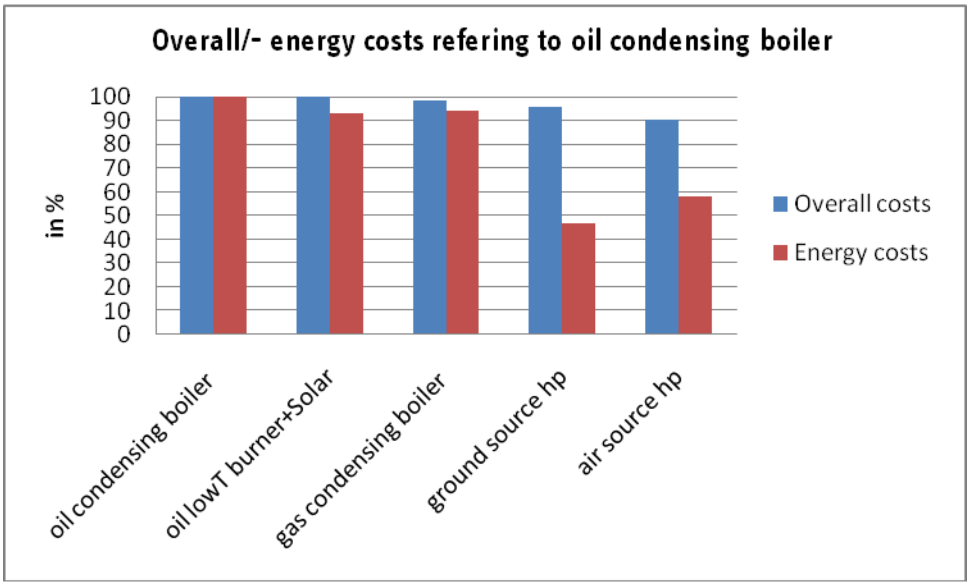
heating systems incl. domestic hot water in existing buildings

			oil	oil	natural gas	electricity	electricity
				concept 1		concept 2	concept 3
			condensing oil boiler + indirect heated buffer cylinder A	oil low T boiler + solar system for DHW I	condensing gas boiler + indirect heated buffer cylinder I	ground source heat pump indirect heated buffer cyl. A	air source heat pump indirect heated buffer cyl. A
value of demand	primary energy heat demand	kWh/m²a	158,7	149,1	149,8	94,7	124,0
	energy demand	kWh/m²a	138,7	129,5	130,7	35,1	45,9
	Anlagenaufwandszahl		1,37	1,29	1,30	0,91	1,19
	annual heat demand (Heating)	kWh/a	15.656	15.656	15.656	15.656	15.656
	annual heat demand (DHW)	kWh/a	1.900	1.900	1.900	1.900	1.900
	annual end energy demand (Heating)	kWh/a	18.024	16.792	16.968	4.090	5.780
	annual end energy demand (DHW)	kWh/a	2.489	2.319	2.344	565	798
	annual energy demand household/supply energy	kWh/a	572	573	550	679	402
energy costs	energy costs Heating/DHW	€/a	1.436	1.338	1.255	559	789
	energy costs household/supply energy	€/a	103	103	99	123	73
	fix costs/meter/basic rate	€/a	-	-	132	58	58
	cost of interests for combustibles	€/a	40	28	-	-	-
	energy costs overall	**€/a**	**1.579**	**1.469**	**1.487**	**739**	**920**
investment	heat generator + controller/source/installation	€	7.500	12.700	6.700	10.500	17.600
	Heating area incl. piping system	€	-	-	-	-	-
	direct house connection	€	-	-	1.700	-	-
	exhaust-gas system/other building costs	€	-	1.000	1.000	13.500	500
	oil/pellet storage	€	-	-	-	-	-
	amount of promotion MAP	€	-	1.160	-	3.000	1.500
	ivestment costs overall	**€**	**7.500**	**12.540**	**9.400**	**21.000**	**16.600**
operating/capital costs	anticipated average life	years	20	20	20	20	20
	average ammount of annuity		0,0736	0,0736	0,0736	0,0736	0,0736
	overall costs refering to capital	**€/a**	**552**	**923**	**692**	**1.546**	**1.222**
	maintenance/servicing	€/a	320	320	320	190	190
	chimney cleaner	€/a	80	80	40	-	-
	spare parts/repairs	€/a	-	-	-	-	-
	assurence	€/a	58	58	-	-	-
	overall costs refering to operation	**€/a**	**458**	**458**	**360**	**190**	**190**
result	overall costs	€/a	2.589	2.850	2.538	2.475	2.332
	overall costs	€/m²a	17,03	18,75	16,70	16,28	15,34
	overall costs refering to oil condensing boiler	%	100,0	110,1	98,0	95,6	90,1
	energy costs refering to oil condensing boiler	%	100,0	93,0	94,1	46,8	58,3
	CO_2-emission	kg/CO_2/a	6.812	6.371	4.779	3.270	4.279
	CO_2-emission reffering to oil condensing boiler	%	100,0	93,5	70,1	48,0	62,8
	energy demand Heating/DHW	kWh/a	20.513	19.111	19.312	4.655	6.578
	energy demand reffering to oil condensing boiler	%	100,0	93,2	94,1	22,7	32,1

Comparison of different heating systems for a renovated house, ground source heat pump with standard air conditioning scroll compressor, air source heat pump with EVI scroll



Comparison of primary and end energy demand for different heating systems



Comparison of costs for different heating systems

Because of the increase of energy costs during the last years the use of heat pumps in renovated buildings is today economical. Capital costs and energy costs are approximately the biggest part of the total heating costs. For ground source heat pumps the necessary investment is approximately 65 % higher than, for example, the investment for a low temperature boiler in combination with a solar thermal heating of the domestic hot water. On the other hand, the energy costs for the ground source heat pump are only 50 % of the energy costs of the more conventional alternative. Air source heat pumps are even more economical than conventional alternatives while being slightly less energy efficient in comparison to ground source heat pumps.

References

[1] DIN V 4701-10, *Energetische Bewertung heiz- und raumlufttechnischer Anlagen*, 2006, Beuth Verlag, Berlin

[2] EN 12831, *Heizungsanlagen in Gebäuden - Verfahren zur Berechnung der Norm-Heizlast*, 2005, Beuth Verlag, Berlin, ISBN 3-410-15720-4 / 978-3-410-15720-5

Policy Instruments to Support Uptake and Appropriate Application of Micro-CHP

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Abstract

Micro combined heat and power (micro-CHP) is a promising near-to-medium term technology that is designed to replace existing boiler systems and provide the thermal needs and some electricity to single residential dwellings. It has the ability to provide cost-effective greenhouse gas emissions reduction, and has a very large potential market of several million units per year in Europe. Studies and field trials to date have suggested that micro-CHP can reduce CO_2 emissions for a dwelling, although observed results have not been as good as initially hoped, largely due to poor performance of emerging technologies and inappropriate applications.

This paper briefly considers the context of UK energy policy, focusing on the residential sector. It then defines the key elements that demarcate successful micro-CHP technology and installations. Next, it applies this information to consider government support for micro-CHP in the form of upfront investment support and/or performance-based support, highlighting shortcomings in two existing policy instruments applied to micro-CHP in the UK. The possibility of providing perverse incentives is examined, and the alternative of providing no support is shown to result in sub-optimal CO_2 reductions. Financial incentives can be justified if micro-CHP systems are properly matched to the target dwelling and if appropriate operating strategies are employed. Given these findings, a hybrid policy instrument to support micro-CHP is suggested, combining upfront and output-based support. Finally, dependency of achievable emissions reduction on the fair CO_2 credit rate for micro-CHP generated electricity is discussed, demonstrating the necessity for further research in this area.

Introduction

Spurred by international concern regarding climate change, the UK government indicated an aspiration to achieve a 60% reduction in greenhouse gas emissions by 2050 (relative to 1990 levels) in the 2003 Energy White Paper [1]. This target was increased to 80% and became a requirement in law when the recent Climate Change Act [2] attained royal assent, with the higher target believed to be more appropriate for a developed country such as the UK to do its part in limiting atmospheric greenhouse gas concentration at levels required for climate stabilisation.

More than 25% of current UK greenhouse gas emissions derive from heat and electricity use in the residential sector. This sector is seen as an area where substantial emissions reduction can be made at low cost [3] with appropriate intervention and it has become a focus of policy and regulation. Amongst a variety of measures that could make an impact, microgeneration is seen as one class of technologies that can aid in meeting the ambitious emissions reduction targets, whilst also providing a measure of energy security through diversity of primary energy sources and geographical distribution.

This paper focuses on appropriate policy support for one microgeneration technology; micro Combined Heat and Power (micro-CHP). This technology could be an important element of the future residential energy system because it has a very large potential market, can be cost-effective, and can provide CO_2 emissions reductions in certain circumstances [4]. Given the wide array of policy instruments at work in the residential sector, and the potential of micro-CHP, it is of interest to consider what impact policy instruments could have on its economic and CO_2-reduction credentials. This paper first presents a brief picture of current policy instruments at work in the UK residential sector. It then explores the technical, tariff, and demand-related factors that demarcate successful micro-CHP installations, focusing on economic and environmental performance. Finally it draws upon this information to suggest appropriate types of financial policy instruments that could be used to support the technology as it enters the market.

Existing Policy Instruments for the Residential Sector in the UK

Financial Support Instruments

Financial support instruments relating to introduction of a technology can be broadly classified as grants or incentives, regulatory market intervention, output or performance-based support, and tax incentives. A combination of all of these types of instruments has been adopted in the UK, although many do not yet specifically support micro-CHP, arguably because there are very few commercial micro-CHP systems currently available.

Probably the most historically important policy instrument in the UK is the Carbon Emissions Reduction Target (CERT). This is a regulatory requirement for energy suppliers (i.e., the retail element in the liberalised energy market) to perform "qualifying actions" with respect to their residential customers. A set of eligible qualifying actions are laid out by the regulator, including energy efficiency measures such as loft and cavity wall insulation, low energy lighting, and more advanced or capital intensive measures such as installation of microgeneration or investment in community CHP schemes. The supplier must install enough measures such that the aggregate of deemed CO_2 reductions from those measures is equal to or above their allocated portion of the overall target. They have flexibility regarding which actions to support, targets and actions are tradable, and actions are bankable for future commitment periods. In this sense, the CERT broadly emulates a cap-and-trade system, with the critical difference being that the "cap" is not fixed; it is a reduction with respect to business as usual rather than an absolute CO_2 reduction. Micro-CHP is currently included in the CERT as a "market transformation action", which implies that it would receive a 50% uplift in terms of deemed CO_2 emissions reduction for that installation (i.e., 50% more deemed CO_2 reduction credit than the installation would nominally receive), although an administrative burden exists in that the supplier must demonstrate the achieved CO_2 reduction to the regulator. In practice the CERT currently delivers a great deal of energy efficiency measures, particularly loft insulation, but in the future it may be an effective instrument for providing some capital cost reduction for supplier-assisted purchase of micro-CHP systems.

Another important policy instrument is grant funding, which has been available for dwellings installing microgeneration since 2006 under the Low Carbon Buildings Programme (LCBP). The "households" stream of the LCBP was allocated £18 million by the treasury to be distributed before June 2010. At the time of writing just over 8,000 microgeneration installations had been supported under this programme, at a cost to the government of just under £10 million. The programme provides up to £2,500 towards the capital cost of installation of a microgeneration system, although this figure varies greatly according to the technology chosen. Micro-CHP is listed as a technology that will be supported by the LCBP, but it is not currently included in the microgeneration certification scheme because corresponding standards do not yet exist for the technologies, and therefore LCBP support is not yet provided.

A variety of further financial policy instruments are relevant for micro-CHP. These are value added tax (VAT) reduction for "energy saving items" including microgeneration, income tax exemption for revenue from microgeneration electricity export, and stamp duty exemption for "zero carbon" dwellings, which would typically incorporate some microgeneration. The final two measures are largely ineffectual in comparison to the primary instruments, but VAT reduction provides a universal capital cost reduction of approximately 12% (currently 10% due to the UK's responses to the "credit crunch" economic crisis) regardless of application of the microgeneration technology.

Importantly in the context of this paper a new financial policy instrument has recently been announced for renewable and low carbon microgeneration. This is a feed-in tariff for these generators, introduced by the Energy Act 2008 [5]. The theory is that a feed-in tariff is more accessible for small generators when compared to the relatively onerous renewable obligation certificates (ROCs).

Regulatory Developments

On the regulatory front, sweeping changes are apparent. In particular, rapid strengthening of the building regulations is proposed in the UK under the controversial Code for Sustainable Homes ("the Code"). The Code sets out levels of sustainability required for new dwellings in the UK, including an energy performance standard that would be implemented via the building regulations, and measured via the government's Standard Assessment Procedure (SAP) [6]. The original proposal was such that all new homes should be net zero carbon for all energy use by 2016, with several exacting interim stages between now and 2016. The Code has been widely criticized, primarily due to a perceived lack of the economically-efficient measures and skills necessary to deliver the targets. The government has since announced a consultation on the meaning of the term "zero carbon" suggesting that the Code was too ambitious and asking for opinions on how to formulate the definition.

In tandem with these high level policy developments, the technique by which energy and carbon savings are measured has recently come under scrutiny. The current version of the Standard Assessment Procedure (SAP 2005) makes broad assumptions regarding energy use according to construction, materials, glazing, lighting, and heating, ventilation and air conditioning (HVAC), etc. One specific assumption of the SAP of relevance to micro-CHP is the assumed grid CO_2 rates, which are set at 0.422 kg CO_2/kWh for onsite consumption and 0.568 kg CO_2/kWh as a credit rate for when generation from a microgenerator displaces consumption of grid electricity. A recent 5-year rolling-average (2001-2005) grid CO_2 rate in the UK was approximately 0.52 kg CO_2/kWh [7], and recent data suggests this figure has increased recently due to preference for coal-fired generation under high natural gas prices. The 0.422 figure in the SAP may stem from an assumption that, in the long term, grid electricity has conventionally been assumed to come from new combined cycle gas turbine (CCGT) stations. Recent developments in UK energy policy, such as the recent report from the Committee on Climate Change [8] suggest that this may be an erroneous assumption. Indeed prediction of future CO_2 rates is a challenging research area with conflicting opinions [9, 10].

Other regulatory developments include widespread adoption of the "Merton rule", home energy labeling, easing of onerous connection requirements, removal of requirement for half-hourly metering, suspension of the 28-day rule (where customers could give 28 days notice to switch suppliers), and movements towards changes in the Balancing and Settlement Code (BSC) which may allow microgenerators better access to the value of the energy they produce. The Merton rule originally required all new developments over a prescribed size to source 10% of their energy from renewable sources (in the London Borough of Merton), and has been adapted and adopted by many other local authorities. This local strengthening of building regulations should be a strong driver for uptake of microgeneration. Other regulatory changes are largely simplifying measures to remove obvious inconveniences, with the exception of changes to the BSC which will become critical if microgeneration is to achieve a significant market share.

Applicability of Existing Policy to Micro-CHP

Many of the measures discussed above explicitly include, or have provision to include, micro-CHP. The CERT, LCBP and new feed-in tariff – the core financial policy instruments – can accommodate the technology directly into their structures with relative ease as it becomes commercially available. VAT reduction already specifically identifies micro-CHP, and SAP 2005 outlined a proposed methodology for including it in energy performance calculations. Although the current SAP methodology will likely change, these initial steps are promising for those seeking support for commercialization.

Overall, it is clear that this class of technologies has the attention of policy makers. It remains to be seen if the existing set of policy instruments can provide appropriate support in terms of meeting policy aims, specifically CO_2 reduction. The remainder of this paper assesses how, where and why micro-CHP installations may exhibit performance commensurate with policy goals, and explores a potential structure of policy instruments that could be applied. This assessment is based on a modeling exercise.

Circumstances Required for Economic Value & CO_2 Reduction from Micro-CHP

The circumstances required for CO_2 reduction from micro-CHP with regard to vetting installations for investment support have been investigated in Hawkes and Leach [11], which concluded that a set of tests are required to ensure only installations that are likely to perform obtain support. This paper extends that assessment to pin down the fundamental drivers of economic value and CO_2 reduction from micro-CHP installations, and then adapts this information to interpret the impact of the recently enacted feed-in tariff for microgeneration in the Energy Act 2008 [5].

The following analysis assumes that the micro-CHP system is installed instead of a condensing boiler, which is arguably the conventional alternative, and therefore chosen as the reference heating system.

The reference electricity system is a medium-term estimate of UK grid electricity, with an embodied CO_2 rate of 0.43 kg/kWh, which assumes improvement on the present situation. The marginal cost of natural gas (which is assumed to fuel either the boiler or competing micro-CHP system) is set at 2.5 pence/kWh. The marginal electricity tariff is assumed to be 10.25 pence/kWh. Four pence/kWh is the central estimate of the buyback price when electricity is exported to the grid. The marginal tariffs are average London rates (although significant variation can be observed between suppliers) and the buyback price is based on the average wholesale price of electricity on the UK spot market. The modeling approach applied is based on unit commitment optimization, more details of which can be found in Hawkes et al [12]. Micro-CHP system technology characterizations are based on the published literature [13-17], adapted to form a view of near-to-medium term technology, and abridged in Table 1.

Table 1: Selected Key High Level Micro-CHP Performance Characteristics

	Internal Combustion Engine (ICE)	**Polymer Electrolyte Membrane Fuel Cell (PEMFC)**	**Solid Oxide Fuel Cell (SOFC)**	**Stirling Engine**
Electrical Efficiency (part load, full load)	10%, 20%	30%, 26%	45%, 40%	6%, 10%
Overall Efficiency – heat+power (part load, full load)	80%, 85%	75%, 85%	75%, 80%	80%, 90%
Supplementary Boiler Efficiency	86%	86%	86%	86%
Minimum Set Point (kW_e)	0.2	0.2	0.2	0.2
Maximum Ramp Rate (kW_e/min)	0.2	0.2	0.05	0.2
Approximate Heat-to-Power Ratio (HPR)	3:1	2:1	1:1	8:1

The final row in Table 1 approximates the heat-to-power ratio of the micro-CHP prime movers. This is an important technical characteristic because (as demonstrated in the following paragraphs) system economic value and potential for CO_2 reductions is driven by the ability of the system to produce electricity. This ability is limited by both supply and demand-side thermal constraints, where the system cannot generate electricity if there is insufficient thermal demand because it is (theoretically) not technically enabled to dump heat. The demand-side constraint relates to the presence of thermal demand, where a site with larger space heating and domestic hot water (DHW) demand generally allows the micro-CHP prime mover to operate more consistently, and therefore generate more electricity. The supply-side constraint is dictated by the heat-to-power ratio of the micro-CHP prime mover. The heat-to-power ratio is a measure of how much electricity can be produced for a given thermal output; a prime mover with low heat-to-power ratio can therefore produce relatively more electricity than a high heat-to-power ratio (HPR) prime mover in the case of low thermal demand. Therefore, the low HPR prime mover can generate more electricity overall, which is in turn associated with a more positive economic and CO_2-related outcome.

The thermal demand related influences can be seen in Figures 1 and 2, which plot modeled annual CO_2 reduction and economic value against annual thermal demand for four micro-CHP technologies operating in five typical UK dwelling variants. Clearly the performance of the SOFC-based system is more resilient to changes in annual thermal demand for both CO_2 and economic outcomes. This is due to its low HPR in comparison to the other technologies. In contrast, a higher HPR system such as the internal combustion engine (ICE) is more sensitive to reducing thermal demand because it must modulate or switch off more frequently due to the thermal constraint.

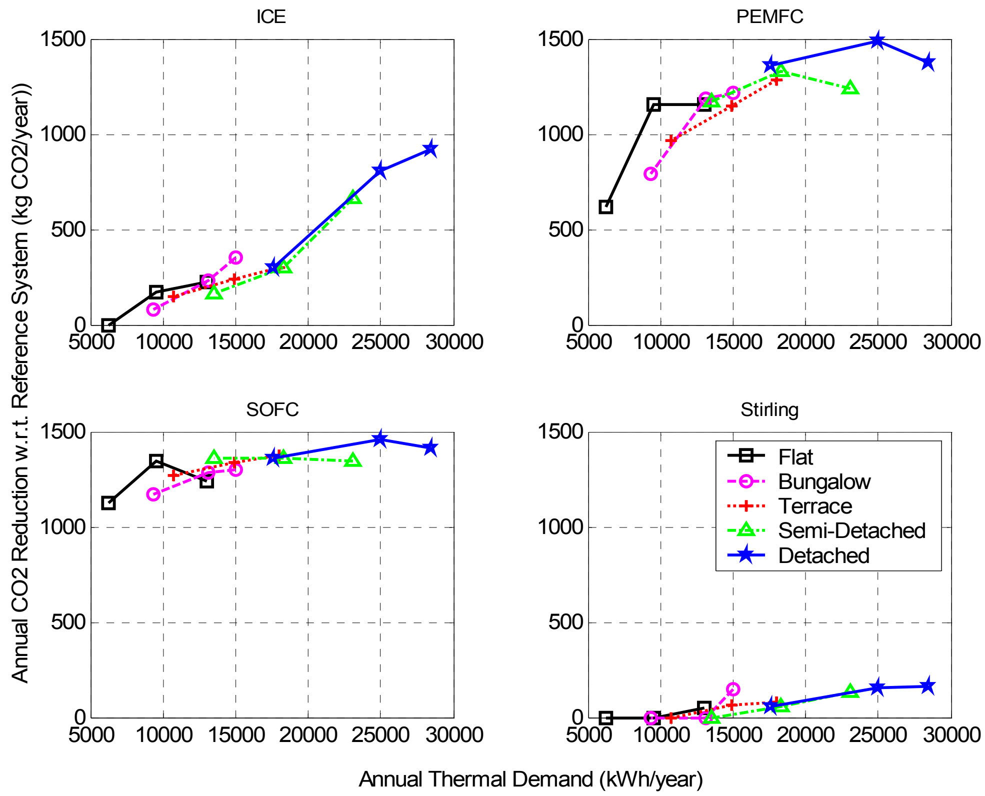

Figure 1: Dependence of CO_2 Savings on Annual Thermal Demand for Four Micro-CHP Prime Mover Technologies with Different Heat-to-Power Ratios and Five Dwelling Variants

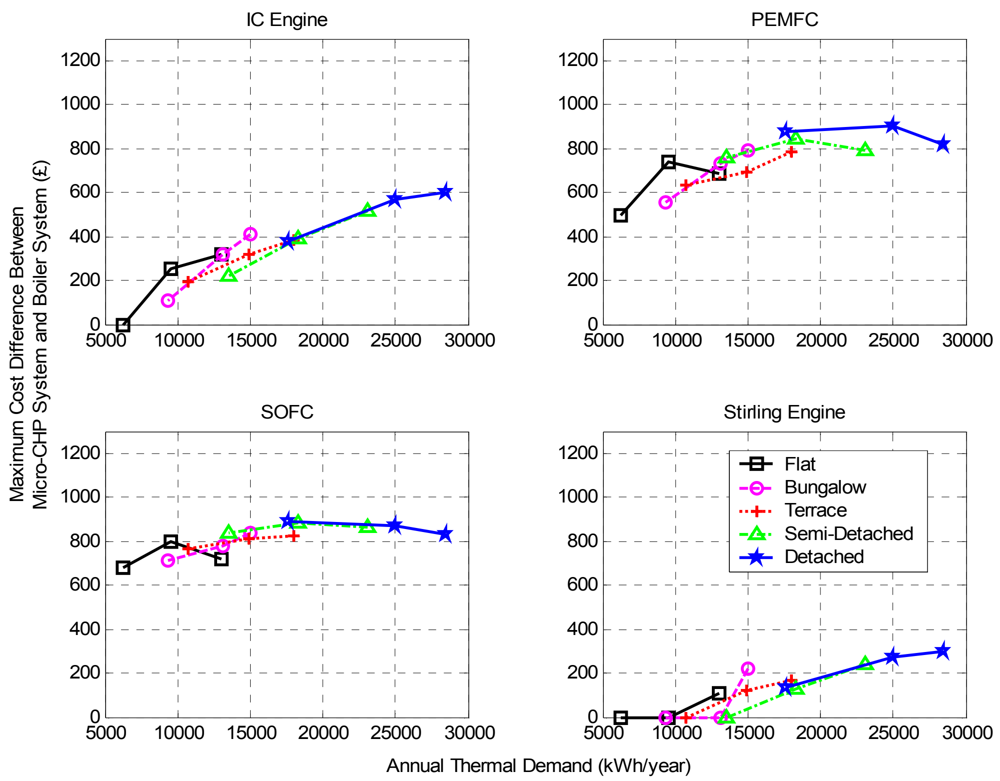

Figure 2: Dependence of Economic Value on Annual Thermal Demand for Four Micro-CHP Prime Mover Technologies with Different Heat-to-Power Ratios and Five Dwelling Variants

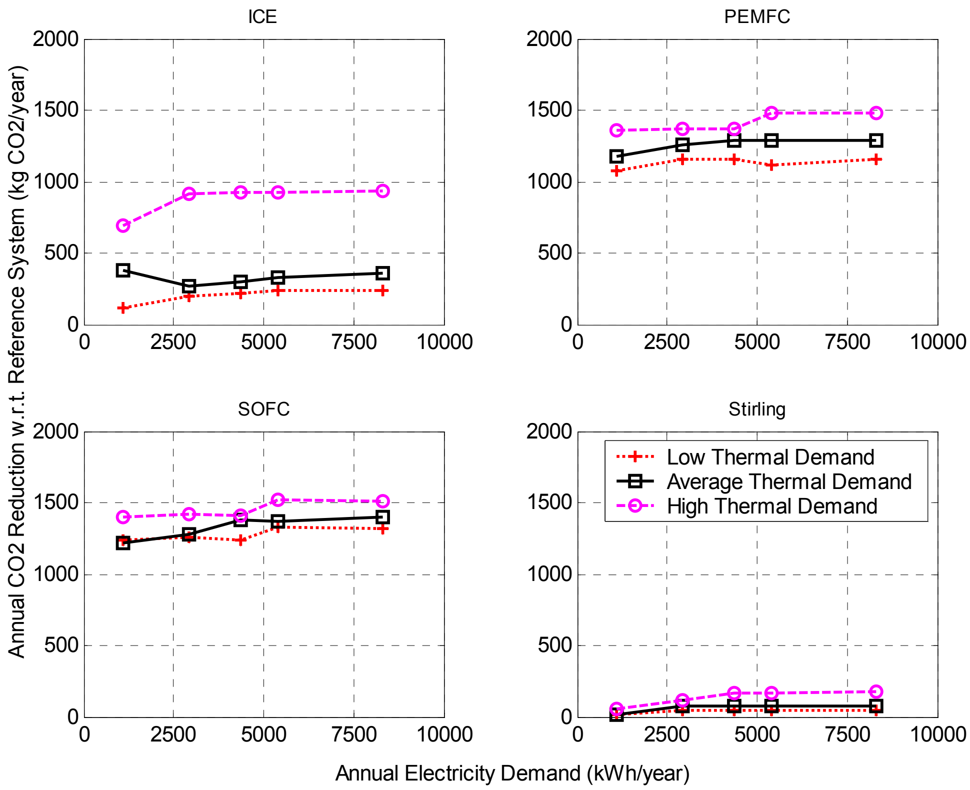

Figure 3: Dependence of CO_2 Savings on Annual Electricity Use for Four Micro-CHP Prime Mover Technologies with Different Heat-to-Power Ratios and Three Thermal Demand Cases

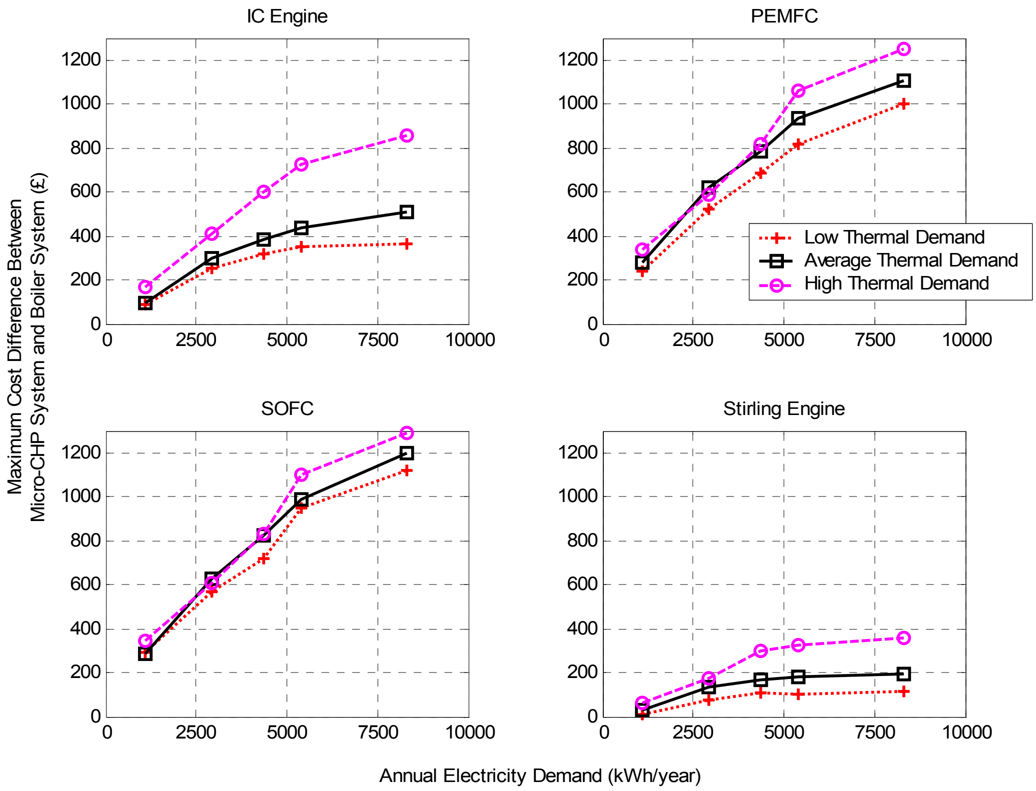

Figure 4: Dependence of Economic Value on Annual Electricity Use for Four Micro-CHP Prime Mover Technologies with Different Heat-to-Power Ratios and Three Thermal Demand Cases

In contrast to Figure 1, Figure 3 demonstrates the lack of dependence of CO_2 reduction on annual electricity use (as opposed to stronger dependence on thermal demand as per Figure 1). This is because the CO_2 rate credited to the micro-CHP installation is the same regardless of whether the electricity is consumed onsite or exported to the grid. Furthermore, it is clear that the CO_2-related result displayed in Figure 3 is not reflected by the corresponding sensitivity of economic result to annual electricity use displayed in Figure 4. These relationships imply that the drivers of the economic result differ in important ways to drivers for the CO_2 related result. The difference lies in the fact that the economic value of electricity exported to the grid is substantially lower than the value of displacing onsite electricity demand, whilst on the contrary CO_2 reduction performance is unrelated to whether the electricity is consumed onsite or offsite.

The above discussion presents an overall picture of the key demand and technology-differentiating drivers of economic and CO_2 related performance for micro-CHP. These can be summarized as follows:

1. For a strong economic result, a micro-CHP prime mover is better off with a low heat-to-power ratio when serving a dwelling with high onsite electricity use. High dwelling thermal demand is also important if the prime mover has a higher heat-to-power ratio, but is less important if it has a very low heat-to-power ratio. The reader should note that this tension between thermal demand and performance of micro-CHP has important implications for its use in highly energy-efficient buildings as discussed in [11].

2. For a good CO_2 reduction result, a micro-CHP prime mover is better off with a low heat-to-power ratio. A high thermal demand also helps, especially if the prime mover has a higher heat-to-power ratio. Dwelling electricity demand is not directly relevant to CO_2 reduction.

These basic rules of thumb can be directly applied or adapted to consider a possible structure of policy instruments that could support the introduction of micro-CHP, as is performed in the following sections.

A Possible Structure of Financial Support

Upfront Investment Support

Micro-CHP systems are expected to have high capital and/or installation costs, over and above the cost of the competing conventional condensing boiler system. Given the risk-adversity of typical dwelling owner/occupiers as discussed in Hausman [18], it may be appropriate to provide upfront capital support for investors such that this barrier is reduced. Hawkes and Leach [11] suggested the following set of requirements for investment support:

- Minimum standard regulation to ensure high overall efficiency (i.e. heat + power) for micro-CHP systems, similar to SEDBUK ratings (i.e. seasonal efficiency rating) for boilers in the UK.

- Classification of micro-CHP systems according to the heat-to-power ratio of the prime mover.

- Provision of support based on matching heat-to-power ratio and thermal capacity of the prime mover with the predicted thermal demand of the target dwelling.

This basic set of rules, which are practical to implement, and can significantly improve the probability that a particular installation will provide CO_2 emissions reductions, because they speak to the primary drivers of CO_2 reduction as explored in the previous section. They will, however, require assessment of the dwelling prior to micro-CHP system installation, but it is suggested that such assessment could already be present in the form of a dwelling energy performance certificate (as required by home energy labeling in the UK) in many cases. In cases where such information does not exist, a regulator or grant-awarding body could seek to obtain energy consumption information for the dwelling, or require that an energy performance assessment is carried out. Furthermore, a SEDBUK-like rating system could be used to determine a seasonal heat-to-power ratio in addition to ensuring overall efficiency, which would probably not be a significant administrative burden, and would provide the final element of information required for vetting of the installation.

Therefore, this paper confirms the method of vetting of installations proposed in Hawkes and Leach [11], but additionally notes that such vetting does not guarantee an economically efficient installation. However, whilst profitability of the investment is an important consideration regarding the potential for success of a policy instrument, it is not specifically the domain of policy makers. The investment decision can be left to the investor, who if well informed would choose to install micro-CHP only in dwellings with relatively high annual electricity demand.

A final conclusion that can be drawn from this analysis is that existing policy support instruments for upfront capital cost support (i.e. primarily the CERT, grant support under the LCBP, and VAT reduction) are mixed in terms of their ability to provide effective support. Both the CERT and LCBP could be easily adapted to ensure supported installations are appropriately vetted, albeit with some administrative burden. On the contrary, VAT reduction is a poorly directed instrument that provides blanket support regardless of the potential for performance of the installation, and this forfeiture of taxation revenue could be better directed through one of the other upfront investment support instruments.

Performance-Based Support

Often government support for renewable or low carbon energy technology is not provided in the form of upfront capital grants or similar instruments. For example, the UK's Renewable Obligation Certificates (ROCs) and Germany's feed-in tariff scheme reward generators based on energy production. As such, they can be interpreted as performance-based instruments (as opposed to investment support instruments) because they require not only that the beneficiary invest in green technology, but also that they ensure it performs well.

A similar support structure can be provided for micro-CHP, although a complex matter emerges in that, as described in previous sections, performance depends on a set of interrelated demand and technology factors. This implies that provision of a simple reward scheme proportional to energy output (such as a feed-in tariff) may not provide an incentive that will result in policy aims being achieved in an acceptable proportion of supported installations. Furthermore, additional factors play a role in the success of feed-in tariff type instruments, as discussed below.

Although micro-CHP systems in the UK are required by regulations to be technically constrained to prevent them from discarding significant quantities of thermal energy (i.e. heat dump), an identical outcome can be achieved through the actions of a dwelling occupier.[1] This has important environmental consequences, as heat dump is generally associated with poor CO_2 related performance of micro-CHP, as discussed in Hawkes [19]. Figure 5 below displays the potential interaction between a feed-in tariff incentive[2] and CO_2 reduction where the dwelling occupier attempts to minimize their cost of meeting energy demand via optimal operation of the micro-CHP system. The figure is designed to capture the range of micro-CHP electrical efficiencies, from Stirling engine at approximately 10%, through to long-term fuel cell technology at 50%.

It is apparent from inspection of Figure 5 that a perverse incentive is created by the feed-in tariff arrangement. Under modeled assumptions, a dwelling occupier motivated by cost reduction would be encouraged to operate the device as much as possible, with the result of a sub-optimal and possibly even entirely counter-productive CO_2 result. The instrument motivates them to produce as much electricity as possible in order to access the value of the feed-in tariff, and dump any thermal energy not required in the dwelling. Some would argue that such heat dump is unlikely, but this paper posits that many dwelling occupiers would appreciate higher internal temperatures, and certainly a micro-CHP owner/operator would have little incentive to improve thermal insulation after micro-CHP installation. Therefore, it is concluded that this perverse incentive is a tangible threat to micro-CHP CO_2 reduction performance, and indeed would disincentivise introduction of further energy efficiency measures in the dwelling.

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[1] Heat dump, or unnecessary demand for heat, can be achieved by increasing air turnover in the dwelling (opening windows, etc.), avoiding or deferring insulation upgrade, or simply demanding higher internal temperatures.
[2] The feed-in tariff modeled here is identical to that proposed in the Energy Act 2008. It provides a reward proportional to the aggregate amount of electricity generated.

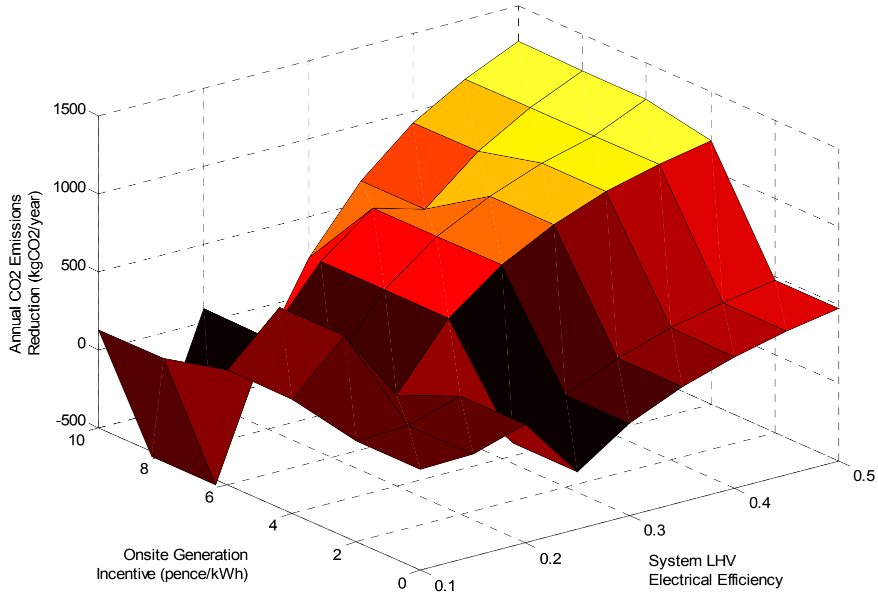

Figure 5: Dependence of CO_2 Reduction on Feed-In Tariff Price and Electrical Efficiency[3]

Several alternative performance-based instruments do exist [20], but for the purposes of this paper the focus is maintained on reward for electricity export. This is not necessarily a policy instrument because the level of reward for electricity export could be a "fair reward", where a supplier pays the generator for metered export to the grid and has means to receive settlement for that export via mechanisms in the Balancing and Settlement Code. Alternatively the government could intervene to bolster the level of reward for electricity export if such actions were deemed appropriate. Figure 6 presents the sensitivity of CO_2 reduction across export reward rates for the range of micro-CHP electrical efficiencies and under the same assumptions as per Figure 5.

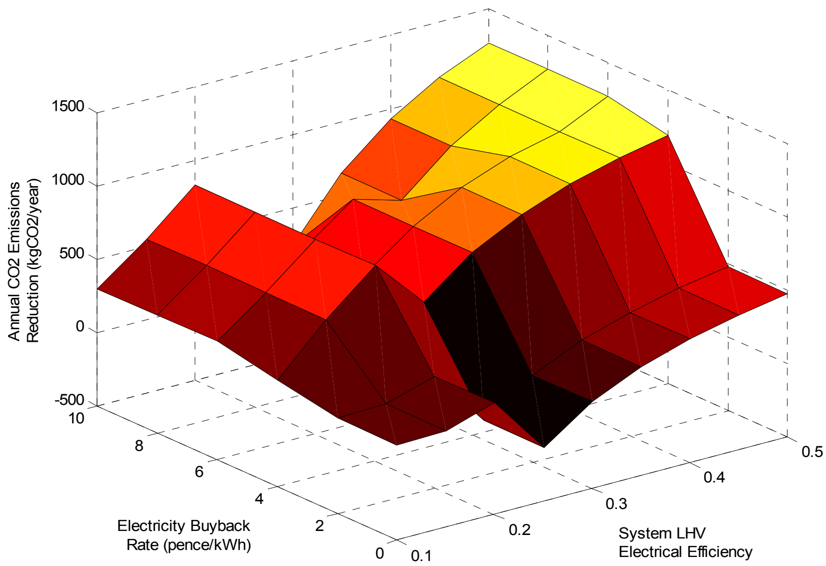

Figure 6: Dependence of CO_2 Reduction on Export Reward Price and Electrical Efficiency

[3] All micro-CHP system parameters except electrical efficiency from Table 1 have been made equal to that of the Stirling engine to enable this analysis.

Similarly to Figure 5, Figure 6 shows a potential for a perverse incentive. However, the potential negative influence of reward for export is not as severe as that of a feed-in tariff, and low levels of export reward in the range of 4 to 6 pence/kWh show reasonably solid CO_2 reduction performance across the range of electrical efficiencies.

Importantly, very low levels of reward of zero to 2 pence per kWh under either a feed-in tariff or export reward arrangement result in poor CO_2 reduction performance. In the case of either instrument, substantially more CO_2 reduction can be achieved by a small increase in the level of reward.

Given the problems associated with a feed-in tariff, and improvements based on a low level of reward only for exported electricity (rather than all electricity generated), a hybrid instrument that addresses both the need for investment support and performance-based support can be formulated. This is discussed in the following section.

A Hybrid Instrument

The hybrid policy instrument provides revenue from a performance-based instrument that is "front-loaded" to provide upfront capital investment support. Such an instrument allows the investor to access upfront capital support according to some deemed output (kWh electricity) from the micro-CHP system, and then receive additional output-based support as the system is used. This combination of actions tackles the investment cost barrier and avoids the possibility of incentivising poor performance via feed-in tariff type arrangements. It also avoids the possibility of providing insufficient operation-based reward to motivate low CO_2 behavior.

Based on the analysis above, it appears likely that a low level of reward for electricity export is a better instrument than a feed-in tariff for micro-CHP. Furthermore, the level of export reward that provides strong emissions reduction is close to the current average wholesale price of electricity in the UK, suggesting that minimal public money may be required to provide the proper incentive for the non-capital portion of support. The level of capital support could then be expressed as a premium on the export reward tariff which is deemed and paid on purchase of the micro-CHP system. The primary caveat to such an arrangement is that the dwelling owner/occupier should not be exposed to having to earn back the deemed portion of output, as this may incentivize the same behavior as per the feed-in tariff where electricity generation is maximized (with poor corresponding CO_2 performance).

A Further Policy Consideration

As displayed in Figure 7, the CO_2 reduction that is attributable to micro-CHP is heavily dependent on the amount on embodied CO_2 in displaced grid electricity.

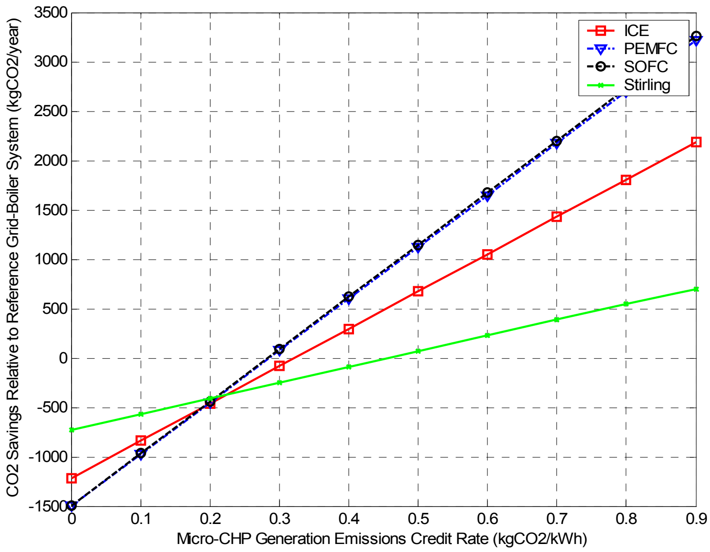

Figure 7: Dependence of CO_2 Reduction on the Credit Rate for Micro-CHP Generation

It is clear from Figure 7 that as the appropriate credit rate for micro-CHP falls below approximately 0.3 kg CO_2/kWh, no (natural gas-fuelled) micro-CHP technology can provide an emissions reduction in comparison to the conventional reference system. Given that the UK's Committee on Climate Change [8] has suggested that this level of decarbonisation of grid electricity should be achieved in the next few decades to have a chance of meeting the government's ambitious 80% CO_2 reduction by 2050 target (relative to 1990 levels), it seems arguable that micro-CHP could be at best a near-to-medium term technology in terms of plausible emissions reduction. However, this point of view ignores the fact that micro-CHP generation does not displace grid-average electricity, but rather has an impact on the margin of generation and generator investment. This means that it is possible that these technologies will displace fossil fuel plants in the future rather than the new low carbon plant that is required to meet the government targets. Furthermore, there is potential for use of alternative fuels (such as biogas) with micro-CHP, significantly changing their relative operational CO_2 footprint. More futuristic possibilities also exist for virtual power plant (VPP) style control of a large number of micro-CHP systems, where control could be implemented to ensure that high carbon rather than low carbon sources are displaced by the micro-CHP generation.

Nonetheless the issues surrounding grid decarbonisation are clearly important ones that need to be addressed by the micro-CHP industry in a credible manner. Yet given the possibilities for alternative fuels and appropriate control strategies, there is a reasonable argument for government support of these technologies as a promising candidate to provide emissions reductions, particularly given that current grid-average CO_2 rates are relatively high.

Conclusions

This paper has presented a brief overview of residential sector energy policy in the UK, considered its applicability for supporting emerging micro-CHP technology, demarcated the primary drivers of their economic and CO_2 performance, and then used this information to discuss a possible policy support structure for the technology.

In general, microgeneration and residential sector energy policy in the UK is well equipped to support micro-CHP with minor amendments. Instruments such as the Carbon Emissions Reduction Target and grant support under the Low Carbon Building Programme either already provisionally support micro-CHP or could be easily adapted to provide support. Further developments in the residential sector also bode reasonably well for mass uptake of the technology, particularly via tightening of the building regulations and streamlining of connection and metering processes. However, further developments are certainly required to appropriately support the technology, including provision of more effective settlement rules via the Balancing and Settlement Code, and ensuring that no perverse incentives are created.

The key economic and CO_2 performance drivers for micro-CHP systems in the UK have been presented. This demonstrated the relationship between annual onsite electricity demand, thermal demand, and micro-CHP prime mover heat-to-power ratio for economic performance, and between thermal demand and heat-to-power ratio for CO_2-related performance. Essentially, CO_2 performance is dictated by the ability to produce electricity, and that ability is constrained by either demand-side or supply-side thermal constraints. On the demand-side, an installation is more likely to perform if the target dwelling has a high annual thermal demand. On the supply-side, an installation is more likely to perform if the micro-CHP prime mover has a low heat-to-power ratio. In relation to economics, performance drivers are identical; but, it is also important that the target dwelling has significant onsite electricity demand.

Regarding policy support, this paper proposes a hybrid policy instrument to provide upfront capital investment support and utilization-based support to micro-CHP installations. It reiterates the conclusion in Hawkes and Leach [11] that installations should be vetted for investment support to ensure applicability of the micro-CHP system to the target dwelling. Furthermore, it is shown that the government's currently proposed feed-in tariff can provide a perverse incentive for micro-CHP owner/operators. A reward for electricity export (as opposed to all electricity generated under a feed-in tariff) provides better motivation for micro-CHP operators, although it is noted that even this has deficiencies. A hybrid support instrument could be created by providing a certain portion of deemed electricity output as upfront investment support, and the remainder through an export reward scheme. This would address two important issues; a) the need for investment support, given the high observed costs of capital in the residential sector, and b) the need to provide an in-use incentive to micro-CHP owner/operators such that they are motivated to deliver the best possible CO_2 reduction.

Finally, it is noted that the potential for CO_2 reduction from micro-CHP installation depends strongly on the fair CO_2 credit rate for their electricity generation. If the grid decarbonizes rapidly, this fair credit rate may relate to displacement of renewable or low carbon electricity, and in that case, natural gas fuelled micro-CHP may not be able to provide any emissions reduction. This issue requires research attention to determine what a fair credit rate is under rapid grid decarburization, and to explore the possibilities for control of micro-CHP or use of alternative low carbon fuels to ensure the technology contributes to climate stabilization.

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References

1. DTI, *Energy White Paper 2003: Our Energy Future - Creating a Low Carbon Economy,* URN 03/660, London, UK; 2003

2. HM Government, 2008, *Climate Change Act 2008*, c. 27. The Stationary Office (TSO), London, UK

3. IPCC, *IPCC 4th Assessment Report: Synthesis Report,* Available from: http://www.ipcc.ch/; 2007

4. A.D. Hawkes, I. Staffell, D.L. Brett, and N.P. Brandon, *Fuel Cells for Micro-Combined Heat and Power Generation*, Energy & Environmental Science (Royal Society of Chemistry) In Press (2009).

5. HM Government, 2008, *Energy Act 2008*, c. 32. The Stationary Office (TSO), London, UK

6. BRE, 2005, *The Government's Standard Assessment Procedure for Energy Rating of Dwellings:* 2005 Edition, BRE, Watford, UK,

7. DEFRA, *Guidelines to Defra's GHG conversion factors for company reporting,* London, UK; 2007

8. CCC, *Building a low-carbon economy - the UK's contribution to tackling climate change,* The Stationary Office (TSO): London, UK; 2008

9. R. Bettle, C.H. Pout, and E.R. Hitchin, *Interactions between electricity-saving measures and carbon emissions from power generation in England and Wales*, Energy Policy 34 (2006) 3434-3446.

10. K. Voorspools, P. Voets, and W. D'Haeseleer. *Small scale decentralised electricity generation and the interaction with the central power system*. In: International Conference on Power Generation and Sustainable Development. 2001. Liege.

11. A.D. Hawkes and M.A. Leach, *On Policy Instruments for Support of Micro Combined Heat and Power*, Energy Policy 36 (2008) 2963-2972.

12. A.D. Hawkes, P. Aguiar, C.A. Hernandez-Aramburo, M.A. Leach, N.P. Brandon, T.C. Green, and C.S. Adjiman, *Techno-economic modelling of a solid oxide fuel cell stack for micro combined heat and power*, Journal of Power Sources 156 (2006) 321-333.

13. P. Aguiar, C.S. Adjiman, and N.P. Brandon, *Anode-supported intermediate temperature direct internal reforming solid oxide fuel cell. I: model-based steady-state performance*, Journal of Power Sources 138 (2004) 120-136.

14. U. Arndt, I. Beausoleil-Morrison, M. Davis, W. D'haeseleer, V. Dorer, E. Entchev, A. Ferguson, J. Gusdorf, N. Kelly, M. Manning, L. Peeters, M. Sasso, D. Schreiber, S. Sibilio, K. Siemens, and M. Swinton, *Experimental Investigation of Residential Cogeneration Devices and Calibration of Annex 42 Models,* Annex 42 of the International Energy Agency Energy Conservation in Buildings and Community Systems Programme: Paris, France; 2007

15. Osaka Gas Co, Toho Gas Co, Saibu Gas Co, Honda Motor Co, Noritz Co, and Chofu Seisakusho Co, *Development of "ECOWILL" Cogeneration System for Residential Applications,* Osaka Gas Co: Osaka, Japan; 2004

16. C. Wallmark and P. Alvfors, *Technical design and economic evaluation of a stand-alone PEFC system for buildings in Sweden*, Journal of Power Sources 118 (2003) 358-366.

17. Carbon Trust, *Micro-CHP Accelerator Interim report,* CTC726, The Carbon Trust: London, UK; 2007

18. J.A. Hausman, *Individual Discount Rates and the Purchase and Utilization of Energy Saving Durables*, The Bell Journal of Economics 10 (1979) 33-54.

19. A.D. Hawkes, *Feed-in Tariffs for Micro-Cogeneration: how to maximise carbon benefits*, in *COSPP (Cogeneration and Onsite Power Production)*. 2008, Penwell International Publications Ltd.

20. A.D. Hawkes and M.A. Leach, 2008, *Utilisation-Based Policy Instruments to Support Residential Micro-CHP* **in** *7th British Institute of Energy Economists (BIEE) Academic Conference*. September 24-25. Oxford, UK.

California's Solar Water Heating Program: Scaling Up to Install 200,000 Systems by 2020

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Abstract

Water heating is the largest natural gas end use in California consuming 285 PJ per year or 38 percent of residential and commercial gas. Approximately 65 percent of energy used to heat water in California can be saved with solar water heating. From 1975 through 1985 California installed approximately 159,000 solar water heaters with utility incentives and tax credits. However, when world oil prices dropped in the 1980s and solar tax credits were withdrawn in 1986, most solar water heating companies left the business. Since 1980 the solar water heating industry has suffered from high initial cost, lack of incentives, permitting problems and lack of quality installation standards. The California Solar Water Heating Efficiency Act (AB1470) authorizes $250 million to transform the solar water heating industry and provide incentives for 200,000 solar water heaters starting in 2010. To get the program started, the California Public Utilities Commission authorized a $2.6 million solar water heating pilot program in San Diego implemented by the California Center for Sustainable Energy. The pilot program provides quality installation standards and verification, training, technical assistance, and incentives to encourage widespread implementation of solar water heating. For residential systems, the maximum incentive is $1500 per dwelling. For larger commercial and industrial systems, the incentive is based on collector area. For open-loop systems the incentive is $161.46/m^2, and for closed-loop systems the incentive is $215.28/m^2. In late 2009, the pilot program will be scaled up statewide with a goal of installing 200,000 solar water heating systems by 2020.

Introduction

In 2006, water heating accounted for 15% of residential energy use in the United States, consuming 111 billion kWh of electricity, over 1,084.6 PJ of natural gas, 106.1 PJ of fuel oil, and 67.6 PJ of liquefied petroleum gas (i.e. propane) [29]. In California, approximately 85% of water heating is provided by natural gas, with the balance provided predominantly by electricity [10]. Natural gas used for water heating accounts for 38 percent or 285 PJ per year of residential and commercial natural gas consumed each year in California by customers of the investor-owned utilities and electric water heating accounts for 6% of total residential electricity consumption by customers of the investor-owned utilities in California [19] [20]. Approximately 65 percent of the energy used to heat water in California can be saved with solar water heating [9] [19] [20]. Solar water heating systems use the sun to provide a portion of the total hot water requirement for residential and commercial customers, reducing the quantity of natural gas, electricity, propane, or fuel oil used to heat water. From 1975 through 1985 California installed approximately 159,000 solar water heaters with utility incentives and tax credits [3]. However, when world oil prices dropped in the 1980s and solar tax credits were withdrawn in 1986, most solar water heating companies left the business. Since 1980 the solar water heating industry has suffered from high initial cost, lack of incentives, permitting problems and lack of quality installation standards. The California Solar Water Heating Efficiency Act (AB1470) authorizes $250 million to transform the solar water heating industry and provide incentives for 200,000 solar water heaters starting in 2010 [1]. To get the program started, the California Public Utilities

Commission authorized a $2.6 million solar water heating pilot program (SWHPP) in San Diego implemented by the California Center for Sustainable Energy [2].

This paper provides an overview of the California SWHPP and progress to date. The paper presents an analysis of the effective useful life of SWH systems based on warranty claims for 27,000 systems installed in Hawaii, and provides cost effectiveness results based on the CPUC-approved E3 calculator. The paper also discusses best practices lessons from successful U.S. and international SWH programs.

California Solar Water Heating Pilot Program

The California Solar Water Heating Pilot Program (SWHPP) began in July 2007 as an 18-month solar water heating (SWH) incentive program implemented in the San Diego Gas and Electric (SDG&E) service area under the auspices of the California Public Utilities Commission (CPUC) and administered by the California Center for Sustainable Energy (CCSE).[1] The CPUC modified the SWHPP on July 2, 2008 to extend the program through December 2009 or until funding is exhausted, allow new residential and commercial construction, and extend market research work beyond San Diego to determine what type of market interventions are needed to stimulate greater adoption of solar water heating systems in California by improving cost effectiveness [4]. Itron is evaluating the SWHPP, and this paper provides an overview of the interim evaluation results [17]. Based on final evaluation results of the pilot program, the CPUC will consider expanding SWH incentives across the state in accordance with the California Solar Water Heating Efficiency Act (AB 1470) which authorizes $250 million for a statewide incentive program [1].[2] The goal of the statewide incentive program is to install at least 200,000 SWH systems on homes, businesses, and government buildings by 2020. The CPUC established the pilot program to test solar water heating incentives and evaluate the impact incentives have on: 1) equipment and installation costs, 2) market demand, and 3) cost-effectiveness.

The SWHPP has two incentive options: the prescriptive incentive and collector area incentive. The prescriptive incentive is used for residential and small multifamily or commercial systems. To qualify for prescriptive incentives residential customers must install an SRCC OG-300-rated system [26]. The maximum incentive under the prescriptive method is $1,500 and is dependent on the climate zone, orientation, and SRCC Annual Savings Rating for that system. The collector area incentive is used for large multifamily and commercial systems, and the collectors must be SRCC OG-100-certified. The collector area incentive is based on the SRCC Collector Performance and Solar Orientation Factor (SOF). For open-loop systems the incentive is $161.46/m^2, and for closed-loop systems the incentive is $215.28/m^2. The maximum collector area incentive is $75,000. Systems that receive a collector area incentive must have at least one month of post-installation metering. The SWHPP received 174 applications through December 2008. **Table 1** shows the distribution of applications by incentive method, retrofit, new construction, and incentives. The total paid incentives are $166,734 with $132,834 paid to 107 residential customers who used the prescriptive incentive and $33,900 paid to 12 commercial customers who used the collector area incentive.

Table 1. SWHPP Applications and Paid Incentives Through December 2008

Total Applications	Pending Applications	Reserved Incentive Amount	Number of Paid Applications	Paid Incentive Amount
Retrofit				
Prescriptive	44	$56,087.00	100	$124,884.00
Collector Area	3	$9,370.00	12	$33,900.00
New Construction				
Prescriptive	6	$8,150.00	7	$7,950.00
Collector Area	0	$0.00	0	$0.00
Total	**53**	**$73,607.00**	**119**	**$166,734.00**

Source: CCSE 2009.

[1] SWHPP is funded by electric ratepayers in the San Diego Gas & Electric Company (SDG&E) service area authorized by the CPUC in Decision 06-01-024 as part of the California Solar Initiative (CSI).

[2] Assembly Bill 1470 (Huffman), October 12, 2007. Funded by public benefits surcharges on natural gas ratepayers.

While 89 percent of residential customers use natural gas to provide back-up water heating, only 44% of SWHPP residential applications have natural gas back-up heat. **Table 2** summarizes the residential solar water heating applications by fossil back-up heat. Residential SWH systems using electricity and propane back-up heat have slightly greater average costs and incentives than systems with natural gas back-up heat. The residential SWH systems using electric and propane back-up heat are installed in rural areas where freeze protection is more important, and thus, represent a different mix of system types having higher SRCC-rated savings compared to systems with natural gas back-up heat.

Table 2. Summary of Residential Solar Water Heating Incentive Applications

Fossil Back-up Heat	Percent of Total	Average Incentive	Average Savings	Average Cost
Residential Natural Gas	44%	$1,189.63	11.8 GJ	$6,457.38
Residential Electric	32%	$1,295.16	2697 kWh	$6,539.55
Residential Propane	24%	$1,292.13	14.2 GJ	$6,700.74

Source: CCSE 2009.

The most common residential system types chosen by participants are passive open-loop thermosyphon representing 37% followed by active closed-loop glycol with 32%. Open-loop direct-forced circulation represents 13%, closed-loop drainback represents 12%, and passive closed-loop internal collector storage (ICS) represents 6% of installed systems

The lowest cost SWH residential system installed thus far in the SWHPP is approximately $3,200 and the highest cost is $11,600. The median cost for all residential systems participating in the SWHPP is $6,750. Interest in the SWHPP has been relatively constant but lower than anticipated considering the average incentive of $1,250 per system and available federal tax credits of $2,025 (average) [25]. May 2008 had the most applications (i.e., 15), while applications in August 2008 were very low (only 3). The SWHPP has received an average of eight residential applications per month.

The program has received significantly more interest from residential customers than commercial customers. Residential customers paid an average of $6,750 per SWH system and received an incentive of $1,250. If all customers claimed and received a federal tax credit, the net cost would be decreased to $3,475. New construction was incorporated into the program in mid-2008 and is still a relatively small part of the program, with only 13 residential applicants through December 2008.

SWHPP Marketing and Outreach Efforts

The SWHPP implemented marketing and outreach efforts to raise awareness of the SWH incentive program including television, radio, print, web, direct mail, email, and community outreach. Consumer awareness and understanding of the benefits of SWH are critical to future development of the SWH industry. Consequently, SWHPP staff conducts training for potential SWH adopters in addition to regular and specialized training for contractors and self-installers. Since September 2007, over 550 homeowners have attended the program's SWH Basics for Homeowners workshop. The course provides a basic background on SWH system types, installations standards, and simple financials.

An important market barrier for contractors installing SWH systems is obtaining building permits. SWHPP is working to overcome this barrier by conducting training workshops with contractors and building officials. SWHPP staff held three workshops for building officials of the City of San Diego, County of San Diego, and City of Chula Vista. Additional presentations were given to the City of Oceanside, as well as local chapters of the International Code Council (ICC) and the International Association of Plumbing and Mechanical Officials (IAPMO). SWHPP is coordinating a SWH Inspector training session in collaboration with the Interstate Renewable Energy Council (IREC). SWHPP also developed training courses highlighting lessons learned from program installations to ensure that contractors apply the most current installation best practices for reliability, longevity, and performance.

Cost Effectiveness Analysis

One reason the CPUC established the pilot program was to evaluate the impact of incentives on cost-effectiveness. The key elements of cost effectiveness are equipment and installation costs, energy savings, and effective useful life (EUL) of the SWH system.

Equipment and Installation Costs of SWH

The average installed system cost in the SWHPP and in other regions is presented in **Table 3** [17]. The typical system type is provided for comparison because closed loop active systems are generally more expensive than open loop or passive systems. ICS and thermosyphon are passive systems.

Table 3. Average Installed SHW System Cost Comparison

Source	Average Installed System Cost	Typical System Type
CCSE SWHPP[3]	$6,518	Thermosyphon
Eugene Water and Electric Board (EWEB)[4]	$7,129	Closed loop, active
Hawaii Electric Company (HECO)[5]	$5,250	ICS
Northern Europe[22]	$6,592 - $9,229	Closed loop, active
China, India[22]	$395 - $527	ICS

Source: Itron 2009

Many of the regions investigated also have incentive programs (e.g. EWEB and HECO). Unfortunately, there are not enough data available from sources in regions without incentive programs to be able to make a comparison. The cost of systems in China and India is not reflective of the same quality of systems being installed in the US and Europe. Most of the installed system cost is equipment, which accounts for 57 percent of the total. Labor accounts for 23 percent of the total installation cost. Manufacturers and contractors who were interviewed stated that they did not expect these two cost components to decrease, as they believe material and fuel prices have increased and labor costs are already artificially low due to the limited market [17].

Energy Savings

The average annual energy savings for residential SHW systems reported by the SWHPP and shown in **Table 2** are based on SRCC estimated savings. The annual gas savings are 11.8 GJ, representing a solar fraction of approximately 54 to 60 percent of the California average annual natural gas water heating unit energy consumption (UEC) of 19.3 to 21.7 GJ for average residential single family customers [21]. The annual electric savings are 2,697 kWh representing an 88% solar fraction with respect to the California average annual electric water heating UEC of 3,079 kWh. CCSE is monitoring a sample of systems installed in the program to evaluate the actual average savings.

Effective Useful Life of SWH Systems

Warranty claim information from Hawaii is used to quantify the reliability of SWH components and evaluate the effective useful life of SWH systems [16]. **Table 4** shows warranty claims in Hawaii for 25,000 to 40,000 SWH components installed on SWH systems from 1996 to 2004. The Hawaii Electric Company (HECO) collected warranty claim data for systems receiving incentives under their SWH program. The Hawaii data shows 0.16 percent of collectors have warranty claims within 5 to 10 years. Approximately 0.08 percent of tanks have a warranty claims over a 5-year time frame and 0.14 percent of pumps and controllers have warranty claims within 1 to 10 years. Performance data are not yet available from the SWHPP, but equipment and installation requirements are similar to those required by the HECO incentive program, with additional freeze protection requirements. Trends in performance and reliability are expected to be similar to those seen in Hawaii.

Table 4. Warranty Claims in Hawaii from 1996 to 2004 (Source: HECO 2007)

Component	Equipment	Claims	Percent	Warranty Length (years)
Collectors	~ 40,000	63	0.16%	5 & 10
Tanks	~ 27,000	24	0.08%	5
Pumps	~ 27,000	38	0.14%	1.5
Controllers	~ 25,000	36	0.14%	10

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[3] SWHPP data from October 3, 2008 including systems not yet receiving incentive payments.

[4] Cost of average system in EWEB based on EWEB program data for 2008.

[5] Hawaii Electric Company (HECO). February 2009. Solar Water Heating Program Data. http://www.heco.com/portal/site/heco/

The HECO warranty data are used to estimate failure rates and the EUL of SWH systems [18] [24]. **Table 5** shows the hazard rate estimate for SWH systems based on HECO data. The hazard rate is defined as the number of failures per year divided by total installations. The time series of hazard rates is used to develop the survival function power curve fit coefficients and Weibull distribution parameters. **Equation 1** is used to calculate the survival function curves for the Weibull distribution.

Eq. 1. $\hat{v} = EXP(-\alpha * t^{\beta})$

Where, α = alpha, the estimated scale parameter,

t = time, years, and

β = beta, the estimated shape parameter.

Figure 1 shows the survival function for SWH systems with lower and upper bounds based on the Wiebull Analysis of the HECO data [8]. The median EUL is 72.4 years, the lower bound is 38.3 years, and the upper bound is 161.4 years.

Table 5. SWH Hazard Rate Estimate Based on HECO Data from 1996-2004

	Power Curve Fit Coefficients			Weibull Distribution Parameters	
Type of Measure	**A**	**B**	**R-squared**	**α (Scale)**	**β (Shape)**
SWH removed/failed	0.00046	1458613	0.863959	0.000018753	2.458613323

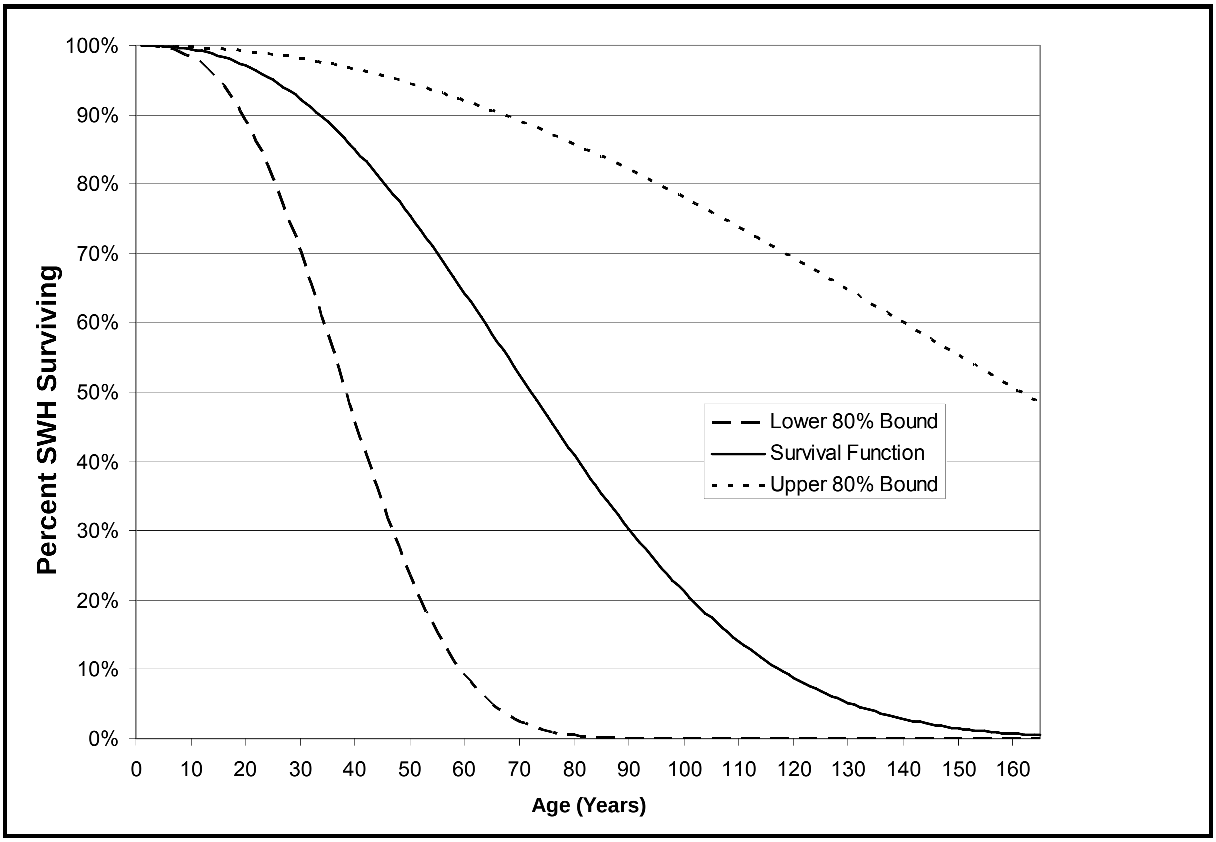

Figure 1. Survival Function Based on Warranty Claims for 27,000 SWH Systems

Societal Value of SWHPP

The societal value of the SWHPP program is evaluated with the total resource cost (TRC) test using the CPUC-approved E3 calculator developed by Energy and Environmental Economics, Inc. [11] [12]. Inputs to the E3 model are the incentives per SWH (**Table 2**), administrative budget per SWH incentive ($0.6875 per SWH incentive dollar), incremental measure cost per SWH (**Table 2**), energy savings per SWH (**Table 2**), number of SWH systems installed (Table 2), net-to-gross ratio (1.0), and EUL (lower bound of 38.3 years from Weibull Analysis). Based on these input assumptions, the TRC test is 1.13, indicating a positive benefit-cost ratio from ratepayer funds invested in the SWHPP.

A study by the California Solar Energy Industries Association (CALSEIA) quantifies the societal value of SWH and demonstrates how incentives pay for themselves many times over in the form of energy savings, cleaner air, and economic development. According to CALSEIA, every $0.40 invested in SWH returns between $0.90 and $3.50 to ratepayers in energy savings, health benefits, greenhouse gas reductions, and job creation [6]. The CALSEIA study quantifies the societal value of SWH in terms of: (1) direct savings from SWH versus indirect savings due to avoided water heater efficiency losses, (2) hedges against price volatility, (3) avoided emissions and associated health benefits, (4) avoided distribution losses, (5) avoided or deferred distribution capacity, and, (6) job creation potential.

Other SWH Programs

SWH Programs in the United States

Table 6 summarizes fourteen US SWH programs offering incentives, incentives with loan options, and utility-owned systems where the customer pays a monthly fee. Nine programs offer incentives similar to the SWHPP. The incentives include a one-time upfront incentive for residential projects and performance based incentives (PBIs) for larger commercial systems. Three programs offer zero- or low-interest loans in addition to incentive payments. One program offers utility-owned systems, where the utility pays for the system and metering equipment and the customer pays a monthly fee for water heating at a rate less than electric water heating. Programs with significant installations include PG&E, SoCalGas, SCE, and SDG&E programs with approximately 158,923 installations from 1980 to 1983, and the ongoing HECO program with 47,275 installations since 1996 and average installations of 3,940 per year [3]. The HECO and Eugene Water and Electric Board programs offer incentives plus loans to achieve greater participation rates. The Eugene program introduced a zero-interest loan option in 1995, resulting in a 67 percent increase in systems from the previous year. Offering loans in addition to incentives increases participation by lowering initial cost and spreading out payments over time. If loan payments are less than bill savings, then homeowners realize immediate savings.

Table 6. Summary of US Residential SWH Programs

Implementer	Program	Start-End Year	Eligible Fuel Types	Incentive	Installs	Annual Installs
SWHPP	Rebate	July 2007	Gas, Elec., Propane	Up to $1,500/Res and $75,000/Com	119	49
PG&E	Rebate	1980-83	Electric, Gas	$720 (E) $960 (G)	66,437	16,609
SoCalGas	Rebate	1980-83	Gas	$960 (Gas)	69,153	17,288
SCE	Rebate	1980-83	Electric	$720 (Elec.)	11,879	2,970
SDG&E	Rebate	1980-83	Electric, Gas	$720 (E) $960 (G)	11,454	2,864
City of Palo Alto Utilities	Rebate	May 2008	Electric, Gas	Up to $1,500/Res and $75,000/Com	6	6
Marin County	Rebate	June 2005	Electric, Gas	$300	8	3
Redding Electric Utility	Rebate	Jan. 2002	Electric	$1,000 1st Panel, $500 2nd, $250 3rd up to 50%	29	20
Arizona Public Services (APS)	Rebate	2002-2007	Electric	$0.45/kWh of est. 1st yr savings; up to 50%	258	51
National Grid	Rebate	Aug. 2007	Electric, Gas	15% up to $1,500	30	30
Hawaii (HECO)	Rebate/Loan	1996	Electric	$1,000	47,275	8,207
Eugene WEB	Rebate/Loan	1990	Electric	$600	1,030	57
SMUD	Rebate/Loan	1980, 2005	Electric	$1,500	200	67
Lakeland Electric	Utility-owned	1997-2002	Electric	n/a	60	12

Source: Itron 2009, CPUC 1984, City of Palo Alto 2009, HECO 2009,

International SWH Programs

A growing number of European municipalities, regions, and countries (e.g. Spain, Portugal, Italy, the Baden Wuerttemberg region in Germany, and some Austrian regions) are implementing **solar thermal ordinances,** legal provisions requiring owners of buildings to install a solar thermal system for new buildings or for buildings undergoing major renovation (http://www.solarordinances.eu/). Spain and Israel currently mandate SWH on all new construction. The European Solar Thermal Industry

Federation (ESTIF) estimates that there are currently 15.4 GW (22 million m^2 collector area) of solar thermal capacity installed in the European Member States with 1.918 GW (2.739 million m^2) installed in 2007 [14]. This achievement was accomplished through incentives, training, certification, standards, and public information on the technology [13].

Many successful SWH incentive programs have been implemented internationally. A report by the European Solar Thermal Industry Federation (ESTIF) provides an overview of successful incentive programs as well as case studies of European models which have succeeded or failed [13]. The primary features of successful SWH programs are consistent and continuing marketing support of SWH incentives. Offering consistent and long-term SWH incentives provides industry with confidence to make business investments. Programs that do not provide continuous support for SWH are likely to fail, and programs that stop and start are likely to cause more issues within the industry than having no incentive at all. Additionally, the ESTIF report stated that "By discussing, or even announcing, a support scheme in the future, the market actually decreased rather than increased" [13]. To develop a sustainable SWH market, the initial incentive must be high enough to stimulate market growth. Providing long-term guarantee of an incentive of any amount builds the confidence of industry participants, end-use customers, and financial organizations that may provide loans or financing to stakeholders. Creating this confidence will lead SWH businesses to invest in their companies and to hire and train new employees.

China has no government involvement or subsidies, but increasing interest in SWH. In 2004, China accounted for approximately 80 percent of world sales of collectors for SWH or heating buildings [22]. Some reports indicate that China has implemented quality control standards, while others indicate low quality products are still abundant in China [23]. In China, the demand for SWH is from an increase in the demand for hot water supply coupled with electricity and natural gas being unavailable in some areas. A similar situation existed in Israel in the 1950s when the government mandated that hot water only be used at certain times of day [26]. This influenced households to install SWH systems.

Best Practices Learned from Successful U.S. and International Programs

A number of best practices were learned during California's first experience with large-scale SWH programs from 1980 to 1983 including the development of standards for quality installation, solar collector performance certification, and solar system performance certification. The California utilities and solar industry also learned that sizing SWH systems based on number of bedrooms in a home (as required by the CPUC-mandated program) resulted in system failures because oversized systems stagnated (SWHPP requires system sizing based on number of occupants) [6]. Prior to the California large-scale SWH programs in 1980-83, there were no uniform rating systems, so the California utilities, CALSEIA, and California Energy Commission (CEC) worked together to establish testing and rating programs for solar collectors [6]. Inconsistencies between state testing and rating requirements created an impediment to manufacturers who marketed in more than one state. In order to develop a uniform national standard for testing and rating solar equipment, the solar energy industry and a national consortium of utilities, state energy offices, and regulatory bodies joined together to lay the groundwork for the Solar Rating and Certification Corporation (SRCC) [28]. In 1980 the SRCC was incorporated as a non-profit organization to develop and implement certification programs and national rating standards for solar energy equipment. SRCC is the only US certification program established solely for solar energy products. It is also the only national certification organization whose programs are the direct result of combined efforts of utilities and state organizations involved in the administration of standards and an industry association.

Recent experiences from successful U.S. and international SWH programs help identify the following five best practices to achieve success and avoid problems.

1) Incentive programs must include quality installation standards, training and verification of quality installation, technical assistance, and long-term warranties to increase system life.

2) Incentive programs must be established and guaranteed long-term so that the industry can make investments and grow their businesses with confidence that the support will not suddenly disappear. Programs supported with ratepayer funds are more likely to meet a long-term program design, as opposed to tax-supported programs that can be cut in times of economic hardship.

3) Incentive calculations must be designed with system performance in mind, as opposed to system size or cost. This will prevent oversized systems or over-priced systems, and will encourage higher-performing systems designed with the building owner's needs in mind. If the incentive is paid to the contractor, then the incentive needs to account for additional time for program requirements.

4) Incentive programs must be accompanied by a strong marketing campaign. Homeowners and business owners need to be made aware of the technology and benefits provided by SWH and marketing cannot be done by contractors and installers alone. A state- or utility-backed technology awareness campaign lends credibility to the industry and increases public knowledge. A joint marketing campaign between the incentive program and industry stakeholders will ensure success.

5) To avoid lost opportunities for energy savings, incentive programs should provide additional information and incentives for comprehensive energy efficiency measures, including WaterSense® showerheads and aerators, Energy Star® clothes washers and dishwashers, Energy Star® tankless gas water heaters, Energy Star® radiant barrier roof sheeting, and Energy Star® cool roofs (or recently installed roofs) at installation to reduce cooling loads and avoid the possibility of reroofing and removing the solar collectors.

Conclusions

The California Solar Water Heating Efficiency Act (AB1470) authorizes $250 million to transform the solar water heating industry and provide incentives for 200,000 solar water heaters starting in 2010. To get the program started, California is conducting a $2.6 million solar water heating pilot program in San Diego implemented by the California Center for Sustainable Energy. The pilot program provides quality installation standards and verification, training, technical assistance, and incentives to encourage widespread implementation of solar water heating in California. For residential systems, the maximum incentive is $1500 per dwelling. For larger commercial and industrial systems, the incentive is based on collector area. For open-loop systems the incentive is $161.46/m^2 and for closed-loop systems the incentive is $215.28/m^2. In late 2009, the pilot program will be scaled up statewide with a goal of installing 200,000 solar water heating systems by 2020.

The SWHPP paid a total of $166,734 in incentives through 2008, with $132,834 paid to 107 residential customers who used the prescriptive incentive and $33,900 paid to 12 commercial customers who used the collector area incentive. The program has received significantly more interest from residential customers than commercial customers. On average, residential customers have been paying $6,750 for a SWH system and receiving an incentive of $1,250. If all customers claimed and received a federal tax credit, the net cost would be decreased to $3,475. SWH has the technical potential to displace up to 127.9 PJ of natural gas per year in California. The 2.74 PJ per year of projected residential natural gas savings from the SWH measure included in the AB 32 Proposed Scoping Plan and AB1470 is a conservative estimate that represents less than 2% of the combined residential and commercial market technical potential for SWH estimated by KEMA-XENERGY. The expanded SWH measure considered in the AB32 Draft Scoping Plan represents only 10% of the total technical potential natural displacement for SWH in California.

The average SWHPP system installed cost is $6,518, and except for China and India, this cost is comparable to the cost for SWH systems in the US and Europe. The average annual residential energy savings are 11.8 GJ for SWH with gas back-up and 2,697 kWh for SWH with electric back-up. The effective useful life of SWH systems is estimated at 38.4 years based on Weibull Analysis of warranty claim data for 27,000 systems installed in Hawaii. Including program administration costs of $0.6875 per SWH incentive dollar, the total resource cost test is 1.13 for the SWHPP based on the E3 calculator demonstrating that the program is cost effective. The following best practices lessons can be learned from successful U.S. and International SWH programs: incentives and/or low-interest loans need to be long-term, based on system performance as opposed to size or cost, and accompanied with strong marketing campaigns to stimulate demand for solar water heating and the supply of contractors who can provide high quality installations. In addition, incentive programs must also include quality installation standards, training and verification of quality installation, technical assistance, and long-term warranties to increase system life. To avoid lost opportunities for energy savings, incentive programs should provide additional information and incentives for comprehensive energy efficiency measures including WaterSense® showerheads and aerators, Energy Star® clothes washers and dishwashers, Energy Star® tankless gas water heaters, Energy Star® radiant barrier roof sheeting, and Energy Star® cool roofs (or recently installed roofs) at installation to reduce cooling loads and avoid the possibility of reroofing and removing the solar collectors.

References

[1] California Assembly Bill 1470 (Huffman), October 12, 2007. Available online: http://www.californiaprogressreport.com/2007/10/california_sola.html.

[2] California Center for Sustainable Energy, October 12, 2007, *Solar Water Heating Pilot Program Handbook*. Available online: http://energycenter.org/uploads/SWHPP-PROGRAM-AND-TECHNICAL-HANDBOOK-071012.pdf.

[3] California Public Utilities Commission. May 1984. Order Instituting Investigation No. 42. CPUC ordered the four largest investor-owned utilities (PG&E, SCE, SCG, and SDG&E) to implement SWH programs to install 200,000 SWH systems serving 375,000 existing residences.

[4] California Public Utilities Commission, January 12, 2006, Decision 08-06-029. http://californiaenergyefficiency.com/docs.

[5] California Public Utilities Commission, September 2008, *California Long Term Energy Efficiency Strategic Plan: Achieving Maximum Energy Savings in California for 2009 and Beyond.* http://californiaenergyefficiency.com/docs/EEStrategicPlan.pdf.

[6] California Solar Energy Industries Association (CALSEIA). September 12 2008. *California Solar Energy Industries Association Post-Workshop Comments on Evaluation of the Solar Water Heating Pilot Program.* CPUC Rulemaking 08-03-008.

[7] California Solar Energy Industries Association (CALSEIA). January 2009. *The Value Proposition of Solar Water Heating in California*. http://calseia.org/news/calseia-report_swh-value-proposition2.

[8] Collett, D., 1994. *Modeling Survival Data in Medical Research*. Chapman & Hall. pp. 260-264.

[9] Del Chiaro, Bernadette, and Timothy Tellen-Lawton, April 2007, *Solar Water Heating: How California Can Reduce Its Dependence on Natural Gas*, Environment California Research & Policy Center. http://www.environmentcalifornia.org/uploads/Solar-Water-Heating.pdf.

[10] Denholm, P., March 2007, *The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States*, NREL, Technical Report, NREL/TP-640-41157. http://www.nrel.gov/docs/fy07osti/41157.pdf.

[11] Energy and Environmental Economics, Inc., and Rocky Mountain Institute, October 25, 2004, *Methodology and Forecast of Long Term Avoided Costs for the Evaluation of California Energy Efficiency Programs*, prepared for the CPUC. http://www.ethree.com/cpuc_avoidedcosts.html.

[12] Energy and Environmental Economics, Inc., March 20, 2006, *Avoided Cost Calculation Spreadsheets, Updated Electric and Gas Avoided Costs – 2006 Update (5/23/06 Draft Decision): Natural Gas Avoided Costs*. http://www.ethree.com/cpuc_avoidedcosts.html.

[13] European Solar Thermal Industry Association (ESTIA). April 2003. *Sun in Action II – A Solar Thermal Strategy for Europe, Volume 2, The Solar Thermal Sector Country by Country: 21 National Reports*. http://www.estif.org/publications/market_data/detailed_analyses_of_21 national_solar_thermal_markets.pdf.

[14] European Solar Thermal Industry Federation. 2006. *Financial Incentives for Solar Thermal: Guidelines on Best Practice and Avoidable Problems.*

[15] European Solar Thermal Industry Association (ESTIA). June 2008. *Solar Thermal Markets in Europe: Trends and Market Statistics 2007*. http://www.estif.org/publications/market_data/Solar_Thermal_Markets_in_Europe_2007.pdf.

[16] Hawaii Electric Company (HECO). January 19, 2007. *Solar Water Heating Program Details*. Presentation by Ron Richmond. Hawaiian Electric Company (HECO 2007).

[17] Itron, Inc. January 16, 2009. *California Center for Sustainable Energy Solar Water Heating Pilot Program: Interim Evaluation Report. Final Report*. http://www.calmac.org/publications.

[18] Kalbfleisch, J.D., and Prentice, R.L., 1980. *The Statistical Analysis of Failure Time Data*, John Wiley and Sons, New York, NY.

[19] KEMA-XENERGY Inc., May 14, 2003, *California Statewide Commercial Sector Natural Gas Energy Efficiency Potential Study (Study ID #SW061): Final Report*. http://www.calmac.org/publications/Commercial_Gas_EE_report_V1.pdf.

[20] KEMA-XENERGY Inc., April 2003(a), *California Statewide Residential Sector Energy Efficiency Potential Study (Study ID #SW063): Final Report*. http://www.calmac.org/publications/Res_EE_Potential_Study_V1.pdf,

[21] KEMA-XENERGY, Itron, and RoperASW. *2003 California Statewide Residential Appliance Saturation Survey*. Publication # 400-04-009. Prepared for California Energy Commission. 2004. http://www.calmac.org/publications/RASS-CALMAC_V1.pdf.

[22] Menanteau, Philippe. *Policy Measures to Support Solar Water Heating: Information, Incentives and Regulations*. World Energy Council. May 2007.

[23] Milton, Samuel and Steven Kaufman. *Solar Water Heating as a Climate Protection Strategy: The Role for Carbon Finance*. January 2005.

[24] Mowris, R. Noack, R. February 24, 2005. *Ninth Year Retention Study of the 1995 Southern California Gas Company Commercial New Construction Program. Appendix C – Weilbull Analysis of Measure Effective Useful Life.* Study ID 718A. http://www.calmac.org.

[25] Navigant Consulting, September 15, 2008, *Economic Impacts of Extending Federal Solar Tax Credits: Final Report*, Prepared for the Solar Energy Research and Education Foundation (SEREF). http://www.seia.org/galleries/pdf/Navigant%20Consulting%20Report%209.15.08.pdf.

[26] Ramlow, B. *90% of Israeli Homes Have Solar Water Heaters*. http://www.metaefficient.com/hot-water-systems/90-of-israel-homes-have-solar-water-heaters.html.

[27] Solar Rating and Certification Corporation, December 5, 2008, *Summary of SRCC Certified Solar Collector and Water Heating System Ratings*. 1679 Clearlake Road, Cocoa Beach, FL 32922. http://www.solar-rating.org/SUMMARY/Dirsum.pdf.

[28] Solar Rating and Certification Corporation. http://www.solar-rating.org/ABOUT/ABOUT.HTM

[29] U.S. Department of Energy, June 2008, Table A4 (pp. 122-123) and Table G1 (p. 215). Swimming pools are not included in water heating consumption statistics. *See* Residential Energy Consumption Survey Glossary, http://www.eia.doe.gov/emeu/recs/glossary.html.

Heating, Ventilating and Air Conditioning (HVAC)

Dynamics of the AC Markets Worldwide

Tanja Heidingsfelder
Tobias Kupczyk

GfK Retail and Technology

Abstract

Against the background of an increasing popularity of air conditioners (ACs) around the world and the implications of this development in terms of energy consumption, this paper is going to provide empiric information on the current situation of the AC markets. The analysis is mainly based on market information from GfK AC Retail Panels, but also on GfKs World Market Estimation.[1]

The importance of energy-efficient appliances is acknowledged in most countries today. When examining the present state of the markets in China, South America, the Arabian Peninsula and Southern Europe, it becomes clear that only demanding efficiency standards and decided action by all players involved will lead to the necessary changes in customers' buying decisions.

Introduction

Much debated in the past, the ongoing rise in average temperature all over the world is a widely accepted fact in 2009 (see figure 1). These changes affect moderate climates. The further one approaches the equator, though, the more unpleasant are the consequences of such a development.

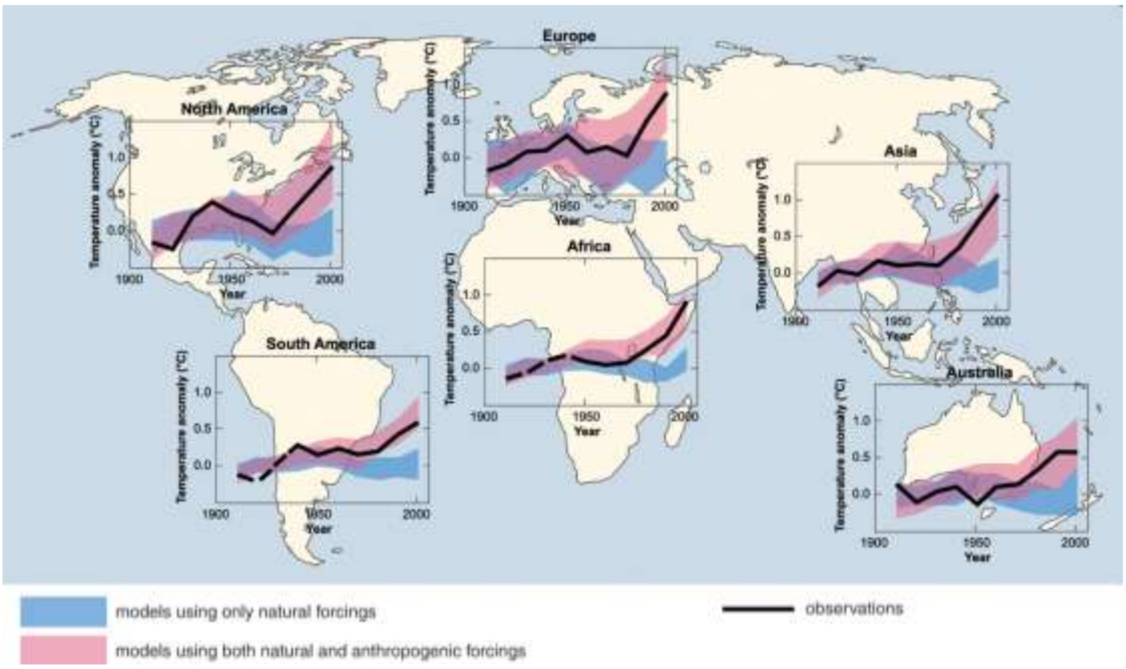

Figure 1: Development of average temperatures during the past decades

Source: Intergovernmental Panel on Climate Change, www.ipcc.ch

1 The *GfK World Market Estimation* [1] consists of estimated information (market size in units and value, average prices) for many technical consumer goods markets and all countries of the world. Furthermore, GfK is tracking AC sales in 45 countries by means of its *Retail Panels* [2]. These panels provide a detailed overview of the markets during the past weeks, months and years and include information from the total market sizes down to single model information (sales, distribution, features etc.).

At the same time regions that are strongly affected by these climate changes have been experiencing a constant growth of their GDP per capita during the past years. [3] [4] This is why the sales of ACs – not yet a standard appliance in many of these developing countries [5] – have been rising considerably during the past years and can be expected to rise further in the future. The number of people who have to endure a hot climate and do have the money to enhance their quality of life by buying an AC is getting bigger and bigger.

This in mind, it is crucial to establish mechanisms soon, which foster the diffusion of energy-efficient appliances around the world. For once somebody has bought an inefficient AC, it might run for many years before it breaks down and is replaced by a more efficient model.

State and Structure of AC Markets around the World

According to GfK's World Market Estimation [1] China held the highest share of the worldwide AC market (23.0%) in 2008. Brazil (3.3%) was the biggest market in South America. Saudi Arabia (1.9%) and the United Arab Emirates (0.9%) are going to be analyzed as representatives from the Middle East. Spain (1.2%) and Italy (0.8%) were the most important European countries.[2] A units-based approach is chosen for this case study analysis, because it is the single unit that consumes energy, not its sales value.

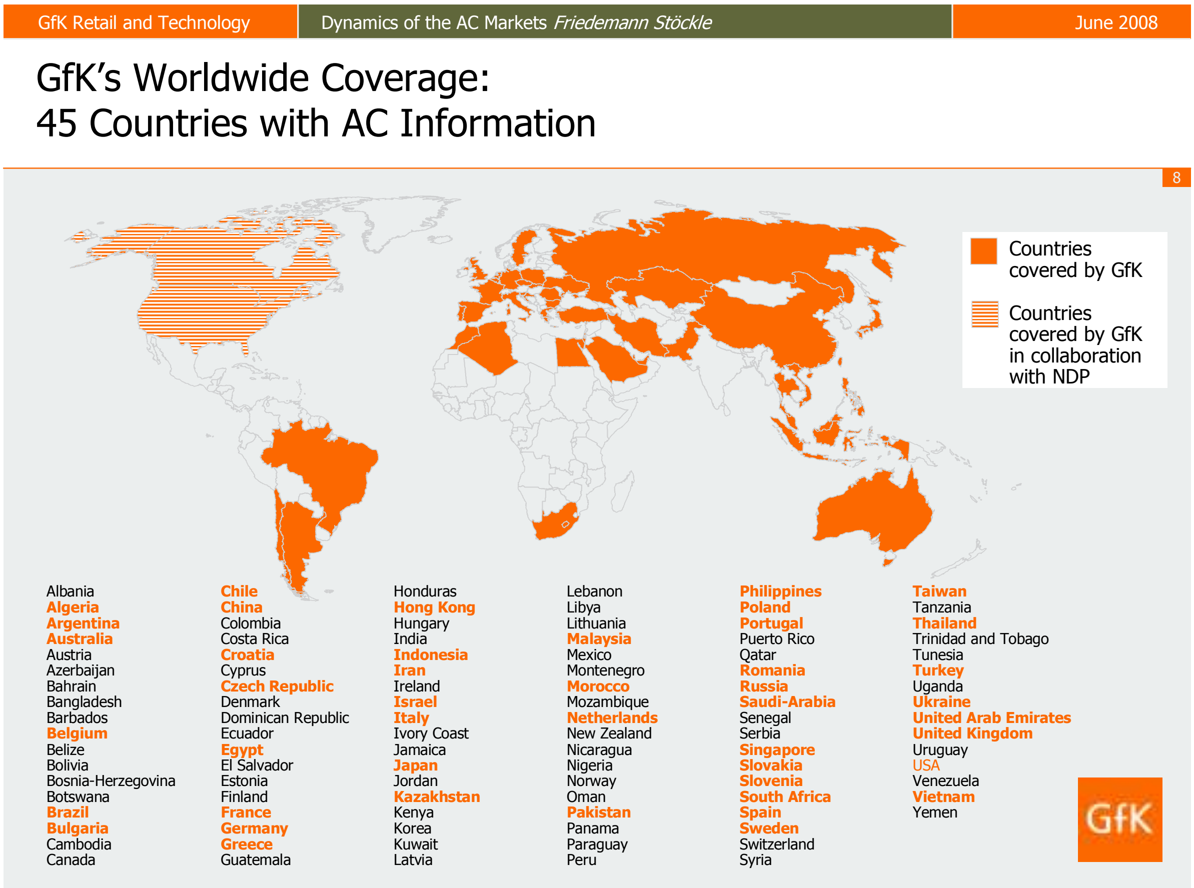

Figure 2: GfK AC Retail Panel information from 45 countries around the world

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[2] GfK is running an AC retail panel in North America with its partner company NDP. Since the data are not directly comparable to the pure GfK panel data, the region is excluded from this analysis. It definitely is one of the largest AC markets worldwide, though, especially because of the high importance of powerful and energy consuming central ACs. [6]

The Efficiency Label Situation

The countries of interest currently are at very different stages in the process of defining, implementing and enforcing energy efficiency standards. Saudi Arabia and the United Arab Emirates are aware of the need of such standards today. [7] However, a mandatory label for ACs has not been introduced yet. In China, such a label exists since 2000 and was revised in 2005. Still, the resources necessary for monitoring of the compliance with the defined standards seem not to be sufficient. [8] Brazil has introduced an energy efficiency label in the framework of a national initiative aiming at the conservation of electric energy. However, like in China the effects on the market are small due to insufficient funding. [9] The European administration has issued several directives introducing uniform energy efficiency standards for all its member states in 1998 and has developed a related mandatory label. [10]

This in mind, it is not surprising that valid energy efficiency information cannot be obtained from the GfK Retail Panels in all countries. Still, it is possible to show links between price, maximum cooling power and energy efficiency in the following.

Price, Cooling Power and Energy Efficiency

The demand for cooling power is different from one region to another (see figure 3). In Italy and Spain most units are equipped with 8.000 to 12.000 BTU, whereas in Saudi Arabia and the United Arab Emirates there are hardly any sales below 16.000 BTU. In contrast, most units in Brazil are less powerful (most units with less than 8.000 BTU). The same applies to China (most units below 12.000 BTU). However, considerable sales can be observed for the ranges beyond 16.000 BTU in both countries, too.

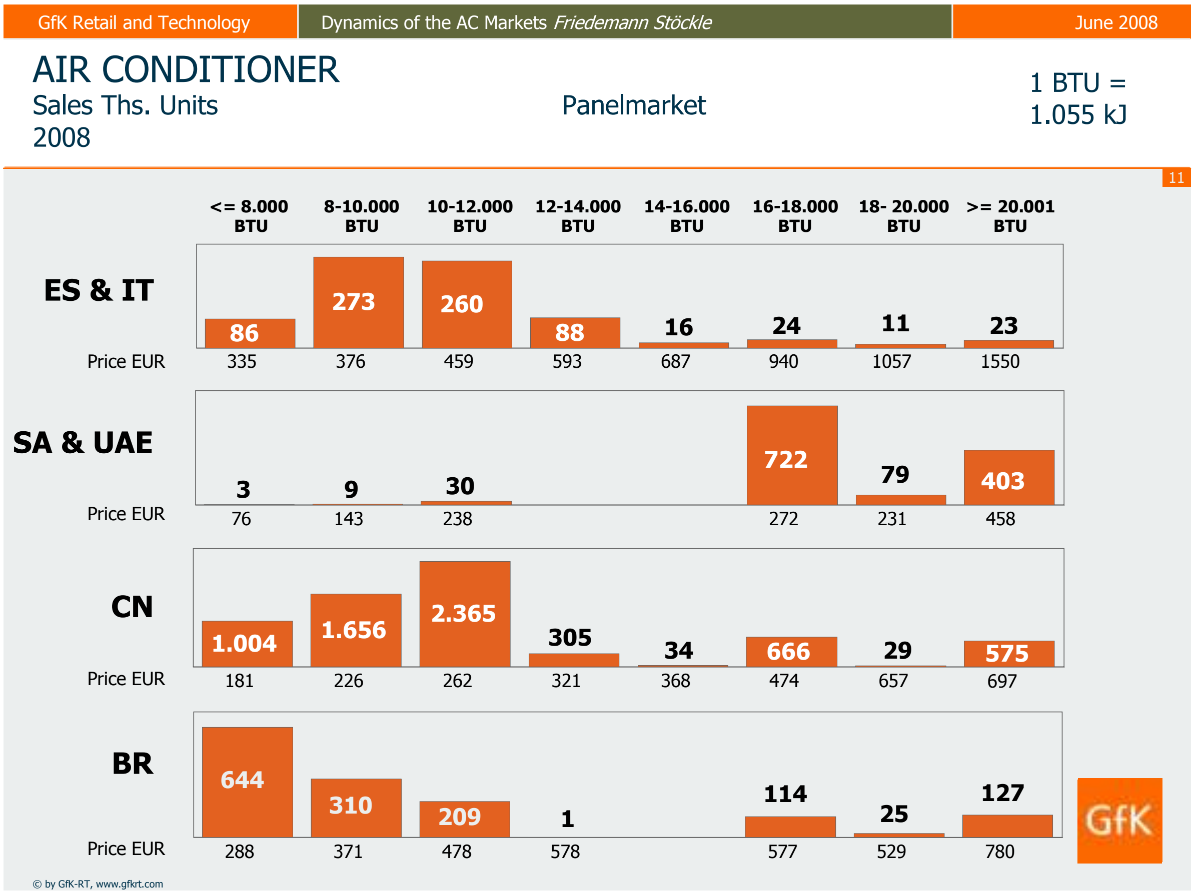

Figure 3: Sales units and average prices in different BTU classes

Source: GfK AC Retail Panel

A clear interrelation between cooling power and price can be attested for all countries assessed. This could be expected. However, the price for a unit with a certain cooling power varies strongly from country to country. The cheapest ACs one can buy in China and Saudi Arabia followed by Brazil. The average prices in the single BTU classes are highest in Southern Europe.

When comparing the top 3 models from Southern Europe and China in the range from 8.000 to 12.000 BTU, which is very important in these countries, it becomes clear where the price differences come from (see figure 4). In Europe the price for a certain feature equipment is higher in general. In addition, there are two models with an inverter among the top 3. These models cost considerably more than models without inverter technology. Both of them do have an A energy efficiency rating. In China, in contrast, there is no model with an inverter among the top 3 and only one among the top 10. Prices are generally lower.

The top models in both hitlists are a relatively cheap, though. The No. 1 appliance from Italy and Spain only carries a D efficiency label. For the Chinese models energy efficiency information is not available. Still, it is not likely that these models are less expensive and worse equipped, but more efficient at the same time. Thus, the enforced energy efficiency regulation in Europe might be seen not only as a driver of prices, but also as a driver of innovation.

The share of labeled units is still pretty different around the world. Against the background of the previously described varying needs for cooling power, it might be interesting to define important BTU ranges for single markets and examine them closely now.

In 2008 less than one quarter of the units sold in the Arabian countries were carrying a label A to C (16.000 to 18.000 BTU). This could be expected, because an energy efficiency label does not exist yet in Saudi Arabia and the United Arab Emirates. Thus, the labeled appliances presumably were imported from other countries. The average price of the ACs not labeled is a little lower. Although there is no information available regarding the energy efficiency of these less expensive models, it might be lower, too. Should it be the same, it still could not be controlled by comparing the actual energy consumption of a certain model to its efficiency claimed by a defined label. That is why the need for an effective efficiency regulation is indisputable.

When looking at the AC market in Brazil (0-12.000 BTU) the picture is different. Half of the units are sold with a Brazilian A-label. The other half carries no label. The average price of the latter is slightly higher than the price of the former. This can be explained by the popularity of an inexpensive type of AC that uses cool humidified air and does not consume as much energy as a conventional AC.

CN		TYPE	ENERGY EFFICIENCY	HEATING INCL.	INVERTER	SINGLE/ SPLIT	Sales Ths. Units	Price EUR
1.	Model	FIXED		YES	NO	SPLIT	65	227
2.	Model	FIXED		YES	NO	SPLIT	52	206
3.	Model	FIXED		YES	NO	SPLIT	46	254

IT&ES			ENERGY EFFICIENCY	HEATING INCL.	INVERTER	SINGLE/ SPLIT	Sales Ths. Units	Price EUR
1.	Model	FIXED	D	NO	NO	SPLIT	9	362
2.	Model	FIXED	A	YES	YES	SPLIT	9	564
3.	Model	FIXED	A	YES	YES	SPLIT	8	664

Figure 4: Top 3 models (8.000-12.000 BTU) in Southern Europe and China 2008

Source: GfK AC Retail Panel

This supports the previously cited finding that the efficiency labeling is not enforced in Brazil despite of the aforementioned system that was introduced by the government. The high shares of A-labeled models on the one side and not labeled appliances on the other side suggests that energy efficiency is more a marketing tool in Brazil than an objective help for the customer when buying an AC.

Finally, in Italy and Spain roughly 60% of the sales units with 8.000 to 12.000 BTU did carry an A-label in 2008. The average price of these units was considerably higher than the prices of units with B-, C-, and D-labels. If you wanted to buy an energy efficient appliance, you had to pay a surcharge in these countries. What catches the eye is that for around 20% of the units there is still no energy efficiency information available. The main reason for this situation is missing information on the efficiency from the manufacturers' side, since GfK relies on this information when coding the single AC models.

To sum up, in Southern Europe the AC energy labeling seems to impact the markets in the desired way. Most units are sold with an A-label despite of a higher average price of these units. As figure 5 shows, this was not always the case: Since 2005 the share of efficient ACs has been growing in Italy and Spain. At the same time, the importance of less efficient appliances has been decreasing, as well as the share of models without label information available. This suggests that the current regulations by the European Union have successfully changed the AC markets in Europe in terms of energy efficiency.

This interpretation does not deliver a complete picture, though. During the past four years the share of ACs with inverter technology sold in Southern Europe has been rising from 14 to 30%. As figure 6 shows, these inverter ACs do have a significantly higher maximum cooling power and, thus, a higher maximum energy consumption than models without inverter. Whether their actual energy consumption is higher, too, cannot be evaluated based on GfK's panel information. Yet, what is

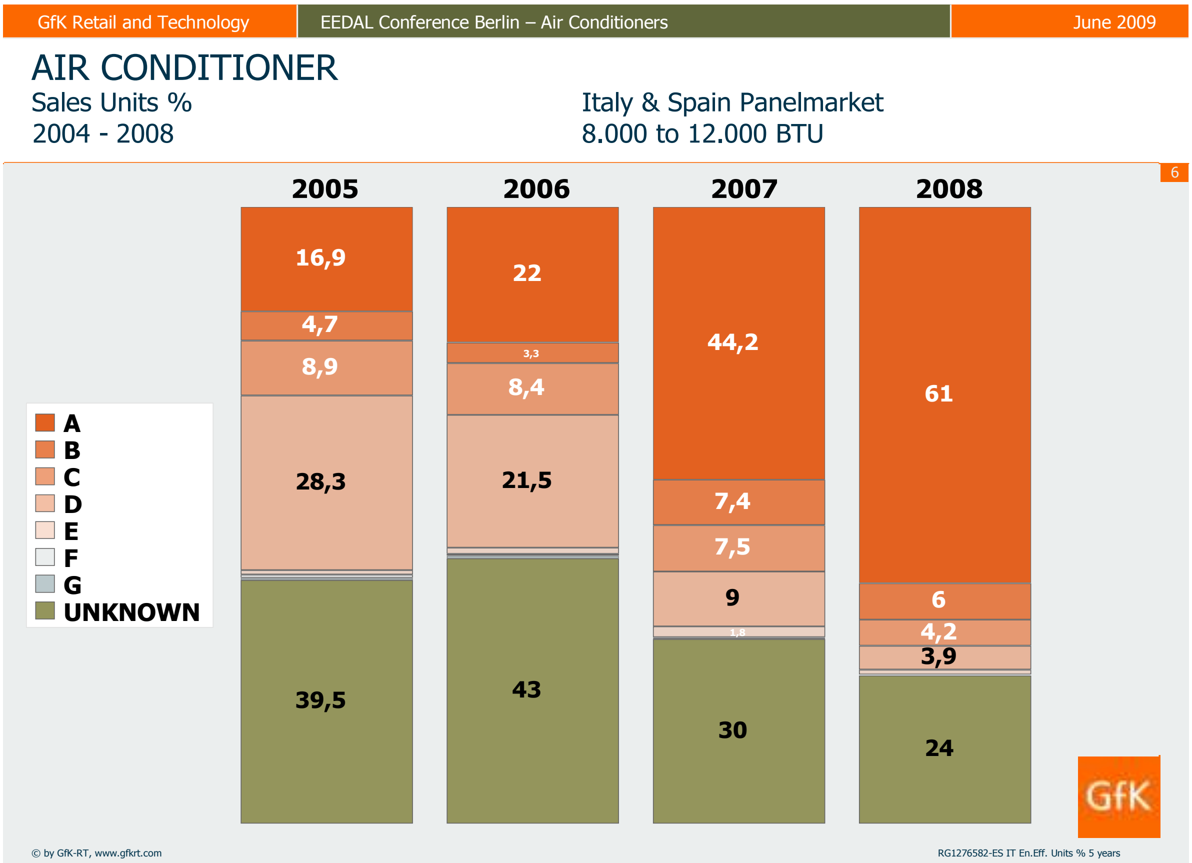

Figure 5: Share of energy efficiency classes in Southern Europe (2005-2008)

Source: GfK AC Retail Panel

obvious is that the desired development towards an increasing share of A-labeled units in Southern Europe might have been undermined by a trend towards more powerful inverter ACs from a viewpoint of total energy consumption.

Conclusions

This paper has shown that despite an increasing demand for ACs in most countries, the appliances sold in the various regions under examination are quite different. They are different regarding price and cooling power, which are correlated in all countries. They are different regarding their feature equipment and last, but not least they are different as regards their energy efficiency.

This situation can be interpreted as a reflection of the varying degrees of regulation. For Europe, it is obvious that the compulsive labeling introduced in 1998 is a success in terms of an increasing share of efficient models. Whether this development came along with a decline of the total energy consumption is questionable, though, due to the trend towards more powerful inverter ACs.

It is arguable whether the European labeling system can be directly transferred to other regions of the world, for certainly it did not do the whole job in Europe. The labels only hint at the energy consumption and, thus, the eco friendliness of an appliance. From the customer's point of view, purchase price, cooling power and the development of energy prices will also be considered in the train of the buying decision. This is why, when thinking about the regulation of AC markets around the world, a framework adequate to the local context has to be developed and put in to practice, which accounts for all these factors and, thus, can influence the customers and manufacturers in the aspired way. This is successfully happening in the field or major domestic appliances these days. So, why should it not be possible for ACs?

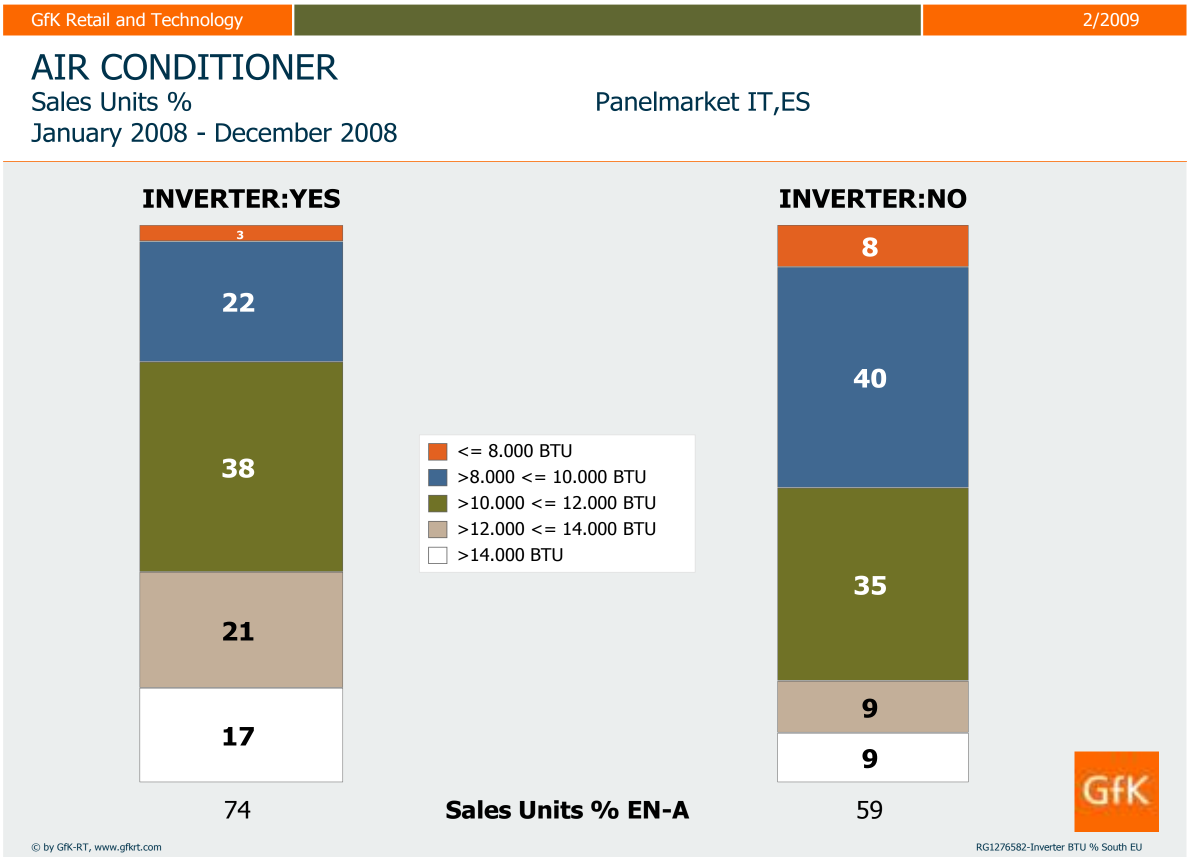

Figure 6: Share of BTU classes in models with and without inverter (Southern Europe)

Source: GfK AC Retail Panel

References

[1] GfK Retail and Technology (2008): *World Market Estimation 2008*
The GfK World Market Estimation consists of estimated information (market size in units and value, average prices) for technical consumer goods markets and all countries of the world. It is based on GfK Panel Data and panel coverage, but also on socio-economic indicators like the population number, the number of persons per household, religion, climate, and cultural peculiarities. However, it is an estimation of the B2C sales via electric retailers and mass merchandisers. Thus, for countries where B2B sales are playing an important role, the figures might seem lower than expected by readers familiar with the AC markets. Sales via professional bulk buyers (e.g. in the context of housing projects) or via electric installers are not included. The same applies to powerful central air conditioners for office buildings as well as private homes. Further information is available from http://www.gfkrt.com

[2] GfK AC Retail Panels
GfK is tracking AC sales in 45 countries by means of its retail panels. These panels provide a detailed overview of the markets during the past weeks, months and years and include information from the total market sizes down to single model information (sales, distribution, features etc.). They cover the same market segments as described under [1]. Further information is available from http://www.gfkrt.com

[3] OECD Factbook (2008): *Economic, Environmental and Social Statistics*.
Can be downloaded at: http://dx.doi.org/10.1787/266710014804

[4] The World Bank (2008): *World Development Indicators*, p. 194
Can be downloaded at: http://siteresources.worldbank.org/DATASTATISTICS/Resources/WDI08_section4_intro.pdf

[5] Fridley, David et al. (2001): *Technical and Economic Analysis of Energy Efficiency of Chinese Room Air Conditioners*. Lawrence Berkeley National Laboratory, University of California, Berkeley.

[6] BSRIA (2008): *Review of the World Air Conditioning Market 2007*. Available from: http://www.bsria.co.uk/news/1997/

[7] Emirates Energy Award (2008): *EEA Brochure*, p. 2. Can be downloaded at: http://www.eeaward.ae/eeaward_brouchure.pdf

[8] Zhou, Nan (2008): *Status of China's Energy Efficiency Standards and Labels for Appliances and International Collaboration.* Lawrence Berkeley National Laboratory, University of California, Berkeley. Can be downloaded at:
http://china.lbl.gov/files/LBNL%20251E.%20Status%20of%20China%27s%20Energy%20Efficiency%20Standards%20and%20Lables.%20Mar2008.pdf

[9] Robert P. Taylor et al. (2008): *Financing energy efficiency: lessons from Brazil, China, India, and beyond.* The World Bank 2008.

[10] Deutsche Energieagentur (2009): *EU-Label in der Übersicht*. Further information at: http://www.stromeffizienz.de/eu-label/eu-label-in-der-uebersicht.html

Energy consumption of European residential comfort fans

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Abstract

A recent study in the "Ecodesign of EuP" frame allowed for the first time to address this product. We summarize here the estimated energy consumption of this product. We are speaking of more than 200 million pieces of equipment in use in year 2005. We are speaking of about 3 to 4 TWh of electricity consumption each year in Europe.

Introduction

Market research about comfort fans is almost inexistent in Europe. A recent study in the "Ecodesign of EuP" frame allowed for the first time to address this issue. We summarize here the estimated energy consumption of this product by using the methodology drafted in [1] the detailed results can be found in [2].

Comfort fans are used to increase local comfort in residences. For the first time sales data were interpreted to generate a market model and future sales and stock figures for that equipment which is in competition with air conditioners to provide some thermal discomfort release in Summer.

Is it a negligible plug-in product? We are speaking of more than 200 million pieces of equipment in use in year 2005. We are speaking of about 3 to 4 TWh of electricity consumption each year in Europe, as will be shown.

Ventilation fans, whose objective is to maintain Internal Air Quality (not thermal comfort), are not treated in this paper. Three products that occupy the main market shares in the European country (local (small fans in rest rooms), kitchen hoods (with a number of non-ventilation functions) and central ventilation, frequent in countries with stringent building air tightness regulations) are studied in [3].

Comfort fans in Europe

Description of appliances in the scope of the study

Using fans and moving air in a room is a way people can choose to improve their individual summer comfort. By generating air movement close to the body, comfort fans increase convection and evaporation and by this way the feeling of comfort. Thus, using comfort fans improve the individual summer comfort without lowering the room temperature. In fact, the inside temperature is even likely to increase since the comfort fan motor produces heat.

On the other hand, fans should not be used as a primary cooling device during extended periods of excessive heat. Electric fans may provide relief, but when the temperature is above 35 °C, fans will not prevent heat related illness [4] but on the contrary will contribute to heat exhaustion. An indoor climate stress diagram should guide use of summer comfort fans.

Comfort fans can be used to avoid the use of air conditioners during the summer period and provide an "acceptable comfort", but it can also be used as a complement to this device. When air conditioning is used, a fan can help to better circulate the cool air through the room, allowing the system to run less often . Comfort fans have various subtypes, see Table 1.

Table 1. Different types of comfort fans and their technical characteristics

Type	Typical characteristics	Example
Table fan – Desk fan 	Propeller diameter: 250-400 mm Air flow: 1300-3600 m^3/h Electrical supply: 35-60W	Delhongi
Pedestal fans 	Propeller diameter: 250-450 mm Air flow: 2000-4500 m^3/h Electrical supply: 40-70 W	Alpatec
Floor standing fans 	Propeller diameter: 300-500 mm Air flow: 3000-6000 m^3/h Electrical supply: 40-120W	Alpatec
Wall mounted fans 	Propeller diameter: 250-400 mm Air flow: 1300-3600 m^3/h Electrical supply: 35-60W	
Ceiling fans 	Propeller diameter: 900-2000 mm Number of blade: 3-5 Electrical supply: 50-150W (without lights)	Coolandwarm
Tower fans 	Height: 350-1400 mm Air flow: 400-2200 m^3/h Electrical supply: 35-50W	Alpatec
Box fans 	Propeller diameter: 250-400 mm Air flow: not specified Electrical supply: 35-60W Louvers available to orientate the flow	Rovex

Most fans have various speeds. Part of the fans are oscillating horizontally (if the user demands it) and a few even oscillate vertically. We have observed the existence of a new type of fan (called "2cool" by Bionaire) with a higher electricity consumption than usual products (90 W) using two "fans": higher velocity in the center (25 cm), large coverage of sides (40 cm) (see Figure 1).

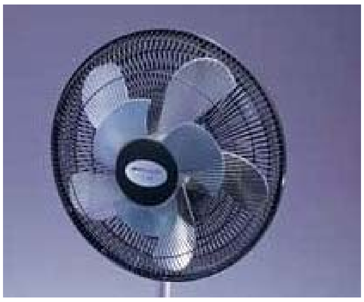

Figure 1. "2cool" fan by Bionaire

Some important figures

The shares of types in the offer of models are dominated by Pedestal, Table and Tower fans as shown in the Figure 2.

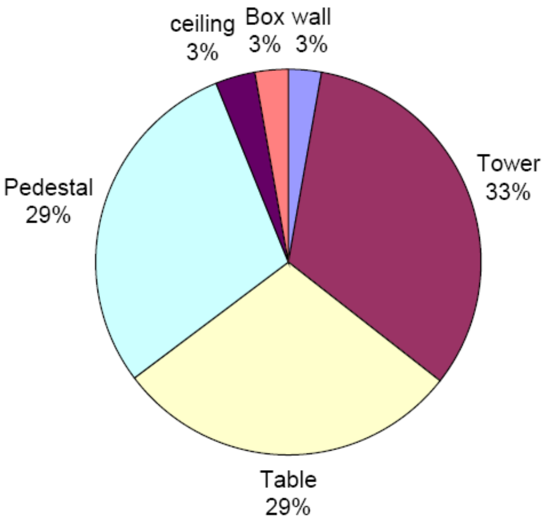

Figure 2. Market shares between the different models of comfort fans [2]

Gathering information from different sources (stakeholders, Prodcom data…), sales figures were reconstructed [2]. The market, which is only covered by imports, is around 25 million units per year, displaying huge variations that we can relate with the 2003 heat wave: from 10 to 36 million units per year (see Figure 3). All those products are imported and come from one single country, China, where they are produced with the lowest possible cost.

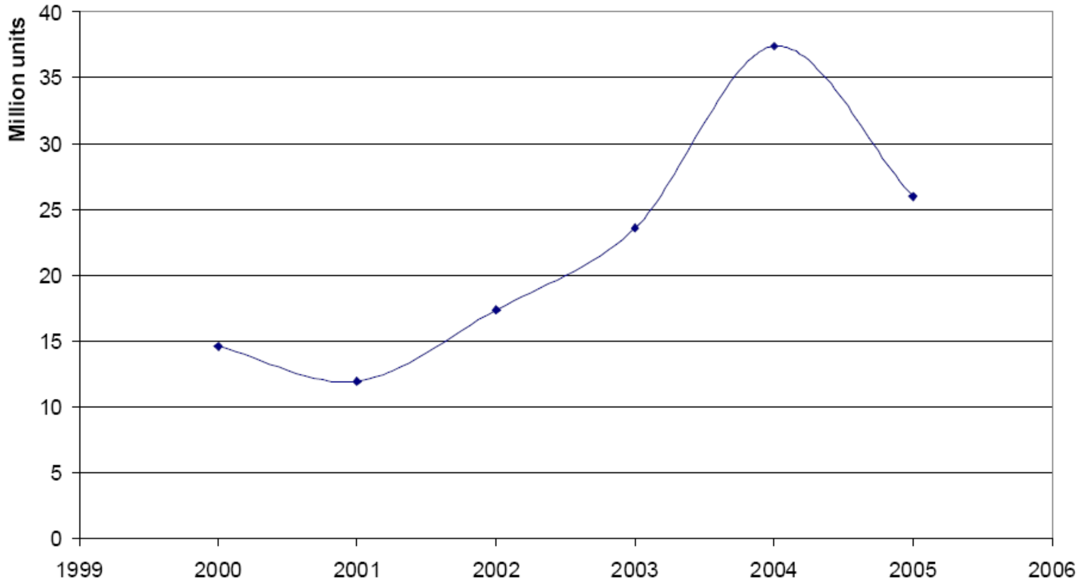

Figure 3. Sales of comfort fans between 2000 and 2005 for EU 25 in Million of units

Estimate of the average number of operation hours in Europe taking into account part load

In order to access energy consumptions due to comfort fans, it is necessary to calculate operation hours. Our approach consisted in starting from the very theory of thermal comfort assessment.

Does a comfort fan provide comfort?

In order to understand the time duration during which fans are used and the speeds of operation that are used, it is necessary to come back to the comfort definition itself. What the user is expecting from the product and what he obtains finally determine its way of using it. Hence, the number of hours of operation will be estimated from the study of discomfort.

Numerous human thermal comfort studies have been carried out to analyze and quantify the positive and negative effects on thermal comfort of air flows and in particular of airflow due to comfort fans. Arens [5] showed that the cooling effect of personally controlled fans was approximately 1 °C by 0.1 m/s increment of air speed. This study was carried out under specific conditions, mainly air temperature from 24 °C to 31 °C, activity level of 1.2 met (sitting in activity) and clothing equivalent to 0.5 clo (summer light clothes). Furthermore, Arens compared his results from experiments to results obtained with Fanger's indexes and found that they were close with a 5 % difference. Effects of ceiling fans on the summer comfort zone have also been studied by Roshles [6] in experiments gathering eight subjects. They considered that air movement was pleasant up to 1 m/s at 29.5 °C and the turbulence of the flow was a beneficial aspect.

First of all, potential cooling benefits of air flow in summer are presented in several standards: it translates the idea the summer thermal comfort zone may be extended by increasing the air speed. For instance, the 2004 ASHRAE standard 55 proposes in summer conditions, to relate the comfort temperature to the air speed and the difference between the mean radiant temperature and ambient temperature [7] (Figure 4). The combinations of air speed and temperature defined by the lines in this figure result in the same heat loss from the skin. The indicated increase in temperature pertains to both the mean radiant temperature ant the air temperature. That is, both temperatures increase by the same amount with respect to the starting point. When the mean radiant temperature is low and the air temperature is high, elevated air speed is less effective at increasing heat loss.

The 2004 ASHRAE standard 2005 contains some limitations and obligations when air speed is increased inside a room. Thus, elevated air speed may be used to offset an increase in the air temperature, but not by more than 3 °C above the values for the comfort zone without elevated air speed. The required air speed may not be higher than 0.8 m/s in order to avoid disturbance like paper flying and draft but also because there are large individual differences between people with regard to the preferred air speed. In this way, the elevation of air speed must be controlled by affected occupants and adjustable in steps no greater than 0.15 m/s. This kind of approach consisting in expressing the cooling sensation (temperature rise in °C) of uniform air flow according to the air speed can also be found in many research works like for example those of Szokolay [8].

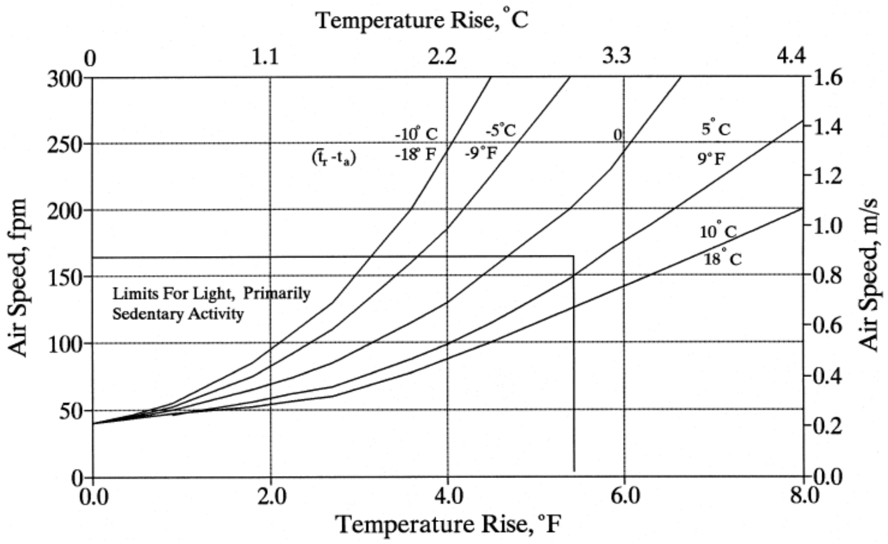

Figure 4. Airspeed required to offset increased temperature, source ASHRAE

This approach is based on comfort indices developed by Fanger [9]: the PMV ("Predicted Mean Vote") and the PPD (Predicted Percentage of Dissatisfied). These indexes mainly depend on six parameters, four ambiance ones (air temperature, mean radiant temperature, air velocity, relative humidity) and two concerning the individual (physical activity, clothing thermal resistance). In order to predict thermal sensations, Fanger assumed that the human thermal balance must be null which leads to a first formula. It means that the individual exactly looses the heat produced by the metabolism. In addition, Fanger realized experiments in climate chambers to correlate metabolism with mean skin temperature and sweating. In more details, the PMV equation assumes that deviations from the human thermal balance vary with thermal comfort vote. A PMV equal to zero represents the optimum comfort when the thermal balance is null. This index can vary from –3 (cold) to 3 (hot). It is also possible to predict the reaction of individuals thank to the PPD index that aims at calculating the expected number of thermally dissatisfied people in a group according to the PMV. PMV and PPD are used in several standards where comfort zone are often defined by limiting the PMV between –0.5 and 0.5 (ie less than 5 % of unsatisfied people according to the PPD). In a further study ([10]), Fanger stated that the quantitative influence of air velocity is in good agreement with PMV and PPD equations.

So, our conclusion is that comfort fans do provide a cooling function that can be compared with the cooling obtained with an undersized air conditioner, so that there will be a remaining discomfort in the case of the comfort fan whereas there will be a perfect comfort in the case of an air conditioner.

How much comfort provide a comfort fan?

Based on these indices, a study has been carried out by [11] to assess the benefits of fans in terms of comfort in three French cities by using experimental measurements of air speed along with building simulations with free temperature and humidity evolution; it was made possible to access inside climatic conditions when using a comfort fan. The three French cities considered are Pau (South West), Rennes (West), and Trappes (North West). It appears that the number of discomfort hours are at least divided by a factor of three with regard to a room without cooling device (figure 4). With a comfort fan, occupants would have to face from 70 discomfort hours in Trappes to 145 in Pau, which correspond respectively to 6.4 % and 13.3 % of the occupation time.

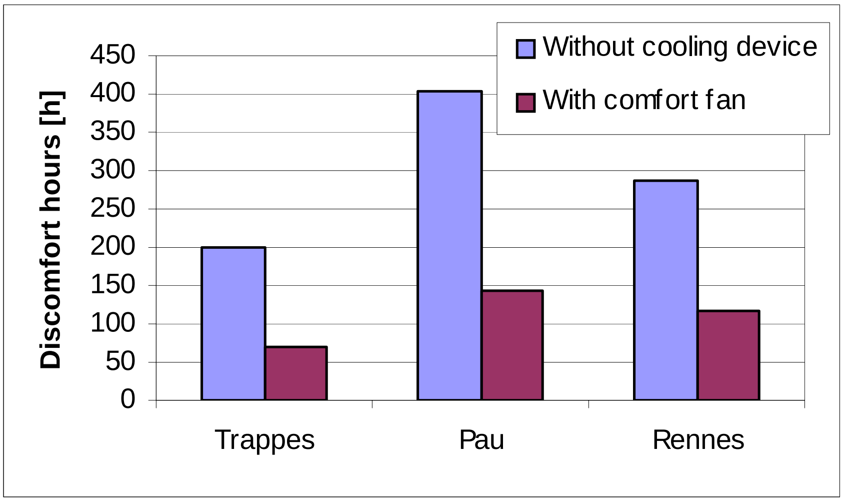

Figure 5. Number of discomfort hours over the summer period for 3 French locations, from [11]

Hence it was possible to calculate the number of hours with the fan on, ranging from 200 h to 400 h for a dwelling representative of the stock of residential housing in France. Translated in terms of equivalent full load hours, it gave between 60 and 100 hours in this case, meaning that for an important number of hours (between 25 % and 33 % of the operation time), the fan was operated at reduced speed only. The same calculation for Spain (Madrid) gives more then 2000 hours of occupation above the set point limit (25 °C or 26 °C) with the larger part of hours above 28 °C.

Estimate of the average number of use in Europe taking into account Part Load

From simulations of European buildings described in [12], utilization periods were estimated using the method previously described. Partial load behavior has been characterized for the first time in energy terms: how people use the (generally available) three speeds and what is the efficiency of doing so (by an experimental campaign).

Starting from a classic calculation of the air conditioner load, we can determine the number of hours when a cooling load appears (i.e. the temperature set point is not respected). During these hours, comfort conditions (set point of 25 °C) will not be reached. Hence, in a building without air conditioning and with a fan, the fan is likely to be used. This calculation leads to a number of hours lying between 25 hours in Ireland and more than 1000 hours for Southern countries. Sales weighted average figures are used to determine an average EU value of usage hours for Europe.

More important is the equivalent number of hours at full load (energy/capacity). Efficiency at reduced air flow rate falls by 50 % as compared to full speed for about 40 % of high speed air flow rate. Given that the weighted average number of hours is about 320 hours for EU and that it operates at about 50 % air flow rate in average, it can be deduced that as compared to nominal index, the energy consumption is to be multiplied by the degradation of SFP at 50 % air flow rate, ie 50 % efficiency.

Translated in a corrected number of full air flow equivalent, this simply gives the weighted average number of full load equivalent hours, ie 320 hours. This number of hours will be kept to translate the energy consumption of comfort fans.

Assuming that comfort fans are used mainly during summer months of July and August in the EU, this leads to 1440 hours with fans plugged in for 1440 – 320 = 1120 hours for stand-by (fans equipped with a remote controller), while they remain unplugged (O W off-mode) outside of this period.

Energy consumption due to comfort fans in EU 25

Unitary consumption of comfort fans

In operation

The number of operation hours has been determined, it remains to define the average energy efficiency of comfort fans. We used our own data basis from internet and store surveys (26 brands with exactly 185 distinct models)

The correlation between Wattage and Air flow is shown in Figure 6. We admit that air flow reported has been measured according to IEC 60879 which is never said in product brochures.

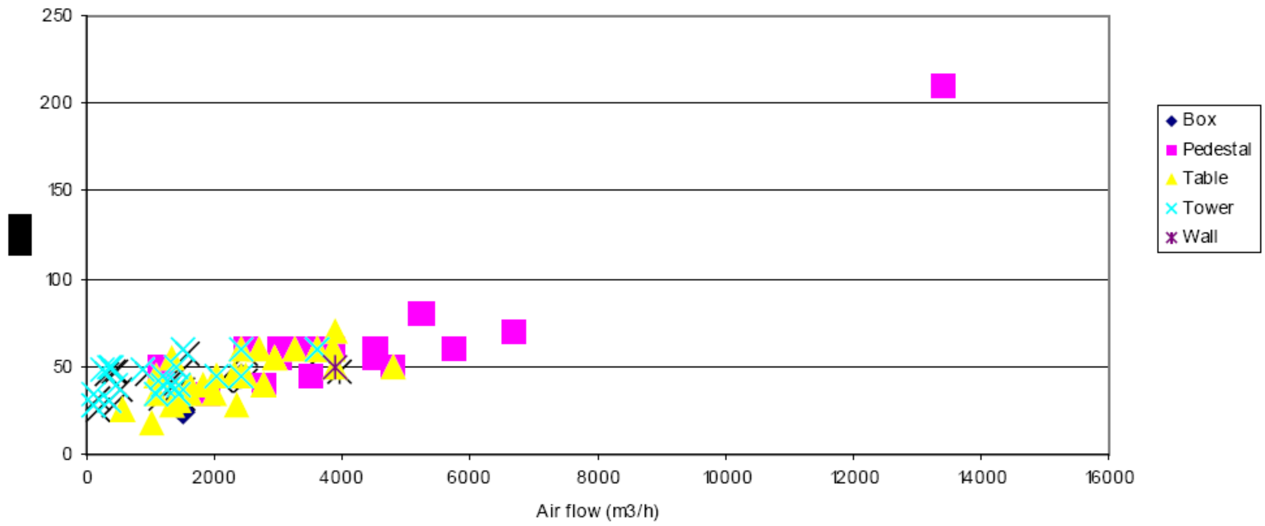

Figure 6. Correlation on data base (Wattage (W) versus Air flow (m3/h))

The efficiency, if defined as SFP=Pelec/Flow varies largely: 10.5 to 68.0 mW/(m3/h), excluding tower fans which are worse (see Figure 7). Ceiling fans within Energy Star (not perfectly comparable) reach 3.8 to 7.9 mW/(m3/h), which shows anyway a large margin for improvement. The tower fans display the worse efficiency in general.

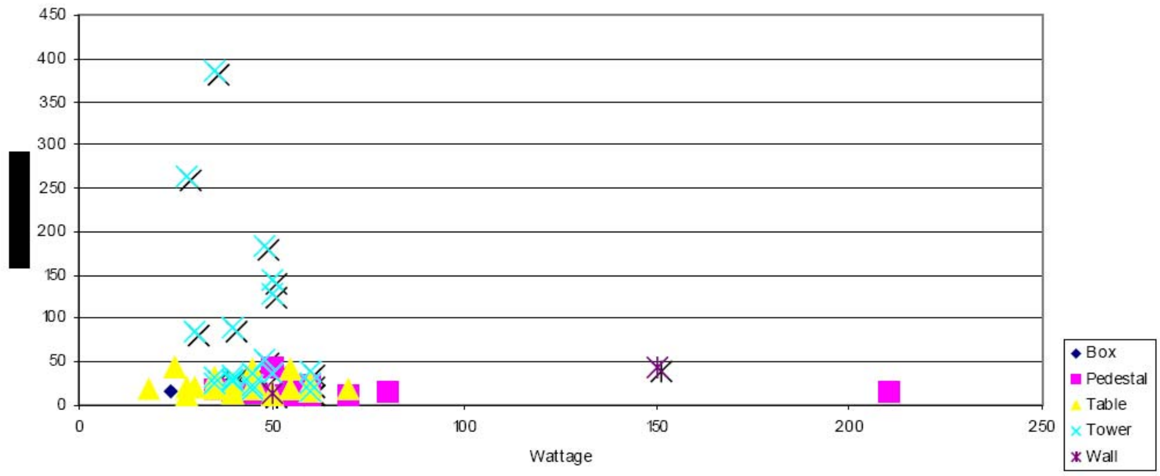

Figure 7. Use of traditional SFP (W/(m^3/h) versus Wattage (W)

We keep as base cases 50 W for table/pedestal fans and 40 W for tower fans, that are the average electric power values in our database of products. Due to the uncertainties about declared and measured flow values, we will admit without total confidence a service value of 0.22 (m3/min)/W and 0.60(m3/min)/W.

In Stand-by mode

As soon as there is a remote control, there is a standby consumption. It's infrequent except for ceiling fans and tower fans, and this stand by consumption is never indicated in commercial offers. We have measured ourselves standby and off mode power for a typical tower fan ; tower fans are now about all supplied with remote control. Standby was of 2 W with 0 W off mode.

Finally a value of 2 W for the tower fan in stand-by mode and 0 W for others product types.

Unitary consumption

This leads to the following yearly energy consumption for the 3 main types of European comfort fans :

- table fan and pedestal: 16 kWh (active mode)
- tower fan: 15.7 kWh = 12.8 kWh (active mode) + 2.9 kWh (stand-by mode)

Stock model

Prodcom statistics were used to reconstruct the size of the market and a stock model was built to reconstruct overall figures. On total, Figure 8 gives the stock of all comfort fans in use in Europe. The main assumptions are a simple change of trend of market due to 2003 heat wave, a ten years lifetime (equipment reaching ten years is substituted by a new one, or put out of service in another way) and a decrease of sales by 2 % per year after 2005 (competition with air conditioning).

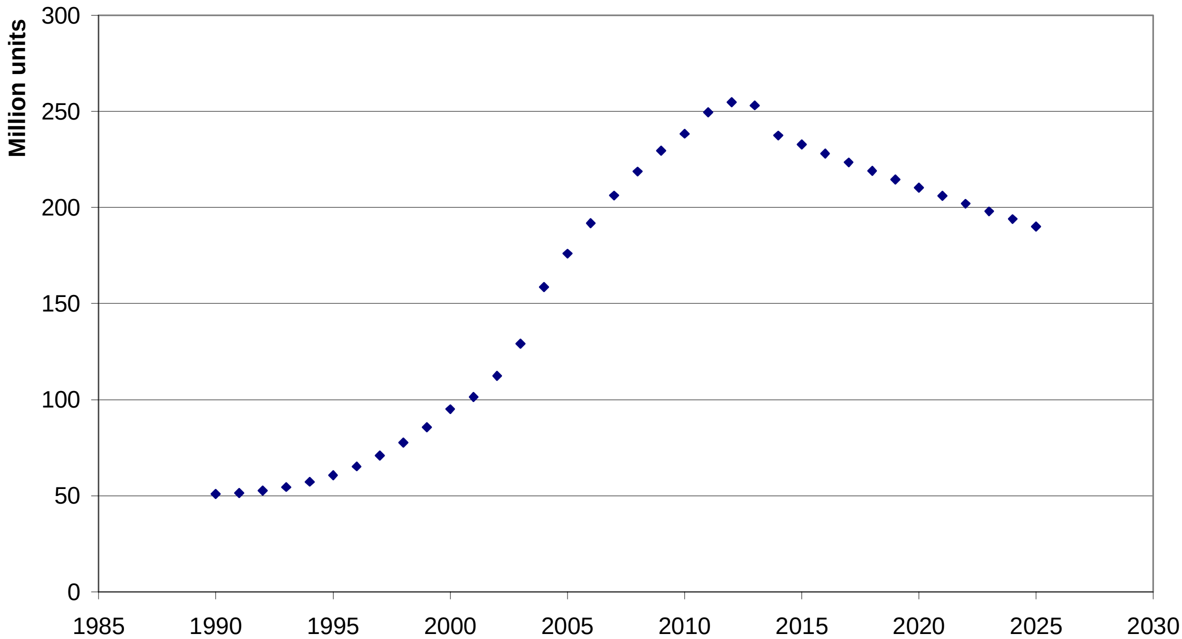

Figure 8. Historical stock and projected stock for EU25

EU 25 consumption

The stock model combined with unitary consumptions enable to calculate the electricity consumption in EU 25 due to comfort fans (Table 2). This end-use finally represents an electricity consumption of 2.9 TWh in 2005 and 4 TWh can be expected in 2010.

Table 2: Electricity consumption and Greenhouse Gases emissions due to EU comfort fans, Using the estimates of (Kemna, 2005) to estimate emissions

	2005	2010	2015	2020	2025
Total Electricity [Twh]	2.9	4.0	3.9	3.5	3.2
Greenhouse Gases in GWP100 [mt CO2eq]	2.6	3.5	3.4	3.1	2.8

Conclusions

We have reconstructed the part load behavior and the electrical consumption of comfort fans used in EU residences. We have tested both part load procedures described here on a number of models sold in the EU. To sum up: we are speaking of a market of more than 200 million pieces of equipment in use in year 2005. We are speaking of about 3 to 4 TWh of electricity consumption each year in Europe, as will be shown. All those products are imported in Europe and come from one single country, China, where they are produced with the lowest possible cost. The energy consumption is about one tenth of the one of air conditioners for the stock of products in 2005 and remains stable until 2020 while the air conditioner consumption increases largely by 2025 if no measure is taken [13].

We expect that the procedure proposed in [2] will allow a real comparison of efficiencies and will lead to some kind of Ecodesign of new equipment and to the purchase of LLCC (Lowest Life Cycle Cost) equipments.

Acknowledgements

part of work was used as a basis for the www.Ecoaircom.eu report

References

[1] Van Holsteijn en Kemna BV, René Kemna, Martijn van Elburg, William Li Rob van Holsteijn, *Methodology Study Eco-design of Energy-using Products*, report to CEC, 2005

[2] Rivière et al., 2009, Full report on comfort fans on the www.Ecoaircom.eu web site.

[3] Rivière et al., 2009, Full report on residential ventilation on the www.Ecoaircom.eu web site

[4] (Adnot, 2007) Adnot J., Rivière P. et al., 2007, *Improving Public Health Responses to extreme weather/heat-waves* EuroHEAT Euroheat project, Indoor heat protection measures and human health, WHO

[5] Arens, 1997, Arens E., Tengfang X., Katsuhiro M., et al 1997. *A study of occupants cooling by personally controlled air movement*. Energy and Buildings. Vol. 27, pp 45-59

[6] Roshles, F., S. Konz, and B. Jones. 1983. *Ceiling fans as extenders of the summer comfort envelope*. ASHRAE Transactions, Vol. 89, Part 1, pp. 245-263

[7] ASHRAE, 2004, ANSI/ASHRAE Standard 55-2004, *Thermal Environmental Conditions for Human Occupancy*, Atlanta: American Society of Heating, Refrigerating, and Air conditioning Engineers, Inc.

[8] Szokolay S. 1998. *Thermal comfort in the warm-humid tropics*. Proceedings of the 31st Annual Conference of the Australian and New Zealand Architectural Science Association, The University of Queensland, Brisbane, 29th September – 3rd October 1997, pp. 7-12

[9] Fanger, P.O. 1970. *Thermal Comfort*. Danish Technical Press.

[10] Fanger, P.O. Ostergaard J., Olesen. S., Lund Madsen T. 1974. *The effect on man's comfort of a uniform air flow from different directions*. ASHRAE Transactions, Vol. 80, Part 2, pp. 142-157

[11] GRIGNON-MASSE, Laurent, ADNOT, Jérôme, RIVIERE Philippe. *Environmental impact and discomfort relief of summer comfort appliances*. In: Proceedings of CLIMA 2007, 9th REHVA world congress "WellBeing Indoors", Helsinki, Finland, June 10th-14th, 2007 [CD-Rom].

[12] Rivière P. et al., 2009, *Preparatory study on the environmental performance of Air Conditioners – Task 4 – Technical analysis of existing products.*

[13] Rivière P. et al., 2009, *Preparatory study on the environmental performance of Air Conditioners – Task 8 – Scenario, policy, impacts and sensitivity analysis*.

Energy Efficiency Standards for Residential Air Conditioning and Heating Equipment – The U.S. Experience

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Abstract

Energy efficiency standards for residential air conditioning and heating equipment have been used in the United States for over 30 years through a combination of voluntary and mandatory measures. A review of minimum energy efficiency standards currently in place in the U.S. will be provided. A particular emphasis will be put on the U.S Department of Energy (DOE) appliance standard program and its process to establish minimum federal energy efficiency standards will also be examined. Recent Federal legislative activities and their impact on residential heating and cooling products will be reviewed and discussed. A look at the installed base of residential central air conditioners and energy saving opportunities that the replacement of old and inefficient products presents will be analyzed. Finally, tax credits enacted by the U.S. Congress and market pull energy efficiency specification programs such as the U.S. Environmental Protection Agency (EPA) Energy Star as they relate to residential air conditioning and heating equipment will be discussed as well.

Introduction

The annual energy consumption in residential and commercial buildings accounts for close to 39% or 38.5 quads (41 x 10^{18} Joules) of the total annual U.S. primary energy consumption, more than the transportation and industrial sectors [1]. In residential buildings alone, the primary annual energy consumption in 2004 was in excess of 21 quads (22 x 10^{18} Joules), 44% of it was used in space and water heating applications and 11% in space cooling.

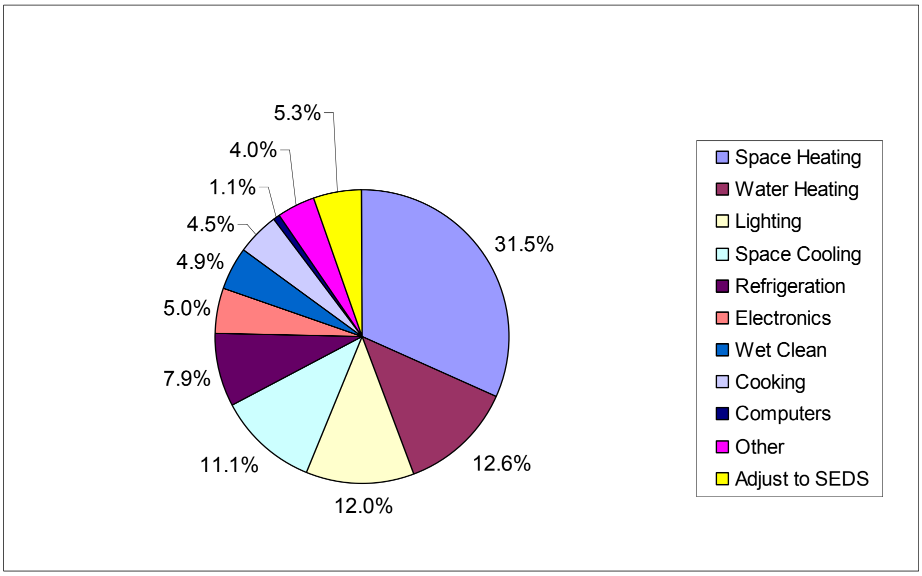

Figure 1: Residential Buildings Primary Energy End-Use Splits -- 2004 (21.07 quads, source EIA)

The energy crisis of 1973 and the desire to reduce the energy intensity of buildings prompted the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to launch the development of ASHRAE standard 90 [2]. Through the efforts of the ASHRAE 90 committee, the first energy efficiency standards for residential and commercial heating, ventilating and air conditioning (HVAC) products were introduced in the U.S. in 1975. These standards were voluntary and covered unitary air conditioners, chillers, packaged terminal equipment and water-source heat pumps. In 1976, the state of California prescribed the first mandatory minimum efficiency standards. These standards applied to residential appliances such as refrigerators, freezers, room air conditioners and central air conditioners. Meanwhile at the federal level, the U.S. Congress enacted the Energy Policy Conservation Act (EPCA) of 1975 that directed the Federal Energy Administration to establish test procedures and voluntary energy efficiency improvement targets for certain home appliances [3]. In 1978, the National Energy Conservation Policy Act (NECPA) amended EPCA and directed the U.S. Department of Energy (DOE) to establish energy efficiency standards in replacement of EPCA voluntary targets [4]. NECPA also preempted all state energy efficiency standards prescribed after January 1, 1978. However, it is under the National Appliance Energy Conservation Act (NAECA) of 1987 and its amendments of 1988 that minimum federal energy efficiency standards were established for twelve categories of residential appliances including residential water heaters, boilers, furnaces and central air conditioners and heat pumps [5]. The legislation also established schedules for DOE to review these standards.

These federal energy efficiency standards are expected to save a significant amount of primary energy - 54 quads (57.0 x 10^{18} Joules) cumulatively through year 2030 [6]. Yet, the U.S. Congress has been very active in the past few years enacting legislation giving authority to the Department of Energy (DOE) to regulate standby power, establish regional standards for residential furnaces and central air conditioners and update existing federal standard for a variety of products such as residential boilers.

This paper reviews the minimum federal energy efficiency standards for residential furnaces, boilers, water heaters and central air conditioners and heat pumps. The process used by the U.S. DOE in revising these standards and their enforcement at the federal level will be examined. Recent actions taken by the U.S. Congress will be discussed. A look at the installed base of residential central air conditioners and energy saving opportunities that the replacement of old and inefficient products presents will be analyzed. Tax credits and market pull energy efficiency specification programs such as the U.S. Environmental Protection Agency (EPA) Energy Star as they relate to residential air conditioning and heating equipment will be reviewed as well.

Federal Minimum Energy Efficiency Standards

The Energy Policy and Conservation Act (EPCA) as amended by the National Appliance Energy Conservation Act (NAECA), established energy efficiency standards for 12 types of "consumer products" including residential central air conditioners and heat pumps, residential furnaces, boilers and water heaters. In 1987, NAECA prescribed the first Federal minimum energy conservation standards as shown in Table 1. Depending on the product class, these standards became effective between on January 1, 1990 and January 1, 1993.

NAECA also required the DOE to update the standards and publish final rules by various dates to determine whether the standards should be amended. The dates by which DOE was required to publish final rules were January 1, 1992 and 2000 for water heater; January 1, 1994 and 2001 for central air conditioners and heat pumps; and January 1, 1994 and 2007 for residential furnaces. However, DOE missed most of the deadlines and in 2005, 14 states and various other entities brought suit alleging that DOE had failed to comply with statutory deadlines and other requirements. In 2006, DOE entered into a consent decree under which it agreed to publish final rules for 22 product categories by specific deadlines.

The minimum federal energy conservation standards for residential central air conditioners, heat pumps, furnaces and water heaters were revised as shown in Table 2. According to EPCA, any new or amended standard must be designed so as to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. In order to determine economic justification, the DOE must demonstrate that the benefits of the proposed standard exceed its burdens by weighing several factors including (1) the economic impact of the standard on manufacturers and consumers; (2) the savings in operating costs throughout the estimated average life of the covered product;(3) the total projected amount of energy savings likely to result directly from the imposition of the standard; (4) any lessening of the utility or the performance of the covered products likely to result from the imposition of the standard; (5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard; (6) the need for national energy and water conservation; and (7) other factors the Secretary of Energy considers relevant.

Table 1: Minimum Federal Energy Efficiency Standards Enacted by the National Appliance Energy Conservation Act (NAECA) of 1987

Product Class	Efficiency		Effective Date
Residential central air conditioners and heat pumps < 65,000 Btu/h (19 kW)	Seasonal Energy Efficiency Ratio (SEER)	Heating Performance Seasonal Factor (HSPF)	
Split systems Single package systems	10 9.7	6.8 6.6	1/1/1992 1/1/1993
Water Heaters Gas water heater Oil water heater Electric water heater	Energy Factor 0.62-(.0019 x rated volume in gallons) 0.59-(.0019 x rated volume in gallons) 0.95-(.00132 x rated volume in gallons) 0.93-(.00132 x rated volume in gallons)		 1/1/1990 1/1/1990 1/1/1990 4/15/1991
Residential furnaces < 225,000 Btu/h (66 kW)	Annual Fuel Utilization Efficiency (AFUE)		
Furnaces (excluding classes noted below)	78%		1/1/1992
Mobile Home Furnaces	75%		9/1/1990
Small furnaces < 45,000 Btu/h (13.2 kW)			
(A) Weatherized	78%		1/1/1992
(B) Non-weatherized	78%		1/1/1992
Boilers (excluding gas steam)	80%		1/1/1992
Gas steam boilers	75%		1/1/1992

However these revisions were not completed without controversy. For residential central air conditioners and heat pumps, the final rule published during the last days of the Clinton Administration was withdrawn by the Bush Administration on the basis that the standards were not economically justified. A new rule was published a year later setting the federal standard at a lower level (i.e., 12 SEER/7.4 HSPF instead of 13 SEER/7.7 HSPF). However, the final rule was challenged in court by the National Resources Defense Council (NRDC), 9 states and several other entities and the 13 SEER/7.7 HSPF standard was reinstated. Although the standard has been in effect for just over 3 years, a new rulemaking already started in 2008 and will be completed in June 2011. New standards will become effective in 2016.

The final rule updating the minimum federal energy conservation standards for residential furnaces was published in November 2007 and was immediately challenged in court by NRDC and several states claiming that the standards were not stringent enough. DOE recently filed a motion for voluntary reconsideration of the furnace finale rule. The motion was granted by the court and DOE announced that a final rule will be published in May 2011.

The least controversial product class so far has been residential water heaters. The standards were first revised in 2001 and a new rulemaking is currently underway to update the standards listed in Table 2. DOE is expected to publish a final rule in 2010 and new standards will become effective in 2015.

Table 2: Revised Minimum Federal Energy Efficiency Standards

Product Class	Efficiency		Effective Date
Residential central air conditioners and heat pumps < 65,000 Btu/h (19 kW)	Seasonal Energy Efficiency Ratio (SEER)	Heating Performance Seasonal Factor (HSPF)	
Split systems	13	7.7	
Single package systems	13	7.7	1/23/2006
Through-the-wall split systems[1]	10.9	7.1	1/23/2006
Through-the-wall single package[1]	10.6	7.0	1/23/2006
Space constrained products	12	7.4	1/23/2006
Water Heaters	Energy Factor		
Gas water heater	0.67-(.0019 x rated volume in gallons)		1/20/2004
Oil water heater	0.59-(.0019 x rated volume in gallons)		1/20/2004
Electric water heater	0.97-(.00132 x rated volume in gallons)		1/20/2004
Tabletop water heater	0.93-(.00132 x rated volume in gallons)		1/20/2004
Instantaneous gas water heater	0.62-(.0019 x rated volume in gallons)		1/20/2004
Instantaneous electric water heater	0.93-(.00132 x rated volume in gallons)		1/20/2004
Residential furnaces < 225,000 Btu/h (66 kW)	Annual Fuel Utilization Efficiency (AFUE)		
Weatherized gas furnaces	80%		11/19/2015
Non-weatherized gas furnaces	81%		11/19/2015
Mobile Home gas furnaces	80%		11/19/2015
Oil-fired furnace	82%		11/19/2015
Gas hot water boiler	82%		11/19/2015
Oiled-fired hot water boiler	83%		11/19/2015

1- Applies to products manufactured prior to January 23, 2010. Through-the-wall products manufactured after January 23, 2010 must meet the requirements for space constrained products.

Labeling and Enforcement Requirements

The Energy Policy and Conservation Act (EPCA) directed the Federal Trade Commission (FTC) to develop regulations to require manufacturers to disclose energy information on appliances covered under NAECA. The purpose of the regulations was to enable consumers purchasing appliances to compare the energy use or efficiency of competing models. FTC first published a rule in 1979 that covered residential furnaces, water heaters and other appliances such as household refrigerators. The rule was subsequently amended in 1987 to cover central air conditioners and heat pumps. According to the requirements, manufacturers of covered products must disclose specific energy consumption or efficiency information at the point of sale in the form of an EnergyGuide label that is affixed to the covered product. Manufacturers must derive this information from test procedures that EPCA directs DOE to develop. Figure 2 shows an example of the EnergyGuide label for central air conditioners. In this particular case, the seasonal energy efficiency ratio (SEER) of the central air conditioners product is shown over a "range of comparability" bar that shows the highest and lowest SEER for all similar models.

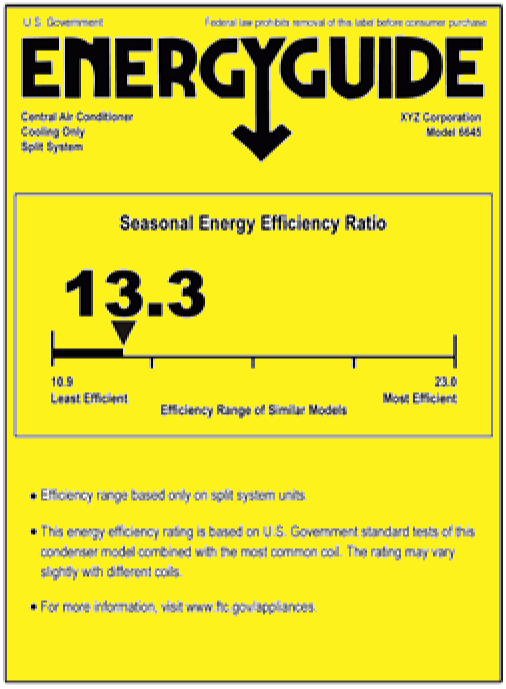

Figure 2: EnergyGuide Label for Residential Central Air Conditioners

EPCA also provided the DOE with the authority to issue rules requiring each manufacturer of covered products to submit information and reports to ensure compliance with the federal standards. These rules require manufacturers to submit a compliance statement, as well as a certification report that provides energy efficiency information for each basic model groups of covered products distributed in commerce in the U.S. However, while DOE is responsible for enforcing the federal standards, it rarely used its authority in the last 20 years to enforce the law. The lack of DOE's intervention in policing the federal standards is mainly due to effective voluntary third-party industry certification programs that are in place for most of the products covered under NAECA. The Air-Conditioning, Heating and Refrigeration Institute (AHRI) certification programs for residential furnaces, water heaters and central air conditioners and heat pumps verify the performance (including energy efficiency) of these products through continuous testing. Products that fail to meet the performance claimed by the manufacturer are de-rated and penalties (financial and by requiring additional tests) are assessed to encourage proper rating. In addition, products found not to meet the applicable federal minimum energy conservation standard are de-listed for the AHRI directory of certified equipment, and DOE is promptly notified so that appropriate actions (i.e.; equipment recall etc.) could be taken. These industry certification programs have been extremely successful in enforcing the federal energy conservation standards and ensuring that products sold on the market are correctly and appropriately rated.

Recent Amendments to EPCA

The Energy Policy and Conservation Act (EPCA) was recently amended by the U.S. Congress in 2005 and 2007. The Energy Policy Act (EPACT) of 2005 [7] established several energy efficiency standards for a number of products including commercial ice makers and large air conditioners. The legislation required DOE to regularly report to Congress when efficiency standard rulemakings are behind schedule. EPACT 2005 also directed the Federal Trade Commission (FTC) to review and revise the EnergyGuide label to make it more effective. FTC undertook a rulemaking in 2006 and after input from stakeholders opted not to make changes to the EnergyGuide label.

On the other hand, the 2007 amendments to EPCA with respect to residential furnaces and central air conditioners were more significant. The Energy Independence and Security Act (EISA) of 2007 [8] directed DOE to issue a final rule by 2014 regulating the fan electric energy use of residential furnaces. EISA also directed DOE to amend federal test procedures for residential furnaces, boilers and water heaters to include standby mode and off mode energy consumption. Final rules must be published by September 30, 2009 for residential furnaces and boilers and March 31, 2010 for residential water heaters. Additional changes to EPCA authorized DOE to review standards every six years and to adopt revised standards based on consensus recommendations more quickly.

However the most important change to EPCA impacting residential furnaces and central air conditioners was the authority given to DOE to establish regional energy conservation standards for these products. EISA provided authority to DOE to set a national minimum energy efficiency standard and one additional regional standard for residential furnaces. For residential central air conditioners and heat pumps the provisions of EPCA call for one national federal energy efficiency standard, and up to 2 additional regional standards. However, before establishing one or two regional standards, DOE will have to (1) demonstrate that the additional standards produce significant energy savings and are economically justified, and (2) consider the impact on consumers, manufacturers and the other interested parties such as distributors and contractors.

The regional standards provision of EISA present unique enforcement challenges. The current federal standards being applicable to the entire country have been effectively enforced by industry certification programs. With the current scheme, all federally covered products entering interstate commerce must meet one national standard. The standards are enforced at the manufacturing and importation levels. On the other hand the provisions of EISA will require enforcement of the regional standards at the installation level, and although DOE is required to develop an enforcement plan, it is unlikely that these regional standards will be effectively enforced.

Energy Saving Opportunities – Addressing the Installed Base

The federal minimum energy conservation standards enacted by EPCA have saved a significant amount of energy since they first became effective in the early 1990's. In the case of residential central air conditioners and heat pumps for example, the minimum seasonal energy efficiency ratio (SEER) shown in Figure 3 increased by more than 45% since 1987 and over 90% since 1970. However, there is evidence that product equipment efficiencies are approaching their thermodynamic limits. While energy efficiency gains in the seventies were achieved at a relatively low cost, the efficiency improvements realized recently resulted in significant increase in equipment cost. As illustrated in Figure 4, we are entering a phase where energy efficiency gains in the future will be minimal but very costly. There is further evidence of that by looking more closely at annual shipment data of residential central air conditioners. Figure 5 shows that annual shipments of central air conditioners and heat pumps significantly dropped in 2006 when the new federal minimum standards became effective. Since then shipments have continued to decline while at the same time sales of compressors have increased, suggesting that many consumers have opted to repair rather than replace their old and inefficient products.

It is clear that the current policy of increasing the minimum energy efficiency standards of federally covered equipment has reached a point of diminishing return (in terms of energy savings) for many products. In fact, there are indications, in the case of central air conditioners and heat pumps, that the current policy is discouraging consumers from upgrading their products to more efficient equipment. However, it is estimated that over 20 million residential air conditioners and heat pumps, 15 years and older, are currently on the market. These units have low energy efficiencies and upgrading them to the current federal minimum standards presents a unique energy saving opportunity. It is estimated that 0.2 quad (0.22 x 10^{18} Joules) of energy and 14 MMT CO_2e of emissions could be saved by replacing 10 million air conditioners over the next 5 years. However, such a program could only be successful if incentives are put in place to offset part of the new equipment cost and encourage homeowners to replace and upgrade their units. Industry and other stakeholders are currently looking at ways to make this program a reality.

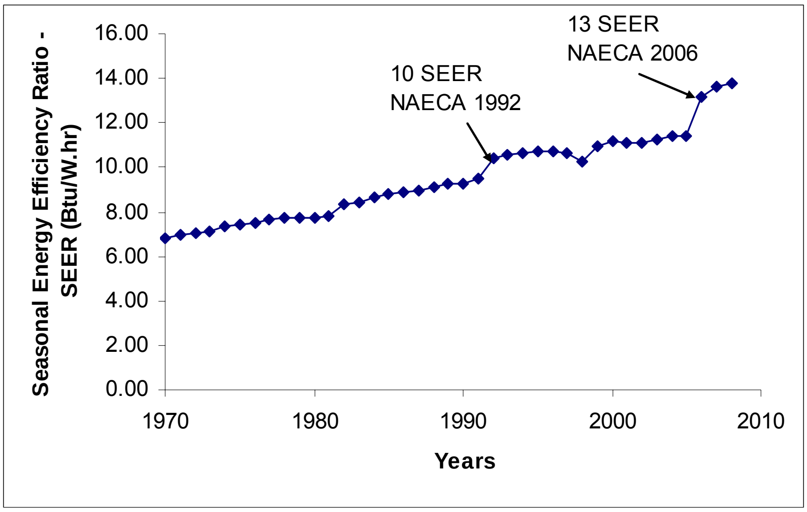

Figure 3: Shipment Weighted SEER for Residential Central Air Conditioners and Heat Pumps - 1970-2008

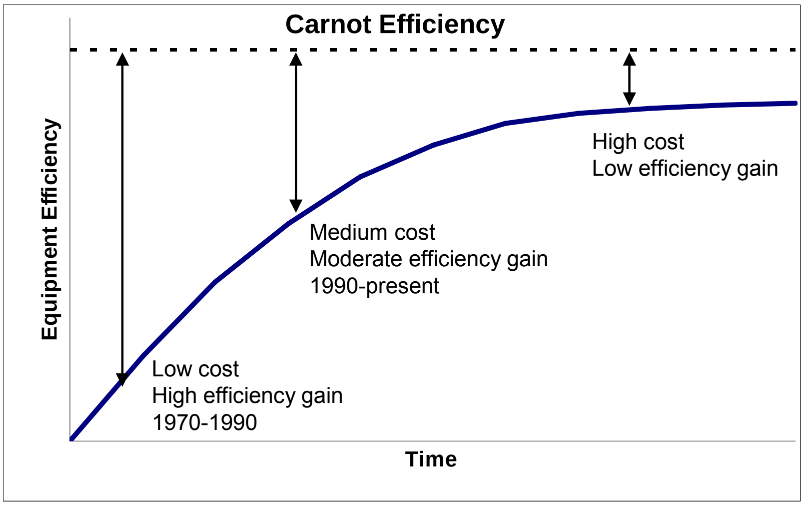

Figure 4: Equipment Costs and Efficiency Gains over Time

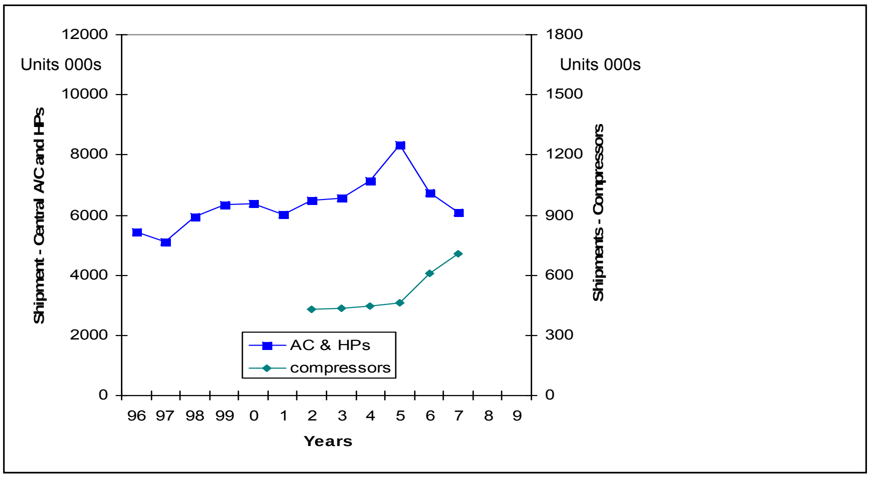

Figure 5: Shipments of Residential Central Air Conditioners and Compressors

Tax Credits and Market Pull Programs

Market pull programs such as Energy Star administered by the U.S Environmental Protection Agency (EPA) have been successful in promoting the use of high efficiency heating and cooling products. In addition, tax credits have recently been used to accelerate the market penetration of very high efficient products. The U.S. Congress enacted legislation with such provisions twice in the past 4 years, first in 2005 [7] and then just recently in February 2009 [9].

Tax credits of up to 30% of total cost of the equipment (with a $1,500 maximum cap) can be claimed for high efficiency products placed in service between February 2009 and December 2010. Table 3 summarizes the Energy Star and tax credit provisions for residential air conditioners/heat pump, furnaces and water heaters.

Table 3: Energy Star Requirements and Tax Credit Specification for Residential Central Air Conditioners/Heat Pumps, Furnaces and Water Heaters

quipment Type	**Minimum Energy Efficiency**	
	Energy Star	Tax Credit
Central air conditioners		
Split system	≥14.5 SEER, 12 EER	≥16 SEER, 13 EER
Package system	≥14 SEER, 11 EER	≥14 SEER, 12 EER
Central air source heat pumps		
Split system	≥14 SEER, 12 EER, 8.2 HSPF	≥15 SEER, 12.5 EER, 8.5 HSPF
Package system	≥14 SEER, 11 EER, 8 HSPF	≥14 SEER, 12 EER, 8 HSPF
Furnaces		
Gas	≥90% AFUE	≥95% AFUE
Oil	≥83% AFUE	≥90% AFUE
Propane	--	≥95% AFUE
Gas hot water boiler	≥85% AFUE	≥90% AFUE
Water heaters		
Gas	≥ 0.62 Energy Factor	--
Gas condensing	≥ 0.80 Energy Factor	≥ 0.82 Energy Factor
Tankless	≥ 0.82 Energy Factor	≥ 0.82 Energy Factor
Heat pump	≥ 2.0 Energy Factor	≥ 2.0 Energy Factor
Solar	≥ 0.5 Solar Fraction	--

Conclusions

Energy efficiency standards for residential heating and cooling products have been in place in the U.S. for 30 years. These standards have saved a significant amount of energy. By year 2030, these savings are expected to reach 54 quads (57.0 x 10^{18} Joules) of cumulative primary energy. However, the current federal rulemaking process is showing signs of weakness and has been challenged in courts several times in the past few years. In addition, there are indications that the current policy of periodically increasing the minimum energy efficiency standards of federally covered equipment has reached a point of diminishing return. Equipment efficiencies for many products are approaching their thermodynamic limits, making future gains in efficiency difficult and very costly. The current installed base of old and inefficient heating and cooling products is significant and presents a unique energy saving opportunity. However, financial incentives are needed to offset part of the equipment cost and encourage homeowners to replace their systems. Efforts should focus on developing and implementing policies that would stimulate the replacement of heating and cooling products.

References

[1] U.S. Department of Energy, *2006 Buildings Energy Data Book*, Washington, D.C., 2006

[2] American Society of Heating Refrigerating, and Air Conditioning Engineers, Standard 90, *Energy Conservation In New Building Design,* ASHRAE, Atlanta, GA, 1975.

[3] U.S. Congress, *Energy Policy and Conservation Act, Public Law 94-163,* U.S. Government Printing Office, Washington D.C., 1975.

[4] U.S. Congress, *National Energy Conservation Policy Act, Public Law 95-619,* U.S. Government Printing Office, Washington D.C., 1978.

[5] U.S. Congress, *National Appliance Energy Conservation Act, Public Law 100-12,* U.S. Government Printing Office, Washington D.C., 1987.

[6] Meyers S., McMahon J, and McNeil M., *Realized and Prospective Impacts of U.S. Energy Efficiency Standards for Residential Appliances: 2004 Update*, Lawrence Berkeley National Laboratory, Berkeley, CA, 2005.

[7] U.S. Congress, *Energy Policy Act of 2005, Public Law 109-58,* U.S. Government Printing Office, Washington D.C., 2005.

[8] U.S. Congress, *Energy Independence and Security Act of 2007, Public Law 140-110,* U.S. Government Printing Office, Washington D.C., 2007.

[9] U.S. Congress, *American Recovery and Reinvestment Act of 2009, Public Law 111-5,* U.S. Government Printing Office, Washington D.C., 2009.

Energy Efficiency Labelling of Ceiling Fans in India: Challenges and the way forward

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Abstract

The service value of the ceiling fan has been identified by BEE (Bureau of Energy Efficiency) as one of the main parameter which is used as a measuring yardstick for comparative energy efficiency labelling. Since, the service value of the ceiling fan is nothing but the output by input which is the Air delivery in cm /minute by the input power in watts. Hence, the obvious choice is to take the service value of the ceiling fan as the energy efficiency indicator. The IS -374 is the Indian Standard which looks after regulates the overall product standard of the ceiling fans and BEE just mandates the minimum energy performance values for ceiling fans manufactured and sold in India . However, even though this looks very straight forward it has not been the same for BEE energy labelling programme for ceiling fans from the initiation of the program from year 2006. There are a number of reasons to this it ranges right from non-adherence to the prescribed BIS service values by the unorganised sector (even organised in some cases!!), testing protocols which needs to be revised, lack of calibrated laboratories as per NABL and the different climatic conditions in India. Over the years BEE along with BIS and other stakeholders have constantly worked together to get each of these issues resolved and has been successful in most of them. However, it always comes down to stipulating the right service value for ceiling fans in the current scenario of the Indian Market therefore the scope of this paper deals with arriving at the right conclusions for setting the MEPS for BEE labelling program and does not look into the details of testing protocols, manufacturing constraints etc., although the conclusions would on be based on some of these aspects. Also this paper would look at the overall cost – benefit analysis of manufacturers whom apply for the star rating and their implications on the pricing of the equipment and the pay-back benefits to the consumer in-terms of the electricity savings by purchasing a quality product. This paper also intends to convey that, primarily countries should try to set standards such that the harmonization with international standards is not a hindrance. However, some products may require tailor made specifications and policies to tackle the various bottlenecks acting along the growth of the market for the product, such as market volume share dynamics, overall regulation of the standards , keeping moderate specifications as per various regional conditions which would work rather than stringent standards which would only act as a bottleneck.

The Indian Market Scenario

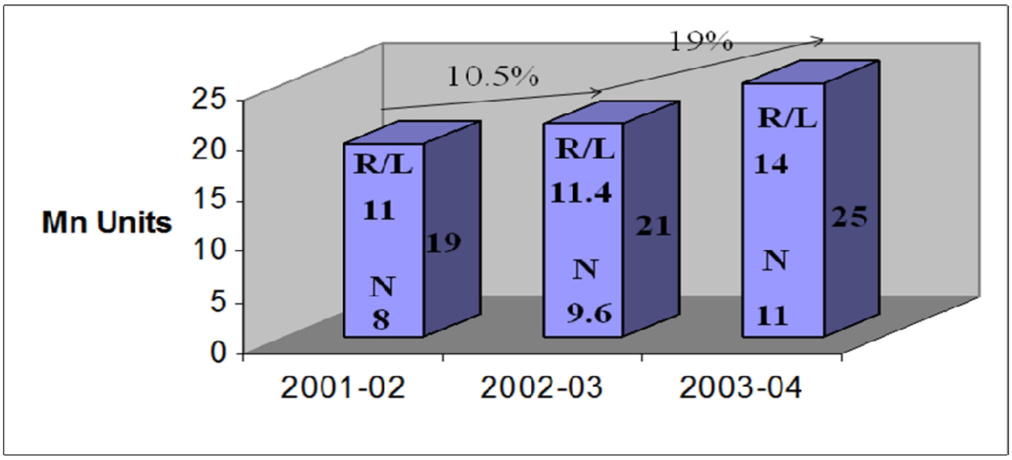
The Indian Market for Ceiling fans consists of the following type of manufacturers:

- **National Players** : they are basically big firms , with large distribution network and organised channels of marketing. They have good technical knowledge and are concerned about energy efficiency of their products.

- **Regional Players**: these are manufacturers which have a considerable market size in a particular region, they have good distribution networks within the region. They may have technical knowledge. They may be categorised under the organised sector.

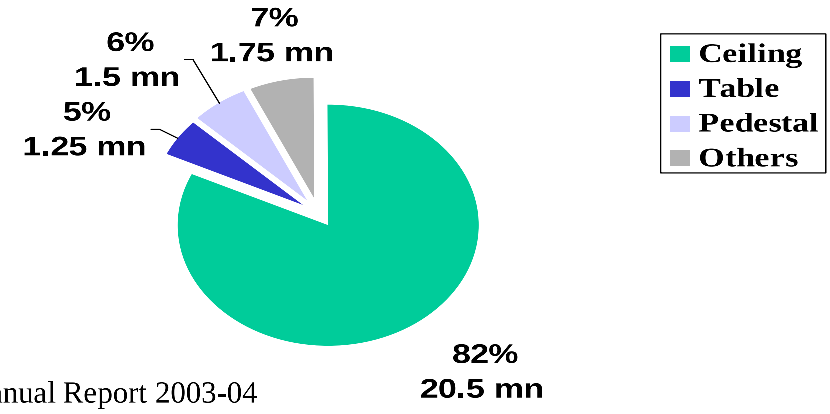
- **Local Players**: These are manufacturers which are basically season based , they may not have any technical knowledge and no standard manufacturing process and routine. They do not have any organised structure and are generally not made in conjunction with the Indian Standard. They are categorised also as the unorganised sector.

The organised sector reported an annual growth of 20% in 2007 (Source: IFMA). The estimated market volume for electric ceiling fans in India was report to be 25 millions in FY 2003-04. It was reported that the around 80% market volume for electric ceiling fans basically consist of the 1200 mm sweep ceiling fan. The 1200mm ceiling fan market share has also been reported be growing at a rate of 14% , it is estimated that the total 1200mm ceiling fan market volume is reported to be approximately 40 million units in India in FY 2008-09.



Source: IFMA Annual Report 2003-04

The Indian Fan manufacturer association reports that out of this market volume only 60% comprises of the production by the organised sector consisting of the National and Regional players. The other 40 % is production by the unorganised sector. Since , the 1200 mm sweep ceiling fans comprises of the majority of the market share and having the largest energy saving potential , they were targeted such as to formulated a MEPS and energy labelling program.



Source: IFMA Annual Report 2003-04

The Ceiling Fan Standards

Indian Standards:

The standard in India to regulate the specification in India is IS -374. Since, the scope of this paper is to focus on the characteristics of the India Standards Regulation which effect the energy consumption and the performance characteristics of ceiling fans, the other details are not going to be illustrated. The IS-374 stipulates the minimum energy performance standards in terms of service value of the electric ceiling fans. The following is the energy consumption standards stipulated in IS 374 (3rd revision) for various sweep sizes:

Minimum Air Delivery(Cu M/Min)	Minimum Service Value	Max Power Consumption in Watts
130	3.1	42
150	3.1	48
200	4	50
245	4.1	60
270	4.3	63

From the above table it can be seen that the Indian Standards lays out maximum energy consumption limit and the minimum air delivery for a particular rated size of the ceiling fan. The minimum air delivery for 1200 mm sweep fans as per Indian Standards had been stipulated as 200 m3/min with a maximum power consumption of 50 watts. The standard is one of the most stringent standards for ceiling fans in terms of the energy efficiency. The National players always contest that although the IS provides the consumer with a superior energy consumption standard, they provide customers with better performing fans as the most popular fans have higher air delivery. Due to the demand of higher air delivery by consumer due to the climatic and regional conditions in India, the manufacturers contest that it is not possible to make fans with higher air delivery with the stipulated maximum power consumption of 50 Watts. The following is a table which illustrates the energy efficiency as per regulations and the energy efficiency of 1200 mm ceiling fans of the national players:

	Air Delivery	Wattage	Service Value (stated)
IS Fan	200	50	4
National Players Models	220-240	70-77	3-3.5

Source : AFF report on_rotating machines

International Standards and Labelling for Ceiling Fans

There a very few program globally which have standards and labelling focussed on ceiling fans , to name a couple of programs globally is the Chinese Standards and the US Energy Star program . For sake of easier comparison of the energy standards and labelling program for ceiling fans, the US Energy Star program is compared with the Indian Program. The minimum requirements to qualify for the Energy Star program are as follows:

Fan Speed	Minimum Air Flow(CFM)	Efficiency Requirement (CFM/Watt)	Power Consumption(W)
Low	1250	155	8.065
Medium	3000	100	30
High	5000	75	66.67

The US Energy Star Program considers 3 modes of operation, namely of low, medium and high fan speed. The minimum air flow for each mode is stipulated as above in cubic feet per minute. The efficiency requirement (CFM/Watt) for each mode is as above. Under the stipulated efficiency requirement the rated power consumption for the 3 modes is as shown above. From the above comparison it can be easily seen that the Indian Standard is comparatively the stringent, however , the energy star program includes fans with lighting housing and thus it may act invariably on the performance of the ceiling fans.

Challenges

The India manufacturers face a number of roadblocks when it comes to implementing the standards stipulated by Bureau of Indian Standards. The Indian tropical climatic conditions forces the manufacturers to make fans with higher air delivery and this makes it very difficult to curtail the power consumption of the fan within 50 watts as prescribed in the IS standard. Although the national players are able to manufacture the ceiling fan under the prescribed standards, these forces the capital cost of the equipment to go up. The additional requirement or improvement in the winding, stator stampings, and laminations to achieve a service value of 4 for ceiling fans is as follows:

Sweep(mm)	Copper(g/piece)
600	240-290
900	220-240
1050	~240
1200	250-290
1400	320-350

The above table shows the copper consumption for various sizes of ceiling fans as per industry data. Most of the manufacturers in India use 29- 34 SWG copper. The National Players use ETP copper, whereas the local players/ unorganized sector use commercial grade or recycled copper. To achieve as service value of 4, extra copper required is close to 50 – 100 gm for 1200mm, 1400 mm ceiling fans. Similarly for 600mm, 900mm, 1050mm sweep around 50-60 gms of copper. This would increase the manufacturing cost by Rs. 15 – 30 / fan for incorporating higher quality and quantity of ceiling fans. Also, the steel stampings have to be increased as the general stamping is of 0.5-0.6 mm. Some of the local manufacturers use CRCA steel or re-rolled car steel and oil tin scraps. Most of the manufacturers use high perm CRCA , industry sources recommend the changing to better quality steel CRNO from high perm CRCA. The quantity required to increase the service value from the present manufacturing process is as follows:

Sweep(mm)	Steel(kg/piece)
600	~1
900	~1.8
1050	~1.8
1200	~2+
1400	~3

The rise in the market prices is also a major constrain in the sales of energy efficient fans as the Indian market has a significant presence of the unorganised sector , which is able to have around 40-45 % of the market volume share due to their competitive pricing as they do not comply a particular standard or manufacturing process. The unorganised sector has varying trends of ceiling fans energy consumption due to inferior quality of raw materials used as the core of the fans and the laminations, these unorganized sectors have significant local/ regional presence having very little traceability. Due to the stringent standards of the BIS it becomes tough for organised sector players to manufacture and commercially sell fans confirming to the minimum energy standards and also the competitive pricing from the unorganised sector becomes a big factor, the national players usually are priced at Rs. 900-1100 per fan compared to Rs. 400- 500 per fan priced by local manufacturers.. The Directorate General for Supply and Distribution (DGS&D) in India is the agency which fixes the rate contract for equipments that are procured by the public and local bodies. The DGS&D procures and fixes the rate keeping the technical pre-qualification criteria as that prescribed by BIS; hence this is the only market share in India which forces the manufacturers to manufacturer as per Indian Standards. However, this share is only about 10 % of the market share comprising of national manufacturers, but most of the local manufacturers register for the ISI licence to participate in the bidding process. Hence, it is pretty evident that there is not enough market pull towards energy efficient fans and this is a major hindrance in the availability of energy efficient appliances.

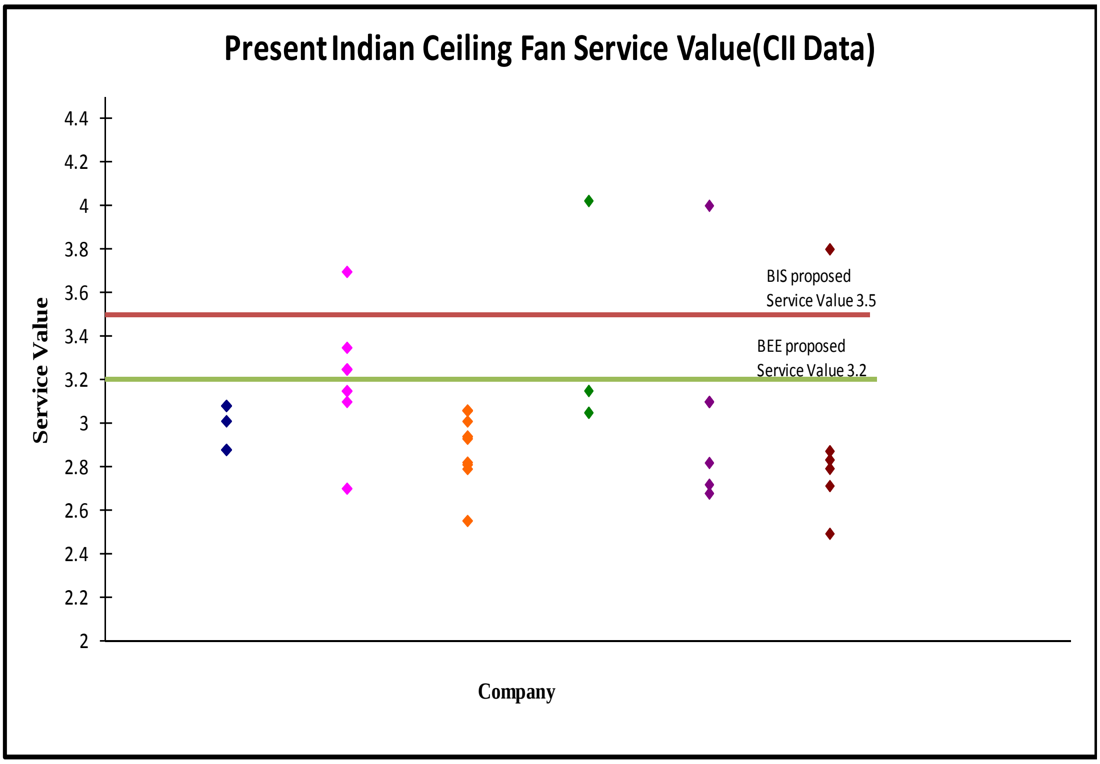
Bureau of Energy Efficiency Standards and Labelling Program

The Bureau of Energy Efficiency (BEE) was formed in 2002 under the framework of Energy Conservation Act, 2001. BEE has been established to implement the provisions of the Energy

Conservation Act, 2001. Once of the flagship programs of BEE is to establish energy standards and labelling program for equipments consuming, generating, transmitting energy. BEE energy labelling program was established in 2006. The standards and labelling program in India is prevalent for 11 products and many other products are waiting to be included in the pipeline . The standards are launched as a voluntary compliance and in stakeholder review and industry participation the mandatory phase is notified. Ceiling fans is one of the equipment for which the standards and labelling program was launched in late 2008 , which adopts the comparative labelling system. The following is the energy performance index for the subsequent star ratings for increasing efficiencies:

Star Rating Index Calculation for Ceiling Fans	
Star Rating	Service Value for Ceiling Fans
1 Star	≥ 3.2 to < 3.4
2 Star	≥ 3.4 to < 3.6
3 Star	≥ 3.6 to < 3.8
4 Star	≥ 3.8 to < 4.0
5 Star	≥ 4.0

From the above table it can be seen that the 1 star is MEPS and the ceiling fan must have a minimum air delivery of 210 m^3/min . The BIS prescribed minimum service value in the previous standard was 4 and it was proposed to be revised to 3.5. This shows that the BEE standards are kept lower than the prescribed standards of BIS , however, there is a reason for this decision by BEE. The manufacturers contested in the BEE technical committee meeting that due to the various aforementioned roadblocks. BEE requested data from the industry and the CII (Confederation of Indian Industries) forwarded some of the data for the service value of various models of the national players. The following graph depicts the energy efficiency of various models and some analysis of the market share of models for different services values for 1200mm sweep fan(considering due to the fact that it if of the largest market share of sizes).



From the above depicted graph it can be seen that only a few present day models qualify for the proposed BIS standard for service value of 3.5.The graph shows that the only 10 % of the models are qualifying as per the BIS norms. The BEE and BIS follows a consultative process of Standards Formulation , since BEE is an organisation which exclusively looks after the formulation energy standards and uses the BIS energy standards as the base if any. BEE proposed a service value of 3.2 as the MEPS qualifying for 1 star level to which a majority of the industry agreed as although as per the graph most 60 % of the models are in the 2.6-3 service value bandwidth. Even though most of the models are not in the 3.2 category but the necessary technological and manufacturing process changes would enable the manufacturers without having significant cost and process changes implications. Another reason for the BEE to set a service value of 3.2 is that the BEE believes that the standards should be such that they are achievable and compliance can be achieved without difficulty and the stringency of the standards can be implemented in a phase manner. The implication of the above said standards can be seen from a cost implication analysis obtained from industry sources although this would not show the actual raw materials and various other prices used for manufacturing star labelled ceiling fans . It also does not reflect the actual increment in the maximum retail price of the star labelled products as their are other factors such as process change costs , other market dynamic factors.

The increase in the lamination quantity and cost is as follows:

PER FAN INCREASE IN LAMINATION COST								
Present	Proposed	Star	Difference	Per Lam	Cost /	Per Lam	Cost /	Per Fan

C.L. (m.m)	C.L. (m.m)	Rating	(m.m.)	no. of Lamination	Weight (Stator)	Lam(Rs.)	weight (Rotor)	Lam(Rs.)	Cost(Rs.)
12	14	4	2	4	33.41	3.09	16.3	1.41	18.01
12	14	3	2	4	33.41	3.09	16.3	1.41	18.01
12	14	3	2	4	33.41	3.09	16.3	1.41	18.01
12	14	2	2	4	33.41	3.09	16.3	1.41	18.01

The increase in the copper quantity and cost is as follows:

PER FAN INCREASE IN COPPER COST				
Star Rating	Present Copper(gm)	Proposed Copper (gm)	Diff(gm.)	Per Fan Cost(Rs.)
4	258	270	12	5.55
3	255	270	15	6.66
3	255	270	15	6.66
2	264	270	6	2.66

The final increase in cost and its impact on the energy consumption:

OUTPUT ACHIEVED				
Air Delivery(m^3/min)	Input Power (Watt)	Service Value	Star Rating	Cost Difference(Rs.)
220	56	3.93	4	24
221	59	3.75	3	25
222	60	3.7	3	25
218	61	3.5	2	21

Hence, from the above table it can be seen that the final cost implication is minimal compared to the energy saving potential of the equipment . It can also be seen that for the various star rated products the rating the cost difference is almost the same however there is a difference in the power consumption and also the air delivery. The above estimates are only indicative of the cost of some of the raw materials it does not take into account the increase in the steel consumption and other technologies know how which can increase the efficiency of the fans is not considered.

Conclusion

It can be broadly seen that by slightly moderating the correct level of standards the industry would be able to meet the standards without any exorbitant increase in the manufacturing cost. In this way the organised industry is interested in participating in a market transforming activity. Along with the MEPS formulation BEE also looks into various other initiatives which can push a market and can create a demand towards energy efficient equipments. The market transformation tools such as consumer awareness, ease in public procurement, strategic media campaign , branding of energy efficiency etc are very important tools which can determine the success of labelling program. The energy savings that are estimated are an avoided capacity potential of upto 200 MW (considering present average of 2.8 as the baseline service value for FY 07-08) by the BEE standards and labelling program and that is only through the MEPS and without taking into account the impact of the labelling program. If the local and regional players are also encouraged the potential of avoided capacity can be even up to 350 MW. BEE also understands that the overall credibility of the program is extremely dependent on the monitoring and verification and impact assessment of the standards and labelling program in India as it is for any such program. BEE has a robust monitoring mechanism, which is not going to be discussed in detail. Hence, it is important there is a strategic approach towards standards implementation which should be complimented by a market driven tools such that the energy standards can be developed and enhanced with smooth transition.

References

[1] Market Study on certain end use segments of Rotating Equipment and Electro-Magnetic Ballast , Public Private Partnership , A.F. Ferguson & Co.,Mumbai

[2] IS 374 , Indian Standard for Electric Ceiling Fans type and regulators. www.bis.org.in

Analyses of the energy consumption of complex HVAC systems in residential buildings taking into account the thermal comfort

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Abstract

The increase in the energy prices especially for oil and gas in the last years has resulted in a development of highly efficient components for HVAC systems. Especially for boilers the over-all thermal efficiency is very high and reaches values up to 99% (related to the gross calorific value). Heat pumps have also achieved an acceptable level of thermal efficiency in the last years. But in combination with the complete HVAC systems the over-all thermal efficiency is often much lower than the values given by the manufacturers. One reason for this is that the installed heat distribution system is not fine-tuned with the heat generator. Another reason is that in most cases the control strategy is not detailed enough and not well adjusted.

In this paper the focus is on existing and future control strategies (adaptive control strategies) for heating systems in building. The advantages and disadvantages for these control strategies were presented in detail. In this context an analysis of the thermal comfort attained in the buildings takes place. The presented values are derived from numerical simulations that allows to compare efficiency of different heating systems' configurations under identical local weather conditions.

In future the results will be compared with related existing standards and recommendations for the revision of national and international standards will be given.

Introduction

The gas and oil prices have dramatically risen in the course of the last few years as seen in figure 1. This was caused not only by the speculation on the energy market but also by a growing energy consumption in the developing countries (especially China and India) as well as reports about the depletion of easily available resources. Today's slump in the prices has been caused by the global financial crisis and is not likely to outlast it.

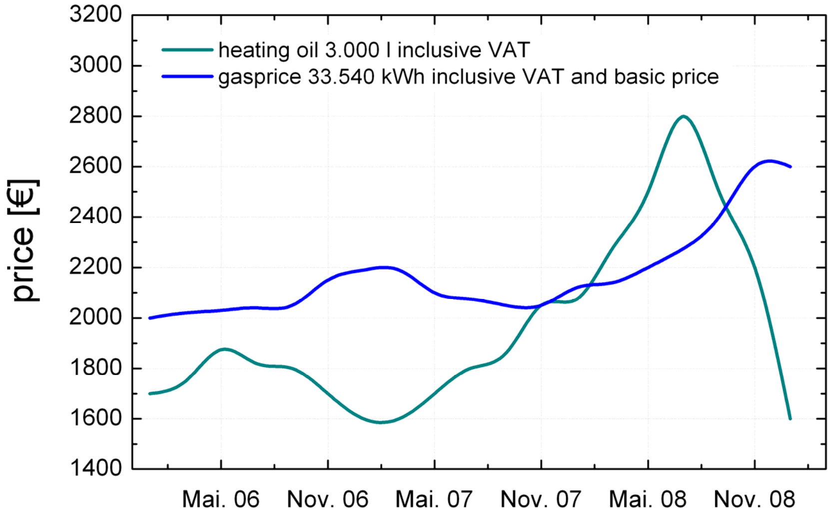

Figure 1: Average price of oil and gas in Germany in the course of the last three years

The European governments have responded to this long-term trend by putting some teeth into their energy saving policies. This effort has been concentrated on minimising the energy demand of the buildings. Figure 2 shows the maximally allowed energy demand of the building according to the German national standards. The proclaimed policy of the German government is to reduce the allowed specific energy consumption for new buildings by 30% every 3 years.

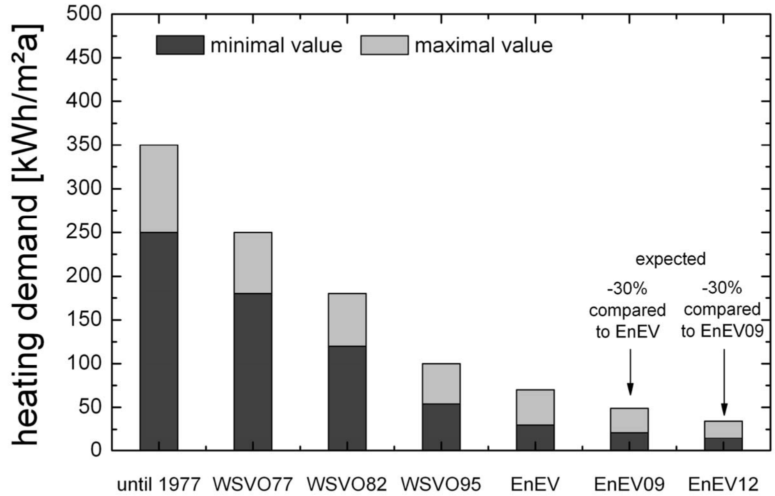

Figure 2: Heating demand according to different regulations

This aim has been mainly achieved by increasing the thermal insulation of the buildings. It is worth noting, that significant economies of energy can be gained by application of modern facilities and modern control strategies in the existing building facilities. The fields in which a change of control strategy can bring meaningful savings are shown in figure 3.

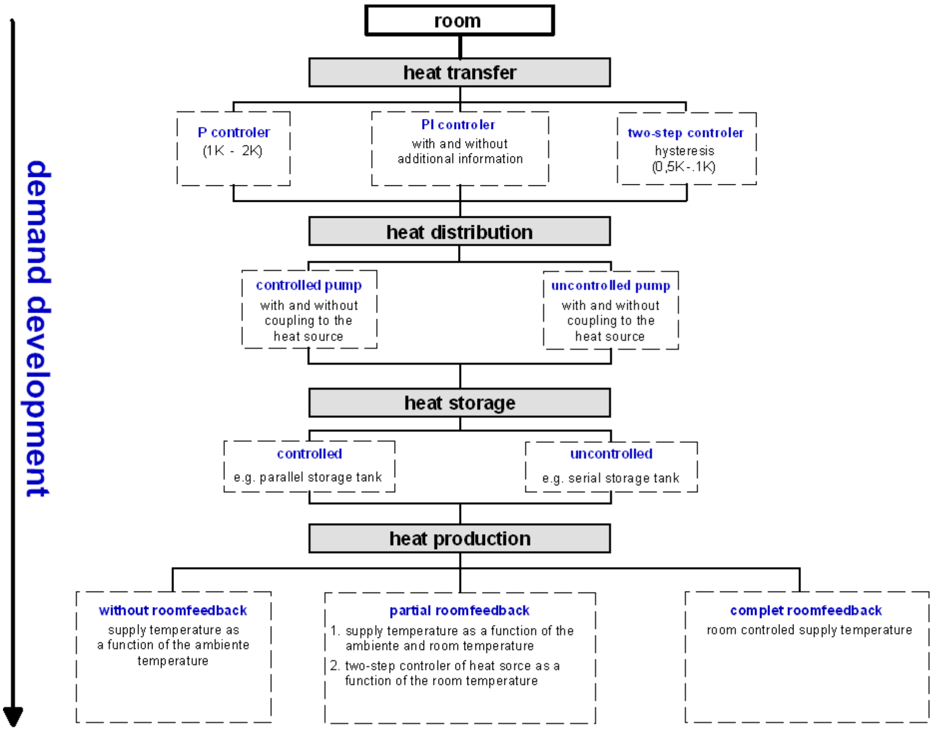

Figure 3: Control strategies in buildings

Overheating, hydraulic losses, specific circuit configuration and sub-optimal control strategies of the existing heating systems can make up to 20% of the primary energy consumption of the building, whereas the heating demand consumes only 30%.

This paper discusses ways of reducing the energy losses inherent in the different heating systems. In order to compare the influence of the heating systems' control on the energy consumption one should compare their operation in identical buildings exposed to exactly the same weather conditions. This is possible only by means of the computer simulation.

Simulations

The numerical investigations are carried out with the version 14.2 of TRNSYS® [Klein1976] which has been further developed and validated at TU Dresden. With this software the following phenomena are modelled:

- thermal behaviour of the house,
- the heating distribution system
- the heat pump
- all boundary conditions (weather, internal loads)

The detailed mathematical models of the house and the heating distribution system are presented in [Perschk00] and [Felsmann02]. A well-insulated house that meets the requirements of the German standard [EnEV2004] is investigated. The annual predicted energy consumption for this house is lower than 45 kWh/a/m^2. Figure 4 shows a sketch of the investigated building.

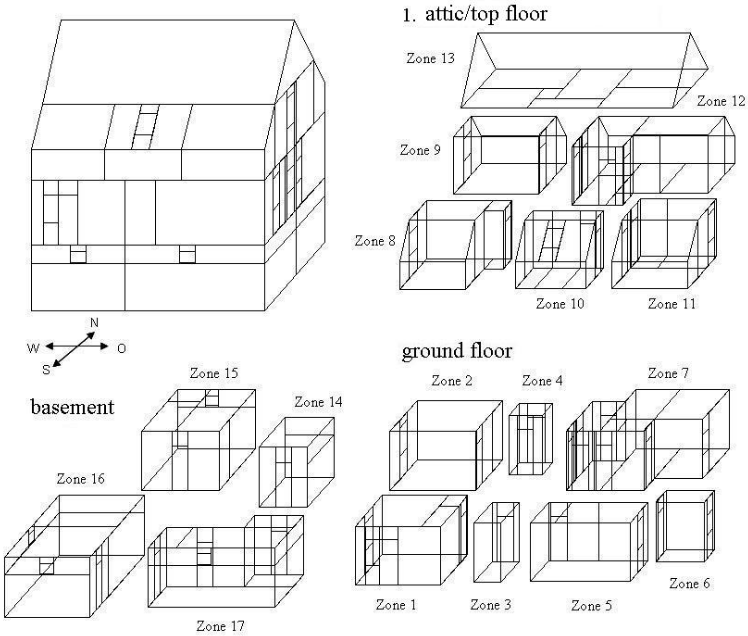

Figure 4: Sketch of the modelled building

The investigations are carried out for the radiators' heating systems with different system temperature levels of 90°C/70°C/20°C, 70°C/55°C/20°C and 55°C/45°C/20°C. The set point temperature for all rooms except the bathroom was set on 20°C and on 24°C in the bathroom. The weather-conditions from the TRY-04 [Christoffer04] that are typical for Germany are used for the investigations. The presence and activity of people has been modelled as internal, time depended thermal loads. The detailed description of all boundary conditions can be found in [Richter2008].

Results and discussion

In this section the influence of different configurations of the heating system as well as the assumed control strategies will be discussed.

1. Control strategies

The control strategies are divided into three groups:

1. room control
2. distribution control and
3. control of the heating source

1.1 Room control

The typical appliances used in the control of the room temperature are P-controller, PI-controller and two-step controller. Figure 5 shows by what measure the energy demand of the above control system exceeds the energy consumption of an "ideal heating system" (ideal heating system – no deviation of the room temperature under the set point temperature) for the above named real control systems.

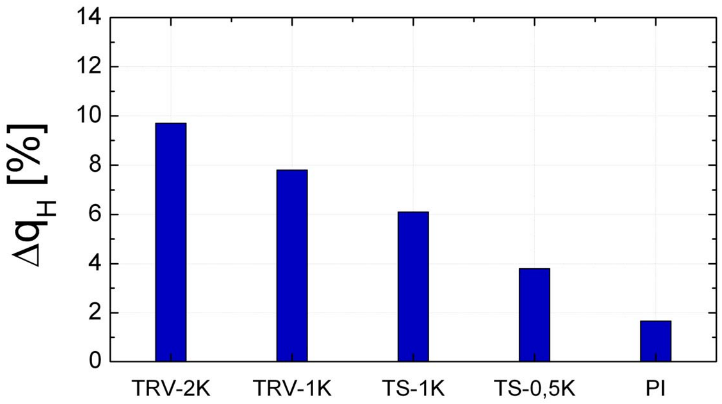

Figure 5: Additional energy expenditure of investigated room controllers compared to an ideal one.

The system controlled by the PI-controller consumes less energy than one controlled by the P-controller with proportionality range of 2 K. The P-controller (2 K) needs approximately 10% more energy than an ideal heating system. The reduction of the proportionality range of the local room controllers results in the energy savings of 2%. The energy consumption of the 2P-controllers differs greatly in dependence on their control differential. The PI-Controller has the lowest additional energy demand of 2% in comparison with the ideal control system.

The discussion of energy consumption is not complete without looking at the thermal comfort in the rooms. Figure 6 shows the cumulative frequency of the operative temperature (set point temperature 20°C) for a typical residential room. The curves express the amount of time during the heating period in which room temperature is lower than a given value. If suddenly significant heat gains enter the investigated room, the overheating will take place and all systems try to turn the heating system off. That is why there is almost no difference among them for higher room temperatures. The temperature range between 20 and 21°C is most relevant for the energy consumption of the heating system. Whereas the PI-controller keeps the room temperature at exactly 20°C for most of the time, other systems tend to overheat the room persistently. This results in the additional energy consumption which has already been discussed in the figure 5.

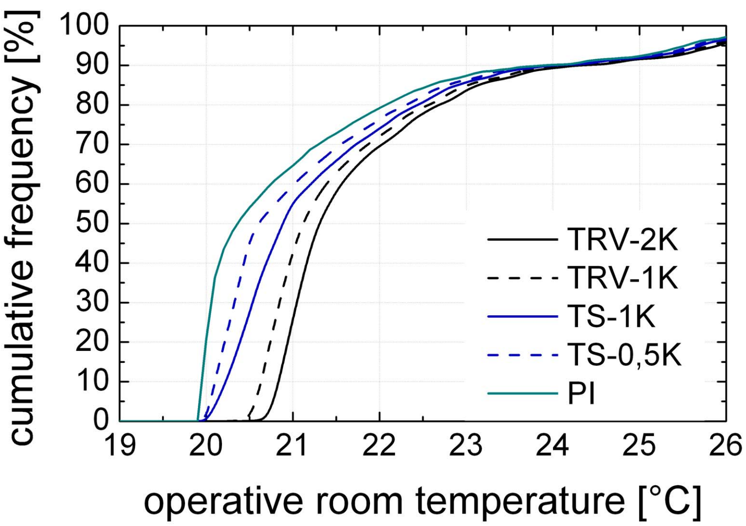

Figure 6: Operative room temperature for different room controllers (room 1)

1.2 Distribution control

The strategies of distribution control can be divided into following three groups:

- no direct control
- constant head loss strategy ($\square p$=const.)
- variable head loss strategy ($\square p=a*m+b$)

The above control concepts are schematically presented in figure 7.

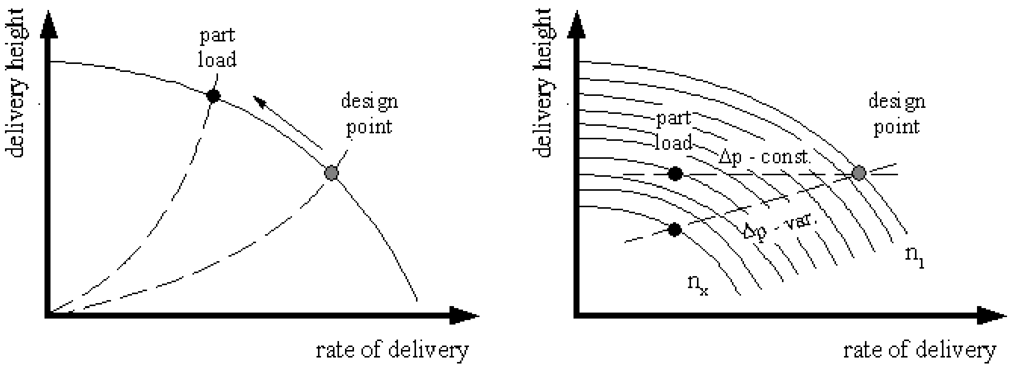

Figure 7: Different control strategies of the central pump

Figure 8 shows the energy consumption for the above strategies. It is apparent, that the system with no direct distribution control has obviously the highest energy consumption as the adaptation of the pressure head is effected by throttling on the local room controllers (thermostatic or other valves). In comparison with it, the strategies of keeping the pressure head constant or linear function of the flow save more than 75% of energy. The difference between the two latter strategies is not significant from the energetic point of view.

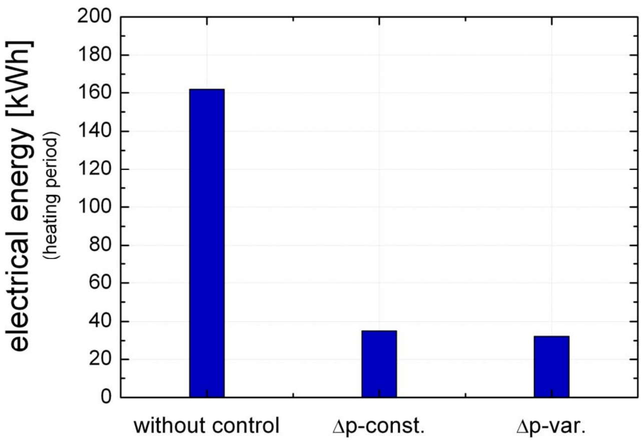

Figure 8: Electrical energy of the central pump depend on the control strategy

1.3 Control of the heating source

The following control strategies for control of the heat source are investigated:

- control of supply temperature as a function of the outside temperature ($\square\square=f(\square_a)$)
- control of the supply temperature as a function of the outside temperature and temperature in the representative room ($\square\square=f(\square_a+\square_i)$)
- two-step control of the source as a function of the temperature in the representative room ($\square\square=f(\square_i)$)
- control of supply temperature as a function of the valves' lift in all heated rooms.

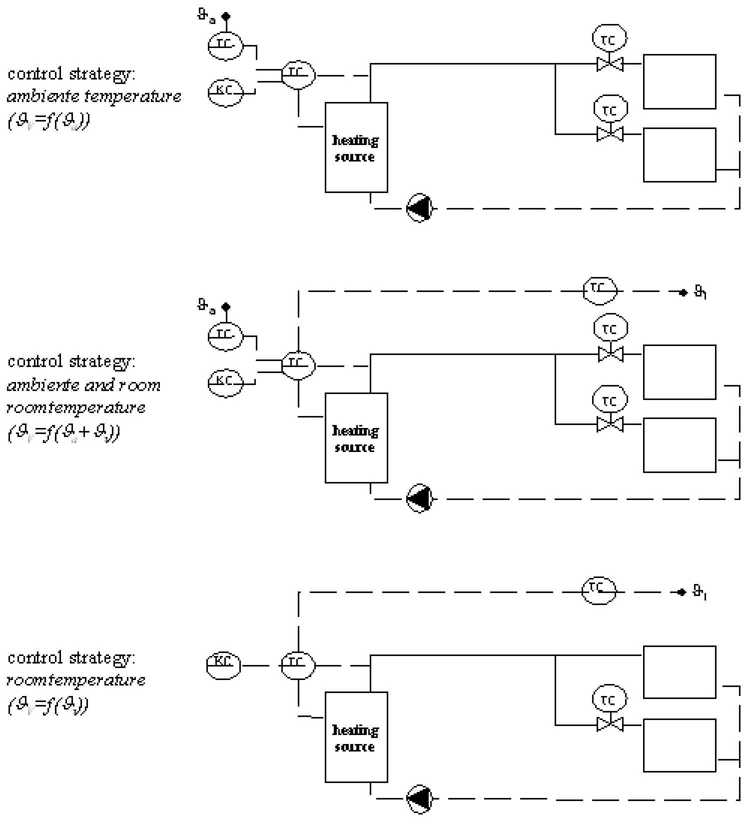

Figure 9: Control strategies for the heating source

The energy consumption of systems using the three first control strategies is more or less independent of the type controlled heat source. The results for the fourth strategy differ significantly for systems with heat pump and ones with different boiler types. Therefore, the first three strategies are discussed and compared first. The schemata of the first three systems are shown in figure 9. Their energy consumption is analysed for two types of local room controllers: PI-controller, shown earlier to be very economical solution and thermostatic valve with proportionality range of 2 K – shown to have a poor economy. The results of analysis are presented in the table 1 for a system with temperature level of 70/55/20°C.

Table 1: Energy consumption for different controls strategies of the heating source

room controller	energy consumption [kWh]		
	$\vartheta_V=f(\vartheta_a)$	$\vartheta_V=f(\vartheta_a+\vartheta_i)$	$\vartheta_V=f(\vartheta_i)$
PI	7703	7649	6207
TRV-2K	8375	8093	6209

The traditional control strategy taking only the ambient temperature into account gives as expected the worse results. The two-step control of the heat source based on the temperature in the representative room is by far the most economical from all three. Moreover, it is efficient regardless of the local control device used. However, it comes at some cost. If the set point temperature in the representative room is 20°C, the rooms with higher set point temperatures like bathroom will not be warm enough. If the bathroom is chosen as the representative room, the other rooms will be overheated or will be forced to throttle strongly and turn into two-step controllers as well. This disadvantageous pattern of the thermal comfort does not occur in the two first systems.

The fourth strategy makes it is possible to reduce the energy consumption in comparison to the two first ones. If he heat source is constituted by a low-temperature boiler, the primary energy consumption of the system will be 2% lower than for the first control strategy ($\vartheta_V=f(\vartheta_a)$). This reduction amounts to 8% for the calorific value boiler and ranges between 8 and 12% for the system with heat pump.

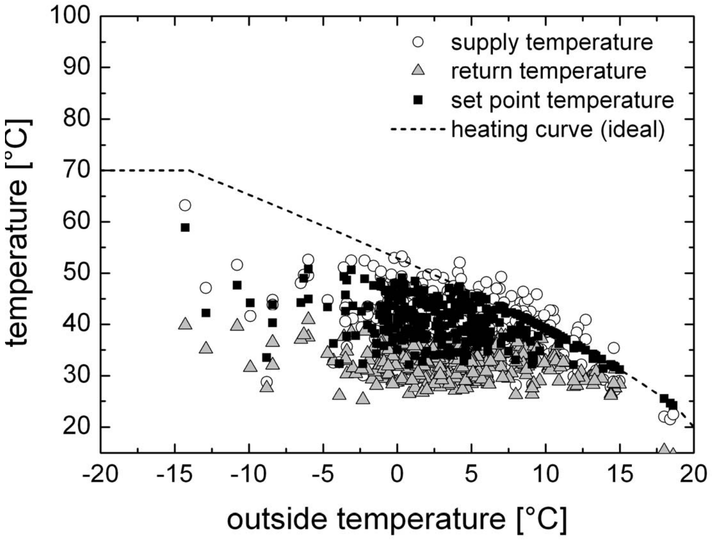

Figure 10: Supply and return temperature for an adaptive control strategy

The variations in the efficiency of the heat pump systems are caused by different (serial or parallel) configuration of the heat storage tank in the hydraulic circuit. The fourth strategy is decoupled from the traditional heating curve and the set point temperature of the heat source is dynamically determined based on the valves' lifts of the local controllers. The resulting temperatures are shown in figure 10. Such low supply temperatures result in the energy savings.

2. Comparison between systems

The configuration of the heating system also has a significant influence on the energy consumption of the whole system.

The decisive factors in the system setup are:

- Temperature level of the system
- Type of the heat source
- Type of the hydraulic circuit

The primary energy demand for various boiler types and different temperature levels of the heating system are presented in figure 11. The primary energy consumption of the heating system seems to grow with its temperature level. Therefore, the system with system temperature of 55/45/20°C is most efficient among the low temperature boilers. Still the system with the condensing boiler is even better thanks to its operation principle.

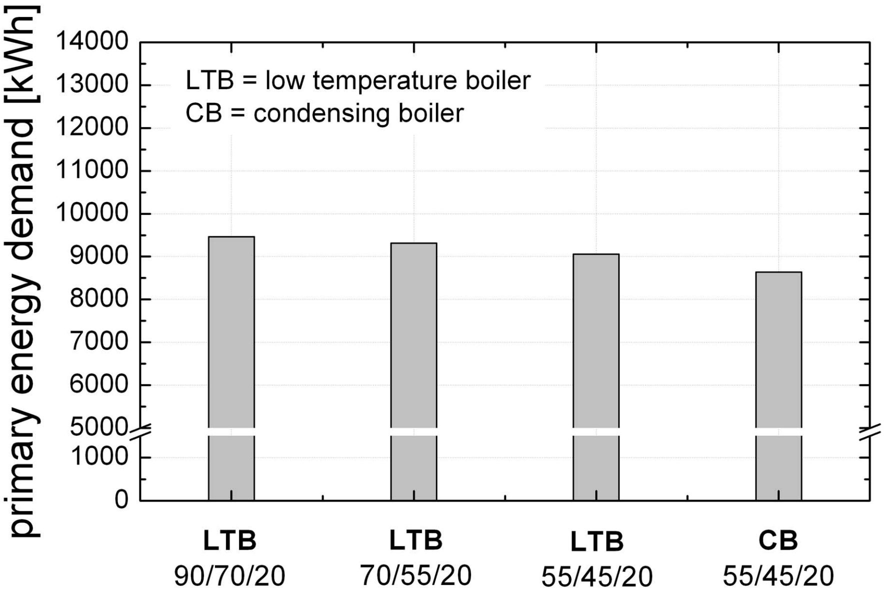

Figure 11: Primary energy demand for different boilers

Figure 12 shows the influence of the system's temperature level and the configuration of the hydraulic circuit (storage tank serial or parallel) on the efficiency of the heat pump system. The system with higher temperature level consumes more energy than systems with lower temperature level. The comparison of the serial and parallel configuration of the storage tank show clearly that the latter one is more energy efficient.

The systems analysed above have been controlled using the most traditional and least efficient strategy, i.e. the control of the supply temperature as a function of the ambient temperature.

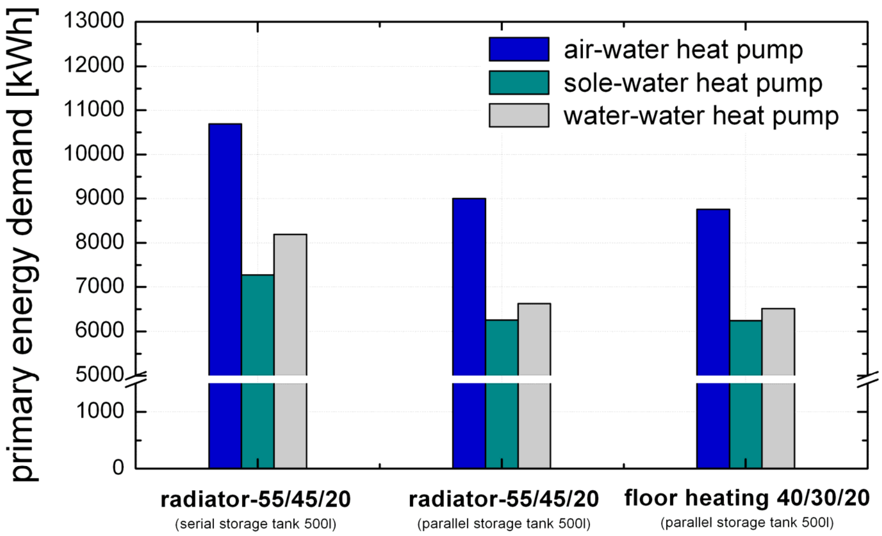

Figure 12: Primary energy demand for different heat pump systems

Comparison to national and international standards

If the energy efficiency of heating systems is calculated according to the existing European and German standards, interactions between system components are usually not or not enough taken into account. These effects have to be considered when standards are revised in future.

Conclusions

In the present paper the influence of control strategies, heat source type and heating system configuration have been presented and analysed. As a result the following conclusions could be drawn:

1. The use of PI-controllers as local control devices in the rooms results in the lowest energy consumption and optimal thermal comfort.
2. The use of cheaper local controllers results in overheating and respectively higher energy demand of the building
3. The energy consumption of the traditional system (no direct control) is fourfold higher than for the systems with controlled pressure head.
4. The absolute value of the energy consumption of the hydraulic devices is by an order of magnitude lower than the heating energy demand.
5. all investigated control strategies for the heat source have resulted in increase in energy efficiency of the system in comparison with the traditional solution (control of the supply temperature as a function of ambient temperature)
6. The two-step control of the heat source resulted in higher energy efficiency at the cost of the decreased thermal comfort in the heated rooms.
7. The strategy controlling the supply temperature as a function of the valves' lift in all heated rooms turned out to be most efficient without negative side effects for the thermal comfort.
8. The lower the temperature level of the heating system the lower its primary energy consumption.
9. The most efficient heat sources are in growing order: low-temperature boiler, condensing boiler and the heat pump system.
10. The heat pump systems with parallel heat storage tank are more efficient than the ones with serial storage tank.

Acknowledgment

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Nomenclature

HP - heat pump
TRV - thermostat
TS - two-step-controller

References

Christoffer, J.; Deutschländer, T.; Webs, M.: *Testrefernzjahre von Deutschland für mittlere und extreme Witterungsverhältnisse TRY*, Deutscher Wetterdienst (2004), ISBN-Nr.: 3-88148-398-5

EnEV2004 2004. *Energieeinsparverordnung 2004*, Bundesregierung von BRD, Berlin, Germany

Felsmann2002. Felsmann, C., *Ein Beitrag zur Optimierung der Betriebsweise heizungs- und raumlufttechnischer Anlagen*, PhD-Thesis, TU Dresden 2002

Klein, S A, Duffie J A. and Beckman, W A.1976. *TRNSYS - A Transient Simulation Program*. ASHRAE Trans 82 (1976), S. 623

Perschk2000. Perschk, A., *Gebäude-Anlagen-Simulation unter der Berücksichtigung der hygrischen Prozesse in den Gebäudewänden*, PhD-Thesis, TU Dresden 2000

Richter W, Seifert, J., Kozak, W. and Oschatz, B. *Energetische Gesamtanalyse, Bewertung und Verbesserung von komplexen HLK-Systemen für Wohngebäude unter Berücksichtigung wärmephysiologischer Aspekte*, TU Dresden 2009

Sustainable Building

Sustainable Building Operation – Experiences from Danish Housing Estates

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Abstract

Energy saving in the existing building stock has become a main goal of national and international policies. Often focus is on building-renovations, whereas the potential of sustainable building operation has to a large extent been neglected. Nevertheless, international research as well as practical experiences from Danish housing estates indicates that there are large potentials for energy savings by focusing on the operation of buildings. We suggest that in order to achieve sustainability in the existing housing stock, renovation and operation should be seen as integrated parts and that sustainable building operation can pave the way for sustainable building renovation.

This paper discusses the use of sustainability building operation in Danish housing estates: What tools, methods and technologies are being used, where are the barriers and where are the potentials? We define sustainable building operation as an 'umbrella' for various ways of reducing flows of energy, water and waste in the daily operation of buildings, for instance by regularly monitoring the consumption, by using 'green accounting', by applying policies for sustainability etc. The paper is based on case studies of sustainable building operation and a survey amongst building administrators from the private and the social housing sector.

Our results shows that there are many good examples of sustainable building operation in Danish housing estates, where local building managers, residents etc. have gained impressive results. In the broader sense, however, there is a limited use of available methods and technologies. Barriers for the use of sustainable building operation have been identified, and related to different types of ownership (social housing, private rented, owner-occupied and private co-ops). The survey indicates that the social housing sector has better conditions for implementing sustainability goals in their building management compared with other types of ownership and that a considerable expertise has been generated in the sector. Our study raises questions on how to spread this knowledge to other actors in the sector and how to overcome barriers for sustainable building operation.

Introduction

There is a growing interest in integrating sustainable measures in building operation; more and more facility managers and building owners show an interest in sustainable issues. It is increasingly acknowledged that facilities managers and 'building operators' are key actors in implementation of sustainable measures in the building operation [1]; [2]. Facility managers need to develop a 'sustainable strategy' that can fit into the organisation's financial management, where new management tools such as Total Cost of Ownership (TCO) can be an important tool for promoting sustainable building operation [1]. However, it has also bee stressed that there is often a gap between the environmental benefits that users demand of building operation, and the services delivered by the facility management. For example, customers have too little knowledge of the environmental services that facilities management operators are able to deliver, or facility managers have too little knowledge of user demands [3]; [4]. Also, these services can be very diverse, as there are big differences between facility managers and administrators concerning the environmental themes that are considered essential [5]. Some of the barriers for implementing sustainable measures in the building operation are the limited data on local consumption of energy, water etc., lack of incentives to create routines related to environmental issues, limited knowledge about environmental themes in the housing organisation, and that housing administrators have too little time and too few resources [5].

Other studies conclude that the organisation of housing companies have great importance for their environmental performance [6]. Brunklaus identifies a wide range of studies showing that there are several technical options for reducing environmental impact, but that an offensive attitude amongst owners and administrators is missing, and that limited resources within the organisation and lack of long-term maintenance are significant barriers to environmental performance [6]. The results of a survey of consumption data over 10 years in two residential areas in Gothenburg suggest that a housing organisation based on flexible planning and control are better able to absorb new energy- and environmental requirements than an organisation built of more rigid procedures. Therefore the local organisation and the housing management are crucial factors for the implementation of sustainable measures, possibly leading to a 25-30% difference in energy and water consumption [6].

In a Danish context the thesis on how organisational structures influence sustainable building operation is highly relevant, mainly in relation to different types of ownership; in relation to implementation of sustainable measures in new buildings, the social housing sector has for many years been leading, compared with other types of ownership (private renting, co-ops and owner-occupancy). Although we expect that this is also true of the building operation due to the generally well-organised organisational structure of the social housing sector [7], we have so far not had any significant picture of the differences between different types of ownership on how and to which extent sustainable measures are being implemented in the building operation.

The Danish context: Buildings, ownership and environmental regulation

In the project that this paper is based on [8], our goal was to focus on what happens in the daily and ordinary operation of the buildings, and to discuss possible implementation of different sustainability measures. This includes only multi-storey residential buildings, where there is often professional operation services related, making concepts for facility management and sustainable building operation relevant.

As the political focus on energy use in buildings is increasing, the role of the existing building stock needs to receive more attention. Hitherto research, development and public regulation related to energy in buildings has primarily focused on new buildings, although new buildings represents, at best, only 1% of the total building stock (per year). Reducing energy use in buildings will have a very long-term perspective, if focus is only on new buildings.

The existing building stock has to a much smaller extent been an objective for research, development and public regulation. One main reason for this is that regulation and technological development of existing buildings is complicated, as the buildings are in use, with owners, residents and a physical structure that it might be difficult and problematical to change. Moreover, there is a widespread discourse on 'energy renovations' as a way to improve energy efficiency in existing buildings generally, although it is rather obvious that 'energy renovations' is a purely theoretical concept which hardly exists anywhere in real life. There are renovations of the existing building stock, but in the oldest part of the building stock, they are mainly related to the renewal of the dwelling (e.g. new kitchens, new bathrooms, merging of flats etc.), and less to the building itself [9], making it less relevant to include sustainability measures, for instance external insulation, low-energy windows or more effective energy management systems. In the social housing sector that consists mainly of buildings from the 1960-1980s there is much renovation going on, supported by the National Building Foundation. This includes not only the dwellings, but also the whole buildings. However, so far the policy of the National Building Foundation has been that sustainability measures should only be implemented if it does not involve extra costs that will raise the rent for the residents; in practice there are often limited economic benefits related to investments in energy saving measures that go beyond 'standard'. This means that although the renovations often include external insulation of the buildings, and possibly more energy-effective buildings, very few sustainability measures have been included, and certainly no 'energy renovations'. All in all, 'energy renovations' is a nice concept, but so far it has had very little reality. For building owners, residents and administrators, there are other and more practical problems and purposes related to the renovations: Improving the standard of the flats, attracting new customers, changing the image of the properties etc.

On this background, we find it essential to focus on the building operation. Sustainable building operation involves both residents' behaviour, use of the building and overall organisation of operation and maintenance. Both practice and research in the field show that environmental performance is linked to how knowledge, resources and local organisation are present locally and that significant energy and water savings can be achieved through building operation. We also see indications that owners who focus on sustainability in the building operation are more willing to include sustainable measures in building renovations. However, there is limited knowledge about the extent to which the various forms of sustainable building operations are carried out in practice and what is perceived as a barrier to use them.

Danish housing estates and the environment

There are about 1 million multi-storey dwellings in Denmark (2006), representing 38% of all dwellings in the country. Due to their relative small sizes (on average 79 m^2), they represent only 27% of the residential area. There are about 87,000 multi-storey buildings for housing in Denmark. They have in average 12 dwellings per building, and an average floor area of 923 m^2. There are however differences amongst the different types of owners (Figure 1):

- Private renting and private co-ops. In private rented dwellings, the building operation is mainly decided by the owner and residents have limited influence. For private co-ops, the residents buy a share of the co-op which gives them a right to rent the dwelling and the right to vote at the general assembly, where all decisions about the co-op are made. In recent years a large amount of private rented dwellings have been transformed to private co-ops, as new legislation gave the residents the option of buying the building when it was going to be sold. This has been very popular amongst the residents, who get much more influence on their dwelling and building as co-op sharers. Private renting and private co-ops each represents 14% of the dwellings in multi-storey buildings. They are dominated by many small buildings (100-1.000 m^2) with a limited number of dwellings.

- In social housing, the residents rent a dwelling in a social housing department, which is an independent organisational and economic unit. It is typically administered by a larger administrative social housing organisation. The residents have the right to vote at the general assembly of the housing department, which makes all important decisions relating to economy, maintenance, election of the local board etc. This is the essence of the extensive 'residential democracy' in the sector. Social housing represents 36% of all dwellings in multi-storey buildings, and has a relatively high proportion of buildings ranging between 1,000 and 5,000 m^2.

- Owner-occupied dwellings are dwellings in multi-storey buildings individually owned by the residents. Here, the common decisions concerning the building are made by an organisation between the owners. The owner-occupied dwellings represent 21% of the all dwellings in multi-storey buildings. Like for private rented and private co-ops, the owner-occupied dwellings are dominated by many small buildings (100-1,000 m^2).

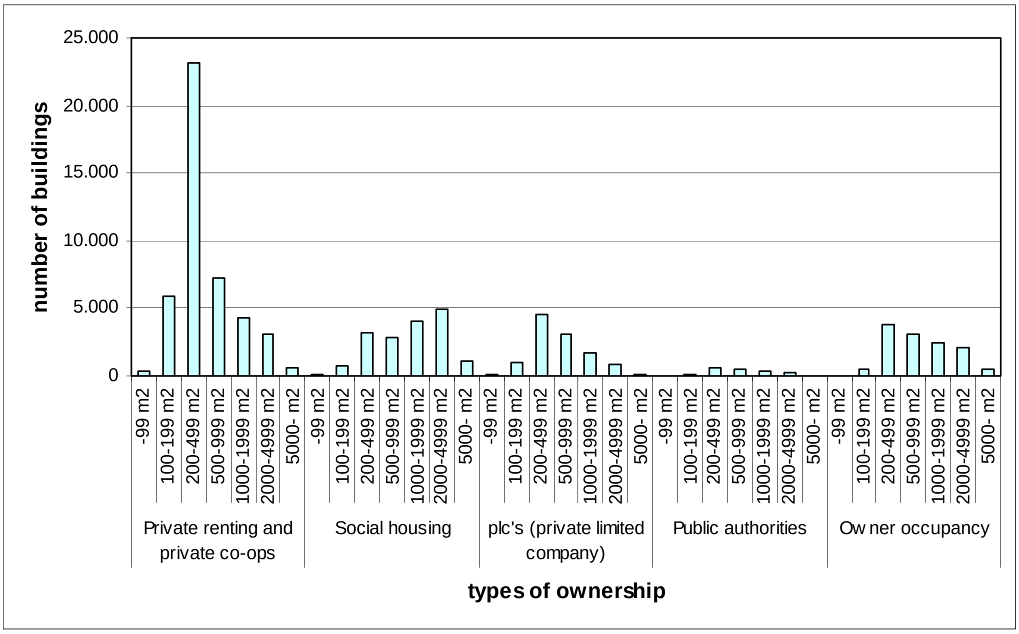

Figure 1. The number of multi-storey buildings in Denmark (y-axis), divided by size of building (m2) and type of ownership (x-axis).

Source: Statistics Denmark.

The other types of ownership, private limited companies and public authorities represent a total of 12% of the multi-storey dwellings, but have been left out of this research.

Type of ownership as well as size of the buildings is relevant for the way they administered and managed. The different types of ownership give different influence to the residents, and different ways of making decisions. The many small buildings in private rental, private co-ops and owner-occupied dwellings mean that there are many small owners and administrators in this sector, whereas in social housing there are many relatively large housing organisations that take care of the building operation and facilities management for the different local boards. Table 1 gives a brief overview of the characteristics of different types of ownership.

Table 1. Characteristics of the building operation under different types of ownership

	Social housing	Owner-occupancy and private co-ops	Private renting
Manager	Housing organisation	Private administrator, or self-administration	Private administrator; can be smaller or larger
Residents influence on building operation	Residential based democracy. Residents selects local board and decides on local budgets	Residents select local board and decides on local budgets	Limited formal influence (for instance to veto decisions)
Organisational unit	Local department board	Local board	local renters organisation (optional) with very limited influence
Owner	Local housing department	Owner-occupied (residents) or by a co-op	Private landlord
Operation staff (janitor, inspector, gardener etc.)	In-house and employed by the housing organisation, limited service from the outside	Service from operators (contracts and ad-hoc), and from DIY work.	Smaller administrators have no operation staff (owner must arrange service-operators). Larger administrators have in-house staff

Regulation and tools for sustainable building operation

Sustainable building operations is used in this project as a collective term for the variety of environmental projects and initiatives that deal with the daily building operation - including the ongoing maintenance, monitoring and maintenance of installations and heaters, etc. Parts of this concerns mandatory arrangements due to public regulation, part of it concerns voluntary tools, arrangements and initiatives.

In 2007 the Danish government proposed an ambitious energy plan, 'A visionary Danish energy policy', advocating for energy conservation of 1.25% per annum for the period 2006-2013. In February 2008 it was re-decided and with the even more ambitious goal of 1.5% savings of the final consumption of energy until the year 2020. This approximately 3 times more than what has been achieved with up to date energy-saving efforts. However, the actual initiatives launched in order to achieve the goal have been few so far. In the plans, the main potential is seen in 'energy renovation' of existing buildings, and in initiatives related to Energy Labelling of Buildings. The Energy Label, which requires an energy review of the building at every sale or as minimum each 5th year, has been widely criticised by building owners, residents, administrators and consultants for being too costly and causing too few changes in the owners' practice. The Energy Labelling of Buildings in 2007 substituted a former arrangement, where energy consultants each year made a review of buildings over 1,500 m^2 where they noted the energy consumption of the building and suggested ways to improve the energy efficiency of the building. Although this arrangement was also criticised for not being efficient, it has the quality of delivering annual registrations of the energy consumption, which many owners and administrator are missing today with the Energy Labelling of Buildings. A recent evaluation of the Danish energy saving initiatives rated the Energy Label of Buildings as the worst initiative, in terms of efficiency gained in relation to costs [10]. As this is the primary regulation tool for existing buildings, the present action plan on energy savings is rather un-ambitious in relation to the operation of existing buildings.

Concurrently with the mandatory regulation, a number of voluntary tools and methods have been developed to systematically manage sustainable issues in buildings. This includes for instance green accounting for residential buildings: This is a programme for a standardised consumption monitoring of a building, for calculating CO_2 emissions and enabling the comparison of key figures with similar buildings [11]. Another example is the 'Green Diploma', an environmental management scheme developed for social housing departments by the National Organisation for Housing Associations. It requires that the housing department establishes an action plan to reach a number of self-defined environmental targets. The scheme has recently been opened for other types of ownership, private co-ops being the most relevant.

In addition to these schemes there are a number of other well-known methods, for instance Energy Management, a method for monitoring and visualising energy flows in a building, making it possible to react quickly if consumption rises, or improving the basis for investments decisions in energy-efficient building technologies. Through building operation and ordinary maintenance there are a number of smaller initiatives and investments that can improve the environmental performance of the building, for instance by using technologies as low energy windows, low flush toilets, low-energy bulbs on shared spaces etc. To realise these potentials however requires skills, knowledge and competences amongst the operation staff, as well as a determined building owner and dedicated residents. Sustainable building operation therefore acknowledges that behaviour and use of the residents are as important factors as the purely technical qualities of the building.

Methodology

The aim of this research project was to identify how and to what extent sustainability issues are integrated in the operation of buildings, with different types of ownership and in different organisational contexts. The methodology consisted of different parts:

- A workshop on sustainable building operation was held with a range of leading practitioners and researchers in the field. A number of examples of environmentally controlled building operation from practice was presented and key issues in the area was discussed, including the potentials and barriers for further learning.
- A questionnaire survey to about 350 private and public housing administrators. The questionnaire included on the one hand general questions on the administration and on the other hand questions about specific environmental actions in the operation and detailed questions about particular barriers to integrating environmental aspects into operations.
- Finally, five case studies of practical examples of sustainable building operation were conducted, based on document studies and interviews with key persons.

One of the main questions behind the survey was whether the implementation of environmental and sustainable issues depended on how the housing is owned and organised. This included the types of organisational resources, the knowledge, competences, the structure of the housing type and the ways decisions were made.

Survey on sustainable building operation

The questionnaire included three groups of questions:

1. General questions about the administrator and relations to the customers

2. Questions on the implementation of sustainable measures in the building operation

3. Additional questions about sustainable building operation

The questionnaire was distributed to 196 public housing administrators and 161 private administrators via email. Overall, there was a response rate of 31% for the study as whole, broken down to 42% for the social housing administrators and 17% for private administrators.

The social housing administrators in average managed 57 housing departments as customers, with almost 4,200 dwellings. The average private administrator managed 58 clients, with approximately

2,100 dwellings. This difference reflected the larger number of dwellings in each building in social housing (see also Figure 1).

In the following tables, answers are divided between ‘social’ and ‘private’ administrators, referring to the dominant types of ownership administered by the managers: Social administrators managed mainly social housing departments, and private administrators managed mainly private rented, owner-occupied and private co-ops.

Provision of tools for sustainable building operation

The first question referred to the environmental services that the administrator provided, either as a regular part of the administration or as a service that it is possible to buy (Table 2).

Table 2. Services related to sustainable building operation from social and private housing managers.

	Administration of heating and water accounting		Energy management		Green accounting		Support on sustainability issues on renovation projects		Support on green procurement		Information and campaigns aimed at residents and staff	
	social	private	social	private	social	private	social	private	social	private	social	private
Is a part of ordinary administration, %	73	70	67	16	25	0	29	0	53	6	59	11
Can be delivered as an additional service, %	14	10	9	21	17	12	21	28	6	17	14	17
We do not offer this service, %	13	20	24	63	58	88	50	72	41	78	27	72
Total, %	100	100	100	100	100	100	100	100	100	100	100	100

The answers shows that social housing administrators as part of the general administration includes various environmental services to a much larger degree than private housing managers does. For instance, energy management is a part of the overall administration for 67% of the social housing administrators, but only for 16% of the private administrators. Private administrators generally offer very few environmental services as standard, but more are available as supplementary services. However, this does not preclude private customers finding these services elsewhere without contacting the administrator.

Another question referred to the emphasis that managers themselves put on providing environmental services. Among the social housing managers a larger share (71%) answers in the affirmative that they put emphasis on acquiring and provide environmental competences, than among private housing managers (33%).

In contrast, 62% of the social housing managers fully or partly agreed that their customers do not demand the services, where the number is only 45% amongst private administrators. One might see it as expressing that the social housing managers are more settled in their assessment (there are fewer 'do not' than among private) since many social housing managers have tried to offer their customers various environmental services, while relatively few private housing administrators had gained experience in this area and therefore 39% answers 'do not know'. Another interpretation of these answers is the social background of the residents; residents in social housing often have a shorter time-horizon and less attachment to the place than private administrators' customers (residents in private renting, owner occupancy or co-ops).

A final and major difference between the social and private administrators is their own perception of their role. A total of 72% of the social housing managers disagreed that environmental benefits are not relevant to offer as an administrator, while the private total is 28% - and vice versa: 17% of the social housing managers wholly or partly agrees that it is not relevant to offer, whereas 55% of the private managers wholly or partly agreed on this. There is a significantly different view of the administrator's role among the public and private. The social housing managers offers many environmental services and see it as an important part of their administration, well knowing that the residents only to a limited degree demands this.

Implementation of environmental measures and initiatives in the building operation

The administrators were asked what environmental measures were implemented in the properties they manage. This included 4 areas:

- Cleaning and care of shared outdoor and indoor spaces
- Operation and maintenance of buildings
- Operation of heating and water installations
- Information and capacity-building amongst residents and staff

The questionnaire gave the administrators' options to estimate four ranges of implementation (0-25% of all buildings, 25-50%, 50-75% and 75-100%) of environmental measures in the properties they manage. The reason for these options was that it could be very difficult for a housing manager to say exactly how many properties certain measures had been implemented in, as the measures were adjusted to local conditions, especially the standard and economy of the building, and the residents' preferences.

Although there were some variations amongst the four themes, and in the various sub-questions, the overall picture is that environmental measures are to a much wider extent implemented in the social housing properties. In relation to the operation of the heating and water installations, there is a much higher degree of monitoring, controlling and optimising boilers and monitoring consumption in the properties with social housing management, compared with the private managed properties (Table 3). For instance, 77% of the social housing managers have monitoring routines for the boiler system of most of their properties, whereas only 32% of private managers have such routines. For a similar monitoring of the energy and water consumption in the property, 72% of the social housing managers have regular monitoring routines of this in most of their properties, compared with 26% of the privately managed.

Table 3. Implementation of measures related to operation of heating and water installations

Implemented in percentage of properties managed	Monitoring and optimisation of boilers etc.		CTS control of heat supply		Monitoring of consumption in the property		Energy-saving pumps		Night-reduction of temperature	
	social	private	social	private	social	private	social	private	social	private
0-25%	0	32	44	21	9	21	7	16	38	21
25-50%	4	11	14	21	6	16	18	16	19	26
50-75%	19	26	14	5	12	21	26	26	19	11
75-100%	77	32	18	5	72	26	41	11	20	11
Do not know	0	0	11	47	1	16	7	32	4	32
Total, %	100	100	100	100	100	100	100	100	100	100

For the use of administrative tools for sustainable building operation, the picture is the same; the answers suggests a more widespread use of such tools amongst social housing managers compared with the administrators on the private part of the housing market. However, the administrative tools for sustainable building operation is generally used relatively little, for instance the 'Green Diploma'. Although it has been launched by the Danish Social Housing Association and heavily promoted amongst social housing administrators for several years, 'no knowledge' of the tool accounted for about one third of the administrators' answers to why it is not being used. This indicates the problems of communicating information on sustainable building operation from the top of an association to the floor of the administrators, and probably also reflects that housing administrators have a number of other and often higher prioritised agendas than sustainable building operation.

Table 4. Implementation of administrative measures related to sustainable operation of the building

Implemented in percentage of properties managed	Green accounting		Energy management		Green diploma		Danish Standard for building operation		Key figures from Danish Facility Management Network	
	social	private	social	private	social	private	social	private	social	private
0-25%	69	65	32	35	78	65	66	40	67	45
25-50%	3	0	9	30	3	0	7	5	3	10
50-75%	1	0	8	15	0	0	10	10	5	5
75-100%	10	5	42	10	0	0	2	5	8	5
Do not know	16	30	9	10	19	35	16	40	17	35
Total, %	100	100	100	100	100	100	100	100	100	100

Energy management can be quite an effective way of monitoring the consumption in the property, to keep energy consumption from escalating, and to prepare owners to implement measures to reduce energy costs. Therefore, it is surprising that only about 10% of the private administrators have implemented it in their management. Their reasons for not doing so is not related to lack of knowledge (only 7% sais they do not know it), but rather to lack of relevancy and motivation (more than 50%) – this is in line with the large amount of administrators who do not see it as their role to promote sustainable building operation towards the clients.

Motivation and barriers

Administrators were asked different questions on their motivations and barriers to use measures for sustainable building operation.

Table 5. Administrators' motivations for including sustainable measures in the building operation.

	Economic benefits		Common sense		Concerns for sustainability		Requested by residents		Related to other improvements		Not relevant for us as administrators	
	social	private	social	private	social	private	social	private	social	private	social	private
Totally agree	37	33	55	56	41	17	0	6	28	17	0	11
Partly agree	46	44	42	39	46	61	28	33	55	44	9	17
Do not know	6	0	1	6	9	17	24	28	9	28	16	33
Partly disagree	9	17	1	0	4	6	38	22	7	6	27	33
Totally disagree	3	6	0	0	0	0	10	11	0	6	49	6
Total, %	100	100	100	100	100	100	100	100	100	100	100	100

The two groups of administrators generally agreed on 'common sense' as the most important factor for motivation, general concerns for sustainability and economic benefits as the most important factors – and that requests from residents counts relatively little. The social housing managers more frequently see the sustainability measures in relation to other improvements, which might reflect a higher level of building renovation on the social housing sector, compared with the private. Interestingly, the largest disagreement concerns the administrators' role in relation to sustainable building operation: as noted before, a high proportion (28%) of private administrators do not see it as their role to suggest and implement sustainable measures for their clients, whereas this is only the case for 9% of the social housing administrators.

The question about where the initiative to include sustainable measures typically comes from reveals some differences between the two groups (Table 6). Whereas both types of administrators agreed that legislation was the most important single reason for implementing sustainable measures, the social housing administrators generally appointed greater responsibility to local actors (residents, building inspectors, owner and administrator) to taking the initiative, than did the private administrators. This suggests that bottom-up initiatives for sustainability measures might play a more important role in the social housing sector, than in buildings from the private sector.

Other questions shows that there is also significantly more influence of residents and staff in the social housing sector through information, campaigns etc. – according to the questionnaire, 1/3 of the social housing administrators says that this takes place in most of their properties, whereas this is only the case amongst 5% of the private administrators. Therefore, the initiatives for sustainable building operation are not just a matter of bottom-up or top-down, but also a matter of mutual encouragement.

Table 6: Where does the initiative to include sustainable measures come from?

	Legislation		Residents		Building inspector/ janitor		Owner		Administrator	
	social	private	social	private	social	private	social	private	social	private
Totally agree, %	37	39	12	0	26	0	22	5	23	0
Partly agree, %	56	50	41	44	57	67	52	53	45	68
Do not know, %	3	11	12	22	4	17	10	32	19	26
Partly disagree, %	3	0	29	28	10	11	13	11	13	5
Totally disagree, %	1	0	7	6	3	6	1	0	0	0
Total, %	100	100	100	100	100	100	100	100	100	100

Although the administrators and other stakeholders might be motivated to take up initiatives for sustainable building operation, they encounter different barriers. For instance, it is a well-known problem in the private rented sector that due to the legislation, only some building improvements can be 'put on the rent', meaning that the residents actually pay for the improvement. In other cases, the owner has to pay for the improvement himself, although the residents get the benefits resulting from the improvement. This is also true of improvements related to sustainability (for example new windows with better insulation): The owner will have to pay for the majority of the investment, but the residents get the benefits in terms of a reduced heating bill and a better indoor climate. For many owners of privately rented property, this is regarded as a main barrier to implementing sustainable measures. This question was also raised in the questionnaire, although it is primarily a problem amongst private administrators, which is also reflected in the answers. In spite of the often used argument in the Danish debate, other barriers were rated equally high amongst private administrators in the questionnaire – including the lack of environmental potential in the existing solutions, and scant interest from the owners (clients). However, the private administrators are more sceptical towards the environmental and economic potential of existing measures for sustainable building operation than their partners from the social sector; and again, the social and private administrators have very different views on the role of the administrator.

Table 7: What are the major barriers for sustainable building operation?

	The residents get the benefit, the owner pays		Small environmental potential		Small economic benefit		Owners are not interested		Administrators do not have the competence		Not relevant for us as administrators	
	social	Private	social	private	social	private	social	private	social	private	social	private
Totally agree, %	11	19	3	12	11	12	8	12	3	6	4	12
Partly agree, %	16	44	39	65	35	47	52	53	26	25	11	18
Do not know, %	13	19	16	18	22	35	23	24	18	44	13	41
Partly disagree, %	23	19	27	6	22	6	11	6	39	13	38	24
Totally disagree, %	36	0	15	0	10	0	5	6	13	13	36	6
Total, %	100	100	100	100	100	100	100	100	100	100	100	100

Practical examples on sustainable building operation

A brief comparison of two case studies on sustainable building operation illustrates some of the differences between social and private housing in terms of implementing sustainable measures. This relates especially to the different organisational forms, and the organisational environment of the initiators.

Example 1: Valby Bakkegård, a private co–op

The private co-op Valby Bakkegård consists of 48 dwellings (3-4 rooms) with a total area of 4.500 m2. It is located in Copenhagen, in a 5-storey building from 1954. This is rather typical for the private co-ops, private rented buildings and owner-occupied buildings in Denmark (figure 1).

The local Board of Valby Bakkegård consists of five residents, both older and younger residents. As the board members are all laymen, they have limited expertise. The administration is carried out by a small law firm, who takes care of bookkeeping, collection of rent, housing court cases and other personal service. A caretaker is attached to the property. He comes a couple of hours three times a week, and takes care of waste discharge from the property, adjustment of heating system and other related functions. A main part of the building operation is based on the knowledge that the members of the board gather over time. When this is not enough, they turn to outside consultants, for example energy and engineering consultants. The board-based building operation however is vulnerable due to exchanges in the board; the knowledge and competences acquired by one board-member is suddenly lost when the member moves.

The present chairman has been the initiator for a number of different sustainability initiatives. This includes better insulation of the property, using energy-saving bulbs on shared spaces, a better sorting of the waste, and less use of chemicals for the green areas. Although the initiatives have been relatively successful, there have been a number of obstacles: The residents are rather reluctant towards the sustainable initiatives. This means that the suggestions often are changed and compromises have to be made, reducing the environmental efficiency. Also, this frequently leads to conflicts between the board and the rest of the residents. Finally, it is difficult for the board to plan and manage the building operation in a professional manner that integrates sustainable solutions in the ordinary building operation. For instance, when a kitchen is being renovated, and afterwards the board afterwards discovered that the floor could have been isolated to save energy – which however will require an entire new kitchen. The example illustrates that although there might be plenty of ambitions to improve the environmental performance of a small co-op, the organisational conditions might not be sufficient to fully implement the measures.

Example 2: Brændegårdsparken, a social housing department

Brændegårdsparken is a social housing department with 324 dwellings, built in 1966-68. It is administrated by a social housing organisation (Fruehøjgaard) that includes 20 housing departments, with a total of 1.430 dwellings. Three staff members are permanently employed in Brændegårdsparken, moreover they can use the staff (carpenters and painters) from the housing organisation. The housing organisation Fruehøjgaard has employed an environmental coordinator, who has been working with environmental initiatives in the various departments. In Brændegårdsparken she has been a main reason why the department has achieved the Green Diploma, a sustainability scheme for social housing departments (see also p. 5). This includes that a sustainability policy, an environmental plan and a green accounting should be outlined and communicated to the residents, in order to promote savings on water and energy. As an example, their goal in 2007 for the environmental theme 'water' is to save 2.5% of their consumption, compared to 2006. In order to reach this goal the water meters will be read once a month, and from this 4 pillars will de designed, illustrating the water consumption in each of the four parts in the department. It is expected that this will motivate the residents to reduce their water consumption. Already within the first year with the Green Diploma (from 2005 to 2006), the water consumption dropped by 13,2%, due to various initiatives. Other projects include use of LED-lights on shared spaces, which has reduced the electricity consumption with 9.5% from 2005 to 2006.

The initiative to make the department apply for the Green Diploma came from the environmental coordinator. As there were several environmentally interested board-members in Brændegårdsparken, the department decided to apply for the Green Diploma. According to the board, the initiatives are based on a combination of the voluntary work carried out by the board members on one hand, and the paid work carried out by the housing organisation, including the staff and especially the environmental coordinator. Also, the department has collaborated with other local actors and organisations, for instance the local 'Energy Center' and the municipality of Herning. But the board members also use their professional background in the environmental initiatives. For instance, one of the board members is a former plumber, which has been very useful in the initiatives for water savings. This case illustrates how the organisation of the housing department is able to initiate and maintain initiatives that the local board is receptive towards, and thereby support a local interest in sustainable building operation to actually complete a number of measures.

Comparisons and conclusions

Compared with the example from the private co-op Valby Bakkegård, there are more technical and administrative resources available for the board members in Brændegårdsparken. This has proven to be crucial for the implementation the environmental initiatives, as the board members in Brændegårdsparken – as well as in Valby Bakkegård – are both voluntary and laymen. As indicated in the survey, top-down initiatives might often support or encourage local bottom-up initiatives, where residents, staff and board members in the department get the necessary support (knowledge, expertise, administration etc.). In Valby Bakkegård there was also local interest as well as initiatives, but very limited support from the administrator or others.

There are similarities in the way that the local board in both examples is a central actor for the environmental initiatives. The difference is however, that the knowledge, experiences and competences gathered by the group of people working with the environmental initiatives in the social housing department, including the board members, will to a much greater extent be 'embedded' in the housing organisation, in contrast to the private co-op, where the knowledge and competences gathered by the individual board member more or less disappears from the co-op when the person moves.

These differences suggest a reason for the differences we see in the survey between social housing departments and owner types administrated privately. The answers from the questionnaire suggest that it is especially the social housing departments that use sustainable building operation, while other types of ownership exhibit a greater reluctance. The examples illustrates the organisational differences between a private co-op and a social housing department, and the necessity of having local resources at an organisational level to support and encourage voluntary initiatives and activities from the local boards. From the survey it is also clear that the private administrators define their role very differently than the social housing administrators: They do not see it as their role to provide support on sustainable solutions to the clients – whereas the social housing administrators have the opposite opinion. The consequence is that residents or board members in a social housing department has a much better offer for support from the administrator on sustainable initiatives, than residents with a private administrator.

This is partly due to structural and historical reasons; traditionally, administrators on the private market are lawyers, providing the primary service of collecting rent and taking care of the complex regulation between landlords and residents. Therefore, in the prevailing efforts for environmental improvements and energy efficiency in the existing building stock, it is not enough to launch traditional types of regulation, for instance economic incentives. A more profound understanding of the background for the problems is necessary and new innovative incentives that could overcome these challenges. This could for instance include initiatives to establish ESCO arrangements in multi-storey-buildings, or to find arrangements where the knowledge and experiences from the social housing sector could be exploited by other types of ownership.

References

[1] Hodges, Christopher P. (2006) *The Facility Manager's Role in Sustainable Facility Management.* Proceedings of the FM 2006 Conference in Frankfurt.

[2] Aune, M & Bye, R (2005) *Buildings that learn – the role of building operators*. Paper for ECEEE 2005 Summer-study.

[3] Nousiainen, Mikko & Junnila, Seppo (2006) *Customer Requirements for Sustainable Facility Services.* Trondheim International Symposium – Changing User Demands on Buildings, 12-14 June 2006, Proceedings.

[4] Madritsch, Thomas (2006) *User Demands for Sustainable Homeservices: An Austrian Survey.* Trondheim International Symposium – Changing User Demands on Buildings, 12-14 June 2006, Proceedings.

[5] Malmqvist, Tove (2004) *Fastighetsförvaltning med miljöproblem i focus. Om miljöstyrning och uppföljning av minskad miljöpåverkan i fastighetsförvaltande organisationer*. Licentiatavhandling. KTH Infrastruktur. Stockholm.

[6] Brunklaus, B (2005) *Organisational background to environmental impacts. Field study on housing management in Gothenburg*. Environmental System analysis, Chalmers University of Technology. Göteborg, 2005.

[7] Elle, M ; Balslev Nielsen, S.; Hoffmann, B.; Jensen, J.O. (2005) *Sustainability in the existing building stock - the role of sustainable facilities management*. Paper for The 2005 World Sustainable Building Conferece in Tokyo, "Action for Sustainability", 26-29 September 2005.

[8] Jensen, J.O; Jensen, P.A; Elle, M; Hoffmann, B.; Balslev Nielsen, S.; Quitzau, M.-B. (2008) *Miljøstyret bygningsdrift i danske boligejendomme*. SBi 2008:15. ISBN 978-87-563-1348-3. Statens Byggeforskningsinstitut, Aalborg Universitet.

[9] Jensen, J.O. & Clementsen, A. (2008) *Barrierer for energibesparelser i private udlejningsboliger*. Report for the Ministry of Social Welfare.

[10] Ea Energianalyse, Niras, RUC and 4-Fact (2008) *En vej til flere og billigere energibesparelser. Evaluering af samtlige danske energispareaktiviteter*. Report for the Danish Energy Agency.

[11] Jensen, O. M. (2005) *Visualisation turns down energy demand*. ECEEE Summer Study, 2-7. June, 2003.

Dynamic Analysis Methodologies Applied to Energy Management in Residential Buildings

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Abstract

The paper focuses on the use of dynamic analysis methodology for energy savings and efficiency in residential buildings. Dynamic analysis tools, as have been developed during several European research projects, now are available as reliable applications and can be used as a very valuable tool for getting accurate information about the thermal characteristics, including thermal mass of the building in general, as well as advices on how to obtain the most efficient energy saving in building operation.

Introduction

The EU has set ambitious targets in Energy Policy for Europe [Ref 1] of 20-20-20% for:

- reducing greenhouse gas emissions by at least 20 % (compared with 1990 levels) by 2020;
- improving energy efficiency by 20 % by 2020;
- raising the share of renewable energy to 20 % by 2020;

This set out the need for the EU to draw up a new energy path towards a more secure, sustainable and low-carbon economy, for the benefit of all users and urgent actions are required to achieve these. One aim is to give energy users greater choice, and another is to spur investment in energy infrastructure. The building sector can contribute importantly to achieve the goals.

The buildings sector – i.e. residential and commercial buildings - is the largest user of energy and CO_2 emitter in the EU and is responsible for about 41% of the EU's total final energy consumption and CO_2 emissions mainly used for heating and cooling (roughly 2/3) and electric appliances (about 1/3). Therefore it is important to achieve a proper assessment of thermal characteristics of building components (such as windows, walls etc.) as well as occupancy behaviour under real conditions. Traditionally the assessment of building performance is based on static analysis technique. However dynamic methods for analysis and simulation of building energy consumption have been developed over the last two decades [Ref 2].

When the society succeeds to reach the aforementioned targets as well as those given in several energy related Directives then the whole energy supply, distribution and demand side will be more dynamic by nature. The use of renewable energy sources is seen as a key element in energy policy, reducing the dependence on fuel from non-member countries, reducing emissions from carbon sources, and decoupling energy costs from oil prices. An important key element is also constraining demand, by promoting energy efficiency both within the energy sector itself and at end-use.

In ten years time buildings might be more integrated in the whole chain for energy supply (like for example, photovoltaic electricity generators), demand (charging of electric cars) and distributed storage (potential of car batteries as a huge dynamic electricity storage). The management of energy end-use in the building sector will play a more important role. Currently ESCO's take that position already in some of the tertiary sector and it is with high probability that the domestic sector will follow.

Energy consumption in the building sector

Energy consumption in buildings is rising over the last decades (481.5 Mtoe or 41% of the final energy consumption in 2006 according to Eurostat data, [Ref 3]) due to rising income, resulting in higher standards of living. In particular the electric demand for appliances for increased comfort levels, communication and information technology has increased the demand for electricity in this sector. Hunderd years ago energy was consumed for space heating only, while nowadays, on average in Europe, roughly 2/3 is required for space heating/cooling and 1/3 (mostly electricity) for other use in buildings. Although space heating and cooling are the most energy demanding the integrated energy consumption in buildings does not decrease as illustrated in figure 1. Several studies notice this trend from regular observations [See for example Ref 4]

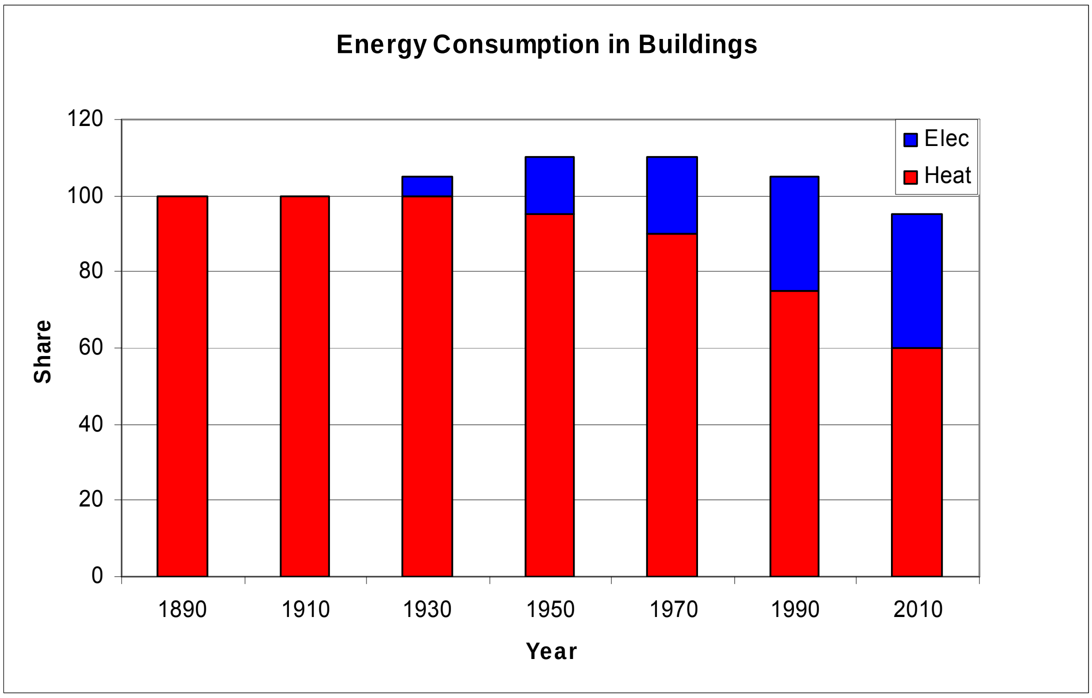

Figure 1. Energy consumption in buildings over 100 years

In 1912 electrical light was introduced when metal was used as a filament. It was a luxury good, first in hotels, restaurants and office buildings. After the WO II, the white good appliances became very popular, as well as radio and introduction of TV in the ’60’s. Although overall energy consumption in buildings has hardly changed over the last 100 years, it is used in different ways. Nowadays there is less energy needed for space heating, but electricity consumption is still increasing. Space cooling, electricity for heating water and standby consumption are major consumption areas where they end-user can contribute to a significant reduction. When primary energy source consumption is considered the picture becomes even worse because of the conversion from fossil fuels to an increasing demand of electricity.

Efforts to reduce overall energy consumption by improving insulation are turned down by a higher electricity demand leading in some case to black-out due to electricity intensive air-conditioning.

An important observation is that heating and cooling energy demand is mostly defined by the building characteristic parameters while the electricity demand mostly by occupancy behaviour and decisions, a result of higher living standards.

Electricity end-use in the residential sector

Continuous survey of end-use electricity consumption in residential and tertiary sectors shows that the electricity consumption in the residential sector for the EU-27 has grown by 13.17% on the period 1999-2007, from 707.52 TWh in year 1999 to 800.72 TWh in year 2007 and by 2.11% on the period 2004-2007. The electricity residential consumption in 2007 was 800.72 TWh, what represent a slight decrease comparing with 2006 and almost the same consumption as was registered in 2005.

Note that the gas consumption of the residential sector has continued to grow in the period 1999 to 2007 in the EU-25 from 103.822 Mtoe to 113.176 Mtoe (9% grow), but the yearly growth rate decrease from 0.24% over the period 2004-2005 to -5.73% over the period 2006-2007.

Electricity consumption in the EU-27 residential sector continued to grow until 2006, but the growing rate decrease significantly in the last year from 1.95% in 2004-2005 to 0.33% in 2005-2006.[1]

The share of main domestic appliances electricity consumption in total EU-27 residential consumption was around 31% in 2004, with significant differences between EU-15 and NMS-12 (30% and 43% respectively) [Ref 5]. However, analysing the sales of new appliances, significant changes happened after 2004, and was registered a strong penetration of very energy efficient equipments.

The share of the A+ energy class washing machines is in 2007 almost 4 times higher in Western Europe and around 10 times higher in Central European NMS, reaching on both markets 40% of the sales. The share of the A+ energy class cooling appliances is in 2007 almost 3 times higher in Western Europe and around 10 times higher in Central European NMS, reaching around 18% and 23% respectively (higher in NMS) [Ref 6].

The largest electricity consumers in EU-27 households are the electric heating systems (18.8%), cold appliances (15.3%), lighting (10.8%) and water heating systems (8.6%). The home appliances stand-by consumption cumulate 5.9% or 47.5 TWh/yr, being the eighth main consumer, more than air-conditioning, almost the same like home computers and dishwashers all together. (figure 2, table 1).

Table 1: Breakdown of residential electricity consumption in EU-27 in 2007

EU-27 residential electricity consumption	[TWh]
Cold appliances	122,0
Washing machines	51,0
Dishwashers	21,5
Electric ovens & hobs	60,0
Air-conditioning (cooling & heating)	35,0
Ventilation	22,0
Water heaters	68,8
Heating systems/electric boilers	150,0
Lighting	84,0
Television	54,0
Set-top boxes	9,3
Computers	26,0
External power supplies	15,5
Home appliances stand-by	43
Others	41,9
Total electricity consumption in TWh	800

[1] Calculation based on EUROSTAT data

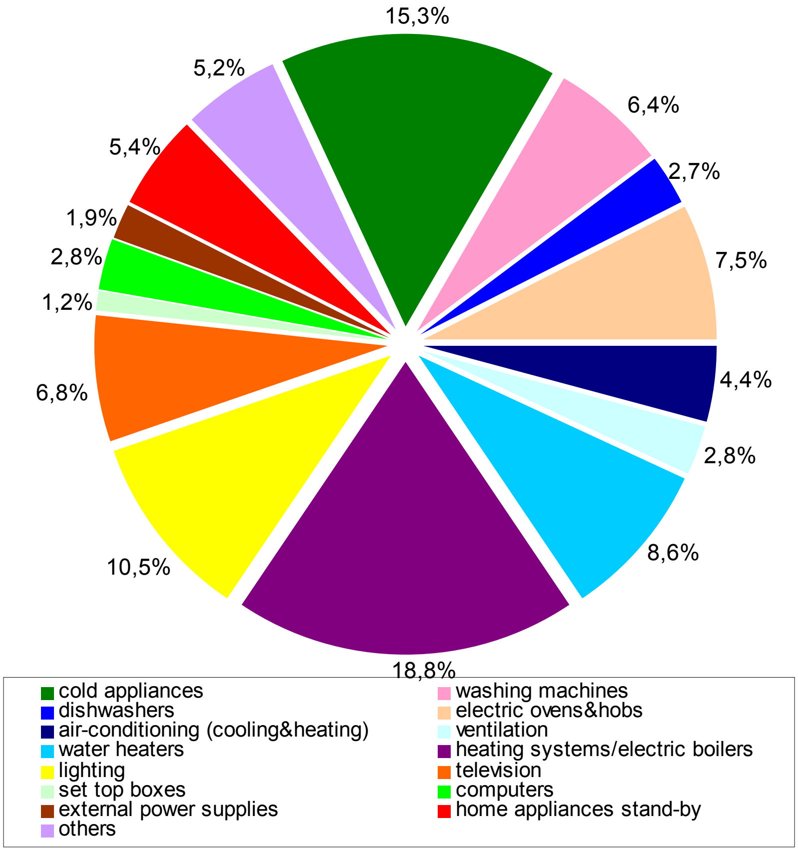

Figure 2: Breakdown of EU-27 residential electricity consumption (2007; source JRC)

Dynamic characteristics in building energy consumption

Traditionally the assessment of building performance is based on static analysis technique of the heat loss coefficient due to building insulation. Data presented are annual means and by Member States. However more and more complex electric installations and energy flows require a dynamic approach that can cope with peak supply from renewable energies sources such as wind and solar power plants and peak demand like electricity use for air conditioner installations.

The daily electricity consumption patterns show peaks that reflects time of use of for example washing machines and of power demand from the appliance. Distributed electricity generators like PV-roof installations might reduce peak demand.

For a proper understanding the energy in the built environment has to be considered in supply and demand parts. A future building situated in the 2020 energy world will take another place as the traditional building is nowadays. Energy consumption for thermal space conditioning will depend mainly on insulation level and thermal mass, the latter responsible for the dynamic characteristic of the building. Electricity consumption for appliances will continue to increase and will be mainly due to user behaviour, responsible for the dynamic behaviour of electricity demand. Decentralised electricity production by PV-roof installations or micro-turbine will be more common.

The main parameters of interest in the research area of energy in buildings are the thermal transmittance and the solar aperture. Whilst these parameters can be derived from observations with a relatively long duration, the use of dynamic system identification techniques can reduce the observation period and improve accuracy. Such powerful methods for the identification of physical parameters can enable the utilities to optimise the demand/supply balance for the efficient use of renewable energy. It can also be applied to fulfil legislative requirements, like energy labelling.

Dynamic analysis and simulation methods

By dynamic evaluation techniques (parameter identification) dynamic effects due to accumulation of heat in the equipment, room envelope and dedicated building components are properly taken into account. Periodic electricity demand patterns can be identified too. In general, parameter identification is needed to be able to derive the steady state properties as well as dynamic properties from regular observations with dynamic (e.g. fluctuating climate) conditions.

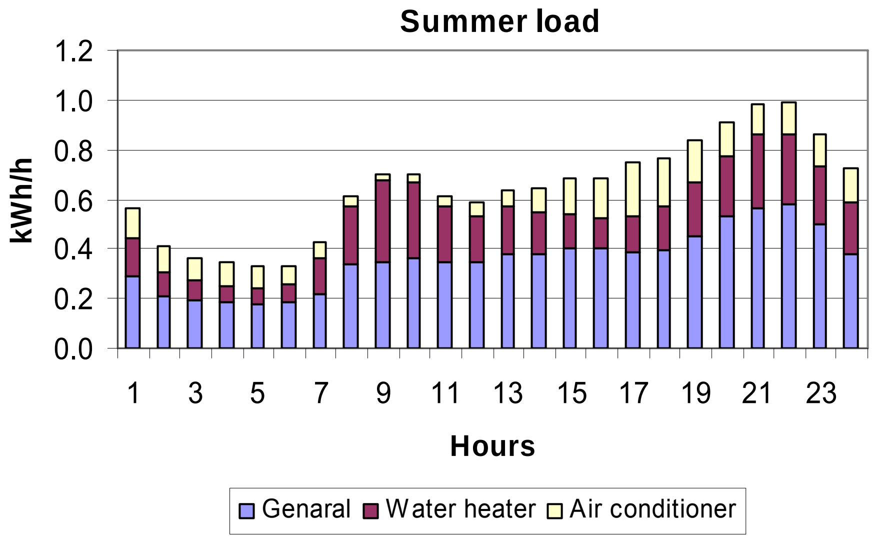

Figure 3: Average hourly load curve for summer (considered from June to September). In this case the water-heater and the air conditioner consumption has been added to the general load curve.

In addition the applied mathematical techniques are able to parameterise dynamic behaviour in electricity consumption. Standby consumption as well as repeated peak demand like refrigerator or washing machine electricity consumption can be modelled.

The building energy sector can be considered as a complex system but therefore be described by a dynamic model containing different parameters. The defined mathematical model parameters may correspond with different time-constants and/or with different physical parameters. Developed models can be validated against measured data but also be used for prediction of the behaviour of a system, e.g. energy consumption of a building in a changing climate. Heat supply for district heating demand can be balanced too when knowledge of thermal mass and outdoor temperature are taken into the dynamic mathematical model. The process of identification of these parameters representing a system is called System Identification and is well known in chemistry, physics and econometric.

System Identification

What is System Identification in the context of energy use in buildings? [See also Ref 8 and 9]. In principle the application of system identification is the construction of a mathematical model that represents a physical system and that is optimised for its parameters by using measured data. In the case of energy use in buildings the user is interested in thermal parameters such as the heat loss and solar aperture coefficients of the building envelop. The user of identification techniques for the analysis of measured data plays an important role, and practise has shown that a certain skill is required for best results.

In order to arrive to the desired result in obtaining useful values for thermal parameters, the user has to collect reliable data series, to construct a mathematical model and to convert the mathematical parameter estimates into physical ones.
Beside the fact that different physical systems exists, the user may apply different mathematical models. Below the various aspects will be presented and a way to tackle the problem by applying identification techniques will be discussed.

Energy conservation in the building sector is one of the major sources for reduction of fossil fuel consumption and hence for reduction of the related environmental impact.

Passive solar design has been recognised as an important potential for energy conservation by reducing the heating and cooling needs in both residential and commercial buildings or at equal energy consumption an improvement of the internal comfort. Many new building components and complex systems, like dynamic ventilated windows or building integrated photovoltaic systems, have been developed during the last decades. However, very little is known about their energy performances when applied in a real building.

A *model* is a mathematical description of a physical system or process. By definition it is a simplification of the reality. Models can be categorized in different ways. A list of possible models to be used is the following:

- lumped parameters models
- state-space models
- modal models
- linear regression models
- frequency domain models
- neural network models

A *method*, here a system identification technique, consists of two major parts: the mathematical model (e.g. an ARMAX model) and the routine to estimate the parameters by a specific algorithm (e.g. least squares method). Minimization is used in the context of minimizing the difference between measured and corresponding data obtained from the model. Optimization is used in the context of optimizing the mathematical parameters of the model to fit the data obtained from the model with the measured data.

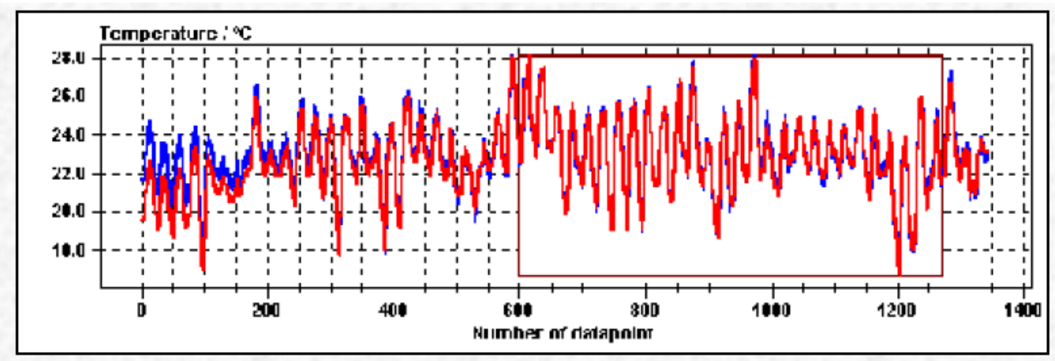

Figure 4. Dynamic modelling of regular observations

A *tool* is a sophisticated software program which allows the user to a method in a user friendly way. It is a ready-to-use product. Often these types of tools come with pre-processing routines and statistical information about the identification process and accuracy of the estimates. The selection and creation of models is one of the items which is simplified in a graphical way. LORD [Ref 10] is a good example of a tool that has been applied with success on linear models. CTSM is being mainly used for describing non-linear behaviour [Ref 11]. Toolboxes are popular among researchers. It offers the freedom of the creation of own methods using reliable algorithms and routines. The system identification toolbox in MATLAB is a good example of such an environment.

A *smart metering device* is an instrument that contains software to measure and analyse energy consumption. The software has the ability to signal dynamic characteristics and communicate with the building owner and utilities. The applications may include a procedure for detection of unwanted standby electricity consumption, and methods for identifying the time constants of the building for optimal control of the energy supply. The internet application may also include new methodologies for online identification of the dynamic energy signature of buildings. This dynamic signature provides a detailed knowledge of the energy performance of the building. Apart from giving an accurate characterization of the energy performance, the tool also provides hints for improvements of the energy performance of the building.

How can these mathematical techniques support a more efficient energy use in the building sector?

- Monitoring and analysis at local scale (building level)
- Forecasting of supply and demand (district heat, air-conditioners)
- Optimisation of supply and demand through management

Smart metering

Reducing energy consumption in the residential building sector starts with informing people what is actually consumed [Ref 15]. Thus monitoring and displaying the consumption is a first and important step. The involvement of the end-user, in particular through the price of electricity is important too. He might take decisions upon meter reading and act instantaneous. At present most of the end-users pay a fixed rate or a day-night rate for power without having a possibility in the decision making phase when electricity is consumed. The electricity market can manage the grid balance much better when tools will be available to monitor and control electricity consumption. Feedback to the utility will improve grid balance

Several campaign and projects are running dealing with smart metering. [See also Ref 16]. Also Google announced recently to develop a PowerMeter tool that could help households to reduce the amount of electricity they consume by monitoring their energy use at an hour interval.

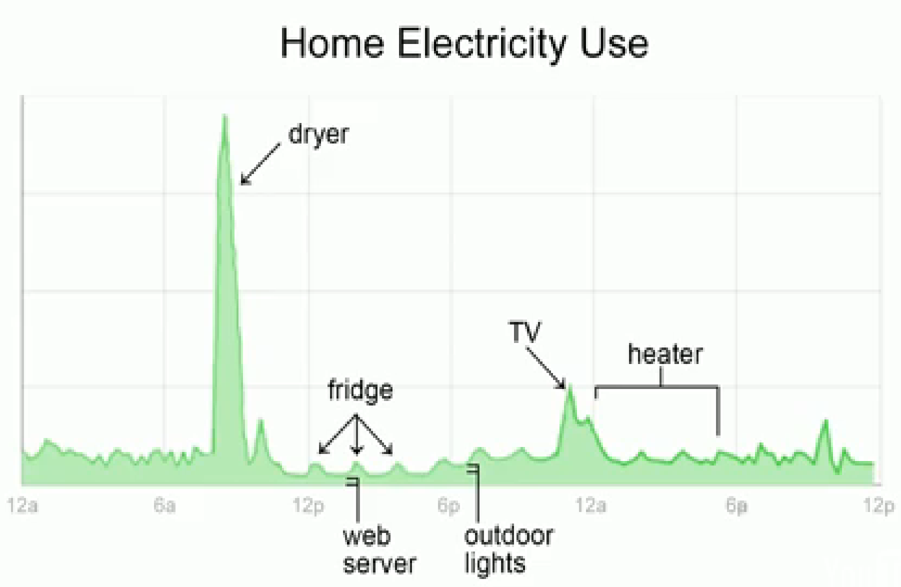

Figure 5 Source Google 2009. Dynamic characteristics in daily electricity consumption.

In Denmark frequent readings of the energy consumptions together with methods for dynamic analysis will be used in new WEB based applications for optimal energy management of buildings and households [Ref 12]. About 20% of the Danish residential building stock is equipped (December 2008) with advanced metering systems and make the data available for a detailed energy signature of the building.

The conclusion from several studies is that smart metering is required for managing a smart grid. Customers, e.g. house owners, may play another role in the future in the energy consumption sector. At present contracts with electricity utilities are for a constant tariff or sometimes a day/night tariff while their involvement in direct negotiation might be more advantegous for both parts.

Dynamic methods for forecasting

The electricity produced from distributed renewable energy sources such as roof integrated photovoltaic system or wind power plants depends on changing weather conditions. The time delay between actual production and weather forecasting can be modeled in such a way that supply and demand balance is optimized. This can take place at a small scale, a building but also at grid level. [Ref 13 and 14]

As an example for heat demand, a case study in Denmark considers the modelling of the heat consumption in a large district heating systems, called VEKS (Vest-Egnens KraftvarmeSelskab). This system actually covers about half of the Copenhagen area. VEKS is a transmission company (established in 1984) supplying surplus heat generated from combined heat and power (CHP) plants to 19 local district heating companies at Western part of Copenhagen. The purpose of this case study is to investigate time series of measured heat production in the VEKS district heating system, and to establish models for predicting the heat consumption one to several hours ahead.

Conclusion

Dynamic methodology has proven to be successful in analysis and forecasting. It enables more accurate and direct information to the energy end-user and regulator. For heating in the building sector the impact of thermal mass can be taken into account to set a comfort temperature in a variable climate. Electricity standby consumption as well as peak demand can be identified and reported to the energy end-user and regulator who can act accordingly. Online forecasting of wind and solar power supply will be possible using dynamic mathematical techniques. The near future will ask for more expertise in dynamic methodology in particular in the energy sector.

References

[1] Commission Communication; An Energy Policy for Europe COM (2007)1

[2] J.J. Bloem. *Dynamic Analysis Methods and Modelling. Application to Energy Performance Assessment*. PALENC conference, Crete 27-29 September 2007

[3] EUROSTAT Pocketbook (2008): *Environment and Energy Indicators; data 2006.* EC ISBN 978-92-79-09566-5 Luxembourg http://epp.eurostat.ec.europa.eu

[4] Jens Petter Burud, Enova SF (Norwegian Government Energy Agency). *How to encourage the building sector to build energy efficient Buildings. How to design an incentive programme*; J.P. Burud (Tokyo 2005)

[5] P. Bertoldi, B. Atanasiu, EC JRC: *Electricity Consumption and Efficiency Trends in the Enlarged European Union - Status report 2006-.* EUR 22753 EN, ISBN 978-92-79-05558-4, European Communities, 2007 http://re.jrc.ec.europa.eu/energyefficiency/pdf/EnEff Report 2006.pdf

[6] M. Soregaroli, GfK: *Latest Trends in Major Domestic Appliances in CEE. Focus on Energy Consumption.* Proceedings of the 6th JRC annual workshop on energy efficiency in buildings "Energy Efficiency in Buildings: Policies and Financial Instruments, 3/5 June 2008, Ljubljana, Slovenia", available at: http://re.jrc.ec.europa.eu/energyefficiency/

[8] Soderstrom T. *Theory of System Identification: An introduction and overview.* In: Bloem J.J. editor. System identification applied to building performance data. JRC; 1994, p. 3-19. EUR 15885 EN.

[9] Bloem JJ. (Ed.). *System Identification Competition.* 1996. EUR 16359 EN

[10] Gutschker O, *Parameter identification with the software package LORD.* Building & Environment, Vol 43 - 2 (Elsevier 2008)

[11] M.J. Jimenez, CIEMAT H. Madsen, DTU-IMM *Models and methods for describing the thermal characteristics of buildings and building components using experimental data.* DYNASTEE Conference, 12th -14th October 2005, Athens

[12] Danish Energy Trust; see www.elsparefonden.dk/MinBolig

[13] Bacher P. *Short-term Solar Power Forecasting*. Master Thesis IMM 2008-13. TU Denmark (2008)

[14] Madsen H, Kariniotakis G., Nielsen H. A., Nielsen T. and Pinson P. *A protocol for standardizing the performance evaluation of short-term wind power prediction models*. In Wind Engineering Vol 29, no 6 (2006).

[15] Jonathan Koomey, Richard E. Brown, *The role of building technologies in reducing and controlling peak electricity demand*. LBNL (2002)

[16] ESMA & JRC Workshop on "Smart metering and improved billing" 16-17 February 2009, Varese, Italy http://re.jrc.ec.europa.eu/energyefficiency/

Beyond Solar Decathlon – Germany's contribution to the international competition in energy efficient residential building design and residential appliances

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Abstract

In October 2007 a team of 25 architecture students, supported by TUD energy efficient building design group and 83 industry sponsors, were able to present their "prototype home 2015" as the winning design of the Solar Decathlon solar home competition. The authors will present the main innovations in the winning design and describe outcomes of the accompanying research with reference to future energy efficient building design strategies.

In order to mediate between simulation and real world data of the ongoing long-term monitoring process the implemented evaluation methodology and instrumentation concept are being described. Excerpts of the monitoring data will also be presented to support the conceptual considerations.

Based on the design and energy concept of the "prototype home 2015" the authors will describe the paradigm shift in the relationship between the building energy and domestic appliances demands in energy efficient and plus energy homes. Thus new strategies are proposed to evaluate and dimension the operational energy demands in an integrated design approach in an early stage of planning.

The last paragraph illustrates new potentials and sustainable technology advancements that can help reach the next stage of energy efficient building design.

Project description - architectural concept / energy concept

In the context of the bi-annual „solar decathlon" competition, hosted by the US department of energy (DOE) 20 international universities are continuously invited to design and construct a two person residential building which covers all necessary demands solely by solar energy. During the competition phase the teams operate their solar houses publically on the national mall in Washington, D.C., USA, thus, for one week, forming a small solar village which also serves as a public building fair.

Within a maximum footprint of 800 square feet (approx. 75 m²) all functional element of a domestic building, including a fully functional kitchen, bathroom, living, dining, working and sleeping accommodations have to be realised and are subject to jury reviews. All consumptions, also covering Media installations, lighting or the charging of an electrical car are monitored and have to be covered by solar energy only. During the competition week extensive monitoring equipment evaluates the vital data of all building parameters, e.g. the thermal comfort, which had to stay within a 22,5 – 24,5°C room temperature range for full score.[1] A total of 10 performance and jury contests had to be passed by each of the buildings, hence the name of the contest.

The German contribution to the 2007 competition was designed and constructed by 25 TU Darmstadt architecture students with the practical aid and the support of the energy efficient building design group and 83 industry partners, which formed the "Team Deutschland" working together to present a state-of-the-art energy efficient building showcase “made in Germany”. The building was able to reach the highest score of all competition participants.

Design criteria of the SD07 prototype home

Design methodology

The building design process was realised in the manner of a multi-stage architectural contest, resulting in a passive building design which, appealing mainly to architectural, sustainability and usability qualities, offers the capability to minimize and control the major part of all building energy demands by itself.

During the following planning and optimisation stages the building design was adapted to meet the passive house standards. Utilising the layered building design, photovoltaic and solar thermal elements as well as active technology components could be effectively integrated into the different

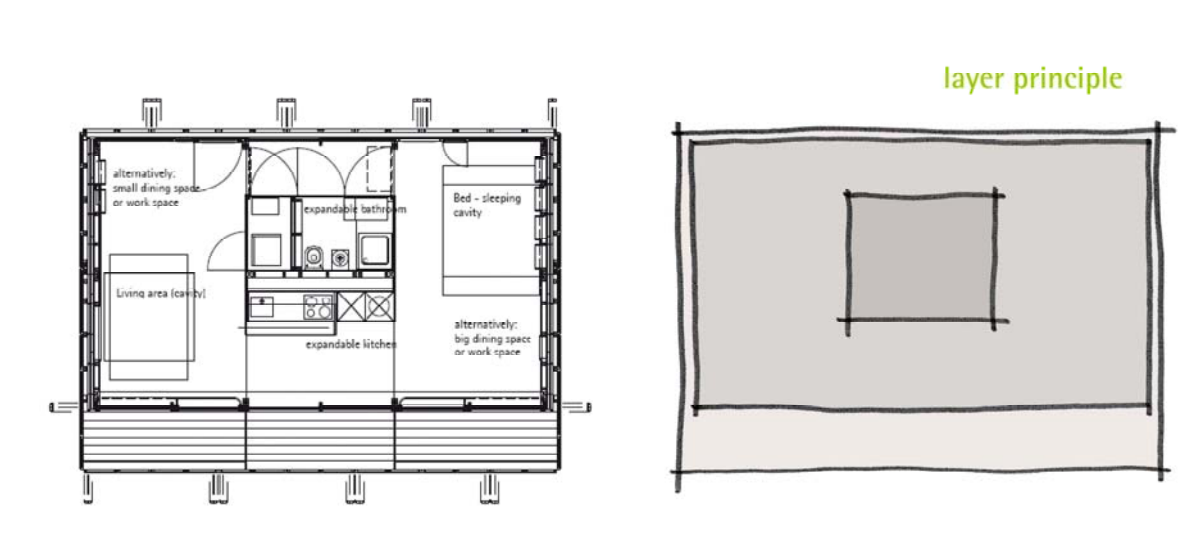


Fig.1: Building ground floor of the Team Deutschland contribution to the Solar Decathlon 2007 – the layer principle comprises the following areas: exterior (weather and sun protection, pv integration, natural lighting), comfort zone (living area, insulation, solar gains), the core (bathroom and kitchen, installations, domestic appliances)

Design Goals: active versus passive

As one of the only all-architecture teams in the competition the students decided to put “architecture first” and integrate all energetic and technological installations harmonically into an aesthetic and functional design. This goal was pursued primarily by promoting the use of passive (high- and low-tech) building components over active technology solutions, thus resulting in a low installation complexity.

Table 1: design parameters of building energy concepts		
	Minimise energy demands	**Optimise energy supply**
heating	conserve thermal energy provide thermal storage	efficiently gain thermal energy use renewable sources / environmental energy
cooling	Avoid overheating provide thermal storage	use efficient cooling use renewable sources / environmental energy
ventilation	Use natural ventilation	Use efficient mechanical ventilation
lighting	Use natural lighting	Optimize artificial lighting
electrical energy	Conserve electric energy	Decentralize energy production use renewable sources
user related demands	Use efficient appliances provide good usability	Enable synergies

From: TUD, energy efficient building design group

Table 1 shows the main energy design paradigms pursued in the development phase. The concrete passive technologies and active system components are listed in Table 2. Detailed description of the developments are given later in the Building Energy Concept Design and Evaluation section of the text.

Table2: Implemented passive and active elements of the building energy concept	
Passive technologies	**Active systems**
compact building shape	solar thermal collector
highly insulated shell	compact device: heat pump, heat storage, heat recovery
overheating protection through overhang shading and lamellae facade	energy-efficient appliances
utilization of passive solar gains	energy-efficient lighting
thermal mass through latent thermal storage materials (PCM)	Integration of photovoltaic modules
nightly cross ventilation as natural cooling	
passive cooling system	
natural daylight concept	

From: Team Deutschland Solar Decathlon 2007

Optimisation of the energetic design concept

It was clear from the earliest design stages that a good energetic design would help with the integration of efficient active systems. Therefore the building design was evaluated and optimized using static and dynamic simulation technologies using e.g. the TRNSYS package or the PHPP Passivhaus development tool.

With an optimized passive energy demand balance, further theoretical simulations (as with the INSEL simulation tool) but also practical laboratory test scenario evaluations of the building technology components followed.

Special attention had to be paid to the specific fact that all electrical positive and negative loads could only be managed via a 100kWh battery storage system which left a small tolerance margin.

The results of this optimized integrated planning proved to deliver a robust solar house concept, that performed successfully and in a flexible fashion under various weather situations (Fig.2).

Energetic performance

The main parameters of the building are:

- total footprint 72 m²
- comfort zone 50 m²
- *total volume 182 m³*
- *heating demands (EnEV) 12,00 kWh/m²a*
- *workplaces 5*
- *effective area (EnEV) 58 m²*
- *s/v ratio 1,15 m^{-1}*
- *electrical production (PV) 11,4 kWp*

Solar Decathlon 2007 competition performance

Figure 2 depicts the overall energy input and performance balance of the Solar Decathlon building during the competition week, taking place between october the 20th and the 24th 2007. The building

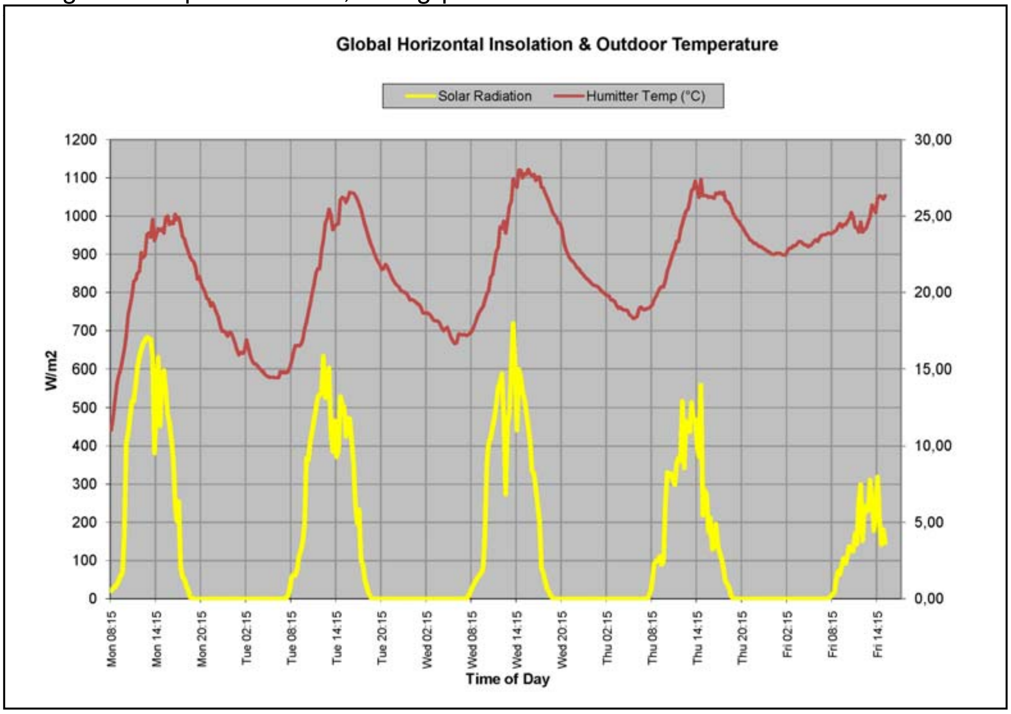


Fig.2a: Development of outdoor temperature and solar radiation versus..

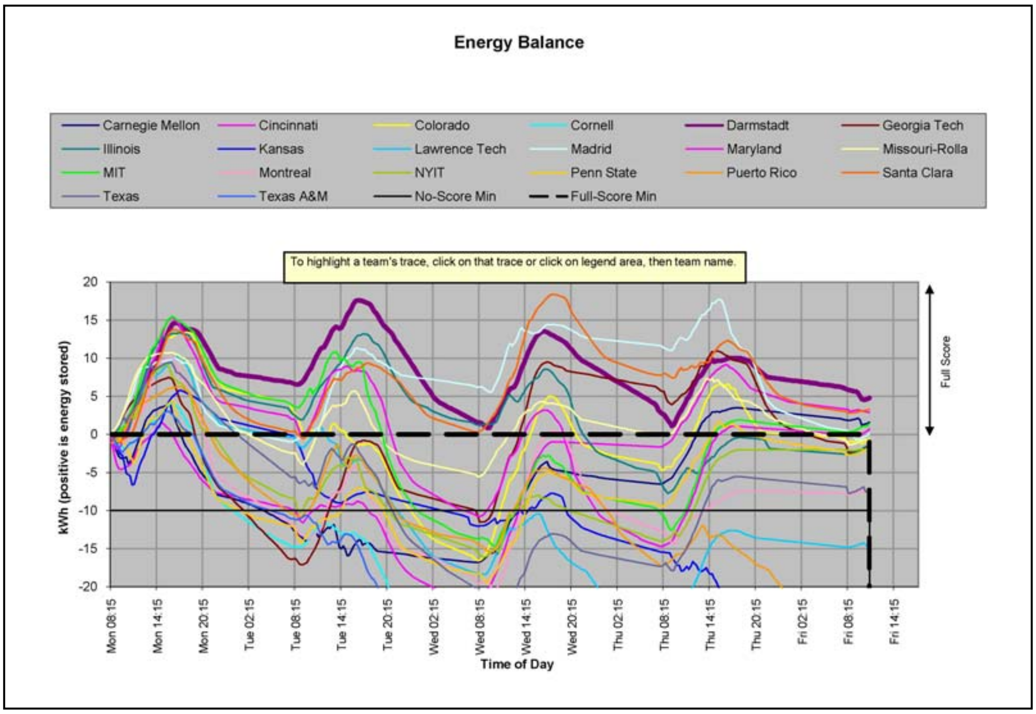


Fig.2b: .. building energy balance during the competition week

Competition performance and manageability

During the competition the building could be operated in a very flexible fashion. As the weather conditions deteriorated noticeably during the end of the competition week, the importance of effective load balancing of the different consumers proved vital to maximise the overall competition score.

Both passive technologies, such as e.g. passive cooling and ventilation as well as efficient household appliances were the key factors to further optimise the individual contest scores. This concept has major benefits, compared to the building stock but also compared to recent building concepts.

A-priori energy demands estimations from standards

Current European and German legislation mainly focuses on the regulation of energy demands to supply the building with heat. The comparison of demands in the building stock supports this approach. In optimized buildings like the solar decathlon the potentials to safe energy in these areas are exhausted. Demands like the domestic appliances are now responsible for more than half the energy consumption (Fig.3).

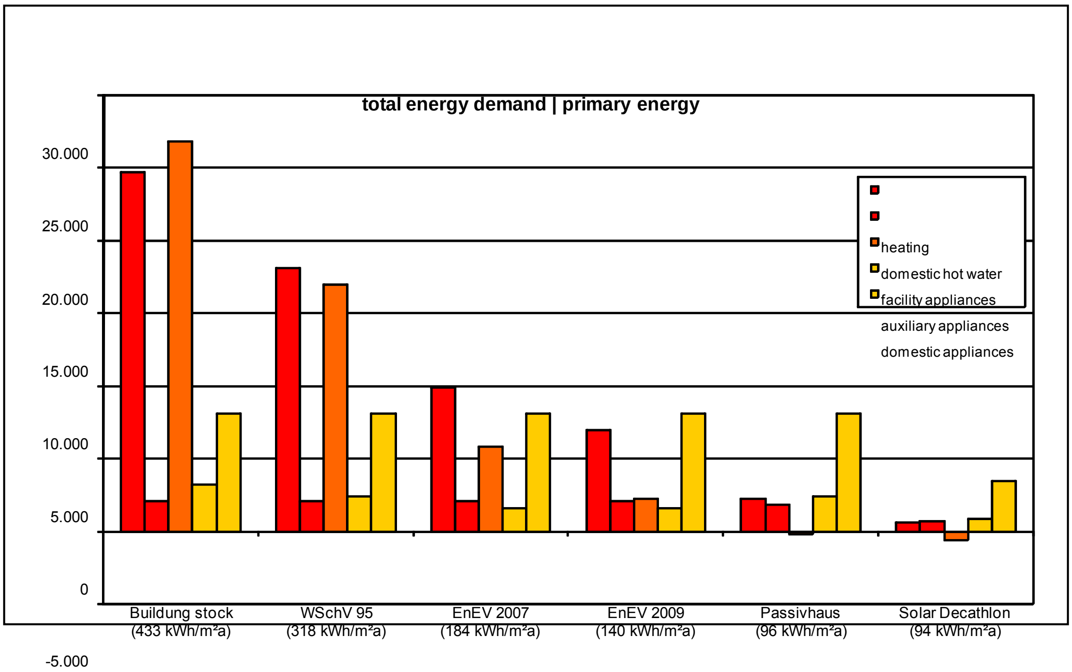


Fig3: Comparison of site energy distribution including appliances between different standards (real projects)

With DIN V 18599 the demands for cooling, ventilation and lighting become a vital part of the calculation (Fig.4). In these areas, non-residential buildings spend more than 60% of their electric energy demand. [6,7] Accordingly, in residential buildings domestic appliances would have to be

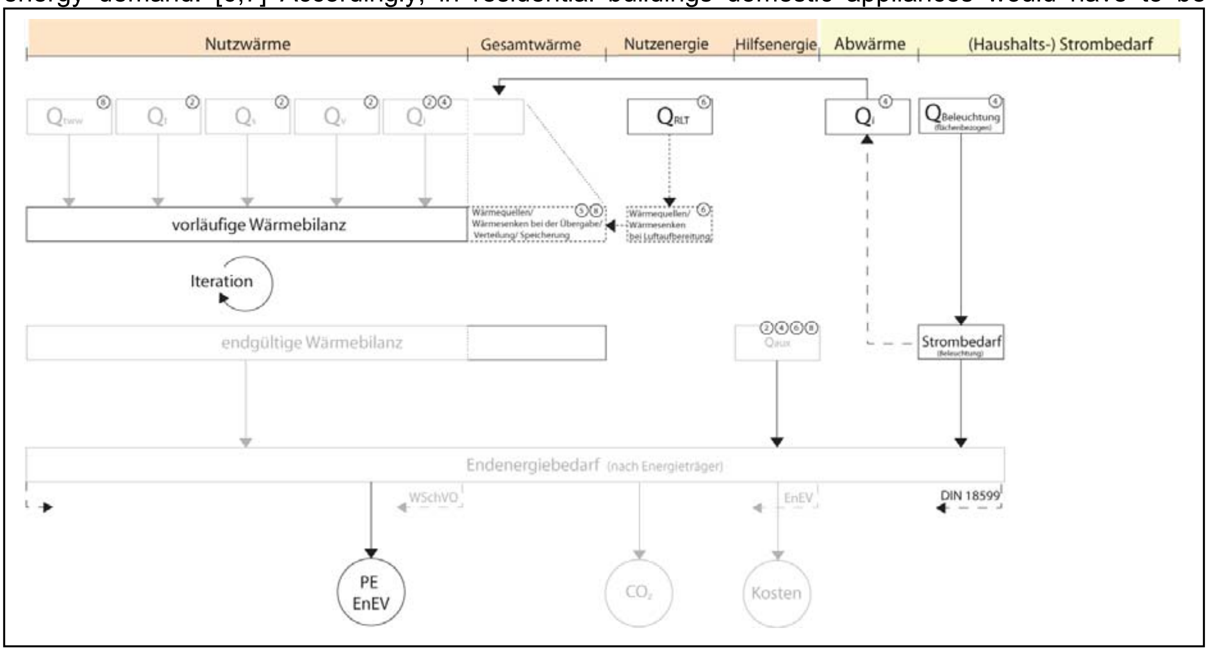


Fig.4: Parameters of energy balance evaluation systems - calculation method DIN V 18599

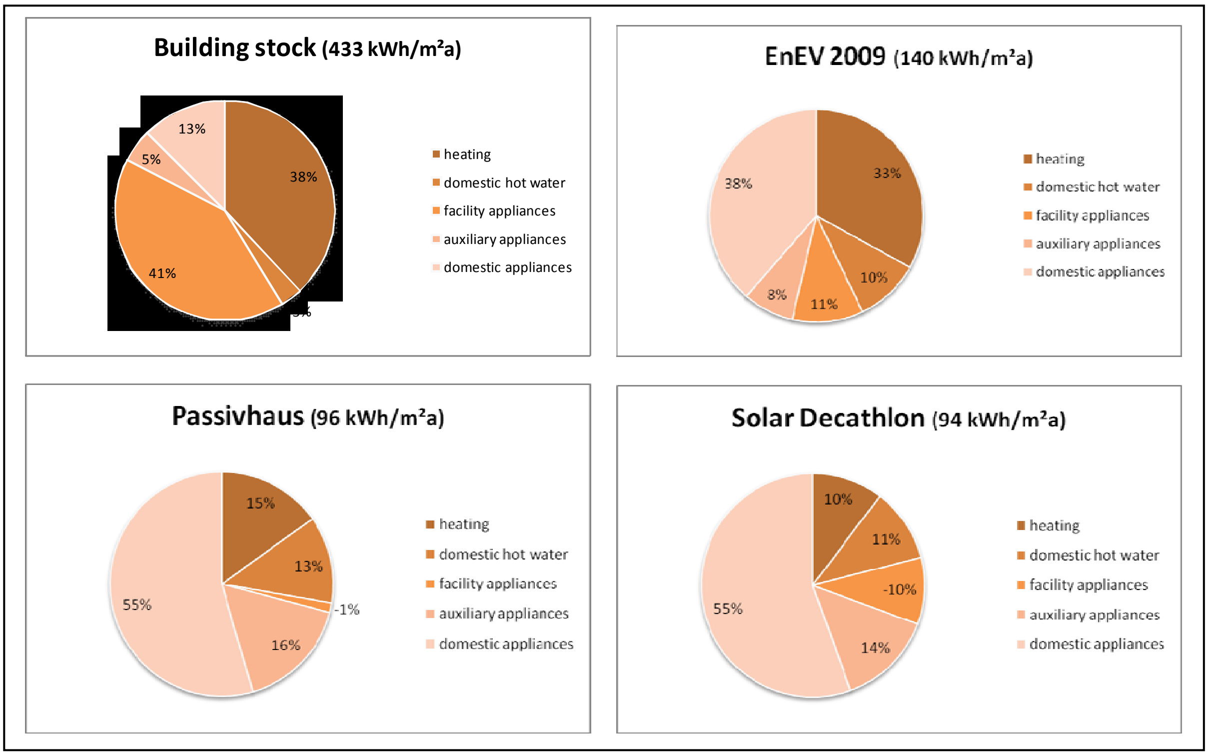


Fig.5: comparison of different building energy standards using data from representative buildings

Course of action – the new frontier

Whereas current legislation offers an economically sensible background for power generating building elements, none of the existing evaluation systems rewards their integration into the building energy concept. Until the introduction of plus-energy-aware evaluation systems the best option is to further minimise the energy demands, the new frontier being the demands of domestic and facility

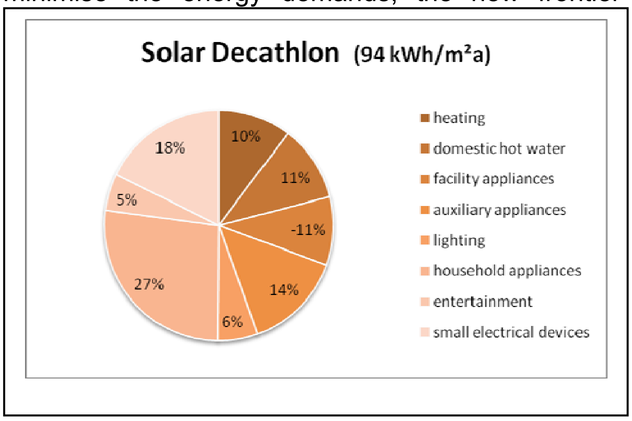


Fig.6: While auxiliary and household appliances represent more than 40% of the total primary energy consumption, the percentage of small electrical devices and entertainment is rising continuously. [6,7]

Until the introduction of large-scale regenerative energy networks, the decentralised utilisation of regenerative sources, such as building-integrated photovoltaic elements and cogeneration systems offers a valid option to compensate for the remaining primary energy loads. With a simple connection to the electricity grid, even today the step beyond zero-net to surplus-energy-homes is possible.

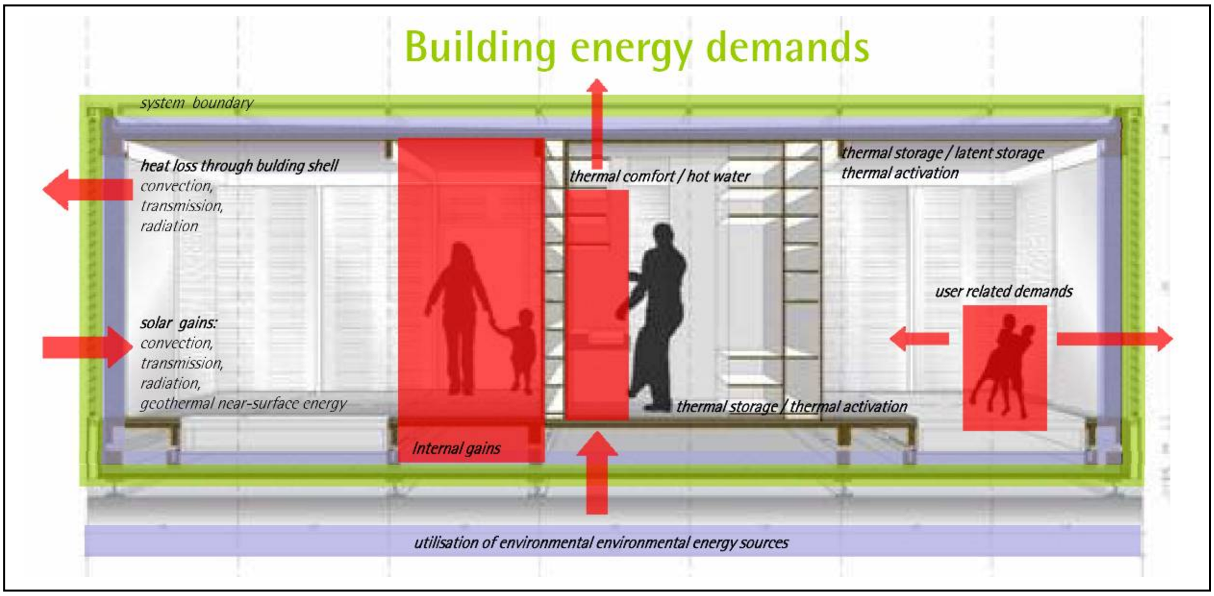


Fig.7: system boundaries and system variables

During a two year monitoring project the solar decathlon house, as a specific representative prototype building, will be monitored under a controlled full-time utilisation as a small office space. The building has been recently re-erected on the TUD campus ground and is fully functional. In addition to the original design, a fresh air ground collector and a floor heating have been installed in the course of the general maintenance. The benefits of these improvements will be evaluated separately.

Goal of the monitoring project is the logging of a holistic energy balance, in order to gain information on internal and solar gains, electrical and household consumers, auxiliary and facility energy etc. following the relevant official evaluation standards that were also taken into account in the development phase (Fig.7).

The project will provide public online access to monitoring data, e.g. within the scope of the federal building information initiative “EnOB: Research for energy-optimised construction” [8] or via sponsor information portals, such as the sunny portal website displaying the current electrical production [5].

Passive technologies

Compact building shape and highly insulated shell

The opaque components are insulated as thinly as possible with double layer vacuum insulation panels (VIP) in order to provide a larger effective surface. Both the southern and northern facades are glazed so that the primary views and the house in general appear as welcoming as possible. In order to retain a high insulation standard in spite of this design, the northern facade is equipped with quadruple glazing and the southern facade is triple-glazed, with VIP-insulated wooden frames.

In the monitoring process the system energy balance is evaluated at different levels (Fig.8). General energy states such as hot water system, room temperatures, heat flows through water, solar thermal, heating and cooling devices are recorded by an automated m-bus system to give a qualitative overview and a basis for further energy balance estimations such as e.g. internal and solar gains.

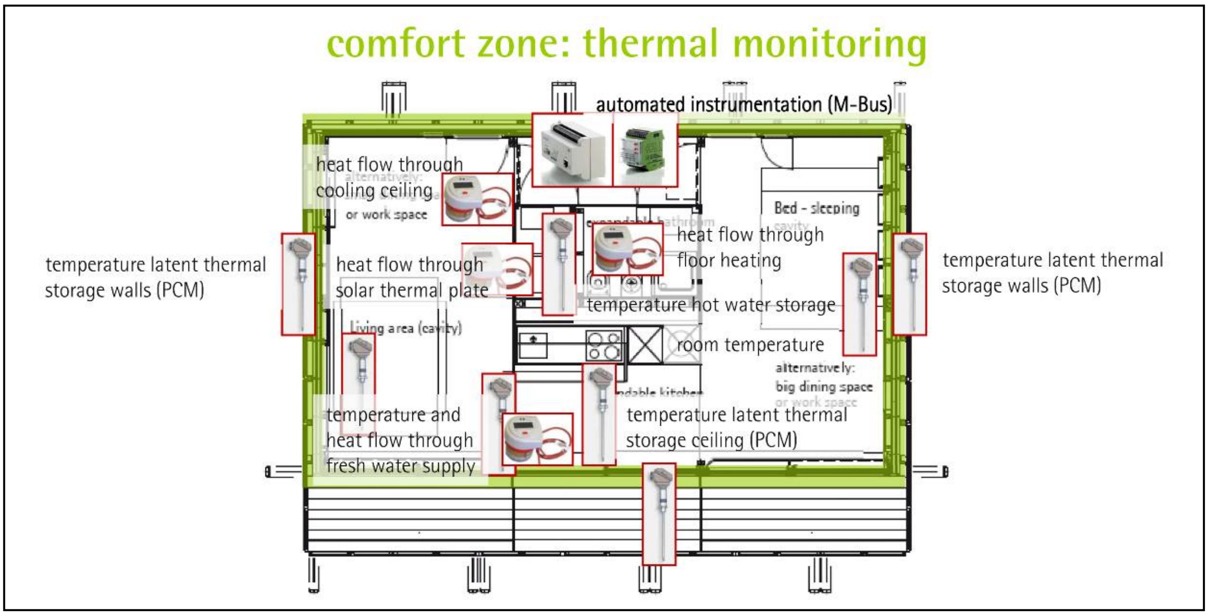


Fig.8: Basic measurement setup for passive system variables (thus excluding compact device)

Overheating protection, solar gains, natural lighting concept

The so-called "porch" area covering the southern façade is designed to act as a fixed summertime shading element for the Darmstadt site. It enables shading for overheating protection in the summer, whereas its dimensions allow for the necessary solar gains in spring, autumn and winter.

The shading element features translucent photovoltaic ("glass-glass"-) elements which not only provide the necessary shading and electrical energy, but also allow for diffuse natural lighting of the interior throughout the year. In combination with the room-high window elements in the northern façade full coverage of natural lighting is provided, thus saving a great part of the electrical energy usually spend for artificial lighting.

Thermal mass

Thermal mass plays an important role in both establishing a comfortable room climate and regulating the daily indoor temperature energy balance. Despite the light-weight construction, thermal storage could be integrated into the design by using latent heat storage gypsum wall elements - so-called "smart boards" implementing Phase Change Materials, PCM [2]. 60m² of the opaque interior walls are covered with this latent storage material, the ceiling elements (approx. 50m²) are further enhanced by a regenerative cooling facility, as explained in the following text. [1]

Regarding thermal comfort the latent storage elements offer an additional advantage in that the sensible temperature of the indoor surfaces is stabilised around an adjustable fixed room temperature. In the chosen setup the melting point of the PCM-Material was chosen to be 23°C to accommodate the warm Washington climate.

Special attention will be put to developing estimation algorithms in order to determine the actual impact of latent storage on the room energy balance. Temperature sensors are applied to both air and core material temperatures. The non-linear nature of these elements will demand for specific measurement setups during summer, winter and the transition phases between, as the latent storage

[1] Note: The accounting of a very small and dynamic building such as the SDH is hardly feasible using PHPP (the Passivhaus-Project-Planning tool). The effects of new materials (such as VIP, PCM) must be taken care of, especially in highly efficient buildings; the same holds for innovative facades (movable sun protection, light guidance) and for new system technologies (compact devices, hybrid collectors).

effect exists only in a very small temperature range. Basically the holistic evaluation and estimation of all relevant energy streams and states (Fig. 8 and 11) will enable the research on further details on these effects.

Nightly cross ventilation as natural cooling

The main temperature control of the solar decathlon building is given by passive means of cross ventilation. The building is specifically designed to maximize the effectiveness and usability of this cooling concept on a day-to-day basis. The two sliding door elements in the south façade as well as the opaque door and an extra ventilation opening (in the shape of a narrow door) offer in combination

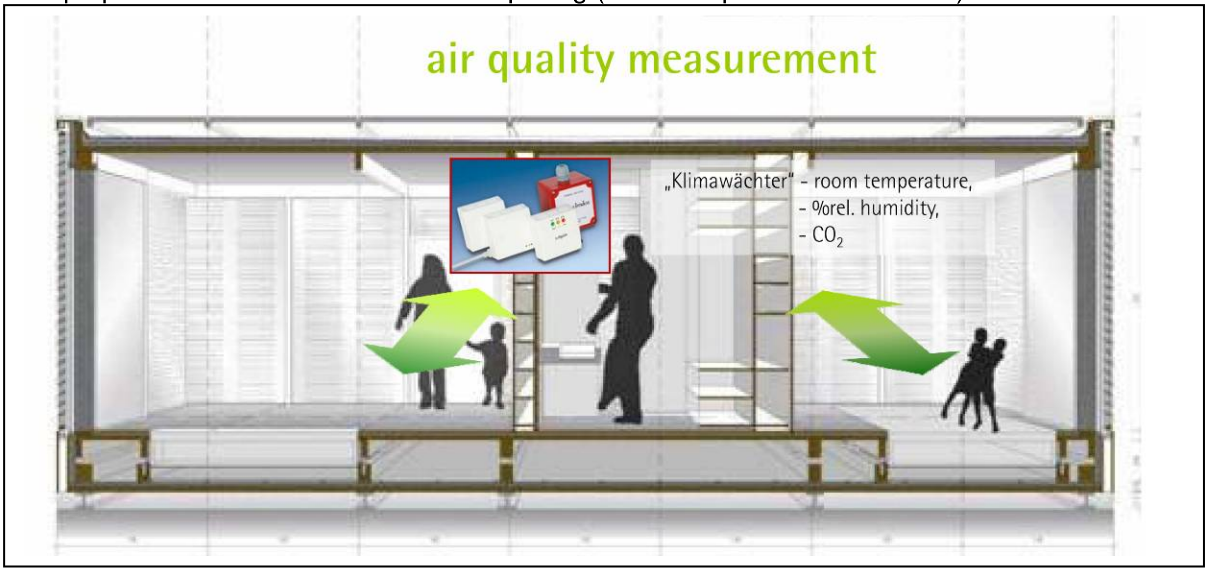
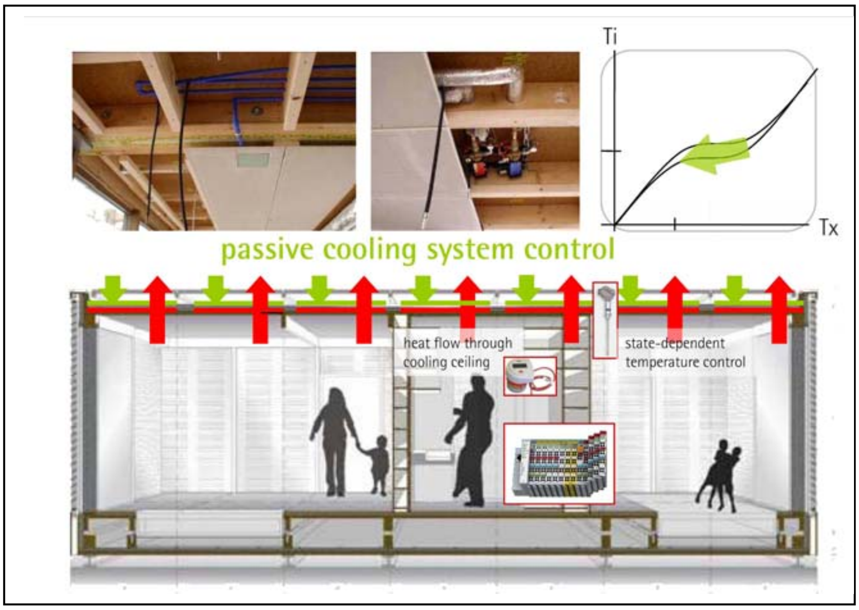


Fig.9: air quality measurement as additional reference for the effectiveness of ventilation

User factor plays a great role in realistic energy balancing. To capture user behavior both automated (logging of bus system signals with relevance to behaviour patterns) and manual log-data of individual user actions will help in the (qualitative) evaluation process.

Passive cooling system

Capillary tube mats inserted into the ceiling allow for passive cooling power by extending the thermal capacity of the aforementioned latent storage ceiling elements. Thus "invisible" enhanced indoor cooling capacity can be activated for extreme climate situations.



elements, rain water tank

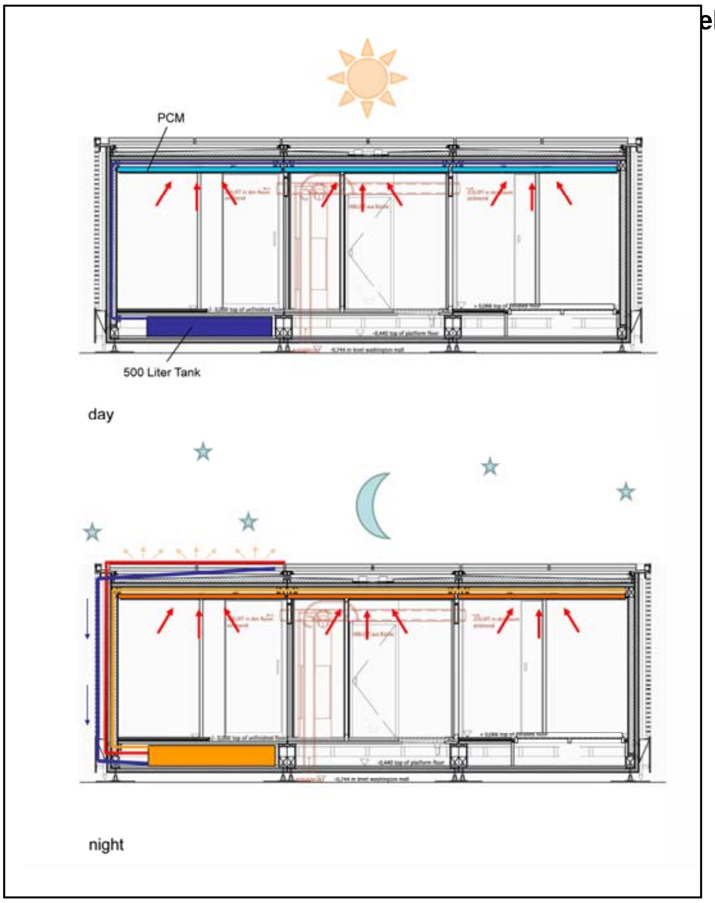


Fig.10b: daytime pcm cooling / nighttime radiation cooling: while at daytime the passive cooling system drains the latent storage elements of heat energy, at nighttime the contents of the cooling tank are exposed to the night sky for radiation cooling

The system feeds on a 500 liter insulated cold water storage integrated in the double floor. The system is fed via the rain water system and is able to statically provide 3,5kWh of cooling energy via the ceiling elements, delivering around 3 hours of full cooling power, depending on the actual demands. During the night, water is sprayed onto the roof, thus cooling it atmospherically. The night cooling regenerates the cooling capacity and provides additional thermal activation energy to store in the ceiling elements. Smart control helps coupling the cooling power with the internal state of the latent storage device and coping with the high thermal latency of the system (Fig.10).

In combination with the measurement of electrical comsumtions (auxiliary pump energy), heat flow through capillary system and the impact on the indoor temperature energy values the efficiency and renewable energy content will be evaluated. At the same time the influence on the comfort zone measurements will be observed.

Active systems

Solar thermal collector

The generation of domestic hot water is supported via 2.3 m² of solar heat collectors. These are flat plate collectors custom-built to fit into the photovoltaic module grid. This results in optimum surface

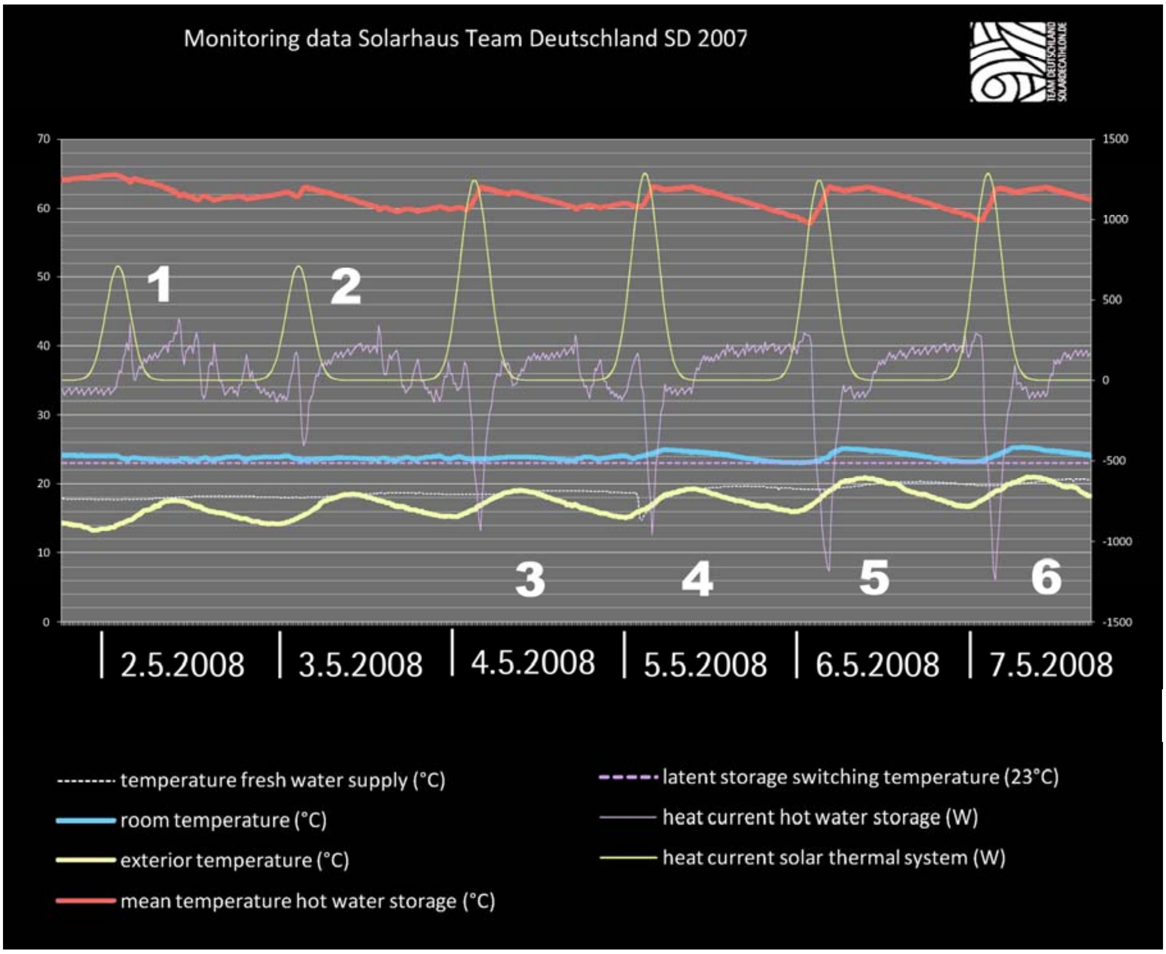


Fig.11: solar heating support (1-6) and solar hot water generation (3-6) between May 2nd and 7th, 2008 – solar thermal energy generation (green line,W) and heat energy exchanged with the hot water storage (violet, W) are displayed over room temperature (blue) and external temperature (bright green), fresh water supply temperature is monitored as a proof, that no hot water demands exist in the observation period

In Figure 11 the heat energy balance of the solar thermal and hot water storage system are displayed against the temperature values of room air, exterior and hot water storage (as a measure for the potential energy content of the hot water system). The observation period covers 6 days between the

2nd and 7th of May, 2008. The contribution of the heat pump is not displayed, thus the diagram only visualizes the additional contribution of the solar thermal system to the energy balance of hot water and room heating consumptions.

For the given period, the climate situation could be described as drifting from a rather cold weather situation towards a moderate and warm spring weather period. It can be observed, that during the early phase the heat energy can be gained through the solar thermal collectors (points 1 and 2). Heat energy is absorbed in the compact device and directly transformed into room heating energy, thus relieving the heat pump system.

At the later stages (3-6) a surplus of solar thermal energy flows into the hot water storage system, thus being available for additional or subsequent consumption (e.g. in household appliances, for showering or transformation into room heating).

Given further information on electrical consumptions and solar radiation the overall energy balance and synergetic efficiency can be evaluated. Therefore the monitoring equipment also includes a digital weather box, measuring climate information.

Integration of photovoltaic modules

Different types of photovoltaics are used for producing energy. The "easiest" is the utilisation of opaque, mono-crystalline ready-made modules placed on the roof. The solar modules on the horizontal wing facing south, which covers the external terrace area between the southern glazing adjoining the heat room and the outer lamellae layer, consist of a glass-glass module constructed of two plates with photovoltaic cells between them, positioned at a distance from each other. The opaque parts of the module prevent the steeply inclined summer sun from entering the building and at the same time generate energy without completely blending out the daylight.

A further layer of lamellae surrounds the entire thermal envelope which is activated photovoltaically via thin film cells. As the motor-driven, rotatable lamellae follow the path of the sun, they can ensure optimum output at any time. In particular during the winter months, this facade activation can pay an important contribution.

The active energy generation must always be in alignment with the primary functions of the windows - allowing a view to the outside world and letting in daylight. The overall capacity of all photovoltaic modules installed onto the building is approximately 11,4 kWp. For this, more than 50% of the building's thermal envelope is activated photovoltaically, a total of 99.9 m² PV elements are installed and an average efficiency of 11.5 is achieved. With an output of 900 kWh/a*kWp (Darmstadt site), approximately 10,000 kWh/a or nearly 170 kWh/m²a results.

Compact device - ventilation, heat recovery, heat pump, heat storage

A modified model of the Nilan VP 18-10P ventilation device with combined passive and active waste heat recovery was installed as a compact device. A heat recovery component reduces the involved ventilation heat losses by up to 80%.

Downstream a heat pump recovers the rest of the heat from the exhaust air to heat a hot water accumulator and to re-heat the incoming air. The fresh air can also be cooled using the ventilation device in summer by reversing the refrigeration circuit. The waste heat is used for the production of water for domestic use. The cold fresh water supplies the required temperature drop. This pre-cools the supply air. However, this device cannot replace a fully-fledged air conditioning.

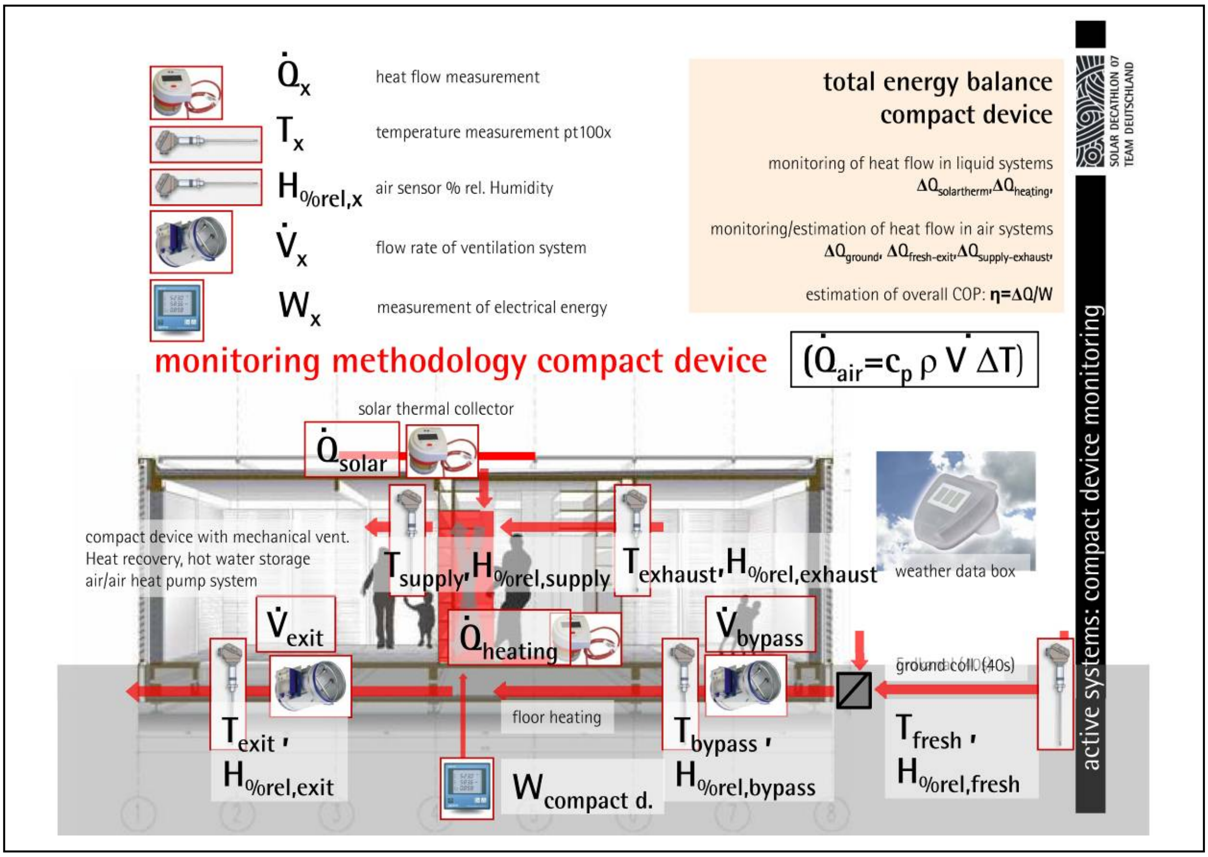


Fig.12: compact device – ventilation, heat recovery, air/air heat pump and solar hot water, the monitoring sensors enable a heat flow balance estimation of incoming and outgoing air, as well as the generated hot water and heating energy.

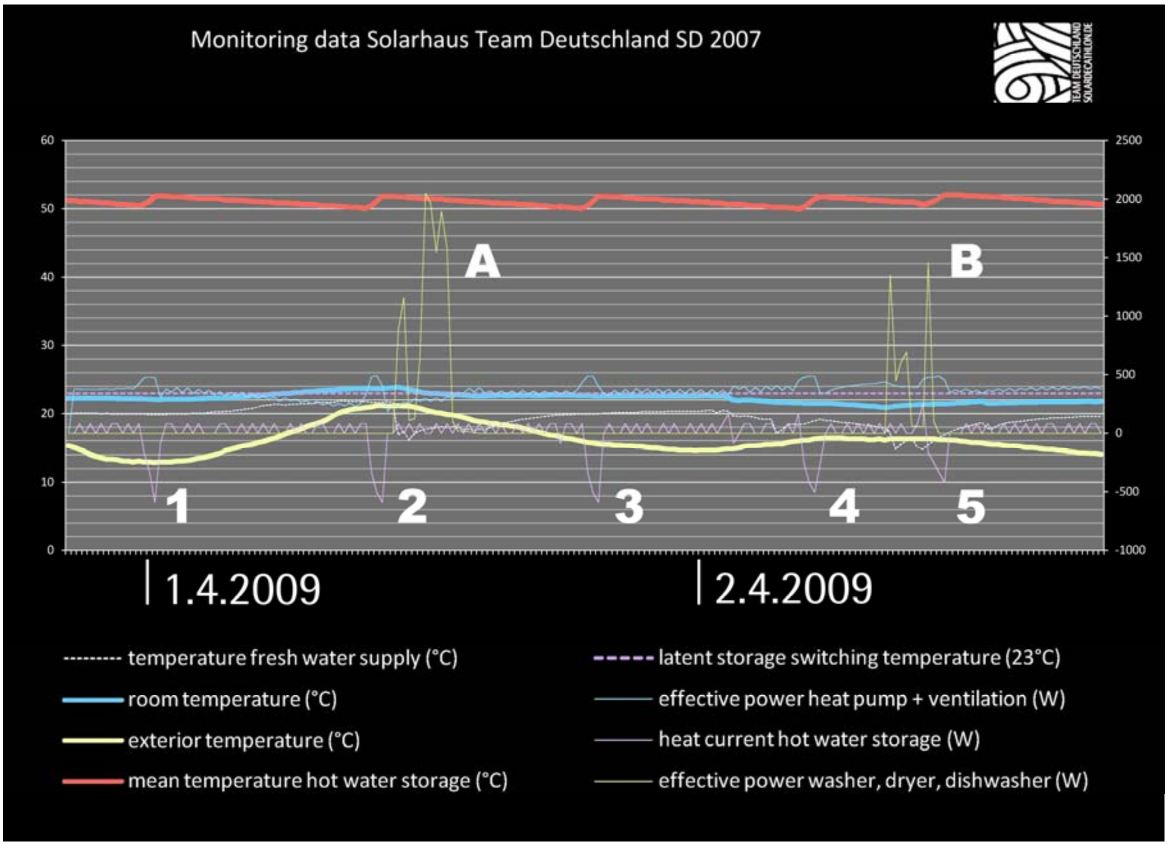


Fig.13: heat pump and appliances performance between April 1st and 3rd 2009 - hot water generation (1-4) and warm water support for dishwasher (B), clothes washer with cold water supply (A) – the power (W) values of electrical and thermal consumption and production allow for the calculation of overall hot water efficiency using the heat pump system and appliances performance

Figure 12 shows the compact device and the attached air ground collector. For the monitoring evaluation process the system has been divided into 5 different sections of air/heat flow measurement. Thus the effects of the ground collector can be individually evaluated, as well as the amount, heat energy and relative humidity of fresh, supply, exhaust and exit air can be evaluated.

By estimation of the heat energy of each transport process the gains and losses can be accounted. Given the measured electrical consumptions of the compact device an estimation of the weather-related performance and COP (coefficient of performance) can be derived.

In Figure 13, the electrical and thermal powers within producers (compact device heat pump), storage (180l hot water storage tank) and consumers (general room heating and dishwasher hot water supply) are estimated and displayed over a 4 day period.

Using these values the general synergies and efficiency coefficients (COP) can be derived. From this limited observation period a mean COP of at least 3,5 for the heat pump hot water generation circuit could be derived. Reliable values, however, demand for greater observation periods and sophisticated consideration of auxiliary consumptions, such as ventilation or pump energy. In a holistic approach also the exact nature and source of hot water and heat pump energy must be taken into account.

On completion of the complete monitoring network in June 2009 the measurement system will be completed according to these requirements

Energy-efficient appliances

After a two months laboratory test-phase with different combinations of building appliances an optimised selection of household appliances was chosen, that could efficiently perform under the competition requirements. Along with the compact device setup, two students were invited to a research facility of Bosch-Thermotechnik, were all relevant tests and calculations were performed.

As electrical consumption of household appliances was identified as a prominent factor in the building energy balance very early in the engineering phase, great attention was dedicated to the correct setup and selection of devices. Thus the best appliances of BSH Bosch und Siemens Hausgeräte available in 2007 have been used. All the corresponding US-types of appliances used are "Energy Star" qualified (except for the dryer where currently no such certification exists).

Refrigerator/Freezer-combination: This regfrigerator/freezer-combination is consuming energy 295 kWh/year under standardized ISO/IEC conditions. This corresponds to EU Energy Label class "A+". Meanwhile BSH Bosch and Siemens GmbH has developed combination devices with much lower energy consumptions. A modern equivalent device consumes 211 kWh/year only, which corresponds to EU Energy Class "A++". Clothes washer: The cloth washer has a capacity of 8 kg laundry. It consumes 1,36 kWh under standardized conditions. This corresponds to 10 % lower energy as EU Energy Label class "A". The washer is equipped with an advanced load detector and unbalance control. Both improvements are significantly contributing to energy reduction. State-of-the-art BSH Bosch and Siemens Hausgeräte GmbH washers meanwhile rate 20 % lower than standard "A" class devices. Dryer: A condense dryer has been used in Solar Decatholon house – the technology was chosen for several reasons: 1) with nearly 90% condensation rate practically no humidity is evaporated into the room, 2) all heat energy is given into the room where it can be used as an internal gain or can be directly disposed of via cross ventilation. The dryer itself was the most efficient one on market in 2007. It is rated "B" of EU Energy Labelling scheme. It is very important that the dryer is sensor controlled in order to save energy when being used even under not standardized conditions. Strategically the team decided to use an extra 1400rpm spin cycle of the washer to further reduce the moisture and thus noticeable saving unnecessary clothes drying energy. Energy consumptions are: 0.56 kWh/kg (EEK B E-Label value), respectively 0.27 kWh/kg (EEK A E-Label value), following IEC 61121 ed. 3.1.

Meanwhile BSH Bosch and Siemens Hausgeräte GmbH has introduced a new heat-pump dryer. It is currently the most efficient product on market. The energy consumption under standardized conditions is 40 % lower than the best EU Label Class "A". More about this see EEDAL´09 Presentation of Clarl-Otto Gensch “Environmental Impacts and Costs of Different Ways to Dry Clothes”. Dishwasher: the dishwasher was installed with a hot water connection, feeding from the compact device´s hot water storage, thus using the solar and heat pump generated heat energy, saving electrical energy (Fig. 13). The dishwasher is equipped with an water deflector (Wasserweiche) in order to optimize the operation when using different loads. A sensor is detecting the degree of dirt which enables to run an energy and water optimized process. A special low energy consumption program can also be selected. Under standardized conditions this eco-program consumes only 0,95 kWh.

Currently BSH Bosch und Siemens Hausgeräte GmbH is offering a new platform which is even more energy efficient. A new sorption technology using zeolite has been implemented to dramatically reduce the energy demand in drying. Under standardized conditions the energy consumption is 0,83 kWh (for 13 place settings) only. More about this see EEDAL´09-Presentation of H. Heissler et al. "Large Energy Savings by Sorption-assisted Dishwasher" [9]

Energy-efficient lighting

Main design goal of the lighting concept was, in a sustainable fashion, to deliver the best quality lighting quality inside the building. Apart from the daylight concepts, different types of artificial lighting were included in the building design. Basically the lighting energy demands were reduced as far as necessary. As the electrical lighting demands are well below those of other domestic installations, attention to the visual quality could be paid as a limited “architectural investment”.

To deliver low-energy basic illiumination in the interior and exterior, LED elements were used. Thus LED spots illuminate the exterior deck area, whereas LED stripes were installed internally behind the translucent shelves and walls as well as in hidden ceiling elements.

*For a good vi*sual quality halogen lighting currently offers the best solution in domestic applications due to the specific spectral characteristics. Downlights were installed in all mayor areas to deliver brilliant, dimmable lighting. In non-domestic installations compact tube fluorescent lighting would be able to substitute this lighting type.

Building automation and monitoring system

Using a decentralised building automation bus system for the monitoring and control of all electrical consumers, the electrical consumptions of e.g. household appliances and lighting could be controlled to a high degree. For example, at night a "standby" setup can be selected, disabling sockets, lights and turning off unused electrical consumers.

Online visualisations for both house tours and for scientific evaluations are available via network, the most interesting of which being the electrical meters for energy production and consumption. The monitoring concept includes the observation of 21 electrical consumer circuits and 5 photovoltaic inverters.

Further user controls include dedicated lighting setups and media controls, as a further benefit of installing the bus system.

As a monitoring data system the decentral instrumentation devices are linked together to a complex mesh of more than 250 direct sensor values, internal system variables (e.g. relay states or control variables) or calculated internal estimator outputs. The system will communicate and store these complex measurement vectors via network to the project participants.

Outlook and perspective: less is more

The existing German energy pass is suitable for illustrating basic information on typical existing and new buildings, and incorporating these into a linear assessment scale. The spectrum of buildings is so large that buildings with minimum energy consumption are pushed to the outer edge of the scale. The visualisation of innovative energy concepts beyond demand reduction for heating supplies is hardly possible, as energy from renewable sources, by definition, disappears from the balance range. [2]

In order to achieve the necessary mediation of information between planners, administrations and the end users, an independent plus energy certificate must be devised. The certificate should support designers, energy planners and specialists during the early planning phase of their collaborative work by delivering a closed-loop visualization of the decision effects and regulatory aspects as a communication platform. Main target is the visualisation of holistic concepts concerning the design and operation of residential buildings.

In the process we suggest equal treatment of all energy sources (fossil, renewable, vital, solar, heat and electricity) and the calculations in absolute final energy amounts. If zero and plus energy houses are the objective, we must do without fossil fuels, or their use should not be balanced as fulfilment of demand. A primary energetic weighting can then be excluded, as no more fossil fuels are being used.

On the abscissa, the site energy demands for the building and its use are entered. On the ordinate, the energy conversions of regenerative, vital and solar energies taking place in or at the building are entered, meaning all non-fossil energy sources. Energy demand and energy conversion span a square in which positions are shown in diagram form, defined and fixed by this variate pair, for different buildings or different design variants of the same building.

The centre line of the square marks the zero energy balance, for which own demands and local generation are considered the same. This non-dimensional boundary line is expanded into its own mean zone so that the building class "zero energy building" can be defined. As well as the "zero

[2] Solar output is usually multiplied with primary energy factor $f_{P,solar} = 0$

energy home", four further classes have been created, two below - meaning with net energy demands, and two above, meaning with net energy surpluses per year.

Another result is concerning the quality of the accounting itself. In the design process the need of dynamic simulation as an instrument to dismiss or to prove architecture and energy concepts became apparent. Today's accounting methods use typical mean characteristic values to replace dynamic calculation steps. Reliable results can only be produced within a certain range of building standards.

The key questions in the design process of innovative building concepts can only be answered by dynamic simulation. These are minimum insulation levels, orientation, size and kind of glazing, sensible and latent thermal mass, resulting heating and cooling demand, automatic control and load management, integration of facilities and grid connection etc. With this information at hand, minimum demand and comfortable and robust homes don't exclude each other.

Résumé

It could be shown that with a combination of existing development tools and regulations certain standards can be accounted, visualised and rewarded to be introduced into the market on a large scale. These optimisation goals are minimisation of total site energy demand, exploitation of renewable energy sources and building operation cost reduction. In state-of-the-art energy saving building concepts household appliances and auxiliary appliances constitute the new frontier in energy saving potentials. Developments and efficiency potentials have been identified and are being exploited with growing success. Surplus energy homes are at the top of this development. A proof of concept will be delivered in the years to come with the monitoring of today's prototype buildings such as the solar decathlon building.

For a more comprehensive approach to sustainable building further topics must be addressed in the future. These topics cover for example ecological accounting, low life cycle costs (LCC assessment), evaluation and optimisation of synergies between building energy components, smart meters, load management, virtual networks, and many more.

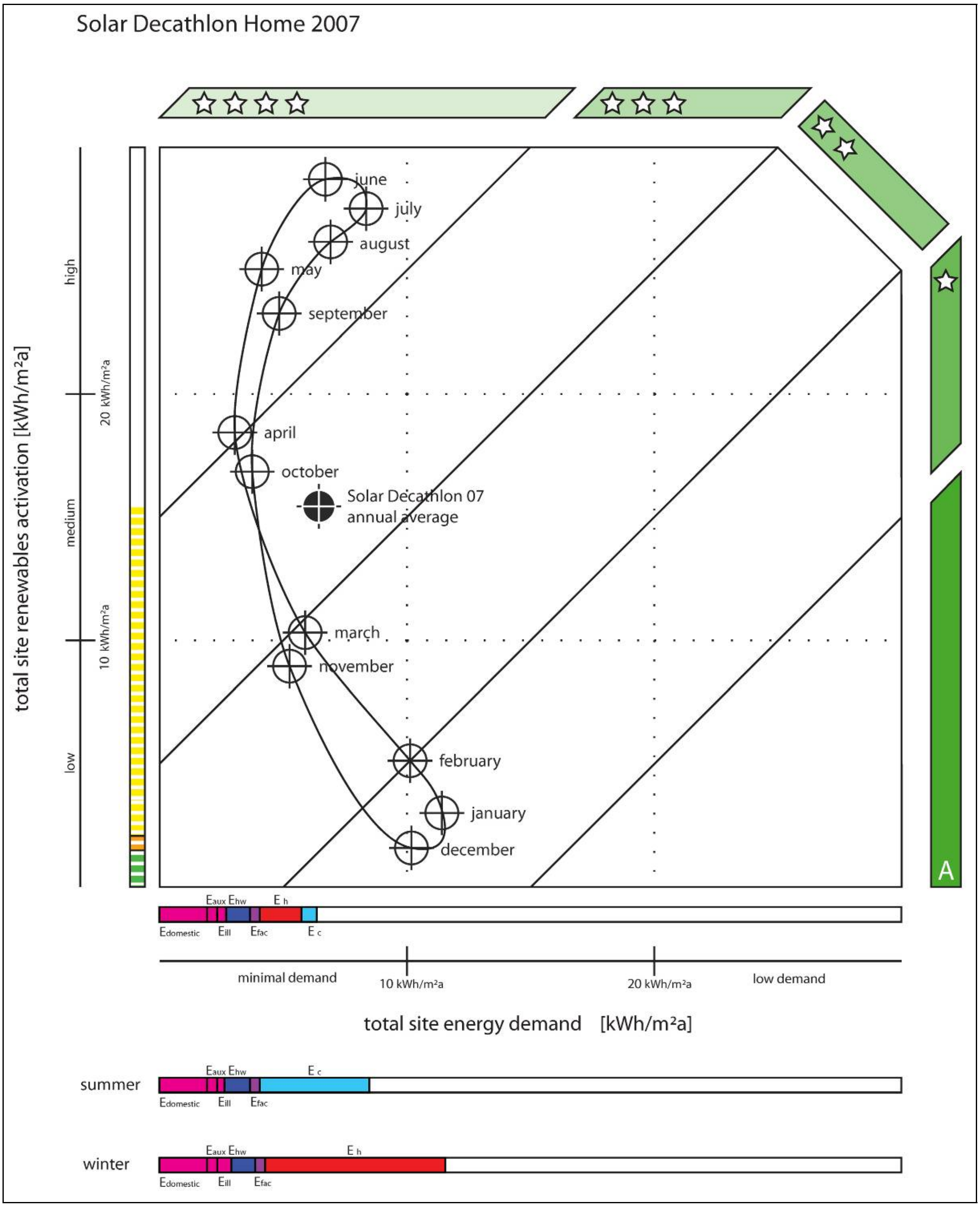


Fig.14: Proposal for future plus-energy-home evalutions: "plus-energy-certificate"

References

[1] Rules and Regulations, Solar Decathlon, U.S. Department of Energy (DOE), http://www.solardecathlon.org/rules_regs.html

[2] Knauf Gips KG, *K764 Knauf PCM SmartboardTM 23/26 - Gypsum board with latent heat storage,* Technische Blätter Trockenbau- und Bodensysteme, http://www.knauf.de/wmv/?id=2298

[3] Hegger, Fuchs, Stark, Zeumer. *Energy Manual – Sustainable Architecture*, Edition Detail, Birkhäuser, 2008. ISBN 978-3-7643-8764-8.

[4] Research project energy:label. *Holistic evaluation of a plus energy home.* TU Darmstadt (GER), 2008, Bundesamt für Bauwesen und Raumordnung (BBR), Z6-10.08.18.7-06.11/II 2.

[5] http://www.sunnyportal.de/Templates/PublicPageOverview.aspx?plant=4a588861-bd5a-444a-a953-54ec19f3d6ee&splang=de-DE, Sunny Portal website with online monitoring of the SD07 photovoltaic production rate

[6] Dr. Detlef Hennings u.a., LEE, *Leitfaden Elektrische Energie im Hochbau*, Institut Wohnen und Umwelt IWU, Darmstadt, im Auftrag des Hessischen Ministeriums für Umwelt, Landwirtschaft und Forsten, Juli 2000

[7] http://www.initiative-energieeffizienz.de/, http://www.stromeffizienz.de/ , federal initiative „*Strom sparen in privaten Haushalten*“

[8] http://www.enob.info/ , federal initiative “*EnOB: Research for energy-optimised construction*”

[9] H. Heissler et al., *Large Energy Savings by Sorption-assisted Dishwasher*, proceedings of EEDAL´09

Set Top Boxes

Energy efficiency trends in STBs

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Abstract

There is increasing awareness throughout the world on the energy used in the on and standby modes of consumer electronics, not only from environmental groups, but also from politicians and general consumers, with little understanding of the reasons for this.

This paper seeks to show the relative power consumption of the different content delivery methods of STBs in on and standby modes for a range of different complexities of STBs from simple zapper boxes to complex multi-tuner PVR products. It references the historical basis of STB energy requirements and moves forward to current practices and limits, and suggests likely future industry trends in power consumption.

It covers the current and proposed key programs in Europe and the USA which influence STB energy efficiency and gives guidance in best practice for power requirement reduction. Some of the possible methods to reduce energy consumption in both operation and standby modes are overviewed

Introduction

The digital Set Top Box (STB) has been in volume deployment for over 12 years. In that time it has developed from being a simple box capable of receiving multi-channel TV into a sophisticated product that replaces a range of other consumer products in the home. Whilst the STB itself has relatively low power consumption, it is always used in conjunction with a television, which has a more significant consumption and its presence in a household represents incremental power consumption.. As digital switchover is implemented in different countries, and as high definition broadcasts and time shift viewing gain momentum the quantity and complexity of STBs deployed will increase dramatically. A significant proportion of these products are defined as 'complex' boxes, which are ones that contain a Conditional Access (CA) system. This CA system may have an 'always on' function, which increases the power used, particularly in standby. The increasing integration and functionality increases the power consumed, at the same time the political and environmental pressures to reduce or remove these standby losses is becoming a critical issue, particularly over the last 2-3 years.

Technology history

Early STBs used what are now considered to be relatively simple processors running at speeds in the region of 16MHz, with less than 3Mbytes of memory and capable of decoding/ displaying Motion Picture Experts Group (MPEG)2 standard definition video.

Since the early development of STBs in 1995 the typical STB has doubled the memory requirement each year, every 2½ years the processor speed has also doubled. The development of digital video recording on hard disk drives in 2001 started with disk capacities of 40Gbytes and every 2 years this has doubled giving typical disk capacities today of 320Gbytes, and this is expected to increase still further (see figure 1).

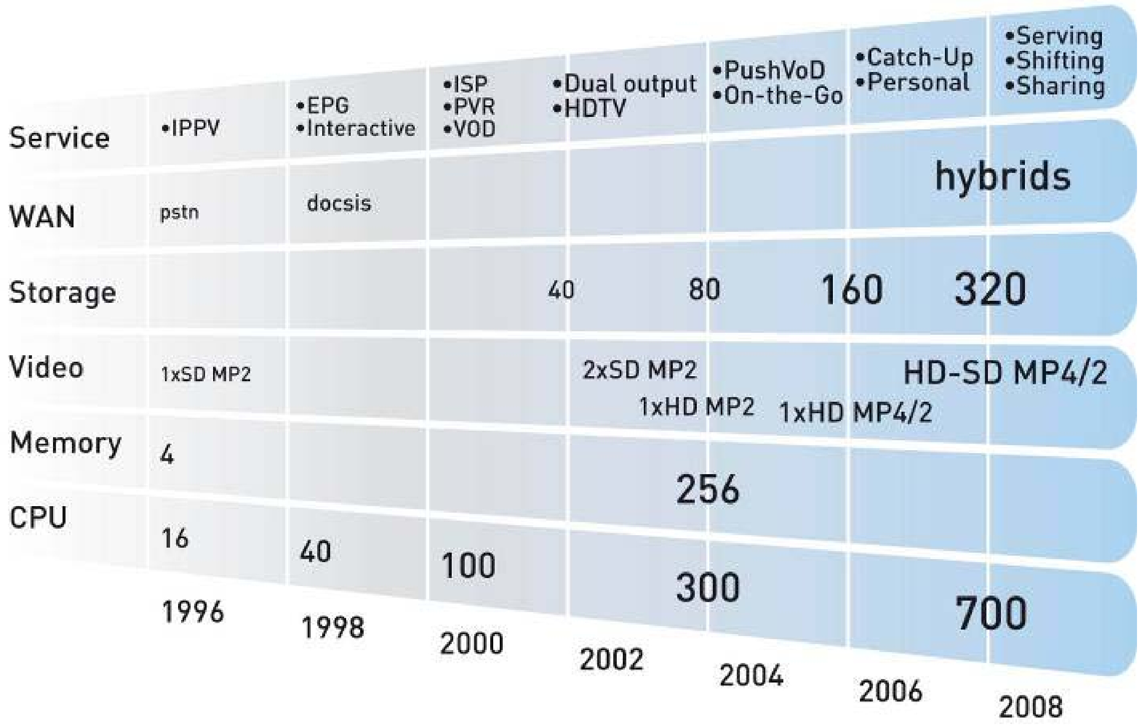

Figure 1 Leading Edge Technology Evolution

The networking and communications protocols have also evolved; from the relatively simple PSTN V22 modems for the return path in the early boxes to the latest Data Over Cable Service Interface Specification (DOCSIS) 3 cable modems. At the same time the encoding and display technologies have progressed from standard definition 4:3 ratio TV to High definition, with automatically switchable 16:9 widescreen and more sophisticated compression algorithms such as MPEG4.

All these significant increases in technology should have led to a significant increase in the power consumed by the STB, but in reality the power consumption for 'like for like' technology (e.g. Standard definition simple STBs from 1996 and 2006) has actually fallen considerably, whilst at the same time the speed, usability and additional functionality has increased, see figure 2

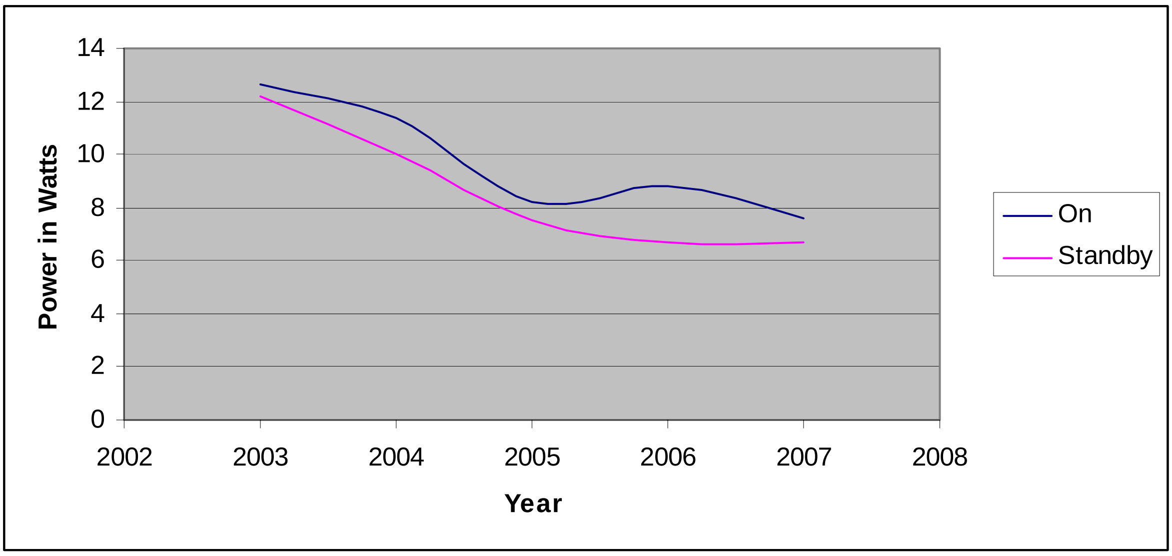

Figure 2 – Power consumption in Standard STBs

Until recently there was limited demand from service providers to maximize energy efficiency; specifications concentrated on performance and cost. The only incentive for manufacturers to reduce power was to increase reliability, as reduced power equals reduced heat, which equals less stress on components and therefore greater reliability. More recently we have seen a greater number of service providers become interested in energy efficiency and general 'green issues'. This is partly due to the political climate, global warming publicity and increased energy cost. However with STBs there is a dilemma, the service provider specifies the product by feature and performance and the consumer purchases a service that requires a STB and pays for the energy used. As the service provider does not have to pay for the running cost of each STB he has limited incentive to reduce the STB power consumption The consumer purchases a tier of service and is provided with the service provider's choice of STB to deliver that service, often not knowing who the original manufacturer was, or the energy consumption in use.

We are now seeing an increasing number of service providers using energy efficiency criteria in specifications and in some cases taking a proactive approach to minimizing energy in use. For example BSkyB in the UK are upgrading their installed base of STBs to implement an automatic standby function via an over-air software upgrade.

Platforms

There are a number of delivery platforms, each significantly different, both in technology and in the power consumed. Of these Satellite and Cable platforms dominate the pay TV market; these will be briefly considered in turn.

Satellite

With a pay TV satellite system the broadcasts are made from a head-end transmitter to a satellite where they are then beamed to a receiving dish at each consumers home. The return path for satellite receivers to validate the conditional access system and to purchase extra services is typically via the phone network. On reception the signals are decoded and processed for viewing. For pay TV the transmitted data stream is encoded and contains programme content as well as conditional access information and transmission data within the Electronic Program Guide (EPG), such as transponder frequencies. These can vary in accordance with network requirement. As conditional access authorizations are transmitted at pseudo random times the system must be 'always on'. As a result of this the Low Noise Block (LNB), receiver front end, decoder, processor and memory must also be active even when the product is in standby. The only significant opportunities for power saving come in the more complex products where there are hard disc drives, High Definition (HD) decoders and multiple tuners.

Cable

Broadcasts are sent from a head-end by fibre to either the street or the dwelling, where the transmission is converted to copper for the final short distance to the STB. As for satellite, the STB then decodes the signal and administers the conditional access information. Typically cable receivers conform to the DOCSIS transmission protocol. This protocol requires that the receiver is permanently 'on' to receive and acknowledge data packets. The standards for DOCSIS modems do not currently support power saving modes, requiring the full video path to be always on. As a result of this power saving in simple cable receivers is minimal. With the higher complexity cable receivers it is possible to switch off high definition circuit blocks, hard disk drives and other peripheral circuits, thereby saving power.

System issues

As the introduction mentions, the STB is never used without being connected to at least one television. The STB gets the publicity as the power hungry device as it typically consumes 10-30W in operation and 5-25W in standby, whereas a principal TV consumes 1-2W in off mode and 150-300W in operation, therefore over any 24 hour period 70-80% of the energy consumption is due to the TV, not the STB.

A greater proportion of TVs are now supplied with integrated digital tuners, which negate the need for an additional simple STB, however with the increase in ‘HD ready’ TVs once again an external additional STB is required to receive and process the incoming HD signal, which again increases the total system power

Future Power Saving Options

There are a number of key constraints to producing low energy STBs, and the key to maximizing energy efficiency in the STB industry is for the main parties to work together. These are the manufacturer, the service provider, the silicon vendor and the software suppliers. Each in isolation will have minimal impact on the power consumption, particularly in standby, but in harmony significant efficiencies can be gained.

As technology matures and demand increases, circuit blocks will become more and more integrated, giving effective System on Chip (SoC) solutions. These solutions require fewer external components; have fewer power losses and greater efficiency. At the chip level the same approach is being taken by the silicon industry with smaller (and hence more power efficient) architectures. Normal market forces drive these changes and the consequential power savings are generally a side effect, rather than the prime motivator. (See figure 3 below)

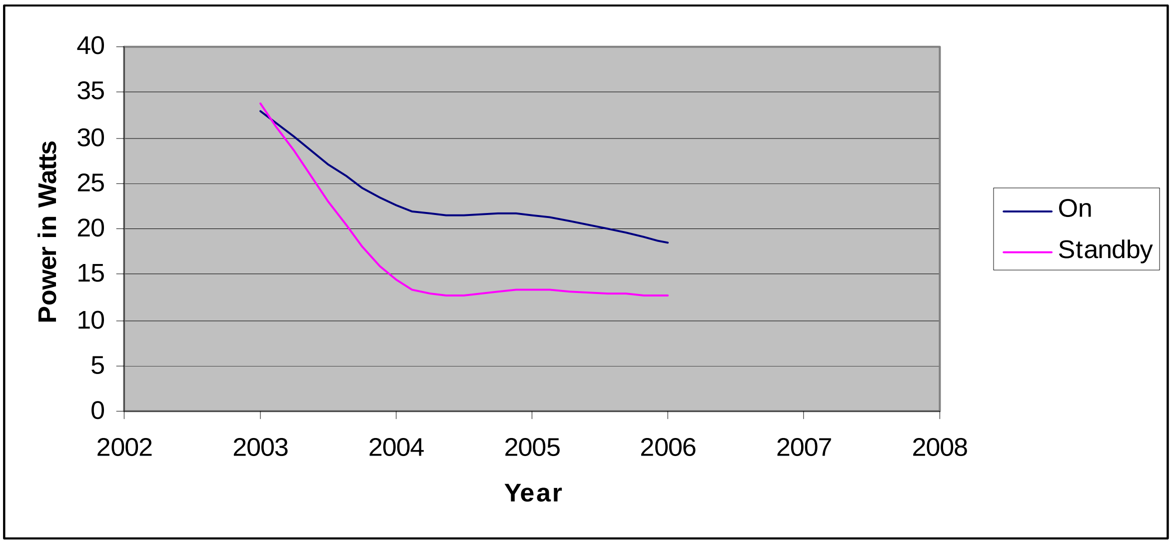

Figure 3 Power consumption improvements in PVR STBs

From figures 3 it can be seen that significant improvements (up to 50% reduction) in energy efficiency have been achieved without significant effort by increased integration of silicon and in the case of Personal Video Recorders (PVRs) improvements in the power management, particularly turning the hard disk off in standby.

The major silicon providers are all working on next generation processors and SoCs, which will have significantly greater power management incorporated. The next generation will have the ability to dynamically switch off (and switch back on again) circuit blocks that are not in current use (E.g. HD decoding when a standard definition program is being viewed).

Once core silicon is available with suitable power saving capabilities the key to maximising power savings will be in the hands of the Conditional Access and Middleware vendors. Their systems hold the key to being able to switch off and on circuit blocks and to cache data to disk or memory and then utilise a deeper (lower power) sleep mode. Again these changes will require considerable resources to implement, by all parties in the supply chain, but the power savings per STB could be significant (10W+). To gain the greatest benefits a fundamental redesign of the Conditional Access systems validation may be required to permit a STB to be put into a low power passive standby mode for a significant time and woken up to receive data only when required. A change of this magnitude could require an investment of many millions of euros by the service provider, who would not get a direct payback on investment, but would give a benefit of 50-150W/h per satellite STB per day.

In order to achieve significant power savings on cable products the DOCSIS standards need amending. These new or revised standards should permit, clock speeds to be dynamically reduced on the primary channel when no high bandwidth data is required and allow all but the primary channel to be turned off when not required, without triggering a fault message. This change will involve both the STB and the head-end equipment, and thus has large implications for the Service Provider. However with the higher revisions of DOCSIS (2+ onwards) significant power savings can be achieved at the hardware level at both ends of the system. Again to be able to turn off a second DOCSIS channel and dynamically reduce the data speed in the primary channel could give a power saving in cable products of 100-300W/h per cable STB per day. Such saving is threatened by the increasing integration of delivery platform services. STB's are increasingly used as gateway devices to the home, providing access to not only cable TV but also phone services, broadband internet access etc. Many of these additional functions require the connection to be 'always on' to support functions that are remote to the STB. In these circumstances the DOCSIS communication paths become more difficult to turn off or to run at reduced data rates.

The integration of additional functions incrementally increases the power consumed by the STB, , but it can be shown that the process of integrating additional functions, e.g. web browsing, video on demand and broadband internet access, can lead to a reduction in the overall power requirement.This is in part due to efficiencies in using a single power supply in place of 2 or 3 power supplies (with their attendant on and standby losses) and greater component integration. A STB with a DOCSIS modem will use the same input channel for video and data, with only the output driver requiring a small amount of incremental power (in the order of 0.1W), in comparison with a separate cable modem, which consumes in the order of 4W.

Data from the USA[1] suggests that video on demand technology will increase the consumption of individual STBs but will have an overall energy efficiency benefit. The argument is that consumers will no longer have to drive to the store to collect and return DVD's etc. In the USA it is claimed that the net energy saving by converting half the DVD / video hires from shops to watching video on demand will save enough energy to power a town of 200,000 inhabitants.

International Power Saving Initiatives

There are a number of schemes in various areas of the World, targeting voluntary or compulsory limits of power consumption. The two with the widest impact are the European Union's Code of Conduct on Energy Efficiency of Digital TV Service Systems and the USA Energy Star Program for Set Top Boxes. Both are voluntary schemes. In addition to these voluntary schemes there is an industry group, comprising the major manufacturers, service providers and some of the silicon and software vendors which is developing a proposed voluntary code.

US - Energy Star Program

The Energy Star Version 2 Program[2] has been re-launched this year, and encompasses manufacturers and service providers. The program is a voluntary scheme that aims to endorse only the best performing products (top 20-25% of the market). The manufacturer's agreement is a commitment to manufacture and supply one or more Energy Star compliant products, the Service Provider's commitment is to purchase or deploy a minimum percentage of Energy Star qualified products.

Its approach is to measure the total energy consumed in both 'on' and 'sleep' modes (Sleep mode is known in Europe as 'Standby') and to then calculate the total energy consumption over a year (based on standard duty cycles). There are no fixed Energy Star power limits for the sleep mode, so a manufacturer or service provider can chose to have a lower average power or a very low sleep mode with a higher on power, as long as the total annual energy consumed is below the Energy Star limit. The test criteria requires that the power consumption is measured with the software that will be deployed on the STB in the field, thus ensuring that the declared consumption matches the practical consumption that the consumer will experience.

Europe – Industry initiative

The Energy Using Products Directive (EuP) was published in 2005 by the European Commission (EC) In 2007 a study was commissioned by the EC on Eco design criteria for complex STBs The consultants completed this in December 2008 [(3)] with recommendations for introducing a mandatory implementing measure under the EuP Directive. With this probability in mind an industry consortium was formed to produce a voluntary industry code, which could be acceptable under the EuP Directive in place of legislation. In this context it should be noted that industry generally supports legislation to eliminate the worst products from the market. However industry has concerns (which are shared by the EC) that in a market segment such as STBs, where the rate of change of technology is extremely rapid, legislation may not be able to keep up; therefore an effective voluntary measure may be more appropriate. At the time of writing this industry Voluntary Agreement (VA) document is in an advanced draft. The VA follows the Energy Star approach of total energy consumption in declared criteria and related measurement methodology

Europe – Code of Conduct

The current European Code of Conduct on Energy Efficiency of Digital TV Service Systems (CoC) version 7 [(4)] concentrates on the power consumed in active standby only, with no on mode limit for complex STBs, this version of the code expires in December 2009 (it is reviewed annually). At the time of writing version 8 is under discussion. This is a significant revision led by the same working group producing the industry VA. It proposes the use of the total energy consumption model from 2010 onwards. Unlike the VA which sets minimum energy efficiency standards, the CoC seeks to set challenging but practicable energy efficiency criteria for STBs. This takes longer to negotiate with the industry since criteria often reflect best practice in Silicon and Software application.

The Code of Conduct up to version 7 has a limited number of signatories; however it is a very influential document both at a governmental level, where it is used as a broad basis for codes of practice or legislation in non-EU countries (e.g. the Australian Minimum Energy Performance Standards) and extensively used as a purchasing or supply requirement in contracts between service providers and manufacturers, where one, or both may not be Code of Conduct signatories.

Conclusion

The global STB industry is a great innovator, adding new features and increased operational speeds whilst at the same time reducing the power consumed per feature. Whilst undoubtedly the number of features and operational speeds will increase with time, there are significant opportunities for further innovation in energy efficiency.

The only method of maximising these gains is by all sectors of the industry working in harmony, from the silicon and software vendors, through the manufacturers to the Service Providers and standards bodies. The drive for these improvements will have to come from the Service Provider, as they specify the system performance, the CA system, the Middleware and sometimes the silicon to be used. With a united effort we will see greater levels of performance and higher levels of integration for lower comparative power consumption.

References

[1] Consumer Electronics Association presentation IEA / Indian Bureau of Energy Efficiency New Delhi India 3rd April 2008

[2] USA Environmental Protection Agency Energy Star Program Final Version 2 23rd April 2008

[3] Bio Intelligence Service, Complex STB final report http://www.ecocomplexstb.org/

[4] European Union Joint Research Centre Code of Conduct on Energy Efficiency of Digital TV Service Systems version 7 15th January 2008

Policies for reducing environmental impacts and improving energy efficiency: the case of complex set-top boxes

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Abstract

This paper highlights the key findings of the EuP Preparatory Study Lot 18 on complex set-top boxes (STBs), which provides the basis for considering implementing measures for this product group, in the context of the Ecodesign Directive. The analysis is based on the methodology MEEuP taking into account a life cycle perspective and follows a logical series of steps: scope definition, market analysis, user behaviour aspects, systems analysis, environmental assessment of the current products, and improvement potential achievable through product design. The improvement options consider life-cycle costs (LCC) and the point of least life cycle costs for the consumer is identified as a short-term target, whereas "best available technology" option might serve as a target for long-term future. The analysis takes into account all major technical parameters relevant for complex STBs and also looks at the role of service providers and end-users in improving the environmental performance of STBs. The study analyses seven average EU products ("Base Cases") covering complex STBs for standard and high definition resolution, and with additional functionalities (e.g. second tuner). These Base Cases serve as reference points for the assessment of the environmental impacts and improvement potential of the STBs existing currently on the EU market. Final results highlight sixteen improvement options (for both short and long term future) with a focus on their potential to reduce the total energy requirement of STBs along their life cycle and on the additional cost for their implementation.

Background

The Ecodesign Directive is a framework Directive on ecodesign requirements (EC/2005/32). Since 2005, analyses of different product groups are under process to develop detailed ecodesign requirements for specific products. These requirements are developed in a multi-step process:

1. **Preparatory Studies,** by independent consultants, analyse a specific product category regarding environmental performance throughout the full product life cycle and regarding improvement potentials, i.e. technology options with significantly lower environmental impact at any life cycle step.

2. On the basis of preparatory study, the European Commission outlines possible product requirements in a **Working Document**, which are presented and discussed at a **Consultation Forum** meeting with stakeholders.

3. Based on these discussions and further evidence, the European Commission drafts an **Implementing Measure** for vote by the **Regulatory Committee**.

4. After an inter-service consultation at the Commission, a scrutiny by the European Parliament, and a **notification to the WTO**, the adapted **Implementing Measure / Commission Regulation** is be adopted and published in the **Official Journal of the European Union**.

5. The requirements laid down in the Implementing Measure are **directly effective** in all the Member States from the date of its publication itself.

The preparatory studies comprise technical, economical, and environmental impact assessments which will provide the technical basis to draft any possible implementing measures (legislation) for setting generic and specific ecodesign requirements of Energy using Products (EuP). The analysis follows the Methodology for Ecodesign of Energy-using-Products (MEEuP) [3] which is a common approach for all preparatory studies. In brief, this methodology includes a definition of the product categories (task 1), market analysis (task 2), aspects of user behaviour and related barriers for ecodesign (task 3), analysis of real products being identified as representative of the European situation (task 4), environmental assessment of average products defined as Base Cases, system analysis (task 5), in depth technical analysis of best available (and not yet available technologies) and possible improvement potential of different design options (tasks 6 and 7), and policy and scenario analysis (task 8). The MEEuP also includes a spreadsheet model (EuP Eco Report) using an internal database that converts material quantities from Bill of Material (BOM), energy consumption data and economic data into standard environmental indicators and Life Cycle Cost (LCC).

While the Preparatory Study on complex STBs has been published recently (December 2008) [2], the European Commission has already adopted the implementing measures for simple set-top boxes (February 4, 2009) [4], see table 1. The future measures for complex STBs are intended to complement the requirements for simple STBs, i.e. the product scope should allow for a clear distinction of complex and simple STBs.

Table 1: Simple STB EuP Power Consumption Limits

	Standby mode	**Active mode**
Tier 1: 25 February 2010		
Simple STB	1 W	5 W
Allowance for display function in standby	+ 1 W	—
Allowance for decoding HD[1] signals	—	+ 3 W
Tier 2: 25 February 2012		
Simple STB	0.5 W	5 W
Allowance for display function in standby	+ 0.5 W	—
Allowance for hard disk	—	+ 6 W
Allowance for second tuner	—	+ 1 W
Allowance for decoding HD signals	—	+ 1 W

Source: [4]

Product scope and existing legislations and testing procedures

Product scope

Definition of a complex STB

An STB is a device that connects to a television and some external source of signal, and turns the signal into content then displayed on the screen. The signal source might be a satellite dish antenna (satellite television), a coaxial cable (cable television), a telephone line (including DSL connections), Broadband over Power Line, an Ethernet or optical fibre cable (Internet Protocol Television or IPTV), or a VHF (very high frequency) or UHF (ultra high frequency) antenna. From the functionality point of view, STBs are best divided into two types: simple boxes that decode digital signals for analogue televisions (DTA) and more complex boxes that operate in an interconnected environment such as exists in subscription services and networked home entertainment systems. When defining the scope of the complex STB study, taking into account the previous preparatory study on simple STB [5] and other product definitions already available (e.g. in the European Code of Conduct on Digital TV service systems (EU CoC), Energy Star requirements for “Digital television adapters”, Australian MEPS (Minimum Energy Performance Standards)), the following definition of complex STBs has been established, fixing the scope of the study:

[1] HD - High definition

A complex STBs is an STB which allows conditional access[2]. It is a stand-alone device, using an integral or dedicated external power supply, for the reception of Standard Definition (SD) or High Definition (HD) digital broadcasting services via IP, cable (DVB-C), satellite (DVB-S) and/or terrestrial transmission (DVB-T) and their conversion to analogue RF and/or line signals and/or with a digital output signal. Complex STBs might have additional features, e.g. return path / integrated modem / internet access, multiple tuners (for picture-in-picture or to serve several end-devices), connectivity with external devices (video recorders, pc, digital cameras, external hard disks or memory etc.), recording with internal mass storage media, and entitlements.

Digital receivers with recording function based on removable media in a standard library format (DVD, VHS tape, "Blu-ray" disc etc.) are excluded from the scope of this study, but complex STBs with players for removable media are included.

The following appliances were not covered in the scope:

1. Simple set-top boxes (as defined by the preparatory study on simple STBs)
2. Digital TVs with integrated receiver and decoder (IRD)
3. USB-port digital receivers for computers (as they fail the definition "using an integral or dedicated external power supply) and TV add-in card for computers
4. Devices that require a separate signal processing device (e.g. PC, or PS3 or XboX)
5. Larger reception installations, such as communal satellite installations, which are not intended to serve one household only
6. Personal computers with the add-on functionality of a STB

Related to the point 6 above, so called Media Centres including the functionality of STBs were covered by the study, if they do not allow recording on removable media (a DVD or CD-ROM writer disqualifies a media centre to be a "complex STB") and/or if they are not intended for standard office software, such as text editing and calculation programmes. The product scope also included internal components of complex STBs considered as being part of the STB (e.g. external power supply (for the STB), remote control, modem (if they are required for the functionality of the STB and dedicatedly specified for the STB it is sold/provided with, e.g. external ADSL modem for IPTV; including external power supplies for these modems, if applicable).

Definition of operating modes

The specifications of the various operating modes were also provided which could apply to complex STB. Correlations with the definitions used in the previous preparatory study on standby and off-mode losses [6] ("lot 6") are also provided. According to the EU CoC, following are the modes definitions:

1. On: The appliance is connected to a power source and fulfils a main function, including the provision of signals to supported devices ([6] "active mode")
2. Standby active: The appliance is connected to a power source, does not fulfil a main function but can be switched into another mode with the remote control unit or an internal signal. It can additionally be switched into another mode with an external signal or it is receiving a minimal level of data from an external source ([6] "Networked Standby").
3. Standby passive: The appliance is connected to a power source, does not fulfil a main function but can be switched into another mode with the remote control unit or an internal signal ([6] "Passive Standby").

[2] "Conditional Access" means an active system that enables the STB to process and apply targeted data from a service provider. Conditional access is related to Pay-TV. Parental control systems are not considered as conditional access since they intend to restrict viewing times and/or content by control of the user.

4. Off: The equipment is connected to a power source, serves no function and cannot be switched into any other mode with the remote control unit, an external or internal signal other than by the user pressing the “ON” button located on the product (off-mode definition adapted from the EU CoC) ([6] “off-mode”).

5. Disconnected: The appliance is disconnected from all external power sources ([5] “disconnected-mode”).

Existing legislation and standards

Several test standards on energy consumption relevant for complex STBs exist and they have some discrepancies about testing conditions and the measurement modes. The standard EN 62087:2003 is the reference for several European (Code of Conduct and GEEA) and third country programmes (Switzerland, Australian MEPS, and Korea). Nevertheless, it is currently under revision (FprEN 62087:2009 just published). The identification of the relevant legislation world-wide reveals that currently only Switzerland is developing obligatory standards related to the energy consumption of complex STBs.

Economic and Market Analysis

Market stock and sales data (2010 outlook)

About 22 million complex STBs were sold in the EU-27 during 2007and sales projections for 2009 are estimated to be 42 million [8]. Assuming a constant annual growth rate of 40 %, it was estimated that the complex STB sales will reach about 58.8 million in 2010.

The data for complex STB was estimated on the basis of the number of pay-TV subscriptions in the EU [9]. However, the data on the number of pay-TV subscribers was available only for Western Europe. This data was extrapolated to EU-27 as a function of the population in Western Europe and EU-27. Such extrapolation by reception platform estimates the overall stock of complex STBs in EU-27 to be 65.7 million for the year 2007 and to 81.9 million units for the year 2010 (see Figure 1).

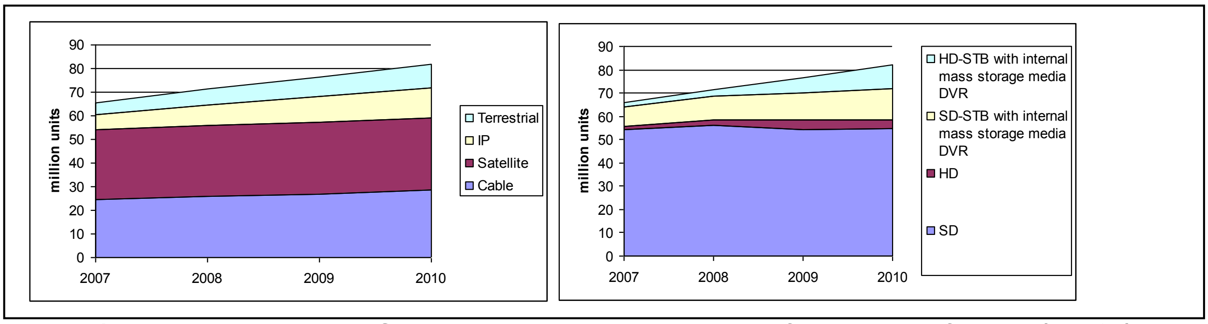

Figure 1: Estimated complex STB stock per transmission platform and by feature (EU-27)

Market trend and 2020 outlook

Analysis of relevant market and technical trends show that the level of complexity of complex STB will grow in the coming years, i.e. growing number of STB with HD resolution (very high market penetration by 2015), internal mass storage media, return path, multiple tuners, wireless connectivity, and networked STB / client STB. This will hold true at least for the devices which will be still on the market in 2015 and beyond – as it is not predictable, whether STB will survive at all or will be absorbed by other products (TV sets, computers, media centres). Consequently, it was assumed that by 2015 the stock of complex STB will see a dominance of HD products with internal mass storage media (assumed 80%). Assuming further that the trends for and against a growing market for complex STB outweigh each other, the stock of 2010 in terms of total units will remain the same until 2015. After 2015, the number of STB may decline due to merging with other devices. As a very rough outlook in 2020 the number of complex STBs in use might be half of that in 2015 (i.e. 41 million units), but all of them can be expected to have HD and with integrated mass storage media. These figures, though highly speculative, remain the best available assumption for the long-term (2015/2020) market evolution of STBs.

Consumer Behaviour: Use pattern

Like all consumer electronics products, complex STBs' energy use depends on both the power requirements in different operation modes and on the use pattern (average time in each of these modes). Complex STBs can operate in five different modes: on, standby active, standby passive, off and disconnected modes. However, most of the existing STBs typically do not have a standby passive mode, except for retail ones. The implementation of this mode is currently under development, mostly within the companies complying with the EU CoC. Off mode is hardly used either, since complex STBs need to be constantly in on mode for updating properly and be able to receive, transmit, and/or recording broadcasting signals, and also because of the long delay time for the STB to reboot and switch from off to on mode (due to software/firmware updates). Also, a majority of STBs supplied by service providers do not even have the on/off hard switch. In relation to the on mode, results of an internal large-scale customer survey BSkyB UK [10] estimates the on mode time of complex STBs without internal mass storage media to 9 hours. Following use pattern was calculated to represent the typical European use pattern for complex STBs (Table 2).

Table 2: Complex STBs use pattern

	On mode (hours/day)	**Standby active mode (hours/day)**	**Off mode (hours/day)**	**Disconnected mode (hours/day)**
Complex STB without internal mass storage media	9	14.76	0.12	0.12
Complex STB with internal mass storage media	10.5	13.38	0.06	0.06

Source: [2], [10], [11]

Moreover, typical product life was estimated to 4 years on the basis of stakeholder consultation and literature review.

Product Assessments

Approach

In order to evaluate the life cycle impacts of complex STBs, a technical analysis of individual real life products representative of the EU market was performed, with a focus on the collection of Bill of Materials (BOM) for complex STBs in different configurations (i.e. with/without additional technical features) and energy consumption data for different operating modes (e.g. on mode, active standby mode). Such data was compiled to serve as inputs to define the Base Cases.

Collection of Bill of Materials

A total of 13 complex DVB-S STBs with different configurations were acquired from Stiftung Warentest in Germany and disassembled at Fraunhofer IZM laboratories to establish detailed BOM data and investigate mechanical construction aspects. Results of the real life product analysis show that the main components (see Figure 2) of a complex STB are: front panel (including buttons, remote control sensor, display, etc.); housing (with backside interfaces, occasionally with hard-off switch); printed wired board assemblies (main PWB[3], power supply circuitry, flex circuitry for display, HDD[4] circuitry, tuner circuitry, etc.); common Interface (CI) slot; hard disk drive (if any); internal cables, external cables, and screws; external power supply (if any); and packaging (including manual). All these components have an influence on the raw material requirement and thus contribute to the

[3] Printed Wiring Board

[4] Hard Disk Drive

environmental impacts caused during the production and end-of-life phases. Typical packaging for complex STBs appeared to be optimised and the packing box was found to be only slightly larger than the STB itself for all the investigated STBs.

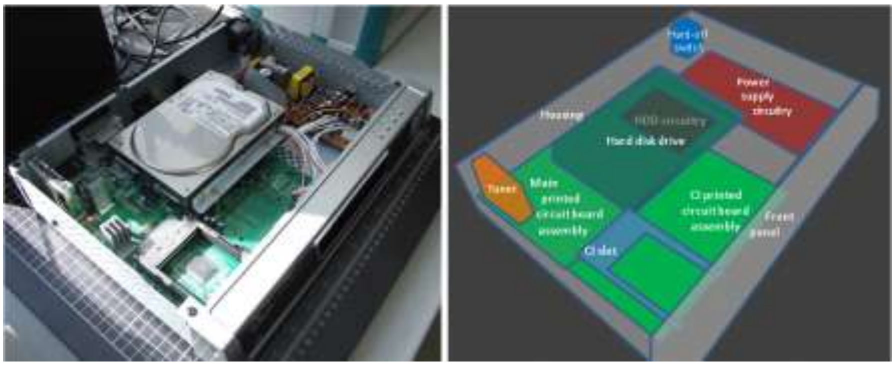

Figure 2: Main components of a complex STB

Collection of Energy consumption data

Based on extensive literature review (in total power requirement data of 208 complex STBs was analysed from [12], [13], and [14]) and stakeholder consultation, the following typical[5] power consumption data was investigated distinguishing: (1) Transmission platform, (2) Return path, (3) Second tuner, (4) Internal mass storage media (HDD / PVR), and (5) HD capability.

The focussed on the most significant technical features contributing to power consumption. However, these 5 criteria are not the only features responsible for power consumption in an STB, some other features causing significant power consumption are: wireless connectivity and integrated disk players, e.g. DVD, CD-ROM, Blue-Ray. All other major functionalities of complex STBs (mid-term perspective) are intended to be covered by the five selected features. Estimates for typical levels of power requirements for these functionalities are presented in Table 3:

Table 3: Typical on mode and active standby power consumption per functionality

Complex STB (DVB-C, -S, -T, IPTV)	**Typical power consumption (W)**	
	On mode	**Active standby**
Basic “complex” STB, including all typical interfaces, digit display, CI and/or CAM, etc.	10	5
Additional power consumption for:		
Hard disk drive	+ 8	+ 2
Second tuner / multiple tuners	+ 5	+ 1
High definition capability	+ 8	+ 8
Return path	+ 10	+10

Source: [2]

[5] Typical” means, a majority of the STBs on the market have got approximately this power consumption (easily with a range of +/- 50%, see individual data above).

Definition of the Base Cases

In order to cover appropriately the broad range of technical specifications and functionalities of complex STBs, seven[6] Base Cases were defined as summarised in Table 4.

Base Cases 1 to 3 cover STBs for standard definition resolution, and Base Cases 4 to 6 similar products, but with high definition resolution. Base cases 1 and 4 have a very "basic" configuration without any other major features besides conditional access. Base Cases 2 and 5 cover STBs with internal mass storage media, i.e. HDD as dominating medium. Base cases 3 and 6 represent abridged Base Case (no extended BOM) for high-end STBs with HDD, second tuner, and return path. These two Base Cases specifically illustrate the differences in power consumption of more sophisticated STBs.

Table 4: Base Cases/ Product Case Overview

Base cases / Product Case	**Data source**		**Market data (2007)**	
	BOM	**Power consumption**	**Sales (Million units)**	**Stock (Million units)**
(1) "basic" complex STB with SD	Typical DVB-S STB	Table 3	18.2	54.2
(2) complex STB with SD, HDD	Typical DVB-S STB	Table 3	2.8 assumed split: (2) – 20%, (3) – 80%	8.2 assumed split: (2) – 20%, (3) – 80%
(3) complex STB with SD, HDD, second tuner, return path	Typical DVB-S STB; second tuner and return path not accounted for in the BOM	Table 3		
(4) "basic" complex STB with HD	Typical DVB-S STB	Table 3	0.6	1.6
(5) complex STB with HD, HDD	Typical DVB-S STB + BOM for HDD parts, additional housing "overhead" etc. not accounted for in the BOM	Table 3	0.6 assumed split: (5) – 20%, (6) – 80%	1.6 assumed split: (5) – 20%, (6) – 80%
(6) complex STB with HD, HDD, second tuner, return path	Typical DVB-S STB + BOM for HDD parts, additional housing "overhead" etc., second tuner and return path not accounted for in the BOM	Table 3		
(7) Triple play box	Sample triple play box	Table 3: Additional power consumption for return path only	2.0 (IPTV)	6.0 (IPTV)

Source: [2]

Environmental Assessment and Life Cycle Costs of the Base Cases

The Base Cases serve as reference points for the assessment of the environmental impacts of current products on the EU-27 market and calculation of the associated Life Cycle Costs (LCC). The life cycle environmental impacts were evaluated through the EuP Ecoreport spreadsheet model based on the inputs presented in Table 4 and on a typical product life of 4 years. A typical end-of-life scenario for complex STBs was also estimated, based on literature review.

[6] A Product Case for triple play boxes was analysed. However, as it does not include the functionality of transmitting TV signal, but requires an additional IPTV STB for this purpose, it was named as a "Product Case" and not a Base Case. Actually, such a triple play box will be combined with a STB similar to any of the six Base Cases. There exist integrated triple play / receiver boxes, but they do not represent the majority of the triple play market.

Results of the life cycle environmental assessment of Base Case 1 are presented below (Figure 7).

Nr	Life cycle Impact per product:								Date	Author
0	Base Case 1: "basic" complex STB with SD								0	KSchi

	Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE*			TOTAL
	Resources Use and Emissions		Material	Manuf.	Total			Disposal	Recycl.	Total	
	Other Resources & Waste							debet	credit		
8	Total Energy (GER)	MJ	239	68	**307**	**77**	**2518**	62	47	**16**	**2918**
9	of which, electricity (in primary MJ)	MJ	88	16	**103**	**0**	**2516**	0	20	**-20**	**2599**
10	Water (process)	ltr	147	4	**151**	**0**	**169**	0	18	**-18**	**302**
11	Water (cooling)	ltr	86	18	**104**	**0**	**6707**	0	4	**-4**	**6807**
12	Waste, non-haz./landfill	g	6067	145	**6212**	**64**	**2978**	669	57	**612**	**9866**
13	Waste, hazardous/ incinerated	g	276	1	**277**	**1**	**61**	371	22	**349**	**689**
	Emissions (Air)										
14	Greenhouse Gases in GWP100	kg CO2 eq.	15	4	**19**	**6**	**110**	5	3	**1**	**137**
15	Ozone Depletion, emissions	mg R-11 eq.	negligible								
16	Acidification, emissions	g SO2 eq.	154	23	**176**	**19**	**649**	9	17	**-7**	**837**
17	Volatile Organic Compounds (VOC)	g	1	1	**2**	**0**	**1**	0	0	**0**	**3**
18	Persistent Organic Pollutants (POP)	ng i-Teq	9	2	**12**	**0**	**17**	5	0	**4**	**33**
19	Heavy Metals	mg Ni eq.	138	6	**144**	**3**	**45**	18	2	**15**	**207**
	PAHs	mg Ni eq.	20	1	**21**	**3**	**5**	0	2	**-2**	**27**
20	Particulate Matter (PM, dust)	g	13	6	**19**	**8**	**14**	81	1	**80**	**122**
	Emissions (Water)										
21	Heavy Metals	mg Hg/20	113	0	**113**	**0**	**17**	5	11	**-6**	**124**
22	Eutrophication	g PO4	4	0	**4**	**0**	**0**	0	0	**0**	**4**
23	Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

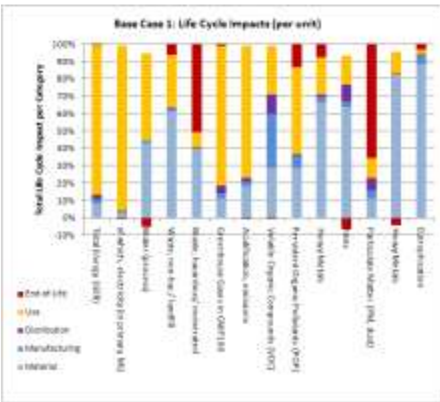

Figure 7: Base Case 1 – Life Cycle impacts

For Base Case 1, the analysis shows that:

1. Materials acquisition is clearly dominating the total environmental impacts in the categories: Water (process); Waste, non-hazardous / landfill (mainly from gold coatings of connectors / CI-slot); Heavy metals emissions to air and to water (mainly from steel housing, heavy metals to water also from large ICs); PAH emissions to air (mainly from large capacitors and coils); Eutrophication (mainly from steel housing and connectors)

2. Manufacturing is not dominating any of the categories, but contributes roughly one third of the total impacts to: Volatile Organic Compounds (VOC) to air (mainly from printed circuit boards).

3. Distribution is not dominating any of the categories.

4. The use phase is dominating (>70%) for the following environmental impact indicators: Total Energy, and electricity (on mode 55%, active standby mode 45%, off mode <0.15%); Greenhouse Gases; Acidification.

5. End-of-life impacts are dominating (> 50%) in categories: Waste, hazardous / incinerated; Particulate Matter emissions to air.

For the other Base Cases, the correlations are similar but the absolute values differ. For example the Global Warming Potential, it was calculated: 137kg CO_2-eq. for Base Case 1 and up to 573kg CO2-eq. for Base Case 6.

These results do not allow making a robust assessment regarding which life cycle phase is the most relevant because comparison across categories is not feasible. However, it can be observed that materials acquisition, use, and end-of-life phases are of relevancy when assessing the improvement potential for different options. Regarding the use modes, both on mode and active standby need further consideration, whereas off-mode is of minor relevancy. Components and materials with a high contribution to certain life cycle indicators are identified to be: Steel / Aluminium housing parts (STB and HDD); large integrated circuits; large capacitors and coils (batteries); printed circuit boards (manufacturing); and gold / precious metal content in printed circuit board assemblies, connectors and in HDD platters.

Total electricity costs were also calculated for each Base Case/Product Case. Results show that these vary from 35€ for Base Case 1 (i.e. 21% of the LCC) and up to 166€ for Base Case 6 (i.e. 25% of the LCC).

The total EU-27 life cycle environmental impacts and life cycle costs of the stock of complex STBs were also evaluated. The results shows that the Total Energy Requirements (TER) consumption of the EU stock (produced, in use, discarded) for the reference year 2007 is 74 PJ, of which electricity is 6.2 TWh. The Preparatory Study on simple STBs calculated a use phase electricity consumption of 6.2 TWh (business-as-usual scenario for 2010)[7] as well, but one can observe the differences regarding market dynamics. Whereas the market for complex STBs sees significant growth rates and consequently the potential for rising total electricity consumption, the market segment of simple STBs is likely to grow at much lower rates beyond 2010.

Analysis of the Improvement Potential

A thorough description and technical assessment of Best Available Technologies (BAT) and Best Not yet Available Technologies (BNAT), either at product or component level, and an analysis of best available products on the market allowed identifying relevant technical options which could be feasible and available (short and long term) to improve the environmental performance of complex STBs.

The analysis of the improvement options has to consider life cycle costs (LCC) and especially the point of least life cycle costs (LLCC) for the consumer, whereas BAT point, i.e. leading to the best environmental performance might serve as a target in the long-term.

Sixteen improvement options were identified as the most relevant (short and long term future): (1) Low power standby mode (1W): 30 min wake-up interval; (2) Low power standby mode (1W): 2 h wake-up interval; (3) Automatic Power Down; (4) Power down components; (5) 3.5" State-of-the-art HDD; (6) 85% Power supply efficiency; (7) Good design practice: General; (8) Good design practice: General and for high definition; (9) Modem ASIC[8]s; (10) Modem standby; (11) Hard-off switch; (12) 2.5" State-of-the-art HDD; (13) Solid state disk; (14) Design for Recyclability; (15) Slim design; and (16) Disable functionalities.

Consequently, the improved Base Cases (i.e. by implementing one improvement option on the top of a Base Case) were analysed again using the EuP EcoReport and the results were compared with the Base Case analysis from Task 5.

Results indicate that power management (Options 1 and 2) and good general design practices (Option 7) seem to be the most promising individual options in terms of TER and LCC reduction. Combinations of improvement options were also analysed and results show that combinations leading to LLCC points allow TER reductions between 44%-59.5% while decreasing the LCC of between 9.5%-22%. Those leading to BAT points achieve TER reductions between 44%-65.5%, however, with higher LCC (up to 50% increase). Figure 8 summarises the LCC and Total Energy Requirement (TER) reduction potentials (in comparison with the values obtained for the Base Case/Product Case in Task 5) for the combinations of options leading to the LLCC point.

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[7] Final report EuP Preparatory Study Simple Digital TV Converters (Simple Set Top Boxes) p. 113

[8] Application Specific Integrated Circuit

Base Cases / Product Case	LLCC point is a combination of Option																LCC reduction potential	TER reduction potential
	1	2	3	4	5	6	7	7+8	9	10	11	12	13	14	15	16		
(1) "basic" complex STB with SD – LLCC Option	●		●	●			●							●			11.4%	53.0%
(2) complex STB with SD, HDD – LLCC Option	●		●	●	●	●	●										9.5%	53.9%
(3) complex STB with SD, HDD, second tuner, return path	●		●	●	●	●	●		●	●							18.8%	58.4%
(4) "basic" complex STB with HD	●		●	●		●		●									11.9%	54.8%
(5) complex STB with HD, HDD	●		●	●	●	●		●									11.9%	57.7%
(6) complex STB with HD, HDD, second tuner, return path	●		●	●	●	●		●	●	●							18.3%	59.7%
(7) triple play box						●	●		●	●				●			22.1%	43.9%

Figure 8: Overview of the LLCC options

Scenario Analysis

The analysis of improvement options shows that the implementation of LLCC design options with direct impact on maximum on-mode and active standby mode power consumption are:

1. Good design practice: General (option 7) and high definition (option 8)
2. 85% power supply efficiency (option 6)
3. 3.5" State-of-the-art HDD (option 5)
4. Modem ASICs (option 9).

These measures and related energy saving are summarised in Table 5.

Table 5: Typical on mode and active standby power requirement levels of complex STBs at LLCC taking into account only the options 5, 6, 7, 8, and 9

STB (DVB-C, -S, -T, IPTV)	**Typical power consumption → point of LLCC (taking into account only the options 5, 6, 7, 8, and 9) (W)**	
	On-mode	**Active standby**
Basic "complex" STB, including all typical interfaces, digit display, CI and/or CAM, etc.	10 → **7.5**	5 → **2.8**
Additional power consumption for Hard disk drive Second tuner / multiple tuners High definition capability Return path	 + 8 → **+ 5.2** + 5 → **+ 4.7** + 8 → + **7.5** + 10 → **+ 8.9**	 + 2 → **+ 1.9** + 1 → **+ 0.9** + 8 → **+ 2.8** +10 → **+ 8.9**; plus modem standby: → **+ 5.2**

Three scenarios (over a time horizon 2007-2020) were drawn up to illustrate quantitatively the improvements that could be achieved through the increased penetration of complex STBs achieving such levels of power requirements and further improved though the implementation of other LLCC options identified in Task 7, i.e. Option 4 (Power down components), Option 10 (Modem standby) and Option 14 (Design for Recyclability) (this was assumed under the LLCC1 scenario), and further through the implementation of Option 1 and 2 (Low power standby modes) and Option 3 (Automatic Power Down) (this was assumed under two LLCC2 Scenarios).

Each of the three scenarios assumed different timings for the full penetration of the more efficient STBs on the market (in terms of proportion of sales), and different stages of performance levels.

These scenarios allowed estimating the effects of an increase in the energy efficiency of complex STBs in Europe. The Business-as-usual (BAU) scenario shows that the total stock of complex STBs could represent an annual electricity consumption of 11.6 TWh in 2020 compared to 4.4 TWh in the case of a more optimistic scenario, based on the improvement potential identified in Task 7.

The improvement potentials were calculated in terms of reduction in total TER (PJ/year), of reduction of annual electricity consumption (TWh/year), and reduction of annual life cycle CO_2-eq. emissions (Mt. CO_2-eq./year) for the whole stock of complex STBs (see Figure 9).

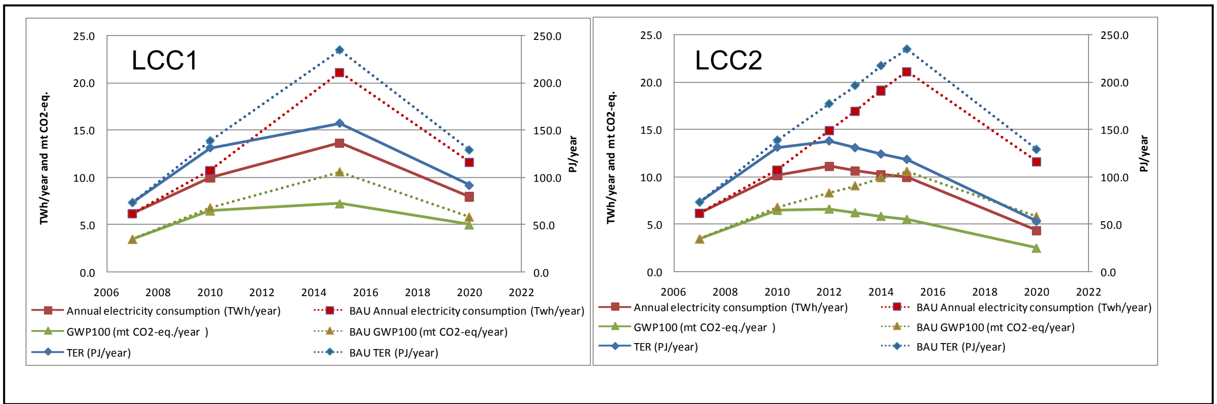

Figure 9: Improvement scenarios (LLCC1 scenario and LLCC2 scenario) versus business-as-usual scenario

Conclusions

The calculations made in the Task 7 show that the potential TEC savings range between 43.9% (for the Product Case 7) and 59.7% (for the Base Case 6) when cumulating several options. Hence, by integrating some of these improvement potentials in the design, significant energy savings could be made by using more energy efficient complex STBs. Mandatory and/or voluntary measures (e.g. industry agreement) could help in achieving these improvement targets.

An industry working group has been established to propose a voluntary measure though the preparation of the next version of the European Code of Conduct for Digital TV services. The draft of this voluntary code suggests setting limits in terms of total electricity consumption limits ("TEC approach"). In general, the proposed draft CoC Tier 1 [15] is significantly more ambitious than the current status quo (i.e. Base Cases), except for DVR: there is a clear mismatch of the proposed annual allowance with the typical power consumption values. As most of the complex STBs in the future are likely to be equipped with DVRs this could significantly weaken the CoC limits. Moreover, the CoC does not require the implementation of Auto Power Down, or of a low power standby mode. Also, the draft CoC Tier 2 limits are more ambitious then the Base Case levels, but in general they remain less stringent then the levels that could be reached at the point of LLCC identified in Task 7 (LLCC1(a) level).

Mandatory measures through Minimum Energy Performance Standards (MEPS) could be set either in terms of power requirements ("mode approach") limits or in terms of total electricity consumption limits ("TEC approach"). However, MEPS do not (and cannot) address the following LLCC design options: Power down (non-used) components in on-mode, Design for Recyclability, Disabling functionalities which would be tackled through requirement either related to user instruction, product documentation or other generic requirements. In an upcoming study, the Commission is going to analyse the network standby issue and that will also have a direct influence on STBs.

Next steps to be carried out by the Commission will be the consultation forum where any possible implementing measures will be discussed before being presented to the regulatory committee and the European Parliament for final adoption.

References

[1] Directive 2005/32/EC. Official Journal L 191, 22/07/2005 P. 0029 - 0058

[2] BIO Intelligence Service and Fraunhofer IZM: *EuP Preparatory Study Lot 18, Complex Set-top Boxes, Final Report*, December 2008.

[3] VHK. *Methodology Study Eco-design of Energy-using Products Final Report. Prepared for the European Commission DG ENTR*. 28/11/2005.

[4] Commission Regulation (EC) No 107/2009 of 4 February 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for simple set-top boxes, Official Journal of the European Union, L 36, Vol. 52, 5 February 2009

[5] Harrison, R.; Jehle, C.: *Preparatory studies for eco-design of EuPs, Simple Digital TV converters (Simple set-top boxes). Final Report*, 2007

[6] N.F. Nissen et al.: *EuP Preparatory Study Lot 6 Standby and Off-mode Losses, Task 1 Definition, Final Report*, October 2, 2007

[7] BIO Intelligence Service and Fraunhofer IZM: *EuP Preparatory Study Lot 7, Battery Chargers and External Power Supplies*, Final Report, October 2, 2007

[8] Booz Allen & Hamilton: *Set Top Box Market Assessment Europe*, 2007

[9] e-Media Institute: *European Pay-TV Forecasts Map (Western Europe)*, 2008

[10] Internal large-scale customer survey B-Sky-B UK

[11] Discussion held during the final stakeholder meeting for the lot 18 held in Brussels on October 15th 2008

[12] E. Bush, M. Schalcher, P. Kühne, S. Kammermann, S. Gasser, J. Nipkow, *Settop-Boxen: Bestimmung der energetischen Eigenschaften,* Final Report, May 7, 2007

[13] *Vom Himmel geholt - Digitale Sat-Empfänger,* test, 11/2007 (Stiftung Warentest: measurements of tested STBs in 2007 and 2008, published in the “test” magazine)

[14] Catalogue data published on www.digitalfernsehen.de

[15] Voluntary Code on STB power consumption Initial proposals from the informal industry group 27 August 2008.

The international effort to develop a new IEC measuring method for Set Top Boxes (STBs)

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Abstract

This paper covers the development of IEC 62087 Ed 3 which addresses shortcomings in the power measurement of STBs. The new requirements are contained in Section 8 of the draft Ed 3 of IEC 62087. The paper also provides insight into how the new power measurement method was developed and the basic principles of the new method. Contrast is made by comparing with other STB measurement methods. These other methods it is hoped have formed the basis of harmonization with IEC 62087 Ed 3 with the hope that IEC 62087 Ed 3 will become the preferred STB power measurement method for existing and new energy conservation programs.

Introduction

This Paper reviews the growing problem of set top boxes in the context of their growing use and the lack of an appropriate international power consumption measuring standard. Set top boxes are used to provide subscription television services to end users as well as providing a means to watch the emerging free to air digital television services on existing analog televisions. A number of programs have been established in number of countries to try and address this emerging problem. Each of these programs has adopted their own energy measurement method. As yet no internationally agreed method has been developed.

State of play for set top boxes and related issues

The projected growth of STB use across the world.

Digital CEnergy Australia modeled the projected growth for STBs through to 2030. The result of this modeling is shown in Figure 1 and Figure 2

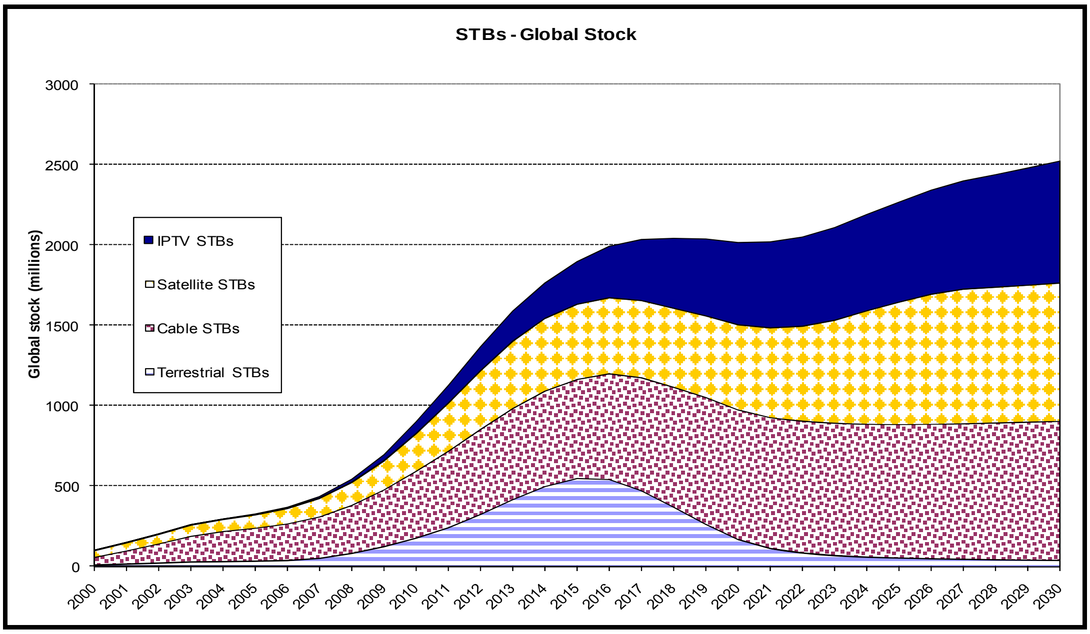

Figure 1: The projected growth in the stock of set top boxes to 2030.

Figure 1 shows the dramatic growth in the global stock of various STB platforms as subscription services develop and the developing world gains better access to TV services. [1] Free to air STB show an increase between 2010 and 2030 due to their use as converters of FTA digital signals with existing analog televisions. Of the other categories of STBs IP TV types are expected to establish a significant position in the provision of TV services.

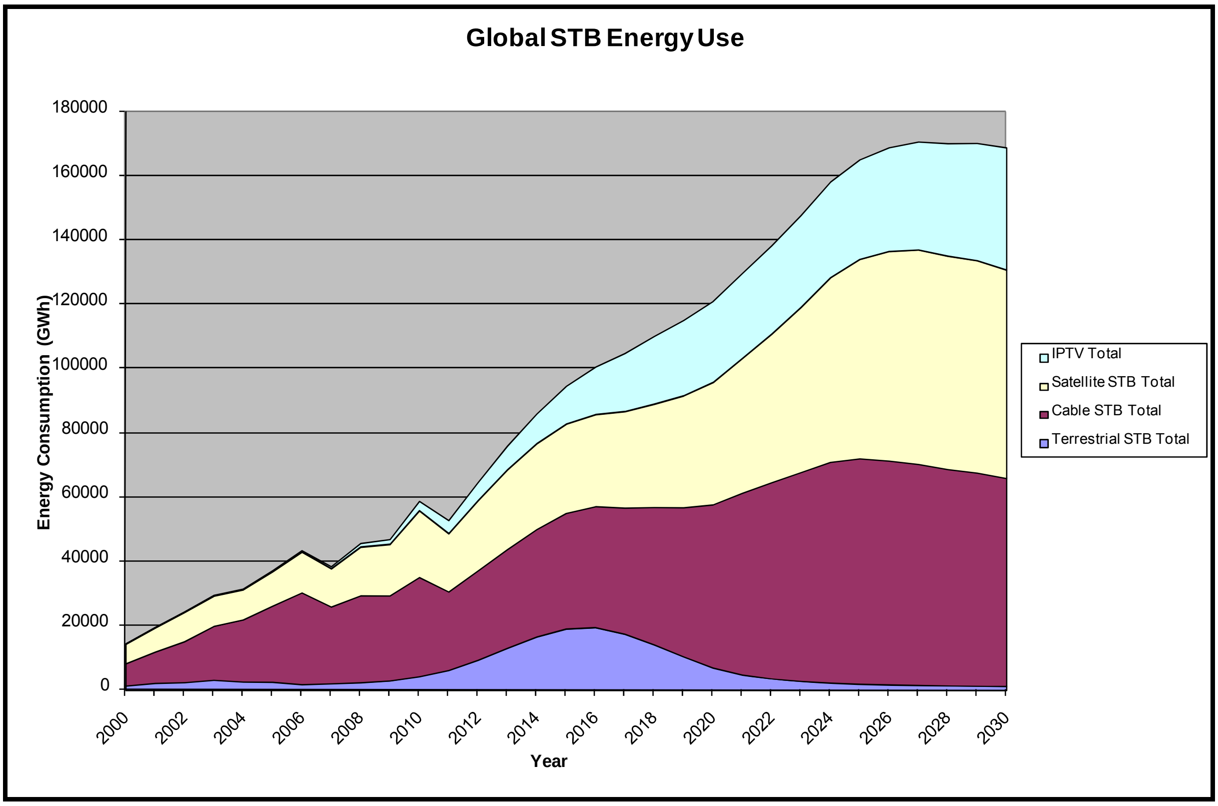

Figure 2: The projected growth in the energy use of set top boxes to 2030.

Figure 2 shows the increased energy consumption that is forecast as a result of the increase of STB stock world wide.[2]

Given the dramatic increase in STB stock and the impact this will have on energy consumption it seems clear that there is a need to develop a uniform energy measuring standard for STBs that can be adopted as the method for the existing and emerging energy programs around the world.

Support for Various Energy Efficiency Programs Around the World

Energy efficiency programs have been and are continuing to be developed in various regions around the world.

With a consistent method of STB power measurement it will also be possible to compare and contrast the effectiveness and progress of existing programs which will allow effective improvements of existing programs and the introduction of new programs based on best evidence.

Types of STBs

In the last few years the type and nature of STBs have changed considerably. STBs were originally analog TV receivers connected predominately to cable and/or satellite subscription services. With the introduction of digital television services over the last several years STBs have evolved into product

[1] Modelled by Digital CEnergy from information available in 2008.

[2] Also Modelled by Digital CEnergy from information available in 2008

varying from the basic provision of pictures and sound to STBs that can receive services from multiple platforms including broadband. Many STBs have hard disk drives for recording and later playback of programmes or so that functions such as review, fast forward and pause can be used (so called time slipping).

A further class of digital receivers are emerging that have removable media such as DVDs or Blue Ray drives. It is anticipated that STBs with removable solid sate storage will also emerge shortly.

Operating Platforms and their relationship to Power Consumption

It is not only STBs that have developed over the last short while. The delivery platforms have also developed to provide users of STBs with more elaborate services and the operators of these services with improved security to protect against unauthorized use of the services. In addition free to air terrestrial analog services have been consistently converted to digital services over the last 10 or do years.

As this development has progressed it has become apparent that the platform in which the STB is operating may have a profound effect on the power consumption of the STB. Terrestrial free to air environments have the lowest propensity to cause STB to consume more power in standby modes as for the most part they do not require regular updating of conditional access keys so STBs operating in these environments are able to switch into passive standby modes requiring little power consumption while in this mode. Specifications now exist that require FTA STBs operating in passive modes consume less than 2 watts.[3]

Often, however, even STBs in a free to air terrestrial environment require conditional access this is particularly true where services are on the boarders between two countries and there is a requirement not to allow the broadcasts from one country to be received in the adjoining country. Free to air terrestrial services have also developed to offer new features within services such as electronic programme guides. In such cases these guides need to be downloaded at regular intervals to ensure the information the STB is up to date. This often means that the STB must cycle through differing power modes to ensure that this updating occurs.

STBs used in a subscription environment not only require STBs to potentially receive electronic programme guides but also conditional access keys to maintain the integrity of the security system to protect from unauthorized use.

All these features and functions affect the operating modes and power consumption of STBs. To ensure appropriate assessment of the power consumption of STBs a power measurement method must be able to measure the power consumed in all the operational circumstances for an STB.

Review of existing STB Measuring Methods

IEC 62087 Ed 2 2008

EC 62087 Ed 2 2008 contains a measuring method for STBs in section 8. This section was written for STBs that were used on, predominately, analog cable and satellite based delivery platforms. Many of these platforms have either been superseded by digital delivery systems or are rapidly being so. In addition the conversion to digital television on terrestrial platforms, that is occurring in many countries around the world, is causing demand for STBs to increase at a rapid pace. Associated with the increased demand is the increased complexity and type of STBs.

EPA Energy Star Method of measurement

The EPA's energy star measurement method was derived from a number of other sources such as the CEA method and earlier versions of IEC 62087. The method is designed to factor in actual use of the STBs under test by cycling through many different operating conditions. For this reason it requires a large number of operating modes to be described and defined.

[3] AS/NZS 62087.2.1 2009, Available from SAI Global, Sydney Australia

European Code of Conduct and Voluntary Agreement Method of Measurement.

This measurement method is also based on trying to simulate real use of current STBs. STBs with multiple tuners and recording media are covered by this method. The method covers many of the pertinent issues of STB energy measurement. It is centered around the TEC approach of the CoC and Voluntary Agreement and as such is quite specific in its measurement approach.

CEA 2022

This method has at its core the notion that STB power consumption is very much a function of the mode in which it is operating. CEA 2022 is focused solely on the “On” mode power consumption but distinguished “On” mode consumption into primary and secondary modes of operation.

Comments

All the existing methods have elements that are useful in STB power measurement. All, however, address the needs of specific programmes which reduces their usefulness as an international standard. For this reason the IEC committee TC100 decided to start a project to revise IEC 62087 Ed 2 2008 to make it relevant to current STB technology and useful as a measuring method to existing and developing STB energy use programmes.

It is interesting, however, to compare the similarities of each method with the CD version of the revision of IEC 62087 which is which is demonstrated Table 1. The table shows that there is similarity in many of the items covered by the differing methods and where there are differences they are relatively minor.

One difference of note is that of the number of operating modes used in the Energy Star method as opposed to the other methods. This is an important issue and is discussed further in the next section of this paper.

Modes of operation for STBs

General.

An inescapable complexity for STB power measurement is the number of operating modes that need to be measured.

STBs perform an ever increasing number of functions through an increasing number of features. This means that measurement of energy consumption for STBs is not an simple matter. It is clear that a number of operating modes are required for STBs. IEC 62087 Ed2 defines many differing operating modes for Audio Video equipment. The EU CoC method and the CEA 2022 methods also require measurement of a number of power consumption modes. The deliberation of the IEC working group identified that for IEC 62087 Ed 2 2008, a number of the modes that were already defined were suitable for STBs. This include the mode created for TVs a short while ago called On (Average)..However it was also clear that a number of modes would need to be created to adequately provide power measurements for STBs.

Proposed IEC 62087 CD operating modes

Table 2 shows the operating modes currently adopted for the CD version of IEC 62087.

It was decided that On (Average) would be used for the basic On mode for a STB. New modes were proposed to cover the STBs operation for the following situations:

1. The STB is providing video and audio but is also recording another service.
2. The STB is providing Multifunction operation

Apart from for the On modes described above STBs also need Active standby modes. To ensure that there was not a proliferation of other modes the standby modes covered in Table were adopted.

Table 1: Comparison of Energy Star, CoC, CEA2022 and IEC 62087 CD energy measurement methods for STBs.

Criteria	ENERGY STAR	IEC 62087 CD	CEA 2022	CoC
Ambient Temperature	23°C	18°C ~ 28°C	18°C ~ 26°C	18°C ~ 28°C
Air speed need unit under test				≤ 0.5m/s
Supply Voltage	115V ±1%	230V ±2%	230V ±10V	230V ±1%
Supply Frequency	60Hz ±1%	50Hz ±2%	50Hz ±3Hz	50Hz ±1%
Total Harmonic Distortion (Voltage)	≤ 2%	≤ 5%	≤ 3%	≤ 2%
Power Measurement Device				
Units of measurement	Watt	Watt	Watt	Watt
Crest Factor			1.4 ~ 8	1.34 ~ 1.49
Minimum resolution (on 1W measurement)	≥0.01W	≥0.01W	0.1W	≥0.01W
Minimum resolution (< 10W measurement)	≥0.01W	≥0.01W	0.1W	≥1W
Minimum resolution (>10W ~ 100W measurement)	≥0.1W	≥0.1W	0.1W	≥1W
Minimum resolution (> 100W measurement)	≥1W	≥1W	0.1W	
Uncertainty (power ≥ 0.5W)		≤ 2% @ 95% Confidence		≤ 2% @ 95% Confidence
Uncertainty (power < 0.5W)		≤ 0.01W @ 95% Confidence		≤ 0.01W @ 95% Confidence
Measurement Procedure				
Set up	All normal connections	All normal connections	All normal connections	Live stream or pre-recorded
Antenna/LNB power	Subtract Antenna/LNB power	Without Connection or with the Antenna LNB power consumption subtracted	Subtract Antenna/LNB power	
USB attachments	Only those needed for operation covered by test		Subtract USB power	
Stabilisation	≥15 minutes warm-up	≥15 minutes warm-up	"Allow to stabilize"	Maximum 30 minutes
Normal SD non-PVR	Average power measurement or average over x minutes	Instantaneous power measurement or average over x minutes		Average over 10 minutes
Normal HD non-PVR				Average HD & SD over 20 minutes

Criteria	ENERGY STAR	IEC 62087 CD	CEA 2022	CoC
Normal SD PVR	where x is specified in the TP			Average over 20 minutes
Normal HD PVR				Average HD & SD over 20 minutes
Input Signals				
Analogue terrestrial input terminal	Standards Compliant for Quality	70dB(μV)		
Cable television input terminal	Standards Compliant for Quality	60dB(μV)		
Digital terrestrial input terminal	Standards Compliant for Quality	60dB(μV)		
Satellite input terminal	Standards Compliant for Quality	60dB(μV)		
Broadband Input Signal	Standards Compliant for Quality	"Appropriate signal"		
Video Test Signal	Standards Compliant for Quality	STB's highest resolution signal		
Audio Test Signal	Standards Compliant for Quality	Signal to all normal STB outputs		
MPEG-2 data rate SD				≥5GB
MPEG-2 data rate HD				≥17GB
Operating Modes				
On (Average)	Normal viewing	Normal viewing	Normal viewing	
On (Play)	Playback (buffered if DVR)	Playback	Playback	
On (Multifunction)	Live TV (Buffered if DVR) + recording on Multiple Tuner Only	Playback + recording	Playback + recording	
On (Download)		Downloading firmware, EPG etc	Downloading firmware, EPG etc	

Criteria	ENERGY STAR	IEC 62087 CD	CEA 2022	CoC
On (Record)	Recording live only but actual record operation, and not buffering.	Recording only	Recording only	
Standby Mode	Off - using standby	Off - using standby	Off - using standby	Off - using standby
Off Mode		Off - using mains switch	Off - using mains switch	
Auto Power Down	Measure after x min			Measure after 30 min
On SD	Normal viewing			Normal viewing
On HD	Normal viewing			Normal viewing
ON SD PVR	Buffered Playback			Playback + recording
ON HD PVR	Buffered Playback			Playback + recording
Record SD	Recording only			Recording only
Record HD	Recording only			Recording only

The rows in Table 2 coloured blue were the new power mode definitions created to adequately cover the power measurement of STBs.

Consideration of "On", "Active" and "Standby" Modes and Harmonisation with other standards.

As discussed above .STBs are designed to work in a number of power modes and each of these modes must be able to be measured. A number of standards exist that characterize the operating modes of equipment. The development of a measuring standard for STBs is further complicated by the need to ensure that the STB measuring method is consistent with the other standards. The other standards that need to be considered in the STB measurement work are IEC 62310 and IEC 62542.

The work that has been done for STBs in IEC62087 Ed 2 has attempted to harmonize as far as possible with IEC 62301 Ed 2 and IEC62542 Ed 1.

Table 2: The table of operating modes in IEC 62087 Ed 2.

Mode	TV	Video recording equipment (e.g. VCR)	STB	Audio equipment
Disconnected	The appliance is disconnected from all external power sources	The appliance is disconnected from all external power sources	The appliance is disconnected from all external power sources	The appliance is disconnected from all external power sources
Off	The appliance is connected to a power source, produces neither sound nor picture and cannot be switched into any other mode with the remote control unit, an external or internal signal	The appliance is connected to a power source, does not perform any mechanical function (e.g. playing, recording) and cannot be switched into any other mode with the remote control unit, an external or internal signal	The appliance is connected to a power source, fulfils no function and cannot be switched into any other mode with the remote control unit, an external or internal signal	The appliance is connected to a power source, does neither produce sound nor performs any mechanical function (e.g. playing, recording) and cannot be switched into any other mode with the remote control unit, an external or internal signal
Standby-passive	The appliance is connected to a power source, produces neither sound nor picture but can be switched into another mode with the remote control unit or an internal signal	The appliance is connected to a power source, does not perform any mechanical function (e.g. playing, recording), does not produce video or audio output signals but can be switched into another mode with the remote control unit or an internal signal	The appliance is connected to a power source, does not fulfil the main function and can only be switched into another mode with the remote control unit or an internal signal	The appliance is connected to a power source, produces neither sound nor performs any mechanical function (e.g. playing, recording) but can be switched into another mode with the remote control unit or an internal signal
Standby-active, low	and can additionally be switched into another mode with an external signal	and can additionally be switched into another mode with an external signal	and can additionally be switched into another mode with an external signal	and can additionally be switched into another mode with an external signal
Standby-active, high	and is exchanging/ receiving data with/from an external source	and is exchanging/ receiving data with/from an external source	and is exchanging/ receiving data with/from an external source or is performing any functions other than its main function	and is exchanging/ receiving data with/from an external source

Mode	TV	Video recording equipment (e.g. VCR)	STB	Audio equipment
On (play)	The appliance is connected to a power source and produces sound and picture. This mode is maintained for backward compatibility.	The appliance is connected to a power source and plays the tape or disc inside the appliance	The appliance is connected to a power source and is playing back a previously recorded programme	The appliance is connected to a power source and is performing one or more of the following modes: produce sound, wake-up signal, or play a tape or disc
On (average)	The appliance is connected to a power source and produces sound and picture		The STB is performing the function of providing a viewer with video and audio from a broadcast. Which may or may not be providing time shifting functions.	
On (record)		The appliance is connected to a power source and records a signal from an external or internal source	The appliance is connected to a power source and records a signal from an external or internal source and is providing its main function.	The appliance is connected to a power source and records a signal from an external or internal source
On (Multifunction)			The appliance is performing multiple functions simultaneously	

NOTE The definitions give essential but not exhaustive descriptions of each mode.

Not all equipment can be switched in each mode.

Video Cassette Recorders and STBs normally provide RF feed-through in standby and active modes; sometimes this feed-through is maintained in the off-mode.

The terms "internal" and "external" as used in this table refer to the appliance as it is delivered to the user.

One area that at the time of writing this paper has not been completely resolved is that of Standby Active. In both IEC 62301 and IEC 62542 On modes and Active modes are treated the same. It may be that consensus to follow that convention may be reached during the comment phases as the new draft IEC62087 moves through the normal standards adopting process.

User controlled functions and their likely impact on STB Power Consumption

During the development of the new STB measuring method discussion took place on whether the user function controls shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**Figure 3. Need to be covered as part of the measurement of each mode.

Figure 3: User Control Functions associated with recording and time shifting on STBs

Some standards such as the EPA's Energy Star program require measurement of the STBs power through a process of activation designed to mirror actual use. After some deliberation and analysis it was determined that it was not likely that activation of such controls would significantly affect power consumption. For this reason and to avoid a proliferation of new power modes which in turn would lead to increased complexity of testing the new method does not require measurement in these user controlled functions.

A review of the draft measuring Method.

Measurement of power vs energy programme metrics

An important aim of the new method was to avoid any requirements other than power measurement. Reference to any factors involved in specifying energy use metrics has been avoided. What is specified is how to measure the power consumption in each of the defined operating modes. It is left to the differing regulators and energy use programme developers to specify how these measurements are then used to determine their programmes energy use.

Real World use of STBs

The new measuring method is predicated on measuring the power consumption of a STB in as real world environment as possible. Section 8.2.1 of the committee draft says;

"In general terms input signals should be of type, strength and quality for the type of platform that the STB is intended to be used on. Where a STB is a multi platform it should be tested for each platform in which it operates. Each measured result shall be described in the report. In some circumstances the dynamic broadcast-content video may be suitable for use as the video and audio test signal content but will need to be multiplexed and modulated as per clause 8.2.2 below"

And in 8.5.2.1

All inputs and outputs should be connected in a manner to simulate a normal operating environment. The inputs to the STBs can be either live signals provided by service providers or generated test streams that simulate the live services that the STBs are designed to receive and decode. The appropriate choice would be dictated by the end user of the specification based on desired outcome.

Where an LNB or antenna amplifier power supply is provided, the measurement should be made without that device included in the power consumption measurements. Accordingly, the LNB or antenna amplifier should either be: (1) powered from a source other than the STB, or (2) it'spower consumption can be subtracted from the measured power consumption of the unit under test. The test report shall indicate which method was used for the power measurement.

Both of these clauses are establishing the notion that the most appropriate way to test the STB is as close as possible to how it is actually used. This is a similar notion to that created for TV power measurement covered in Section 11 of the same document.

In addition it is desirable to have readably available test signals that are either real life signals or are as close to real life as possible in order to ensure that the STB is tested appropriately. This is covered in clause 8.2.2.1 of the committee draft which says;

"The STB should be tested using input signals at the highest resolution that the STB is capable of decoding using the most advanced decoding standard that the STB can decode. For example, an STB capable of decoding H264 transport streams at 1080i formats requires an input signal conforming to this requirement.

If the STB under test is an HD decoder, testing may also be conducted with an SD input signal

Where the STB is operating in a download or recording mode the input should contain content that simulates the material being downloaded or recorded.

Where a STB has conditional access activated, the test signal should either be un encrypted and free of conditional access keys or should be suitable to pass through the conditional access requirements. In the case that no other source is available, the STB should be tested with a signal that is available from the service provider that supports the STB.

Where an STB can record other services than the one being watched the test signal should contain sufficient services to enable this feature to be tested."

Power Consumption Modes

The following list is a summary of the power measurements that are described in the new method.

Table 3: Summary of the operating modes of STBs.

Power Mode Category	Mode Name	Mode Description	Mode Numonic
On	On (average) Non Time Shifted	On but no time shifted recording function	P_{AV_NTS}
	On (average) Time Shifted	On with time shifted recording function	P_{AV_TS}
	On (Play)	On and playing back a recorded program	P_{PL}
	On (Mulifunction) Single tuner	On and playing back a program while recording another through a single tuner.	P_{MF}
	On (Mulifunction) Multi tuner	On and playing back or showing a program while recording another through multiple tuners	P_{MF2+_AV} P_{MF2+_PL}
Standby	Active High General	Downloading CA keys of Programme Guides	$P_{SAH\_D.}$
	Active High Record	Downloading onto recording media	$P_{SAH\_R.}$
	Active Low	Waiting for a network signal to switch into another mode	P_{SAL}.
	Passive	Can only be switched on via a remote control signal or internal signal	P_{SP}
Off	Off	No Power connected	P_{OFF}

Much work has been done to ensure that the new method covers all the likely power modes that are likely to be used by STBs in practice. In all 11 measurements are described which it is thought to cover all the modes that a STB may be operating in. In practice any specific program may not actually require all these modes to be measured and not all STBs will have all these modes.

The project plan and progress.

Figure shows the project plan agreed to and the progress to date. The project is currently slightly late in that it was originally hoped that the CD would be available after the Sao Paolo in November 2008 meeting but was not available until the middle of March 2009. It is hoped that the project will progress on schedule for the remaining time and be completed for publication in the middle of 2010.

The work to date includes 4 face to face meetings in Bangkok, Paris, Sao Paolo and :Las Vegas and a 6 WEB based meetings between November 2008 and February 2009.

The closing date for comments on the CD is mid June 2009. It is hoped that comments will be dealt with quickly and effectively so that the document can move onto the Committee Draft for Voting (CDV) stage and from there to publication in the first half of 2010.

Conclusions

This paper has presented the work that has been undertaken by TA1_STBpower the working group established to create a new STB power measurement method for STBs as a result of the decision of IEC committee TC 100 to review IEC 62087 Ed 2 2008.

At the heart of this work is the desire to have an international method that is relevant to current STB technology and could be used to support the measurements that need to be done by existing and developing STB energy use programmes.

The working group has produced a committee draft (CD) that has produced a measurement method that is designed to;

1. Harmonize with existing methods
2. Measure STB power under real use conditions
3. Use as close as possible normal STB use signals
4. Measure any of the possible operating modes that STBs use.

The current status of the work is at CD stage and the comment period will finish in mid June 2009. It is expected that the comments received will result in changes to the draft that will further strengthen the draft.

Operating modes will remain an important issue and further work is expected to ensure appropriate consideration and harmonization with other standards.

The final publication of the new edition of IEC62087 is expected in the first half on 2010.

References

[1] International Electrotechnical Commission. IEC 62087 Ed2 2008 *Power Measurements of Audio Video equipment.*

[2] International Electrotechnical Commission. AS/NZS 62087.2.1 2009 *Power Measurements of Audio Video equipment.- MEPS requirements for STBs.*

[3] Consumer Electronics Association of America. CEA 2022 *Digital STB active power consumption Measurements*, July 2007.

[4] *ENERGY STAR® Program Requirements for Cable, Satellite, and Telecom Service Providers* 2008.

[5] *Code of Conduct on Energy Efficiency of Digital TV Service Systems* Version 8 Draft 2 January 2009.

Information and Communications Technology (ICT)

Energy Consumption for Information and Communication Technologies in German households – present state and future trends

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Abstract

In recent years, the importance of information and communication technologies in every day's life increased strongly. According to a recent study for Germany on behalf of the Federal Ministry of Economics and Technology, the present electricity consumption for information and communication technologies in German households denotes a share of almost a quarter of total electricity consumption in the residential sector. And about half of this consumption is caused by televisions and side-equipment like set-top-boxes and DVDs. In the years to come, a further increase in energy demand for these purposes is expected, especially because of the ongoing trend to larger screen sizes. Other drivers for this increase are the development towards an “always-on” connectivity as well as the change in using patterns of the internet like “triple play”. This will require new combinations of equipment and also interrelate with an increase of both, household as well as general communication infrastructure.

Introduction

The term information or knowledge society describes the penetration of all economic and other areas of life with information and communications technologies (ICT). Alongside the growth in the stock of ICT appliances, new applications and services are constantly being introduced to the market. On top of this, the fixed boundaries between voice, video and data communications are starting to blur and with them also the boundary between consumer electronics and ICT. This convergence of ICT services is described by network and media suppliers under the marketing term "Triple Play Services". This results in demands for the provision of more broadband services both for network access and for fixed lines as well as greater compatibility requirements of end-use appliances. There is a basic trend towards increased computing and memory requirements. These combined developments cause an increase to start with in the energy demand for ICT applications. On the other hand, technology dynamics, which still adheres to Moore's Law, produces a large potential for energy saving which is being discussed under the heading "Green IT". There is a need to reconcile these two developments. Against the background of sustainable development being based on a balanced use of resources, ICT should be used with the goal of energy and resource conservation and, at the same time, should be designed to be energy- and resource-efficient in the sense of Green IT.

The most important share of energy consumption for ICTs in Germany falls to end-use appliances in private households. This was shown in three studies which have been conducted on the investigation of energy consumption for ICTs in Germany during the last years [1] [2] [3]. All studies were carried out on behalf of the Federal Ministry of Economics and Technology and were based on a comparable method.

The main focus of this paper is on the results of the last-named investigation [3] and includes:

- an inventory of ICT-related electricity consumption in German households for the reference year 2007 and a comparison with results for earlier years,
- identifying and analyzing the main trends influencing the future development of energy demand for ICTs in private households and
- based on this, a forecast of the energy demand for domestic ICT consumption in the medium term up to 2020

Method

The term ICT was coined in the context of the digitalisation of telecommunications and computer science. In reality, however, there are hardly any clear boundaries left here because of the fast pace of technology and market development. The spectrum of appliances is increasing on the one hand and blending on the other due to a convergence of functionalities and services. This has become possible technically due to the digitalisation of information based on the increasing miniaturisation of electronic, optical and mechanical systems.

Total energy consumption for information and communication technology in a country not only includes the energy demand of end-use appliances, as e.g. TVs and PCs, but also the related energy consumption for data centres and network access and core network both for mobile communication and fixed line. Whereas the energy consumption for end-use appliances can be clearly assigned to private households on the one hand and private and public companies on the other hand, this assignment is not possible for data centres and networks. Though this paper focus on energy consumption of end-use appliances in private households, it has to be taken in mind that this does not reflect total ICT consumption of this sector, but that parts of the energy consumption for data centres and networks have to be added.

In order to capture the wide variety of applications and products belonging to the ICT domain as fully as possible, the ICT end-use appliances in private households were differentiated according to the main functions of data processing, entertainment, and communication, data processing and subdivided into the following five groups:

(1) *Computers and peripherals*: desktop PC, home server, notebook, monitor, printer, scanner.
(2) *Portable devices*: mobile phone, PDA, gameport, digital camera, camcorder.
(3) *Television and peripherals*: television by four groups of screen size, set-top-boxes (STBs), video recorder, DVD player/recorder, game console.
(4) *Audio devices*: radio/CD/tape recorder, hifi system
(5) T*elephones*: cordless phone (DECT), fax machine, router

A computational model is used to determine the current and future electricity consumption for ICT applications in private households which includes the following demand-determining components: the stock of appliances for each product, the average power input of the products and applications in the different operating modes[1] and the respective patterns of use (Figure 1).

[1] On or active mode and standby mode, including: networked standby, passive standby and off-mode.

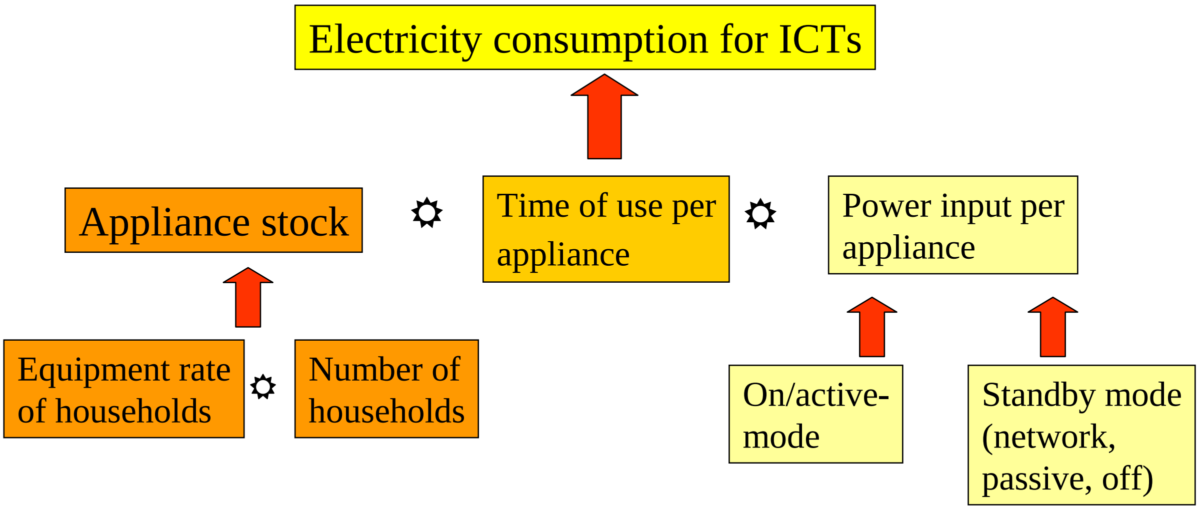
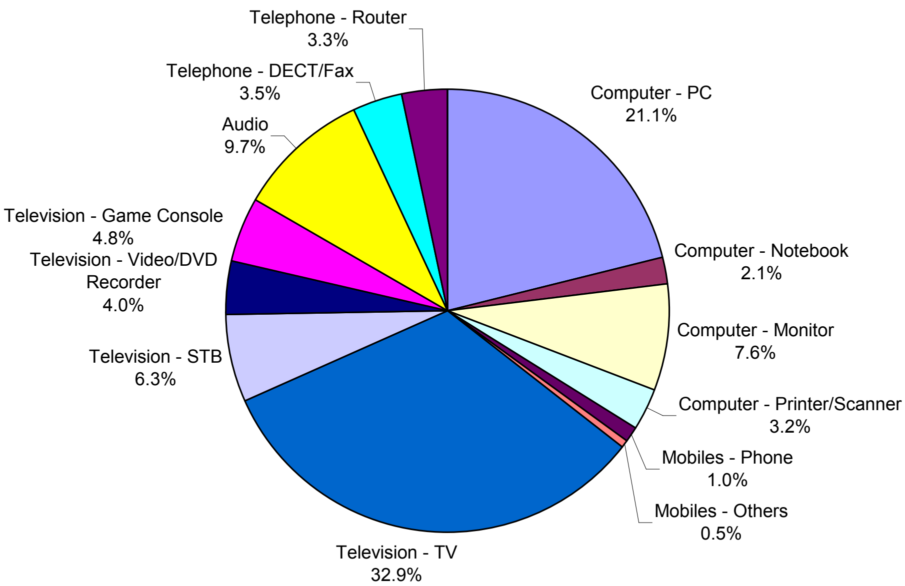


Figure 1. Model to calculate current and future electricity consumption for ICTs in households

Current electricity consumption for ICT end-use appliances

Based on this model, a total electricity consumption of 33 TWh results for ICT end-use appliances in German households for the year 2007. This is equivalent to a share of 23.4 % of total residential electricity consumption in Germany, which amounts to 141 TWh [4]. Figure 2 provides an overview of the composition of ICT-related electricity consumption by type of product.



Total electricity consumption for end-use appliances in households 2007: 33 TWh

Figure 2. Electricity consumption for ICTs in private households by product type 2007

Source: [3]

This is based on the following data and assumptions about demand-determining components of the appliance stock, patterns of use and power input:

- The basis for determining the stock of ICT end-use devices in private households were data on household equipment taken from official statistics, company and sector association statistics as well as from market and opinion research. The stock of appliances was extrapolated using the number of private households (2007: 39.7 million).
- The figures used in the model for the patterns of hours of use and power input in the various operating modes of ICT end-use devices in households are mainly based on the preparatory studies under the Ecodesign directive of the EU (Lot 3 to 7) [2]. The respective assumptions in these studies are based on a very detailed analysis of data sources all over Europe. With regard to the time of use, the assumptions from the Ecodesign studies were partly supplemented with specific national figures for the time of use, when available from German surveys. For televisions, e.g., an average viewing time of 3.5 h/d was assumed [10], which is a little lower than the assumptions in the Ecodesign study on televisions [7].

TV sets are responsible for the largest share of ICT-related electricity consumption by far with about one third or 10.9 TWh (Figure 2). If peripherals, i.e. set-top-boxes and Video/DVD recorder are also included, the electricity consumption for televisions even amounts to about half of total ICT consumption in private households. The other important product group are computers with another share of one third. Among them, the desktop PCs are the most important electricity consumer. Electricity consumption in standby mode, i.e. off-mode losses, passive standby and network standby, is 11.2 TWh/a in private households, which is a share of almost 30 % in total ICT consumption of private households. However, technical modernization and increasing consumer awareness together with legal regulations will contribute to a clear reduction in this share in the medium term. Comparing these results with a study for the U.S. using the same methodological approach [11], the structure of electricity consumption for ICTs is very similar. As in Germany, television sets are the most important electricity consuming IT device in U.S. homes, accounting for 36 % of total ICT electricity consumption in 2006 (Germany 2007: 33 %).

When looking at the development of electricity consumption of the main product groups since 2001, total consumption for ICT end-use devices in the household sector increased from 23 TWh to 33 TWh (Figure 4). The highest increase was observed for computers and peripherals, which is both due to higher equipment rates with PCs, monitors, printers and multifunctional devices and an increasing power demand of desktop PCs. The share of energy consumption for ICTs in total household electricity consumption rose from 17.2 to 23.4 % during that period.

[2] Lot 3: PCs [5]; Lot 4: Imaging Equipment [6]; Lot 5: Television [7]; Lot 6: Standby [8]; Lot 7: Charging devices [9]

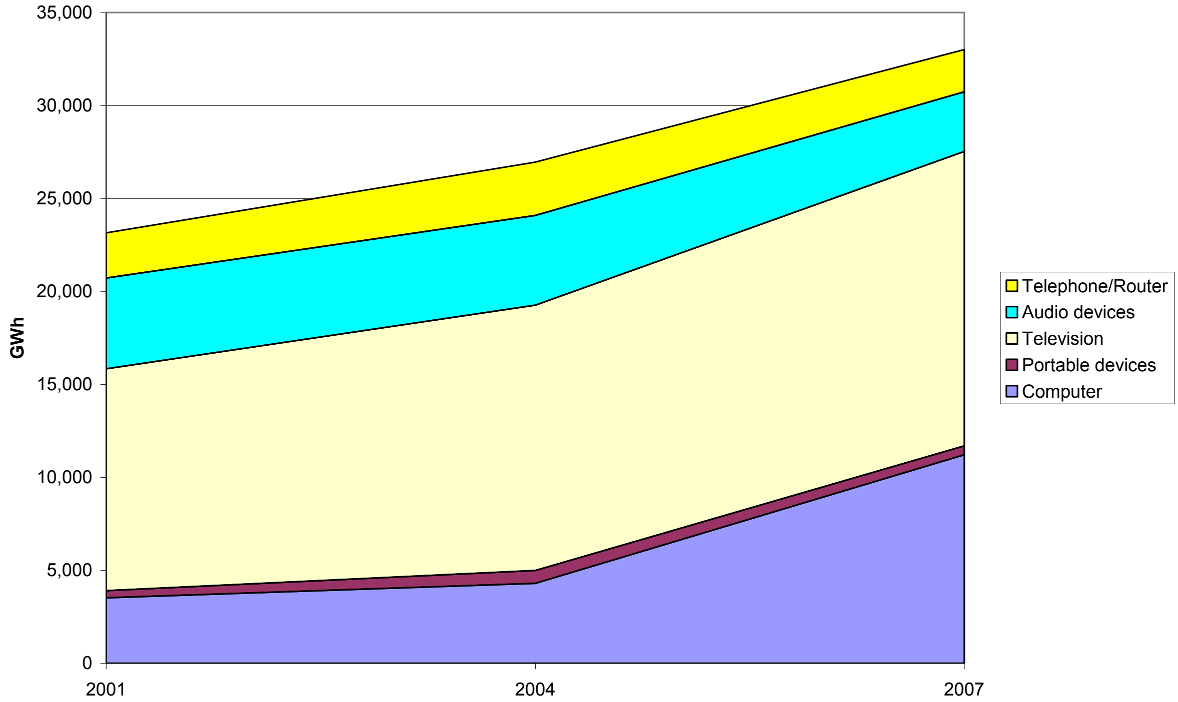


Figure 3. Development of electricity consumption for ICTs in private households between 2001 and 2007

Sources: [1] [2] [3]

The observed consumption growth was only due to an increase of the active mode, whereas energy consumption for standby slightly decreased from 10.4 TWh to 9.5 GWh between 2001 and 2007.

Trends

Long-term or even middle-term forecasts in such a dynamic market environment as the ICT branch are difficult. The development of the ICT sector is not only ruled by the overall macroeconomic situation as much as all other sectors, but a characteristic feature of the ICT branch is the ongoing dynamic evolvement of technology and applications. This includes

- a fast-moving, sometimes parallel technology development,
- an ongoing intrinsic development paradigm in the semiconductor technology,
- a partial hardware-independent software development,
- a high cost share for research and development,
- a strong patent and licence trade with high costs,
- parallel technology standards and long-winded standardisation processes,
- a heterogeneous network infrastructure, especially within access networks,
- an Investment risk for measures concerning the network infrastructure.

As a basis for the forecast of ICT electricity consumption in private households, several important trends were derived from the general characterization of the ICT branch which could have an influence on future electricity consumption. The trend analysis focused on four domains: the possible development of data traffic, ICT applications and content, new computing concepts which could be relevant for private households, and the technical development of components and end-use devices. The following main trends were identified in these areas:

(1) Increasing data traffic through internet video and TV

Industry forecasts a considerable increase of data traffic. According to Cisco [12], 75 % of the data traffic will be caused by private end-users. The main applications are thereby video and TV with more than 65 %. The use of online media centres and the streaming of videos on demand will increase medium term through a range of products on offer. The data volume will also rise because of the increasing image quality, although high definition is in Germany mainly a long-term trend. Data traffic will evolve more symmetric in future, which means that the upload data rate will also increase. Peer-to-peer video communication is pushing this development.

(2) Interactive internet usage and individualised offers

The interactive use of the internet will rise through all-IP and thereby the demand for symmetric bandwidth capacity will increase. One main point is the individualisation of advertisements and information based on online activities of the users. The IP address leaves a trace in the net, which is analysed by software. It has to be seen that with interactive use of the internet such as shopping, user generated platforms (e.g. Wikipedia), video on demand (e.g. YouTube) and video communication (e.g. Skype), the individual use time will increase.

(3) Longer active times of end-user devices

Consequences of the intensified use of the internet are longer active times of PCs and monitors and a constant network standby of home server. There will also be a shift from small PC monitors to larger TV monitors for the data output. Because these devices need more electricity, this development has to be considered. Requirements or this development are video and TV contents with very high image resolution and an adequate broadband access.

(4) Uncertain development of broadband supply and Triple Play Services

The dimension of the increase of data traffic in Germany is directly linked to the expansion of broadband access networks and the configuration of Triple Play Services. Especially in the area of TV, there are shortcomings in the digitalization in Germany. At the moment, there is no nationwide supply of broadband access in Germany. Direct fibre optic connections (FTTX) have the highest potential concerning energy efficiency. They enable a symmetric bandwidth of several hundred Mbit/s and the needed convergence of access and transport networks. The house connection is quite difficult as fibre optics cannot be winded, but have to be laid in big radiuses. Therefore the installation costs are very high. Short-term alternatives in rural areas are VDSL, TV cable, satellite TV and mobile radio. But these technologies are inferior to optical networks in long term.

(5) Private Thin Clients ambivalent

In companies and public authorities, Thin Clients become more and more an alternative to full-appointed workstations. This trend is pushed by increasing electricity prices and potential energy (cost) savings with Thin Clients. Private Thin Client concepts, which mean that most of the data storage and computing power is realised outside the household over the internet, are discussed more ambivalently. Ideally these energy savings can also be reached in households, but data security and availability is here a crucial element, but the biggest obstacle seems to be the missing confidence in the data privacy protection. Private Thin Client concepts seem therefore more a long-term development. In Mid-term, hybrid server and storage systems for households have a higher potential. Home server and from internet decoupled (storage) server could achieve acceptance in households because of cost-efficient CPUs and storage performance. But also hybrid systems with partially data storage over the internet and a shift of (computing) services “into the net” seem possible. In this case the client-server concept would be replaced by peer-to-peer (P2P) concepts.

(6) Energy efficiency of electronic components and end-user devices increases

The energy efficiency of electronic components such as CPU, graphic cards, storage systems, displays and power supplies increases step by step. These progresses are achieved by a continuous miniaturization, new materials and heterogeneous system integration. This trend supports the successive modernization of the technical equipment in the private and commercial sector. When regarding such a strategy, also the resource consumption over the whole life cycle has to be considered. Energy savings through efficiency gains have to be accumulated over longer periods otherwise they will be overcompensated by a higher use of resources. European minimum requirements and energy efficiency labels for electrical appliances will in mid-term enhance the energy efficiency level of the ICT branch. The German EBPG[3] implements the Energy-using Products

[3] German EBPG online: http://bundesrecht.juris.de/bundesrecht/ebpg/gesamt.pdf

(EuP) framework directive (2005/32/EG[4]) of the European Union (enacted in June 2005) in Germany. The law aims on energy-using mass products, which environmental aspects can be improved especially in the field of power consumption, materials and hazardous waste.

Forecast

To start with, a **reference forecast** was made for the development of electricity demand for ICT applications up to 2020 in Germany. This was done based on the comprehensive analysis of trends. For this reference forecast, a business-as-usual scenario was assumed, although this did take into account foreseeable technical improvements for certain product groups. The forecast follows the same model used to calculate the present state (Figure 2). This means that assumptions had to be made about the future development of the stock, the power input in the different operating modes and the typical future patterns of use for the individual product groups distinguished here. In addition, a "Green IT scenario" was compiled in which substantial technical improvements are assumed in the energy efficiency of devices and installations (Best Practice), while the assumptions on stock and patterns of use remain unchanged compared to the reference scenario.

As an overall result, the ICT-related electricity consumption of private households will continue to grow in the future. By 2020, an increase of almost 25 % is expected from 33 TWh in 2007 to almost 40 TWh. This growth is mainly in televisions and computers, while the remaining product groups show stagnating consumption to a large extent (Figure 4).

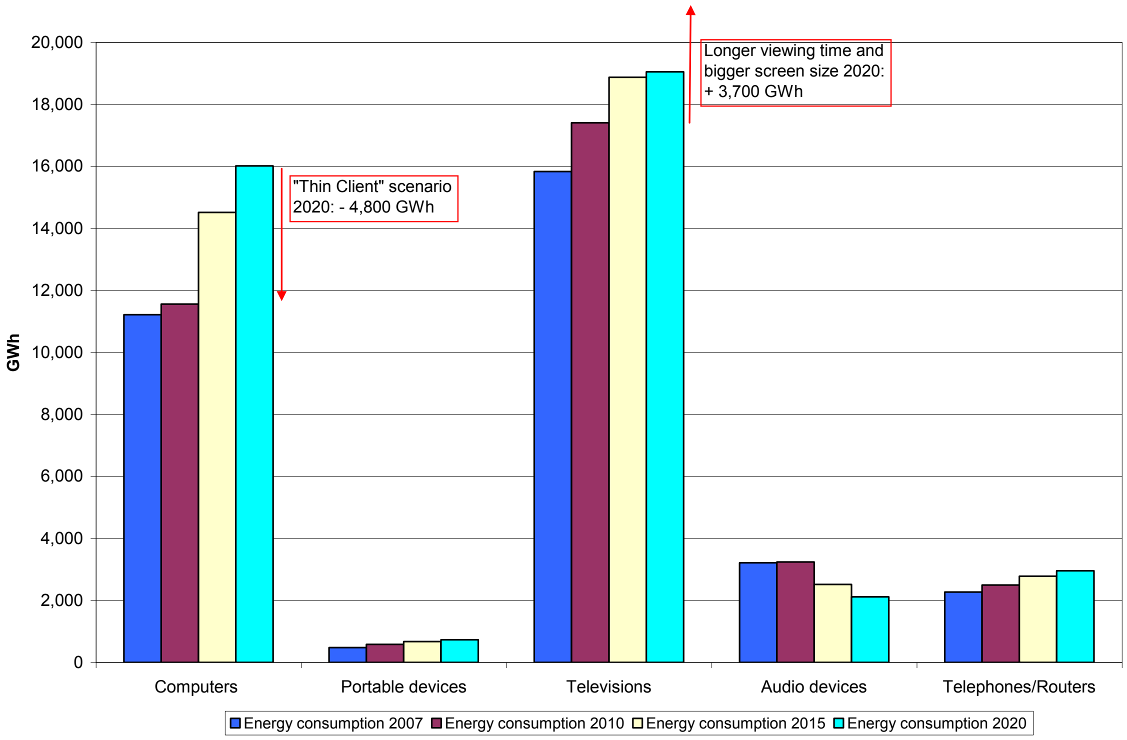


Figure 4. Forecast of electricity consumption for ICTs in private households by product groups

Source: [3]

The expected increase in electricity consumption for **televisions** and peripherals in the reference scenario amount to 3.2 TWh (from 15.8 to 19 TWh) until 2020. The main reasons are the expected shift to considerably bigger screen sizes and an increasing electricity consumption of set-top-boxes due to a considerable increase in the stock because of the digitalization of TV in Germany (Figure 5). Here, especially an increase in cable boxes is assumed, but the final choice of the technology is not important for the consumption increase, since the average power input of the set-top-boxes will not

[4] Framework Directive 2005/32/EG from July, 6th 2005 establishing a framework for the setting of ecodesign requirements for energy-using products:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0058:EN:PDF

vary a lot between the technologies. The two most important influencing factors on future electricity consumption of televisions are the screen size and the time of use. Whereas in the reference scenario, a considerable shift to bigger screens was already taken into account, only a moderate increase in the average time of use from 3.6 h/day to 4 h/day was assumed. In order to show the influence of these two factors, an additional TV scenario was calculated including both an even stronger shift to large screen sizes and a higher viewing time of 5 h/day until 2020. Compared to the reference case, an additional consumption of 3.7 TWh results from the additional TV scenario in 2020, of which 2.3 TWh are attributable to the longer time of use and 1.2 TWh to a further increase in the average screen size (Figure 4).

For **computers** and peripherals, the expected increase in electricity consumption until 2020 is even higher than for televisions, amounting to 4.8 TWh (from 11.2 to 16 TWh). This is a continuation of the rising trend in the past (Figure 3). The main areas of growth are desktop PCs, home servers and notebooks (Figure 6). A further rising stock, longer using times as well as an increasing power input due to higher design and performance requirements contribute to this development. A possible saving option, which is, however, discussed ambivalently, is a further spread of "Thin Client" concepts in private households. However, data security and availability is here a crucial element, but the biggest obstacle seems to be the missing confidence in the data privacy protection. Nevertheless, an additional scenario was calculated in order to show the possible saving options of this new computing concept. A Thin Client concept for private households means that the storage of data is mainly done over the internet on huge external servers, resulting in a reduction of the number of home servers. In addition, most of the computing power is shifted externally, too, so that only "light" PCs consuming less energy are needed in the households. In the scenario, a fast spread of "Thin Clients" in private households is assumed with a share of 50 % in 2020. The resulting energy savings in 2020 compared to the reference case amount to around 4.8 TWh. Though a realisation of this scenario until 2020 is not very likely, it shows the possibilities of energy savings taken into account new usage habits.

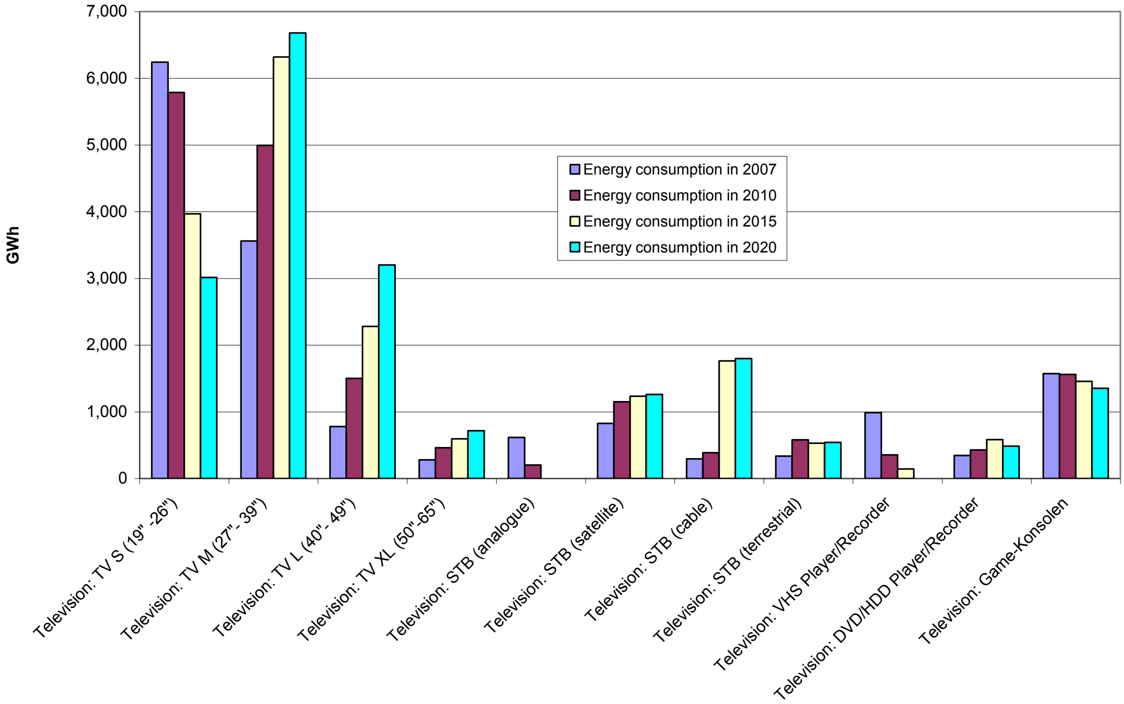


Figure 5. Electricity consumption for televisions and peripherals between 2007 and 2020

Source: [3]

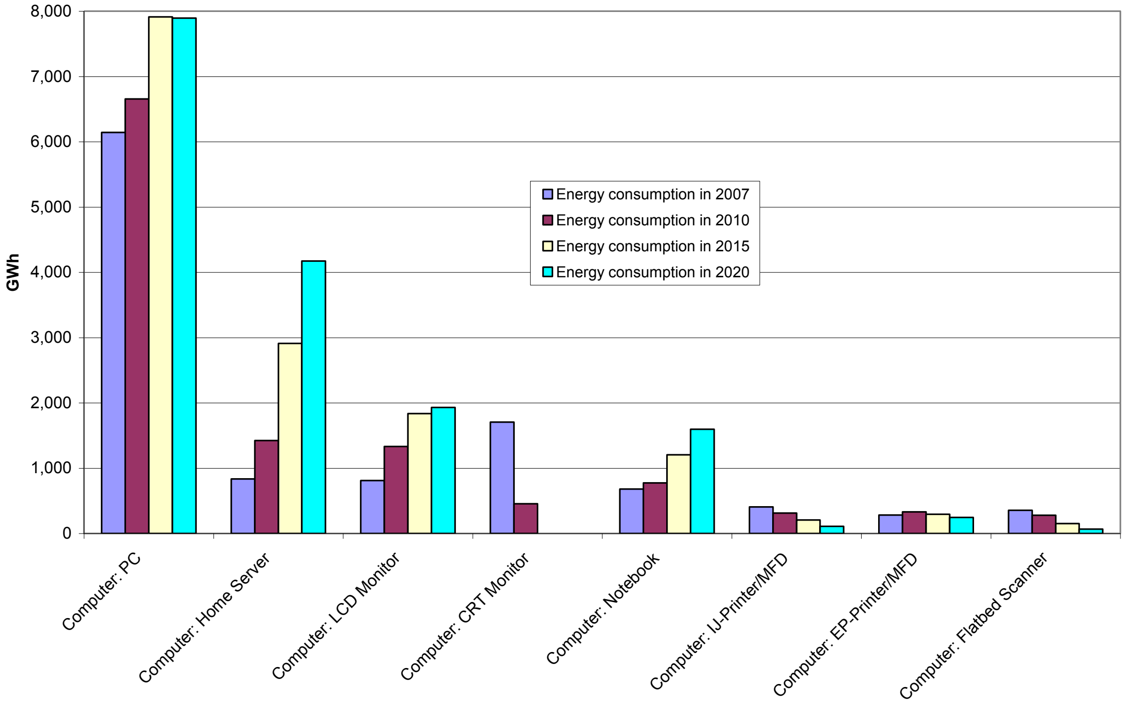


Figure 6. Electricity consumption for computers and peripherals between 2007 and 2020

Source: [3]

If the expected development of power consumption for ICT end-use devices is examined in the reference forecast by operating mode, there will be a disproportionately high increase in active mode electricity consumption by around 47 %, while standby consumption decreases from 9.5 TWh in 2007 to 6.2 TWh in 2020 (Figure 7). This is due to the expected technical efficiency improvements in this operating mode, some of which are autonomous, but some of which are also caused by energy policy measures, primarily at EU level (EuP-Directive). However, the decrease only refers to passive standby and off-mode, which is more than cut by half, whereas electricity consumption for networked standby remains constant.

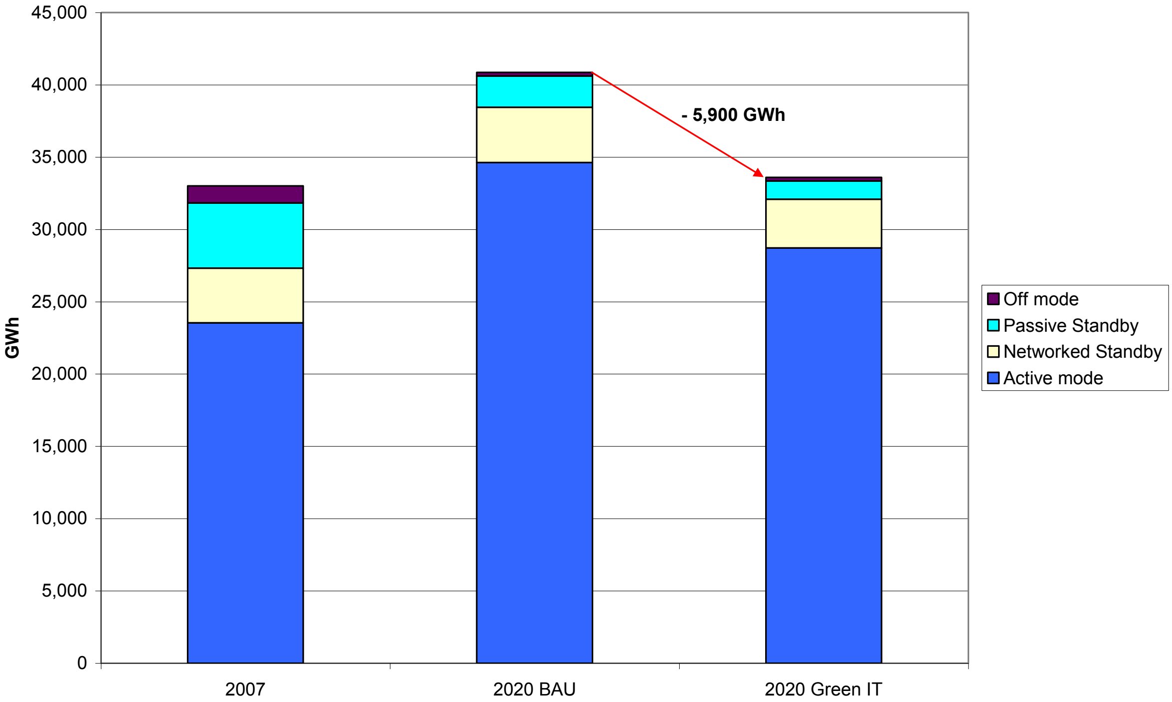


Figure 7. Forecast of electricity consumption for ICT appliances in private households by operating mode

Source: [3]

Besides the reference forecast, which assumes a probable development concerning the power consumption of devices and installations under current energy policy conditions at national and EU level as well as considering autonomous technical change, a **Green IT Scenario** was also calculated. This was done to highlight additional saving potentials which exist technically, but are not necessarily being exploited under current framework conditions. The assumptions about power consumption in the Green IT Scenario are oriented on best practice examples for end-use devices and systems engineering. The efficiency improvements concern the following areas:

- Technical optimization of appliances: larger and faster reduction in power consumption in (network) standby and off-mode than in the reference scenario; greater market penetration of energy-efficient electronic components (displays, processors).
- New utilization forms and patterns: "hybrid" thin clients in private households.

Due to the assumptions about reduced power consumption in the Green IT scenario, the ICT-related electricity consumption in private households in Germany is reduced by 7.3 TWh/a in 2020 compared to the reference scenario (from 40.1 TWh to 33.6 TWh). This means that in the year 2020 the consumption level of the reference year 2007 is almost reached again (Figure 7). With regard to a comparison by operation mode, the additional savings in the Green IT scenario in standby mode are above average, though there were even considerable electricity savings for standby in the reference case. Again, the main savings are achieved for off-mode and passive mode, which are further reduced by almost 1 TWh compared to the BAU scenario, whereas only a slight reduction for networked standby is assumed.

Conclusions and recommendations

The results of the inventory and the forecasts show the urgent need for actions regarding the energy efficiency of ICT applications. The main reasons for the increasing ICT energy consumption are increasing functionality of the devices, further rising equipment rates of households, and the rising times of use, which overcompensate the impact of a growing energy efficiency of the appliances in the reference scenario. Only in the Green IT scenario, which assumes an exploitation of the existing technical saving options for ICT appliances to a great extent, a stabilisation of energy consumption for ICT end-use appliances in private households at the level of 2007 is reached in Germany until 2020.

There is high technological improvement potential to reduce the ICT energy consumption. This potential results from the still continuous efficiency gains in microelectronic (Moore's Law) and most recent microsystems technology (system integration). Increasing functionality at a small form factor is linked ton this. This allows the design of multi-functional devices (MFD) which can replace a number of single-functional devices (SFD). The realisation of function-oriented but at the same time energy-saving hardware and software designs (power management) has a further reduction potential. These efficiency gains at technology and device level are often compensated by two aspects: more intensive use (longer daily time of use) and suboptimal network configuration of the devices (incompatibility of components). For the reference scenario, the energy intensive trends outweigh the other trends and result in increasing electricity consumption. For the Green IT scenario, strong technology improvements were estimated, which would lead to a stabilisation of the ICT electricity consumption until 2020.

This shows that the main factors regarding the electricity consumption are the individual service conditions such as number of devices per household, company, etc., state of the technology of the devices and infrastructure, network connection and the intensity of use. A consequently optimisation of all energy related aspects would lead to even further reductions than shown with the Green IT-Scenario, but such improvements are only feasible on system level and not with individual measures.

Up to now, measures on national and EU-level to improve the energy efficiency of ICT were focused on the improvement of end-user devices in households and companies, especially on the technology level for future products. There are also different information and guidance programmes regarding changes in the user behaviour, e.g. the "Initiative EnergieEffizienz" (Initiative Energy Efficiency) of the German Energy Agency (dena) in cooperation with the energy industry. The advices regarding the user behaviour target the reduction of standby consumption. The recommendations in this study are intentionally beyond the already implemented measures and activities and place the person as user in the centre of the system. Their consciousness, their ability to use the technology and their individual decisions cause the electricity consumption in the use phase of a product. Equipment, network connection and services of internet providers have to be designed according to the user's needs. It has to be differentiated between individual and average user behaviour. At the same time the user has to be involved in system optimisations. They should become aware of how much electricity their user behaviour causes and how to effect it. Measures like integrated electricity metering ("Smart Metering", a measure in the national energy and climate programme) can lead to more transparency and therefore more awareness. Another considerable aspect is the user's competence (digital divide) and their influence on individual option for action.

For a holistic improvement of energy efficiency of ICT application also other environmental aspects like toxicity and use of resources have to be taken into consideration. Current environmental research emphasizes the rising need of resources like rare metals and minerals especially in the field of microelectronics and ICT. Energy-saving technologies depend on these resources..

Taking into account the expected development of energy consumption for ICTs in Germany in the reference scenario, a user-oriented implementation of existing best practice in collaboration with industry and research is recommended. Active measures to stabilize or reduce the ICT electricity consumption on long term should focus on exemplarily implementation of best available technology. The goal is to demonstrate the implementation of newest technology, infrastructure and configuration of end-user devices in collaboration with industry and applied research. In flagship projects the potential for energy savings on the user's side as well as technical and economical potentials for industry and service providers can be judged. From this, marketable incentives can be deduced which support a systemically spread of best practice. Also a voluntary agreement of the industry could be positive for Germany as location for (ICT) industry in the international competition where the subjects energy and resource efficiency become more and more important.

The today's focus of legislative measures and activities in the field of research and product development in industry is primary the electricity consumption of end-user devices. EuP and the German EPBG show this trend but are only minimum requirements. The very high technology dynamic has even greater potential to increase efficiency. This dynamic is also an obstacle, because technologies needs to be compatible and should be standardized. Under the aspect "Green IT key technologies", basic technologies, technology standards, software and assessment methods should be improved continuously to transfer technology potentials in energy and resource efficient products. Recommendations regarding the support of research and development in the field of hardware (photonics, displays, electronics, power supply), reuse and recycling of components and energy optimized software are given. This should also support the market development for energy efficient ICT key technologies in Germany.

References

[1] Cremer, C., Eichhammer, W., Friedewald, M., Georgieff, P., Rieth-Hoerst, S., Schlomann, B., Zoche, P.: *Energy Consumption of Information and Communication Technology (ICT) in Germany up to 2010*. Summary of the final report to the German Federal Ministry of Economics and Technology. Fraunhofer ISI, Cepe. Karlsruhe, Zurich 2003. http://www.isi.fraunhofer.de

[2] Schlomann, B., Cremer, C., Friedewald, M., Georgieff, P., Gruber, E., Corradini, R., Kraus, D., Arndt, U., Mauch, W., Schaefer, H., Schulte, M., Schröder, R.: *Technical and legal application possibilities of the compulsory labelling of the standby consumption of electrical household and office appliances*. Summary of the final report to the German Federal Ministry of Economics and Technology. Fraunhofer ISI, Research Institute for Energy Economocy (FfE), Dresden University of Technology. Karlsruhe, Munich, Dresden, 2005. http://www.isi.fraunhofer.de

[3] Stobbe, L., Schlomann, B., Friedewald, M., Georgieff, P. Leimbach, T., Nissen, N. F., Proske, M.: *Assessment of the Energy Demand by the further Development of the Information Society*. Summary of the final report to the German Federal Ministry of Economics and Technology. Fraunhofer IZM, Fraunhofer ISI. Berlin, Karlsruhe, 2009

[4] Arbeitsgemeinschaft Energiebilanzen: *Summary Tables to the Energy Balances for Germany 1990 bis 2007*. From September 2008. Berlin, Köln, online: http://ag-energiebilanzen.de

[5] Jönbrink, Anna Karin: *EuP Preparatory Studies Lot 3 Personal Computers (desktops and laptops) and Computer Monitors, Final Report (Task 1-8)*, August 2007, online: http://www.ecocomputer.org/

[6] Stobbe, Lutz: *EuP Preparatory Studies "Imaging Equipment" (Lot 4) Final Report*, November 2007, online: http://www.ecoimaging.org/

[7] Stobbe, Lutz: *EuP Preparatory Studies "Televisions" (Lot 5), Final Report*, August 2007, online, http://www.ecotelevision.org/

[8] Nissen, Nils F.: *EuP Preparatory Studies "Standby and offmode losses" (Lot 6), Final Report*, Oktober 2007, online, http://www.ecostandby.org/

[9] Monier, Véronique; Mudgal, Shailendra; Turunen, Lea; Schischke, Karsten; Ciaglia, Christian; Nissen, Nils F.; Lescuyer, Linda; Janin, Marc: *EuP Preparatory Studies Lot 7 Battery chargers and external power supplies, Final Report*, Januar 2007, online: http://www.ecocharger.org/

[10] Reitze, H.; Ridder, C.-M. (Hrsg.) (2006): *Massenkommunikation VII. Eine Langzeitstudie zur Mediennutzung und Medienbewertung 1984-2006*. Baden-Baden: Nomos 2006.

[11] Roth, K. et al.: *Miscellaneous Residential Electric Loads: Energy Consumption Characterization and Savings Potential*. Final Report by TIAX LLC. Cambrigde, MA, 2007

[12] Cisco: *Approaching the Zettabyte Era*, White Paper, 2008, online: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481374_ns827_Networking_Solutions_White_Paper.html

Energy and environmental efficiency for broadband deployment and multi-services implementation

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Dominique Roche

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Abstract

The continuous improvement of the environmental performance is becoming a key factor of success for a telecommunication (TLC) operator, which can not only minimize the impacts related to the current offers, but also deploy specific services allowing controlling energy usage and environmental impacts. Also, TLC services can give significant contributions to the de-materialization. All these possible actions correspond to quantitative contributions to the achievement of sustainability objectives (e.g. Kyoto targets). The connected home represents one of the main areas of improvement, where actions can be planned and implemented following a Life Cycle Thinking (LCT) approach. Home gateway, fixed and mobile terminals, home networking technologies (wired and wireless solutions), services for monitoring and consciously using the energy are the main areas of interest: the paper will focus on possible improvements and priorities identification in this field.

Specifically, one of most important sustainable issues is the energy efficiency: a group of worldwide telecom operators have formed the Energy Efficiency Inter-Operator Collaboration Group (EE IOCG) to lead the ICT sector efforts to increase its energy efficiency, pushing towards an earlier availability of new equipment with optimized power consumption. Energy efficiency is absolutely transversal to the TLC and IT technologies and the many standardization organizations and groups; then EE IOCG is the melting pot where the standardization processes are considered in order to minimize inefficiencies and optimize synergies between the standardisation organisations and forums. The risk today is that, without this kind of action, standardization will be late compared from the Operator's needs, who are starting their deployments of Next Generation Networks and increased Data Centres.

Sustainability and Integrated Product Policies

Telecom Operators are operating towards the achievement of market objectives, but always taking into account the environmental and social context and thus minimising the environmental impacts of their activities, as well as maximising the advantages related to their own services. In this sense, Telcos can give a significant contribution to the achievement of global objectives (e.g. Kyoto Protocol).

In the framework of the Sustainable Development, the punctual actions designed and then implemented in relation to the connected home offers are inspired by the Life Cycle Thinking (LCT) approach, fundamental principle of the Integrated Product Policies [1] defined by the European Commission. LCT concept includes the consideration of the overall life cycle of a product (or service) in order to identify the critical areas from the environmental point of view as well as the improvement actions and the related actors to be involved (manufacturers, service providers, resellers, end of life managers, other stakeholders).

In fact, the various life cycle phases can be under the direct control of different entities; for example, considering the typical telecommunication equipment, production and distribution phases are controlled by the manufacturer, while installation and use phase are under direct responsibility of the operator (plus the final user). Design phase is carried our by the manufacturer, sometimes in co-making with the Telco, whole end of life can involve a number of different additional actors, including NGOs and public authorities. Thus, the identification but mainly the implementation of the corrective actions can become critical.

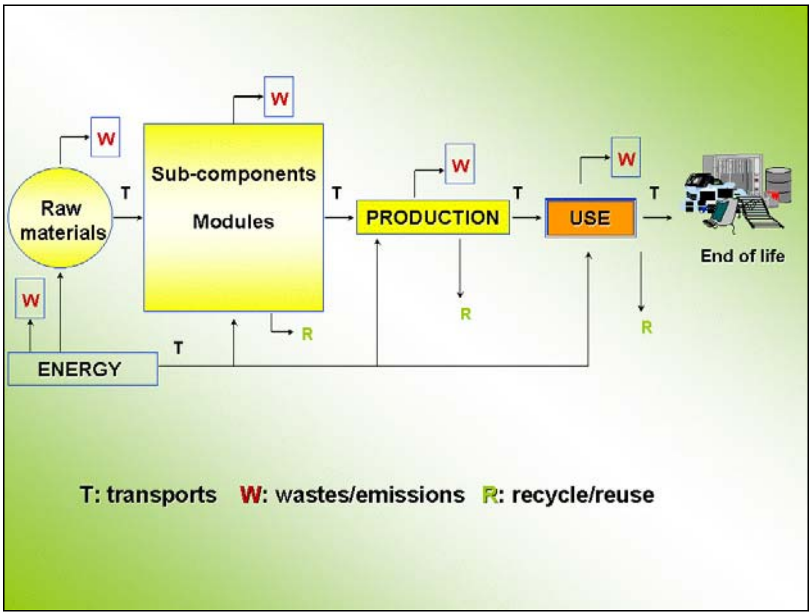

Figure 1 Life Cycle of Products

Initiatives for reducing environmental impacts are to be provided with declarations demonstrating the actual advantages. Environmental product declarations and labels are therefore the right way to proceed, following the guidelines and procedures standardised by ISO in the normative ISO 14025 [6] and ISO 14021 [2], if not following the Ecolabel normative ISO 14024 [5]), that is providing a third-party certification but is applicable only for specific products' categories.

The LCT approach ahs also implications form the point of view of the financial accounting. In fact, specific indexes have been created to give financial value to the company's activities towards the sustainable development (examples: Dow Jones Sustainability Index (DJSI) and FTSE4good). Thus, the TLC operator is interested in quantify the level of compliance to the sustainable development principles and be quoted in those indexes thanks to its good environmental performance.

In this sense, all the activities aimed at optimising the energy efficiency are to be intended as compliant to the main principle of improving the environmental performance of the Telco operator, being the energy usage one of the main sources of impact.

"Willingness to pay" for green products

A number of studies have been published, demonstrating that the final user is more and more oriented at paying more for getting green products. The level of willingness is more significant when young generations are requested to declare their orientation. Additionally, it is to be considered that not always a solution that is improving the environmental impact is necessarily implying higher costs (e.g. sometimes recycled plastics are less expensive that virgin material).

A survey carried out by Canalys shows that around 55% of the consumers can accept to pay up to 10% prices for green electronics products. The expected trend is providing that this percentage will increase as soon as the global offer of green products will be more extended and considering that the environmental awareness is also in high expansion among the consumer's world.

Also the willingness to pay for young generations is around 67% while for elder people is lower (49%).

These results are independent from considerations related to the fact that energy efficiency of home devices will also reduce the costs of electricity supported by the end user and are only related to the actual willingness to contribute to global objectives in terms of environmental protection.

Digital home and areas for eco-efficiency

As already said the digital home is one of the key areas for implementing environmental improvements, optimising the environmental burdens of the products, minimising the energy consumption of devices and appliances, setting up monitoring services allowing an environmentally conscious energy usage. The following sections will be focused on the possibility of improving the performance of specific categories of products on what the connected home scenarios are based: home gateways, fixed (but also mobile) terminals, devices for IPTV, home networking technologies. Then, a short summary of a possible monitoring service for optimising the energy usage at home is provided.

In terms of priorities, considering the energy impacts and intrinsic environmental impacts, the areas requesting more urgent actions in the direction of a real improvement can be identified as follows:

- Power supplies and chargers for all the products' categories analysed
- Home gateways
- Mobile phones

"Green gateway"

The home gateway is the boundary element between the digital home and the access network; by definition this is an always on device (energy consumption is continuous) and it is associated to every user that subscribed to broadband services, so that the volumes of products installed is really high. These two basic features imply that also a single small improvement of the energy and environmental efficiency is really significant because the total amount of energy saved is for sure really high.

The main improvement areas of the home gateways are the energy efficiency and the design for environment. In terms of ecodesign the main actions can refer to:

- assembling solutions, that must be designed having in mind to ease the disassembling phase and the parts separations (e.g. minimise screws, adopt snap-fits)
- materials choice for the external case, cords and cables (network connections, power supply cables etc)
- materials choice for the electronic board, to be built up minimising the presence of brominates substances thus improving the end of life procedures and avoiding the production of toxic compounds in that life cycle phase

As far as the energy consumption is concerned, the home gateway is particularly critical because of the need for uninterruptible power supply, but on the other hand the typical home gateway architecture can allow the implementations of smart energy management mechanisms; in fact, for most of the time, only a subset of the gateway functionalities must be active, depending on the number and type of services supported. Therefore, specific manual or automatic mechanism can be implemented to switch off or put in low power state the functions that are not directly involved in the service usage at a specific point of time.

A typical example is the home gateway (supporting also Voice over IP capabilities) operation during night: in absence of other active services such as IPTV or internet surfing, the HG should in any case remain as active in order to detect possible incoming calls or ensure a fast activation of the service in case of outgoing (e.g. emergency) calls. However, a huge number of functions not directly used by the VoIP service could be switched off.

Summarising, to optimise the design phase, the following steps should be performed:

1) Carry out a deep analysis of the power consumption referred to the single functionality

2) Identify a number of scenarios that can be intermediate states between the fully "ON" operation state and the OFF situation, thus identifying a number of "low power" levels of operation

3) Design software mechanisms for supporting the transition between the different states identified, also optimising the transition times depending on the user's experience requirements

Figure 3 shows how specific consumption limits can be associated to the single functionality (interface, and this is useful to perform a characterisation of the single product, as well as elaborate a forecast of the overall consumption of similar devices.

On the basis of the consumption "per function" it is possible to provide a reference limit for the overall energy impact "per service" and, at the same time, elaborate requirements that the service provider will send to the manufacturer in order to support low power mechanisms and optimise transition times.

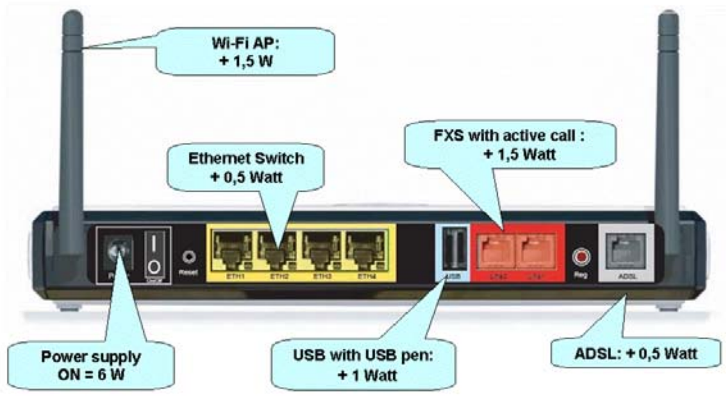

Figure 2 Mean energy consumption values for home gateways

The energy consumption can be associated to an estimation of the associated environmental impact. Thanks to the Life Cycle Assessment (LCA) methodology the single kWh of energy can be associated to the list of resources used, emissions and wastes produced and in this way a sort of environmental score can be calculated. The LC method is however quite complicated and depending on a number of factors, for example including, in the case of energy, the mix of sources on which the energy production is based. Typically, one of the possible ways forward is to adopt simplified indexes, more related to a subset of substances and related impacts that are considered with high priority, having in mind the associated environmental effects,. For this reason one of the widely used indexes is the so-called CO_2 footprint: recognising the CO_2 emission are the most important factor contributing to the global warming effect, being this one of the most significant environmental impacts, and also considering that Kyoto objectives are referred to CO_2 emission reduces, it is possible to associate the energy savings expressed in kW/hours to a specific amount of avoided CO_2 emissions.

Summarising, the implementation of actions aimed at reducing the home gateway's energy consumption can be associated to an objective of reduction refereed to CO_2 emissions. For example, considering to reduce the mean energy consumption of the home gateway from 12 to 11,5 watts 24 hours/day, and including in the calculation the overall amount of gateways currently installed by Telecom Italia, will correspond to a CO_2 emissions reduction equivalent to around 13600 tonnes. This corresponds to the amount of emissions saved if the usage of more than 11000 cars (category B, Euro 4 compliant, mean usage 12000 km/year) will be avoided.

Energy and environmental efficiency of fIxed devices

Telecom Italia and other European Telcos are active in the definition and launch on the market of fixed terminals (wired and cordless phones, videophones, IP phones in general) that can be considered as environmentally improved thanks to materials' choice, adoption of Design For Environment criteria, adoption of design choices minimising the energy consumption, definition and promotion of actions for an optimised end of life management also involving the user's participation.

Telecom Italia is going to launch a new cordless DECT product, designed in direct partnership with the manufacturer, whose environmental performance is significantly improved in comparison to the previous versions of the same device's typology.

In particular, the plastic case will be manufactured using biodegradable plastics able to support a "carbon-neutral" described in the figure: the amount of CO_2 emitted by the product (or the single component in this case) is balanced by the absorption of the same gas during other phases of the plant's life cycle..

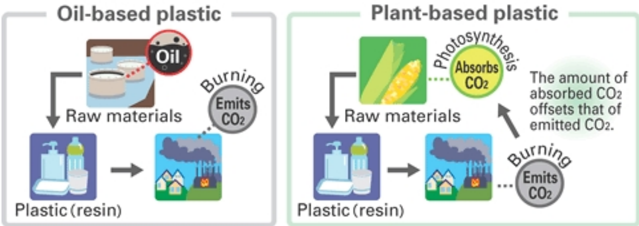

Figure 3: "carbon neutral" concept applied to bioplastics (source: Natureworks LLC)

Optimisation of energy consumption of the new cordless phone allows considerable energy savings in the entire life cycle of the product. In fact, even if power consumption is low as absolute values, reducing the energy needs for standby and conversation operation states and optimising the efficiency and the off load consumption of the power supply is resulting in life cycle energy savings around 40%. Projecting this amount of saved energy on volumes around 100000 pieces the overall reduction of CO_2 emissions corresponding to the use phase of that cordless phone is more than 650 tons.

Energy efficiency of IPTV Set Top Boxes

IPTV services deployed by Telcos require providing the final user with a specific box label to be connected to a TV set for service usage. Usually this device is not directly acquired by the final customer but directly subsidized by the service provider; therefore, the operator is directly causing an additional energy consumption related to the new terminal in the connected home.

In the recent years a few operators already had huge problems with NGOs and pubic because they were attacked as responsible of a big increase in the energy balance mainly due to the fact that those equipment are supporting sort of "false stand-by" state. When the service is not used the user can in fact put the set top box in a "standby" state, however, to guarantee a fast reaction time after reactivation through a remote control, the box maintains in fact most of their functions as active, corresponding to a level of power consumption really similar to the ON state, when service is used. Very significant improvements of the STB's energy efficiency can be thus envisaged optimising the operation state snot corresponding to the full ON.

In fact, the levels of operation of this device can be defined as follows:

- State 1: ON, all functionalities active
- State 2: "active stand-by" when STB is not directly supporting the service usage but can receive configuration messages, react to request of software upgrade and remote management activities in general, and can be able to activate other functions, for example a scheduled recording activity triggered by a timer.
- State 3: "passive stand-by" when STB can only react to a signal sent by a remote control, and no other stimulus can trigger the activation of functionalities

Please note that State 3 could be not applicable for specific types of set top box, depending on the needs for supporting services or remote maintenance activities.

The number of hours in which the STB can enter one of the two standby states is really significant (at least 15-16 hours a day up to 24), so that optimising the power consumption associated to state 2 and state 3 is very important.

The 3 states approach is currently the basis of the Code of Conduct for Digital Equipment – Version 7, elaborated by the European Commission [4]. The code is currently under revision, to optimise the definition of states and revise the power consumption target values, in order to adopt a “duty cycle” approach and define limits per year and in this way take into account that the device can enter states lower than the ON mode for a huge number of hours per day, thus stimulating manufacturers to optimise the consumption for all the operation modes.

As example of the possible huge savings for this category of product, the difference between old and new generations of complex set top boxes can be considered. The products deployed in 2004-2005 had a typical power consumption of around 20 W in the ON state while in the active standby state the difference was very little (2 to 3 W lower). The new reference designs can prefigure a situation in which the ON consumption could be around 12 W with a mean value for active standby states (that can be more than one) around 5 W. Considering the duty cycle and total annual energy consumption formula under discussion in the European Commission, this will allow to pass from around 150 kWh to less than 55 kWh of power consumption per year per product.

Mobile green phones: trends

Mobile terminals are not strictly included in the connected home scenarios, but future scenarios will push for a higher integration of mobile and broadband services, so that the connected home can become a point of service usage in which also this kind of equipment will be present. But mainly, mobile phones are a great area of potential improvement: they are produced in huge volumes and due to marketing reasons their lifetime is quite limited in comparison to the real reliability, and this corresponds to significant amount of devices that become “wastes” in e relatively short time. Thus, the improvement of the single terminal corresponds to a real advantage in terms of environmental burdens reduction.

Also in this case the main areas of improvement are the Design For environment and the Energy efficiency. On the second aspect manufacturers have been implemented already sophisticated energy management mechanisms, considering the battery duration as one of the most important features considered by the potential customer.

As far as DFE criteria application is concerned, a number of vendors already launched new projects aimed at deploying “green” products manufactured with recycled plastics or bio-plastics, implementing design for disassembling requirements, limiting the presence of dangerous substances in the printed boards (halogen-free solutions are adopted). Also, the annual report for GreenPeace on “Green electronics” is devoting a large section to this kind of devices and every year a number of significant improvements are detected, towards a better environmental performance.

The OMTP (Open Mobile Telephony Platform) forum recently launched a new task called “Green mobile phones and accessories”, providing a strong cooperation with GSM Association, and including in the scope the elaboration of requirements for a better energy efficiency (including requirements on the power supply) and a limited environmental impact associated to the production phase and able to ease the disposal of the product at the end of its life. So far, OMTP produced a specification for a Universal Charger for Mobile phones (endorsed by GSM Association): this action will allow reducing the number of chargers being manufactured each year of around 50%, so that the industry can expect to reduce greenhouse gases in manufacturing and transporting replacement chargers up to 21,8 million tonnes a year. Additionally, all devices manufactured following this specification will have a optimised energy efficiency, leading to additional savings in the energy consumption for the use phase.

Services for energy efficiency

As stated by the European Commission, stand-by power of electrical equipment is the electricity consumed by end-use devices when they are switched off or not performing their main function. Stand-by power consumption is an increasing fraction of the European Union’s electricity use and the fast penetration of new and digital technology is likely to increase this share. It is estimated that stand-by power already accounts from 6 to 10% of the overall electricity consumption in homes and offices; making reference to the Italian situation, this means that more than 2% of the overall energy consumption is related to stand-by.

This means that reducing the overall consumption in the standby state is a key action, but also enforcing a real off state when a specific device that is typically reactivated thanks to the user's intervention (e.g. TV, video recorders etc.) has entered the standby state since a long time can help to save energy.

Additionally, implementing a mechanism allowing to detect the risk of overloading the energy network due to a high request of energy coming from the single house will help to use in a more rationale way the energy resources at home.

In order to support this kind of potential improvements Telcos can play a real active and important role, being capable of setting up monitoring systems at home using specific technologies and aggregating data in specific equipment (single terminal, home gateway). On the basis of the data collected the various equipment can be enforced to enter a specific state or the energy usage can be interrupted or diverged depending on the single device or household equipment involved.

For example Telecom Italia is currently performing a trial of a solution including the usage of Zigbee technology and providing to implement a sort of control point in enhanced IP videophones or in the home gateway. A Zigbee Smartplug is installed on every plug which terminal or household appliances to be controlled are connected to: this smartplug is able to send data related to the energy consumption, from which the control point can calculate the current status of the device and identify the devices that are in a stand by state, or the equipment that are going to cause overloads. As second step the control point can enforce off states depending on the equipment's features and on the basis of specific policies, that can impose to treat specific appliances in different ways.

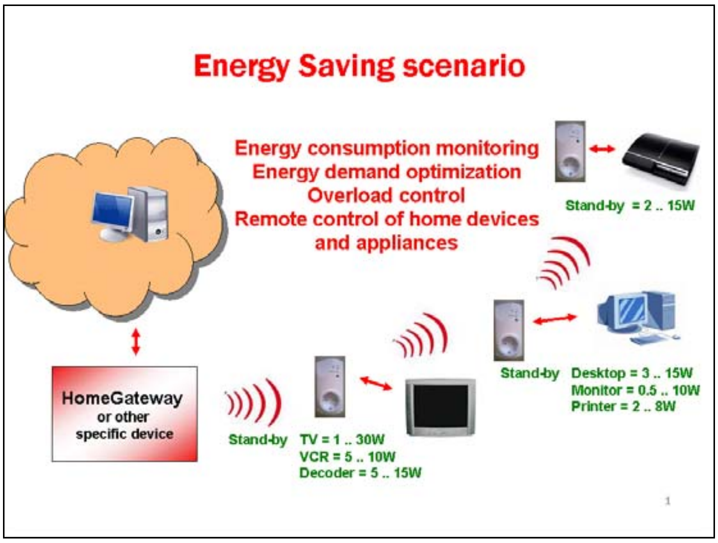

Figure 4 Energy monitoring at home

The policies and the consequent actions can be set up in an automatic way or depending on the specific user's needs and willingness.

Coordination of EE activities

Energy consumption is one of the biggest challenges the Telecom operators are facing. In the last years, both the increase of the energy cost and the awareness on the sustainable development have raised the attention on optimizing the use of energy. Furthermore, Operators are getting strong push from governments and stakeholders as they are among the top three energy users in each nation and the energy consumption of the TLC sector is quite significant (about 1% of the total National energy consumption and tomorrow could even become 3-5%).

All Operators have brought on aggressive plans to increase its efficient use, but have to deal with the contemporary increase of consumption due to the expansion of their BroadBand networks. Further area facing strong expansion is the Data Center, who today represents already more than 10% of the Operator's energy bill.

The energy trend for the next decade, if no strong care is taken, could end up into serious increase which, together with the significant increase of the energy unitary cost, would deeply impact the Operator’s financial balance. Furthermore, excessive energy consumption could even inhibit the techno/economical feasibility of specific architectures/solutions (e.g. FTTCab for Total Replacement Architectures).

The increasing load at the client’s premises caused by the BroadBand related equipment will more than balance any savings actions into the network. If not carefully driven it could have a deep negative impact on overall sustainability. The Operators are the only companies in a position to champion efficiency actions on CPEs, driving not only the products they sell/lend, but the entire market towards a greener approach.

Actions are going on at international level too, but they are fragmented among the various bodies/fora and are proceeding slowly. The risk is that standardization will be late compared from the Operator’s needs, who are starting their deployments of Next Generation Networks (valued many Billions Euros). Without a strong and coordinated action from the Operators towards Standardization and equipment providers we could then face serious increase of the electrical bill both to the Operators and to the Client. Their inability to show clear and substantial actions towards the emission reductions would, together with the negative image, bring serious threat of punitive national caps on prices.

An Energy Efficiency Inter Operators Collaboration Group has been setup, where the Operators could share their energy critical issues and agree common goals and high level strategic actions and guidance towards Standardization and equipment suppliers.

The main goal of the Energy Efficiency Inter-Operator Collaboration Group (EE IOCG) is the definition of a set of high level strategic actions focused on power saving and energy efficiency to be jointly applied towards Standardization bodies and vendors through:

- Cooperation and continuous alignment with the various Standardization bodies (ETSI/ITU-T/DSLF …) trough participation and organization of workshops (e.g. during the plenary of ETSI ATTM-EE-BOARD …)

- Transparent communication, cooperation and request for feedback with vendors and consumers associations

In order to be more effective, the EE IOCG should reach its goal within a short period of time (e.g. by the end of 2008). Possible outputs of the Group could be:

- A first short and effective position paper (based on this ToR) detailing: participants, goals and action points

- Reports and joint contributions

The EE IOCG is not another additional forum focused on deeply technical issues but it will join an existing sustainable actor as soon as possible: the way is now paved to merge with a global sustainable organization GeSI.

The EE IOCG is applying the same working method used in 2006 in the very successful ADF Inter Operator Group, where most European Operators (Belgacom, KPN, OpenReach, Orange FT, PT, TI, Telefonica, Telekom Austria) were able to set in a few months a common RFI that was then used as basis for the European Standard on the ADF (ETSI TS 102 566). The main process followed by the EE IOCG should be the following:

- Highlight the critical areas, for example:
    - xDSL systems consumption/efficiency and trends
    - Data Centers à temperature range, efficiency…

- Powering (and service continuity)
- Efficient cooling
- Energy consumption of network terminations and customer premises equipment

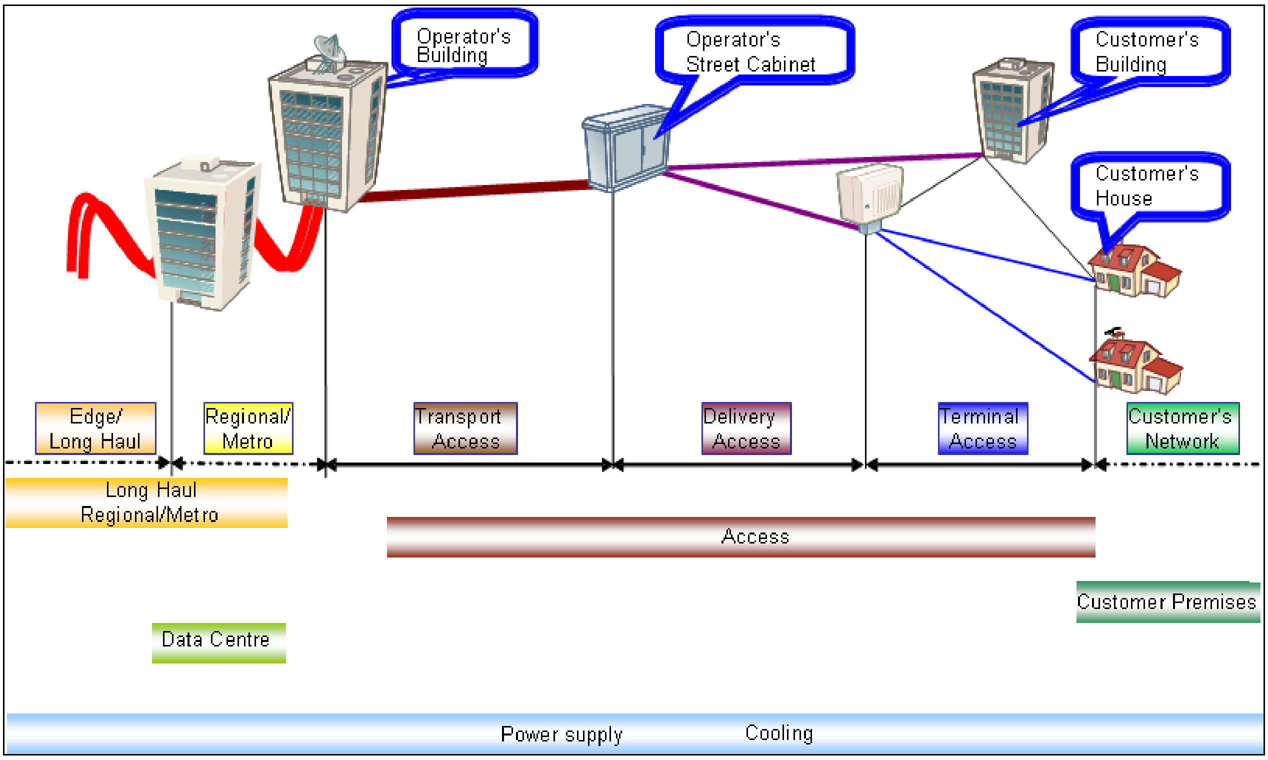

Figure 5 EE IOCG – Identification of most critical areas

- Define the main actions:
    - High level analysis of the various standardization/fora (current status of activities, technical perimeters, references) in order to identify the most efficient way forward (e.g. identification of reference people who could represent the EE IOCG members).
    - Association of each "critical area" with the reference standardization body
    - Launch of joint actions towards the relevant bodies:
        - Actions towards the Boards of the standardisation organizations to address their strategies and priorities
        - Actions towards the Technical Committees to push specific topics (e.g. new common proposals for increased temperature range within the equipment's room/cabinet, etc.)
    - Actions towards vendors (and consumers associations) such as:
        - Sharing a common process of evaluation of the different vendors during a tender. In particular, the evaluation method could be based on a TCO that includes, other than CAPEX, also the Discounted Cash Flow of the energy OPEX, possibly related to at least 5 years (better 10)
        - Giving vendors clear common indications about the operators strong need and commitment towards energy efficiency, spreading the results of this group

▪ Transparent communication and request for feedback from consumers associations

o Finalization of strategic analysis, such as:

▪ Energy consumption trends for different FTTx scenarios, in order to better support strategic decisions towards fire deployments

▪ Definition of KPIs to enable proper monitoring of the actions (e.g. Eco-Efficiency Indicators, Data Center KPI, etc.

Standardisation developments

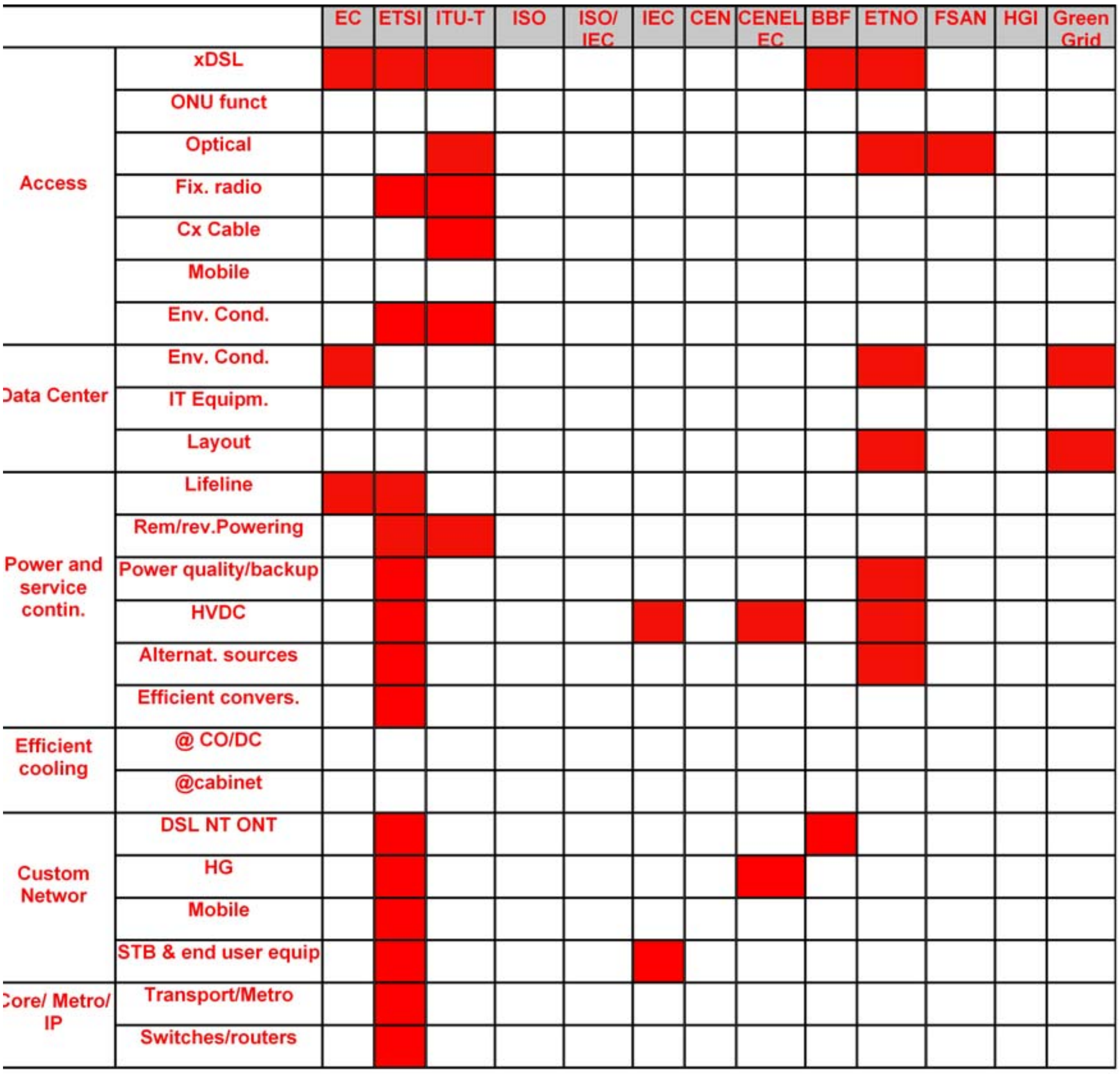

Figure 6 Who is doing what…? (First EE IOCG agreed presentation)

Today many Standardization/regulation bodies and forums are focusing on the energy issue:

- ETNO, the European benchmark actor of telecommunication sector, by means of its Energy Task Team, is operating on benchmarking on various energy saving initiatives among the European operators in order to identify/promote best practices.

- ETSI, some initiatives are currently developed on specific issues (ATTM and EE), but due to the lack of strategic endorsement and guidance from the Top they are proceeding very slowly. This is anyway beneficial, but the risk is to be late compared to the market needs and with only a partial response.

- ITU-T has started activity on energy optimization of DSL and GPON. The DSL activity is coordinated together with ETSI.

- BroadBand Forum has determined to study operator requirements, and how these might be addressed holistically by optimising service, transport, and PHY layer techniques. The DSL Forum encourages international standards bodies to develop techniques for power reduction within the scope of their activities and to cooperate with the DSL Forum in work to maximise the savings while preserving and enhancing quality of service.

- IEEE, several groups work on energy efficiency in order to define mechanisms to reduce power consumption on Ethernet networks (802.3 az) and on Wireless LAN (802.11).

- ATIS, NIPP committee is working on efficient systems and interfaces, sub-committee TEE especially.

- TCG, the USA Telecommunications Carrier Croup started activity on energy saving while Energy Star is active on stand by losses of the home TLC equipment.

- CESI, China Electro technical Standardization Institute has started new specification works in order to support new energy law focusing on energy reduction as energy is a national challenge linked to the significant increase in the demand.

European Commission initiative and broadband deployment

In 2003 European Unio started development of several Code of Conducts. These Code of Conducts cover fast growing technical areas where no standardization action was undergoing (external power supplies, UPS, Set Top Boxes, BroadBand equipment and Data Centers) with the aim of reducing energy consumption of products and/or systems through the setting of agreed targets in a defined development timescale. According to their studies, BroadBand equipment will contribute to the electricity consumption in European Community depending on the penetration level, the specifications of the equipment and the requirements of the service provider, a total European consumption of up to an estimated 50 TWh per year for the year 2015. With the general principles and actions resulting from the implementation of this Code of Conduct the (maximum) electricity consumption could be limited to 25 TWh per year, this is equivalent to 5,5 Millions tons of oil equivalent (TOE) and to total saving of about € 7,5 Billions per year.

Support of Code of Conducts seems to be the unique solution to create active development of energy efficiency. In order to do it EE IOCG pushes evolution of standards including energy efficiency and sustainability in general. Standard evolution is assisted by series actions of several ICT and telecommunication groups. EE IOCG is the core of this series connection.

EE IOCG meets two “tables” of actors of ICT and telecommunication sector: operators and vendors. EE IOCG is yet liaised with public and institutional actors (e.g. European Commission, United Nations) and users (e.g. CRIP/French Club of main companies). EE IOCG began to help evolution of Code of Conducts and will continue to support them by means of strong and active liaisons and proposals toward the main standardisations organizations and forums. The closed liaison with one of main sustainability actor, GeSI, is guarantee of continuity in the Green domain. Development of EE IOCG series connection is already got under way and several tens of targeted actions have been done in recognized critical areas, e.g. data centres, transmission systems. First result is finalization of ETSI Technical Specification Series to speed up standardisation of broadband world and availability of Energy Efficient and sustainable equipment and networks. In order to monitor implementation and operation, of the efficient broadband, this TS Series also defines key performance indicators (KPI) for energy efficiency.

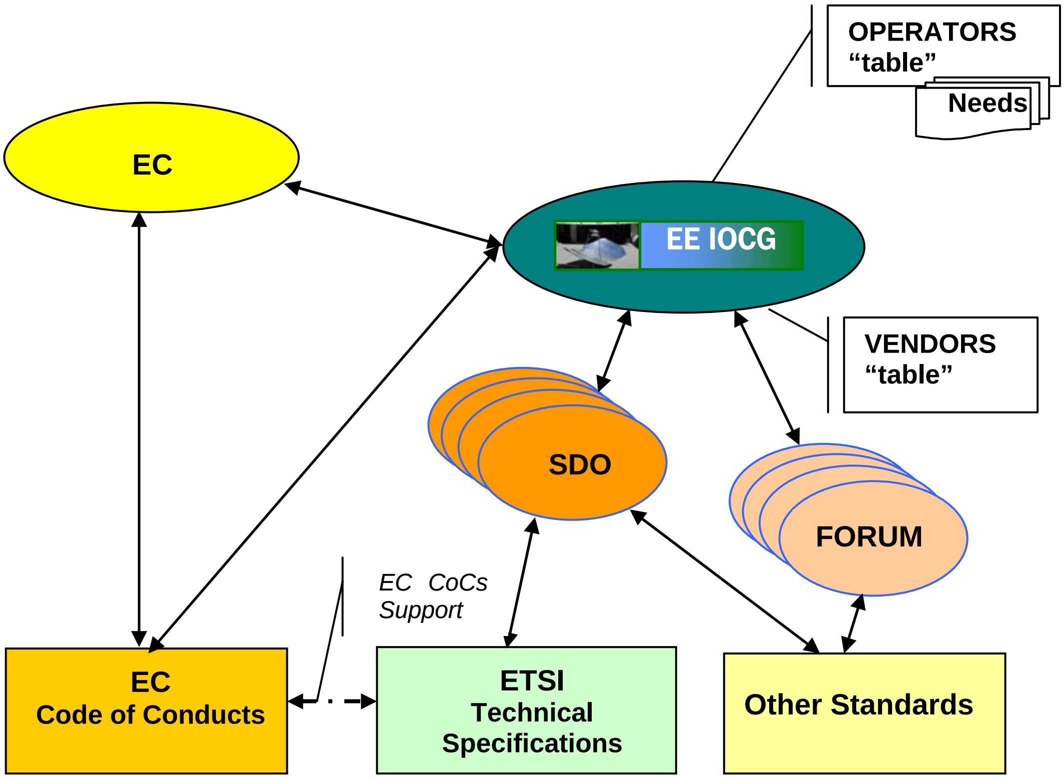

Figure 7 EE IOCG Series Connection

Conclusions

A number of environmental improvements with specific reference to the energy efficiency can be envisaged thanks to the telecommunication operators' activities. From one hand there is the possibility of reducing impacts and energy consumption related to the service scenarios deployed, while at the same time it is possible to implement new services able to perform monitoring actions and enforce corrective actions towards better energy efficiency. This is the reason why environment and energy, but more in general sustainability, is becoming a common topic of interest with high priority for most of the European operators, which decided to launch specific initiatives on the topic.

References

[1] Integrated Product Policy - http://ec.europa.eu/environment/ipp/

[2] ISO 14021:1999 Environmental labels and declarations -- Self-declared environmental claims (Type II environmental labelling)

[3] European Commission - Code of Conduct on Energy Consumption of Broadband Equipment Version 2 – July 2007

[4] European Commission - Code of Conduct on Energy Efficiency of Digital TV Service Systems Version 7 – January 2008

[5] ISO 14024:1999 Environmental labels and declarations -- Type I environmental labelling -- Principles and procedures

[6] ISO 14025:2006- Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures

Network connectivity and low-power mode energy consumption

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Abstract

Since ‘standby’ was recognized as an energy efficiency issue, a growing number of countries have put policies in place that reduce low power mode energy consumption. However, most of these policies, e.g. the EU Ecodesign regulation on standby and off modes, only target the most simple low power modes. Meanwhile, a rapidly increasing number of products have greater numbers and increasingly complex low power modes. The complexity arises from the fact that many products are already or will be in future connected to a network and will maintain a connection to the network when the product is not performing one of its main functions. Most standby definitions and levels do not take this complexity into account. As a result, only a few policies cover network-connected modes, and not in a consistent or comprehensive way.

This paper will review the state of the art regarding low power modes generally, network connectivity, and its relation to standby and other low power modes:

- recent developments in standby / low-power policy
- the “functional” approach to low-power modes
- how to test and regulate low-power mode consumption
- how networks affect low-power mode consumption
- existing efficiency policies and standards
- A horizontal approach to (network) low power modes
- future directions and guiding principles

The aim of the paper is to provide policy makers with guidelines for the development of effective policies to reduce power consumption in networked products and modes.

Introduction

Low power mode energy use has developed from an obscure issue 20 years ago to being widely recognized, and from no recognition within the policy environment to being common within many energy efficiency policies. An infrastructure has been built of ideas, test procedures, measurements, policies, and institutions. Initially, it was seen as a “mode” of a product, and used as a mode name on some products (“standby”). When officially defined, in IEC 62301 [9], standby became a power level (“minimum power level while connected to mains”[1]) that could occur in any operating mode,

[1] Edition 1 of IEC62301 defined standby as the lowest power while connected to the mains. This was intended as an internal definition within the standard itself. The limitations of this definition are widely acknowledged and Edition 2, due in 2009 will have this definition removed.

depending on the product. As it became clear that much low-power mode energy use was due to modes other than the minimum one, the term "standby" became used as a proxy for all low-power modes, and most recently, only covering those modes that are not designated as "off" or as having network connectivity. Modes with connectivity are now called "network modes" in a draft revision of IEC 62301 [8][2].

Past ways of addressing low power mode consumption are generally not adequate to deal with network issues, so low power mode policy needs additional evolution, along with new content that is network-specific. As an example, the EU Ecodesign process on standby did not incorporate network connectivity into its requirements (but has started a new process to address it) [3, 4].

In the first part of the paper, we review the "functional" approach to low power modes, and describe in detail how it is used in practice in testing and policy. The second part then builds on this by including network functionality and its many interesting dimensions. Finally, we have recommendations for research and policy.

The functional approach to low-power modes

Definition: list of functions

Recent years have seen increasing interest in grounding low-power modes into listings of "functions" present in any particular mode as a way of defining and evaluating their energy performance. Collections of functions have been previously listed in the EuP Lot 6 study, in the current draft of IEC 62301, in the EU Codes of Conduct on Broadband Equipment and Set-top Boxes [1, 2], and in several Energy Star specifications [14, 15, 16].

Ultimately, a mode is a collection of functions.

For many reasons, it is desirable to have a list and definitions of functions that spans all product categories, and can be applied globally. Harmonization of power levels associated with functions is desirable, but this may well vary across products and will definitely vary with time as functions evolve and technology allows them to become more efficient.

There are various ways to organize a list of functions, and Table 1 lists one such approach. The functions listed in Table 1 are certainly the majority of those of interest for low power modes in user-oriented products.

Table 1. A proposed taxonomy of low-power mode functions

Communication – Devices

- remote control – power only, 1-way, 2-way
- data connectivity – wired, wireless
- network connectivity – wired, wireless

Communication – People and Environment

- display – indicator, alphanumeric, graphic, audio, tactile;
  functional information / status, power state, time
- electronic controls and switches (energizing a keypad); power control
- sensors – occupancy, ambient light, internal

Time

- clock (keeping time), timer (tracking relative time, switching), and schedules

Power

[2] This to differentiate products with network functions from those within the traditional scope of "standby", in the interests of better clarity of understanding in future.

- EMC filters; ability to power-up on timer; battery-related
- power source (ambient, battery, AC, DC);
  ability to power other devices (e.g. via USB)

Functions required and functions present

The functional approach is a critical development, but needs one additional feature to reach its full potential, which clarifies a core duality of functions. In casual language this can be described as "**what you want** vs. **what you get**". It is easily explained in the context of a test (and a test procedure). A specific test of a particular project will identify a number of specific modes to be evaluated. For each mode, there will be a list of functions that **must** be present in the product during the test. Since a product may have many more functions than distinct modes (and even more combinations of functions than modes), many collections of functions will not have an exact incarnation in the product being tested with *only* those functions present.

For example, a microwave oven being tested has a display and an internal light (that comes on when the door is open). Any time the light is on, the display is on. The test of the mode with the light being on only requested that function, but the display is included in the mode as it occurs. So, depending on the product design, functions of direct interest may be always bundled with other functions of indirect or no interest. This example may seem trivial, but the principle is important: each measurement of a mode has two sets of functions: those required, and those actually present when tested. Any measurement or regulation needs to be clear which is being addressed.

An example closer to the core of this paper is the presence of network connectivity as a function. Some products have network connectivity in all low-power modes; that is, so long as it is connected to power, you always get that connectivity, with the functionality and energy use that implies.

Testing low power modes

A test procedure based on functions must list all required functions for a particular mode, annotated in some cases with standard conditions such as expected network speeds, traffic levels, etc. Some modes could list "prohibited" functions[3]. For many products, there may be a need for some configuration of the product prior to testing to accomplish particular modes (or reflect the intention of the test). Details of this configuration (and the as-shipped conditions as well) need to be carefully reported. An example would be to enable Wi-Fi connectivity during sleep mode (which might be disabled as the default).

As products increasingly alter their energy-using behavior in response to environmental conditions, these will need to be specified, and established for tests for these products. Examples include products with light sensors that adjust display brightness, that change behaviour depending on assessment of room occupancy, or have fans that are thermostatically controlled (and so affected by the ambient room temperature).

Thus, the procedure that a test laboratory would follow is:

- Begin with a product as shipped
- Review a list of required functions from the test procedure (or specification) for each mode of interest
- Modify the configuration and setup as per required functions
- Measure power for each relevant mode and combination of functions
- Report actual functions present in each mode (and level of activity if relevant)

Beginning with a product as-shipped is important to have an unambiguous test procedure, and as many people may never change many or any of the settings. The order of testing can be important; for example, some products enter a different mode when entering their off mode via an automatic power-down feature than they do when done with a manual power control. For testing with this scheme, the forthcoming second edition of IEC 62301 is sound and does not need particular

[3] Whether any prohibitions are needed is not yet known, though one can imagine a product "cheating", as by making strategic use of stored battery power to distort a test result.

alteration, other than being supplemented with additional reporting, and possibly standard terminology to refer to particular types of functions.

Regulating low power modes

This testing method is designed to facilitate voluntary and mandatory limits ("regulation" here used to cover both) on the energy use of products in low-power modes.

Program requirements can address "any mode with *X* characteristics and not *Y* characteristics" and can require that a product "shall have such a mode with a power level of ≤ *x* watts" or "shall have *all* low power modes require ≤ *x* watts"[4]. This is best understood in the context of policy collections of horizontal and vertical efficiency standards [5]. A vertical standard is one specific to a single product type (or collection of like ones). A horizontal standard is one that covers a particular function, set of functions, or characteristic across many or all product types (e.g. power supplies, low power mode consumption, network characteristics, battery characteristics, user interfaces, etc.) [11].

There are two basic methods of setting thresholds on consumption: modal (power) and annual (energy). The **modal** approach specifies one or more low-power modes that are measured and establishes individual limits for each mode. The **annual** approach (or any convenient period of time) sums up the consumption of all modes deemed significant, with an operating pattern that is seen as representative of typical consumption and limits *only* the sum, *not* the components. The annual total often also includes active consumption and is sometimes referred to as a 'duty cycle' or 'typical energy consumption' approach. Both of these have their advantages and for the foreseeable future, both will have good uses for specific product types. The functional approach with adders applies equally well to both.

For a particular mode, a regulation can specify a base power level with additional allowances ("adders") provided for functions beyond the assumed base for the mode. Adders have been widely used in the Energy Star imaging and set-top box specifications, and the Code of Conduct DIgital TV Services. More recently it has been used in the Energy Star computer specification, and the Code of Conduct on Broadband Equipment.

Some view such adders as a way for manufacturers of products that shouldn't qualify for a limit or label to do so by loading up with many spurious functions. This could work if the adder values are too large, but if they are set to the minimum level required for the functionality (and no more) this problem does not arise. A regulator can place a limit on which allowances are valid for a particular mode, and how many can be used[5].

Most efficiency test procedures and policies are limited to AC-powered products. However, there are many reasons to include low-power DC products in these as they can have efficiency (and other) advantages and should be allowed to compete on an even basis with those powered by traditional AC sources.

Network low-power modes

Introduction; general definition

The first step in addressing network modes is to define what actually constitutes a network and a network connection.

A network connection is a digital connection that allows exchange of digital[6] data among a set of (more than 2) devices. Devices connected by the Internet Protocol are the most common and obvious example of those with network connections, but there are other digital networks (e.g. HDMI). In addition to "true" network connections, there are also simple digital data communications mechanisms that connect only two devices. Examples are the VESA connections between a

[4] Special consideration is needed to consider the possibility that a product being tested has no mode of the type being specified so that how these products treatment is clear.
[5] This doesn't preclude a manufacturer from including additional functions, but there will not be additional power for doing so; if there are many such functions, their power levels have to be very low to compensate. Also, in setting adders economies of scale need to be considered, i.e. an adder being additional (on top of other adders) might be lower than a single adder.
[6] In contrast to analogue electronic communications mechanisms that have existed for well over 100 years.

computer and its display, USB links, and the (one way) infrared communication from a remote control to a TV.

Many network technologies are based on simple data links at lower layers, but higher layers enable communications to move transparently across many links to the destination device. In this paper, the design is for network connections, but the conclusions generally also apply to all types of data links so they are implicitly included in “networks”, including in Table 1. We ignore analogue connections, as they are diminishing as a determinant of energy use.

The IEC 62301 draft refers to a “network function” as “reactivation via network command or network integrity communication”. The latter is communication that is essential to having the network connection continue (lack of routine traffic is a way for networks to flush out devices that are no longer present or responding). This in line with the notion of “standby” as “readiness to act”. This definition includes data connections under the general rubric of true network connections, as does EuP Lot 6.

States of networked devices

Some network connections are also qualified by values such as speed, in addition to the core physical layer technology in use. Ultimately, any test procedure or regulation has to be informed by an assessment of what combinations of functions are particularly useful or occur in typical use. Typical or normal use is particularly important – specifying configurations or combinations of functions that are never used in practice is a dubious basis for a regulation or other requirement. The other danger is the stifling of innovation; if broad mode requirements are stringent, suppliers may be forced to eliminate higher levels of functionality from their default settings. Of course the ultimate objective of any efficiency policy is to minimise energy consumption of products while maintaining acceptable functionality.

Network connectivity is not a single function, with a single impact on power and energy use. Rather, we need to deal with a variety of potential conditions that can occur that have inherent implications for energy use, dictate potentials for functionality, and are measureable. These all can depend on the nature of the physical layer interface in use, the status of the connection, and the quantity and nature of any data flowing across the link. Mere data links are almost always much simpler; for example, the infrared sensor (receiver) on a television for a conventional remote control has a power requirement that is essentially constant, and low.

While most functions are either present or not in a mode, for network connections, there are three levels of “presence” that can be distinguished:

- the function **exists** (but is unavailable as configured)
- the function is **available** (but not active)
- the function is **active**

The following discussion refers to a single network connection, though a device may have multiple network connections with the same or different physical layers. A network interface can be in one of several states as follows:

Disabled

The first possibility is that a device has the **capability** to be network connected but the feature is disabled through configuration. In principle, all electronics associated with the connection might be removed from power, though in practice, some power may be expended by the interface or related electronics (including power supply losses). Thus, even a disabled capability may require some power. In the language of functions, a disabled interface only *exists*.

Absent - Wired

For a wired network (e.g. Ethernet), there are several possible paths to no data connection to another device:

- the interface might be enabled but no cable connected;
- a cable might be connected with no device at the other end; or
- a device might be at the other end but not enabled or turned on.

These cases of absent connection are not likely a central focus of standards developers and product designers (who quite naturally focus on designing interfaces and products to actually be in use). Nevertheless, these non-functional conditions are common in practice, particularly for products that have network connections only intermittently, are portable devices (e.g. notebooks PCs), or have multiple network connections (and so may have several commonly inactive even if most of the time at least one is active). An absent connection implies that it is *available*.

Absent - Wireless

For wireless networks, no cable is involved, but that does not mean the end of complications. With an enabled wireless interface, it may find or not find one or more other devices (particularly access points) to connect to, and may be able to make a connection to it or not depending on physical conditions and security limitations. Some types of wireless interfaces expend more power trying to establish a connection than they do to maintain a connection. Since wireless devices commonly can move, there is an inherent dynamism in wireless connections not present in wired ones. As with wired, an absent connection is *available*.

Linked

The purpose of any wired or wireless interface, is to actually establish a link to other devices. Links may be capable of several different operational modes that affect the amount of power required, including different throughput capabilities (e.g. Ethernet which supports speeds that vary by three orders of magnitude and the various “flavours” of Wi-Fi), the length of the data link, or the ability of a link to go to sleep for short periods of time when utilization is low. The ability of the device being tested to enter these speeds or modes can depend on the capabilities of the device to which it is connected. Signal strength and interference can also be important and can dictate the connection speed. A linked connection is *active*, regardless of how much data is flowing across the link (even none).

Full Connectivity

A link can be accomplished with fairly limited communication, but maintaining the device as connected to the network in a more general sense involves much more, including some network infrastructure activity, as well as maintaining presence in an application sense. This requires some additional power (energy) over just maintaining a link — sometimes much more. This is associated more with active consumption.

Special Modes

There are special modes in certain networks that provide for sending a wake-up signal but not ordinary connectivity. Wake-On-LAN is the most widely known of these. The EU Code of Conduct for Broadband references a DSL state in which the interfaces are only looking for wake-up signal. Some sensor network technologies use a “wakeup radio” signal (that can be listened to at very low power) that is separate from the one used to actually transmit data. Other modes useful when a device is relatively inactive are those that introduce latencies in communication, based on knowledge that these are acceptable in the usage context. These modes can be useful and may be a way to leverage significant savings. Thus, they need to be accommodated and recognized by test procedures.

Defining network modes

So, what **is** a network mode? One possible definition is any mode in which a network characteristic changes how much energy or power the device should reasonably use. Whether this include the disabled or absent cases described above is a question of technology and policy. The proposed revision to IEC 62301 defines “Network Mode(s)” as including “any product modes where the energy using product is connected to a mains power source and at least one network function is activated (such as reactivation via network command or network integrity communication)”.

A final aspect of network technology that is unique among energy-using equipment is that the behaviour of one device affect energy consumption of others, either directly, in the nature of the physical layer link between the devices, or more indirectly, in the content of the data sent among them. This interdependency means that efficiency standards need to take into account these behaviours independently of how energy consumption of the product itself is assessed. This also has implications for technology research and development.

Power (energy) impacts of networks

Network low power modes must be considered in the larger context of how networks affect energy use. Networks increase energy consumption in two ways. The first is *direct* consumption of network interface circuitry, and network devices. The second is the *induced* consumption of devices that are in a higher power mode by virtue of being network-connected. PCs and set-top boxes are the most notable examples of this currently. Often devices will wait in an active state for long periods of time on the chance that some useful network communication may occur. This is the most important consequence of network-related energy consumption and the one that requires the closest attention.

Today 'network mode' is relatively small, but it is poised to grow very rapidly over the coming decade as networked products become much more prevalent. Network mode occurs in several types of products.

Products that are already widely or universally networked. These include PCs and set-top boxes, and today they spend little time in a sleep mode, and for PCs the sleep mode lacks real network connectivity. Thus, as a percent of total energy for these products, the network modes are small. In many cases, these devices are left fully on to provide for full network connectivity so that going to sleep is not considered viable. This active mode consumption is a shortcoming of existing technology and effective energy management could result in a large energy savings. We expect that technology advances will allow for these types of devices in future to spend most of their time asleep, greatly increasing time in this mode.

Products that today are rarely digitally networked but likely will be in future. These include many displays, other audio/video devices, appliances, climate controls, security devices, and lighting. Some devices are relatively new, such as digital picture frames, but may usually be networked in the future. In some cases, such as displays or A/V devices, the network connectivity will be core to the product's function, with it replacing more limited data link or analogue connections. For others, the network capability exports the user interface to devices that are more convenient to use or in a different room or part of the world. For most of these, it is not convenient to manually power the device on and off to engage or disengage the network connectivity, so that the default behaviour will be to toggle between on and sleep, resulting in large amounts of network mode time.

The rise of network mode consumption is not all bad. Large savings can result as time in low power modes replaces large amounts of full-on time. The investment in power required to maintain connectivity may enable devices (e.g. lights) to better match their service delivery to people's needs. On the other hand, the *possibility* of savings does not mean their inevitability; it is quite possible that pervasive networking of buildings will lead to substantial increase in consumption rather than the reverse unless strong efforts are made to fundamentally build in energy management into networked product behaviour.

Network technologies have understandably focused primarily on functionality – mostly speed and to some extent versatility and security. The associated issue of energy consumption has received little attention in terms of enabling power management capabilities in network protocols. Power consumption due to networks is strongly affected by the throughput capacity of data links and network devices. The requirements for data flow vary by many orders of magnitude among devices, with video streams requiring the most, and appliances the least. When more capacity is provisioned than is needed, energy is wasted. Some network technologies allow for speed changes, but often only when the connection is initially established. An example of what is needed in general is the IEEE 802.3az process on Energy Efficient Ethernet which changes the paradigm to allow power consumption to scale with data throughput rather than capacity (see: http://ieee802.org/3/az).

Existing policies for network modes

Policy is taken here in a broad sense, including mandatory and voluntary energy standards, policy-driven technology development, and test procedures.

The Energy Star program has dealt with network issues for over ten years, with early versions of the computer specification providing for different sleep power levels depending on the nature of the connectivity provided during sleep. In 2007, the version 1.0 imaging specification (printers, copiers, etc.) went into effect which provided for a range of different allowances for network connectivity in sleep depending on the speed of the physical layer technology, and whether the interface was active or not during the test. As printers often have a variety of connection types present (data and network), sometimes multiple, this scheme allowed the manufacturer flexibility in which were connected so long as at least one was and at most three.

The most important aspect of the V5.0 computer specification is the inclusion of “proxying” as a capability that makes it easier to qualify as Energy Star. This technology increases the functionality of the device when it is asleep so that many people can use sleep instead of leaving it fully on [12]. It also provides new functionality to people who had previously powered down their computer when not in active use. This may require small increases in power consumption in sleep, but enabled avoiding large amounts of on time. This type of more functional low-power mode poses new challenges to policy in this area.

The EuP process on standby specifically excluded “network standby” from its scope. However, a new study on network standby is being undertaken in 2009.

As noted previously the EU Codes of Conduct on Broadband Equipment and Digital TV Services include provision for extra power for additional network functionality of products, and specify some network-specific test conditions.

The IEA Implementing Agreement on Efficient Electrical End-Use Equipment (4E) will address network connectivity and low-power modes through work within its Standby Power Annex [7]. This international project will engage stakeholders from the electronics industry, technology standards organizations, and governments to identify problems and policy solutions to many of the questions raised in this paper.

A horizontal approach to (network) low power modes

The infrastructure for policy in this area relies on network technology, test procedures, and product energy requirements. A key need is a single *horizontal* approach to measuring and regulating low-power modes.

In support of efficiency policies, the first need is a catalogue of the power requirements for different types of network interfaces, both as shown from measurements of actual devices, and as indicated by the requirements of the technologies and standards. This will provide the best basis for efficiency programs.

A workable functional adder approach applicable to all or most products needs to be developed for network functions. This would be derived from detailed assessments of the energy requirements for each of the main network related functions

For testing, a common international reference of standard conditions to apply to network connections will likely be necessary and desirable, to minimize the amount specified in individual procedures and to facilitate timely updating with new technologies. There will also likely be some reporting necessary of additional details of network conditions in testing a product to ensure that it can be reproduced and understood.

In choosing test details when there are many options, there is a tension among the goals of conditions which:

- are typical (which may be changing over time);
- fully exercise the product (e.g. use all ports); and
- provide simple comparability (and so use a minimum of ports).

The number and speed of ports connected for a test are the most immediately apparent detail to specify, but some others can be relevant, such as the distance from a product to the other end of the network link for wired or wireless interfaces (as some can modulate their transmit power to just what is needed). In future, versatility and ability to change connection speed may need to be assessed as well. As an example, the EU Code of Conduct for Broadband Equipment states that for testing, the cable on an Ethernet port should be 5m in length, and makes even more specific requirements for testing standard telephone line equipment.

For *vertical* standards (specific to one product type), many can adopt language and requirements from the horizontal standard to address network issues in the various modes and testing they cover.

The "minimum power mode while connected to mains" concept is still useful for testing and policy, and so should be retained. A good name for this is "minimum power mode".

Guiding Principles and Conclusions

Guiding Principles

Managing energy consequences of network connectivity requires an overall approach to technology and policy. These were summarized for a workshop in 2007 as "Guiding Principles" of behaviour that underpin networks [10] and are reproduced below (a smaller set of principles are in the EU Code of Conduct on Broadband Equipment.

To ensure that digital networks and network-connected devices support the minimisation of direct and induced energy consumption, the following the principles should be adopted:

Digital Networks:

- All network technologies should actively support power management.
- Connection to a network should not impede a device from power management activities.
- The network should be designed such that a legacy or incompatible device does not prevent the rest of the network from effective power management.
- Connections should have the ability to modulate their own energy use in response to
- the amount of the service required by the system.
- Terminology and concepts relating to energy management used in the design of all networks should be internationally harmonised.

Network connected devices:

- Devices should not impede power management activities in other connected devices.
- Devices should expose their own power state to the network and be able to report estimated or actual energy use.
- User interfaces should follow (international) energy management standard principles and designs.
- Devices and connections should have the ability to modulate their own energy use in response to the amount of the service required by the system.
- Terminology and concepts relating to energy management used in the design of all devices should be internationally harmonised.
- The behaviour and communication of devices relevant to energy consumption should adhere to (international) standards.

Energy Efficiency Policy:

- Governments should ensure that electronic devices enter low-power modes automatically after a reasonable period when not being used.
- Governments should ensure that network-connected electronic devices minimise energy consumption, with a priority placed on the establishment of industry-wide protocols for power management.
- Energy efficiency efforts should not favour any particular hardware or software technology.
- Energy efficiency policy should identify digital networks as a promising method for attaining energy efficiency.

Conclusions

Network connectivity is an increasing factor driving energy use in low-power modes (and other modes as well). It poses unique challenges to measurement and policy, and while this will take time to work through, the tasks are not insurmountable, and some principles and the immediate path forward are clear. A key need for networks is one that is extremely helpful for low power modes generally, namely the functional approach to testing and regulation. For networks, it will be key to having common test conditions and methods that can be incorporated into a global horizontal approach.

References

[1] European Commission 2008a, Code of Conduct on Energy Consumption of Broadband Communication Equipment, Version 3, 18 November 2008. http://re.jrc.ec.europa.eu/energyefficiency/

[2] European Commission 2008b, Code of Conduct on Energy Consumption of Digital TV Services, Version 7, 18 November 2008. http://re.jrc.ec.europa.eu/energyefficiency/

[3] Fraunhofer, 2006. *Draft Definition Document for Standby and Off-mode Losses (Lot 6, Task 1)*. Initial report dated 30 August 2006 under the European Commission Eco-design Directive contract. Available from www.ecostandby.org

[4] Fraunhofer, 2007. *Preparatory Study Lot 6 "standby and off-mode losses" – report on task 1 (definition), task 2 (market data) and task 3 (consumer behaviour and local infrastructure).* Interim reports dated 10 January 2007 under the European Commission Eco-design Directive contract. Available from www.ecostandby.org

[5] Harrington, Lloyd, Jack Brown, Shane Holt, Alan Meier, Bruce Nordman, Mark Ellis, *Standby Energy: building a coherent international policy framework – moving to the next level*, European Council for an Energy Efficient Economy Summer Study, June 2007.

[6] Harrington, Lloyd, Hans-Paul Siderius, Mark Ellis, *Standby Power: Building a Coherent International Policy Framework*, ACEEE Summer Study on Energy Efficiency in Buildings, 2008.

[7] IEA, *Implementing Agreement on Efficient Electrical End-Use Equipment (4E): Programme of Work*, January 2008. http://www.iea-4e.org/

[8] IEC, Measurement of Standby Power (IEC 62301), (IEC 59/423/CD – 2008), 2008.

[9] IEC, Measurement of Standby Power (IEC 62301), Edition 1.0, 2005.

[10] Meier, Alan, Bruce Nordman, and Mark Ellis, Buildings as Networks: *Danger, Opportunity and Guiding Principles for Energy Efficiency*, September 2007 http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=285

[11] Nordman, 2006. The Way Forward: *A New Standby Framework*. Paper presented to the international standby power conference, Canberra, Australia, 6-7 November 2006. http://www.energyrating.gov.au/forums-2006-standby.html

[12] Nordman, Bruce, and Ken Christensen, *Improving the Energy Efficiency of Ethernet-Connected Devices: A Proposal for Proxying*, White Paper, Version 1.0, Ethernet Alliance, October 2007. http://ethernetalliance.org/library/white-papers.html

[13] Nordman, Bruce, Alan Meier, Mark Ellis, *Draft Principles for Energy Efficient Digital Networks and Network-connected Devices*, International Workshop on Energy Efficient Set-top Boxes and Digital Networks, International Energy Agency, July 6, 2007. http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=285

[14] U.S. EPA, ENERGY STAR® Program Requirements for Imaging Equipment, Version 1.0, 2006. http://www.energystar.gov/ia/partners/product_specs/program_reqs/Prog_Req.pdf

[15] U.S. EPA, ENERGY STAR® Program Requirements for Computers, Version 4.0, 2006. http://www.energystar.gov/ia/partners/product_specs/program_reqs/Computer_Spec_Final.pdf

[16] U.S. EPA, ENERGY STAR® Program Requirements for Set-top Boxes, Version 2.0, 2008, http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/settop_boxes/Set-top_Boxes_Spec.pdf

Graphics and Microprocessor Technology for More Sustainable Media-Rich Computing

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Abstract

In the past, the "performance" of the microprocessors and graphics processors used in computers were primarily measured by their data processing capability. Today, media-rich audio and video files are common applications run on PCs, leading to changing performance expectations by consumers for their computers. At the same time, the energy consumption of computers is also receiving increased attention. This presentation will describe some current as well as next-generation AMD graphics and microprocessor technology for improved visual performance and at the same time, better energy efficiency, in consumer media-rich computing.

The Issue

In the past, data processing capability was the primary measure of microprocessor (CPU) and graphics processor (GPU) "performance". Clock speed, commonly expressed in megahertz or gigahertz, was a common surrogate measure of performance for both microprocessors and graphics processors, as well as computers. Performance of the graphics processor unit (GPU), has also been measured by its ability to render pictures, in terms such as pixel shader units.

The performance expectations for computers have changed due to the media-rich audio and video files that are now commonly processed by consumers. Use of PCs for viewing, editing and storing family pictures, running video and audio files on Blu-ray, or with HDMI (high-definition multi-media interface); as well as social networking, internet browsing, and multimedia applications, transcoding (conversion of one encoding format to another), and 3D gaming are some of the applications behind this changing expectation for visual computing.

At the same time, the energy consumption of computers is receiving increased attention because of practical considerations such as the desire for ever-increasing battery life in mobile platforms, as well as governmental initiatives such as the ENERGY STAR® program for computers [1], and the EC's Energy-Using Products Directive. The challenge of global climate change and the need to ensure a sustainable future in the face of increasing material and energy constraints, are also resulting in increased media attention and consumer awareness.

Current design considerations for increased energy efficiency and reduced power in microprocessors and GPU's include: dynamic active and sleep mode power management; active, active/idle and sleep mode power reduction; and techniques such as deactivation of inactive circuitry. In addition, enhanced manufacturing technologies, smaller transistor features, multi-core processor designs, as well as higher speed interconnects, and reductions in memory latency are some of the technologies that have resulted in improved energy efficiency in the form of delivered work compared to power consumption.

Happily, some new ways to do computing hold great promise for improving energy efficiency in the 2009-2010 timeframe; one example is "accelerated computing" Accelerated or stream computing combines existing X86 microprocessors with the enormous data processing capability found in existing GPUs to perform applications other than raw graphics. This combination results in performance/watt improvements up to or even greater than 20X, and speed improvements up to 30X when compared to a computer using a dual-core microprocessor alone for data processing. This presentation will describe AMD's current as well as next-generation GPU and microprocessor technology for improving power management and energy efficiency in consumer media-rich computing.

Computer Uses

Worldwide, today's consumer are using their PC's for a number of video and audio applications [2] including the management of personal photos, playing games, listening to music files and viewing and editing of videos (see Figure 1).

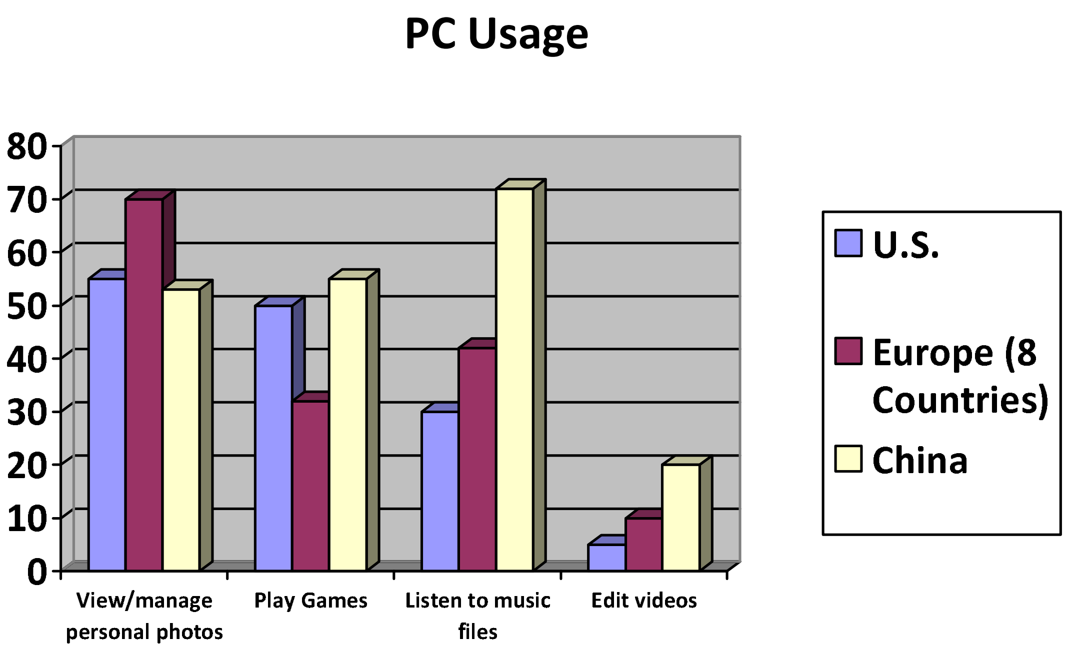

Figure 1: Percent of People Surveyed who Provide a Positive Response to the Question: Which of the following activities do you regularly use a home computer for…?

Source: AMD November 2008 Financial Analyst Day presentation [2], based on data from Forrester, Consumer Technographics Benchmark Surveys North America, Europe, Asia 2008 [3].

For some applications, such as viewing television programming online, there appears to be significant geographical differences. Recent surveys have found that 57% of Chinese consumers responded positively, compared to approximately 10-20% of U.S. and European consumers, when asked if they regularly used their home computers or internet protocol TV to watch television programming [3].

A recent U.S. study found significant generational differences regarding the ways computers are used to access the internet [4]. Teenagers and Generation Y (internet users age 18-32) are the most likely groups to use the internet for entertainment and for communicating with friends and family. These younger generations are also more likely than their older counterparts to seek entertainment through online videos, online games, and virtual worlds, and they are also more likely to download music. Compared with teens and Generation Y, older generations use the internet less for socializing and entertainment and more as a tool for information searches, emailing, and buying products. Video downloads, online travel reservations, and work-related research are now pursued fairly equally across generations.

Table 1: Pew Internet and American Life Project Surveys, Project Data Memo, "Generations Online in 2009" [4]. Generational Differences in Online Activities.

	Online Teens (12-17)	Gen Y (18-32)	Gen X (33-44)	Young Boomers (45-54)	Older Boomers (55-63)	Silent Generation (64-72)	G.I Generation (73+)	All Online Adults
Go online	93%	87%	82%	79%	70%	56%	31%	74%
Play games online	78%	50%	38%	26%	28%	25%	18%	35%
Watch videos online	57%	72%	57%	49%	30%	24%	14%	52%
Use social networking sites	65%	67%	36%	20%	9%	11%	4%	35%
Download music	59%	58%	46%	22%	21%	16%	5%	37%
Video downloads	31%	38%	31%	21%	16%	13%	13%	27%
Travel reservations	N/A	65%	70%	69%	66%	69%	65%	68%

The results of this survey are based on data from a series of telephone interviews conducted primarily between August 2006 and August 2008.

The computer game market experienced strong worldwide growth through 2008. A recent estimate indicated that there were approximately 263 million "gamers" worldwide [5].

Some researchers studying the social aspects of gaming believe that games and virtual environments will expand beyond "play" in the near future, into increasingly effective and engaging tools for collaboration. Interactive games and virtual worlds have many positive characteristics such as enabling social interactions, allowing self-expression and representation (e.g. through use of avatars), promoting competition as fun, providing immediate feedback, and creating an environment where trial and error is accepted [6]. The research firm, Gartner, estimated that by the end of 2011, around 80% of active internet users will experience a "second life" in a virtual world [7], and that 46.6 million employees globally will spend at least one day per week telecommuting, with 112 million working from home at least one day per month [8]. The increased use of virtual worlds for engagements such as meetings or discussion forums, has the potential for energy savings as an alternative to travel for off-site meetings.

AMD recently announced the availability of a free online tool-kit for creating social issue games, through an initiative called "*AMD Changing the Game*" [9]. The mission of *AMD Changing the Game* is to help nonprofit organizations take gaming beyond entertainment, and to inspire youth to learn critical education and life skills by equipping them to create digital games with social content, on such topics as the environment, energy consumption, poverty and health.. The program focuses on 13 to 18-year-olds and emphasizes enriching the overall educational experience. In 2009, AMD plans to implement additional pilot programs with non-profit organizations in order to evaluate the impact of this initiative.

Performance and Power Consumption

Graphics Processing Units

Computer graphics are either discrete or integrated. Discrete graphics are usually in the form of an add-in card that plugs into the expansion slot on a motherboard. Integrated graphics, commonly reserved for less sophisticated 2D graphics, or displaying Windows or text, are integrated with the other components on a motherboard.

Similar to microprocessors, the performance of GPUs depends on a number of criteria: process technology, architecture and clock speed as well as memory and communication interfaces. Graphics memory bus size (bandwidth), clock speed and size (RAM) also have a significant impact on overall performance. Graphics interfaces, which allow for communication with the rest of the computer, are characterized by their bandwidth [10].

Performance demands on GPUs have increased as expectations for higher image quality have increased as a result of more demanding 3D games and other applications. In addition as computer screen size increases, the higher resolutions required for an acceptable visual experience, require more powerful GPUs [10].

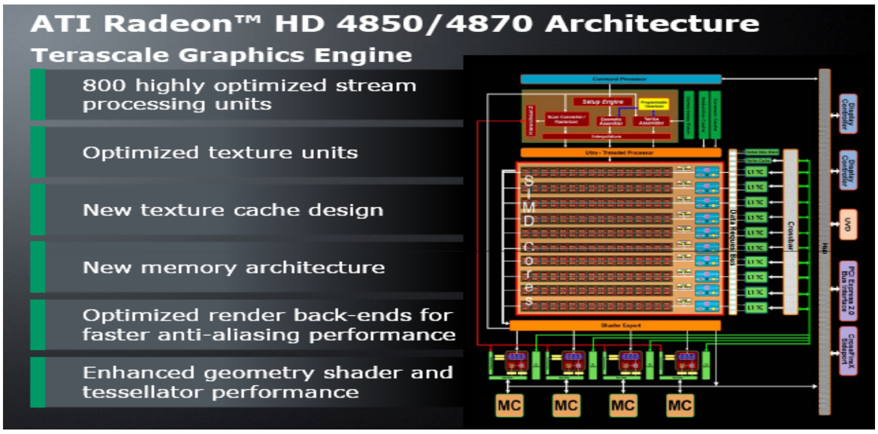

Figure 2: Example of current AMD discrete graphics architecture [11]

An example of current discrete graphics architecture is found in Figure 2. Pixel, which stands for "picture element", is a small dot of graphical information on a display, that allows for the representation of a color. Pixel processors (pixel shader units), which are found on graphics chips use programs to do calculations to represent color values.. Texture is applied to 3D images to simulate its surface features. Geometry shaders allow objects to be broken apart and modified to form geometries that are more complex and that more closely approximates reality. Anti-aliasing technology smooths the appearance of jagged edges around objects, which can be most obvious with moving images. New graphics memory architectures are allowing for reduced latency and power consumption [11].

Energy efficiency has become a key "performance" feature of the modern GPU, as shown in Figure 3. In the 12 month period beginning in July 2007, the energy efficiency of AMD discrete graphics technology, measured in GigaFlops per watt, improved by approximately 4x [11]. Similar to CPUs a variety of power management technologies are used to reduce power consumption in GPUs. For example, ATI PowerPlay™ technology, which is available for both desktop and notebook computers, modulates GPU power and performance according to load so that power is based on real-time demand. As a result, power consumption is greatly reduced when the GPU is idle or when demand is low, for example, when receiving or composing emails. In addition to dynamically adjusting the GPU clocks and voltages, clock gating, which is used in ATI PowerPlay™ technology, allows for functional blocks of the GPU to be shut off when not in use; its impact is shown in Figure 4 [11].

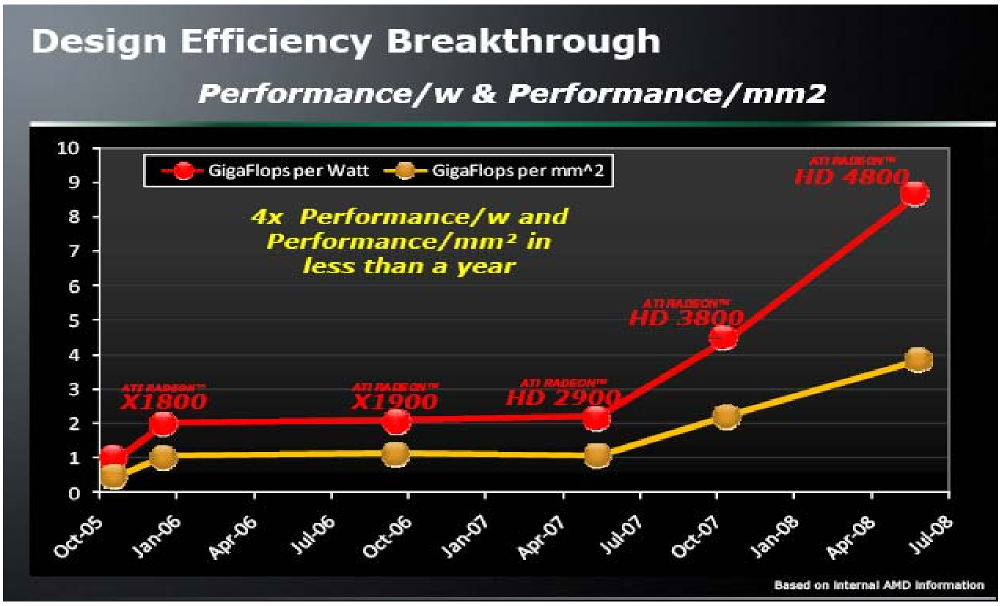

Figure 3: Energy efficiency of AMD discrete graphics card technology [11].

Power consumption is also a key design consideration for the integrated graphics found on current AMD chipsets [12].

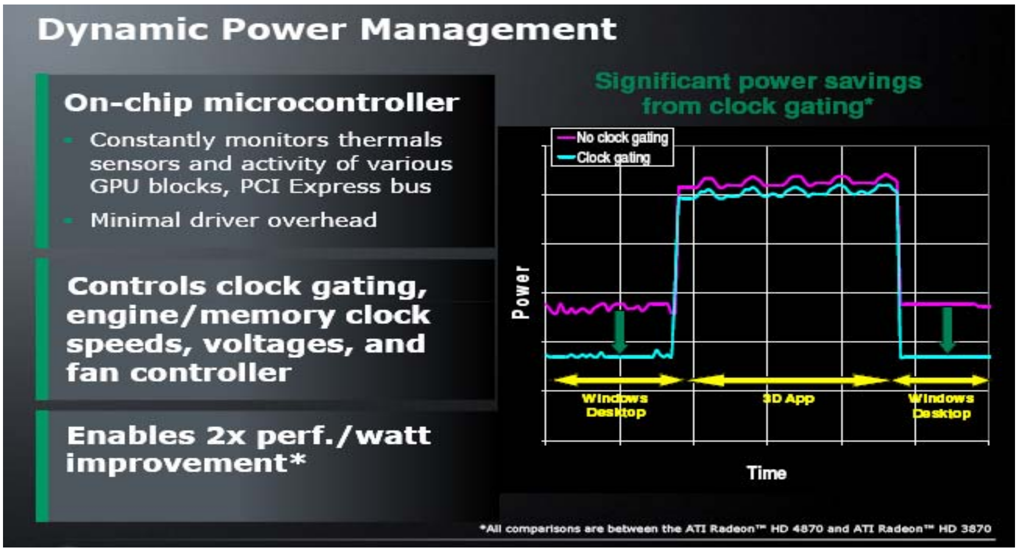

Figure 4: Effect of dynamic power management clock gating in a GPU [11].

The use of chipsets with more powerful and efficient integrated graphics is allowing for reduced PC power consumption. In recent testing, power consumption of 73 W was measured during the playback of a Blu-ray movie on a PC, a significant decrease in platform power compared to earlier generations of technology [13]. In addition, offloading functionality formerly contained in the CPU onto the chipset, for example HD video decoding can result in reduced CPU load and power consumption. For ultraportable PCs, which have a very limited power budget, energy-efficient chipsets can play an important role in reducing overall system-level power consumption [14].

Microprocessors

As stated previously, the performance of CPUs depends on a number of criteria including: manufacturing technology, architecture, transistor and core count, clock speed, on-board cache as well as memory bus and bandwidth. Dual-core processors predominate in today's client market, over single-core and quad-core processors [15]. Current CPUs on the market, are primarily manufactured with 45 nanometer technology, with 32 nm manufacturing technology anticipated in the 2009-2010 timeframe."Shrinks" in manufacturing technology allow for smaller transistors faster transistor switching, lower voltages and reduced capacitance. At the same time, smaller feature sizes also increases the potential for current leakage, which can affect idle power consumption [16]. Energy efficiency and power consumption of the CPU have been key "performance" attributes that have been recognized for a number of years [17].

In 2007 and 2008 AMD introduced a number of new or improved power management technologies for multi-core microprocessors [18]:

- Enhanced AMD PowerNow! ™ technology with Independent Dynamic Core Technology, which reduces processor power consumption by allowing processor cores to operate at various voltages and frequencies, depending on workload.
- Dual Dynamic Power Management ™, which reduces power consumption by allowing independent control of power to the processing cores and the integrated memory controller.
- AMD Wideband Frequency Control, which provides up to eight different performance states to maximize power efficiency.
- Cool'n'Quiet ™ 2.0 technology, which enables nearly-instantaneous adjustment of performance states and features based on processor performance requirements.
- C1 Enhanced (C1E), a feature that works with Cool'n'Quiet 2.0 technology to help

reduce overall power consumption by slowing selected system functions when they are not in use. Power savings of 55 percent have been observed at idle with Cool'n'Quiet technology with C1E support, compared to idle without Cool'n'Quiet technology

In early 2009, AMD's new notebook and desktop platforms, consisting of a processor, chipset and graphics, incorporated both power and performance benefits over the previous generation of AMD technology [15]. A low power platform was offered for the growing ultraportable market segment [14]. New power management technology was also introduced, with extra power states allowing for lower processing speeds and as a result, greater reductions in power compared to the earlier generation of that technology [19].

Future Technology

In the near term, additional performance and energy efficiency improvements are anticipated based on CPU and GPU technology planned for the market in the 2009-2011 timeframe. Cloud computing, an emerging IT deployment and delivery model enables the real-time delivery of products, services and solutions over the Internet. Its use in anticipated to grow significantly through 2012 [20]

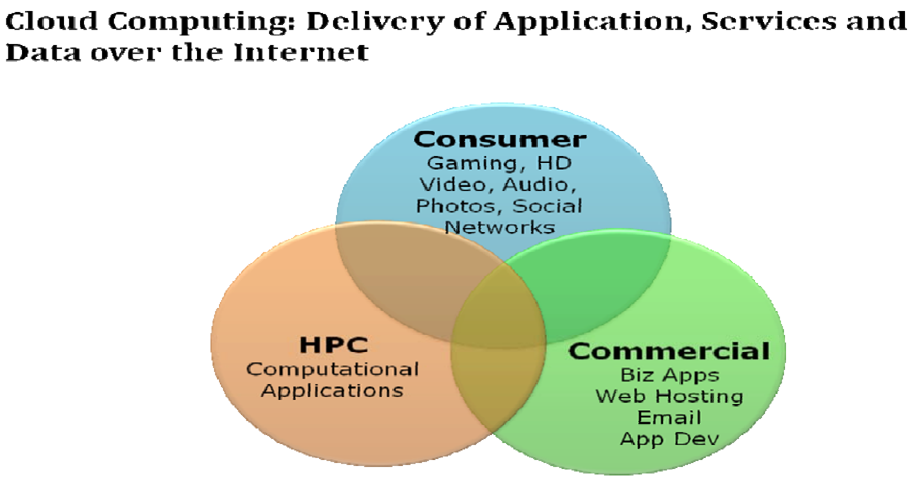

Figure 5: Current and anticipated cloud computing applications [20]

Energy efficiency is a key priority for companies providing cloud services, especially those with large "scale out" data centers. In addition, client computers used for delivery of cloud computing services are likely to have functionality and power consumption profiles similar to today's thin clients, although in some use cases, additional graphics capabilities will be desired.

New computing models, such as the fusion of the GPU and CPU onto the same silicon die, and accelerated computing, are also expected to have performance and energy efficiency benefits. Accelerated computing involves the use of both generalized and specialized processors (or accelerators) for computing. These accelerators may take the form of off-core chips, such as media or network packet accelerators, or they may be additional cores designed for specific types of processing tasks. Overall, accelerators tend to have lower latency and higher throughput for processing tasks, with increased energy efficiency, when compared to general purpose CPUs [21].

Stream processing (or GPGPU) utilizes the enormous data processing capabilities that are found in GPUs for the purposes of computation. Proof of concept testing occurred in 2005-2006 in collaboration with the Folding@Home program at Stanford University, a research program studying the contribution of protein folding to diseases like Alzheimer's. In this evaluation, 20-40x improvements in speed of processing were found [when compared to processing performed with general purpose CPUs [11] [22]. Improved processing speeds can reduce latency and the overall time needed for performing an application. Stream processing holds great promise for future energy efficiency improvements in applications such as game computing, and also for areas of scientific research such as global climate change, water resource management, new energy sources, new material and manufacturing processes, tissue engineering, patient-specific medical therapies and drug design.

Conclusion

The performance expectations for computers have changed due to the media-rich audio and video files that are now commonly processed by consumers. PC power consumption does not need to increase significantly as a result. Current microprocessor, chipset and graphics manufacturing and power management technologies are resulting in energy efficiency and power improvements over the previous generation of technology. For example, in recent testing, power consumption of 73 W was measured during the playback of a Blu-ray movie on a PC, a significant decrease in platform power when compared to the previous generation of technology. Power limitations of current and emerging platforms such as ultraportable computing and cloud computing are also demanding reduced power. The increased integration of the GPU and CPU holds great promise for future power reductions in scientific computing and also in computer gaming.

Ultimately, the protection of global climate must be a key consideration and driver for semiconductor manufacturers like AMD in the development of new technology; partnerships with stakeholders in government, NGOs and universities are welcome in helping AMD to focus on and achieve this goal.

References

[1] ENERGY STAR Version 5.0 computer specification. Can be downloaded at: http://www.energystar.gov/index.cfm?c=revisions.computer_spec

[2] AMD, Nigel Dessau presentation, Financial Analyst Day of November 13, 2008. Can be downloaded at: http://www.amd.com/us-en/Corporate/InvestorRelations/0,,51_306_15891,00.html

[3] Forrester, Consumer Technographics Benchmark Surveys: North America, Europe, Asia 2008.

[4] Pew Internet and American Life Project. Pew Internet Project Data Memo, *Generations Online in 2009.*, 28 January 2009.

[5] PC Gaming Alliance, worldwide computer gaming data.

[6] Melymuka, K. *Revenge of the Gamers: World of Warcraft is Honing Tomorrow's Leaders.* Computer World Management, 12 May 2008. Available at: http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=317260

[7] Gartner. "*Gartner Says 80 Percent of Active Internet Users Will Have A "Second Life" in the Virtual World by the End of 2011"* 24 April 2007. http://www.gartner.com/it/page.jsp?id=503861

[8] Gartner. *"Predicts 2009: A new era in client computing delivery and usage models."* 23 December 2008.

[9] AMD Changing the Game, http://www.amd.com/us-en/Corporate/VirtualPressRoom/0,,51_104_543_15944~130029,00.html

[10] Woligroski, Don *Graphics Beginners' Guide,* Tom's Hardware, 24 July, 2006. Can be downloaded at: http://www.tomshardware.com/reviews/graphics-beginners,1288.html

[11] AMD, Neal Robison presentation, Financial Analyst Day of November 13, 2008. Can be downloaded at: http://www.amd.com/us-en/Corporate/InvestorRelations/0,,51_306_15891,00.html,

[12] AMD chipset specifications, http://www.amd.com/us-en/0,,3715_15532_15533,00.html

[13] Toepelt, B. "*AMD's New 780G Chipset has Powerful GPU*" Tom's Hardware, 4 March 2008, available at http://www.tomshardware.com/reviews/amd-780g-chipset,1785-15.html

[14] Toepelt, B. *"Athlon vs. Atom: Duel of the Energy Savers".* Tom's Hardware, 15 August, 2008, available at: http://www.tomshardware.com/reviews/Atom-Athlon-Efficient,1997.html

[15] iSuppli, *Compute Platforms Q4 2008 Topical Report – Microprocessors,* 5 February 2009.

[16] Kim, NS."*Leakage Current: Moore's Law Meets Static Power".* IEEE Explore, December 2003, available at http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=01250885

[17] Sadowy, D. *Energy Efficient Microprocessor Design: More Performance with Less Power.* Proceedings of Electronics Goes Green conference, September 2004.

[18] AMD 2008 Global Climate Protection Plan, available for download at: www.amd.com

[19] Toepelt, B. "*AMD Phenom II X4: 45nm benchmarked: the Phenom II and AMD's Dragon Platform".* Tom's Hardware, 7 January 2009, available at: http://www.tomshardware.com/reviews/phenom-ii-940,2114.html

[20] Lewis, M. *The Value of the AMD Opteron™ Processor for Web and Cloud Computing.* January 2009, AMD internal communication.

[21] AMD White Paper *The Industry Changing Impact of Accelerated Computing.* Available for download at www.amd.com.

[22] Smith, R. *The GPU Advances: ATI's Stream Processing and Folding@Home.* AnandTech, 30 September 2006. Can be downloaded at: http://www.anandtech.com/video/showdoc.aspx?i=2849

Consumer Electronics

Gadgets and Gigawatts

Mark Ellis

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Abstract

By 2010 there will be over 3.5 billion mobile phones subscribers, 2 billion TVs in use around the world and 1 billion personal computers. Electronic devices are a growing part of our lives and many of us can count between 20 and 30 separate items our homes, from major items like televisions to a host of small devices. The communication and entertainment benefits these bring are being enjoyed by people in wealthier and developing regions alike - in Africa, one in nine people now have a mobile phone using a network which is extending across the continent in a way which fixed telecom lines could never match. But how energy efficient is this equipment and should we be concerned about how much energy these gadgets use?

This paper summarises a new IEA publication, *Gadgets and Gigawatts* [1], which includes a global assessment of the changing pattern in residential electricity consumption over the past decade, and an in-depth analysis of the role played by electronic equipment. It reviews the influence that government policies have had on creating markets for more energy efficient appliances and identifies new opportunities for policies designed to create smarter homes.

Keywords: *energy efficiency; consumer electronics, policies, international*

Introduction

All electrical residential appliances[1] account for approximately 30% of electricity generated in OECD countries and 12% of all electricity generated carbon dioxide emissions [2]. A good understanding of the drivers behind residential electricity consumption is therefore important for policy-makers aiming to mitigate climate change or increase energy security.

As shown in Figure 1, per capita household electricity consumption has increased by an average of 2% per annum in the decade between 1996 and 2006. During this period, population growth and increased access to electricity has driven up overall electricity consumption at even a faster rate, particularly in non-OECD countries [3].

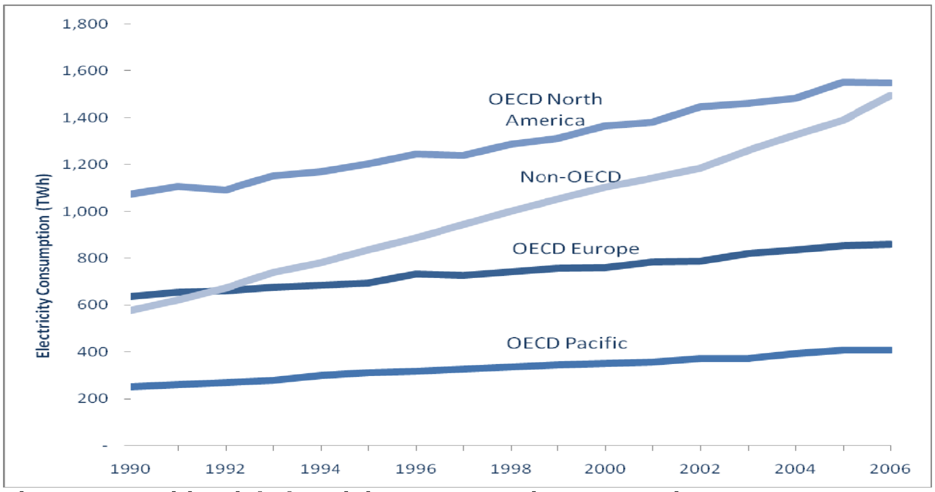

Figure 1: Residential electricity consumption per capita, 1996-2006

Source: Gadgets and Gigawatts (OECD/IEA 2009)

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[1] Residential appliances are here defined as any appliance or type of equipment commonly used in the home.

It is noteworthy that these rates of growth have exceeded many forecasts. For example, in 2003 the IEA publication, *Cool Appliances,* estimated that appliance electricity consumption in 22 IEA countries[2] would grow by 1.3% per annum between 2001 and 2006 to approximately 2,540 TWh. However, actual electricity consumption by these 22 countries grew by 2.3% per annum and exceeded the projection by over 80 TWh in 2006, or approximately 3.3% (see Figure 2).

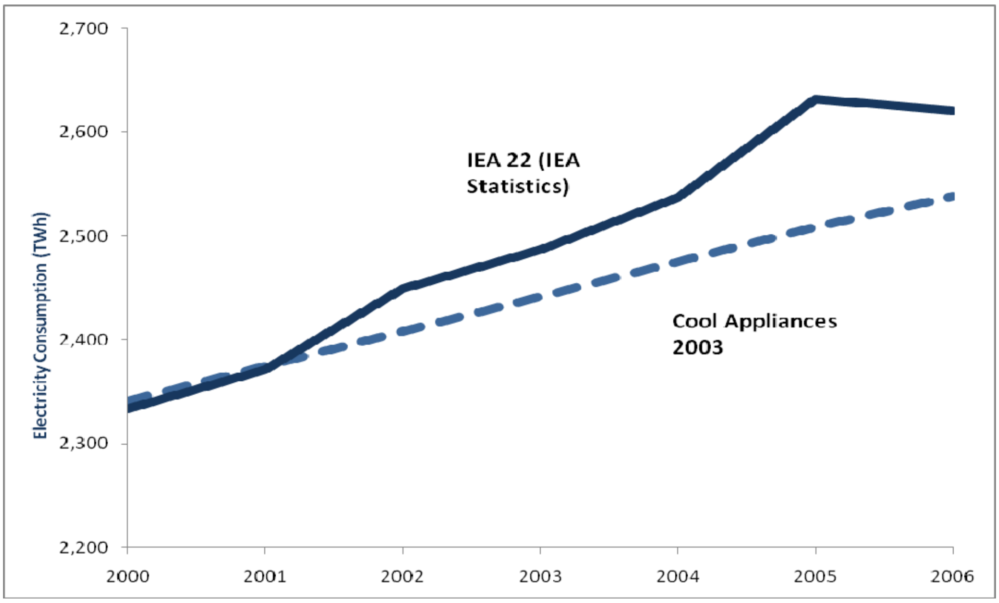

Figure 2: Comparison between Cool Appliance projection and actual residential electricity consumption, 2000-2006

Source: Gadgets and Gigawatts (OECD/IEA 2009) and Cool Appliances (OECD/IEA 2003).

As governments around the world wrestle with the challenges of climate change, energy security and economic development, the growth in residential electricity consumption in all regions threatens to jeopardise many policy objectives in these fields. The remainder of this paper aims to shed more light on the underlying issues behind the growth in residential electricity consumption, and explores the ramifications for future energy policy.

Changing End-Use Patterns

In most countries, policies designed to achieve long-term market transformation in the supply and adoption of energy efficient appliances have been in force for many years – in some for at least 15 years. A wide range of policy measures have been used, generally targeted at different market participants and designed to overcome particular barriers. Minimum energy performance standards and energy performance labels have been the most widely employed measures, frequently supported by government procurement policies, financial incentives such as discounts and rebates, and general awareness raising programmes.

The success of these highly targeted programmes is evident: the per unit energy consumption of many major household appliances has fallen dramatically over the past decade in most economies, while at the same time products have increased in size, capacity and power (see Figure 3) [3]. Appliance prices have also fallen in real terms, confirming that the correlation between appliance prices and energy performance is generally very low or even negative.

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[2] The following countries were included in this analysis: Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States.

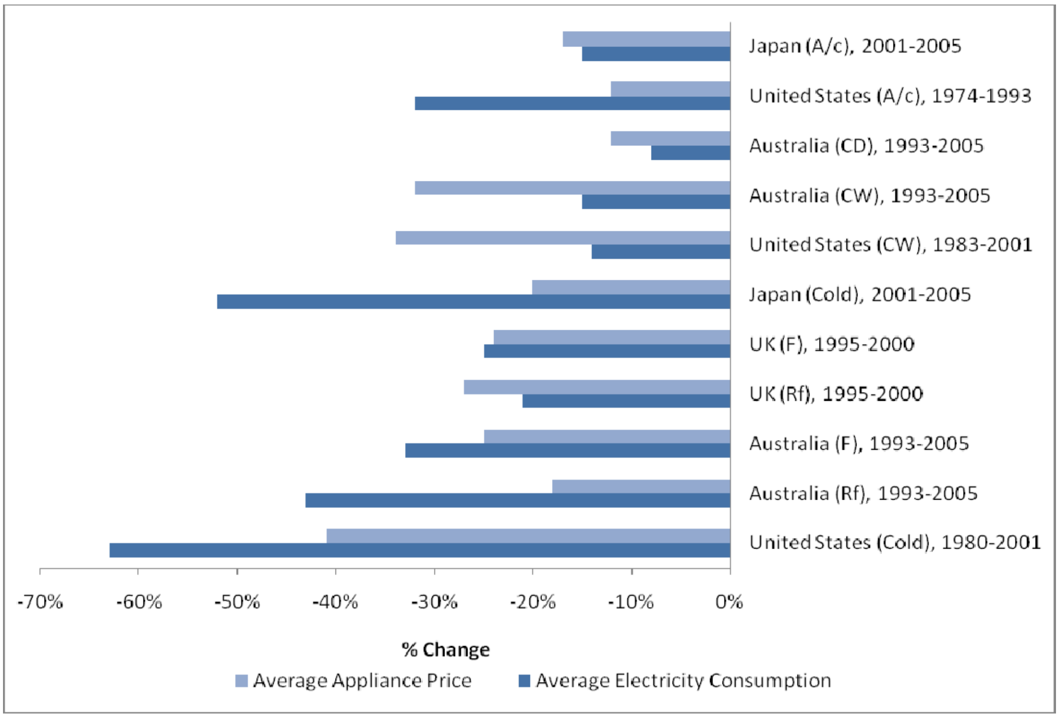

Figure 3: Recorded fall in average electricity consumption and prices for several major appliance types in selected countries

Source: Experience with Energy Efficiency Regulations for Electrical Equipment, (IEA 2007).

Key:

A/c	Air conditioners	Cold	Refrigerators and freezers
CD	Clothes dryers	F	Freezers
CW	Clothes washers	Rf	Refrigerators

In OECD countries those appliances which previously used the majority of electricity, such as refrigerators, clothes washers and water heaters, are close to saturation levels. As ownership rates have stabilised and the efficiency of these appliances improved (partly due to government policies), their share of residential electricity consumption has fallen. In non-OECD countries, while the ownership level for major appliances is already high in urban areas, increased access to electricity in rural areas and growing urbanisation is helping to drive up overall ownership levels.

Yet, despite the improvements in the performance of major residential appliances there has not been a decrease in overall electricity consumption over recent years, as might have been expected.

Changing Patterns of Electricity Consumption

A real understanding of the factors influencing changes consumption patterns can only be gained by examining detailed end-use assessments based on reputable data. While the monitoring needed to support such bottom-up assessments is far from universal, data from several major economies offers strong clues as to why residential electricity consumption has increased markedly over the past decade.

As indicated in the examples taken from the US, UK and Australia, shown in Figure 4, Figure 5 and Figure 6 respectively, some countries have experienced large increases in lighting electricity consumption. The fact that it does not appear to be a widespread trend may indicate differences in the adoption rate of improved technologies between countries (e.g. a greater share of compact fluorescent lighting), changes in user behaviour (e.g. time spent at home) or measurement issues (e.g. inclusion of plug-in lighting). Some of these issues have been discussed in more detail in *Light's Labour's Lost* [5]. In regions with warmer climates, the greater penetration and use of air-conditioning is also noticeable.

However, the growth of electricity consumption by small electrical and electronic devices has been the most rapid of all appliance categories over the past five years in both OECD and non-OECD countries. Despite evidence of the growing significance of information and communication technologies (ICT) and consumer electronics (CE) which surrounds us, there have been few global assessments of the resulting energy impacts, now and into the future.

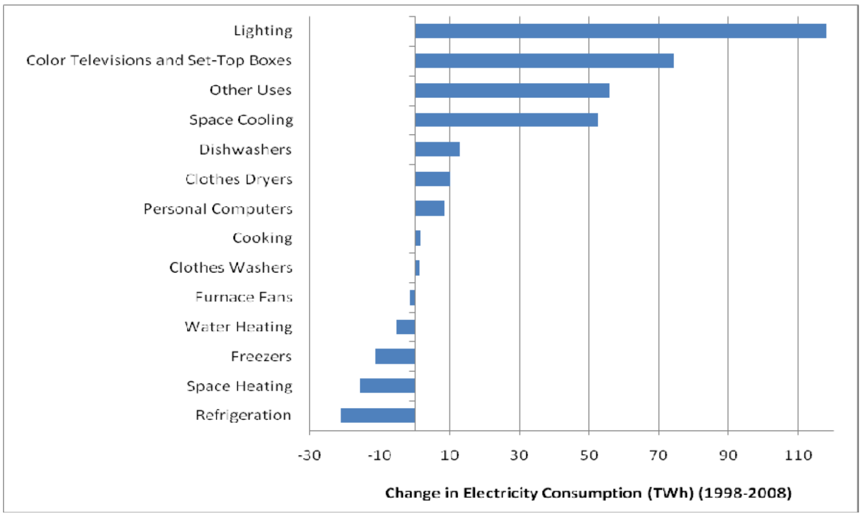

Figure 4: Change in electricity consumption and % change by end-use category, United States, 1998-2008

Source: Annual Energy Outlook (EIA 2000 & 2008).

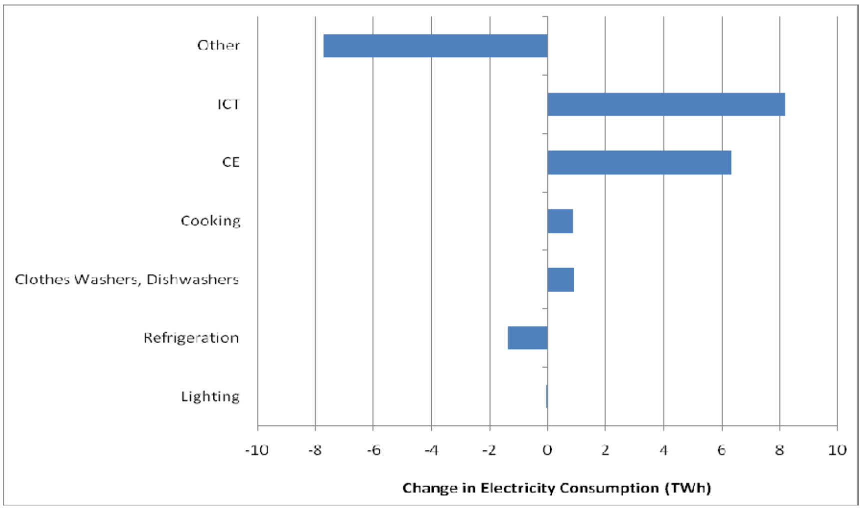

Figure 5: Change in electricity consumption by end-use category, United Kingdom, 1998-2006

Source: UK Market Transformation Program (2008) [8]. Note: Other category includes water heating, space heating and miscellaneous.

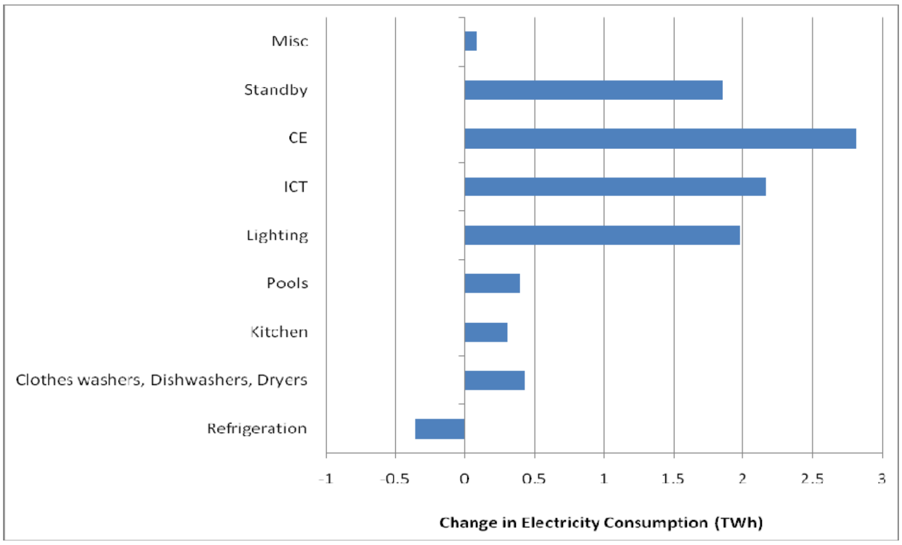

Figure 6: Change in electricity consumption by appliances, Australia, 1998-2008

Source: Energy Use in the Australian Residential Sector 1986-2020 (Commonwealth of Australia 2008).

Global trends in residential ICT and CE electricity consumption

ICT and CE equipment span a wide range of appliances found in varying quantities in residences. In addition to televisions, desktop computers and laptops, these include DVD players and recorders, modems, routers, printers, scanners, set-top boxes, cordless telephones, answering machines, games consoles, audio equipment, battery chargers, mobile phones and children's games. In fact there are at least 40 different appliances which can be included within this sector.

Driven by increasing penetration rates and the adoption of larger TVs and the arrival of digital broadcasting, final residential electricity consumption by ICT and CE equipment grew by nearly 7% per annum between 1990 and 2008. This sector now accounts for nearly 15% of residential electricity use, which is similar to the share for other major appliance categories such as water heating or refrigeration, and can make up a much higher share in some households [1]. Together they consume nearly 700 TWh of electricity each year, requiring over 180 GW of generating capacity and costing consumers USD 80 billion in annual electricity bills.

Despite this, the coverage of electronic devices by energy efficiency policy measures at the present time has failed to keep pace with the development of this sector, with most programmes focused on a minority of products and voluntary in nature.

Looking ahead, it is likely that ICT and CE equipment will take an even greater share of residential electricity consumption unless policy measures are introduced to increase energy efficiency. Under estimated market conditions, the IEA expects that energy use by ICT and CE equipment will double by 2022 and increase threefold by 2030 to 1 700 TWh (see Figure 7). This level of consumption is equivalent to the current combined total residential electricity consumption of the United States and Japan, requiring the addition of approximately 280 GW of generating capacity, and costing householders around the world USD 200 billion in electricity bills.

The share of electricity consumption by these appliances is therefore increasing to the extent that they will most likely comprise the largest residential end-use category in many countries before 2020.

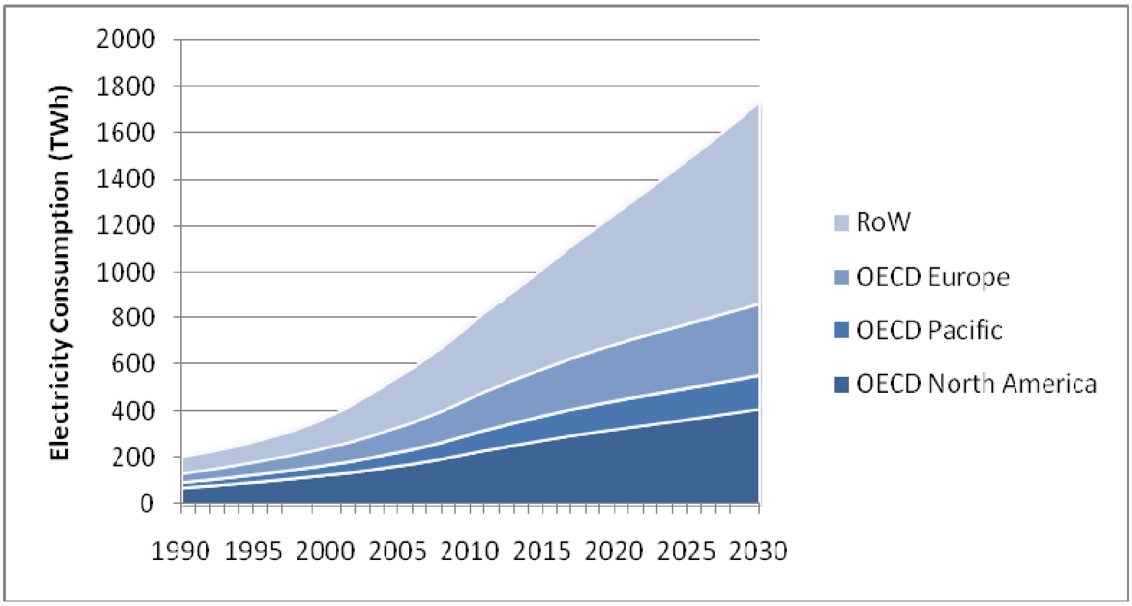

Figure 7: Estimated electricity consumption by ICT and CE equipment in the residential sector, by region, 1990-2030

Source: Gadgets and Gigawatts (OECD/IEA 2009). See [1] for more details of assumptions used in these estimates.

Market and technology trends

There are a number of competing trends that underlie these aggregated figures. For example, new television and computer screen technologies in the form of flat LCD panels have replaced less efficient traditional CRT screens extremely rapidly in OECD countries and a similar trend is now occurring in non-OECD countries. However, the energy benefit has been outweighed by consumer demand for larger screen sizes, so that the average energy consumption of display technologies has risen and continues to do so [1].

Falling consumer prices for electronics have fuelled the rapid uptake of technologies and the availability of broadband and wireless has allowed multiple users within the same household. This has led to an increase in average viewing hours, as householders make greater use of their screens to watch material from the Internet, view stored digital photos or recorded TV programmes and play video games.

Increasingly ICT and CE equipment is connected either to other devices in the home, or via the internet to external devices and service providers. Various modems, routers and set-top boxes are examples of relatively new types of connected appliances which have increasing importance. With the switch to digital broadcasting in many countries by 2015, the increasing penetration of pay-TV, and more people adopting bundled TV and telecom services over the Internet, the energy used by such devices will grow.

On the other hand, there will be efficiency benefits from the convergence of some technologies, such as TVs and computers; and set-top boxes, DVD players and recorders. In the longer term, computers may play a more central role, replacing many individual audio and home entertainment devices. Computers themselves are getting more energy efficient and the growing use of laptop computers in the residential sector is helping to moderate energy consumption.

While individual technology and market trends are complex, with many diverse factors of influence, the overall key drivers in this sector can be summarised by Figure 8 and Figure 9, which show the estimated change in stocks and average unit energy consumption (UEC) of all ICT and CE appliances between 1990 and 2030 in the residential sector.

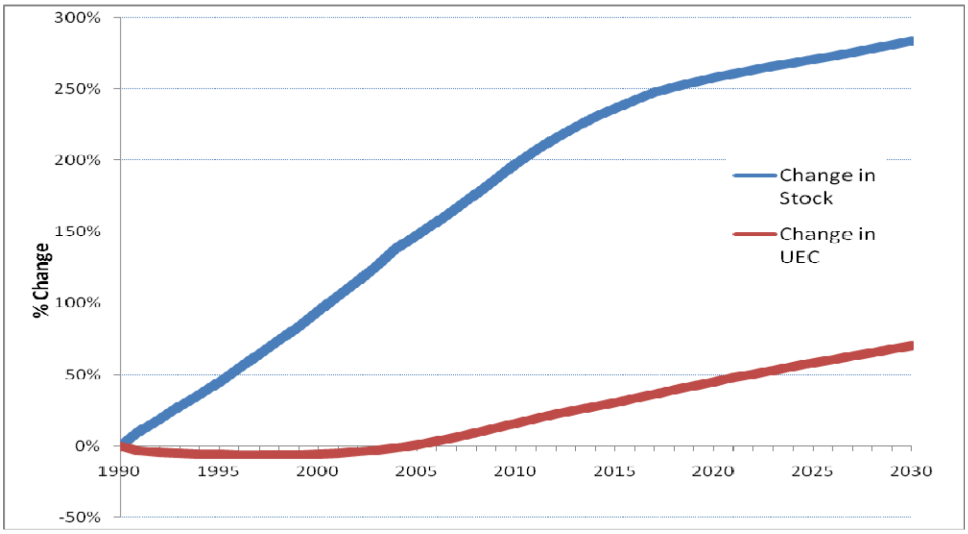

Figure 8: Estimated change in stocks and average unit energy consumption (UEC) of residential ICT and CE appliances in OECD, 1990-2030

Source: Gadgets and Gigawatts (OECD/IEA 2009). The effect of structural changes, mainly the switch to flat screen technologies and laptop computers, is evident in the reduction of UEC values prior to 2005.

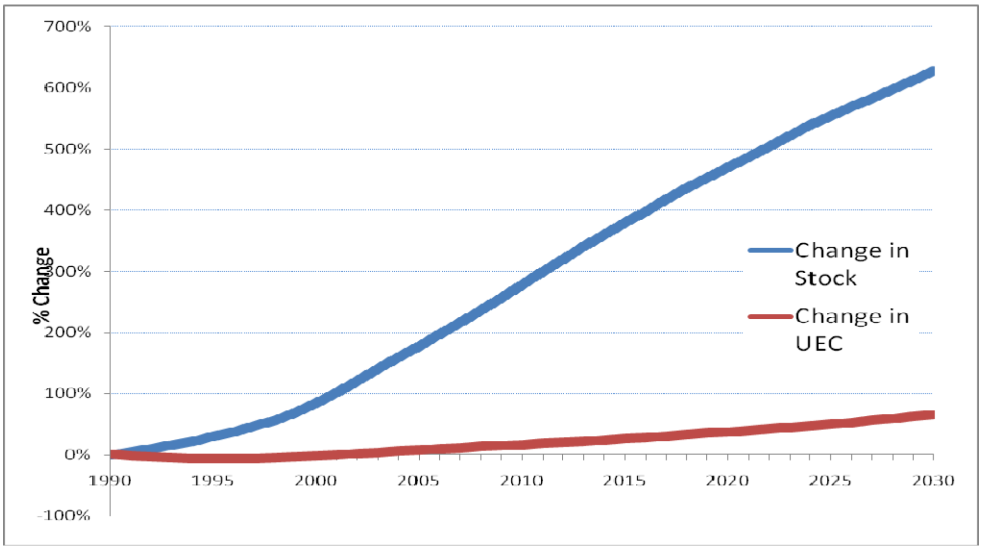

Figure 9: Estimated change in stocks and average unit energy consumption (UEC) of residential ICT and CE appliances in non-OECD countries, 1990-2030

Source: Gadgets and Gigawatts (OECD/IEA 2009). The effect of structural changes, mainly the switch to flat screen technologies and laptop computers, is evident in the reduction of UEC values prior to 2005.

These figures show the rapid and growing penetration of electronic appliances in both OECD and non-OECD countries, and the increase in the energy consumption of individual appliances after 2005. While convergence and saturation will see the growth rate of devices in the OECD fall after 2015, this trend is unlikely to be mirrored in non-OECD countries. Although non-OECD countries already account for the majority of sales of most ICT and CE equipment, the potential markets are extremely large and even modest penetration levels, far less than for the OECD, will lead to a large increase in energy consumption (see Figure 7).

Alternative scenario

Governments should take heart from the fact that alternative technologies exist now which could greatly reduce the impact of electronic equipment. As with many other categories of appliances, there is a large efficiency spread amongst products of similar price which perform equivalent tasks. In the few instances where clear market drivers for energy efficiency exist, such as with mobile devices where size, weight and extended battery life are valued features, the industry has demonstrated an ability to deliver large savings in energy consumption.

Figure 10 shows the potential impact on the business as usual (BaU) projection of switching to more efficient technologies which represent the least life-cycle cost (LLCC), and therefore impose no additional costs on consumers. The global adoption of LLCC technology would cut electricity consumption by an estimated 30% in 2030, compared to the business as usual scenario. Even more dramatically, by using the best currently available technologies (BAT)[3], electricity use could be cut by more than half, saving USD 130 billion in consumer electricity bills and avoiding the need for 150 GW of new generation capacity.

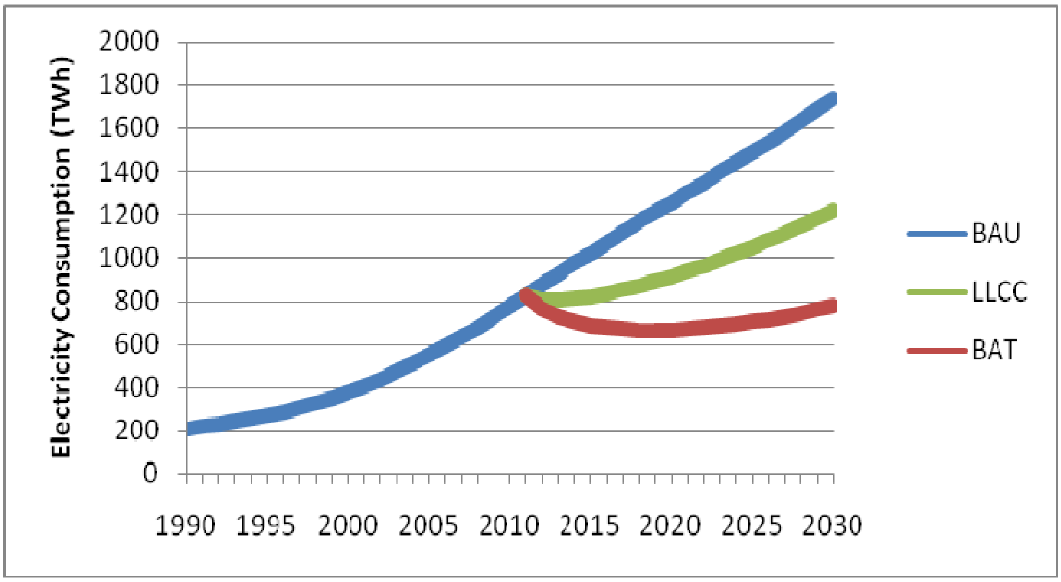

Figure 10: Estimated electricity savings from adoption of least life-cycle cost (LLCC) and best available technologies (BAT)

Source: Gadgets and Gigawatts (OECD/IEA 2009).

Additionally, improving the efficiency of residential ICT and CE equipment could lead to benefits beyond the residential sector, since many of the technologies used in businesses are similar. There is a large potential to use electronics to better control energy consumption in all types of equipment.

In considering policy options to stimulate markets for LLCC and BAT technologies, governments need to be mindful of some unique characteristics of ICT and CE technologies and markets, and the barriers which currently inhibit their uptake.

Technology and market characteristics for ICET and CE

The following summarises some of the most important factors which influence the market for electronic devices:

[3] BAT technologies and processes are not only currently available, but in many cases already have some penetration in commercial markets.

- The combination of (relatively) low purchase costs, short lifetimes and consumer trends allow electronic appliances to reach high ownership rates more rapidly than many traditional household appliances.
- Unlike many major appliances where technology saturation levels are fairly predictable and rarely exceed much more than one per household, the ceiling for ownership levels of electronic appliances is not well understood.
- For many electronic appliances, the rate of increase in ownership has intensified in recent years as new appliances come onto the market offering new or increased functionality.
- Increased features and functionality is a major driver in markets for electronic devices, often causing products to be replaced prior to the technical end of life. Such older products are frequently kept for use by other household members.
- Electronic appliance models are designed to be used in many different ways by consumers, from those requiring high performance and full features, to others which require more basic functionality. Most electronic goods are shipped with a high level of features enabled, which usually have an energy cost, even though the average user may not make use of these capabilities.

Although generally the energy efficiency of most electronic devices is improving, achieving the level of savings represented by the LLCC and BAT scenarios will not occur without policy intervention as a result of considerable market barriers and imperfections. Some barriers are specific to particular technologies or market segments, however a number are more widespread. These include:

- An emphasis on achieving low purchase cost within highly competitive markets, with a low market value placed on lifetime costs;
- Poor consumer information on the performance and running cost of most ITC and CE equipment;
- Energy saving opportunities spread over a large number of different devices, with small financial benefits from improving the energy performance of individual items;
- Long and complex supply chains between component manufacturers, software designers, OEMs and product suppliers, which cause market signals to be diffused;
- Hidden costs and risks, including time spent in developing energy efficient products and potential for additional consumer confusion/complaints;
- Failures due to principal agent issues in some market segments, where the financial benefits of investment in energy efficiency accrue to some other party thereby reducing the incentive to invest.

Where there are clear market drivers for energy efficiency, such as with mobile devices where size, weight and extended battery life are valued features, the industry has demonstrated an ability to be highly innovative in reducing energy consumption. Levels of efficiency are far higher in these devices than in equipment which draw power from the mains electricity supply, illustrating that the market does not provide a strong incentive for energy efficiency for the majority of technologies.

The presence of market imperfections justifies government intervention. However the potential to promote other key objectives, including energy security, greenhouse gas abatement and provision of least-cost energy services, suggests that governments need to pay urgent attention to policies for ICT and CE equipment.

Key policy approaches

Governments have a range of policy tools available to help stimulate a sustainable market for more energy efficient technologies, many of which have already proven to be effective when fully implemented. New policies which internalise a carbon price will generally help to make energy efficiency more cost-effective, however they will not overcome the majority of specific barriers facing ICT and CE equipment. For example, motivated consumers still need to differentiate between the performance of products; and consumers that take equipment as part of a rental or service agreement will still have no say in the product’s efficiency.

Smarter electronics which match the energy used by appliances to the services demanded by the user can lead to large improvements in energy efficiency. Already many portable devices manage their energy consumption effectively and, with the implementation of some key policies identified below, these same techniques would become more generally applied.

- **Setting long-term policy objectives:** Governments should define long-term policy objectives for technology in the electronics field, setting performance targets for individual appliances categories and work with industry and other stakeholders to agree on implementation plans.

- **Direct action by governments:** Policy makers need to select combinations of measures which are best suited to achieve their policy objectives and overcome market barriers. For ICT and CE equipment, all layers of government can play a key role in establishing markets for high efficiency products by adopting strong procurement policies. Where principal agent issues prevent investment in energy efficiency, governments can also include energy efficiency obligations within licensing agreements for third parties, such as TV service providers.

- **Horizontal policy approaches:** One of the major challenges in establishing policies for ICT and CE equipment is the difficulty in closely defining individual devices due to varied functionality and the introduction of new product categories in the market. However, as further convergence occurs, products are increasingly defined by the functions that they perform, rather than by their product description. Policy measures should therefore attempt to be horizontal in nature and based on functionality, thereby spanning common functions provided by any device.

- **Power Management:** For ICT and CE equipment, the largest proportion of savings result from ensuring that products are able to modulate their power requirements according to the services they provide to users. All portable devices have very advanced power management processes which co-ordinate appropriate features within their hardware and software, demonstrating the technical feasibility of these systems. Policies should specify that power management functions are fully automated so that input from consumers is not required for the device to work efficiently, and loaded as the default option within all products supplied.

- **Efficiency scaled to size:** In the past, energy performance targets, thresholds or limits have included a scaling factor such that the energy which is allowed to be used by products is related to their capacity, size or volume. However, when this information is used as the basis for consumer information, consumers may infer that products with the same label rating, or which carry an endorsement label, consume similar quantities of electricity; which can be far from the truth. Policy measures would better reflect national policy objectives for energy and greenhouse gas reduction through re-structuring these thresholds so that larger or more powerful appliances are required to have higher, but attainable, efficiency levels.

- **International co-operation:** Electronic devices are the most globally traded of all household appliances. Considerable progress has been made in recent years on the alignment of policies on ICT and CE equipment as a result of on-going dialogue between energy efficiency programme managers on test methodologies and future policy intentions. Further alignment is possible but will require governments to ensure that their strong support for harmonisation is reflected throughout the processes involved in standardisation and energy policy development.

For governments to adequately respond to the new challenges posed by increasing residential electricity consumption, and particularly in the ICT and CE fields, they will need to build on the established infrastructure of existing energy efficiency programmes to deliver targeted policy measures. For ICT and CE, many of the solutions lie in stimulating the potential within electronic appliances to be cleverer about the energy they, and all appliances, consume. To make this happen will require a scaling-up of government investment in the processes of policy development and implementation.

Such expenditure would be fully justified because many of the same techniques which will save energy in ICT and CE equipment will also have application in other residential appliances, and other in sectors of the economy.

References

[1] (OECD/IEA 2009), *Gadgets and Gigawatts: Policies for Energy Efficient Electronics,* Paris, France.

[2] OECD/IEA (2003), *Cool Appliances: Policy Strategies for Energy-Efficient Homes,* Paris, France.

[3] OECD/IEA (2006a), *World Energy Outlook 2006,* Paris, France.

[4] IEA (2007), *Experience with Energy Efficiency Regulations for Electrical Equipment*, Information Paper, International Energy Agency, Paris, 2007.

[5] OECD/IEA (2006b), *Light's Labour's Lost: Policies for Energy-Efficient Lighting*, Paris, France.

[6] EIA (2000), *Annual Energy Outlook*, Report DOE/EIA-0383 (2000), 2000.

[7] EIA (2008), *Annual Energy Outlook*, Report DOE/EIA-0383 (2008), 2008.

[8] MTP (2008), *Pers. Com.* Mr Kevin Lane, UK Market Transformation Program, 21 May 2008.

[9] Commonwealth of Australia (2008), *Energy Use in the Australian Residential Sector 1986-2020*.

How compatible are Consumer Electronics and sustainability?

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1. Abstract

The market for Consumer Electronics (CE) is currently characterized by a dramatic technological shift: CRT-TVs are replaced by LCD- and Plasma-TVs in more and more private households. This development comes along with a trend towards bigger screens and improved picture quality.

The technological change has led to remarkable improvements with regard to the average stand-by power consumption. On the other hand, the shift to bigger and bigger Flat Screens causes a significant rise of the in-use power consumption. Moreover, on an average household level, the number of devices increases and the daily TV use remains on a high level. As a result, the CE sector becomes more influential for the total private power consumption.

When comparing the manufacturers' assortments considerable differences in energy efficiency can be observed: this is an indicator for existing technical saving potentials which have not yet been exploited.

2. Latest energy relevant developments in the market for Consumer Electronics

2.1 Information basis

If nothing different is mentioned, data are based upon the representative retail tracking of GfK Retail and Technology. The particular advantage of this fact based global market information system is that both long and short term developments as well as trend turning points can be precisely identified and that sales and product data up to the level of individual models are taken into account.

Regional basis of the analysis are 22 selected European countries regularly audited by GfK[1].

NB: all power consumption relevant facts are based upon information given by the manufacturers on their product sites and in their leaflets. Due to the not yet existing binding measuring standard this information is not 100%-ly comparable from product to product, but the massive change of the energy consumption impact of the CE market shown in the following analyses is only marginally qualified by that.

2.2 Influence factors and subjects of the analysis

Energy consumption in the context of this analysis is a function of the

- number of appliances
- product mix
- average consumption per time unit per product (in the various modes)
- daily time in use per product
- daily time in stand-by mode per product

[1] EU22 = A/B/CH/CZ/D/DK/E/F/FI/GB/GR/H/I/NL/P/PT/RO/RU/S/SR/TR/UA

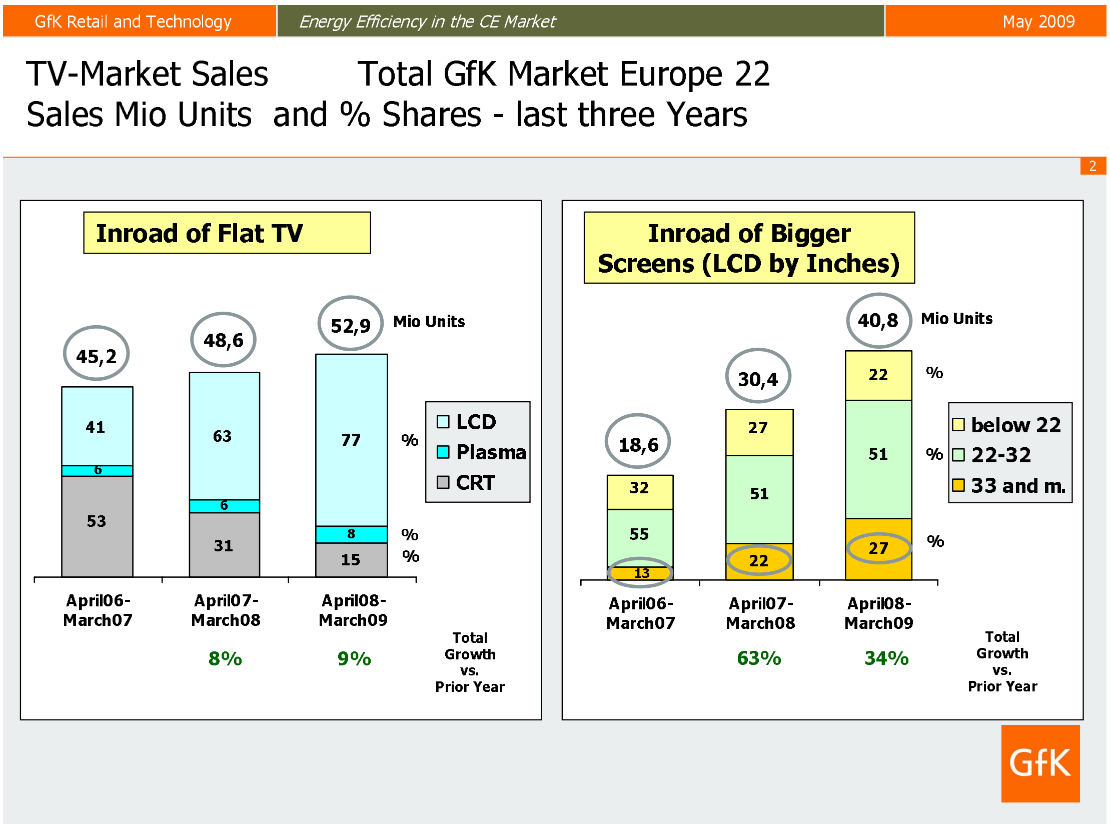
Subject of this analysis are concrete facts regarding the first 3 factors, based upon GfK's retail tracking and upon manufacturers' data regarding power consumption, while for the daily time in use respectively in stand-by mode specific assumptions will be made.

2.3 Market development of Consumer Electronics

The CE market is currently characterized by a dramatic technological shift in its by far most important sector, the TV-segment:

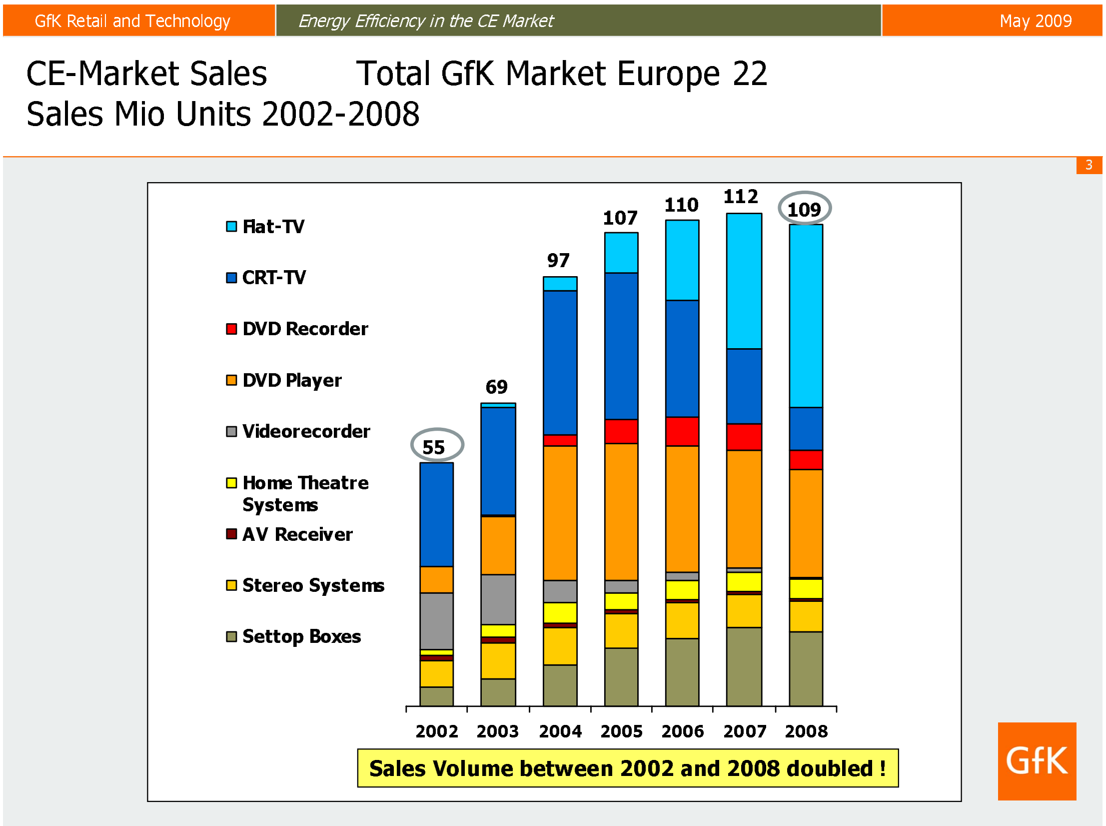
CRT-TVs are replaced by LCD- and Plasma-TVs in more and more private households throughout Europe 8 (EU 22). While in the year 2002 still only 1% of the private households was equipped with a Flat-screen TV, until March 2009 the penetration rate has reached an average European level of approx. 50%.

The following chart in the left part visualises the impressive total market growth and the change in the sales mix over the past 3 years. It also shows in the right part how at the same time bigger screens are gaining more and more importance: while in the period April 2006 until March 2007 only 13% of the LCD-TV sales volume belonged to screen sizes bigger than 32 inches, two years later the latter already counted for 27%:



Not only the TV-market has experienced a massive growth but also other CE categories. When aggregating all home devices of that sector on a sold unit basis we see a growth of 98% compared to the year 2002 (see next chart).

This development meanwhile has led to a far higher number of CE products in use in the private households.



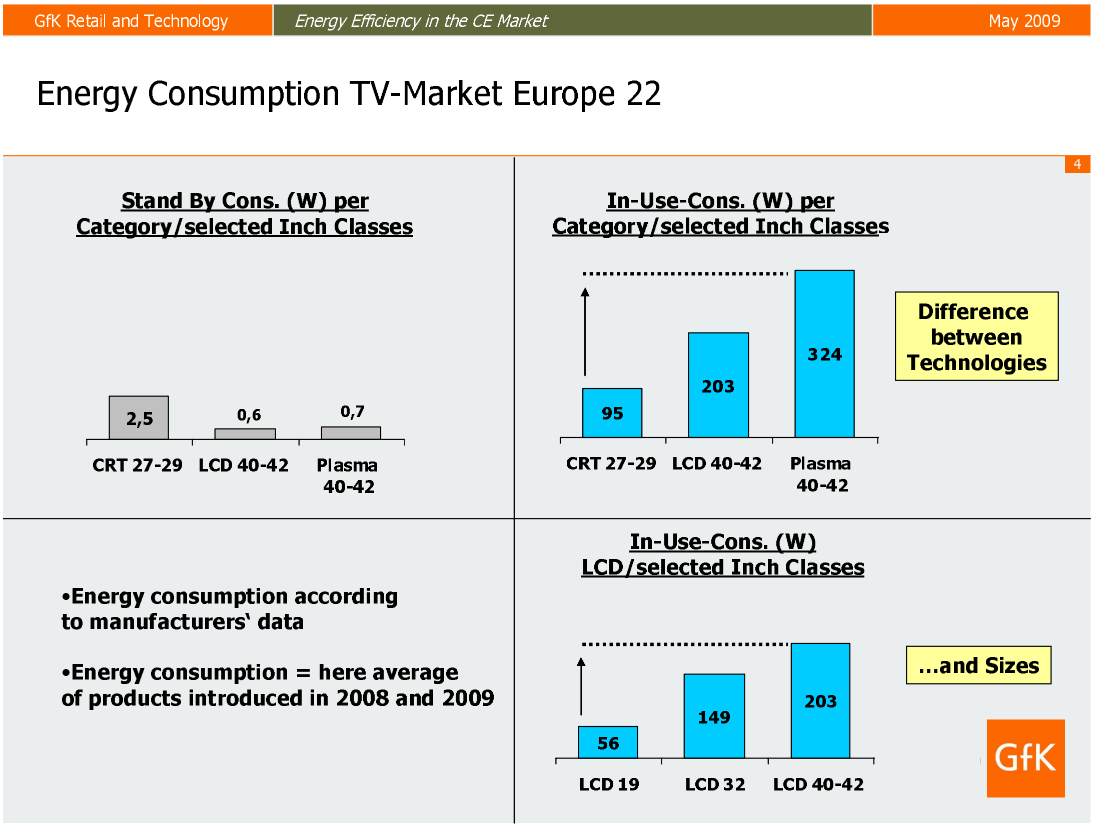
2.4 Key facts regarding energy consumption of Consumer Electronics products

The technological change in the TV market has had a huge impact on energy consumption. On the one hand there is an improved situation with regard to stand-by power consumption, as Flat-TVs do consume less power in that mode than CRT-TVs (see next chart) .

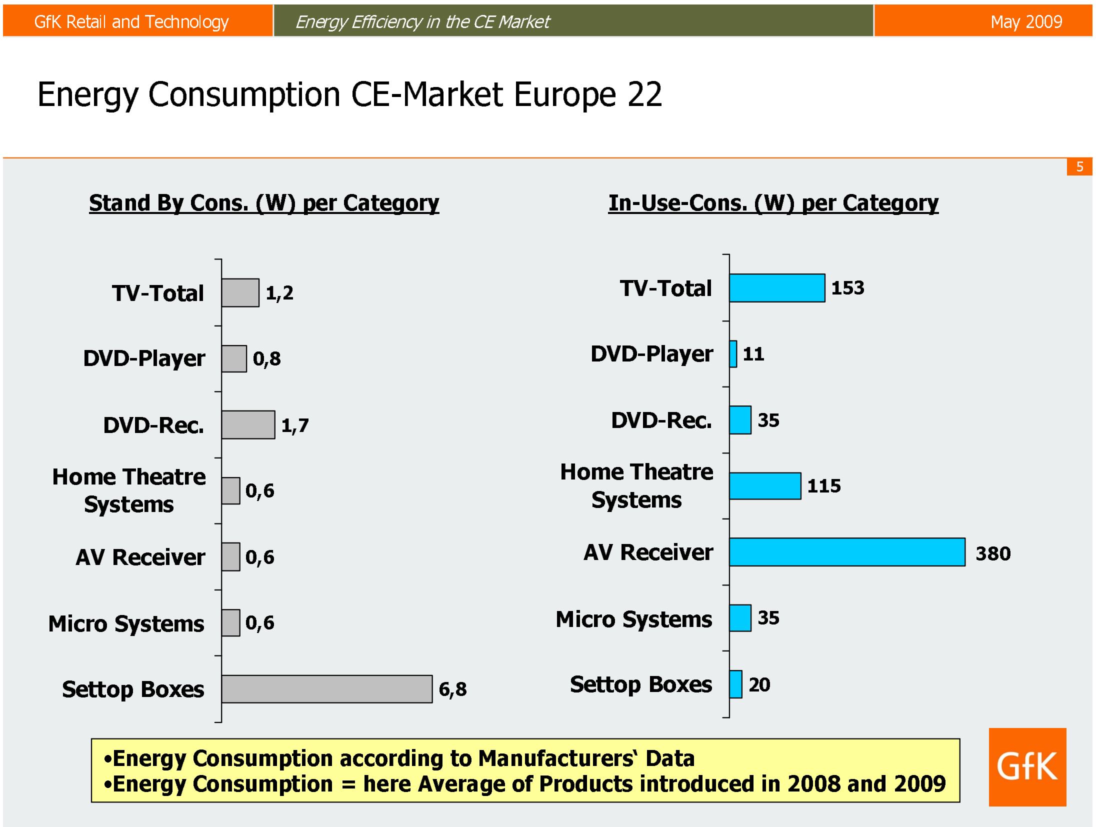
On the other hand the impact for the energy consumption in use is critical: when comparing the technologies on similar Inch-class bases, Flat-TVs do show a significant higher energy consumption in use than CRT-TVs (see same chart). This effect is even strengthened by the aforementioned trend towards bigger and bigger screen sizes.

Of course, it must also be taken into account that in case of replacement purchases normally a product which is approx. 10 years old is replaced by the newest technology. When comparing, for instance, a today's 32 Inches LCD-TV with a 27/29 Inches CRT-TV of 1998 the difference is smaller than when comparing it to a CRT-TV of 2008.

The following chart summarizes the differences in power consumption for the 2008/2009 product generation in selected key product segments:



Of course, there are also other CE products as Audio Home Systems, Hifi-Components, DVD-Players/Recorders and Settop-Boxes which have got an impact on the CE related energy consumption picture:



Because of the outstanding role of the TV-market – approx. 60% of the CE related in-use power consumption is TV induced – the following detailed analyses refer to the TV-market.

2.5 Development over time in the TV market

When comparing the average consumption per device for different product generations, inside important homogenous screen size classes, no energy efficiency gains can be observed:

In use power consumption W in selected screen size segments over time

Product generation:	2006	2008/2009	+/- %
LCD-TV 32 Inches	142	149	5
LCD-TV 40-42 Inches	223	203	-9
Plasma-TV 42 Inches	302	324	7
Average of those 3	222	225	1

Source: manufacturers' data for single models

This average increase in large part can be explained by the fact that the current product generation is better featured than that one of 2006 (e.g. better picture quality, built in tuner, built in harddisc).

2.6 Stand by versus in-use-consumption

As the share of stand-by energy consumption inside the total TV related energy consumption, depending from the usage assumptions made, is below 5%, resp. including other CE products below 10%, the following analyses do focus on the in-use energy consumption.

3. Impacts on TV-induced energy consumption

3.1 'Fleet' consumption approach

What is the combined effect of the market growth, the change in the product-mix and the energy efficiency gains per homogenous screen size category?

A meaningful indicator for that is GfK's 'fleet' consumption approach. This figure represents the cumulated power consumption per hour of the TV sets sold in a specific year when all switched on. It takes into account the technological and screen size related shift as outlined above, while other factors, like the average daily TV use in the households, are considered as stable here (ceteris paribus assumption):

As a matter of fact, as the following table shows, over the past 3 years the sales volume has significantly increased, while the fleet consumption shows a growth even stronger within the same time span. This means the average in-use consumption per sold TV-device over the past 3 years has increased by 36%.

Fleet consumption over time

	April06-March07	April07-March08	April08-March09
TVs sold (million units)	45,2	48,6	52,9
Growth %		8	9
Fleet Consumption (GW)*	5,0	6,5	7,9
Growth %		28	23
Average Cons./Device (W)**	111	133	150
Growth %		20	13

*=Sales volume x average consumption per device

**Source: manufacturers' data for single models; sales weighted average

Key drivers, as already indicated, are the inroad of Flat-TVs and the increasing share of bigger screen sizes. The fleet consumption can be interpreted as an early indicator because significant changes in the consumers' purchase behaviour are quickly perceived, while household penetration data because of the inertia in the figures relating to an installed base, fail to keep up with shorter term developments.

With such a technology induced increase in energy consumption the CE market is on a critical path.

3.2 Impacts on the energy costs of the private households

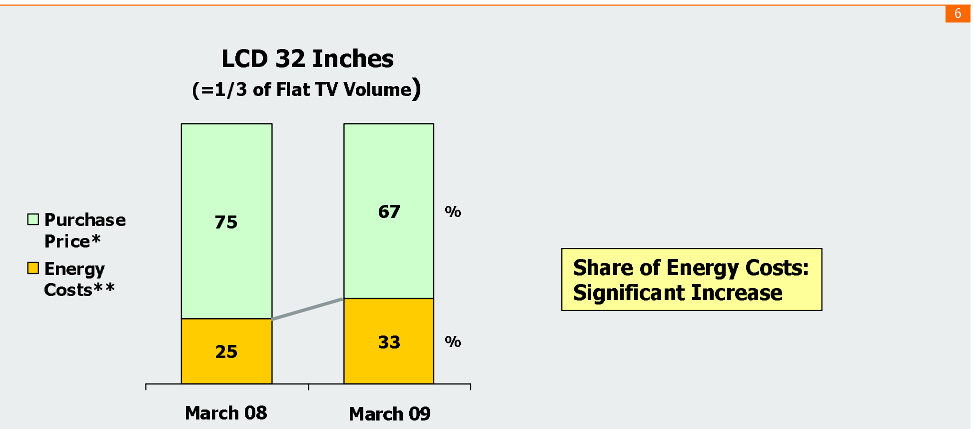
The energy consumption growth gets more influential for the private households the higher the prices for electric power are.

For the following analysis we calculate with an European average electricity tariff of € 0,165 per kwh.

While energy costs have increased by 4%, the average purchase price for the key product segment LCD 32 Inches has fallen by 30% within one year. Thus, the energy costs have meanwhile reached a remarkable share of the entire lifecycle costs (sum of sales price and energy costs) of this type of devices:

GfK Retail and Technology | *Energy Efficiency in the CE Market* | May 2009

Energy Costs TV-Market Europe 22
Share % of Total Lifecycle Costs



	March 08	March 09	
Purchase Price = Average Sales Pr. €*	727,-	511,-	-30%
Energy Costs €**	243,-	253,-	4%

*Average price of all models weighted by their sales
**Calculated with below assumptions and based upon manufacturers' data; average of all models weighted by their sales
Assumptions: 7 years product lifetime / usage 4 hours per day / stable 0,165 € per kWh

4. Benchmarking between manufacturers and between single models

4.1 Differences in energy efficiency between manufacturers

When comparing the top 10 selling manufacturers, inside homogenous screen size classes, it shows that there are still big differences between the most and the least energy efficient brand.

The following table summarises the situation based upon 2 key segments for March 2009:

Power consumption of 10 best selling manufacturers' (EU 22) assortments – index based*

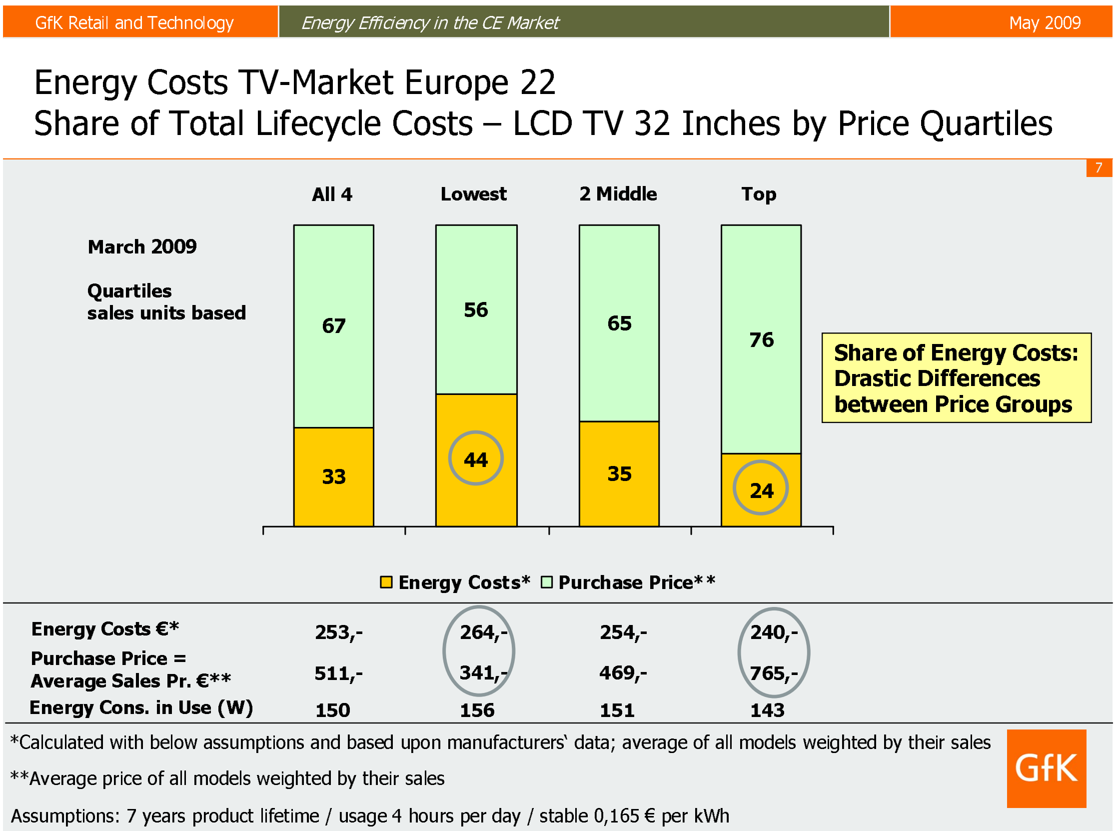
	LCD-TV 32 Inches	Dev. from Average in %	Plasma-TV 42 Inches	Dev. from Average in %
1. (Best Brand)	83	-17	82	-18
2.	90	-10	85	-15
3.	91	-9	94	-6
4.	94	-6	96	-4
5.	94	-6	98	-2
6.	95	-5	101	1
7.	96	-4	102	2
8.	111	11	103	3
9.	122	22	115	15
10. (Worst Brand)	124	24	122	22

Ranking according to power consumption (W according to manufacturers' data)
Brand values = sales weighted average of individual models
100 = average of 10 best selling brands

In the LCD 32 Inches segment the energy efficiency of the best out of the 10 top selling brands is 33% better than that of the worst brand. The same is true for the Plasma 42 Inches segment. This already indicates the huge saving potential not yet converted into higher energy efficiency.

4.2 Differences in energy efficiency between price categories

The following chart shows an interrelation between purchase price classes and the energy costs:



Due to the fact that energy efficiency is the result of higher efforts in research and development and in higher investments into product components, the average power consumption in the top price class is lower than in the cheapest quartile.

It also shows that the relative energy cost impact for a buyer of a low end product is almost twice as high as for a buyer in the top quartile.

4.3 Differences in energy efficiency between single models

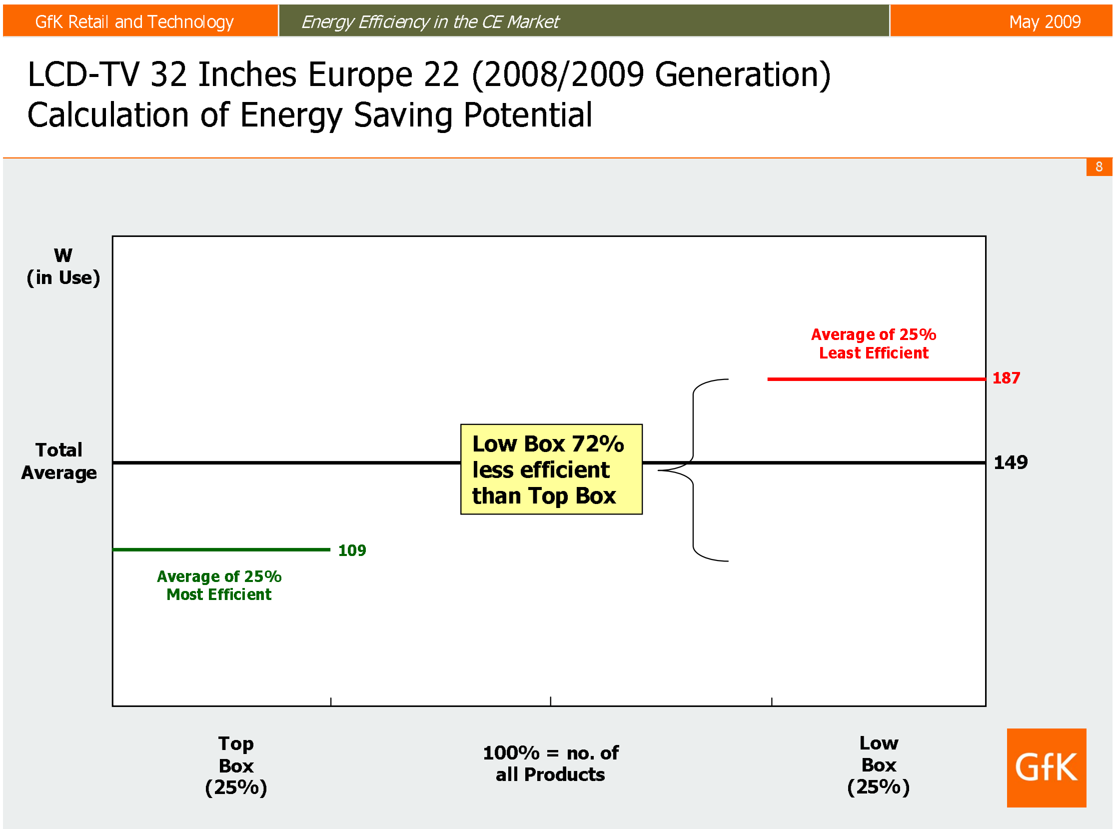
When doing the same comparison as for manufacturers also for single models the differences, esp. for LCD-TVs, get even more distinct. In the following only the 2008 model generation is taken into account:

Power consumption W of all models introduced in 2008 and 2009

	LCD-TV 32 Inches	Dev. from Average in %
Top box (25% most energy efficient)	109	-27
Average	149	0
Low box (25% least energy efficient)	187	26

Source: manufacturers' data for single models

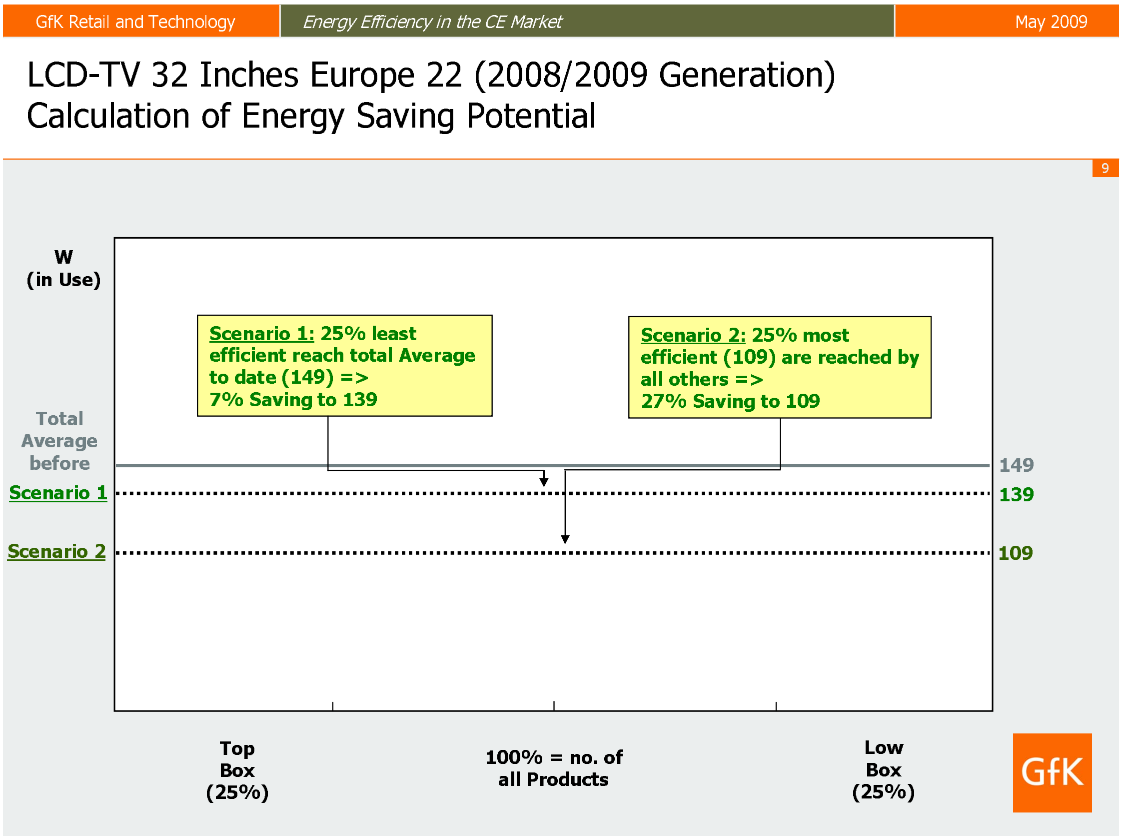
In the LCD-TV 32 Inches sector the low box is 72% less energy efficient than the top box:



Two scenarios for this product category underline the existing energy saving potentials (see next chart):

Scenario 1: if the low box models reached the average to date of 149, this would mean an energy efficiency gain of 7%.

Scenario 2: if, in a more ambitious scenario, all models reached the average of the top box models, this would mean an energy efficiency gain of 27%.



5. Summary

It could be shown that due to the shift from CRT-TVs to – bigger and bigger – Flat TVs ceteris paribus the TV induced energy consumption has increased over the past years. Another impact for energy consumption derives from the growing total number of CE devices purchased and in use in the private households.

Energy costs, even looking into homogenous product segments, are on the rise while at the same time product prices decrease dramatically. That is why the energy cost share of the total lifecycle costs has increased and in some segments already counts for more than 1/3.

When comparing energy efficiencies on a brand level and on an individual product level massive differences become obvious. This indicates energy saving potentials on the product side and gives valuable insights for product class-building in terms of energy efficiency.

Difficulties in the Energy Efficiency Standards Program for Consumer Electronics, By the Case of Set-Top Boxes

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Abstract

As the technical development of the design and manufacture, the market of electronics products changes very quickly. The obvious feature is that the same kind of electronics products has diverse and countless functions. These functions make the criteria for evaluating of power consumption difficult. Furthermore, the integration of different function into one device (Multi-function Devices) is now more and more common. The distinction of the products becomes ill-defined. It also makes the effective category of standards unclear. Additionally, the shorter life cycle of the products challenges standard programs much. The normal way for the establishment of standard program may be inefficient to keep up with the market transformation. The specialties of the electronics products need related standards program more flexible and swift to achieve the energy saving objects.

There are some tentative ways in the recent standard programs to deal with above difficulties. Evaluating the energy consumption of functional modules in the electronics products was accepted in some standard programs. The program on the basis of BAT is also a reasonable way to accelerate the process of establishing programs. Improving awareness of consumers is also beneficial to bring forward the standard program successfully.

Key words: Consumer Electronics, Energy efficiency, Standard, Difficulties, Set-top Boxes

1. Introduction

With the dramatic decreasing of prices and appearance of innovative function, users of home consumer electronics have a sharp increase in decades. CD/DVD players, set-top boxes (STBs), digital TV, home audio etc. have been more common. For example, global sales of DVD player with record function reached 55 million in 2007 from 3.3 million in 2003. In the same way, consumer electronics market has became one of the most important electronics market in China. By evaluation, market share of consumer electronics has an average increasing rate of 18% annually. [1]

Since the large amount of consumer lacking of awareness on energy consumption of products, the energy consumption by consumer electronics became significant. According to the finding of CEA, the energy consumption of consumer electronics excluding digital televisions has occupied a share 11% of U.S. residential electricity consumption in 2006.[2] And EPA predicts this percentage is expected to be 18% in 2015. While in 1999, this share only occupies a percentage of 6.7.[3]

The STBs is a typical product to investigate the energy efficiency standard program for consumer electronics. As a technical trend in the television broadcast, the signals of digital mode are replacing the signals of analog mode globally. Nowadays, many countries in Europe, North America and Asia have conducted the transformation programs of television signal. Schedules have been released for the closure of the analog signals. The STBs is an important terminal device for the transformation of digital signals to analog signals. By the prediction, the production of STBs in the world may reach the 1.1 billion sets in 2007 and 1.5 billion sets in 2009.

As a developing country with the largest population in the world, China has the greatest amount of the TV population and TV sets. Nowadays, there are 40 million TV sets in China, as the quantity of the TV set in the world is about 1.5 billion. Recently, the digital broadcasting television has a dramatic increasing in some larger cities in China. By the year of 2006, there are about 12 million cable-TV users utilizing the digital signals and 25 large cities have completed the entire transformation of the analog signals to digital signals in the whole country.

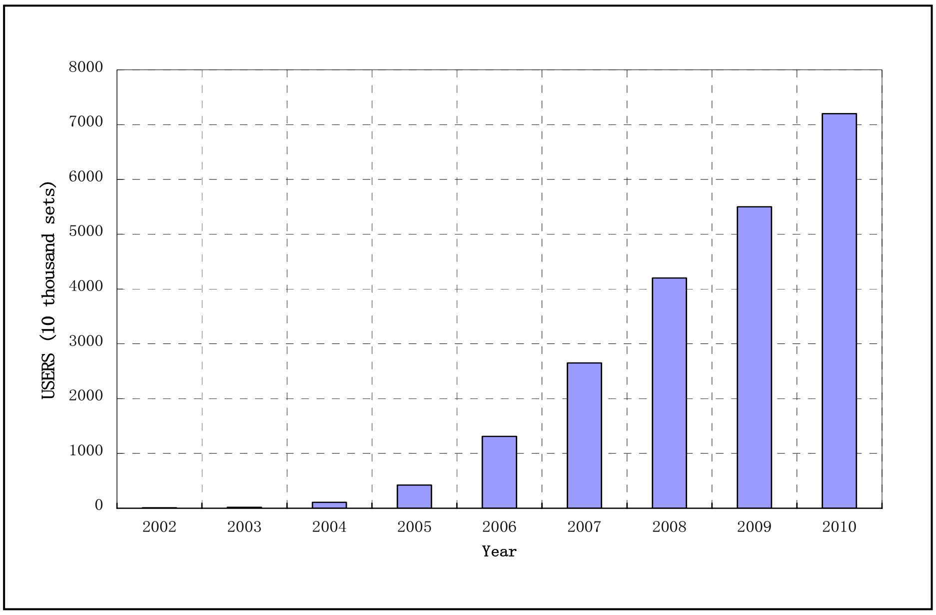

Fig.1 Prediction of the STBs users in China

As shown in Fig.1, there may be a significant increasing of China STB users and it may reach about 70 million in 2010.[4] In U.S., there also has been a quick increase of STB user from 110 million to 148 million between 1999 and 2006.

2. Difficulties in energy efficiency standard programs for STBs

Because of the large number of the installation, STBs with lower energy efficiency will waste a lot of the electricity. Therefore, some new programs about energy efficiency standards were put forward. Energy Star may be the most influential program if not the earliest. Another program named Consumer Electronics Initiative was also set out by CEE. One of the primary goals of this program is to develop a consistent definition of and criteria for energy efficiency in the consumer electronics area. As known, EU has published directive to establish a framework for the setting of eco-design requirements for energy-using products (EuP). Supporting implementation of the directive, a preparatory study for eco-design requirements of simple digital TV converters has been finished in 2007.[5] The voluntary EU Code of Conduct has set base power consumption targets for different types of STBs and allowed power allowances for additional function. The Australian Greenhouse Office has also introduced a similarly structured regulation to STBs.

As the biggest developing country, economy flourish make consumer electronics accepted widely in China. In addition, China became an important country in manufacturing the consumer electronics. The improvement of products efficiency will contribute to the international effort for climate change. By the prediction of CEE, the cumulative energy savings of consumer electronics may reach the top one in 2020 with the amount of 20 TWh in U.S., almost exceeding the total savings of cooling and lighting products.

Lacking of the policy instrument to improve the efficiency of the STBs, the sharp increase of the China digital television broadcast may waste a great deal of electricity. By the preliminary investigation, the program for the establishment and implementation of the MEPS for STBs may reduce electricity consumption about 30 percent. The potential electricity saving will exceed 380 million kWh per year. Considering the notable potential of energy saving, China National Institute of Standardization has started to prepare the national mandatory standard of minimum allowable values of energy efficiency and efficiency grades for STBs. The main contents of this standard will include the minimum allowable values of energy efficiency of STBs and its efficiency grades concerning with labels. Therefore, it will also set the reach minimum allowable values of energy efficiency of STBs and testing method for STBs' efficiency.

There are several obstacles in the development of energy efficiency standard program. These difficulties and some tentative countermeasures frequently in the program of energy efficiency standard for consumer electronics are discussed.

Firstly, the consumer electronics covered by standards is ill-defined. For example, the definition of simple STB is no very clear in the above programs. Normally, the definition of products should keep balance between the robust and flexible. Nowadays, cable STBs, satellite STBs and terrestrial STB are also used widely in China. Each type of STBs will include more kinds as the different broadcast standard used, as cable STBs includes SD and HD STBs normally. Furthermore, most STBs have been distributed to the end user by local network operator. Generally, local operator often set the special standard for STBs and broadcast network. It means the high diversity of STB definition in China. This may be a significant weakness in the implementation of standard. On one hand some products may elude from the mandatory requirement of energy efficiency; while on the other hand some important products may be evaluated improperly.

Secondly, high integration of multifunction in one product makes it hard to design a uniform requirement for the energy efficiency in the standard. Multifunction integration is an important feature of electronics products. It is a good example that evaluation of energy efficiency of MFD for imaging equipment is very hard. In the energy star program of imaging equipment, almost 16 additional functions listed can be integrated into one product.[7] Recently, digital TV set with functional module of STBs became more common in the market. Should all these products and functions be covered by the energy efficiency standard? According with the network operator's need, STBs manufactures usually layout a lot of multifunction into the STBs. Normally, more function means more energy consumption. More attention should be paid to consider the effects on energy efficiency of these functions ensuring the flexibility of the standard program.

Shorter life span of the product gives insufficient time to bring out standard program. Most consumer electronics has a much shorter life span than many traditional electric appliances such as the refrigerator or air-conditioner. Normally, it takes more than 2 years to prepare the standard before final release. Consideration of the assessment period of a standard proposal, the whole period of a standard for consumer electronics may exceed 3 years. While the life cycle of technical upgrade for consumer electronics is much shorter than this. By the Moore's Law, the cycle of electronics upgrade is about 18 months or 2 years. It means not the energy saving of standard programs will be alleviate, but the energy efficiency requirements for consumer electronics may be out of date at the begin of the implementation. While the period of negotiation in standard or label development often last a longer time to ensure reasonable and acceptant.

Because of the fast technical upgrade, consumers used to ignore the energy consumption of consumer electronics. Some consumers may think the manufacture will care about the energy saving, because it means the battery will provide a longer working time, such as the notebook. In fact, sometimes manufactures will intend to improve the energy density of power supply rather than to improve energy efficiency of products or reduce the energy consumption. Some experiences show that energy efficiency standard program with higher consumer awareness of the energy consumption will be successful more easily. Most STBs in China was distributed freely by the network operator. Therefore, most consumers will care more about the cost of broadcasting programs than the energy consumption. Furthermore even though consumer electronics is not free, different from the normal electric appliances, many products may be replaced in 5 years or shorter [8], consumer used to care about the price of the products than its potential energy bill.

3. Tentative ways to overcome the difficulties

To overcome these difficulties, following measures may be selected to address the problem in the energy efficiency standard program for STBs. It will be helpful to promote the energy saving of consumer electronics.

Set the energy efficiency requirement on the basis of functional module instead of product. As mentioned, it is hard to give a clear definition of consumer electronic product like STBs for it diverse function. Whereas, it is clear that function of STBs can be divided to the primary functions and additional functions. It is listed in table 1. Most of the technical innovation in consumer electronics was brought forward by the chip manufactures.[9] So The energy-saving standard program may give more requirement on the chip manufactures for evaluating the energy efficiency by basic limitation and additional allowance. It will provide a side effect that we can find the key module for energy saving easily, such as the decoding and power management.

Table 1 Composition of Typical Cable Set-top Boxes

Functional Module	Type of function
MPEG Decoder	Primary
Audio & Video Interfacing	Primary
Power Supply	Primary
Connectivity	Additional
Front End	Additional
HD Drive	Additional
Memory	Additional
Remote Control	Additional

Find a more efficient way to determine the standard, including the technical fundamental as well as administration mechanism. A timely program will be better than a technical-perfect program while out of date. The mechanism of standard preparation should be harmonized with the feature of consumer electronics. The program based on the best available technology (BAT) should be a good way to set the requirement as the target value corresponds to existing products that are already available on the market. The successful experiences of "Top Runner" program in Japan give a good example. The "Top Runner" program has the particular advantage of making new requirement easier. The period of preparatory work and negotiation for the standard can be shortened obviously.[10] It also means the upgrade of the standard will follow up with the market easily.

An international community on the energy efficiency standard about the consumer electronics should be organized if possible. Some international communities likely have been working to provide technical support for standards and energy efficiency programs. The "International Set Top Box Harmonization Initiative" was carried out to facilitate testing method and rationalization of STB performance requirements, and to propose a concrete set of STB initiatives to the wider international consumer electronics community. The apparent features of consumer electronics make it possible to set and promote the energy efficiency standard program globally. The integration trend of consumer electronics also gives a sufficient reason to evaluate the energy efficiency of product all together. It will be benefit from the shorter cycle of program layout.

Improve the awareness of the consumer is essential for the success of the standard program. It was found that most STBs have a standby power the same as on-mode power in the preparative study of energy efficiency standard for STBs in China. The explanation is that most STBs are provided by the network operator, they prefer the STBs keep activity to receive the EPG (electronic program guidance) or software update although users send the STBs into standby mode. Thus STBs will still consume electricity while users have no idea about this. In fact, the energy consumption of STBs in standby mode may reach two times of the on-mode since the long duration. Therefore the implementation of standard program will benefit from the consumer education as it will raise public attention and promote network operators' care about the energy efficiency of STBs.

4. Conclusions and discussion

Consumer electronics is an important field for energy saving and reduce GHG emission nowadays. STBs may consume 300 GWh electricity in 2010 in China while 4.3 GWh in U.K. The energy consumption of consumer electronics is paid more attention by administration or organization. U.S., EU, Australia, and China have begun or implemented the standard program to improve the consumer electronics' efficiency.

Some difficulties become the crucial obstacle to the standard program for energy efficiency. The unclear definition of consumer electronics, integration of multifunction in one product, shorter life span and lacking of consumer awareness make it hard to propose a suitable measurement to assess and improve the energy efficiency of products in most standard program.

Several tentative countermeasures for the energy efficiency standard program of the consumer electronics are discussed. Evaluation of the efficiency on the functional module instead of products may be the feasible way for setting the requirement. A BAT system to set the efficiency target for products will be more efficient in the preparation and negotiation of the standard. Recent international experiences show that an international community on the energy efficiency standard about the consumer electronics should be organized as possible. Finally, improving the consumer's awareness on energy consumption of consumer electronics is essential for the success of the standard program.

Furthermore, consideration of emerging new consumer electronics, the eco-design of consumer electronics is a key factor to ensure the energy saving. More efforts should be put on the producing phase of consumer electronics, especially for the products with shore life span and high density of electronic components.

References

[1] http://www.globrand.com/2006/22459.shtml

[2] Kurt W. Roth, Kurtis McKenney. *Energy Consumption by Consumer Electronics in U.S. Residences.* Final Report to the Consumer Electronics Association, Jan 2007.

[3] Karen Rosen, Alan Meier, and Stefan Zandelin. *National Energy Use of Consumer Electronics in 1999*.

[4] CCID Consulting. *Annual Report on China Set-top Boxes Market*, Feb 2008.

[5] Robert Harrison and Christoph Jehle. *Final Report of Preparatory studies for Eco-design Requirement of EuP – Simple Digital TV Converters (Simple Set Top Boxes)*, MVV Consulting GmbH, Dec 2007.

[6] Australian Greenhouse Office. *Minimum Energy Performance Standards: Digital Set Top Boxes.* Oct 2004.

[7] ENERGY STAR Program Requirements for Imaging Equipment (Version 1.0)

[8] Pacific Gas and Electric Company. *Consumer Electronics: Market Trends, Energy Consumption, and Program Recommendations 2005-2010*.

[9] Jens F. Christensen, Michael H. Olesen, Jonas S. Kjar. *The industrial dynamics of open innovation - evidence from the transformation of consumer electronics.* Research Policy, Vol. 34, 2005, pp. 1533-1549.

[10] World Energy Council. *Energy Efficiency Policies around the World: Review and Evaluation*. Feb 2008

Domestic Appliances Standby Power Losses: The Case of Eleven Suburbs in the Greater Johannesburg

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Abstract

Standby power losses of consumer electronics appliances found in eleven suburbs of the Greater Johannesburg were quantified. An intrusive survey was conducted in 555 households to establish appliance saturation and penetration levels, appliance use times and user operational behaviour. We coin and define the term 'universal' appliances to standby power losses. Measurements were done in 30 households using the Yokogawa WT210 digital power meter. Measurements of real, apparent, and reactive power; power factor; peak and root mean square voltages and currents were recorded in full and standby modes. Standby power and energy losses estimates obtained by use of sample parameters are 73.52 W and 561.83 kWh per year per household respectively. Estimation results for standby power losses based on cluster parameters range from 28.21 W for the lowest cluster to 181.55 W for the highest cluster. The corresponding standby energy losses estimated for the clusters range between 111.66 kWh and 862.15 kWh per year per household.

1. Introduction

South Africa is the 16th largest consumer of energy in the world. Over many years, low energy costs in South Africa have driven large energy demand in industry, commerce, transport and domestic sectors. It has also been argued that, low energy costs coupled with large electricity reserve margins has led to slow adoption of energy efficiency measures in all of the energy demand sectors [1]. At present, the electricity reserve margin in South Africa has diminished to an all time low of 8% [2].

South African energy sector is dominated by coal and in 2004, coal utilization accounted for 44.2% in electricity generation [3]. South Africa is therefore the largest emitter of green house gases in Africa and one of the most carbon emission-intensive countries in the world [1]. South Africa finds itself in a place where it is compelled to find ways of curbing electricity demand without slowing the economic growth and at the same time critically consider ways to greatly reduce its green gases emission levels.

In recognizing the important role that energy efficiency plays in reducing energy demand, an Energy Efficient Strategy for South Africa was adopted in March 2005 [1]. The strategy objective is to have a final energy demand reduction of 12% by 2015. For the residential sector, the goal of the energy efficient strategy is to have a reduction of 10% in the final demand in the sector by 2015. The interventions outlined for the residential sector are: mandatory energy efficient standards for both buildings and appliances; appliance labeling; and efficient lighting [1]. It is expected that utilisation of energy efficient appliances and change in user behaviour through awareness programs will be instrumental in reaching the proposed goals.

One aspect of efficient domestic appliances is exhibited in the power levels an appliance consumes in all of its possible operational modes which are dependent upon its functionality and design philosophy: The appliance operational modes are: "Full" or "On", "standby", "soft-off" and "off"[4].

In full mode an appliance is performing its intended function at is expected to consume most power. By definition, standby power is the electricity consumed by end-use electrical equipment when it is switched off or not performing its main function [5]. In standby mode an appliance does not perform its main function. The appliance is mostly in a state waiting to be activated to full mode or in a state of maintaining a diminished functionality. In standby mode depending on the level of functionality being maintained the power consumed varies across different appliances. Soft-off is a state in which the appliance cannot be completely switched off using a switch. In this mode the appliance continues to draw very small amounts of power. In some appliances though, there is no difference in the power consumption levels between the standby and soft –off mode. In off mode, an appliance is completely switched off and draws no power. The power an appliance consumes while in standby or soft off modes has been considered to be losses and energy wasted in this manner is commonly referred to as “standby loss’” [6].

Standby power and energy losses are mainly due to consumer electronics and information and communication equipment such as television sets, Hi-Fi systems, set top boxes, computers, monitors, printers, multifunction devices, DVDs, micro wave ovens, and battery chargers to mention a few. Australia has launched an international project to track the low power mode attributes of a standard “basket of products” and countries that are currently involved are USA, Canada, China, Japan, and Europe [7]. It is expected that standby measurements done on common products will make national and international comparisons possible across different regions [7]. However, there are still regions of the world where standby power studies have not been done yet and as such no data or information on standby power and energy losses exists [6,8].

The work presented in this paper provides initial data and information on appliance standby power and energy losses in a sample of South African households. The study carried out had three components namely: Household survey; appliance measurement campaign and standby power and energy estimation. In section 2 the household survey results are presented. In section 3 appliance measurement results are presented and discussed. In section 4 the established standby power and energy estimation results are provided. Section 5 is the Conclusion. The impact of the results presented in this paper on potential energy savings as well as carbon emission reductions are subject of future work.

2. Household Survey

A household face to face survey was carried out on a sample of 555 household in eleven suburbs of Greater Johannesburg metropolitan in South Africa. The eleven suburbs are: Lenasia Extension 1; Lenasia Extension 3; Lenasia Extension 7 ; Lenasia Extension 8, Devland, Florida, Florida Park, Gressworld, Kew, Alexandra East Bank and Waverly. The suburbs were identified on a basis of their degree of accessibility and safety as advised by the electricity distributor in the area [9]. Therefore the sample excludes households in informal areas and in enclosed/gated areas. The objectives of the household survey were to establish levels of consumer awareness, appliance saturation rates, appliance penetration rates, use times, appliance operational behavior as well as some sample demographics [9].

2.1 Sample Demographics

The demographic data obtained from the household sample are: Dwelling type, type of family and family size and electricity billing methodology. Household income data was not readily obtainable because most respondents did not feel comfortable to divulge the information face to face.

86% of the households were found to be housed in conventional homes, 4% in flats and 1 % in town houses and or homes in clusters. Therefore, majority of the households have ample space to accommodate domestic appliances. On family types found in the households, 47% were couples with children, 33% described themselves as a group of family members. 11% of the households are couples without children and 7% were one parent families. Single persons accounted for 1% of the households. Therefore, in majority of households are made up of family groups. On the number of people in the household, the following were the results: 27% of the households had six or more members, 22% had five members, 24% had four, 18% had 3, 10% had 2 and 1% of households are one member households. In general 64% of the households were made up of 4 or more people.

It was found out that 85% of the households received monthly electricity bills from the utility provider and only 15% of the households had pre-paid electricity meters.

2.2 Consumer Awareness

The questions on consumer awareness attempted to establish if the consumers knew what are standby power losses and its impact on the household/national energy consumption. Responses to the statement “I know what appliance standby power losses” were: 38% agreed and 61% disagreed to the statements and 1% did not answer the question. These figures indicate that a majority of the respondents did not know what appliance standby power is and of the 38% some would have known because of the introduction letters that were sent to the households prior to the arrival of the research assistants.

The impact perceived by consumers of standby power losses on household and national electricity demand was established through their responses to the statement “Standby power use is very small and does not have a significant effect firstly on household energy demand and secondly on national energy demand. In both cases more than 65% of the respondents disagreed with the statements indicating low levels of understanding of the standby power issue by the majority of the respondents. This calls for formulation of awareness campaigns geared towards raising consumer understanding of the standby power issue and its impact.

2.3 Appliance saturation rates (s)

In this study appliance saturation rates is defined as the fraction of households that own a specific appliance in the household sample. If each household owns a specific appliance then percentage ***s*** is 100%. If none of the households own a specific appliance, then the percentage *s* is 0%. Saturations rates indicate the extent of ownership of a specific appliance within a household sample. The appliances included in the survey were: Television (TV) sets, digital versatile disk (DVD) players, Hi-Fi systems, digital satellite television (DSTV) decoders, microwave ovens, mobile phone battery chargers, video cassette recorders (VCR”s), personal computers (PC’s) and computer monitors, printers and multifunction devices. At the time the survey was conducted, the saturation and penetration rates of LCD, and Plasma TV’s was very low but the technologies have continued to steadily enter the residential sector over the years mainly driven by decreasing prices and the introduction of digital satellite broadcasting in South Africa.

2.3.1 Sample Appliance Saturation Rates

The appliance saturation rates obtained for the sample for each appliance are presented in table 1 below:

Table 1: Appliance Saturates Rates for Household Sample.

Appliance	Number of Households	Saturation rate (*s*)
Television	532	96.0
Mobile phone battery chargers	488	88.1
Microwave	484	87.4
DVD	371	67.0
VCR	334	60.3
Hi-Fi systems	332	59.9
PC/Monitor	301	54.3
DSTV decoder	227	41.0
Printer	196	35.4
Multifunction Devices	75	13.5

After [9]

The results obtained from the household sample indicate that except for DSTV decoders, printers and multifunction devices saturation rates of all the other appliances are more than 54%. In further analysis the saturation rates were compared across different suburbs.

2.3.2 Appliance Saturation Rates in Different Suburbs

The saturation rates were also determined for each appliance in the different suburbs. The results are presented in Figure 1. The saturation rates obtained for the different suburbs indicate that:

- The saturation rates of television sets, cell phone battery chargers, microwave ovens, Hi-Fi systems, DVD players are equal or above 40% across all suburbs. These five appliances are what we have coined as “Universal Appliances”
- PC/monitors and DSTV decoders set apart the saturation rates of the different suburbs in saturation groups

We define *universal appliances* as appliances with saturation rates greater than or equal to 40% and common in all suburbs. These appliances present large volumes of appliances especially when one considers that the household population is in million of households. Further analysis was done on the suburb saturation rate results to determine the different appliance ownership groups that are formed in the household sample. PC/monitors and DSTV decoders were used as the differentiator appliances because as seen in Figure 2 they set apart the different suburbs into different ownership groups. The different ownership groups formed are referred to as 'saturation clusters'.

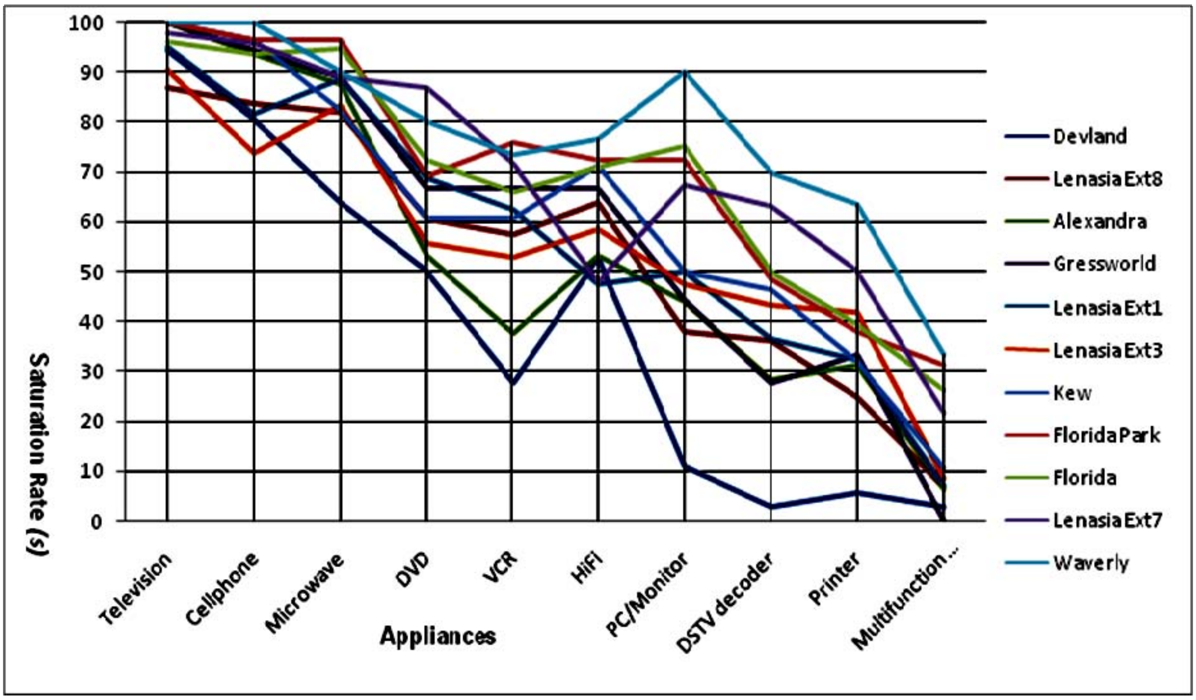

Figure 1: Appliance Saturation rates (S) in Different Suburbs

2.3.3 Appliance Saturation Clusters

The normalized saturation rates of PC/monitors and DSTV decoders are shown in Figure 2.

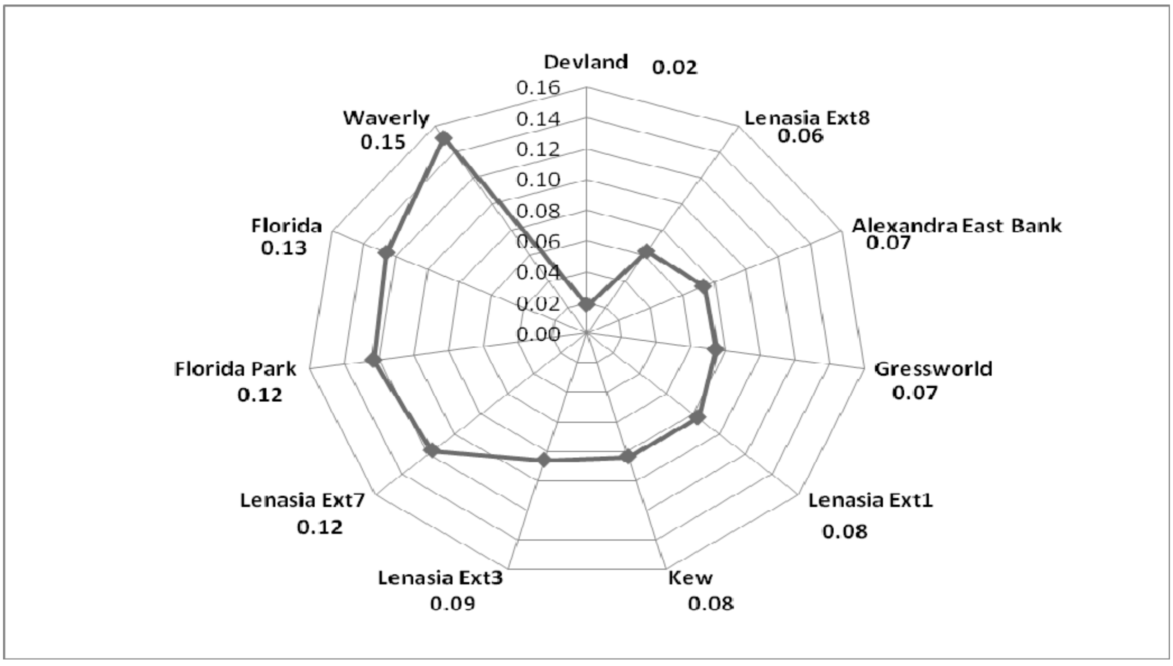

Figure 2: Normalised Saturation Rates for PC's [10]

From figure 2, five saturation clusters emerge as shown as shown in Figure 3.

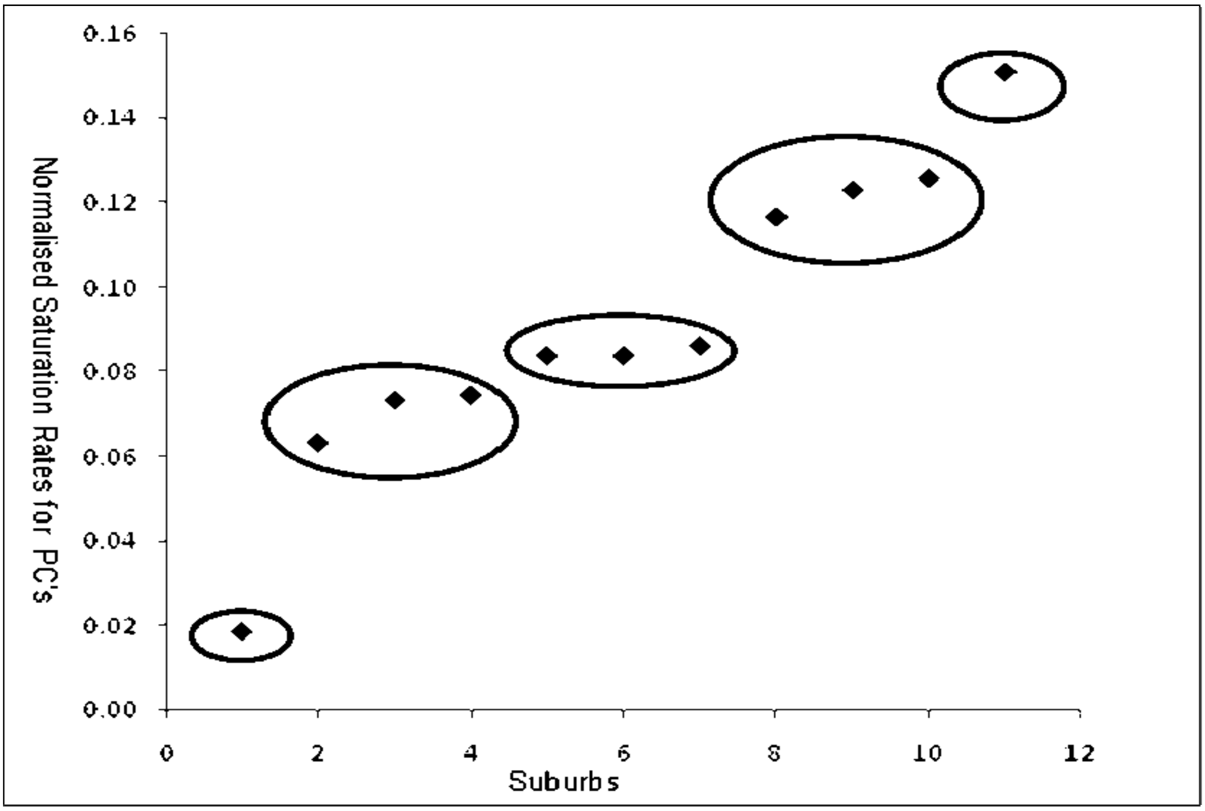

Figure 3: Appliance Saturation Clusters

The Five saturation clusters are made of 1 suburb in cluster 5 (Waverly), 3 suburbs in cluster 3 (Florida Park, Florida and Lenasia Extension 7), 3 suburbs in cluster 3 (Lenasia Extension 3, Kew, and Lenasia Extension 1), 3 suburbs in cluster 2 (Alexandra East Bank, Lenasia extension 3 and Gressworld) and one suburb in cluster 1 (Devland). It was observed that within a cluster, the appliance saturation rates match very closely but there are marked differences across different clusters.

2.4 Appliance Penetration Rates

Appliance penetration rates (*p)* indicate the total number of appliances found in a specified population of households. In computing p, the total number of appliances in the household sample is divided by the total number of households in the sample. Penetration rates can be greater than 1 if households own more than one appliance. Where the penetration rate is equal to 1 then this implies that each household owns only one appliance. The value of *p* is always greater than or equal to the saturation rate *s*.

2.4.1 Sample Penetration Rates

The penetration rates for the sample are presented in Figure 4. Microwave ovens, Mobile phone battery charger, television sets, DVD's and Hi-Fi's are the universal appliances, and as expected they are found in large numbers in the household population. The highest penetration rates are for mobile phones battery chargers indicating how quickly an appropriate technology that is on high demand can be embraced by the population. VCR's are a technology that has been overtaken by DVD players and it is evident that in the household population, the number of DVD's is higher than the number of VCR's.

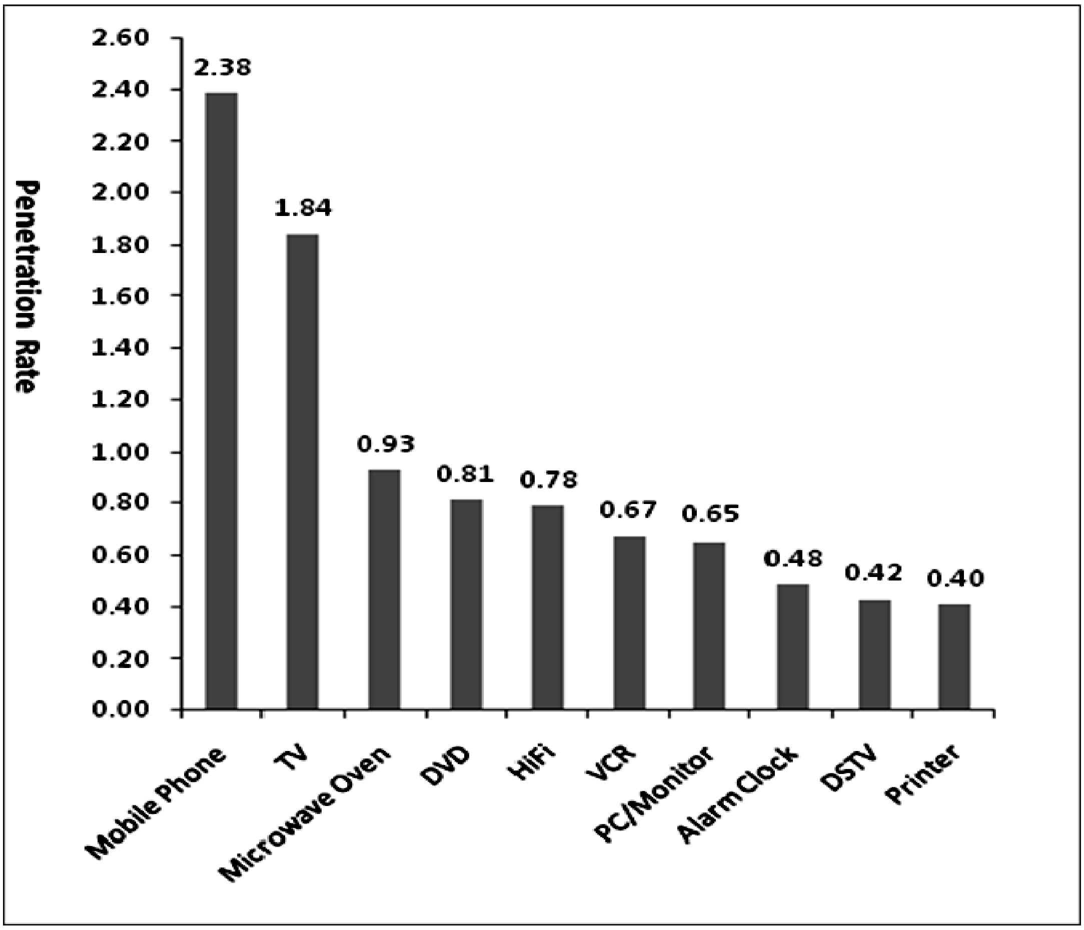

Figure 4: Appliance penetration rates for the Household Sample [9]

2.4.2 Appliance Penetration Rates in Suburbs

In determining appliance penetration rates in the suburbs, the aim was to find out the contribution of each suburb towards the total number of each appliance. The appliance penetration rates in each suburb are provided in table 2. The penetration rates in table 2 indicate that the different suburbs contribute differently to the total number of appliances available in the household sample. For example a suburb like Waverly has penetration rate for PC at 1.33 while in Devland it is only 0.14.

Table 2: Appliance Penetration Rates in Suburbs

Suburbs	**Appliances**								
	TV	MPBC	MWO	DVD	VCR	Hi-Fi	DSTV	PC/Monitor	Printer
Devland	1.28	1.61	0.64	0.58	0.28	0.56	0.03	0.14	0.06
Lenasia Ext1	1.63	1.86	0.90	0.79	0.67	0.62	0.37	0.54	0.41
Lenasia Ext3	1.75	1.82	0.90	0.71	0.60	0.81	0.43	0.61	0.43
Lenasia Ext7	1.98	2.70	1.07	1.11	0.87	0.61	0.65	0.93	0.54
Lenasia Ext8	1.43	2.02	0.84	0.72	0.64	0.74	0.36	0.41	0.25
Florida	2.30	3.30	1.07	0.92	0.76	1.12	0.51	0.93	0.45
Florida Park	2.21	2.86	1.10	0.90	0.86	1.03	0.48	0.90	0.41
Gressworld	2.44	2.67	0.89	0.89	0.83	0.78	0.35	0.72	0.50
Kew	1.89	2.57	0.89	0.93	0.68	1.00	0.50	0.57	0.39
Waverly	2.20	3.53	1.03	0.83	0.87	0.83	0.77	1.33	0.77
Alexandra East Bank	1.84	2.78	0.88	0.53	0.38	0.72	0.28	0.44	0.31

After [9]

The same trend of differentiated contribution to the total pool of appliances by the different suburbs strengthens the clustering effect that was observed in appliance saturation rates. The same procedure was followed to determine the penetration clusters. Five penetration clusters were obtained and the penetration clusters established are the same as the saturation clusters as expected because of the one to one correlation between saturation and penetration rates. Figure 5 presents the penetration clusters.

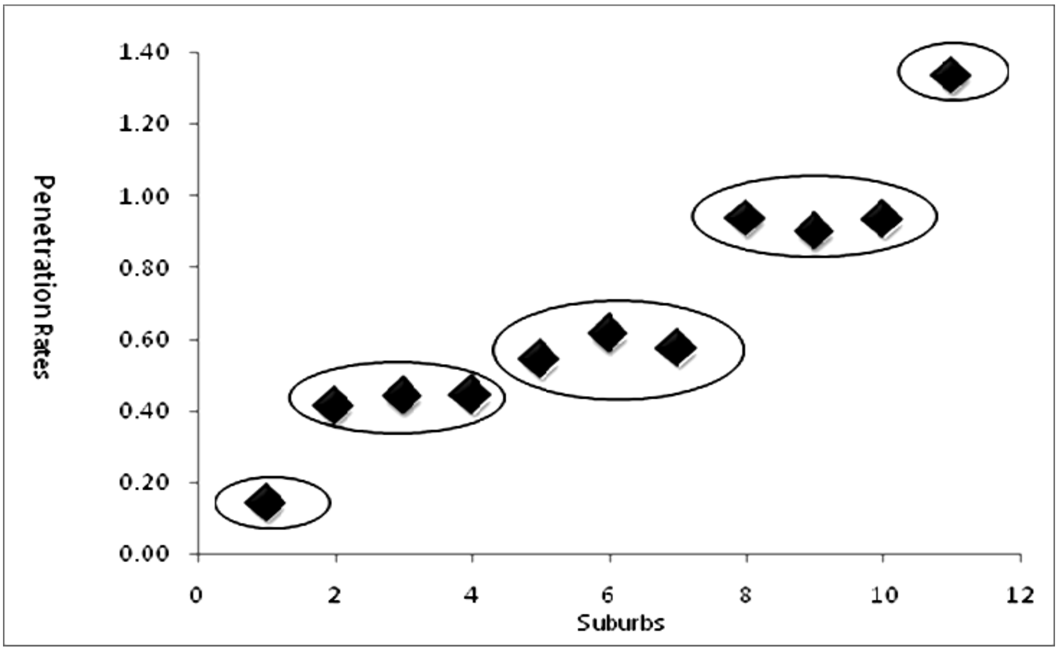

Figure 5: Appliance Penetration Clusters

The saturation and penetration clusters obtained suggest that the households in the sample can be divided into five groups. Within a cluster, the penetration and saturation rates compare very well but across clusters there are differences. Furthermore because penetration rates determine the total number of appliances available in a sample, it implies that each cluster contribution to the total losses is expected to be different. Therefore, across the household sample the standby power losses are clustered due to clustering of appliance saturation and penetration levels.

2.5 Appliance Use Times

Appliance use times were estimated from the responses on how much average time the household spent in use of the different appliances. In the absence of actual appliance activity monitoring, the estimates obtained from respondents are used in the calculation of energy losses. One of the drawbacks in standby energy loss estimations is the low level of accuracy in the determination of time spent in standby [11,12].

In the questionnaire, respondents were requested to report on the average use times of the appliances on weekdays and weekend days. From these figures, the appliance average use times were established for each appliance. The time spent in standby mode per week was computed for each appliance using the appliance use time data obtained for weekdays and weekends. The results presented in table 3 are the cluster results. In general, printers, microwave ovens and multifunction devices (MFD) spend the longest time in standby mode. It is important to notice the differences in time spent in standby of remote controlled appliances and non-remote control appliances. Time spent in standby mode increases across the clusters in remote controlled appliances i.e. TV's, DVD's, DSTV decoders, VCR's and HI-FI's. However, in non-remote controlled appliances i.e. MFD, microwave ovens, printers, PC/monitors, and mobile phone battery chargers the differences across the clusters are much diminished.

In general, it can be observed that appliances spend longer times in standby mode in cluster 5 and the shortest times are in cluster 1. The clustering effect is also evident in time spent in standby mode especially in remote controlled appliances. Appliance operational behaviour of the different households or clusters of household as well as the family composition and size does lend themselves to standby power losses as can be observed in table 3. Households in cluster 1 reported the largest number of members per household i.e. 6 or more members.

Table 3: Time Spent in Standby Mode

Appliance	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
TV's	15.8	15.4	16.2	17.2	19.6
MPBC	22.7	23.1	22.8	22.8	23.0
Microwave Ovens	23.5	23.6	23.4	23.5	23.4
DVD's	16.8	19.8	20.6	20.9	21.7
Hi-Fi's	15.4	20.2	19.9	19.1	21.5
VCR's	23.0	20.0	21.5	22.0	22.4
PC/Monitors	21.0	19.9	20.8	22.0	20.8
DSTV Decoders	15.0	16.3	16.7	17.6	19.3
Printers	-	24.0	23.4	23.8	23.2
MFD	-	23.5	23.8	23.5	23.7

After [10]

3 Appliance Measurement Campaign

A measurement campaign was carried out to obtain appliance power consumption levels in different operational modes. The measurements were done according to IEC 62301 standard for measurement of standby power [13]. The power meter used was the Yokogawa 210 digital power meter specifically made to perform standby measurements accurately [14]. Measurements were conducted in a sample of 30 households spanning the survey sample. In making sure that the measurement sample was representative of the survey sample, households were identified from each suburb cluster. Measurements were taken on all appliances with standby capabilities which were found connected to the power sockets in the house.

3.1 Measured Appliances

In table 4, the detail of number of appliances metered in the measurement campaign is provided.

Table 4: Number of Metered Appliances in Households

Appliance	Number 0f Appliances
CRT TV's	40
LCD TV's	5
Plasma TV's	4
Mini Hi-Fi's	10
DVD players	20
VCR's	14
MPBC	33
Microwave ovens	20
DSTV decoders	17
PC's	17
PC monitors	14
Printers	9
MFD	7

3.2 Measurements Results

Average power consumption in full mode and standby mode are presented in Figure 6 and 7 respectively for all appliances found in the households. Detailed appliance measurement results in all operational modes have been reported [15].

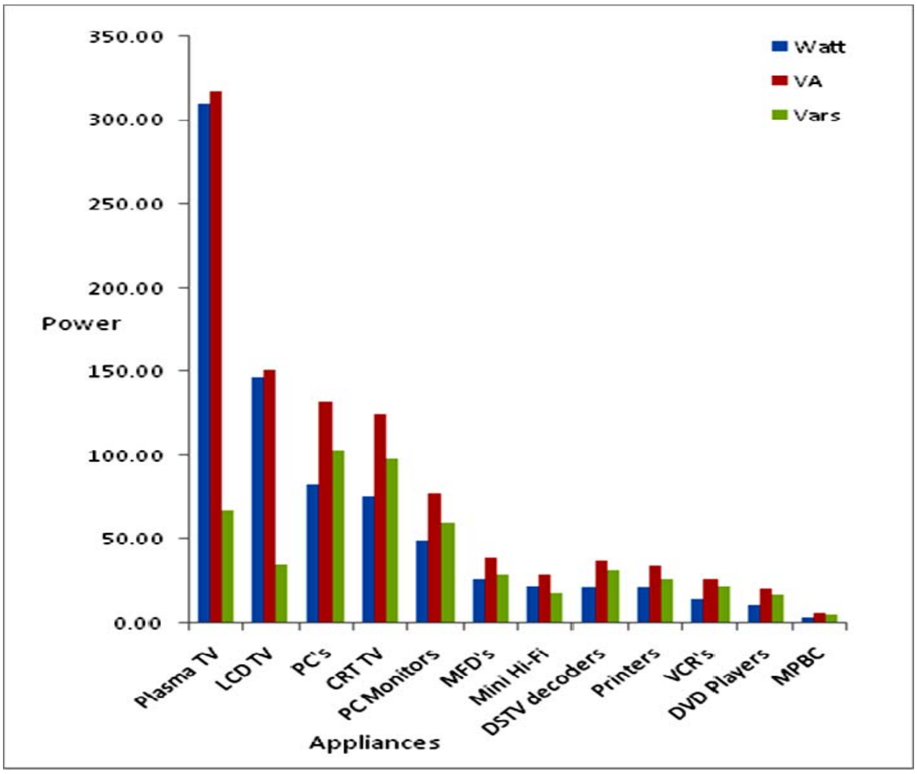

Figure 6: Average Power Consumption in Full Mode

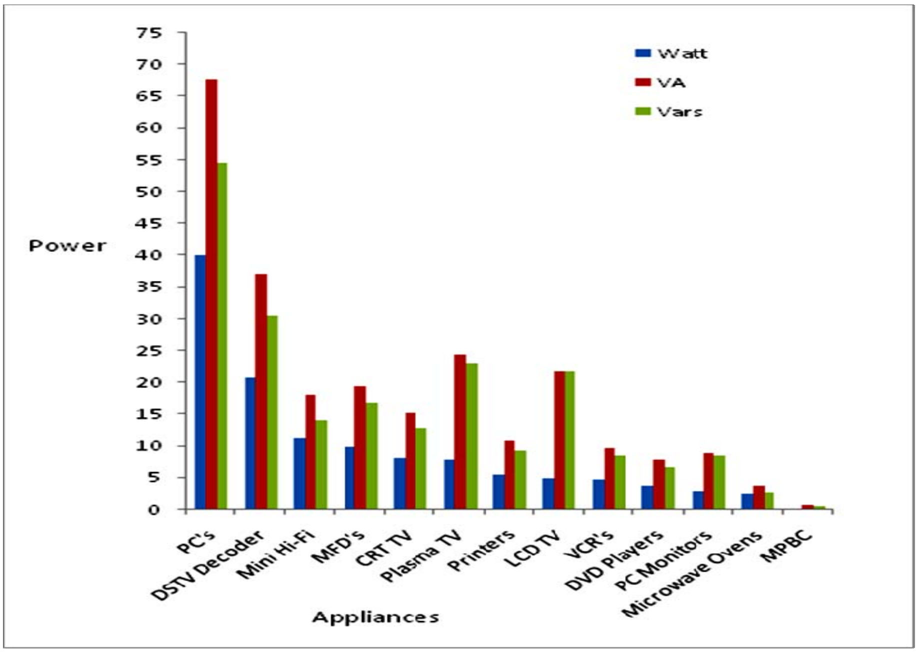

Figure 7: Average Power Consumption Levels in Standby Mode

LCD and Plasma TV's show a good match between apparent and active (real) power indicating good power factors in full operational mode as seen in figure 6. In the other appliances the levels of real power and apparent power suggest poor power factors in full mode operation.

From figure 7 PC's were found to have the largest power consumption levels in standby mode followed by digital satellite television decoders. It is also evident that in all appliances except mobile phone battery chargers the average standby real power consumption is above 1 Watt. From figure 7 the reactive power components are relatively large suggesting poor power factors and the presence of circulating currents in the low voltage network. In the individual measurements it was found that there are large variations in power consumption levels in appliances with same technical attributes and same functionality.

The conclusion from these average power measurements is: Energy efficient appliances with better consumption levels in standby mode have not yet made their way into South African households. Therefore, there is a need to take bold steps to establish appropriate policies on energy efficient appliances and institute appliance efficiency standards.

4. Standby Power and Energy Estimates

Using a bottom-up model, standby power and energy losses per household were estimated based on sample and cluster parameters [10]. The parameters of interest to the estimation model are: Average power in standby mode (P_{sb}), average time spent in standby (t_{sb}), appliance penetration levels (p). The estimated household standby real power loss is 73.52 W and the resulting standby energy losses amount to 561.38 kWh per year based on sample parameters.

Figure 8 and 9 present the estimated standby real power and energy losses based on cluster parameters.

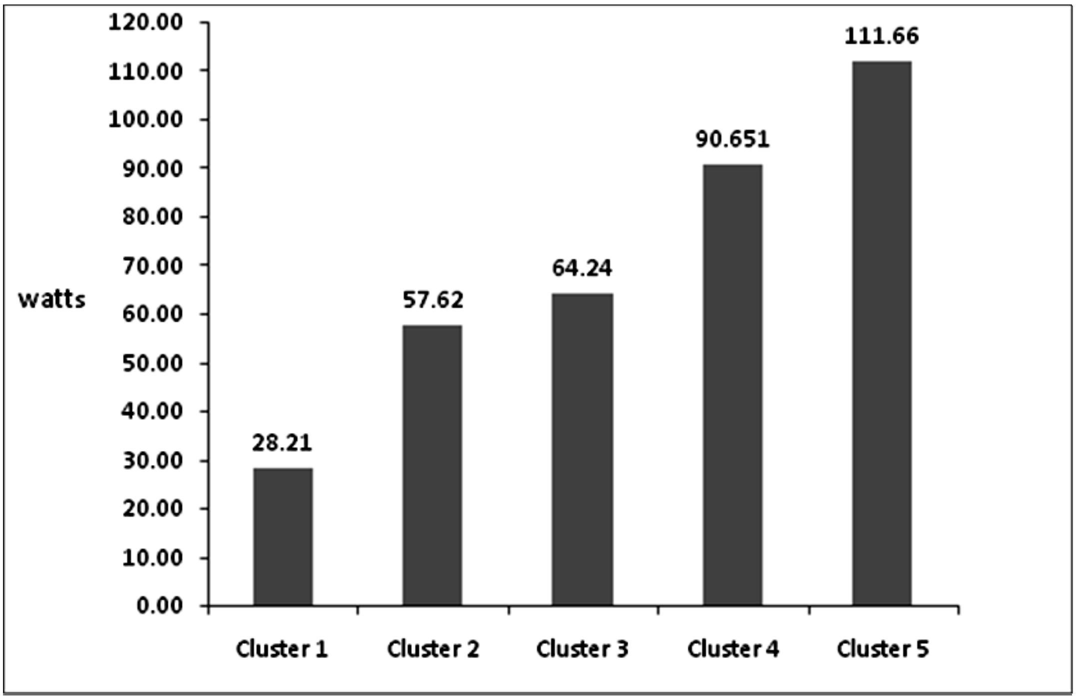

Figure 8: Standby Real Power in Different Clusters

The cluster analysis yields detail results for the different groups of households. If the cluster results are compared to the sample results, it becomes evident that the sample results underestimate the consumption levels of the upper clusters and overestimates by large margins the estimates for the lower clusters. National standby power and energy losses based on cluster parameters are expected to yield more accurate estimates. The results can also be used in consumer awareness campaigns to send focused message intended for the different clusters.

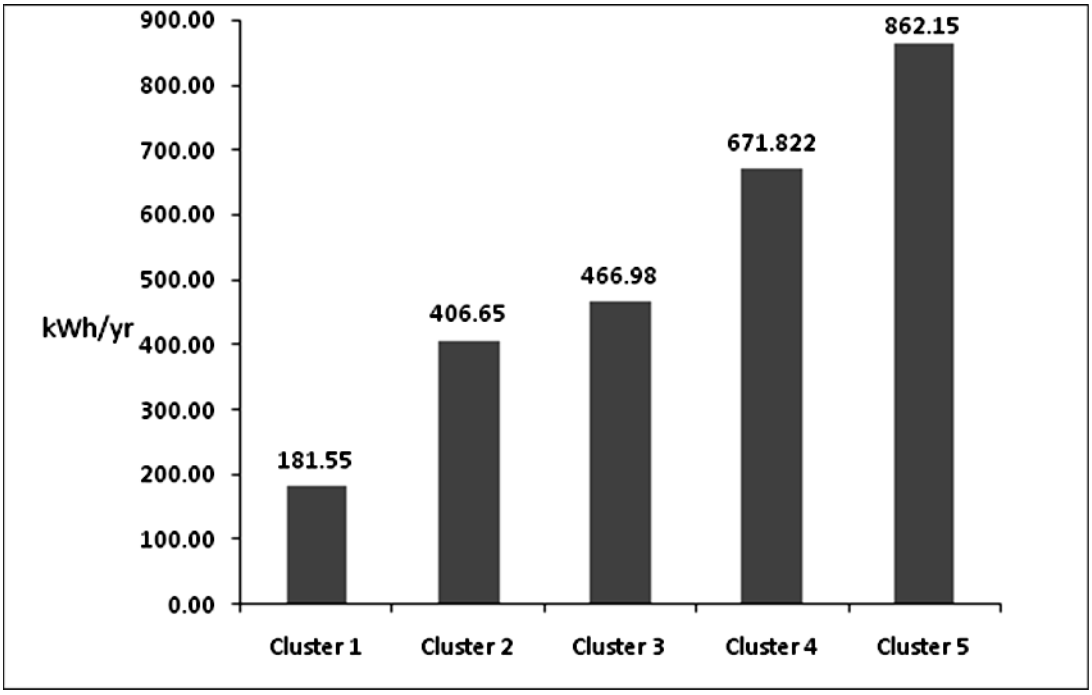

Figure 9: Standby Energy Losses in Different Clusters

The estimated standby power and energy losses present considerable losses per household in both scenarios. It is imperative that government, electricity utility provider, appliance manufacturers and importers, and relevant standards bodies, consumer forums in their different capacities look critically on the impacts of these losses to device strategies to minimize the losses. Work on appliance standby power and energy losses should continue and be aligned to umbrella activities already instituted in other countries.

5 Conclusions

Saturation and penetration rates have been established and characterized in the household sample of eleven suburbs. Appliance use times indicate that all appliances spent long periods of time in standby mode especially non-remote controlled appliances. Measurements carried out in a sample of 30 households drawn from the survey sample, indicate wide variations and high levels of standby power consumption. Standby power and energy estimates based on both sample and cluster parameters are of magnitudes that cannot be ignored by the different stakeholders to efficient energy use in South Africa.

There is a need look into formulation of policies and appliance standards to curb further increases and to reduce the current standby power and energy losses. Appropriate consumer awareness campaigns should be conducted and correct information should be directed and disseminated to the correct clusters.

6. References

[1] Department of Minerals and Energy. *Energy Efficiency Strategy of the Republic of South Africa*, March 2005.

[2] ESKOM. *Eskom Annual Report 2008*; Can be downloaded at: http://financialresults.co.za/eskom_ar2008/ar_2008/downloads/eskom.ar2008.pdf

[3] Department of Minerals and Energy, *Digest of South African Energy Statistics 2006*. ISBN 0-9584376-4-5

[4] Shuma-Iwisi M. V., and Gibbon G. J., *Standby Power Load in the South African Domestic Sector: Why and How to Benchmark*. Proceedings of Domestic Use of Energy Conference (Cape Town, South Africa, 31 March-3 April 2003). ISBN 0-9584246-8-3

[5] Bertoldi P., et al, *Standby Power Use: How Big is the Problem? What Policies and Technical Solutions Can Address It?* Proceedings of 2002 ACEEE Summer Study on Energy Efficiency in Buildings (Pacific Grove, California, 18-23 August 2002)

[6] Mohanty B., *Standby Power Losses in Households Electrical Appliances and Office Equipment*. Proceedings of the Regional Symposium on Energy Efficiency Standards and Labelling, 31st May 2001.

[7] Harrington L., et al, *Standby Energy: building a Coherent International Policy Framework Moving to the Next Level*. Proceedings of ECEEE 2007 Summer Study (Colle sur Loup, France 25 June 2007) ISBN 978-91-633-0894-4

[8] Meier A., *A Worldwide Review of Standby Power Use in Homes. In Symposium on Efficient Use of Energy and Reduction of its Environmental Impact* (Osaka, Japan, February 2002) Also published as report number LBNL-49377

[9] Shuma-Iwisi M. V., and Gibbon G. J., *Estimation of Standby Power Load in South Africa Domestic Sector: Initial Survey Results*. Proceedings of Domestic Use of Energy Conference (Cape Town, South Africa, 11=12 April 2007) ISBN 0-9584901-6-3

[10] Shuma-Iwisi M. V., and Gibbon G. J*., Appliance Standby Power and Energy Consumption in South African Households*, Paper to be presented at Domestic Use of Energy Conference (Cape Town, South Africa 15-16 April 2009)

[11] Meier A., et al, *Standby Power Use in Chinese Homes*, Journal of Energy and Building, December 2004, Volume 36 number 12 pp 1211-1216

[12] ENERTECH, CCE, ADEME and CRES. End-use metering Campaign of 400 Households of the European Community, Commission of the European Communities January 2002

[13] IEC/TC59. Technical Standard IEC 62301 of 2005

[14] Yokogawa Electric Corporation, WT210/WT230 Digital Power Meter Users Manual

[15] Shuma-Iwisi M. V., Gibbon G. J., *Estimation of Appliance Standby Power Load in South Africa: Household Measurement Results*. Proceedings of Domestic Use of Energy Conference (Cape Town, South Africa, March 2008)

7. ACKNOWLEDGEMENTS

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Televisions and Consumer Electronics

The IEC 62087 TV Testing Methodology Review – A Template for International Stakeholder Cooperation in Developing Harmonised Testing Standards.

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Abstract

For many years, the measurement of television (TV) power consumption has been critical to the development of policies that could encourage the improvement in the energy efficiency of these products.

TV on- mode power testing for the UK Market Transformation Programme (MTP) databases in 2003 and 2004, started to raise issues of the suitability, for all TV display technologies, of the then, accepted, EN / IEC test standards. The MTP test team experimented with dynamic test sequences used at the time for the professional assessment of TV picture quality. The team demonstrated that testing for TV on –mode power could be based on such sequences.

Meetings in Australia, USA and Europe involving, key International stakeholders, drawn from governmental and regulatory bodies (AGO, UKMTP, EPA and NRDC) TV industry designers and Industry Associations (CEA, Intellect, and EICTA) led to agreed goals in the development of a new TV testing methodology

The goals were:

- To measure the on-mode and standby power consumption of televisions regardless of the screen display technology and under standard test conditions

- To establish a robust and repeatable power consumption test methodology using TV screen settings that represented normal consumer usage

- To ensure that the video test signals were representative of average world wide TV programme material and not specific to a particular country

- To provide a test methodology that would be independent of the specific technical characteristics of current and future display technologies

- To provide informative guidance to regulators and policy makers on how, power measurements and energy saving features may be factored into regulatory criteria.

This paper describes, in an activity overview roadmap, how these goals were translated into the speedy publication of the revised testing standard IEC 62087 Ed. 2 in October 2008, including, IEC mastered DVDs and Blu-ray Discs of the new video test sequences.

In the paper, this unusual, and possibly unique, International activity roadmap is presented as a possible template for other Consumer Electronic product international standards work, particularly in the context of those standards required to underpin the urgent development of harmonised standards for EuP Implementing Measures.

Historical introduction

In 2003 and 2004 the UK Market Transformation Programme (MTP) contracted a major UK Consumer Electronics test laboratory to provide a power requirement database of a wide cross section of UK and European TV models, including Plasma and LCD display types. The test standard favoured by the European Industry at that time, for TV on-mode power requirement measurement, was EN 62087 which used as the displayed test signal, a static test pattern (fig.1) This pattern and fixed screen contrast and brightness settings were drawn from the IEC standard for comprehensive TV tests, IEC 60107 of 1997. The TV screen setting pedigree for the latter standard was prescribed by professional testing of early, broadcasting studio, black and white CRT monitors. The required peak luminance setting for the display of 80 Cdl. / M², was in 2002, irrelevant to normal domestic TV settings, which could deliver up to five times higher luminance than that required in the standard.

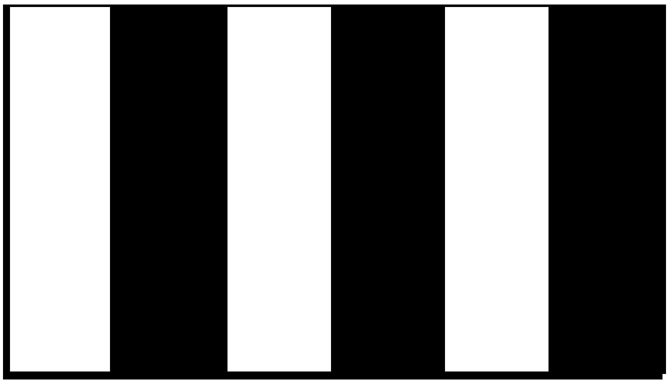

Figure 1: Historic Industry Test Pattern For TV Power Measurement In On-Mode

The MTP testing team noted the difficulties encountered in measuring a stable luminance from LCD screens, unless a long stabilisation period was adopted. They also noted that a Plasma TV, displaying the accepted IEC 60107 static test pattern, demanded a significantly higher power level, than the average power required for broadcast TV programmes. They observed that the peak white luminance of all plasma TVs measured on the white (100%) bars of this pattern was far below the peak white luminance level claimed by the manufacturers.

The testing team further noted that a moving picture sequence used for professional; studio monitor picture quality set-up and for the laboratory's subjective quality testing set up (CCIR -16) provided an average on-mode power close to the average power recorded on long term, off-air, TV programme reception.

The conclusion reached from this MTP TV database work, was that the most relevant measurement of a TV's power requirement should be based on a moving picture test sequence representative of average TV broadcast programme content. In discussion with European TV Industry experts, at meetings hosted by EICTA and Intellect, it was agreed that such a test sequence would produce the dynamic adjustment of the on-mode power requirement of self - emissive displays (CRT, PDP and for the future SED and OLED) in proportion to the change in the average of the black and white level of the picture frames (Average Picture Level – APL) This dynamic adjustment would provide a more accurate measurement basis for the energy requirement of a TV in normal use.

In 2004 the Australian Government Greenhouse Office (AGO) invited an MTP representative to observe discussions with the Australian TV Industry on the establishment of Minimum Energy Performance Standards (MEPS) for TVs. At this meeting, the subject of on-mode power test methodology was discussed and it was agreed that a new measurement methodology should be progressed, in support of the MEPS programme. Ideally, this methodology should avoid the potential inaccuracies of display luminance measurement and correctly reflect the power requirement of a TV displaying average broadcast content in a domestic environment. The CCIR –16 dynamic test sequence was distributed on DVD for TV Industry and AGO representatives to evaluate.

First major International cooperative steps in TV on-mode power measurement

In June 2005, under the auspices of the US NRDC (Natural Resources Defense Council) representatives of the TV Industry, Standards bodies and Government regulatory bodies, met in San Francisco. These included representatives from, the EPA (Energy Star) US Consumer Electronics Association, AGO, UK MTP, California Energy Commission and ACEEE. The aim of the meeting was to develop a consensus for the development of a TV energy performance test method that could be used Internationally.

Delegates from Australia, the EU and the USA made presentations on the dynamic sequence test method. The presentations from Australia and the UK contrasted measurements of the on-mode power requirement of a TV over a period of time, while playing a dynamic sequence, with static test pattern measurements. Data on 200 TV models tested for the AGO and UK MTP using the default manufacture settings for brightness, contrast, etc (called “out-of-the-box” screen settings) was overviewed.

A key presentation came from Dr. Larry F. Weber representing IEC TC110 (Plasma Displays). This focused on the measurement of Average Picture Levels (APL) from USA TV shows and showed by analysis, how these APLs varied with TV broadcast programme genre. He then showed the technical relationship between the APL and the power consumption of the Plasma Display Panel (PDP) TV and the LCD TV. The presentation showed that PDP power consumption (or other self-emissive display technology) was highly dependent on the APL of the programme, while fixed backlight LCD was not. The inadequacy of using fixed test patterns to produce meaningful power measurements on self-emissive display technology was clearly demonstrated.

Dr. Weber’s methodology for measuring the APL of a programme sequence was of particular value. From his presentation it was noted that IEC TC 110 (Plasma Displays) committee were considering the development of a measurement standard based on a sequence of dynamic TV programme clips. They proposed to form a working group with IEC TC 100 (responsible for the main TV and audio equipment on-mode power testing standard IEC 62087)

The meeting agreed that the goal of the measurement standard for TVs was to measure the on-mode and standby power requirement of a TV regardless of the display technology and under basic test conditions. The methodology should also be robust and repeatable, by measuring power consumption with screen settings that represent normal usage on test sequences representative of worldwide TV broadcasting. To that end effort should be put into examining broadcast programme APLs on an International basis using Dr. Weber’s methodology. The urgent objective would be the development of a dynamic test sequence representative of worldwide TV viewing material.

A consensus also started to emerge on a suggested basic metric for TV display efficiency, that of power/unit area (W/m^2) It was agreed that the implications of this metric, in terms of the luminance settings of the delivered TV, the screen resolution and the fixed power overheads of the TV signal processing circuitry other than that associated with the display, would clearly demand cooperative International study and evaluation.

The NRDC, UKMTP and the AGO undertook to encourage US, EU and Australian Standards organisations to establish a working group to pursue the development of a new TV power measurement methodology.

In September 2005 the topic of a new or revised TV power measurement standard was raised at the IEC TC100 plenary meeting in the USA and by December a project leader had been nominated and the drafting of a new project proposal (NP) was under way.

At the same time, In Australia, Dr. Weber’s APL measurement methodology was consolidated into a test programme for the worldwide measurement of typical TV programme genres. The test programme suggested capturing 20-minute sequences for APL analysis according to the spreadsheet shown in fig.2., from, TV Broadcasting over Terrestrial (FTA) Satellite and Cable delivery systems and from DVDs.

Analysis in the USA, UK, Japan and Australia commenced. Eventually an APL histogram was modeled from the APL distribution of over 40 hours of broadcast material captured in Australia, Japan, the Netherlands, the USA and the UK. The results of this analysis were eventually translated into a master histogram that was replicated by the video sequences published by IEC in the dynamic broadcast DVDs accompanying the Standard. Fig 3. compares the master histogram with that of the test disc.

		FTA			Cable			Satellite		
Category	Program Type	Program 1	System	Notes	Program 2	System	Notes	Program 3	System	Notes
Studio	News									
	Variety									
	Current Affairs									
Sport Indoor	Basketball									
	Gymnastics									
	Swimming									
	Squash									
	Tennis									
	Snooker									
	Ice Hockey									
	Skating									
Sport Outdoor	Soccer									
	Gridiron									
	Cricket									
	Baseball									
	Rugby									
	Tennis									
	Hockey									
Studio Sets	Situation Comedy									
	Soap Opera									
	Drama									
Non Studio	Animated Film									
	Non Animated Film									
	Documentry									
	Concerts									
	Cartoons									
DVD	Various Movie Types									
	Various Concert									

Figure 2: TV Programmes for APL analysis

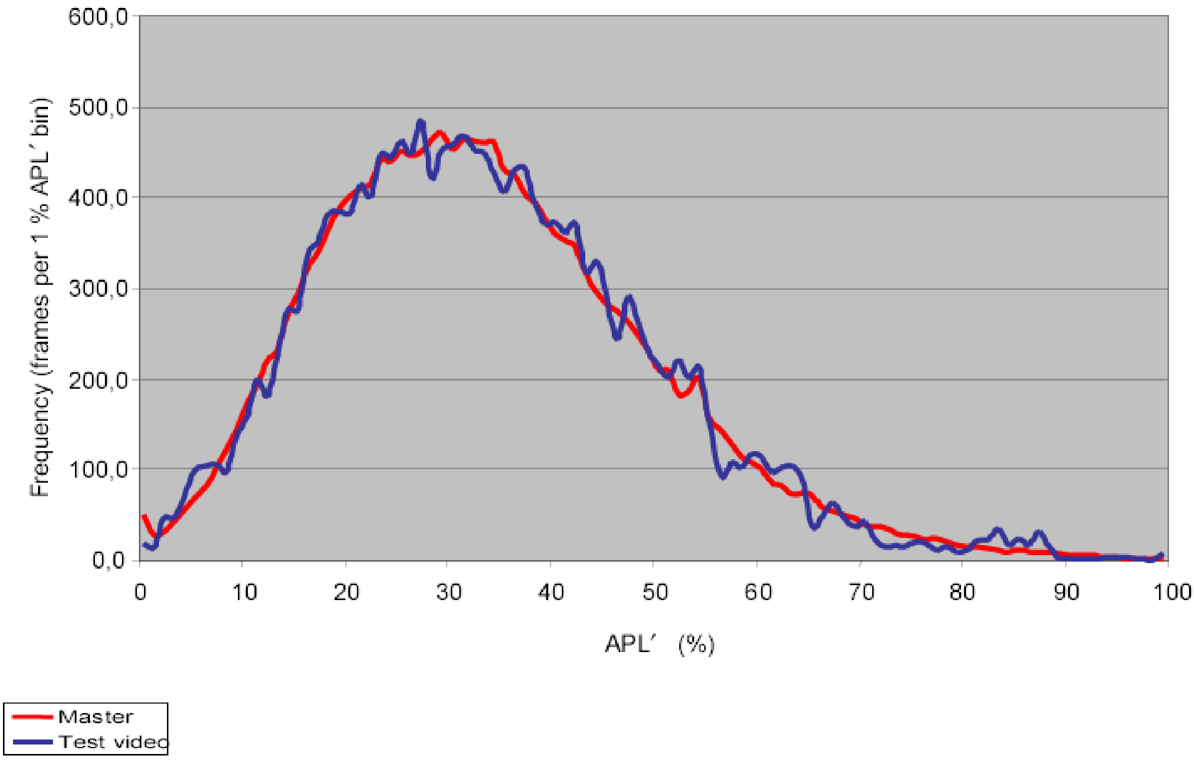

Figure 3: Master Histogram of International TV programme analysis and of published IEC dynamic broadcast sequence DVDs (

Timeline of IEC working group activity

In April 2006 IEC TC 100 issued a new project application from the US with a positive ballot notification. The purpose and justification of the new project was stated as:

There exist hundreds of millions of television sets in the world today. Policymakers and business leaders want a neutral and accurate way to determine the energy consumption of these television sets. An international standard for measuring active TV power consumption will assist. Further, policymakers, business leaders, and consumers want a way to compare between television models and technologies. By creating and implementing this international standard, television manufacturers will be able to provide power consumption measurements for their products that will be consistent across the globe. The efficiency of a single test for all countries and regions benefits manufacturers ("one standard-one-test"). Consistent power numbers across television brands sold in all countries will provide a basis for comparison. Given accurate, standard power consumption measurements, manufacturers can compete on the grounds of low energy consumption, and may choose to employ new manufacturing methods and technologies to decrease average power consumption per square inch of display, while maintaining apparent picture quality.

It was also noted that the project includes the following goals:

• To be TV display technology and display size neutral

• To consider dual function products, such as TVs with computer monitor capabilities

• To allow for fair and consistent comparison of products

• To have international scope and application

• To focus on out-of-the-wall power consumption (i.e., consumption from the power mains)

• To include a rich range of content for the test image

• To be an easy to use measurement technique

• To have an intuitive (measurement) set up (e.g., out of the box/default settings) and run in a reasonable amount of time (i.e., a few hours with the ability to extrapolate results).

• That there should be timely publication and promulgation: 2007/8

An undertaking to consult other international efforts to develop a test procedure, including, "that which is underway in Australia and the United Kingdom" was also made and reference was made to the forming of a joint project team drawn from TC100 and TC1110 (flat panel displays)

In May 2006, an ad-hoc meeting of the project team in Helsinki involving experts from TC100, TC108, TC110 and other experts reviewed the New Project goals and prioritised the actions required to produce and support a new Committee Draft of the Standard.

In June 2006 a working draft of the new project was presented to a special TV workshop in the EEDAL 2006 London conference. Valuable input was received and an expansion of International cooperation on project support agreed. An initial encouraging analysis of TV broadcast APL levels recorded in Australia, UK and USA was presented by AGO experts.

In the second meeting of the project (now formalized as PT62487 under TC100) in Washington, evidence was produced from UK MTP testing, that it would be possible to leave sound settings and specific sound power levels out of TV on-mode power measurement. Results from sound tests on a wide range of current TV models showed that the variation in TV sound amplifier quiescent power (audio just perceptible but not muted) from model to model, was insignificant in the context of display power measurement. It was acknowledged that dispensing with audio considerations would dramatically simplify the intrusive test methodology associated with sound set –up in the existing IEC 62087 standard. This would help to meet two of the goals for an easy to use and set up methodology. It was also proposed that a further dynamic test clip should be considered representing APL levels of typical WEB browser pages since TVs were likely to be used more, in the future, as both broadcast and WEB monitors.

Following a project team meeting in Berlin in September 2006 it became clear that the most timely way to complete the project, under IEC rules, was to move to the maintenance of the normative TV power requirement methodology in the existing IEC 62087 Standard rather than develop a completely new Standard.

To this end the project team became MT 62087. It concentrated on the revision of the TV part of the existing standard and the creation of a new informative section providing guidance for regulators and policy makers on how TV power requirement measurements may be factored into energy efficiency metrics. Following numerous on–line meetings, the Committee draft was circulated and comments fro National Committees and other bodies processed.

In the final physical meeting of the project team in Colmar in October 2007 plans were made to cope with the daunting task of producing and testing the test DVDs in SD 50Hz and 60Hz formats as well as Blu-Ray Disc HD. Between October 2007 and October 2008, the standard was approved and published.

Concluding observations on IEC methodology review

The unusual marriage of the TV design expertise of specialist IEC committee members and the requirements of regulators and policy makers presented through their expert product testing consultants has proven that a harmonised international standard can be produced efficiently to accommodate the impact of new technology on power consumption testing methodology. Some key observations are:

- The development of a dynamic video test loop based on a sequence mirroring the average APL of worldwide television viewing material has produced a TV power testing methodology of proven robustness, accurate repeatability and relevance to the power requirement of the TV in normal use. "Round robin" testing of LCD and Plasma TVs shipped between laboratories in the UK and Australia has shown measurement repeatability of on-mode power in out-of-the-box recommended setting of better than 2.7% in the worst case and 0.2% in the best case. Repeatability in the same laboratory is better than 0.2% between complete non-sequential test runs. The careful consideration given to guidance in the standard on stabilizing the product on test has proved an invaluable contribution to the accuracy of the methodology.

- Considered advice, in the informative part of the standard, on how power measurements may be incorporated into energy efficiency metrics is crucial to regulators and policy makers. A good example of this in the reviewed standard is advice given on how to deal with the power saving potential of room luminance detectors in a TV (ALC)

- In future work on this and other Internationally harmonised power requirement testing standards more detailed consideration must be given to methods of ensuring that the test methodology maintains a level playing field for all products when test set –up is simplified to avoid prescribed, difficult to measure settings.

References

[1] International Electrotechnical Commission. IEC 62087 Edition 2.0 2008-10

Methods of measurements of audio, video and related equipment.

Standby Labeling and Procel Seal on Tvs – The Brazilian Experience

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PBE – Brazilian Labeling Program - INMETRO – National Institute of Metrology, Standardization and Industrial Quality

Abstract

In the middle of the 80's, Brazil began the implementation of a comparative labeling program for energy consumption domestic appliances. This program has been coordinated and ruled by INMETRO - Brazilian Government Institute for Metrology, Standardization and Industrial Quality. For electric appliances such as refrigerators and air conditioners this program has been conducted in partnership with PROCEL, the Brazilian Government Program for Electric Energy Conservation. The use of the energy comparative label became mandatory for all domestic appliances in 2003, due to an agreement with local manufactures to promote safety and efficiency. Since then, all products must be tested, approved, classified and labeled before commercialization. The laboratory tests follow a Brazilian Standard for performance, safety and rational use of energy of domestic appliance. For market surveillance and control, a sample of the production models is selected every year to be retested by INMETRO's accredited laboratories network. In order to highlight the most efficient electrical labeled products to the customers, PROCEL has introduced in 1993 an efficiency endorsement label. The updated data base list of the labeled models of appliances, with their characteristics, efficiency levels and the indication of the most efficient ones endorsed by PROCEL, is available to customers at the Internet.

The paper presents a brief introduction to the Brazilian Labeling Program – PBE and the Procel Seal and about its results, followed by a report about progress of stand by program for home appliances. This program intends to include all home appliances and also SOHO equipments, and began by TVs set because of its great employment. We have 152 models labeled, from 8 manufacturers of CRT category. A label model was developed and implemented, classifying from A to D. Interlaboratorial comparison with 2 official laboratories was also concluded and established the levels' ranges, considering the consumption for A level equal or less than 1 Watt. The Procel Seal is granted for those equipments in the A level. Both label and Procel Seal are in the Brazilian market since September 2007 as voluntary labeling and since July 2008 as mandatory labeling. Voluntary Labeling of LCD and Plasma models started by January 2009 and will turn into mandatory labeling by June 2009.

The compliance with IEC safety standards is also verified. By request of manufacturers, the label was turned to be mandatory. Next steps will be labeling computer monitors and cable TV decoders. After 2 years, efficiency levels will be reviewed. We are developing measurements of TVs in ON mode and possibly in 2010 we will have a new label with both measurements.

1 - Brazil's electricity usage on the residential sector

Most Brazilian households are served with electricity and have one or more TV sets. The residential sector consumption was 24% of Total consumption in 2007 (Fig. 1.A), and TVs represented 9% of this Total (Fig .1.B). These figures show the importance of TVs and others electro-electronic devices in household consumption and, considering that its participation is continuously growing, that its labeling will provide significant reduction in energy consumption.

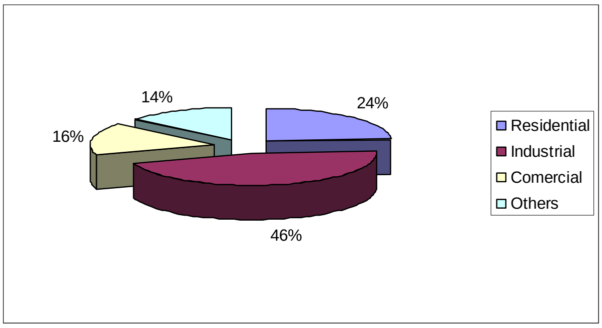


Figure 1.A - Electricity Consumption By Sectors

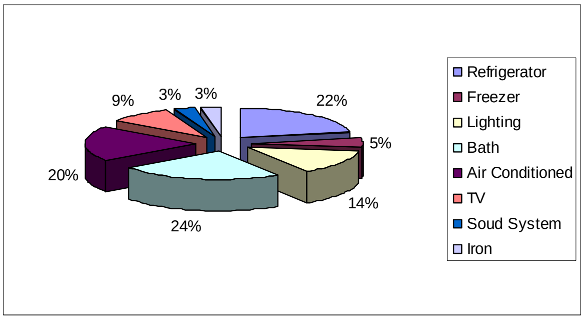


Figure 1.B – Electricity consumption in Households by end use

2 - The Brazilian government energy saving programs

Brazil has two major Government Energy Saving Programs linked to the Ministry of Mines and Energy – MME, the National Program for Electrical Energy Conservation - PROCEL created in 1985 and developed by Brazilian state-run power holding ELETROBRAS and the National Program for Rational Use of Petroleum Derivatives and Natural Gas – CONPET, established in 1991, sponsored and developed by PETROBRAS, Brazilian main petroleum company.

2.1 - The National Program for Electrical Energy Conservation – PROCEL

PROCEL was created in 1985 to improve EE of electrical sector in Brazil. PROCEL is linked to the Ministry of Mines and Energy and is implemented and has the Technical and Financial supports of Eletrobras, that is the state owned holding company of electricity in Brazil. PROCEL's mission is to stimulate the rational and efficient uses of electricity, to fight against electricity waste and to reduce environmental impacts due to electricity generation.
PROCEL's organization is divided in several branches developing actions in different areas, such as industry, public lighting, education, buildings, public sector, technological development and labeling.

2.2 - The National Institute of Metrology, Standardization and Industrial Quality - INMETRO

INMETRO was created in 1973, to support Brazilian enterprises, to increase their productivity and the quality of goods and services. Linked to the Ministry of Development, Industry and Foreign Trade – MDIC, some duties of INMETRO are: to maintain the national measurement standards in the country; to coordinate the compulsory and voluntary certification of products, processes and services; to plan and carry out the activities of accreditation of calibration and testing laboratories; to foster the presence of Brazil in the international activities related to metrology and quality. INMETRO conducts and rules the Brazilian Program for Conformity Assessment for products and services, which can be implemented by different mechanisms such as: Certification, Declaration of Conformity by the supplier, Labeling, Testing and Inspection.

2.3 - The Brazilian Labelling Program and the National Energy Conservation Label

The Brazilian Labeling Program – PBE began in 1982 and is now part of INMETRO's major Program for Conformity Assessment. With partnership of PROCEL for electricity consumption products and CONPET for oil and gas consumption products, INMETRO implemented the National Energy Conservation Label – ENCE. The INMETRO Energy Label compares similar products in terms of energy consumption or energy efficiency and informs customers about the energy use and other technical specifications. Depending on the product, the label also means attendance to other conformity requisites for safety or quality. Energy labeling is already implemented in a voluntary or mandatory mode for several products sold in the country such as: refrigerators; freezers; air conditioners; washing machines; gas cooking appliances; gas, electric and solar water heaters; photovoltaic systems; electric motors; ceiling fans; fluorescent lamps and ballasts; TV standby; light vehicles and buildings.

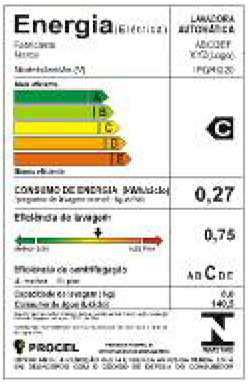


Figure 2

INMETRO / PROCEL

Electric Washing Machine Label

Figure 3

INMETRO / CONPET

Gas Water Heater Label

2.4 - Energy saving and efficiency endorsement labels

A Federal Decree of 1993 created the PROCEL Energy Saving Seal. It is an Endorsement Label to show the customers the products with the best electricity efficiency within each category.

Figure 4:

PROCEL Electric Energy Saving Endorsement Label

Procel Seal is an endorsement seal, voluntary and can only be applied to selected INMETRO energy labeled models that complies the award requisites each year and meets additional criteria depending on the product. These requisites are based on the whole information of INMETRO Energy Label to distinguish the smarter choices for the customers. A washing machine for example, besides having low electricity consumption, must also have high washing and centrifugation efficiency and low water usage to receive the Procel Seal. An official ceremony is organized every year by ELETROBRAS/PROCEL to award manufactures or importers of more efficient appliances with a trophy and a diploma, as recognition of the Brazilian Government. Receiving PROCEL Seals became a marketing aid for the companies and a target for the products.

2.4.1 - Market surveillance and control

All domestic appliances, locally manufactured or imported, should be tested and labeled before commercialization. The results of laboratory data have to be submitted to INMETRO and PROCEL. INMETRO has subordinated official agencies in all Brazilian states to check the stores for the correct use of the Energy Label. Every year INMETRO makes a selection, sampling some models of each supplier, to be retested in one of the independent accredited laboratories. If there is any deviation of the declared data or nonconformity for model's safety the supplier must correct the label information and/or the product. INMETRO also hear consumers complaints and intercepts to solve the problem or improve the products with manufactures.

3 – General view of Brazilian Labeling Program and Procel Seal

The Brazilian Labeling Program, known as PBE (Programa Brasileiro de Etiquetagem) was created in 1982 and is conducted by Inmetro. It is a partnership with Procel. Procel Seal is intended to distinguish the most efficient products, among those labeled. Usually Procel Seal is awarded to products labeled in "A" level and, in many cases, demanding for additional criteria.
PBE labeled products at present are listed below:

- Refrigerators –single door
- Refrigerators - combined
- Refrigerators - combined frost-free
- Vertical Freezers
- Vertical Freezers frost-free
- Horizontal Freezers
- Air conditioners – Window type
- Air conditioners –Split type
- Solar Water Heating Panels for homes
- Solar Water Heating Panels for swimming pools
- Solar Water Heating Reservoirs
- Compact Fluorescent Lamps
- Circular Fluorescent Lamps
- Standard Electric Motors
- High Performance Electric Motors
- Electromagnetic Ballasts for Fluorescent Lamps
- Electromagnetic Ballasts for High Pressure Sodium Lamps
- Electric showers
- Ceiling Fans
- Clothes Washing Machines
- Photovoltaic Electrical Generation systems
- Electric Boilers
- Buildings
- TVs
- Light vehicles

PBE and Procel are currently working on labeling several new products as listed below:

- Eolic Electrical Generation systems
- Electronic Ballasts for Fluorescent Lamps
- Distribution Transformers
- High Intensity Discharge Lamps
- Microwave Ovens
- Lighting Fixtures
- Heat Pumps
- Wine cellars
- Table Fans

In 2008, Procel estimates an energy consumption reduction provided by Procel Seal of 3,725 GWh/year, which corresponds to 94.7% of Global Procel's results in 2007 (3,930 GWh/year). PBE results in 2008 are estimated in 6,700 GWh (including Procel Seal results).

4 – A voluntary program becoming mandatory

PBE and Procel Seal started as voluntary programs with the partnership of Industry Associations, manufacturers and Test laboratories. Since 2001, is in force the Energy Efficiency Law nº 10.295 determining that all equipments should have minimum energy efficiency indexes. PBE was chosen to provide the indexes. Electric motors had its indexes established since 2003 and CFL'S, air conditioners and refrigerators in 2006. Inmetro also determined that every product covered by this law, having its minimum indexes established should also have mandatory labeling covering all other aspects beyond energy consumption.

5 – TV's labeling program

5.1 – Introduction:

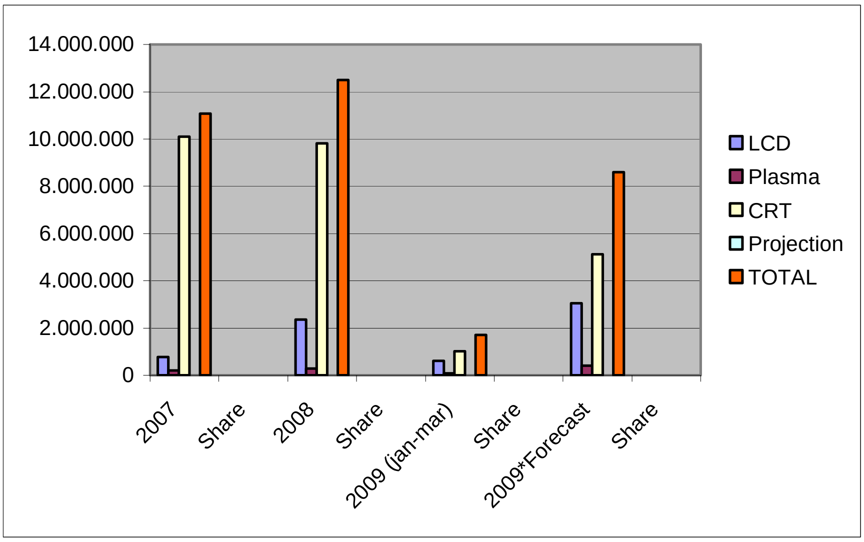
The Brazilian market of home appliances with standby function is growing continuously, especially in TVs sector. The annual sales growth is of 33.2%.

Brazilian population is currently about 190 million people, distributed in 56.8 million households, and 98% (55.3 million) of these are served with electricity. According to Eletros (National Association of Home Appliances Manufacturers) these households have at least one TV set with a total amount of over 60 million of units. The average household monthly consumption is 140kWh and the total consumption of residential sector was 94.7 TWh in 2008.

Manufacturing market of TVs is composed of 8 manufacturers from different origins (USA, Asia, Europe and locals) producing 152 models. Table 1 indicates that the total production in 2008 was about 12.5 million units produced (78.7% CRT) and, although an expected reduction in 2009 due to the economic crisis, it is predicted a growth of 30% for sales in 2010, mainly due to 2010 soccer World Cup. Part of that production is exported for Latin America, USA and European markets and consequently manufacturers are up to date about technological innovation.

Table 1

TV Annual Sales



5.2 –Strategy and Philosophy for Voluntary Labeling of TVs

The voluntary labeling strategy, according to the following items, was based on the system proposed by the Brazilian Program for Labeling (PBE) – under the supervision of INMETRO, together with PROCEL – and on the practice acquired by PROCEL in granting the Procel Seal since 1993.

The steps taken and the operational and labeling philosophies are presented as follows:

Definition of the products to be labeled and granted the Procel Seal: – the first step for a labeling process is to define which products will initially be labeled. In order to do so, it is necessary to gather through information in the marketplace, which will function as a tool for developing profiles of the products that are more relevant to the process. According to a preliminary market survey, the following characteristics have been underlined for the priority segment under discussion:

- 10 to 50-inch TV sets
- Sound systems – both mono and stereo
- Color system – Pal-M
- Screen types – Regular, flat, Semi-flat; Wide
- Screen technology – CRT, LCD, Plasma, Projection.
- Voltage – 127V/220V, 60 Hz

Operational mode of labeling/granting of the Label – Due to the extreme complexity of the process, it was necessary to split it in two phases in order to make it less time-consuming.

Phase 1 – Labeling of Standby mode only.

At this stage, only the Stand-by mode of equipment was tested for its energy consumption. During the implementation of Phase 1, other data focusing on Phase 2 are evaluated in order to present the current state of art, such as the consumption of the Active Mode according to such product operational variables as brightness, contrast etc. For this phase, the minimum levels of efficiency, as well as other basic operational characteristics, was defined for labeling and for receiving Procel Seal.

Phase 2 – Labeling the Active and Standby Modes

This phase encompasses the characteristics already evaluated in Phase 1 and the measurements stated above. In addition, minimum levels of efficiency, as well as other basic operational characteristics besides the ones mentioned in Phase 1, will be defined for labeling and for receiving Procel Seal.

Labeling Philosophy (for Phase 1) – the work philosophy for labeling encompasses the following activities:

- listing and contacting labor representatives (ELETROS), manufacturers and testing laboratories;
- gathering information about existing products in the Brazilian marketplace;
- making a survey of the current national and international norms and standards;
- Organizing the 1st Meeting in order to formalize the initial work by establishing a Working Group (WG) in which the steps to be taken, as well as the philosophy of testing laboratories and efficiency indexes, was determined;

- Organizing the 2nd Meeting for the presentation of the First Standard Draft and setting a work schedule with the following basic stages:

  - Defining a unique test methodology;
  - Defining laboratories capacity;

- Comparing laboratories;
- Setting criteria of labeling, such as family groups, renewal criteria etc.
- Manufacturers tests all models, grouped in categories defined by WG, in order to know its standby consumptions, and inform PBE
- Setting indexes and levels for label.
- Laboratories test one model of each family to compare with manufacturers data
- To announce the consumption and other data in Web Sites of Inmetro and Procel
- To put the label on the TVs Phase 1, and periodically testing a new group of TVs not yet tested in laboratories
- Maintaining the meetings of the Work Groups until the end of Phase 1 and the beginning of Phase 2;
- Defining of the Labeling philosophy of Phase 2;
- Maintaining the meetings of the Working Groups until the end of Phase 2 and carrying on with the tasks, which include the continuous labeling follow-up and the labeling of new products of the same range, such as VCR´s, VCR/TV combos, DVD´s, DVD/TV combos etc.

5.3 – Adopted Standards

IEC 62301 Standard, Ed. 1 – "Measurement of Standby Power", published in November 2003 by the IEC Technical Committee 59 (TC59) was adopted.

5.3.1 – Adopted Electric Safety Standards

Considering manufacturers request, PBE included Safety Standards in the scope of standards. Adopted Standard is IEC 60065.

5.4 – Tests Method and Test Equipment

Both, Method and Test Equipment specification were based on "Product Specification for Energy Star qualified TVs, VCRs, Combination Units, Television Monitors, and Component Television Units (Version 2.0)".

Some changes were needed considering typical Brazilian conditions. Testing should be done only at voltage and frequency of Brazilian Electrical network, 127V or 220V and 60 Hz. Time to reach operating temperature was initially set in 30 minutes.

5.5 – LABORATORIES INVOLVED

Procel improved test capability of IPT-SP (São Paulo) and FUCAPI (Manaus) laboratories, buying new equipments. Procel spent US$ 200,000.00 in resources from GEF grant. Both laboratories where chosen due to its proximity to manufacturing centers.

5.6 – Troubles

Laboratories at the beginning of tests had some normal snags in achieving true standby power readings for low power measuring. Time to unit under test reaches operating temperature and the readings on the power meter stabilize, initially established in 30 minutes, and was increased to 45 minutes and if the readings are still oscillating, the measurement time should be long enough to obtain a true average.

5.7 – Tests results

A summary of First round test results from all manufacturers is shown below in Table 2. manufacturers are identified by letters. The table also indicates the average range from A to D aimed in this round. Though, these were not final results considering that until fixed time limit to begin fixing labels in products, manufacturers should improve their products. Standby average readings are displayed in average values. Table 2 also shows level distribution by manufacturer. We can clearly remark manufacturers on the top of technology, producing only "A" products.

Table 2 - TESTS RESULTS

Table of Stand-by consumption - First round tests						
Manufacturer	***Stand-by Range (W)***		***% products per level***			
	min.	max.	A	B	C	D
A	0,570	0,570	100%	0%	0%	0%
B	0,930	7,500	11%	0%	45%	45%
C	0,652	2,432	45%	55%	0%	0%
D	0,500	2,430	62%	38%	0%	0%
E	0,415	0,759	100%	0%	0%	0%
F	2,200	6,500	0%	60%	20%	20%
G	2,663	5,609	0%	8%	92%	0%
H	2,040	8,200	0%	41%	41%	18%
I	0,910	5,150	13%	50%	38%	0%
J	2,782	5,477	0%	33%	67%	0%

5.8 – Ranges for labeling

Label levels were set considering A level for standby equal or under 1 Watt. B, C and D were set splitting measured values over 1 Watt up to the highest (7.8 Watt) in 3 equal ranges, as shown in table 3.A. These ranges must be revised within 2 years, in order to improve EE. Hence the final distribution in 4 levels lead to the next table 3.B, where ranges are related to models percentage. We can remark that A, B and C ranges have almost same number of products, whereas D range has few products clearly indicating products liable to be excluded of the market in short term. The comparison of these two tables also shows the fast evolution of manufacturers since the beginning of labeling works. We can note that final tests which determined actual ranges, led to higher efficiency indexes than initial.

Table 3.A- Levels participation of models at the beginning of works

Levels	CRT		
	WATTS ≤	MODELS	%
A	**1,000**	29	**31,18**
B	**3,430**	26	**27,96**
C	**5,860**	30	**32,26**
D	**8,200**	8	**8,60**
	TOTAL	**93**	

Table 3.B - Levels participation of models at the label launching

Levels	CRT		
	Watts ≤	Models	%
A	**1,000**	49	**32,24**
B	**3,200**	47	**30,92**
C	**5,400**	52	**34,21**
D	**7,800**	4	**2,63**
TOTAL		**152**	

5.9 – Label layout:

The final label layout is shown below. We remark that the consumption information displayed to consumers indicates monthly consumption. On the following pictures we can see examples of Label and Seal pasted to a TV.

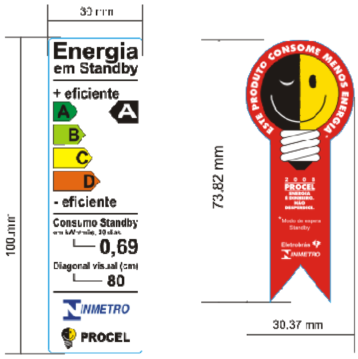


Figure 5 – Label and Seal Layout

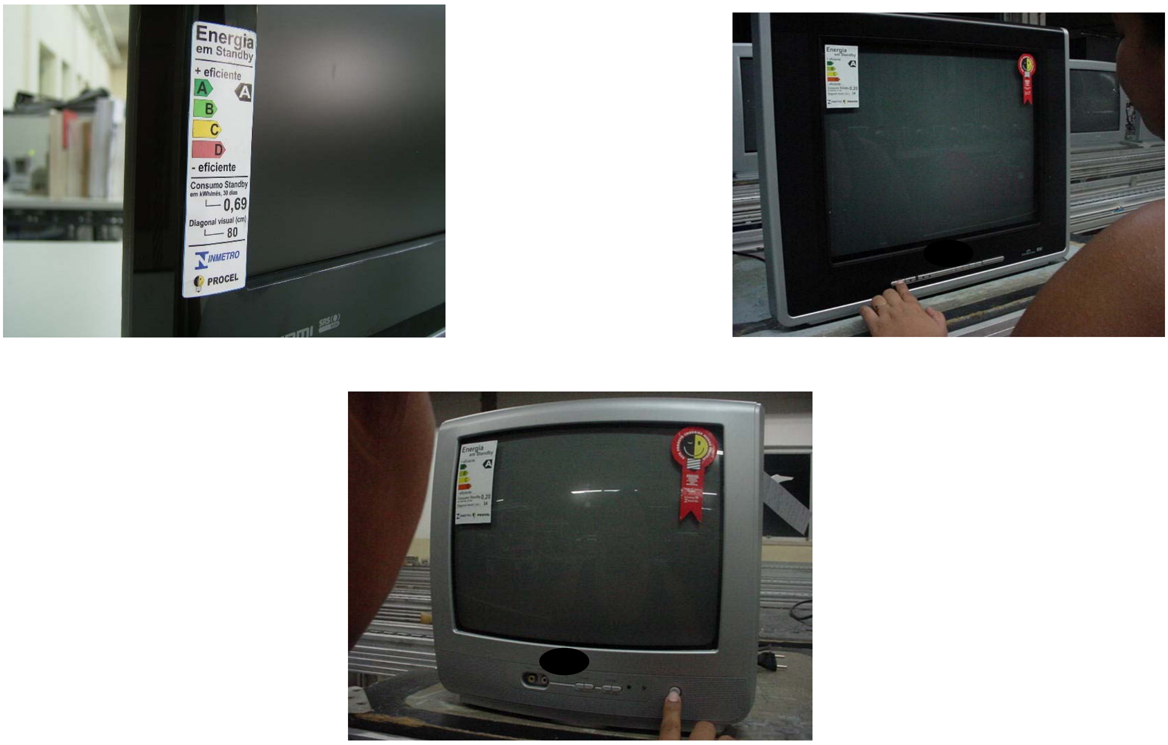


Figure 6 - TVs pictures with Label and Seal

5.10 – Work schedule

Beginning of works: July 2004
Definition of Standards and Methods: February 2005
Laboratories comparison: March - May 2005
Models tests in manufacturers laboratories: June – August 2005
Label ranges definition: September 2005
Confirming Tests in official laboratories: September 2005– June 2006
Beginning of Voluntary Labeling: September 2007
Beginning of Mandatory Labeling: July 2008

5.11 – Expected reduction on energy consumption

By the beginning of the program reduction in energy consumption was estimated as follows:
TVs Annual Sales in 2004: 7,725,000
- Estimated Average Consumption - 4.28 Wh
- Program Goal - ≤ 1 Wh
- Estimated Hourly Average Consumption Reduction per unit – 3.28 Wh

- Estimated Daily Average Consumption Reduction per unit:
  (considering 20 hours on Standby mode) – 65,6 Wh
- Estimated Annual Average Consumption Reduction per unit:
  (considering 365 days / year) – 23.94 kWh
- Total Annual Estimated Average Consumption Reduction:
  (considering 7,725,000 TVs units sold per year with 23.94 kWh of Reduction per unit)
  23.94 kWh X 7,725,000 = 184.97 GWh
- Estimated Annual Average Consumption Reduction – 184.97 GWh
  Corresponds to the energy produced in one year by a 45 MW power plant.

Supposing the substitution of old models, with a 10 years lifetime, plus market growth, we may conclude that in 8 years the Annual Average Consumption Reduction should be of about 1,436 GWh, corresponding to the energy produced in one year by a 350 MW power plant.

Since, as seen before, annual CRT sales have been growing until 2008, and although 2009 estimative aim to a decreasing market due to economic crisis, average figures of total annual sales, considering LCD and Plasma TV sets, are higher than 2004 figures, We can forecast that in less than 8 years most of all old models should be changed by new ones leading to an significant energy consumption reduction.

3.12 – Next Steps

PBE and Procel intend to continue standby program in home appliances, mainly in home electronics. Initially by cable TV boxes, VCRs, DVDs, sound equipments, computer monitors, etc. Procel is accomplishing a survey to determine priorities.

6 – Phase 2 – Active Mode (ON mode)

As mentioned in item 5.2, this phase encompasses the characteristics already evaluated in Phase 1 and the measurements for this new step, in order to establish minimum levels of efficiency, as well as other basic operational characteristics, besides the ones mentioned in Phase 1, that will be defined for labeling and for being granted with Procel Seal.

6.1 – Adopted Standards

- IEC 60107-1/97 - Methods of measurement on receivers for television broadcast transmissions - Part 1: General considerations - Measurement at radio and video frequencies.

- IEC 62087/02 - Methods of measurement for the power consumption of audio, video and related equipment.

Signals employed are international standards of the SMPTE (The Society of Motion Picture and Television Engineers - www.smpte.org - Pictures and sequences derived from CCIR test tape, ITU-R Rec. BT 802).

6.2 – Initial tests results

Preliminary test results, with static signals, from 4 models, in 3 different screen sizes, of 4 manufacturers, were conducted just to verify laboratories ability to test the products and to have a slight overview of the consumption of models in Brazilian market. As the tests were considered appropriate and to complement these data it was necessary to test more equipments, with all static and dynamics signals in order to have a faithful and reliable database, of LCD, Plasma, Projection and LED technologies, with or without digital reception system. The final test results of CRT samples for 14”, 21” and 29” models are shown in table 5. Test with LCD and Plasma samples are in completion. Final results are expected by the end of May.

Table 4 - Preliminary Tests Results ON mode - Monthly Consumption in KWh

(5 hours per day)

		14" TVs				21" TVs					29" TVs				
		A	B	C	D	A	B	C	D	E	A	B	C	D	E
Power consumption Static PicturesSignals	**W**	39,9	37,1	35,7	33,8	57,6	60,6	67,0	67,0	44,7	72,0	79,0	75,3	67,0	72,7
Monthly Consumption Static Pictures Signals	**KWh/month**	6,0	5,6	5,4	5,1	8,6	9,1	10,0	10,1	6,7	10,8	11,9	11,3	10,1	10,9
Power Consumption Moving Pictures Signals	**W**	39,1	35,7	35,2	32,2	56,0	58,8	65,2	65,7	42,6	69,2	75,6	69,6	65,7	69,9
Monthly Consumption Moving Pictures Signals	**KWh/month**	5,9	5,4	5,3	4,8	8,4	8,8	9,8	9,9	6,4	10,4	11,3	10,4	9,9	10,5
Average Monthly Consumption	**KWh/month**	5,9	5,4	5,3	4,9	8,5	8,9	9,8	9,9	6,5	10,5	11,4	10,6	9,9	10,6

The consumption was calculated in accordance with the following formulas:

Static pictures Power Consumption:

$$P_{oe} = \frac{\left[\frac{(Pw+Pb)}{2} + Pc + Pt\right]}{3}$$

Pb: Power at black level picture (W)
Pw: Power at white level picture (W)
Pc: Power at color bars picture (W)
Pt: Power at Grey scale (or stair step) Picture (W)

Moving pictures Power Consumption

$$P_{od} = \frac{P_F + P_B + P_C + P_T}{4}$$

PF: Power at standard movie - Flower Garden ITU index 15 (W)
PB: Power at standard movie - Bicycles ITU index 35 (W)
Pc: Power at standard movie - Carnival Ride ITU index 36 (W)
Pt: Power at standard movie - Tempête ITU index 44 (W)

Monthly Consumption with static pictures:

$$E_{oe(KWh/mês)} = \frac{Poe*5*30}{1000}$$

Monthly Consumption with moving pictures:

$$E_{od(KWh/mês)} = \frac{Pod*5*30}{1000}$$

Average Monthly Consumption:

$$E_{(KWh/mês)} = (E_{oe}*0,2) + (E_{od}*0,8)$$

6.3 – Expected reduction on energy consumption

Although the above figures of Table 5 are just a preliminary test, we can estimate in a very conservative way that an average reduction of monthly consumption of 3 KWh should be obtained in short term (3 years). So, we should expect, considering an average annual market of 10 million units, an annual reduction of 360 GWh, which corresponds to the energy produced in one year by a 90 MW power plant. Or, if we add the expected reduction in stand by mode, a reduction of 540 GWh per year equivalent to a 135 MW power plant.

6.4 – Work schedule

Beginning of works: Jan 2008
Definition of Standards and Methods: Mar 2008
Laboratories comparison: July 2008
Models tests in manufacturers laboratories: Oct 2008
Label ranges definition: July 2009
Confirming Tests in official laboratories: Sep 2009
Beginning of Voluntary Labeling: Jan 2010
Beginning of Mandatory Labeling: Jan 2011

6.5 – New Standby / On Mode Label

PBE and Procel team are working to develop a new label that will mix the 2 concepts in one label. Our purpose is to develop a formula considering standby and on mode times to calculate the final daily consumption and thus split consumptions in 4 levels. A level products should have standby mode bellow 1 Watt.
Procel label will also ask for on/off switches in all models.

7 – Conclusions

The Brazilian TV manufacturing market is able to supply high efficiency products and labeling adoption certainly will lead to the exclusion of poor efficiency models in short term. It is also remarkable the variation in standby power among models in the market, spreading from 0.5 to 8.2 W, showing different levels of technology. In addition, we must consider how distant highest standby values from 1Watt recommended goal are. These results also indicate that, not only standby mode has to be evaluated, but also active mode.
Considering figures obtained in items 3.13 and 6.3 – Expected reduction on energy consumption, we may also conclude that standby limiting in home appliances is a necessity, as well as labeling active mode. Some informal measurements accomplished in Brazilian households indicated a total standby power consumption of 30Wh. This figure shows a giant waste of energy and a terrible menace to the environment. It is also important to remember that TVs are present in almost every Brazilian household (1.41 per household), and that CRT is still the most sold model in Brazil (78%), and that shows how important is to work on all models in the market.

References

Websites (in Portuguese):

ELETROBRAS
http://www.eletrobras.com

INMETRO
www.inmetro.gov.br

PROCEL
www.eletrobras.com.br/procel

MME
www.mme.gov.br

MDIC
www.mdic.gov.br

ABNT
www.abnt.org.br

INMETRO Labelling Programme for Standby Labeling on TVs' Information
http://www.inmetro.gov.br/qualidade/eficiencia.asp
http://www.inmetro.gov.br/consumidor/produtosPBE/TelevisoresStand_by.asp

INMETRO Rule for Conformity of Standby Labeling on TVs'
http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC001431.pdf

INMETRO Data base list of labelled TVs'
http://www.inmetro.gov.br/consumidor/pbe/televisores.pdf

PROCEL Standby Labeling on TVs' Data Consulting
http://www.eletrobras.com/CatalogoSeloProcel2008/tv1.html?cod=vencedores

PROCEL Creation Decree
http://www.eletrobras.com/CatalogoSeloProcel2008/apresentacao.html?cod=oprocel

Green Energy Efficiency Label Decree
www.planalto.gov.br/ccivil_03/DNN/Anterior%20a%202000/1993/Dnn1931.htm

Energy Efficiency Law
www.planalto.gov.br/ccivil_03/LEIS/LEIS_2001/L10295.htm

Energy Efficiency Law Regulation Decree
www.planalto.gov.br/ccivil_03/decreto/2001/D4059.htm

Potential energy savings for televisions due to the application of labelling and MEPS in Australia

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Abstract

This paper discusses the impact that televisions have had on increased domestic energy use. The increase has been due to the increasing trend in the screen size of televisions that has been made possible through the changing technology used to make TVs such as LCD and Plasma. In addition in Australia there has also been a trend in the increased number of TVs per household.

Market failures that suggest that without some intervention the energy consumption of TVs will not be corrected through normal economic processes are also discussed and demonstrated,

These changes have contributed to TV becoming the second highest energy consuming domestic appliance. Australia's response to this is to implement a voluntary energy labelling scheme in 2008 to be followed by MEPS and Mandatory Energy Labelling in 2009.

The need for a program

The problem

Televisions are changing in both technology and size. Both factors have caused the average energy consumption of televisions to increase dramatically over the last few years. In addition to the increased screen size that is now evident in the market place, the number of TVs per household in Australia has also been increasing steadily over the last few decades. Conservatively, the number of TVs per household in Australia is at least two with strong evidence that it is actually between 2.4 and 2.7.

The market share of the smaller CRT televisions has now decreased to below 30% with flat panel display sales now accounting for over 70% of sales. In 2007 plasma sales accounted for around 17% of the market with LCD technology making up the difference with 48% of sales. The average screen size now being sold in Australia is approaching 106cm.

It is estimated that the stock of TVs in Australia is 17.8 Million in 2007. The annual direct electricity consumption of these TVs for 2007 has been estimated at 6604 GWh/yr in Australia and 723 GWh/yr in New Zealand. In terms of greenhouse gas (GHG) emissions in 2007 this equates to 6883 kiloton (kt) of CO_2 for Australia and 505 kt of CO_2 for New Zealand. Figure 1 following provides the estimated annual business as usual (BAU) Green House Gas (GHG) emissions for televisions in Australia and New Zealand to 2020.

The scope for the improvement in energy use of CRT TVs is limited as this technology is rapidly being replaced with LCD and Plasma technologies. The scope for improvement in plasma technology is more significant. Recent announcements suggest that plasma type televisions will rival the energy use of current LCD TVs within a couple of years. LCD televisions have the greatest scope for improvement with the use of modulated backlights and the introduction of LED backlights. Some reports have estimated potential savings in energy use of LED backlit LCD technology as high as 80%.

Energy use of televisions is not apparent in the marketing literature for televisions in Australia. The value of energy efficiency and lower energy use is not factored into the purchasing decision. It is also evident that running costs and the environmental costs of the greenhouse gas emissions are also not prominent in the purchase transaction.

The introduction of MEPS for inefficient energy-consuming equipment continues to form part of Australia's climate change strategy. Energy rating labels have also proved to be a useful policy tool for other types of products such as refrigerators which, as shown in Figure 2, use a similar amount of energy to TVs. For these reason Australia has adopted a voluntary labelling program for TVs in 2008 as a precursor to a mandatory labelling program and MEPOS from October 1st 2009.

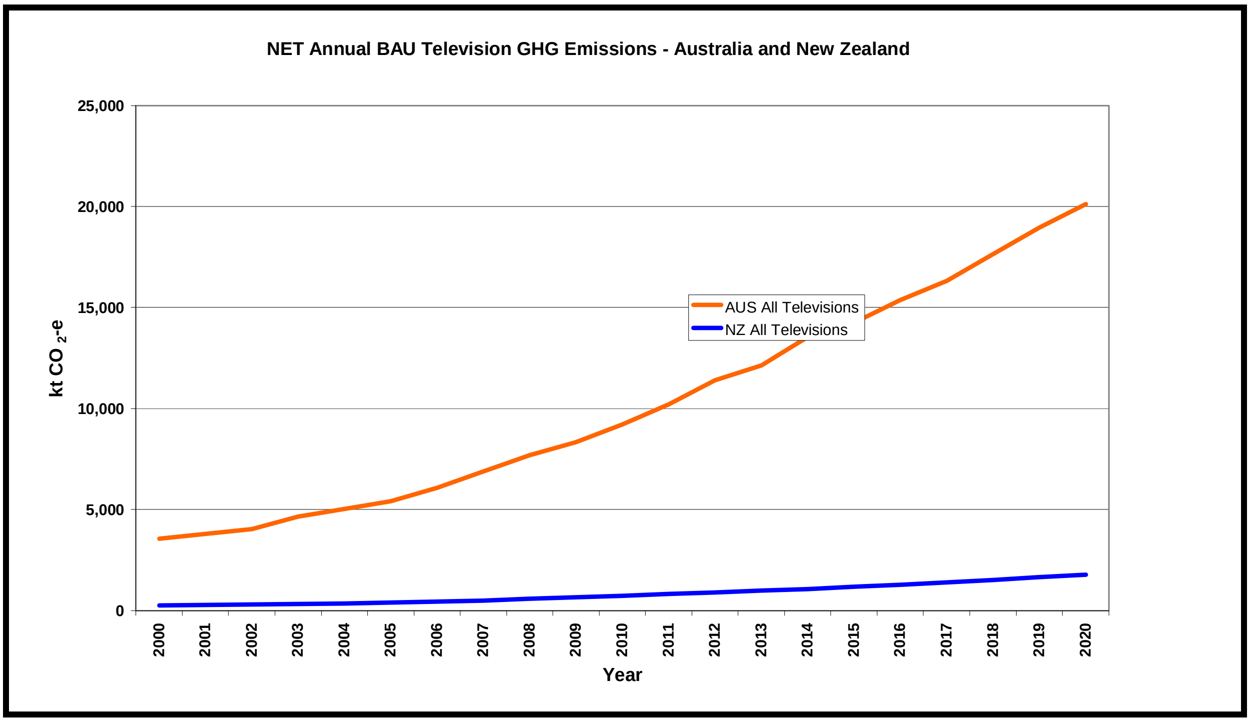

Figure 1: Projections of green house gas emissions due to televisions in Australia

Contribution of Televisions to Energy Use and Emissions[1]

The energy consumption of televisions can be broadly categorized into three modes:

1. Average "On Mode" - energy used by the television when in use and showing typical television video signals
2. Download On Mode – Energy used by the television when no picture is being shown but the television is downloading electronic programme guides (EPG) or new firmware.
3. Standby Mode, where the television is plugged in to mains electricity supply and waiting for a command to switch to one of the two On Modes stated above.

For 2007 it is estimated energy consumption from televisions in Australia is estimated to be over 6604 GWh/yr.

The contribution of standby mode to these estimates is relatively low, being 90GWhrs and 15GWhrs

On average new televisions are consuming more energy now than many other household appliances already subject to the mandatory Energy Rating Label .This has not been the case for traditional CRT televisions, but the trend toward larger screen sizes and technologies such as plasma has changed their consumption profile. In 2006 televisions accounted for around 30% of the energy consumed by common household appliances (see Figure 2)..

[1] Consultation Cost Benefit Analysis for MEPS and Energy Labels for Televisions, DCE July 2008

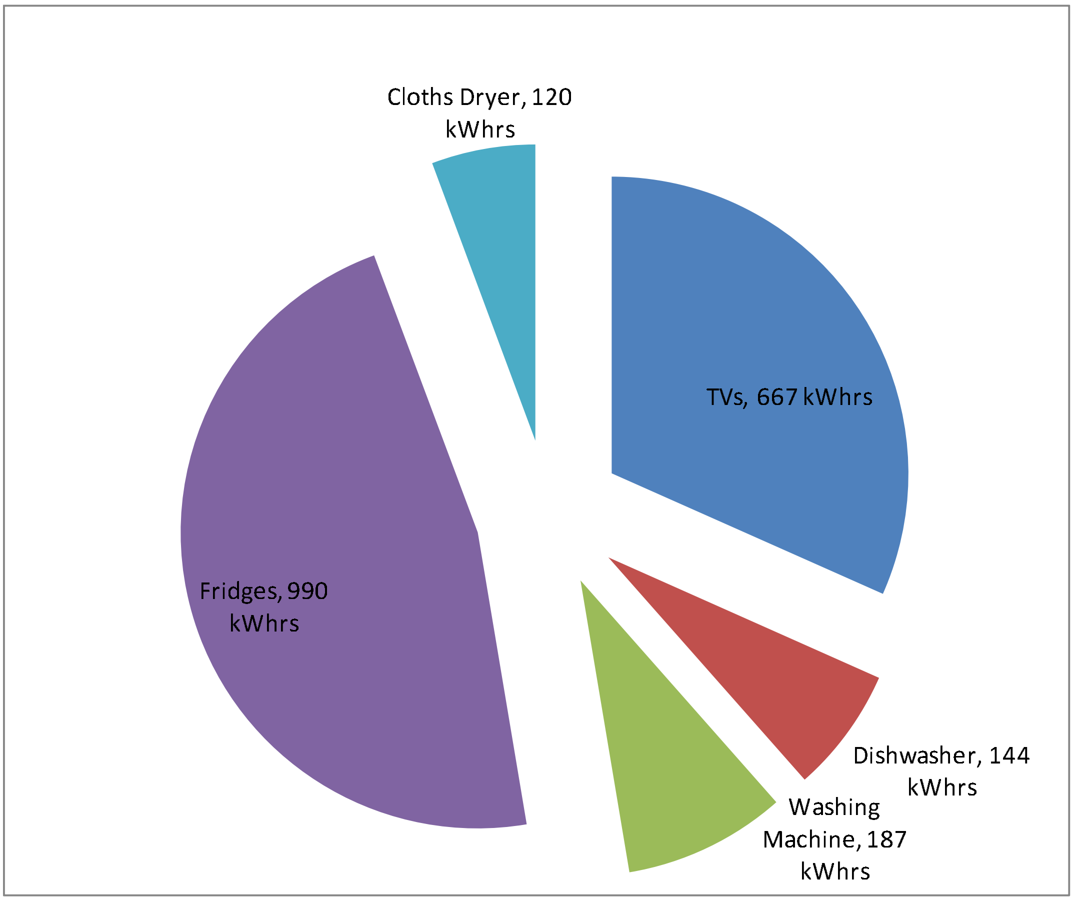

Figure 2: Annual power consumption of consumer appliances[2]

Given the trend toward larger TVs and more TVs per household it is reasonable to postulate that TVs will exceed refrigerators as the highest energy consumption appliance by 2012.

There are also *indirect* energy losses and gains associated with the heat from televisions. During periods of cooling, waste energy adds to the energy required by air conditioning systems and during periods of heating, waste energy is beneficial and reduces the heating energy load.

Like any electrical appliance, the contribution of televisions to energy use and emissions is a function of number of units in use, technical attributes of the televisions units, and usage trends. Televisions are estimated to be operating 10 hours a day, 365 days a year. It should be noted that this is the estimated time on not the time being watched by any particular individual. Televisions are left on for numerous reasons ranging from background noise to the enjoyment of the radio services that now exist with a number of DTV services. Evidence collected from the USA[3] suggests a figure of 8.3 hours daily but TV usage is reported to be on the rise[4] particularly for high definition TV sets which are rapidly becoming the predominant TV sold.

The Television Market

General Market Conditions

All televisions sold in Australia and New Zealand are now manufactured overseas; however from time to time limited assembly of product takes place locally, usually for special purposes. However, this is

[2] The case for and against MEPS and labelling of Televisions: A discussion paper. DCE October 2007.

[3] A Nielson survey as reported in the Sydney Morning Herald in May 17th 2007

[4] TV predictions,com. (February 25, 2008)

insignificant compared to the vast number of TVs sold annually and even these televisions use components that are manufactured overseas, in particular the display panels that account for most of the power consumption of a television.

Since Australia and New Zealand have Digital Television (DTV) requirements that are unique, and televisions are generally produced in large factories for the world market, there is a need to adapt televisions for the Australian and New Zealand markets. These modifications are in general small and are invariably software and firmware in nature. While the majority of televisions are made in China, some are manufactured in other south-east Asian countries such as Japan, Taiwan, Korea, Malaysia and Indonesia.

In the Australian market the dominant technology is now LCD with nearly 50% of the market. Plasma is popular for larger televisions and has around 17% of the market. CRT televisions are rapidly disappearing from the market and are expected to be below 25% market share in 2008. Rear projection televisions are also rapidly losing market share and account for less than 2% of the market.

Average screen size is rapidly increasing and is now approaching 106cm. This increasing trend is expected to continue into the future. Average screen size has increased from 68cm to 106cm over the last 5 years.

Analysis of the TV market shows that the market is dominated by around 15 suppliers that jointly control around 65% of the market. Of these the 5 major suppliers have a joint share of over 50%.[5]. The remaining 35% of the market is made up of around 17 smaller suppliers.

Comparison of LCD and Plasma Pricing

Evidence suggests that larger LCD televisions are not price competitive with similar screen size plasma technology, however, a survey of 50 televisions conducted in April 2008 shows that there is no significant difference in the price between LCD and Plasma in most cases.

Figure 3: Time series of TV retail price changes between samples in July 2007 and April 2008. The prices are in Australian Dollars.

Both the Full HD(1080P vertical resolution) categories show lower prices for LCDs than for the equivalent Plasmas. The higher LCD HD (768P vertical resolution) prices could be a due to older models being offered and the likelihood that LCD suppliers are not pursuing better pricing as Full HD becomes the dominant technology.

5 Figures supplied by Industry.based on various GFK reports

Assessment of Market Deficiencies and Failures

The Spread in the Energy use of televisions

Figure 4 to Figure 7 show a series of scatter charts prepared from data of 50 TVs collected to see if any relationship exists between power consumption and price.

There is considerable technical scope to increase the energy efficiency of televisions. The analysis of the spread of power used by the same type of television and the same screen size shows wide variation in the power use. Table 1 below shows the typical spread for small medium and large televisions.

Table 1: Spread of Power usage for Small, Medium and Large TVs[6]

Screen Size	Min(W)	Max(W)	Spread(W)	Spread %
Small(2090cm^2)	80	114	34	30%
Medium(5393cm^2)	194	328	134	41%
Large(7741cm^2)	342	450	108	31.6%

This table suggests that, unless there is a relationship between price and power consumption, the spread of power consumption values is much larger than would otherwise be expected. It also suggests that the minimisation of power consumption is not a priority in the design of many televisions. Given this, how does the purchase transaction, accommodate the energy usage and GHG emission costs that occur as a consequence of the purchase?

These costs are not apparent in the transaction so they are not being factored in at all. As a result there is a market failure in relation to these costs. The following section explores any relationship between price and energy consumption where there are deficiencies in the television market.

Energy Performance vs Market Price

If there were market price reasons for the spread of energy use then it would be reasonable to expect to see this reflected in the price vs energy consumption data. This however is not the case.

A study was conducted on the 96 TVs sampled in 2007[7] and the results are shown in Figures 9 to Figure 12. To ensure that the comparisons of price vs energy consumption did not unfairly compare different technologies of screen resolutions the study separated these attributes and compared like with like. The conclusion is that the charts do not show a relationship between price and energy consumption.

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[6] Digital CEnergy Australia. Television Energy Labelling::The case, and proposal, for Labelling Televisions. October 2007

[7] Survey conducted by EnergyConsult Pty Ltd results reported in DigitalCEnergy TV Discussion Paper October 3rd 2007.

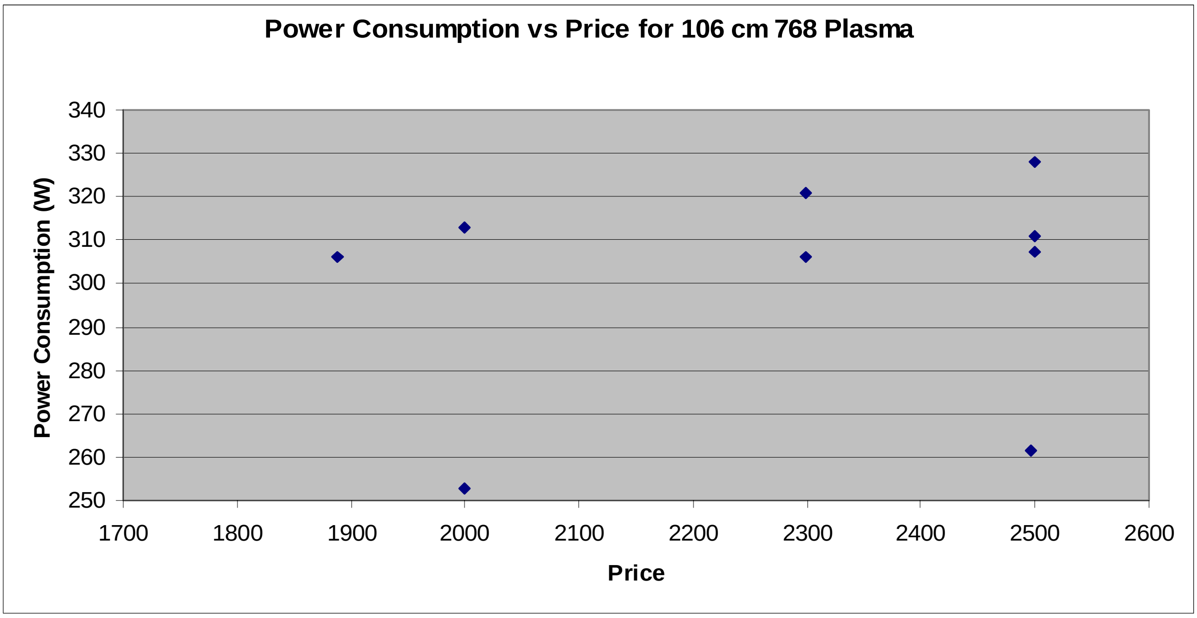

Figure 4: Scatter chart of Price vs Power consumption of 106cm 768 line plasma.

In the above Figure it is evident that the power varies from 260W – 329W (27%) for this category of Plasma televisions. In addition the best performing TV is the equal second least expensive.

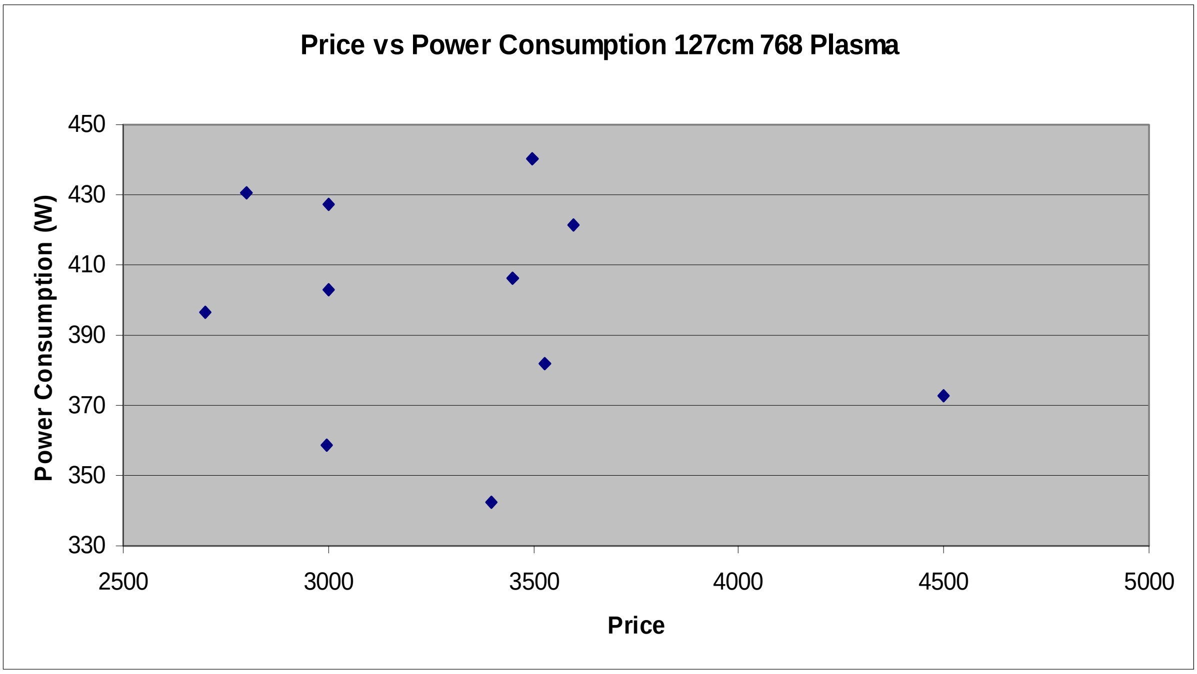

Figure 5: Scatter Chart of Price vs Power Consumption for 127cm 768 Plasma

The lack of evidence for a relationship between price and energy use is even more evident in Figure 5. The best energy performing TV is in the medium price range whereas the most expensive is also in the same range. The second best energy performing TV is actually toward the lower price range.

Figure 6 shows the same analysis for LCD TVs and again it is clear that there is no evidence for a relationship between price and energy consumption.

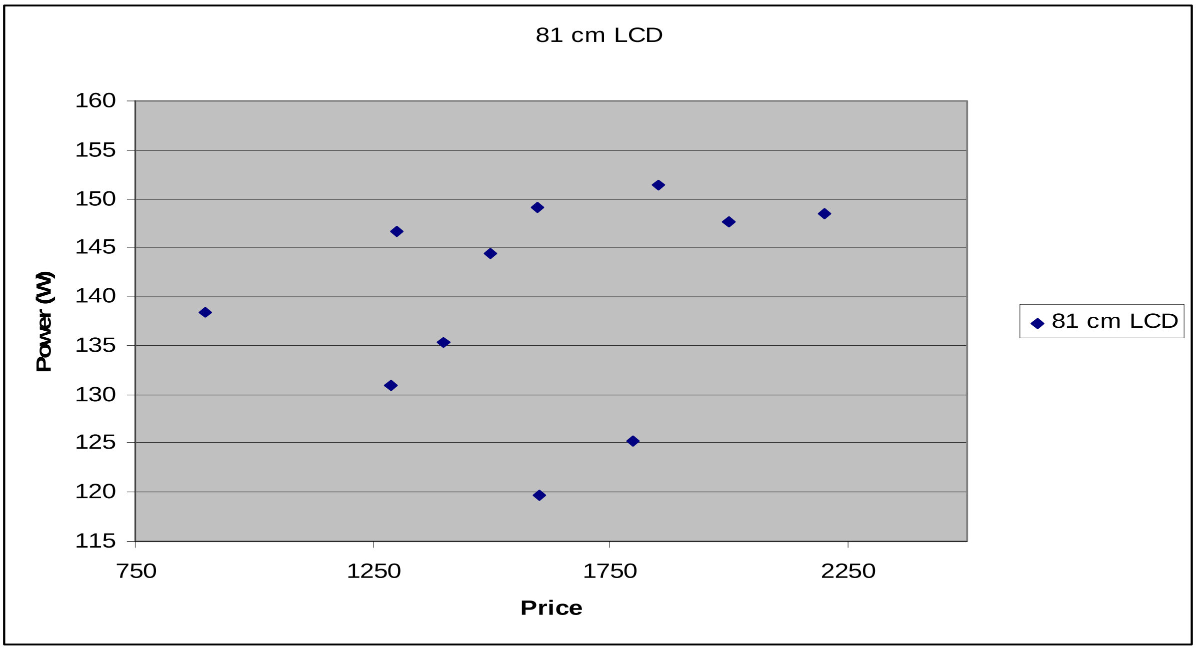

Figure 6: Scatter Chart of Price vs Power Consumption for 81cm LCD 768p TVs

Finally the trend continues for Figure 7. In fact if any trend does exist in this chart it would actually support the argument that better energy performing LCD TV are actually cheaper.

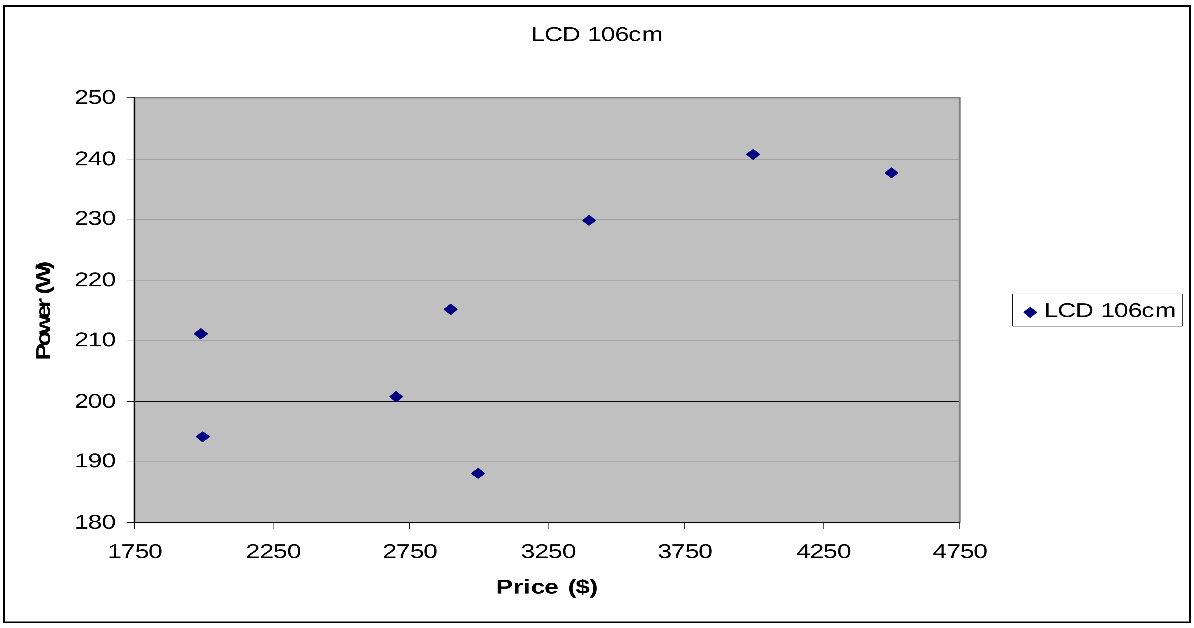

Figure 7: Scatter Chart of Price vs Power consumption for 106 cm 768p LCD TVs

The promotion and advertising of televisions and energy use

To better understand the information provided in the sale transaction of televisions a survey was conducted on the advertising material available for televisions. It has been otherwise observed that if the energy cost of television use was an important consideration for purchasers of televisions then this would be reflected in the energy performance specification being prominent in the televisions advertising and promotion. The survey was conducted using both retail flyers and web based brand information sources.

It was evident from both these sources that energy performance lacks not only prominence but mention. This in turn is evidence of severe market failure as the cost of energy and the subsequent costs of CO_2 emissions are not being factored into the purchase decision or the costs of production.

The weakness of the link between television energy use and consumer purchase decisions means that the suppliers are unlikely to raise the issue in promotion as it is not a positive attribute. Without the issue being raised consumers are unlikely to begin to factor in the energy consumption as part of their purchase decision. It is for this reason that a joint MEPS labelling program is necessary. To make available the better performing television in each technology category a MEPS program is necessary. To complete a market transformation in the longer term and to properly inform the consumer an energy rating label program is necessary.

It has been suggested that the growth of LCD televisions is due to the reported lower energy use of this technology. In turn this is used to suggest that energy use is becoming a factor in the purchase decision of consumers and as such regulation is not needed. This would be true if the growth was in the same screen sizes as alternative higher energy using TVs such as plasma.

In fact when analysis is done on the market figures taking into consideration screen size consumers are clearly not basing their purchase decision on energy use. .With very few exceptions, plasma televisions are not offered in screen sizes under 106cm which is dominated by LCD. In the 106cm and larger categories, however, plasma still remains the dominant technology with over 60% market share. In fact plasma market share is actually increasing currently with a market share by units in the last 3 months of 2007 being 17% overall as opposed to 22% in the first quarter of 2008. Clearly this is showing that it is not energy consumption but screen size that is determining whether a plasma or LCD TV is selected by the consumer.

Television Regulation

Australian and international studies have identified that televisions are candidate products for intervention to address market failure.[8].

This regulatory impact statement (RIS) studies the impact of proposed mandatory MEPS and energy rating labels for televisions, with a nominal 230 Vac. mains supply. The scope includes monitors designed primarily for television viewing and projection televisions both rear and front.

The energy consumed by a television is defined as the energy used in average on mode as defined in the interim AS/NZS 26087 Part 1 and standby modes as defined in IEC 62301 and AS/NZS 62087 Part 2.2. This will include televisions that are powered from an external power supply (EPS). Such televisions will be required to meet both the regulation resulting from this RIS and the existing requirements of regulation for EPS.

Monitors designed primarily for computer display or TVs that are battery operated are excluded from the scope of this RIS.

The use of the voluntary TV energy rating labelling scheme as a marketing tool.

On June 5th 2008 the government announced a voluntary labelling scheme that provides those suppliers who choose to participate a tool to assist in conveying to the consumer the energy consumption benefits of their product offering. The response to this announcement was very positive from several major suppliers who not only announced their support for the initiative but also confirmed their intention to use the new scheme. This support was qualified to the extent that the suppliers also asserted that it should be followed by a mandatory scheme suggested in this RIS and both schemes should have consistent requirements so that consumer confusion can be avoided.

In these tables there is no evidence to support the proposition that plasma TVs are cheaper than LCD in the emerging Full HD segment.

[8] Digital CEnergy Australia Supplementary Discussion Paper on MEPS and Labeling for TVs. December 2007

MEPS and Mandatory Labelling

The Australian government is planning to introduce a MEPS scheme and a mandatory labelling program on 1st October 2009.. The tier 1 MEPS level will remove almost 20% of the TVs sold in Australia in 2008. In addition a Tier 2 is planned for 2012 which will be 3 stars or greater with a likelihood that it could be as high as 4 stars.

Figure 8 shows the resulting CO_2 savings for the differing Tier 1 and 2 scenarios.

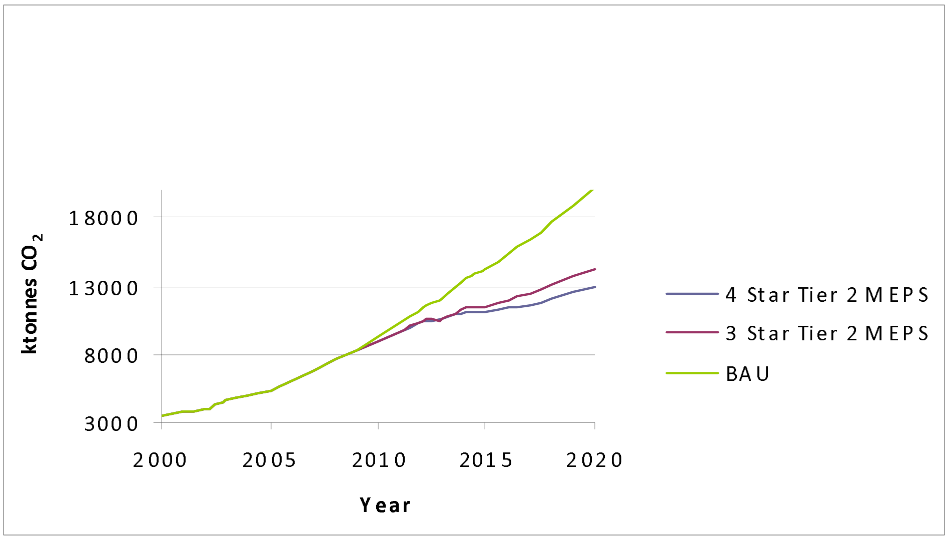

Figure 8: Expected CO2 savings for Tier 1 at 1 star and Tier 2 at 3 and 4 stars.

The mandatory labelling will be similar to that which is used for many existing products. The energy rating calculations allow for a rating of 1 – 6 stars in 0.5 star increments and 7 – 10 stars in 1 star increments. The rating is calculated by equation 1

Equation 1: Star Rating Index Calculation.[9]

$$\mathrm{SRI} = 1 + \frac{\log\left(\frac{\mathrm{CEC}}{\mathrm{BEC}}\right)}{(Log(1-ERF))}$$

CEC = 0.365 × [(television avg on(power) × 10) + (television sets passive(power) × time passive) + (television active(power) × time active)] kWhrs.

where

SRI	=	Star Rating Index
log	=	log to base 10
CEC	=	the Projected Annual Energy Consumption as determined by Equation 3.1
BEC	=	Base Energy Consumption calculated as 127.75 + 0.1825 × Screen area.
ERF	=	Energy Rating Factor and is 20% or 0.2

[9] As stated in the Interim AS/NZS 62087.2.2 2009.

For TVs with 6 stars or less the label used is shown in Figure 9.

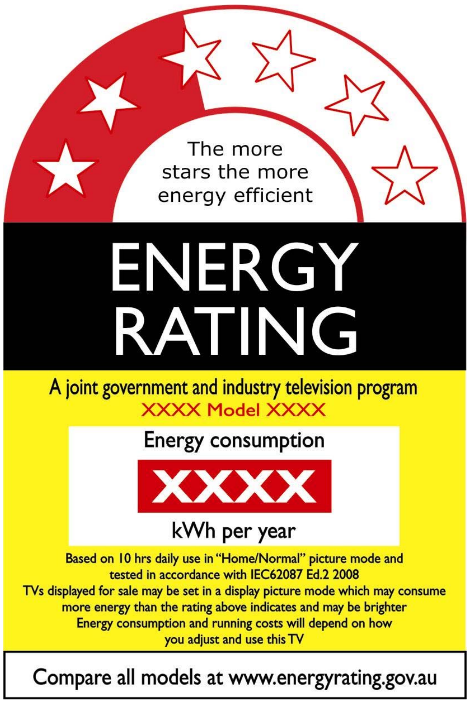

Figure 9: Energy rating label for TV with 6 stars or under

For TVs with more than 6 stars the label is depicted in Figure 10

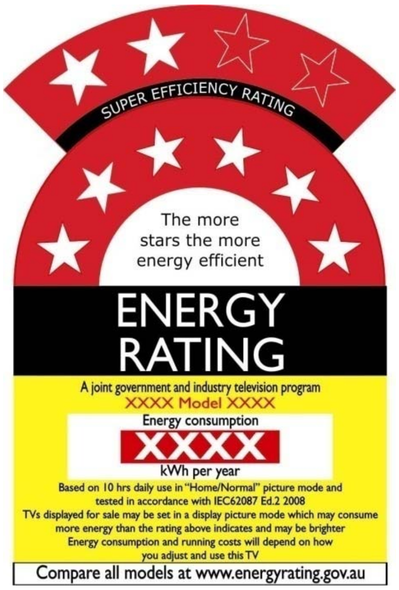

Figure 10: Energy rating label for TV with more than 6 stars

Complete details of the labelling and MEPS specification can be found in the Australian and New Zealand standard AS/NZS 62087.2.2 Minimum energy performance standards (MEPS) and energy rating label requirements for television sets.

Final Comment

Australia like many other countries has identified energy consumption associated with televisions as a significant and increasing problem, It seems clear that significant improvements can be made with TV energy consumption.

It seems unlikely that the market failures associated with the absence of energy consumption as a factor in the purchase decision of televisions will be corrected through normal market forces. Regulation under these circumstances becomes an important policy tool to ensure that energy consumption and the associated CO_2 emissions that are caused by this power consumption are clear to those making television purchases.

By using a combination MEPS and labelling approach not only are the higher energy use televisions removed from the market but thorugh the use of energy rating labels consumers become better informed as to the energy use ramifications of their purchase decision and manufacturers are encouraged to develop and offer more energy efficient televisions as an important marketing tool.

Australia has already implemented a voluntary energy rating labelling program for televisions and as of April 2009 over 70 models now carry labels.

Australia is in the process of implementing a MEPS and energy labelling program to alleviate issues associated with TV energy consumption. This program has had extensive industry consultation and the television supply industry is very supportive of the approach albeit with some concern as to what MEPS level may emerge for the Tier 2 specification in 2012.

References

[1] Digital CEnergy Australia. *Television Energy Labelling::The case, and proposal, for Labelling Televisions. Released September 2007. Available at www.energyrating.gov.au*

[2] Digital CEnergy Australia. *Television Energy Labelling::The case, and proposal, for Labelling Televisions – supplementary paper.. Released September 2007. Available at www.energyrating.gov.au*

[3] Digital CEnergy Australia. *Television Energy Labelling::The case, and proposal, for Labelling Televisions – supplementary paper.. Released September 2007. Available at www.energyrating.gov.au*

[4] DEWHA Voluntary Rules for energy rating labels of TVs October 2008. *Available at www.energyrating.gov.au.*

[5] Sydney Morning Herald, Fairfax Press May 17th 2007.

[6] TV predictions,com. www.tvpredictions.com (February 25, 2008).

The Research of China FPD TV Energy Efficiency Standard Methodology

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Abstract:

The study of the test method of China FPD TV energy efficiency standard was introduced. The size independency and system robust were discussed and compared with Energy Star 3.0 and EuP(5). A new brightness test pattern was brought in, whose average brightness level based on and calculated from the IEC 62087 video clip.

Keywords:
Energy efficiency metrology, post-gamma APL, cd/w,

1. Introduction

Evaluation method is the key of the energy efficiency standard, which will affect not only the present FPD TV market but also the future energy saving technique trend. This paper discussed the evaluation methods of Cd/W in China standard draft and empirical formula based on W/Area in Energy Star and EuP(5).

Cd/W has been adopted in China monitor energy efficiency standard already, which was effective for one year and got support from LCD brand owners, esp. who deliver super-eco monitors. The fundamental discussion on Cd/W can be found in our previous paper [1]. Candela per watt considers the ratio of power consumption and luminous flux intensity on the normal direction of screen. It's the device's efficiency to convert power to normal directing luminous flux intensity. The value is ratio of power and product of brightness multiplies area.

$$Eff = \frac{L \times S}{P_k - P_S}$$

In China standard draft, the brightness, i.e. L, is the average of 9 point [2] on white window pattern that will be introduced in section 3. S is the active area of screen. Operating power, P_K, is tested by IEC 62087[3] video clip. The test status setting follows China HDTV standard [4] and VESA 301-3K [2] using the 8 gray-scale JND-based setup. P_S is the power to process signal, which will be given 10 watt with analog RF or component input, or 17 watt with China digital TV RF input.

The empirical formulas of Energy Star and EuP(5) are based on the linear fit to TV data by out-of-box setting. All display techniques were considered together in the Watt VS area coordinates [5][6]. Though Watt/area efficiency logically needs consider brightness [7], the brightness level was left to manufacture in default modes and not controlled.

As introduced above, the same approach in China standard, Energy Star and EuP(5) is the power measurement, while IEC62087 clip is adopted in all of them to get the operating power consumption value. One of the different parts is China standard evaluates watt with both brightness and size, while Energy Star and EuP(5) evaluate watt with size only. Another difference is China standard partially accepts out-of-box setting, not totally accepts factory default status like Energy Star and EuP(5).

2. Screen Size Independency

Flat panel TV has diversified sizes whose number are getting more and more with the new mother glass dimension and new cutting layouts. None of the 3 standards claimed designing to encourage or discourage any specific size trend. Or say these standards should be considered neutral to all sizes. Thus the difficulty level of “passing” needs to be size independent. In other words, there should not be some sizes easier to pass the line than other sizes.

The statistic data used for comparing different methods were provided by national TV standard committee, which were collected from 10 TV brands and 2 TV test centers in 2008 Q4. The data collection has no tendentiousness on specific market segment. Each TV set was tested by China standard’s method and Energy Star’s method. The 69 LCD TV sets from sizes of 26inch to 52inch, were separated in to 7 groups. The evaluation result by each method to these data was tested whether to be affected by size. Before the ANOVA analysis, math conversion was applied to the empirical formulas.

Table 1: Math conversion applied to the ES3.0 and EuP(5) formulas

	Diagonal	Original	After Conversion
	< 40inch	P < 0.03100 * A + 32	(P-32) / (A*0.03100) < 1
	40~50inch	P < 0.03720 * A + 27	(P-27) / (A*0.03720) < 1
Energy Star 3.0	>50inch	P < 0.02418 * A + 151	(P-151) / (A*0.02418) < 1
EUP(5) M.R.	All Sizes	P < 0.2750*A + 40	(P-40) / (A*0.2750) < 1

The inequality after conversion should have similar distribution of “greater than one” and “less than one” between each size. When the null hypothesis is true, i.e. the data by group have not difference, the converted expression should deliver similar distribution between groups. For the China standard, the cd/w value has no need to do conversion before ANOVA.

The ANOVA result is self explanatory. The cd/w evaluation results by size grouping are NOT significantly different. The two empirical formulas' result by size grouping is significantly different. If we can make conclusion, it is that the difficulty to pass cd/w evaluation is more independent to size than the other two Area VS Watt empirical formula approaches.

Table 2: One-way ANOVA on grouping by size

	F	P-value	R-sq	adj R-sq
China cd/w	1.07	0.388	8.64%	0.58%
ES 3.0	5.19	0.000	31.40%	25.34%
EUP(5) MR	4.62	0.001	28.94%	22.67%

The box plot of these 69 TV sets in the three evaluation metrologies also passed the same information (fig. 1). The vertical axis in Energy Star and EUP figures are the values after math conversion.

The fairness between sizes is more important for the countries that export LCD modules than who imports. One LCD production line can only run with the unchangeable mother glass dimension, and have a few economic panel sizes. The tendentiousness in size will do harm to the manufactures that were designed in "unlucky" sizes.

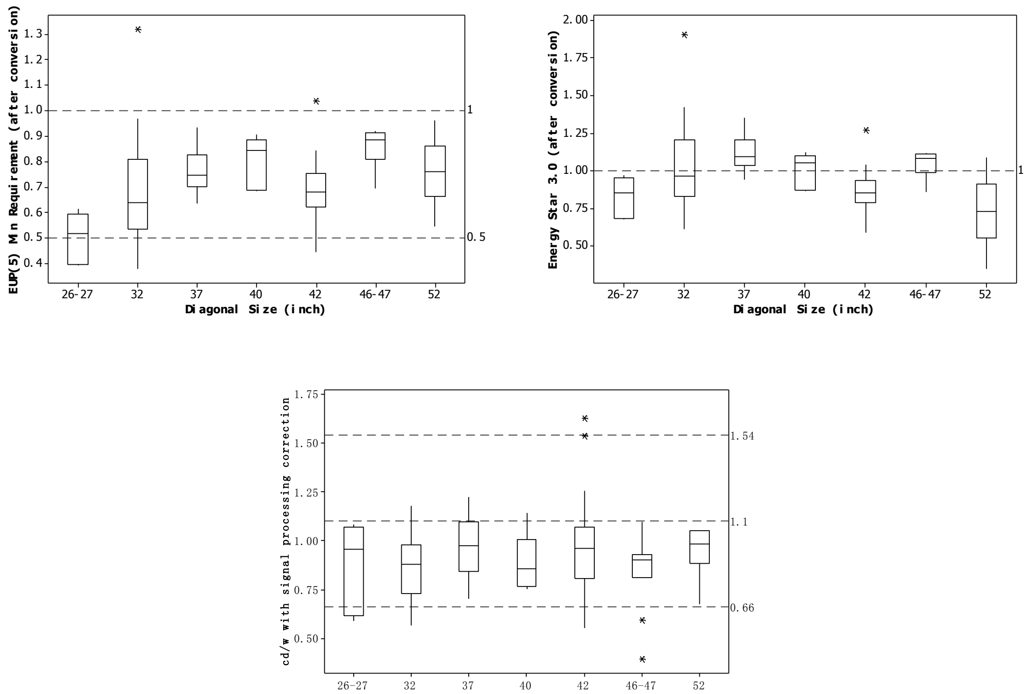

Figure 1: by-size Box-plot of evaluation results of ES3.0, EuP(5) and Cd/W

3. System Robust

Evaluation result must be repeatable on one TV set, which is very important for a mandatory standard. Error will lead unnecessary and unfair penalty or benefit.

The Energy Star and EuP(5) both totally accept factory default settings, i.e. the out-of-box status for test. When the evaluation system of watt VS area has no restriction on brightness, the result variation range can be large with changing factory default setting. Though factory default setting can not be changed in customer end, it’s easy to be adjusted in manufactures. The setting can be tuned to any status consist of the backlight level, panel gamma, panel transmittance level, color temperature and so on. The test result showed power consumption value can vary a lot by changing panel and backlight settings (fig. 2). Energy Star and EuP(5) only evaluate watt with area. Since area won’t change with one identical TV set, the variation range in watt value will be the variation range in the evaluation result.

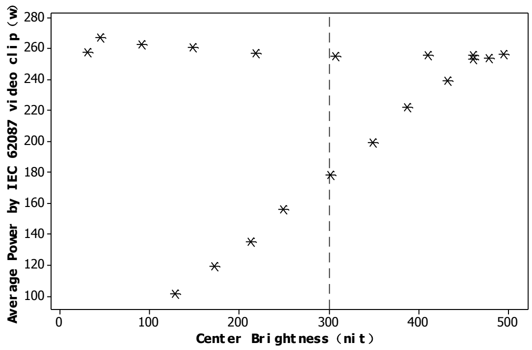

Figure 2: Power and brightness tested value of a 42inch LCD TV under different brightness, contrast and backlight settings.

Test result for new TV models with the forced menu applied can show this variation space also. Manufactures can adjust the factory default settings on given TV while deliver a score from level D to level A, all of which is valid evaluation result of EuP and Energy Star system. Since this change of default setting will lead better evaluation result, we call it manufacture beneficial free range.

Table 3: Power, brightness and EuP(5) levels in home mode and shop mode

	Status	IEC Power（W）	EUP(5) Lvl.	Ctr Lum.（NIT）
40“LCD	Shop Mode	176	D	491
	Home Mode	142	C	286
46”LCD	Shop Mode	268	D	500
	Home Mode	180	C	265
32“LCD	Shop Mode	127	D	408
	Home Mode	84	B	217
37”LCD	Shop Mode	178	D	515
	Home Mode	89	A	170

The China TV standard draft partially accepts the out-of-box setting. The difference from total acceptance is setting the brightness and contrast setting by JND[2] on 8 gray level pattern. One advantage of this setting status is to get alignment with China HDTV performance standards. The China HDTV performance standards for LCD TV and PDP TV both adopt the VESA 8-gray level JND setting procedure for the test status.

The other advantage of this setting is to ensure each TV set can display gray levels correctly when testing. It’s important to an evaluation system with brightness, i.e. the cd/w approach. Some of LCD modules can’t display gray levels at maximum luminance status. The 8-gray adjusting will avoid getting a higher luminance result, i.e. higher cd/w value, under a improper display status. This modified out-of-box setting is not conflicting with the logic of Energy Star pure out-of-box setting. In most of cases, esp. PDP TV sets, the 8-gray level setting status is exactly same or very close to the original out-of-box setting. Only for some TV sets, whose default status can not display gray level correctly, the 8-gray setting will vary from the pure out-of-box setting.

Since 8-gray adjusting more focuses on the gray level display, factory default setting can still affect the cd/w result. The variation on panel transmittance level, i.e. panel dimming, will directly decrease the cd/w result (fig.3 left, circle dot). The variation on backlight level won't affect significantly (fig.3 right, circle dot).

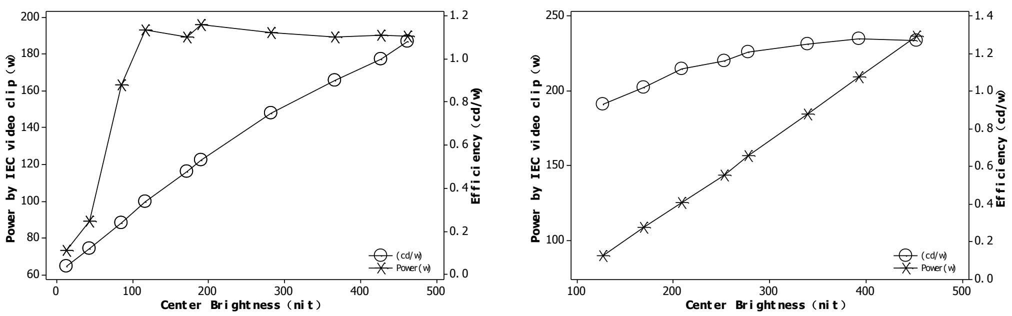

Figure 3: The power, brightness and efficiency values change by panel dimming (left) and backlight dimming (right)

While the panel dimming is a way wasting more energy than backlight dimming, the lower cd/w result may caused by panel dimming will encourage manufactures to adopt the more efficient backlight dimming. Since adding default setting on panel dimming will not lead better evaluation result, we won't call it manufacture beneficial free range.

Both China standard and Energy Star / EuP(5) will be affected by changing the factory default setting. However, while keeping all hardware unchanged, adjusting software factory default setting only, in "pure out-of-box status and watt VS area" system, the evaluation result can have larger manufacture beneficial free range than the "out-of-box with 8-gray and cd/w" system.

4. Brightness Test Pattern

The efficiency is the ratio of output and input. When measuring the output and input on same status, the ratio has its physics significance. The IEC power measurement has one 10 minute video clip which has nearly 18,000 frames (17940 frames for 600s@29.9fps), each of which has 720x480 pixels. The denominator of cd/w is average of integration power of all pixels on all frames. When the numerator is average of integration luminous intensity of all pixels on all frames, the ratio can have good physics significance.

$$\eta_{avg} = \frac{I_{avg}}{P_{avg}} = \frac{(\sum_{frame}\sum_{720x480} I_{pixel})/\ frame\_number}{(\sum_{frame}\sum_{720x480} P_{pixel})/\ frame\_number}$$

When the power measurement already followed the average after integration approach, the luminous intensity should also be measured in this way. But it's impossible to finish the precise measurement with present equipments. An approximation was required to simplify the procedure.

Our approach is to compose one brightness test pattern that can be very close to the average of total luminance integration average. Inverse gamma conversion is required to calculate the signal picture level to the luminance level. With computer program, the average brightness level (ABL) of each frame was calculated and binned by 1% (fig. 4). The gamma value was given as 2.2 which is general gamma of TV signal conversion. The mean value of ABL of all frames is 17% (when gamma equals 1.0, this mean value is 34%).

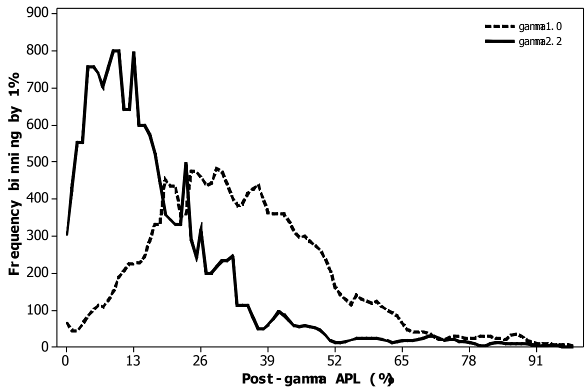

Figure 4: The post-gamma APL distribution of IEC video clip after inverse gamma conversion with gamma equals 1.0 and 2.2

To fit the 17% average post-gamma APL (i.e. ABL), a white window pattern with ABL 17%, whose APL is also 17%, was designed to measure the IEC video clip corresponding luminous intensity, by calculating from brightness and area.

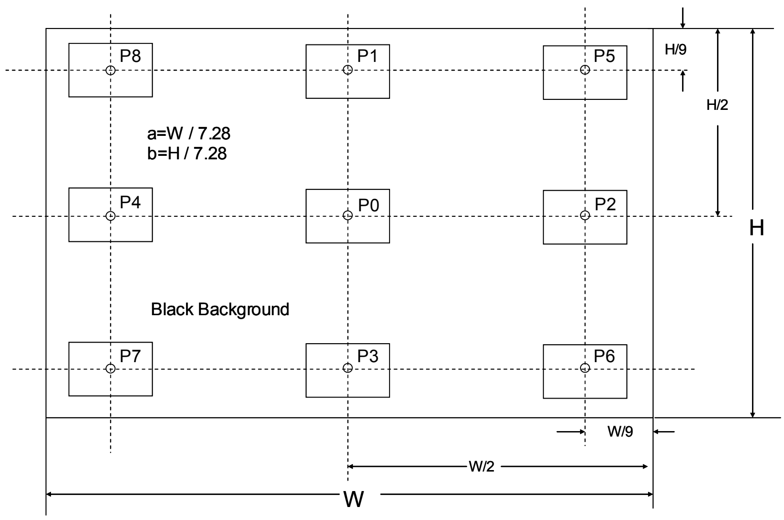

Figure 5: White window brightness test pattern with 17% APL

Precisely, the white part and black part should both be calculated. However, to present TV the contrast usually more than 1000:1, the black part luminous intensity is at the fourth significant figure. The standard evaluates two significant figures in grading. The black part is thus ignored. The coefficient, 17%, is also cancelled, which is same in each evaluation value. As result the final evaluation equation take the 9 point average brightness directly in the calculation of cd/w.

$$I = area(0.17 I_{white} + 0.83 I_{black}) \rightarrow I = area \times I_{white}$$

In PDP TV, there is one ABL control circuit. The ABL will be constrained within a maximum value. As the result, when the ABL is higher than the threshold, the luminance level VS signal picture level relationship is no longer simply inverse gamma conversion. The all IEC video frames' ABL (gamma=2.2) standard deviation is 15%, while their mean value is 17%. The common ABL threshold in PDP is between 20% and 30%. Most of the frames have ABL smaller than the threshold, when inverse gamma conversion still works. The variation brought by the ABL control thus could be estimated relatively small. However the brightness measurement is always affected by ABL control circuit in PDP TV. This 17% APL window pattern is the best in the known patterns to fit with the IEC video implement.

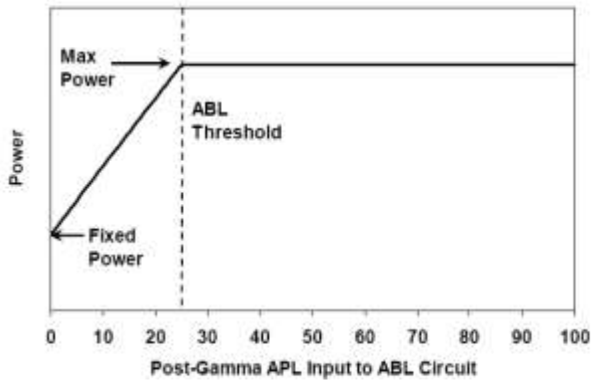

Figure 6: The ABL circuit mechanism.

5. Conclusion

Encourage the sales of high energy efficient products and accelerate the market transform to eco-products will be the same mission of the China standard, Energy Star and EuP(5). However, China standard is drafted from the some different perspective from the other two. Fair competition environments, neutral treatment to each display technology and screen size were more considered in the China standard. Due to the States and Europe are all pure TV consuming regions, standards considering more from one consumer perspective could be quite reasonable.

This paper intends to introduce the technical and statistical basis of the current China TV standard draft. The realistic in China FPD display manufacturing industry, which’s beyond this paper’s scope, should be considered, when discussing the difference between the TV standards.

References:

[1] G. Du, H. Chen, *the Evaluation Methods of LCD Monitor Energy Efficiency* [C], China LCD Tech. Annuals, 2007

[2] *VESA Flat Panel Display Measurements Standard V2.0* [S]

[3] IEC 62087 ed2.0, *Methods of measurement for the power consumption of audio, video and related equipment* [S], 2008

[4] SJ/T 11348-2006, *Methods of measurement for digital television flat panel displays* [S]

[5] L. Stobbe, *EuP Preparatory Studies “Televisions” (Lot 5)* [R], 2007

[6] L. Webber, *Comments on Draft Final Specification* [EB/OL] Can be downloaded at: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/tv_vcr/LarryWeber_DF.pdf, 2008

[7] J. Fairhust, *IEC TC100 TV Power measurement porject overview and status* [EB/OL] http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/tv_vcr/IEC_Overview.pdf, 2006

Washing and Drying

Ecodesign requirements on spinning speed for washing machines? An analysis of the trade-off with the penetration and use of tumble dryers in Europe

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Abstract

To dry wet clothes energy is needed. The more water is removed by mechanical treatment, usually through spinning in a washing machine, the less thermal energy is required for subsequently drying. This requires additional energy for a higher spin speed in the washing machine with a contemporary reduction in thermal energy in the drying phase, whatever drying system and energy source is considered. The article describes a new and simple approach to evaluate the trade-off between the dryer ownership and the need to increase the washing machines spinning speed. A minimum ownership level for the dryer is estimated for the three European Climatic Zones that saves enough energy to compensate the increase in the washing machine energy consumption for the higher spin speed needed to achieve a lower residual moisture content of laundry. The same approach can be used to evaluate the minimum dryer use by the single owner. Although no precise data are available concerning the dryer annual use pattern all over Europe, the preliminary results demonstrate that the existing market division of different spin speed machines is rational and a minimum Ecodesign requirement addressing washing machines spinning speed for the EU is suboptimum.

1. Basic information and analysis boundaries

To dry wet clothes energy is needed in any case. If a 5 kg laundry load is 60% wet, no matter which method is used, including drying around the house on radiators, it must cost at least about 2 kWh to dry it; if this load is dried in a tumble dryer, additional energy is taken up in turning the drum and heating the load and tumble dryer itself and the overall energy consumption increases to 2,4 kWh as estimated by the UK Market Transformation Programme [1].

The more water is removed by mechanical treatment (usually through spinning in a washing machine) the less thermal energy is required for subsequently drying. This causes on one side an additional energy demand through a higher spin speed at the washing machine level and a contemporary reduction in thermal energy demand in the drying action, again whatever drying system and energy source is considered.

A high-speed spinning, above 1 200 rpm, requires between 5% (for the 60°C cotton cycle) and 10% (for the 40°C cotton cycle) more energy than lower spin speeds in a washing machine [2]. The increase in energy consumption for an increase in spinning speed from 1 200 rpm to 1 600 rpm has been evaluated in 50 Wh/cycle with an increase of the purchase price of 30 € for the consumer [3]. Considering that the same 400 rpm increase occurs from 800 rpm to 1 200 rpm, a similar increase in energy consumption can be assumed.

To calculate the influence of different spin speeds on the energy demand for the drying process, the specific energy demand of a conventional condenser drier, belonging to the energy efficiency class C[1], is taken. The energy demand against percentage of water remaining after spin, or Residual Moisture Content (RMC), is assumed to be as shown in Table 1 [4].

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[1]Commission Directive 95/13/CE of 23 May 1995, implementing Council Directive 92/75/EEC with regard to energy labelling of household electric tumble driers OJ. L. 136, 21.6.1995, the energy efficiency classes of condenser dryers depend from the energy consumption (in kWh/kg) of the iron-dry cotton: class A, C ≤0,55; class B: 0,55 < C ≤ 64; class C: 0,64 < C ≤ 73; class D: 0,73 < C ≤ 82; class E: 0,82 < C ≤ 91; class F: 0,91 < C ≤ 1,00; class G > 1,00.

Table 1: Spin speed and energy demand with respect to remaining water after spin

Residual Moisture Content (RMC) for cotton	Unit	62%	56%	52%	49%
Corresponding approximately spin speed	rpm	1 000	1 200	1 400	1 600
Relative energy demand (‘cotton dry’ programme)	%	100	90	86	82
Specific energy demand (‘cotton dry’ programme)	kWh/kg	0,70	0,64	0,60	0,57

A linear correlation is assumed between the water remaining after spin and the specific energy demand (in kWh/kg of dried load), according to Equation 1 which allows to estimate the energy demand also at higher residual moisture contents (or lower spin drying efficiency classes) as shown in Table 2.

$$\text{Specific energy demand} = 0{,}0100 \times \text{RMC} + 0{,}0800 \qquad \text{(Eq. 1)}$$

Table 2: Washing machine spin speed and dryer energy demand with respect to remaining water after spinning

Spin drying efficiency class of the washing machine		A	B	C	D	E	F	G
Residual moisture content	(%)	45	54	63	72	81	90	94
Energy consumption condenser dryer, class C, 5kg	(kWh/kg)	0,530	0,620	0,710	0,800	0,890	0,980	1,020
Washing machine spin speed	(rpm)	1 600	1 300	1 000	800	600	480	400

The analysis of the 2005 technical database for washing machines[2] showed that the 5 162 models, are almost perfectly divided intro two groups: 2 425 machines with spinning speed in the range 400-1 100 rpm and 2 767 machines with spinning speed in the range 1 150-2 000 rpm. Excluding the very few deviating models, 0,65% of the total database, from the analysis the weighted average spin speed and RMC were calculated as shown in Table 3.

Table 3: Average spinning speed and RMC for the two groups of washing machines in 2005 technical database

Machine types	Models number	rpm (number)			RMC (%)		
		min	max	weighted aver.	min	max	weighted aver.
Lower spin speed	2 407	400	1 100	856	63	94	69,4
Higher spin speed	2 751	1 150	2 000	1 367	45	54	52,2

These data are in quite good agreement with the outcome of a consumer analysis [5] developed in 10 EU countries (Czech Republic, Finland, France, Germany, Italy, Hungary, Poland, Spain, Sweden, United Kingdom) where the distribution of the washing machine spin speed showed large differences among countries (Figure 1). Taking the average of the individual range of spin speeds given from ~400 rpm up to ≥1 300 rpm, the average spin speed per country was calculated. In Italy and Czech Republic, where the dryer ownership is respectively 8% and 9%, the average washing machine spin speed is 795 rpm and 772 rpm, on the contrary in UK, Germany and Sweden, where the dryer ownership is about 70%, 55% and 55%, the average washing machine spin speed is 1 062 rpm, 1 096 rpm and 1 069 rpm respectively; the average of all investigated country is 914 rpm (Figure 2).

[2] Made available by CECED, the European Association of the Household Appliance Manufacturers within the LOT 14: Domestic Dishwashers & Washing Machines, preparatory study for eco-design requirements of EuPs. A value of the residual moisture content was associated to each model assuming that for each spin drying class the RMC is the highest compatible with the declared class, for G class a value of 94% has been used.

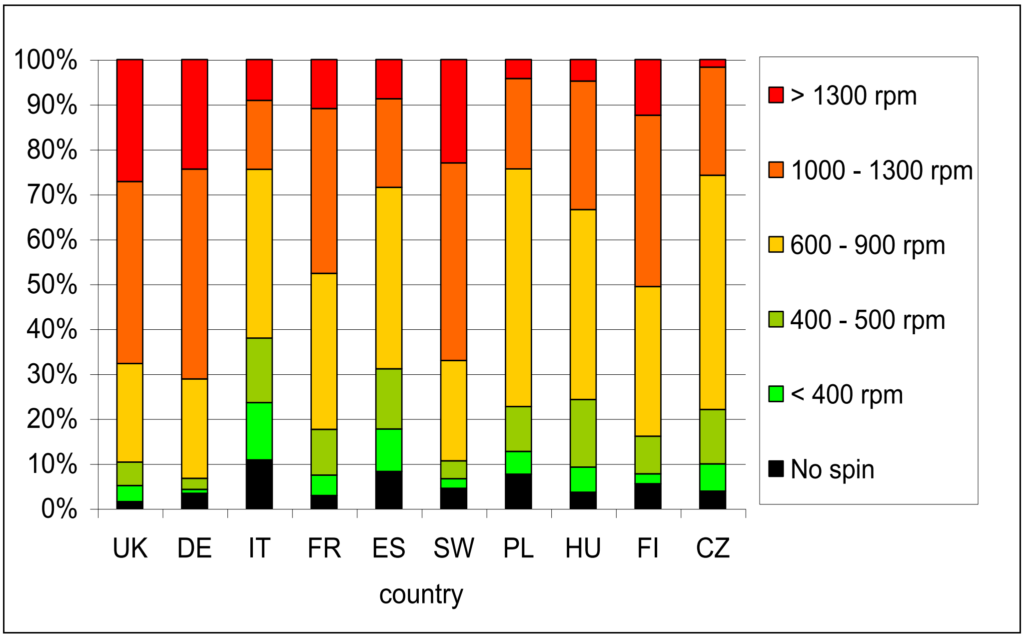

Figure 1: Washing machine spin speed selected per week in EU countries

This outcome is now also supported by the results of the ecodesign preparatory study on dryers [6]: in the new consumer survey the average spin speed of the washing machines in households having a dryer (86% of the sample) is 1 217 rpm[3]. In other words, according to the consumer surveys in the two studies, and with all the possible cautions due to the small samples (250 households) and the semi-quantitative answers achieved, users owning a dryer purchase higher spin speed (~300 rpm) washing machines.

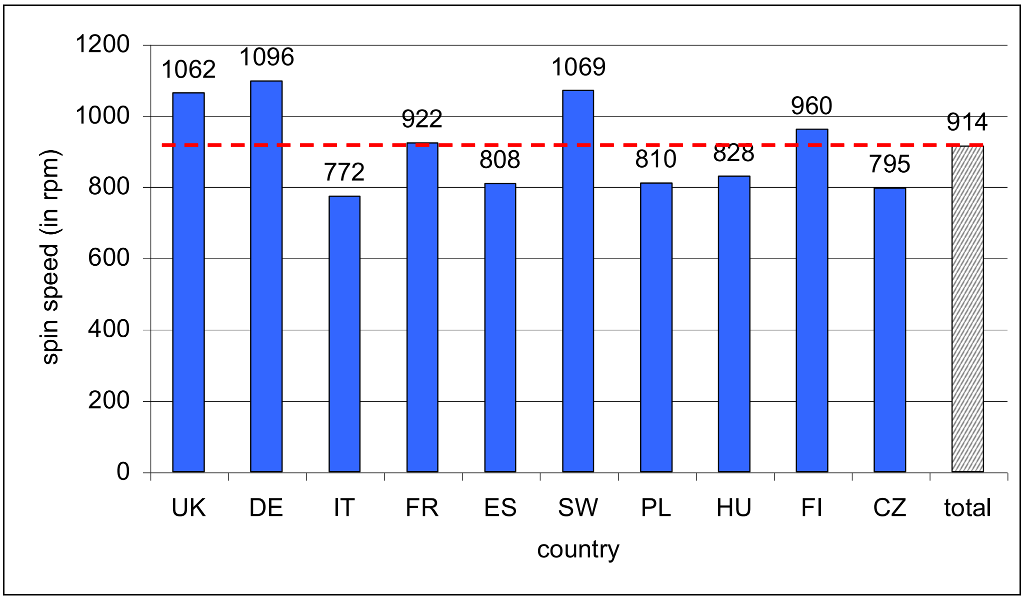

Figure 2: Average spin speed of washing machines in selected EU countries

The same investigation showed also that a large differences can be found between summer and winter time in clothes drying habits: while in summer (Figure 3) about 40% of the consumer always dry the clothes outside on a cloth line and another 28% do it often (total 68%) these figures reduce in winter (Figure 4) to just 7% and 10 %, respectively. The preferred way of drying clothes in winter is to

[3] With a distribution of the mostly used washing spin speeds, as 25% “1 000-1 150 rpm”, 22% “1 600-1 800 rpm” and lower spinning speeds (below 1 000 rpm) represented.

dry them in the house in a heated room: this is always done by 28% and often by 33% of the consumers (total 61%).

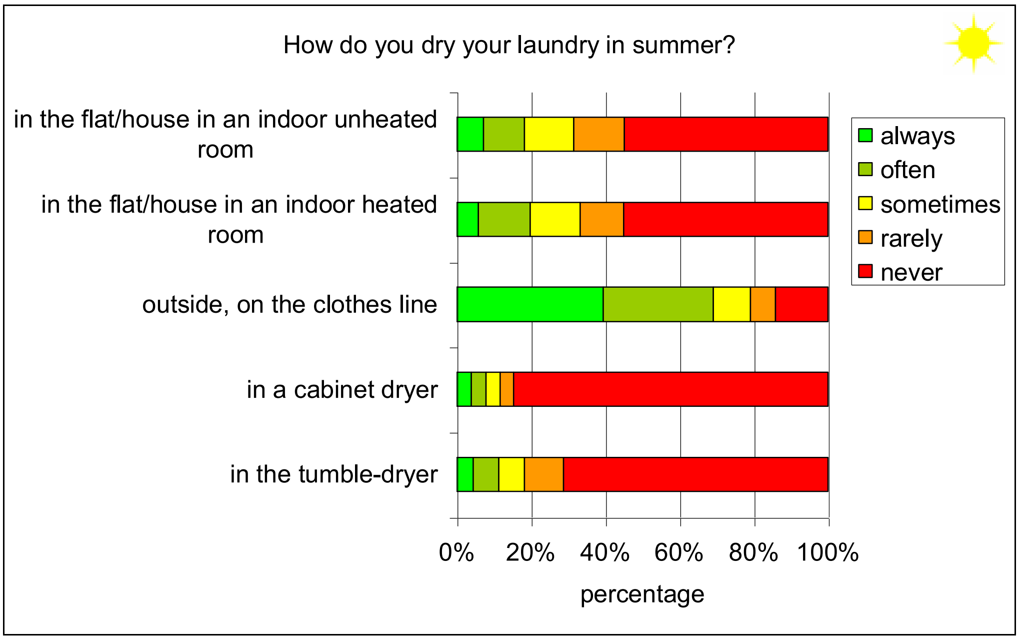

Figure 3: Clothes drying habits in summer time in the EU

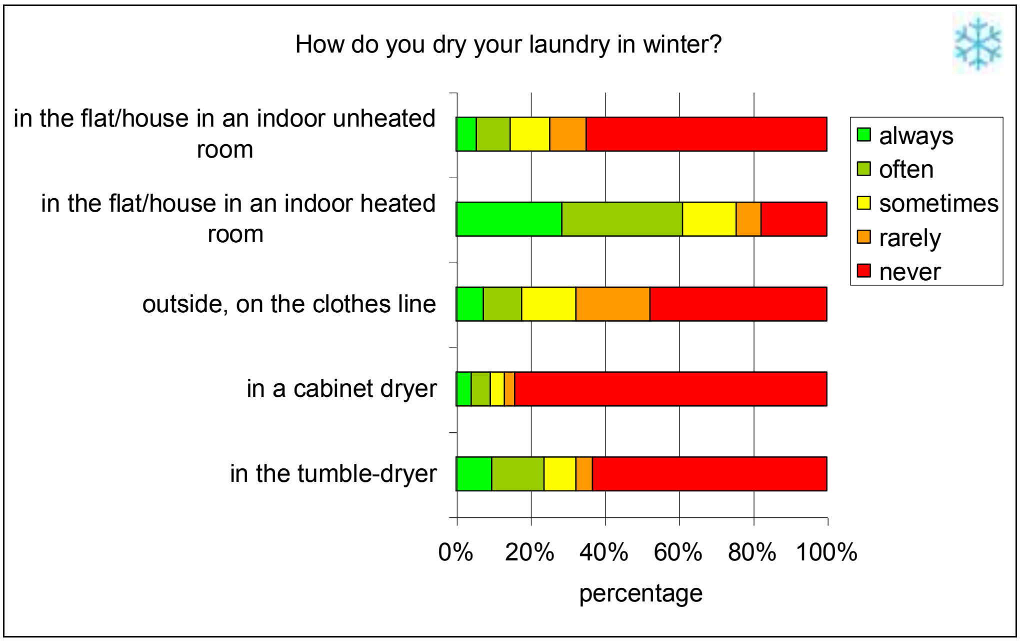

Figure 4: Clothes drying habits in wintertime in the EU

The different climatic conditions in Europe can roughly be summed up in three climatic zones: the '*cold climatic zone*' (including Finland, Norway and Sweden), the '*moderate climatic zone*' (including Belgium, Denmark, Germany, France, UK, Ireland, Luxembourg, The Netherlands, Austria and Switzerland) and the '*warm climatic zone*' (including Greece, Italy, Portugal, Spain and Turkey). With a multi-criteria approach Norway, Germany, France and Spain were chosen as representative countries of their respective climatic zone for a study of the Öko-Institut [7]. Although the task of the Öko-Institut study was to evaluate and compare the energy demand of the air-vented and condenser tumble driers in standard and real-life usage under different ambient conditions, the information about dryers practice in the three climatic zones are at the basis of the further analysis developed in this paper.

To cover different situations both the use of the drier during the whole year and the use of the drier during the 'heating season' only have to be regarded. Some uncertainty also derives considering that the length of the heating period varies between the different countries. In addition, it is also not possible to draw a sharp line between 'heating season' and 'non-heating season', since not only the temperature but also other weather conditions make people use their drier/laundry drying system in summer (e.g. when it is raining), but this is assumed to be compensated by the contrary effect during the heating season when the wet laundry is hanged on a clothesline on a sunny and dry day.

Considering the average mean temperatures per month in the different countries the heating/non heating months could be roughly estimated as "heating season = months when a drying system such as the drier is needed". In Table 4, the months highlighted in dark grey are considered as months where the drier/drying system is needed the whole month; the months highlighted in lighter grey are considered as months where the drier/drying system is needed only half of the month and the other months are considered as months where no drying system is necessary at all.

Table 4: Heating and non-heating (drying system use- and non-use) months according to the climatic zones

Months	J	F	M	A	M	J	J	A	S	O	N	D
Cold climatic zone												
Moderate climatic zone												
Warm climatic zone												

The energy demand of a 5kg class C condenser dryer against different loads is shown in Table 5. Assuming that the rated capacity of the dryer is 5 kg, the average load is considered to be 3,2 kg [6]. It is worth noting that under standard conditions the load for 'cotton dry' programme is set at 5 kg for driers with a rated capacity of 5 kg. Due to the reduced load the specific energy demand of the driers per kilogramme of textile is higher than with full load conditions: for a 3,2 kg load it is 73% of the consumption at full load standard conditions.

Table 5: Total and specific energy demand (%) with respect to the load of the dryer (m=measured; i=interpolated)

Loading	5,0 kg	4,5 kg	4,0 kg	3,5 kg	3,2 kg	3,0 kg
Total energy demand (per cycle)	100	93	85	78	73	70
Specific energy demand (per kg)	100	103	106	111	114	117
Data quality	m	m	m	m	i	m

2. Energy consumption and economic evaluation for countries in the Warm Climatic Zone

2.1 Basic assumptions

The trade-off is evaluated in terms of the minimum dryer ownership that (i) saves enough energy - when using a lower RMC laundry from a washing machine with increased spinning speed - to compensate the increase in the washing machine energy consumption due to the higher spin speed and (ii) saves enough money to compensate the extra purchasing price for the higher spin speed washing machine. The same approach can be used to evaluate the minimum dryer use, which gives the energy and/or the economic trade-off to a single owner. An increase of 400 rpm, from 800 rpm to 1 200 rpm (RMC going from 72% to 56%) and from 1 200 rpm to 1 600 rpm (RMC going from 56% to 49%) and a sharp increase from 800 rpm to 1 200 rpm are investigated depending on the climatic zone.

Basic assumptions (valid for all Climatic Zones):

- washing machine ownership: 100%
- washing machine average standard load: 5,36 kg

- washing machine average actual load: 3,4 kg, with no seasonal differences in the amount of laundry
- number of washing cycles per year: 200 equally divided during the year
- increase in washing machine energy consumption: 50 Wh/cycle for a 400rpm increase in spin speed from 800 rpm to 1 600 rpm
- RMC = 72 % at 800 rpm; RMC = 56 % at 1 200 rpm; RMC = 49 % at 1 600 rpm
- increase in washing machine purchase price: 30 € every 400 rpm increase, from 800 rpm to 1 600 rpm
- dryer type: condenser
- dryer nominal capacity: 5kg
- dryer average actual load 3,2 kg with a 73 % of the full load energy consumption
- dryer energy consumption 0,800 kWh/kg (energy efficiency class C) at RMC = 72 %
- dryer use profile: according to the climatic zone.

Since the washing machine cycles are equally divided during the year, an average of 16,7 wash cycles/month are considered (equal to 200 washing cycles per year). The same maximum number of drying cycles is also considered.

When the spinning speed of the washing machine is increased from 800 rpm to 1 200 rpm a 50 Wh increase in the energy consumption per cycle is assumed. But since the washing machine load is only 3,4 kg, the 50 Wh/cycle are reduced to 36,4 Wh/cycle[4]. For 200 washing cycles per year, this amounts to 7,28 kWh/year or 109,2 kWh over the 15 year washing machine lifetime. Considering 100 washing machines, the additional energy consumption over 15 years is 10 920 kWh. When for the same 100 washing machines the spin speed is increased from 1 200 rpm to 1 600 rpm the extra energy consumption is again 10 920 kWh/15y. If a 1 600 rpm washing machine is used instead of an 800 rpm one (with an increase of 800 rpm) the energy consumption increases of 14,6 kWh/y, or 21 840 kWh in 15 years for 100 washing machines.

2.2 Energy consumption trade-off

In the Warm Climatic Zone the need of the dryer or of a drying system is 1 month for the whole month and 3 months only half of the month, or in other terms the dryer/drying system is fully used 16,7 cycles/month for 2,5 months, equal to 41,7 drying cycle/year.

To dry 3,2 kg of 72% RMC laundry (spun in a washing machine at 800 rpm) and with a water content of 2,3 kg the energy demand is 1,53 kWh. When the RMC is decreased to 56% (corresponding to 1,79 kg of water) the energy demand is 1,19 kWh for drying. The decrease in the energy demand is thus 340 Wh per washing cycle or 14,2 kWh for the 41,7 drying cycles in this Climatic Zone, or 212,7 kWh/15y. When the RMC of the laundry decreases from 56% to 49% the additional energy demand reduction is 5,8 kWh/y or 87,6 kWh/15y; and when the RMC of the laundry decreases directly from 72% to 49% the energy demand reduction is (14,2 + 5,8 = 20,0 kWh/y) or 300 kWh/15y. It is worth noting that the calculated energy demand reduction does not correspond to energy saving, since no specific information is available on the actual drying system used in the households in this Climatic Zone in the ‘heating season’: the dryer, a room heated through a space heating system (burning electricity or fuels), or through a solar system (a greenhouse or a solar porch), or finally through waste heat recovery (such as the heat lost by the boiler). Depending on the drying system, or to the combination of the drying systems, the use of a washing machine with an increased spin speed may result in an electric energy loss or saving. As previously said, the preferred way of drying clothes in winter is to dry them in a heated room always by 28% of the consumers, and often by 33%.

To dry the same 3,2 kg of 72% RMC laundry a 5 kg dryer uses 2,92 kWh/cycle - or 73% of the full load energy consumption. If the RMC is 56% the same dryer consumes 2,34 kWh/cycle, while when the RMC is 49% the dryer consumes 2,08 kWh/cycle. The energy saving is therefore 584 Wh/cycle when the RMC decreases from 72% to 56%, equal to 24,4 kWh/year or 365,3 kWh/15y for the 41,7 cycles per year. When RMC is further reduced from 56% to 49%, the additional savings is 256

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[4] Considering for the washing machine a load adjustment factor for the energy consumption of 0,08 kWh/kg load [5].

Wh/cycle, equal to 10,7 kWh/y or 159,8 kWh/15y. Finally, when RMC decreases from 72% to 49%, the saving in the dryer is 839,5 Wh/cycle or 525,1 kWh/15y.

On a ‘washer plus dryer system’ basis, the use of the dryer with a lower RMC laundry (from 72% to 56%) allows to save 256,1 kWh over 15 years[5]. When the RMC of the laundry decreases from 56% to 49% the additional saving is 50,6 kWh/15y, for a total of 306,7 kWh/15y when the RMC of the laundry decreases directly from 72% to 49%.

But the dryer is not owned by 100% of the families, while the washing machine is assumed to be.

Only when 30 dryers are run for 15 years (for 41,7 drying cycles per year) the saved energy reaches 10 958,8 kWh (365,3 kWh/15y × 30,0) and starts to overcome the addition energy consumption of the washing machines. When for the same 100 washing machines the spin speed is increased from 800 rpm to 1 600 the number of dryers has to be increased to 41,7 (or 41,7% ownership at the national level) to achieve an energy savings of 21 897 kWh/15y. In the Warm Climatic Zone countries this second hypothesis is still acceptable, since the average spinning speed is lower than or at 800 rpm in countries like Italy and Spain (see Figure 2). The upgrading of the washing machine from 1 200 rpm to 1 600 rpm has not been investigated as highly improbable in this Climatic Zone.

When evaluating the above minimum dryer ownership, also the fact that an increased spin speed allows to save some energy when laundry drying is done in a room heated by using electricity (or a fuel) should be taken into consideration. However, as said before, the drying systems combination is not known[6] and this paper concentrates on the machine ‘washer plus dryer’ system.

2.3 Economic trade-off

The difference in price for the consumer of the 1 200 rpm spin speed machine is 30 €, and for the 1 600 rpm machine is estimated to be 60 €, unused for the moment because the difference in energy cost has been considered the trade-off until now. Instead, from an economic point of view the trade-off is when the discounted savings minus the difference in price becomes positive, or positive Net Present Value (NPV).

The NPV could be easily calculated with the existing data as shown in Equation 2. For a tumble dryer machine, assuming 100% recovery that is 100% ownership of the dryer it is (for the 1 200 rpm machine):

$$NPV = (24{,}4 \text{ kWh/y} \times 0{,}17 \text{ €/kWh} \times 10{,}4 \times do) - (7{,}28 \text{ kWh/y} \times 0{,}17 \text{€/kWh} \times 10{,}4) - 30\text{€} = 0{,}18\text{€} \qquad \text{(Eq. 2)}$$

where:

- 10,4 = PWF[7] at 5% discount rate for 15 years
- *do* = dryer ownership (in Eq. 2 *do* is = 1 or 100%)
- 7,28 kWh/y = additional energy consumption of the washing machine with higher spin speed (from 800 rpm to 1 200 rpm)
- 0,17 €/kWh = average price of the electric energy per kWh.

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[5] i.e. the difference between the extra energy consumption due to the higher spinning speed of the washing machine and the reduction in the energy consumption in the dryer due to the reduced laundry RMC.

[6] The possible energy savings can be estimated considering that only in the case 51,4 % of the household use always an electricity heated room to dry the laundry, the saved energy reaches 10 931 kWh/15y (212,7 kWh/15y × 51,4) and starts to compensate the extra energy used for a higher spinning speed that reduces the RMC from 72% to 56%. When the RMC decreased from 72% to 49%, a higher percentage of households (72,8%) need to use an electricity-heated room to dry the laundry in order to save 21 857 kWh/15y (300,2 kWh/15y × 72,8).

[7] PWF = present worth factor. PWF= $\{1 - 1/(1+r)^{N}\}/r$, in which N is the product life and r is the real discount (nominal-inflation) rate.

The upgrade from 800 to 1 200 spin speed washer in the southern climatic just reaches a small positive net present value. But, if the dryer ownership (the '*do*' factor) drops below 99% (or for the individual user the utilization is less than 99% during the drying season) the higher spin speed and higher price washing machines are not convenient in the warmer climatic zone; in fact the NPV will drop to zero Euro.

An indicator of the profitability of an investment (also for a consumer buying a higher spinning speed machine) is the Profitability Index (PI), which is the ratio between the NPV and the investment cost. This is the 'bang for the Euro' or the amount of NPV generated per Euro of investment. Given different investment choices, the ones with the higher PI will be preferred. A similar ranking will be achieved using alternate indicators such as the internal rate of return. In this case of the 100% and 99% ownership (Equations 3a and 3b) PI is shown.

PI = 0,18€ /30 € = 0,006 for a dryer ownership of 100% (Eq. 3a)

PI = 0 € /30 € = 0 for a dryer ownership of 99%. (Eq. 3b)

Instead if the southern consumer should purchase the 1 600 rpm washing machine (upgrading from a 800 rpm one) he/she would have an NPV for drying that is negative at -23,85 Euro (Equation 4), less than that the 1 200 rpm washer. The breakeven dryer ownership is now higher than 100%. It is worth noting that the additional cost for the higher spin speed washing machine is now 60 Euro and also the additional energy consumption has doubled.

$$NPV=(35 \text{ kWh/y} \times 0{,}17 \text{ €/kWh} \times 10{,}4 \times do) - (14{,}56 \text{ kWh/y} \times 0{,}17 \text{ €/kWh} \times 10{,}4) - 60€ = -23{,}85€ \quad \text{(Eq. 4)}$$

Clearly the highest spin speed machine is not optimal for the Southern Climatic Zone. The washing machine used most likely will be the 800 rpm spin speed, because there is little incentive to upgrade; although the upgrades are slightly economic for the improvement from 800 rpm to 1 200 rpm, the Profitability Index is very low at 0,009 and the minimum dryer ownership is 99%[8].

3. Energy consumption and economic evaluation for countries in the Moderate Climatic Zone

The same analysis is repeated for the countries belonging to the *Moderate Climatic Zone*. The 'heating season' and the 'use of the drier/drying system' for this climatic zone lasts for 5 months where the drier/drying system is used the whole month and 2 months where the drier/drying system is used only half of the month, or in other terms, the dryer/drying system is needed 16,7 cycles/month for 6 months, equal to 100 drying cycle/year.

The energy savings for these 100 cycles is 58,47 kWh/year or 876 kWh/15y when RMC is reduced from 72% to 56%; when RMC is further reduced from 56% to 49% the additional savings is 25,6 kWh/year or 383,3 kWh/15y; when RMC is reduced from 72% to 49%, the overall savings is 84 kWh/year or 1 259 kWh/15y.

Under all the general assumptions described for the previous Climatic Zone, here on a 'washer plus dryer system' basis the use of the dryer with a lower RMC laundry - from 72% to 56% - allows to save 767 kWh over 15 years over the amount of extra energy consumed by the washing machine with the improved spinning speed to 1 200 rpm. But again only when 12,5 dryers are run for 15 years the saved energy reaches 10 950 kWh and starts to overcome the extra energy consumption of the 100 washing machines with the spin speed increased to 1 200 rpm; when the spin speed is increased from 1 200 rpm to 1 600 rpm the number of dryers has to be increased to 28,5 but when a 1 600 rpm washing machines is used instead of a 800 rpm one 17,4 dryers are needed to achieve an energy

[8] It is worth noting that under the hypothesis that all consumers not owning (or not using) a dryer will always dry the wet laundry in a (electric) heated room, the NPV for the investment to purchase a higher spin speed machine is always negative:
NPV= [(14,2 kWh/y × 0,17 €/kWh) × 10,4 × 0] - (7,28 kWh/y × 0,17 €/kWh × 10,4) - 30 € = -17,8 € (for rpm 800 → 1 200)
NPV= [(20 kWh/y × 0,17 €/kWh) × 10,4 × 0] - (14,56 kWh/y × 0,17 €/kWh × 10,4) - 60 € = -50,4€ for (rpm 800 → 1 600).

saving that will balance the increase of the energy consumption of the 100 washing machines with increased spin speed.

From an economic point of view, assuming 100% ownership of the dryer, Equation 5 gives the NPV. Thus if ownership of dryers drops below 41,6% the higher spin speed (from 800 rpm to 1 200 rpm) and higher price washing machines are not convenient in the Moderate Climatic Zone, as a whole.

NPV= (58,4 kWh/y × 0,17 €/kWh × 10,4 × *do*) - (7,28 kWh/y × 0,17 €/kWh × 10,4) - 30 € = 60,38 € (Eq. 5)

This means that from an energy consumption point of view, if the dryer ownership is lower than 12,5% the additional energy consumed due to the increase of the washing machine spinning speed is not recovered via the energy savings of the drying process in the dryer. But with the 30€ extra purchasing price and the price for the extra energy consumed for the higher spinning speed subtracted, and the annual energy savings discounted, the economic breakeven point is even higher in terms of dryers ownership and reaches about 42%. For a specific individual user in the moderate climatic zone, if the consumer will use the dryer more than about 42% of the time during the 'heating season', it is convenient; otherwise no.

Instead if the consumer in the Moderate Climatic Zone should purchase the 1 600 rpm washer (upgrading from a 1 200 rpm one) he/she would have a NPV for drying that drops to 2,30 Euro (Equation 6). The economic breakeven ownership is now 95%.

NPV= (25,6 kWh/y × 0,17 €/kWh × 10,4 × *do*) - (7,28 kWh/y × 0,17 €/kWh × 10,4) - 30 € = 2,30 € (Eq. 6)

Finally, if the consumer in the Moderate Climatic Zone should purchase the 1 600 rpm washer (upgrading from a 800 rpm one) he/she would have an NPV for drying that is 62,68 Euro (Equation 7). However, the economic breakeven of ownership increases to 57,8%.

NPV= (84 kWh/y × 0,17 €/kWh) × 10,4 × *do*) - (14,56 kWh/y × 0,17 €/kWh × 10,4) - 60 € = 62,68 € (Eq. 7)

The PI for the three substitution options are 2,0 € (going from 800 to 1 200 rpm), 0,077 € (going from 1 200 to 1 600 rpm) and 1,04 € (going from 800 to 1 600 rpm). This means that most convenient option is substituting the low 800 rpm machine for the 1 200 rpm one.

In the Moderate Climatic Zone, the middle range spin speed washing machine at 1 200 rpm is appropriate. There is ample motivation to purchase this machine with a NPV of about 60 Euro, and the minimum (usage or) dryer ownership is only 30%. To pass from the 1 200 rpm washing machine to a 1 600 rpm one results in a very small incremental gain of about 2,30 Euro and the breakeven dryer usage for the single owner increases to 95%: even if the potential customer has the second 30 Euro to spend and plans to use it with a dryer at least 95% of the time, this is still a questionable choice. In case of substitution of a 800 rpm washing machine with a 1 600 rpm one, the net gain is about 62 Euro but the amount of NPV generated per 1 Euro of investment is negligible, less than one-half the PI of the 1 200 rpm machine.

For the consumers in the Moderate Climatic Zone the washing machine with 1 200 rpm spinning speed gives the greatest gain for additional cost invested and in this sense is preferable if the minimum ownership level (or owner usage) of the dryer is satisfied.

4. Energy consumption and economic evaluation for countries in the Cold Climatic Zone

The same analysis is finally repeated for the countries belonging to the *Cold Climatic Zone*, where the 'heating season' with the 'use of the drier/drying system' lasts 9 months, where the drier/drying system is used the whole month and 1 month where the drier/drying system is used only half of the month, or in other terms, the dryer/drying system (different from hanging laundry on a clothesline outside or in a non-heated room) is needed 16,7 cycles/month for 9,5 months equal to 158,3 drying cycle/year.

In this zone the savings for drying 3,2 kg laundry with a RMC decreasing from 72% to 56% (washing machine spin speed going from 800 to 1 200 rpm) is 92,4 kWh/year, giving a total saving of 1 386,7 kWh/15y when 158,3 drying cycles per year are considered. Although it is highly improbable that consumers in this climatic zone own a low, 800 rpm, spin speed washing machine this hypothesis has been analysed for sake of comparison with the other climatic zones. In the more probable hypothesis of the RMC reduced from 56% to 49% (i.e. washing machines spin speed increased from 1 200 rpm to 1 600 rpm) the additional savings is 40,4 kWh/year or 606,7 kWh/15y; when finally the RMC is reduced from 72% to 49%, the energy savings is 132,9 kWh/year or 1 993,4 kWh/15y.

On a 'washer plus dryer system' basis, the use of the dryer with a lower RMC - from 72% to 56% - allows to save 1 277,5 kWh over 15 years; when the RMC is decreased from 56% to 49% the energy savings is 497,5 kWh/15y; while if the 1 600 rpm is used instead of a 800 rpm one the saving is 1 775,0 kWh/15y.

But again the dryer is not owned in 100% of the families. In the case the RMC is reduced from 72% to 56% in the washing machine, only when 7,9 dryers are run for the same 15 years the saved energy starts to overcome the additional energy consumption for the improved washing machine; when the spin speed is increased from 1 200 rpm to 1 600 rpm the number of dryers has to be increased to 18,1.

From an economic point of view, assuming 100% ownership of the dryers, the NPV is given in Equations 8 and 9 for a reduction of RMC from 72% to 56% and from 56% to 49% respectively:

NPV= (92,4 kWh/y × 0,17 €/kWh × 10,4 × *do*) - (7,28 kWh/y × 0,17 €/kWh × 10,4) - 30€ = 120,57 € (Eq. 8)

NPV= (40,4 kWh/y × 0,17 €/kWh × 10,4 × *do*) - (7,28 kWh/y × 0,17 €/kWh × 10,4) - 30€ = 28,64 € (Eq. 9)

This means that if the dryer ownership is lower than about 8% the extra energy consumed due to the increase of the washing machine spinning speed is not recovered via the energy savings of the drying process. But with the 30€ extra purchasing price and the price for the extra energy consumed for the higher spinning speed subtracted and the annual energy savings discounted, the breakeven point is even higher in terms of dryers ownership and reaches 26,3%. For a specific individual user in the Cold Climatic Zone, if the consumer will use the dryer more than 26,3% of the time, it is convenient under the previously discussed assumptions; otherwise no. When improving the washing machine spinning speed from 1 200 rpm to 1 600 rpm the economic breakeven dryer ownership raises to 60%

The conclusion is that for the consumers in the Cold Climatic Zone, if in the improbable situation that they have been using a 800 rpm spin speed washing machine, it certainly behoves them to move up to the 1 200 rpm one, they save 121 Euro with only about 26% dyer ownership and a PI = 4,0; however, there is also a gain in going from 1 200 to 1 600 rpm with a net discounted gain of 29 Euro, provided at least about 60% of dryer ownership is reached, but the PI is only 0,95. Since the consumers in the Cold Climatic Zone are expected to own a 1 200 rpm machine, there is economic motivation in purchasing 1 600 rpm washing machine to achieve the net gain of 29 Euro.

5. Analysis outcome

The energy consumption reduction and dryer economic ownership breakeven in Warm, Moderate and Cold Climatic Zones for different washing machine spin speeds are summarised in Table 6. Some values of the breakeven were not calculated in the Table since the corresponding spin speed improvement is considered highly improbable. Depending from the climatic zone of a country, the dryer ownership and the dryer use there is an overall energy consumption increase or a savings - and an economic loss or gain - for the 'washer plus dryer system'.

The possible energy savings deriving from the drying of lower residual moisture content laundry (i.e. spun in a higher spin speed washing machine) in a heated room has not been considered in Table 6, since the disaggregation of the room heating system (electric/fuel space heating, solar heating, recover of waste heat) is unknown for the three investigated Climatic Zones and it is out of the scope of the analysis, that instead concentrates on the 'washer plus dryer system'. Nevertheless for the Warm Climatic Zone it is not economically convenient to improve the washing machine spinning speed even under the unlikely assumptions that all consumers not having, or not using the dryer, will dry the wet laundry in a room with an electric heating system.

Table 6: Energy consumption and dryer economic ownership breakeven in Warm, Moderate and Cold Climatic Zones for different washing machine spin speeds (the additional energy consumption is 10 930 kWh/15y for each 400 rpm improvement)

Washing machine spin speed improvement (rpm)	**Dryer energy consumption reduction due to laundry RMC decrease** (kWh/15y)			**Dryer energy breakeven ownership** (%)			**NPV** **PI** (€/15y)			**Dryer economic breakeven ownership** (%)		
	W	**M**	**C**	**W**	**M**	**C**	**W**	**M**	**C**	**W**	**M**	**C**
800 $\rightarrow$1 200	365,3	876,0	1 386,7	30	12,5	7,9	0,18 0,006	**60,40** **2,0**	120,6 4,0	99	42	26,3
1 200 $\rightarrow$1 600	159,8	383,3	606,7	n.c.	28,5	18,1	n.c.	2,30 0,077	**28,64** **0,95**	n.c	95	60
800 $\rightarrow$1 600	525,1	1 259,3	1 993,4	41,7	17,4	n.c.	-23,9	62,68 1,04	n.c.	>100	57,8	n.c.

W = warm climatic zone; M = moderate climatic zone; C = cold climatic zone; n.c. = not calculated

In conclusion, for the Warm Climatic Zone the 800 rpm washer is considered optimum since there is little reward, less than an Euro, for upgrading to the 1 200 rpm one and a loss for going to 1 600 rpm.

Instead for the Moderate Climatic Zone, there is a 60 Euro discounted benefit for converting from the 800 to the 1 200 rpm machine. The consumer will likely consider this optimum, since the additional benefit in going from 1 200 to 1 600 rpm is only 2 Euro with a PI of 0,077. Of course, it is not irrational for the consumer to change to this higher spin speed, if he has no other investment with a higher PI, which is unlikely, and if he/she meets the minimum dryer ownership requirements.

Finally for the Cold Climatic Zone, where very few households are expected to have the 800 rpm washer, it is convenient for the consumer of the 1 200 rpm washer to change to the 1 600 rpm one with a 29 Euro net gain.

As far as the dryer breakeven ownership is concerned, the available data about the dryer ownership in Member States in different climatic zones have been collected from different sources and are reported in Table 7 [5, 6]. Although no complete and updated information are available, it is clear that for countries in the Warm Climatic Zone the ownership/use of the dryer is far below the breakeven energy threshold of a 1 200 rpm machine. In other words, in these countries a 400 rpm higher spin speed machine is not convenient from the energy consumption point of view: the higher energy consumption for the washing cycle will never be recovered through the use of a dryer.

Even for the United Kingdom (in the Moderate Climatic Zone), with a nominal dryer ownership of 42,4% if the use of this appliance is only 60% of the washing cycles [8], then the actual use is 25,4%, which is higher than the energy ownership breakeven (for the transition 800 rpm to 1 200 rpm), but considerably lower than the economic ownership threshold, should the ownership level be confirmed.

Table 7: Dryer ownership for some Member States in the three Climatic Zones

Country	**Climatic Zone**	**Dryer ownership** (%)	**Year**
Malta	Warm	12,2	2001
Portugal		13	2006
Slovenia		18	2003
Italy		9	2006
France	Moderate	35	2008
Germany		39	2005
Poland		5	2008
Denmark		44	2004
Ireland		46	2005
United Kingdom		42,4	2008
The Netherlands		68	2005
Finland	Cold	59	2004
Sweden		52	2004

6. Conclusions

In the above paragraphs the analysis of the additional energy consumption for a 400/800 rpm improvement of the washing machine spinning speed (with the spin drying efficiency going from class D to about classes B and A) and the energy savings of the drying in a class C condenser tumble dryer due to the lower laundry moisture content was developed. Depending from the Climatic Zone of a country, the dryer ownership, and the dryer use there is an overall energy consumption increase or a savings - and an economic loss or gain - for the 'washer plus dryer system' as summarised in Table 6.

To achieve robust results, in the previous analysis an additional energy consumption for the improved spin speed washing machine of 36,4 Wh/cycle only has been considered, instead of 50 Wh, under the hypothesis that a reduced 3,4 kg load could lead to a lower spinning time and energy consumption. However, if this reduction does not occur, i.e. the spinning consumption is independent from the machine load, and the initial 50 Wh/cycle are considered, the dryer ownership breakeven necessary to compensate the higher washing machine energy consumption increases.

The same approach can be also used to estimate the transition between the average machine with 856 rpm and RMC = 69,4% to a machine with 1 367 rpm and RMC = 52,2%, as described in Table 3 although the difference is 511 rpm, higher than the previously hypothesised 400 rpm, and therefore the increase in the energy consumption for the washing machine is expected to be higher.

Our general impression from this analysis is that the existing fragmentation of the market for the different washing machine spin speeds derives from rational energy and economic behaviour, and that 800, 1 200 and 1.600 rpm can be considered the optimum choice for the Warm, Moderate and Cold Climatic Zones respectively. A one minimum "high" spin speed machine for all of Europe would be a suboptimum.

References

[1] BNW19: *Domestic clothes dryers – current and future technologies, market status and priority action plan*, version 1.1, 08 October 2006, downloadable from http://www.mtprog.com.

[2] *Revision of the Energy Labelling System,* Final Report, 2006, Deutsche Energie-Agentur GmbH (Dena)

[3] M. Presutto, *Preparatory Studies for Eco-design Requirements of EuPs* (Tender TREN/D1/40-2005), Lot 14: Domestic Dishwashers & Washing Machines, Task 6, 2007, downlodable from http://www.ecowet-domestic.org.

[4] I. Rüdenauer, C. Gensch, D.Quack, *Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span*, Öko-Institut e.V. Geschäftsstelle Freiburg, November 2nd, 2004.

[5] Dr. R. Stamminger, *Preparatory Studies for Eco-design Requirements of EuPs* (Tender TREN/D1/40-2005), Lot 14: Domestic Dishwashers & Washing Machines, Task 3, 2007, downlodable from http://www.ecowet-domestic.org.

[6] *Ecodesign of Laundry Dryers, Preparatory studies for Ecodesign requirements, of Energy-using-Products (EuP)* – Lot 16, Report Task 3 – Final version, 30 June 2008, downlodable from http://www.ecodryer.org

[7] I. Rüdenauer, C. Gensch, *Energy demand of tumble dryers with respect to differences in technology and ambient conditions*, Öko-Institut e.V. Geschäftsstelle Freiburg, 13 January 2004.

[8] BNW06: Assumptions *underlying the energy projections for domestic tumble dryers*, version 2.0, 19 September 2006.

Energy Efficiency of washing machines – A harmonized standard for a diversified market

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Abstract

Home laundry is not only a highly complex matter, it is also done in very different ways and using very different technology around the globe. Any fair assessment and evaluation of performance and energy efficiency of these diverse systems nevertheless requires uniform testing procedures. That calls for a harmonized globally applicable standard, globally suitable and locally relevant. While this seemed impossible in the case of washing machines until a short time ago, the new Edition 5 of the International Standard IEC 60456 proves it can be done!

Now that the draft text is completed, the IEC expert groups will direct their efforts to an in-depth practice check in many labs world wide as well as assuring the actual application of the standard throughout the world for development, testing and labelling.

An international round robin test (RRT2008) was launched to verify that the revised method is applicable and easy to use for all types of washing machines. Two horizontal axis machines from Italy and Germany, two vertical axis machines (impeller type) from China and Japan and two vertical axis machines (agitator type) from the US and Mexico are all part of the ring test effort with 31 laboratories from all parts of the world running the tests. Additionally, the IEC technical committee SC59D organised training workshops to promote edition 5 in China, Thailand, Brazil and Australia. Plans are being made to expand this effort to other countries in the future. This presentation gives a background overview as well as results of this Round Robin Test project.

The revised standard IEC 60456 is meant to be applied worldwide as a regional measurement method. Based on the information from the international ring test and training workshop effort, it is planned to improve the standard even further by jointly working with key stakeholders including industry representatives, consumer agencies and regulatory bodies.

CENELEC TC59X WG1 has already started its work to introduce IEC60456 Ed.5 as a European standard EN60456 as a basis for a revised European Energy Label. This includes the development of a set of standard tests that improves the representation of today's usage of washing machines in Europe when compared to the current Energy label. A new test procedure for a combined test of 60°C and 40°C with full and partial load was proposed by CECED. The overall energy efficiency rating of washing machines based on such proposals is expected to provide more relevant consumer figures. This paper also outlines this project as an example for implementation of global IEC60456 for regional Energy Efficiency rating and labelling.

IEC 60456 – Edition 5 – a globally applicable standard

IEC 60456 Edition 4 „Clothes washing machines for household use - Methods for measuring the performance" was published in October 2003. The European Version (EN 60456) of that standard has been extensively used as the basis for testing performance and energy efficiency of washing machines according to the European Energy Label. However, short- comings were noted with respect to global application of the standard for other platforms, e.g. vertical axis (VA) agitator and impeller machines, which are not common in Europe but are widely used in other parts of the world. SC59D tasked its Working Groups in September 2003 to make the standard more globally applicable.

IEC subcommittee 59D has since then prepared a substantial revision to the test standard IEC 60456. The objective of the revision was to

1. make the standard more applicable to all types of automatic washing machines,
2. improve the repeatability and the reproducibility of the tests
3. improve structure and clarity of the standard.

The major elements of this latest revision are:

- The 5th edition has a simplified structure for improved clarity.
- The improved method of folding and loading test load items is intended to suit vertical axis, horizontal axis and twin tub wash systems. The load item distribution was modified for small loads, at the same time the maximum load size explicitly covered by the detailed procedures was expanded to 15 kg.
- The stain set was expanded to harmonize the testing with existing regional test methods (e.g. AHAM). The introduction of a body fat stain (sebum) is also considered a substantial step towards improved consumer relevance.
- The two new reference cycles Cotton 20°C and Cotton 30°C were developed and introduced to be used when testing low temperature VA systems. They also reflect the common trend to lower wash temperatures in general. At the same time, a new reference system was developed and qualified to assure applicability of the standard because the older reference washer is no longer manufactured.
- The introduction of the option to test with soft water (50 ppm hardness) was requested by many countries with naturally soft water. This option was tested, qualified and fully implemented in the latest draft including an adjusted dosage regimen for soft water testing.
- The test for rinsing efficiency was refined based on latest studies and information gathered to improve repeatability and reproducibility of the existing alkalinity method.
- The severity test of wool programmes, the wool shrinkage test, was simplified and improved regarding uncertainty.
- The assessment of 'off mode' and 'left on mode' power consumption was introduced. The introduction of these measurements serves the wish to assess all relevant performance aspects of washers. The power consumption in potentially relevant low power or stand-by modes are hereby included.

Finally, a substantially new approach was taken to determine the level of uncertainty of any of the measured and assessed performance parameters. Information about the precision of the various methods is determined in extensive round robin testing. The actual uncertainty data is given in an external document that is separately maintained as required.

RRT2008 – a worldwide exercise to demonstrate: “It works!”

Background

Once the final version of the new standard was completed, the IEC expert groups directed their efforts to an in-depth practice check in many labs world wide.

An international round robin test was launched to verify that the revised method is applicable and easy to use for all types of washing machines.

During the IEC SC59D meetings in October 2006 it was decided to conduct this round robin test to establish figures for repeatability and reproducibility of the revised methods. A project team was formed consisting of 12 experts, including representatives from machine and test material manufacturers supporting RRT2008. In March 2007 the “RRT organization team” started to prepare the necessary documentation and began to coordinate participation, supply of materials and preparation of machines.

Participation was open to all laboratories worldwide; the project was announced by IEC SC59D to all national committees and additionally via E-Mail to all laboratories that had participated over the last decade in several IEC/CENELEC/CECED round robin tests. Thirty-one laboratories in 16 countries decided to participate.

Figure 1 RRT2008: Participation worldwide

Shipment of materials and machines to the first laboratories was finished in March 2008. Some laboratories were able to finish their tests by the end of 2008; some laboratories were running tests during the first months of 2009. Evaluation is ongoing and expected to be finished by the end of 2009.

Test scheme

Laundry is done in very different ways around the globe, using different technologies. The revised standard is applicable to all three main platforms - horizontal axis machines and vertical axis machines of both agitator-type and impeller-type. Two horizontal axis machines from Italy and Germany, two vertical axis machines (impeller type) from China and Japan and two vertical axis machines (agitator type) from the US and Mexico were made available for the exercise.

The 3 types of machines were tested using typical settings and water hardness relevant to the part of the world from which the machines originated.

- Horizontal axis machines with cold fill – Cotton 60°C – hard and soft water

- Vertical axis machines with hot and cold fill (agitator type) – Cotton warm – soft water

- Vertical axis machines with cold fill only (impeller type) – Cotton cold – soft water

	treatment 1	treatment 2	treatment 3	treatment 4
	HA	HA	VA (h/c fill)	VA (cold fill)
	Platform: HA	Platform: HA	Platform: Agitator	Platform: Impeller
Test program	Cotton 60	Cotton 60	Cotton warm	Cotton cold
Reference	Cotton 60	Cotton 60	Cotton 30	Cotton 20
Water inlet temperature	15°C	15°C	15° and 60°C	20°
Water hardness	hard	soft	soft	soft

Figure 2 **Treatment overview**

Participating laboratories were asked to carry out tests on two samples of at least one of the three washing machine types. The tests included the assessment of:

• Washing performance

• Rinsing performance (alkalinity method)

• Spinning performance

• Programme time

• Energy consumption

• Water consumption

Evaluation and Proof of Concept

The tests were carried out in accordance with the revised procedures in the drafted fifth edition of the standard. Before starting tests a questionnaire had to be answered by each lab.

The test results were collected and analysed by the "RRT evaluation team". Evaluation is currently under way. The accuracy of the measuring system in terms of repeatability and reproducibility is evaluated according to IEC 61923 and in accordance with ISO 5725.

Initial results used for this presentation do not contain comparative results of laboratories. The following figures are provided to give an indication of the differences in performance figures across technologies around the globe. The values for 4 parameters (water, energy, time, water extraction) are examples of different technologies that were selected with the settings used for each machine. The figures represent a limited but valid comparison of wash systems and consumer habits throughout the world. Results are comparable due to the uniform test method used. Calculated uncertainties will need expert judgment to differentiate between machine effects and measurement uncertainty linked to the method itself and the lab factor. Performance results for washing and rinsing are not included in the overview because the evaluation is still to be finalized.

1. Water consumption

Water consumption is one of the key elements of any performance or efficiency label. By testing appliances in direct comparison it can be shown that the water consumption of vertical axis machines may be up to 3 times higher than that of horizontal axis machines (see RRT2008 examples in figure 3).

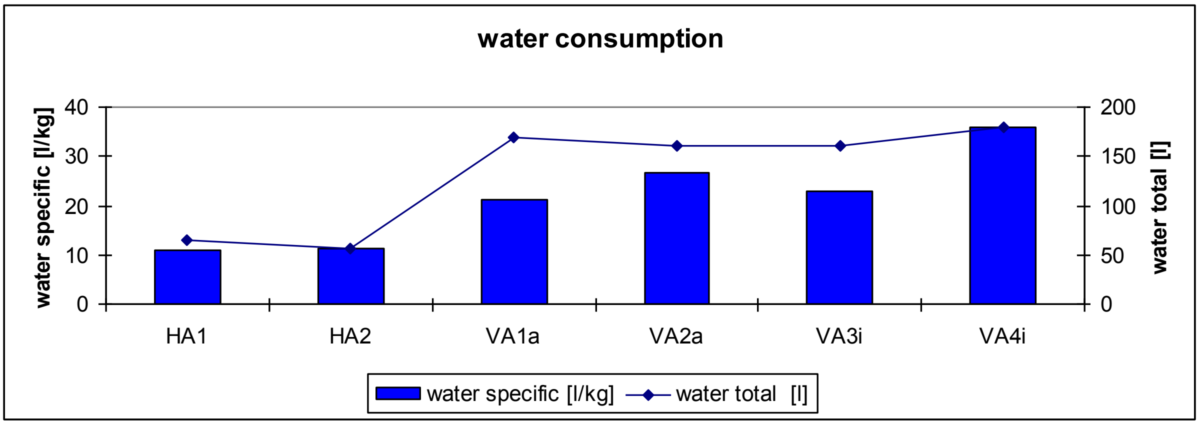

Figure 3 **Water consumption**

2. Energy consumption

Energy consumption is of course *THE* other key element of any performance or efficiency assessment. In the context of this International IEC Standard the energy consumption is represented by two values – the metered energy consumption and the corrected energy consumption. Both values are quite different between the 3 different types of machines; due to different typical settings but also due to different technologies. The metered energy consumption depends on whether water is heated by an integrated heater or hot water is preheated or the machine features cold fill only. The corrected energy consumption makes the values better comparable while accounting for varying water inlet temperatures: The measured data are normalized (calculation) to a common water temperature of 15° (the hot fill is set to 60°C during the tests).

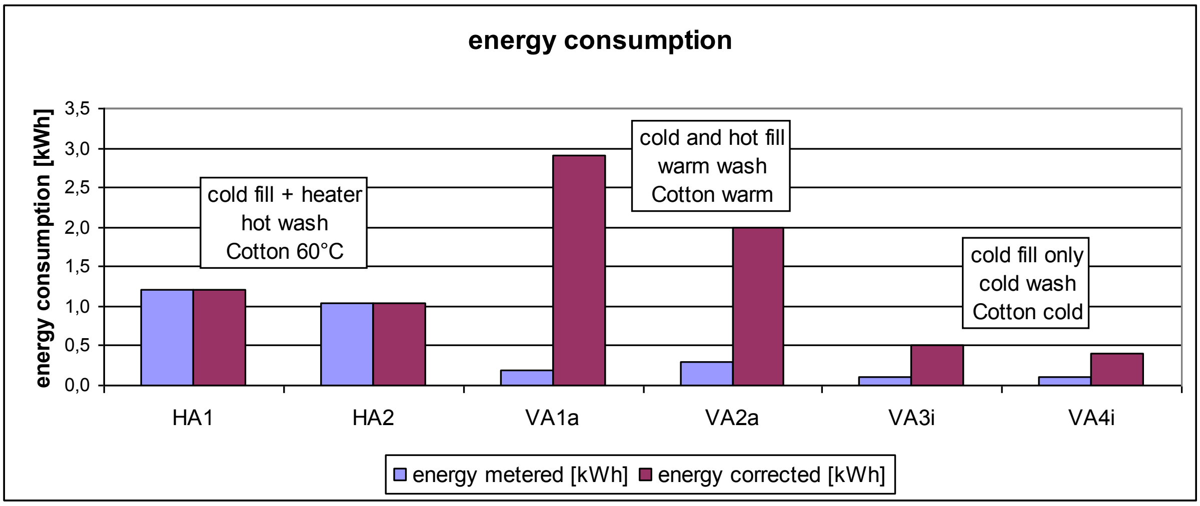

Figure 4 **Energy consumption**

3. Programme time

The programme time largely depends on selected machine settings and reflects and responds to consumer habits (expectation and acceptance). In the round robin test set up it varies with the tested cycles.

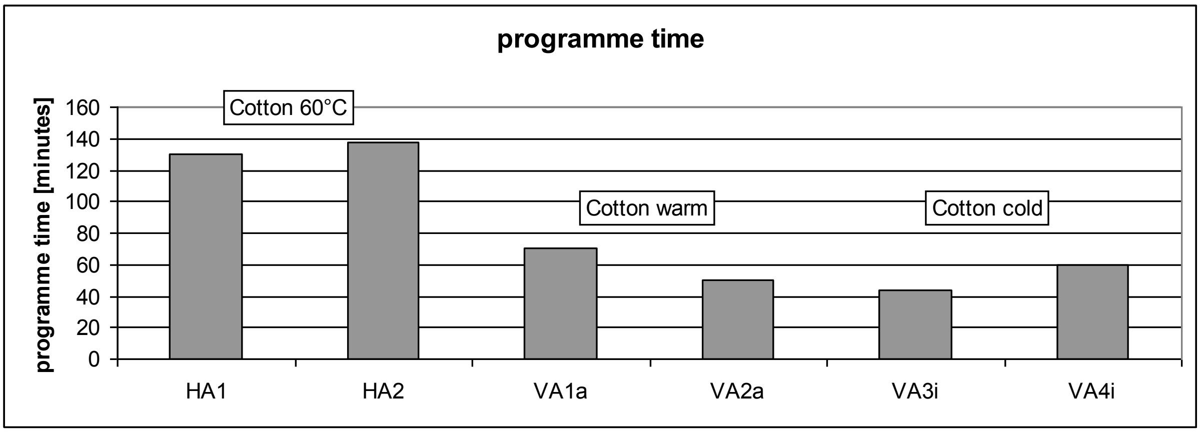

Figure 5 **Programme time**

4. Water extraction

The water extraction in % *remaining moisture content* (RMC) represents the spinning performance, a performance figure that is mandated in several efficiency labels around the globe. It is linked to spin speed, spin duration and characteristics of the relevant machines respective platforms. Where a clothes dryer is used to dry the laundry after washing, this value affects the energy consumption of the drying process. The higher the RMC value the more energy is needed to dry the laundry.

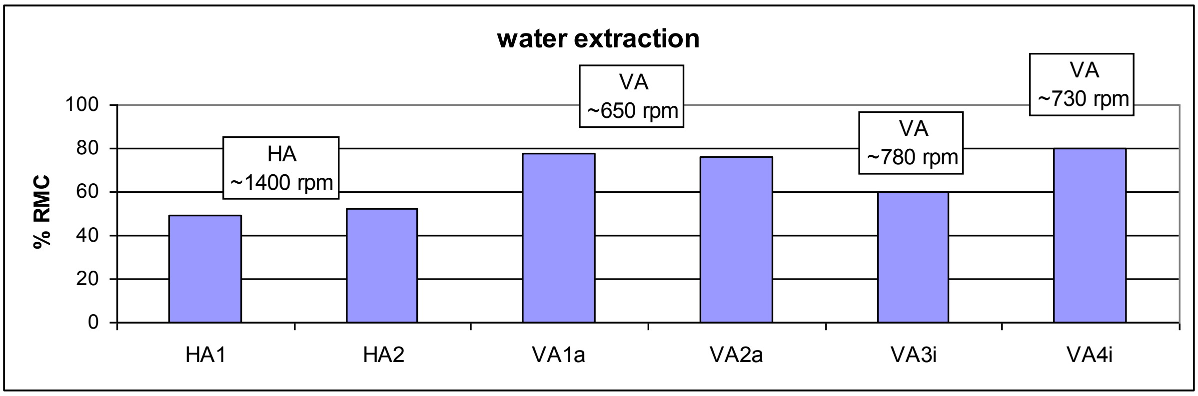

Figure 6 **Water extraction**

IEC 60456 – Edition 5 – on it's way to global application

The experience from working with the standard IEC 60456 during the development of the 5th edition as well as in the global round robin test 2008 confirmed repeatedly that the procedure is globally applicable. After years of development and refinement, the method is now technically fit for being used anywhere in the world. However, the 60456 project –and all the efforts that went into the development – is successful only if the standard is actually applied, i.e. if that procedure - or regional variations – is used as the primary method to assess washing machine performance throughout the globe. Experts of IEC SC 59D have been very active in the last 2 years in explaining and promoting the test method in training workshops in North and South America, Asia, Australia, Europe. Today, IEC 60456 or regional standards based on that test method are actually applied in laboratories on all continents. Some countries use the existing 4th edition; others already implemented the drafted 5th edition in their regional standards.

The most recent examples are

- the revision of the US American standard AHAM HLW-1, that is now largely based on the 5th edition, and
- the currently drafted revised European standard EN 60456, basis for the performance tests according to the revised European Energy Labelling.

The list of countries and organizations using IEC 60456 is still growing, a process that is supported by the continued efforts of IEC SC 59D experts to establish and use the contacts and dialogues with stakeholders representing machine manufacturers, consumer organizations, regulatory bodies and test institutes. Based on such cooperation, the harmonized drafted edition 5 marks a major step for IEC 60456 on it's way to global application.

EN60456 – European Standard and its application for a revised energy label

Background

CENELEC TC59X WG1 has already started its work to introduce IEC60456 Ed.5 as a European standard EN60456:20xx as a basis for a revised European Energy Labelling. Two documents from the European Commission (published last November, revised and accepted by the regulatory committee in March) are relevant with regards to a new test procedure for washing machines:

Working document on implementing measures for Ecodesign for Washing Machines [1]
Working document on Labelling requirements for Washing Machines [2]

Both documents request the development of a set of standard tests that better represent of today's usage of washing machines in Europe than the current Energy label. A proposal for such a new test procedure for a combined test of 60°C and 40°C with full and partial load was already presented by CECED in 2005. [3]

The overall energy efficiency rating of washing machines is based on the new 3+2+2 approach: It includes 3 runs of the Cotton 60°C programme at full load + 2 runs of the Cotton 60°C programme at partial load + 2 runs of the Cotton 40°C programme at partial load. This concept is expected to provide more consumer-relevant figures. The use of the weighted (3+2+2) values based on Cotton 60°C and 40°C programmes at full load and partial load is in line with the results of the preparatory study. The study contains research about the usage pattern of washing machines in 10 European countries. [4]

The Energy Efficiency Index

The European Energy Label displays the efficiency of electrical household appliances to consumers. There is a clear focus on energy including introduction of a new algorithm for the calculation of the Energy Efficiency Index. The Energy Efficiency Index (EEI) is the ratio of the annual energy consumption of a household washing machine to the standard annual energy consumption of a washing machine with the same capacity.

As illustrated below the annual energy consumption is calculated as the sum of the weighted energy consumption of the seven runs for two washing programmes and two load sizes plus the energy consumption of the two most important low power modes, the 'off mode' and the 'left on mode' for the same washing programme.

The following figure illustrates an example of how the overall energy efficiency of a washing machine is expressed via the Energy Efficiency Index.

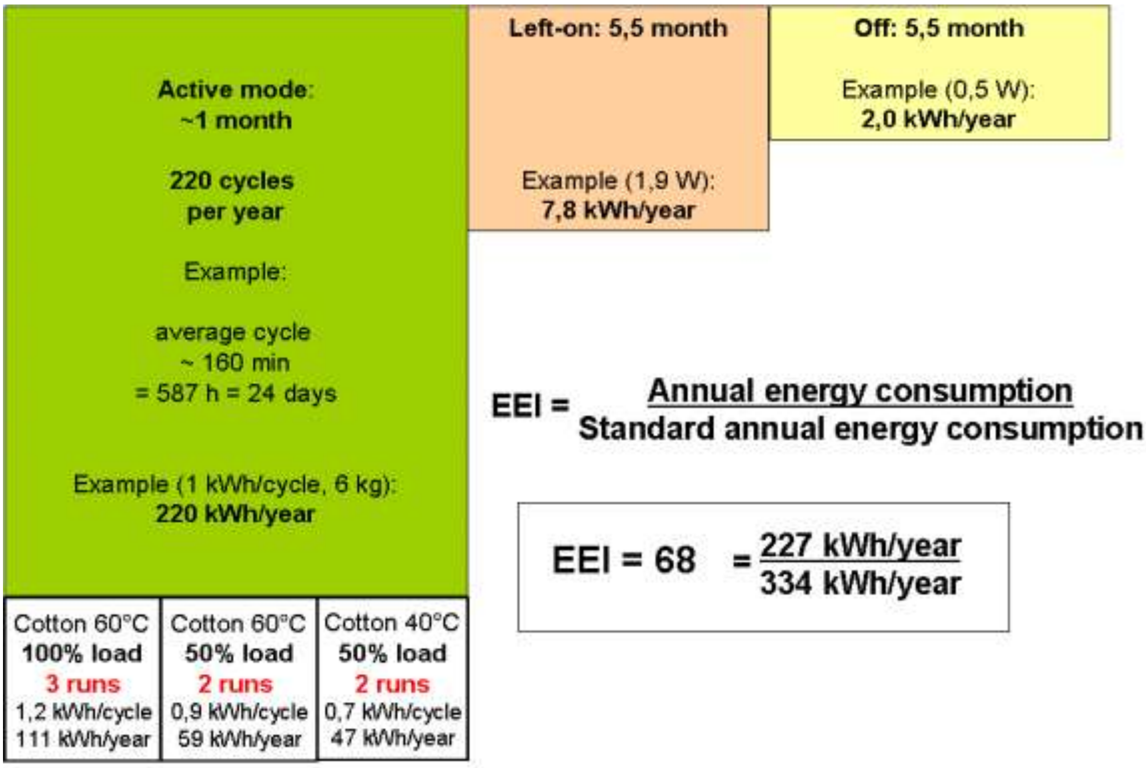

Figure 7 **Energy Efficiency Index (EEI) – one example**

EN60456 – Relevant items to be added for the next edition

The following key issues are identified for the next edition of the European Standard EN60456 based on the IEC60456 Ed.5 and the expected new regulations and the new directive for washing machines:

1. Modifications of consumption and related performance aspects of washing machines, taking into account partial loads (50% of rated capacity) and a combined test series for Cotton 60°C and Cotton 40°C

2. Tests to determine the expected uncertainty of measurements for the proposed 3+2+2 test scheme

3. Definitions for test procedures to measure low power mode for washing machines with respect to EN62301 and with a uniform approach compared to the European standby regulation [5]

The 3+2+2 test scheme needs to be introduced to EN60456 as a set of 'Common Modifications'. An Annex ZZ to the current standard will provide all details for a combined test series consisting of 7 test runs. The 3+2+2 test scheme fits into the current standardized IEC60456 test procedure. The more general IEC test scheme can be adjusted with reasonable modifications for the European-specific test. Splitting the full load (rated capacity) into two almost equal parts and testing each part for 2 test runs (Cotton 60 and Cotton 40) plus three test runs with full load corresponds exactly to the basic test procedure as outlined in IEC60456 which calls for 5 test runs on a full test load before re-conditioning. The combined test scheme allows more information without too much additional effort going from 5 test runs today to 7 test runs in future. Labs should still be able to manage the testing of one machine within a week.

IEC60456 Ed.5 provides a standard approach for testing two low power modes – ‘off mode’ and ‘left on mode’ are described in Annex L of IEC60456 (CDV). [6] This basic procedure can be used for the actual measurement of both modes as defined in the expected regulations for washing machines.

Summary

IEC60456 proves to be a harmonized globally applicable standard, globally suitable and locally relevant. The revised standard IEC 60456 is intended to be applied worldwide as a regional measurement method. The coming EN60456 will be the example of how to apply this measurement standard for Energy Efficiency rating and labelling in Europe. Others will follow.

References

[1] Working document on implementing measures for Ecodesign for Washing Machines: WORKING DOCUMENT ON A POSSIBLE COMMISSION REGULATION IMPLEMENTING DIRECTIVE 2005/32/EC WITH REGARD TO HOUSEHOLD WASHING MACHINES

http://ec.europa.eu/energy/efficiency/ecodesign/forum_en.htm

[2] Working document on Labelling requirements for Washing Machines: WORKING DOCUMENT ON A POSSIBLE COMMISSION DIRECTIVE IMPLEMENTING COUNCIL DIRECTIVE 92/75/EC WITH REGARD TO HOUSEHOLD WASHING MACHINES

http://ec.europa.eu/energy/efficiency/ecodesign/forum_en.htm

[3] Brussels, June 30th, 2005 - Workshop organized by EU Commission and CECED: PERFORMANCE MEASUREMENT - HOW TO BUILD ON SUCCESS OF ENERGY LABELLING AND INDUSTRY SELF COMMITMENT

Minutes and presentations available at www.ceced.org

[4] Output of the preparatory study is available at www.ecowet-domestic.org

[5] COMMISSION REGULATION (EC) No 1275/200 with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment. Official Journal of the European Union, 18.12.2008, L 339/45

[6] IEC 60456 Ed. 5.0: Clothes washing machines for household use - Methods for measuring the performance - 59D/343/CDV

Promotion of energy-efficient heat pump dryers

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Abstract

Drying laundry with laundry dryers is becoming more and more popular. Electricity consumption by dryers will therefore increase considerably in the near future. The promotion of energy efficient heat pump dryers helps to strongly lower this effect. Heat pump dryers cut energy consumption of conventional dryers in half and exceed the energy label A threshold by far. According to market data from 2008, heat pump dryers did not reach the break through yet and achieved a market share of less than 4% in most European countries. The situation in Switzerland however is promising: the market share of heat pump dryers has grown continuously since 2004, and reached 15,6% in 2008, and surprising 11% in Italy). The product range is growing: today there are 11 models for residential and 3 for semi-professional use on the Swiss market. The introduction to the Swiss market was facilitated by Topten and its partners, among them the City of Zurich, which could be convinced to launch a procurement program for heat pump dryers as well as a rebate program. Besides subsidies and information, one of the most important policy recommendations for the promotion is the revision of the EU labelling scheme. Today the energy label does not represent the fact that heat pump dryers – efficiency class A – are twice as efficient as conventional condenser dryers, especially since conventional dryers with energy label B are on the market. The label however should make perceptible to consumers the high efficiency of heat pump dryers – therefore a review of the dryer labelling scheme is urgent. We submit specific suggestions.

Introduction

Important energy consumption of laundry dryers

Drying laundry by conventional tumble dryers needs two to four times the energy needed to wash the same amount at 60°C. This is due to the physical fact that the water has to be evaporated by thermal energy to permit removal in the form of humid air. Water removal by spinning in a washing machine, powering the spinning motor, needs about 100 times less energy than thermal drying.

Considering the market penetration of laundry dryers in European countries (fig. 3), the actual trend to current and intensive use of dryers may raise substantially the respective energy consumption. A conventional tumble dryer thus may become one of the top electricity consumers in a household when drying all wash by this appliance.

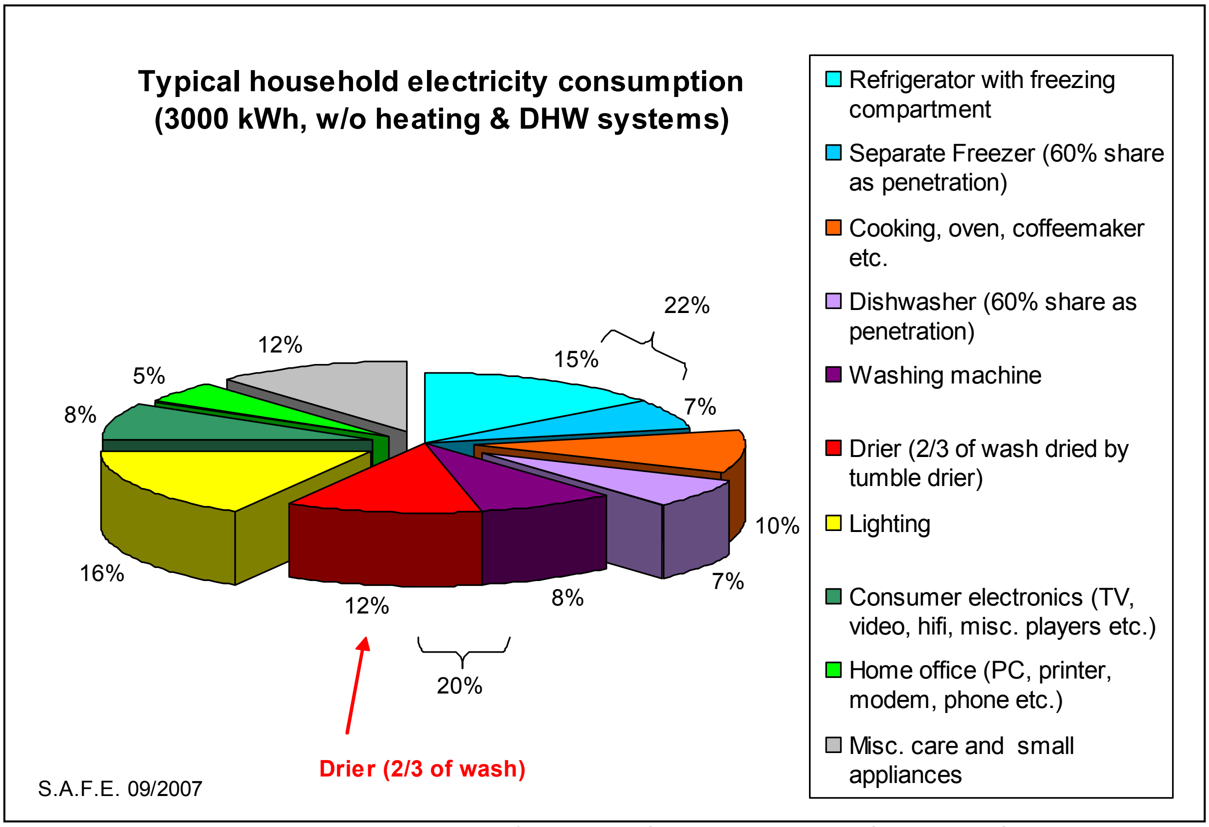

Figure 1 Electricity consumption of a typical Swiss household (2 persons)

In households without dishwasher and separate freezer, and if more than 2/3 of wash is treated, the dryer share of household consumption can be significantly higher.

Ecodesign of laundry dryers – EuP preparatory studies

In the framework of the European Directive on Eco-design or Energy-using Products (EuP) laundry dryers were taken up into the second round of product categories als lot 16. A consortium with PriceWaterhousCoopers (PWC) as leader worked out preparatory studies according to the EuP method; reports are being published on www-ecodryers.org [1]. In 2008, reports on tasks 1 to 7 were published and a final stakeholder meeting held in December. The task 8 report will propose measures and policies; its publication was expected when closing this paper.

Heat pump dryers were treated in task 6 (technical analysis and Best Available Technologies BAT) and task 7 (improvement potential). Their energy saving potential comes out clearly, but the economics (pay back) prove to be critical because of the higher purchase costs.

Heat pump technology cuts consumption in half

Technology

Conventional dryers evaporate the moisture by blowing hot dry air through the wash, the air heated up by electric resistance heating. They use two different technologies to remove the evaporated water:

Air vented dryers are open systems. They blow the exhaust air (initially air from the room) outdoors and cause disturbing smells, steam and noise at the external outlet. If one wants to avoid this, expensive exhaust air ducts over the roof are necessary. Air vented dryers need compensation air to be supplied by an opening. In winter this causes a cooling down of the room.

Air condenser dryers are closed systems. Room air is cooling down the warm damp air from the wash by a heat exchanger and thus condensing the moisture. At room temperatures above 30°C the condensing efficiency is declining.

Water condenser dryers have very high water consumption and are therefore no longer sold on the market.

Heat pump dryers (fig. 2) combine a condenser dryer with an integrated heat pump, making them a highly efficient alternative to conventional systems. Warm, damp air flows out of the laundry drum into the evaporator, where the air is dehumidified and the warm air returned to the drum. They consume only about half of the electricity of conventional condenser dryers: Their efficiency exceeds the EU A-label threshold by far, while conventional (resistor heating) machines are typically B or C-class at best.

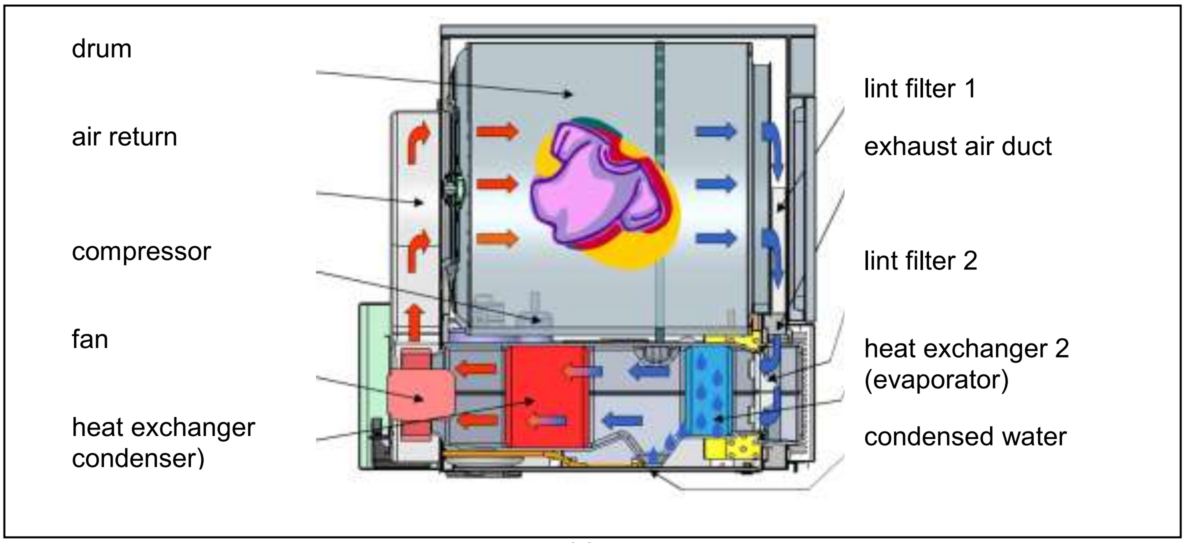

Figure 2 Heat pump dryer, schematic of function

Picture source: Schulthess AG, Switzerland

Further efficiency potentials for heat pump dryers

The market offers of the past years show quite an interesting development of efficiency figures: starting well above 0,3 kWh/kg (at 60% initial moisture, EN 61121) – except a semi-professional model 0,28 – today several models yield 0,28 or 0,27 kWh/kg and, on the other hand, a cheap model with 0,43 kWh/kg is available.

From a technological view, the following principles can raise the overall efficiency of heat pump dryers and give room to stronger efficiency requirements (Minimum Energy Performance Standard MEPS, see below):

- Improve temperature levels by a heat exchanger air-to-air which transfers energy from the warm exhaust air after the drum to the cold air after the evaporator. Realised in a Swiss semi-professional heat pump dryer and a Swiss case heat pump dryer. Requires significantly more space.
- Compressors with permanent magnet motors (EC-motors). Realised in new very efficient air conditioners with EEI above 5 (www.topten.ch > Haus > Klimageräte).
- Fan and drum drive with EC-motors.
- Optimised heat exchangers (may claim more space than usually available).

Further advantages of heat pump dryers

Besides the huge potential in energy savings heat pump tumble dryers create further advantages compared to conventional condensing dryers:

- Wasted heat in the operation room is about 50% lower, what is very welcome in summer and even extends the possible operation hours in hot periods (as conventional condensing dryers hardly work at temperatures above 30°C).
- Compared to air vented dryers, there is no smelling and steaming exhaust air as with conventional air vented dryers. In winter, there is no cooling down of the operating room as caused by compensation air for vented dryers.

Market penetration and trends

Tumble dryers in general

Market penetration of tumble dryers by country for parts of the EU-15 was mentioned in an EMA_E Business Intelligence study for 2005, fig. 3. Actual data referring to individual countries are not published. EuP Lot 16 studies, task 2 [2] says that ownership rates and sales numbers in "new" EU countries are very low compared to EU15.

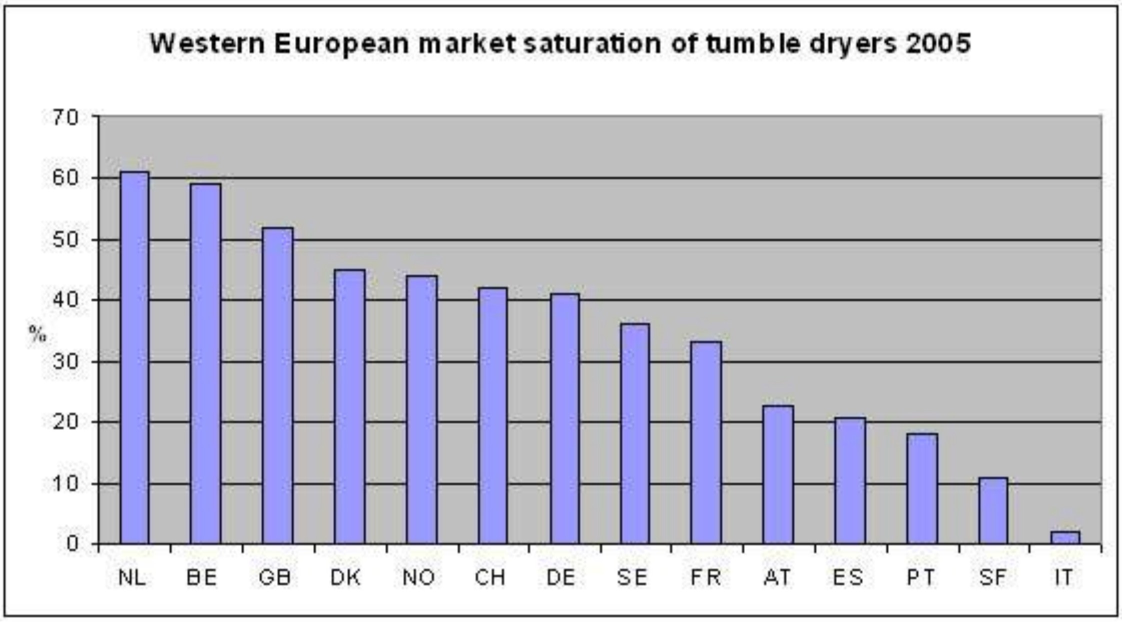

Figure 3 **Market saturation, examples 2005**

Data source: EMA_E Business Intelligence estimation

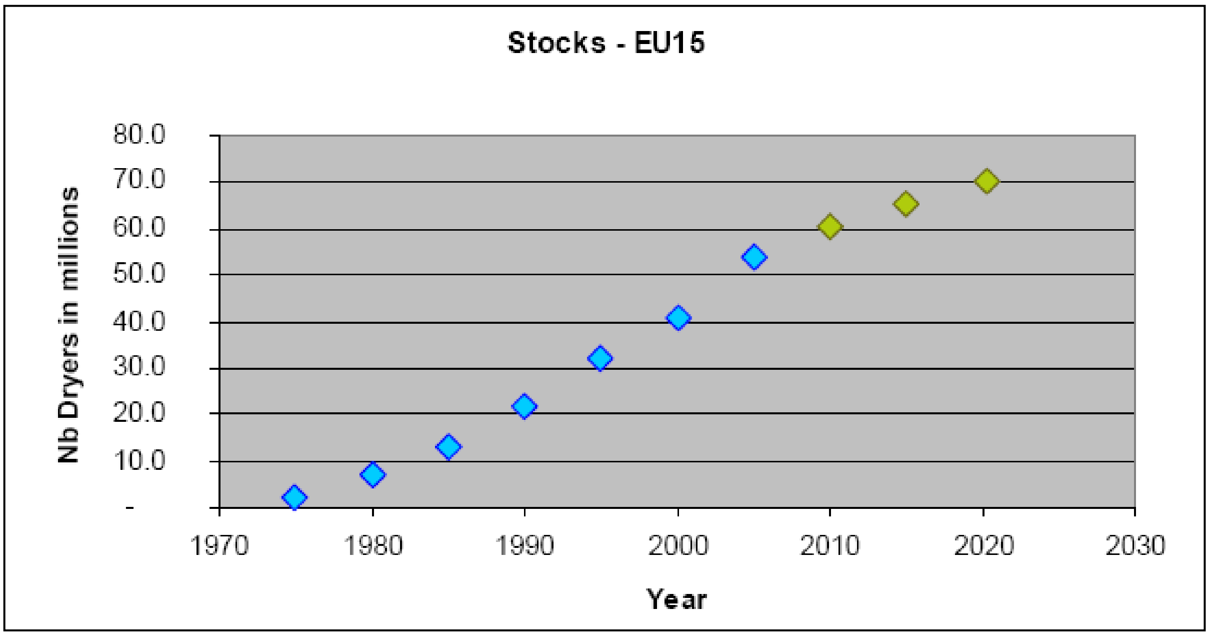

Figure 4 **Tumble dryer stock EU15**

Fig. 4 (source: [2]) gives an impression of the total number of tumble dryers stock in EU and expected growth. For "new incoming" countries the following development of stock is estimated: 1,4 million in 2010, 4,5 million in 2020. This would hardly change the order of magnitude of the numbers in fig. 4. Sales figures according to [2] are close to 4 millions in 2006 and 3,8 million in 2007.

A very rough estimation of usage pattern (cf. EuP Lot 16 [3]) assuming 600 kg dryed wash per year (considering shared appliances) at a specific energy consumption of 0,7 kWh/kg and 60 millions of dryers results in 25,2 TWh per year. The consumption of gas fired dryers can be neglected. Topten standard value for residential use of dryers is 800 kg / year (applicable for mid and northern European countries.

The actual trend towards greater market penetration of tumble dryers (fig. 3) is a result of various factors, including the fast pace of modern life-styles with little time for extensive housework, insufficient space for line drying and air pollution. Despite high energy prices, sales and use of laundry dryers are increasing. Efficiency gain of dryers is indispensable in order to restrict drying energy consumption; heat pump dryers stand for a significant success in drying technology.

Heat pump dryers

Actual sales figures show a very promising raise of the heat pump dryers share in some countries. In Switzerland, this trend started some years ago (fig. 5). But also in other European countries, the market share of heat pump dryer is rising (fig. 6).

Since 2003, many detail questions concerning heat pump driers have been clarified in Switzerland. Among others, laboratory tests of all models available on the Swiss market were carried out and the consumer satisfaction in the everyday life was analysed [4]. The throughout positive experiences with heat pump driers convinced the city of Zurich. Since 2003, the city of Zurich officially favours heat pump driers and has put in place in 2005 a rebate programme to promote heat pump driers and thereby their wider introduction on the market on national level (see below).

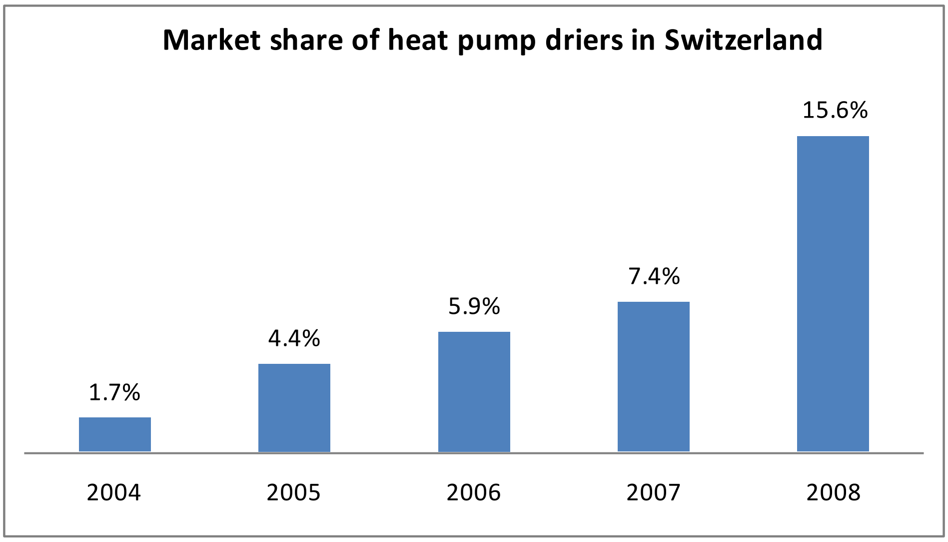

Figure 5 **Market share of heat pump dryers in Switzerland**

Data source: FEA

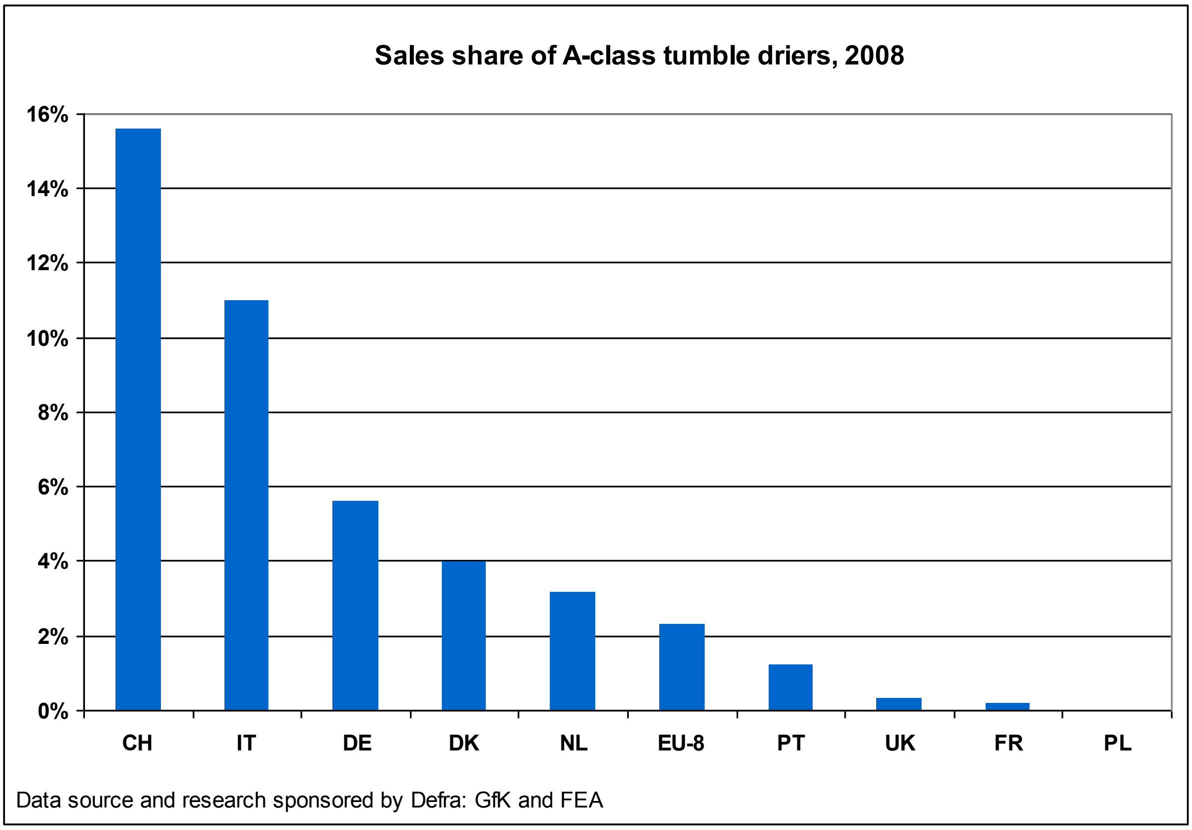

Figure 6 **Comparison of market shares of heat pump dryers**

Data source and research sponsored by the UK Department for Environment, Food and Rural Affairs (Defra): GfK and FEA.

Obstacles and remedies

Economics

Heat pump dryers contain more and expensive components compared to conventional dryers, what causes higher manufacturing costs and therefore a higher purchase price. Actual market data give hope that heat pump dryer prices are moving downwards; a (not very efficient in comparison) product is offered at less than 800 Euros. Obviously, the economic gain for semi-professional use is very clear, while for residential (individual household) use only the cheap but not very efficient model yields a good gain (fig. 7). Energy savings of about 50% and ecological gains of heat pump driers are not affected by smaller economic savings in residential use.

In order to calculate the cost over life time, the following assumptions were taken:

- sales prices: 70% of the list prices (to account for Swiss pricing practice), except cheap residential model: list price
- electricity consumption in accordance with standard consumption values of the EC label, during 15 years
- residential use: 800 kg / year and 12'000 kg / 15 years; semi-professional use: 5'000 kg / year (approx. 20 wash courses per week) and 75'000 kg / 15 years
- electricity tariff: € 0,15 per kWh (EU27 in first semester 2008: 0,16)

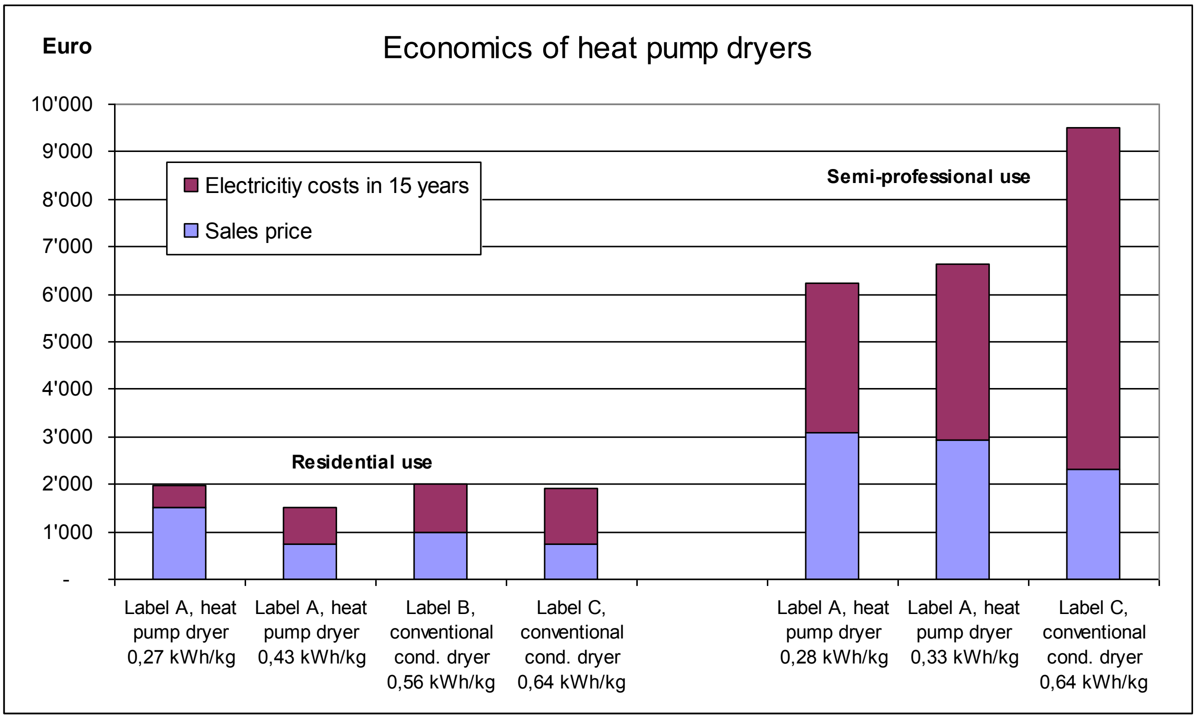

Figure 7 Economy of heat pump dryers, residential and semi-professional use

Source: www.topten.info, actual market data

As most buyers are not used to consider life cycle costing (LCC), they prefer the cheaper product. Lack of knowledge about LCC seems to be the most important obstacle to the dissemination of heat pump dryers. The remedy is not simple: most publicity of the retailers tends to focus on lowest purchase prices, while LCC is more complex to communicate, and future gains (by energy cost savings) seem to be much less attractive than momentary rebates. Therefore subsidies and rebate campaigns have proved successful in fostering heat pump dryer sales.

Subsidies

As the significantly higher purchase price of heat pump dryers seems to be the predominant obstacle to the dissemination, particularly for residential appliances, subsidies or rebates come forward as the best remedy. The rebate campaign of the city of Zurich, first launched in 2005, is very successful, considering the total number of household customers of 200.000 (of which only a very small fraction needs a new drier in a year):

Subsidised dryers, ewz (Elektrizitätswerk der Stadt Zürich, utility of the city of Zurich), Oct. 2005 till Dec. 2008

- Residential dryers, number 716 Euros 133.000
- Semi-professional dryers, number 641 Euros 224.000

The survey of subsidies data issues most of these dryers to be initial purchases, while only a small share is for replacement. Nevertheless, the promotion campaign was noticed very well also by professional landlords, and the ewz personnel communicated the advantages of heat pump dryers in many consultations of customers.

Besides the direct incentive for the individual buyer, an important indirect influence on the market can be observed: retailers and manufacturers refer to the subsidies in their publicity, other communities and utilities tend to copy such campaigns for their own image, buyers and users communicate their (hopefully) positive experience to others.

Requirements for building equipment

Some countries know standards for new buildings or refurbishment that include requirements for building equipment and even appliances. The Swiss MINERGIE® label (www.minergie.ch) actually recommends class A appliances, but the advanced MINERGIE-P® certificate requires class A, including laundry dryers. The standard SIA 380/4 (Swiss Engineers and Architects Association) "Energy in Buildings" stated already in 2006 class A dryers as benchmark. Recommendations and also benchmarks from renowned technical organisations have an important information impact.

Information and publicity

Missing information on the availability of such energy efficient products may be another obstacle, which is actually diminishing, as more and more retailers offer heat pump dryers and dedicate some publicity. Public and consumer organisations should intensify the information work on the subject.

www.topten.info [5] presents an overview on all models of heat pump driers (energy label class A) in the European market. Furthermore it provides recommendations for policy makers.

An important obstacle in publicity actions is the actual energy label classification, which suggests a small difference between conventional condensing dryers reaching class B and heat pump dryer of class A. The label can not visualise that huge efficiency gap of about 50%, while the step between C and B is only about 15%. Consumers may therefore appreciate "B" as fairly efficient. To overcome confusion the scheme should be shifted as to represent this difference. The new classification scheme would also give manufacturers incentives to further improve the efficiency of dryers.

Review of labelling scheme, MEPS

Labelling scheme EC 1996

Fig. 8 visualises the dryer energy labeling scheme of the EC Directive 95/13/EC [6], which refers to 70% initial moisture of the wash, as stated by IEC 61121. In Dec. 2005 an update of the 61121 was published as DIN EN 61121:2005 [7], allowing measuring and declaring of energy consumption and efficiency at 60% initial moisture, as washing machines achieve at common spinning speeds of about 1000 rpm. DIN EN 61121:2005 encloses a correction calculation scheme to get 70% (initial moisture) values out of the now measured 60% values. For condensing dryers this is simply a factor 1,14 (only condensing dryers are of interest in comparison to heat pump dryers).

Evidently the actual energy label classification according to EC Directive 95/13/EC leads to misunderstandings, when buyers get dryer offers of class A, B and C dryers and do not know the scheme figures. The label can not visualise the efficiency gap of about 50% from B (conventional condensing) to A (heat pump).

In fig. 9 we suggest two versions of new labelling schemes as a remedy to that problem. Version "new 1" realises a shift of 2 steps, which results in several available tumblers in class "A", while version "new 2" with 3 steps shifting yields no model in class "A" at present. The most efficient dryer we know (2008) is a Swiss heat pump drying case at 0,26 kWh/kg [8], which might be tuned down to 0,24 kWh/kg when exploiting the tolerances according to DIN EN 61121:2005.

Looking forward to further development potentials we plead for the "new 2" labelling scheme, which leaves space to classify new excellent dryers in A. If the general labelling scheme will be opened to more efficient models (numbered classes A1 etc.), the scheme "new 1" may also be reasonable, yielding several models in class A at the beginning.

Of course the labelling scheme for vented dryers would also have to be reviewed. There may remain a relative difference to the "condensing" figures as it used to be. Not being the subject of our work, we resign to make quantitative suggestions.

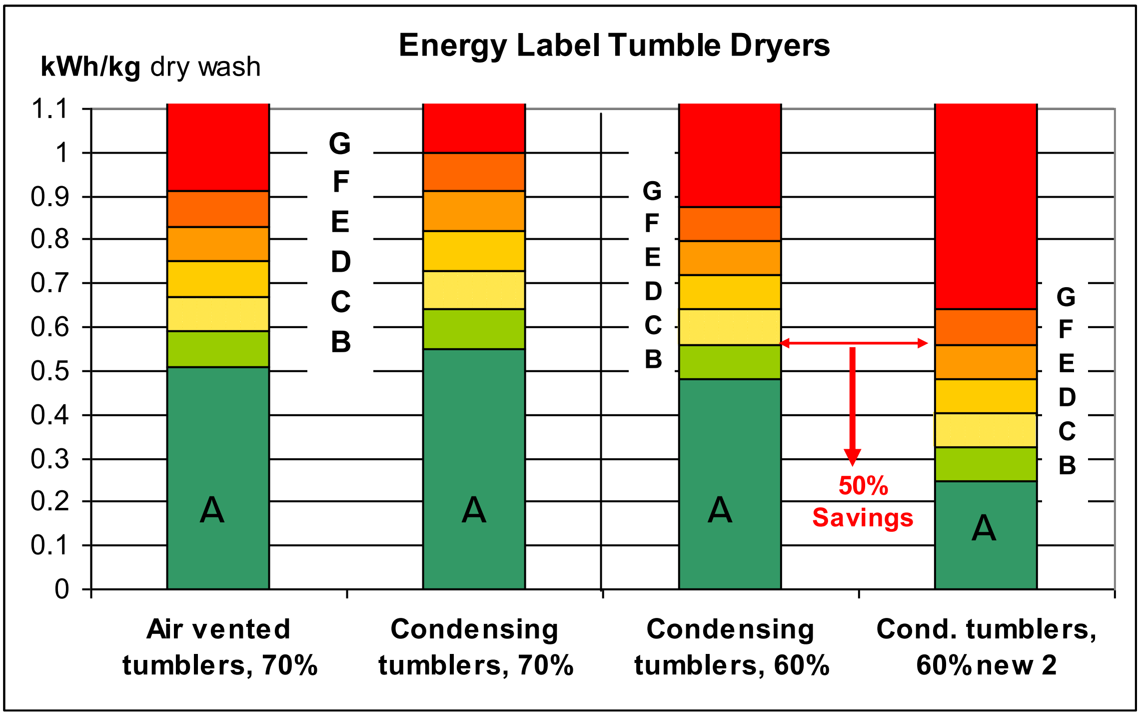

Figure 8 Energy Label for tumble dryers, EC 1996 (70% initial moisture), condensing tumblers 60% and update suggestion "new 2"

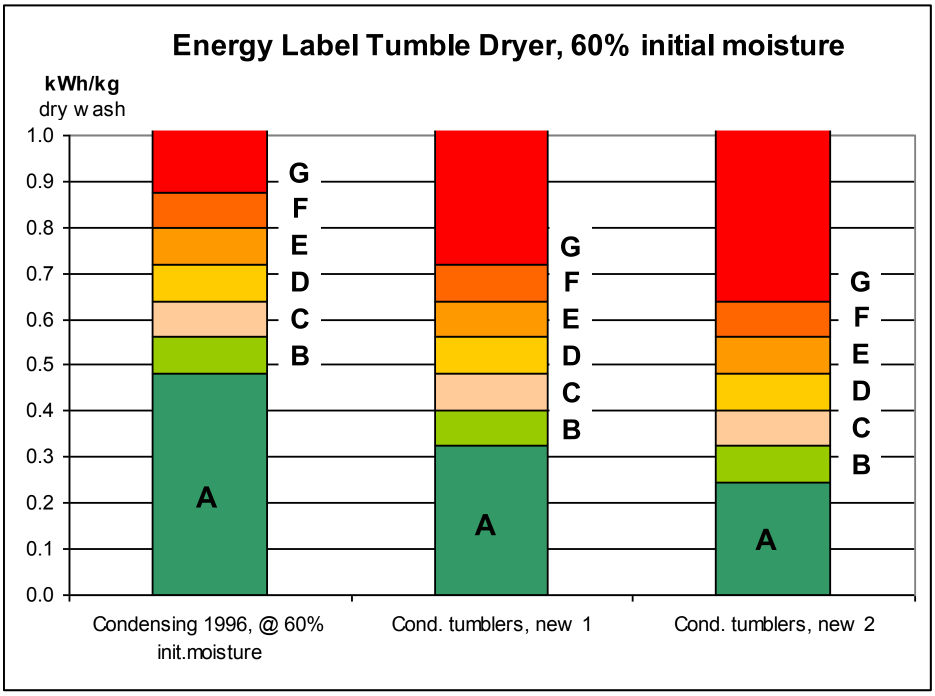

Figure 9 Energy Label for condensing tumble dryers, EC 1996 and suggestions for update

The specific energy consumption values of fig. 9 refer to 60% initial moisture of the wash, while the "official" EU label scheme (Directive 95/13/EC) refers to 70%, cf. fig. 8 and text above.

Minimum energy performance standards MEPS

The preparatory studies of the Ecodryers team will consider suggestions for MEPS in the work of task 8, scenario-, policy-, impact- and sensitivity analysis (publication expected when closing this paper).

The situation for MEPS for laundry dryers is very special: as there is a large gap between the best conventional dryers (resistor heating, consumption > 0,55 kWh/kg, 60% initial moisture, EN 61121) and heat pump dryers (majority < 0,35 kWh/kg, 60% initial moisture), it would not be future-orientated to set MEPS so that conventional technology fulfils. On the other hand, prescribing the new heat pump dryers means to quit the "bad but simple" old technology. A good compromise seems to be to set strong MEPS (class A), but concede a long delay, giving industry time to develop and launch the "new generation".

The Swiss government and its Federal Office of Energy make an effort into the efficient future: they propose to set labeling class A as a minimum efficiency performance standard (MEPS) for laundry dryers from 2012 onwards. The ordinance (to the energy Law) is actually in the consultation process with a deadline for contributions of Feb. 13th 2009. The consolidation of the ordinance may take ½ to 1 year until in force.

If the proposition of the ordinance is accepted, this means that only heat pump dryers would be on the Swiss market in a few years. Switzerland has already a relatively high share of heat pump dryer sales (fig. 6), and a high share of flats with joint washhouses and semi-professional appliances, where highly efficient models are very economic, see fig. 7. These are good reasons to set strong MEPS for that appliance category. It is difficult to judge the chance of being accepted. Innovative manufacturers/ vendors will likely welcome that help to sell more efficient technology.

Conclusions

Heat pump tumble dryers represent a huge energy saving potential. Furthermore, they offer more convenience as wasted heat in the operation room is significantly lower compared to air condenser dryers, and there is no smelling and steaming exhaust air as with conventional vented dryers. The technology proved to be reliable, prices are diminishing, and further efficiency potential is visible.

Because of the higher purchase price and most buyers hardly used to life cycle costs evaluation, promotion by subsidies and by information on long-run profitability come out as primary and simple measures. Life cycle energy cost figures are published on www.topten.ch and www.topten.info for many years. We suggest further supporting measures as follows:

- Revision of the EU labeling scheme for tumble dryers. Heat pump dryers are much more efficient than the actual energy label class A threshold. Many conventional condensing dryers reached class B in the last years, thus appearing nearly as good as A despite consuming twice the energy. To overcome that confusion the scheme should be shifted as to represent this difference. A new classification scheme would provide an incentive for manufacturers to further improve the efficiency of heat pump dryers.
- Dissemination of basic information and procurement recommendations on heat pump dryers for energy agencies and other relevant bodies. The individual countries should create strategies, promotion programs and campaigns according to their specific situation.
- Launch of an international competition for the most efficient condenser laundry dryer – accounting for overall economic and ecologic benefits. Different categories with respect to capacity and/or intensity of use could be considered.

References

[1] www.ecodryers.org, website of the Ecodesign Lot 16 team:
Ecobilan, PricewaterhouseCoopers (in cooperation with CODDE and KERP).

[2] Ecodesign of Laundry Dryers, preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) – Lot 16. Task 2: *Economic and market data*.

[3] Ecodesign of Laundry Dryers, task 3: *Consumer behaviour and local infrastructure.*

[4] Bush Eric, Jürg Nipkow: *Tests and promotion of energy-efficient heat pump driers*. EEDAL, London, 2006.

[5] www.topten.info

[6] COMMISSION DIRECTIVE 95/13/EC of 23 May 1995 implementing Council Directive 92/75/EEC with regard to energy labelling of household electric tumble driers. Official Journal of the European Union.

[7] DIN EN 61121: Wäschetrockner für den Hausgebrauch, Verfahren zur Messung der Gebrauchseigenschaften (IEC 61121:2002 + Corrigenda 2003, modifiziert); Deutsche Fassung EN 61121:2005.

[8] www.topten.ch/index.php?page=trockenschranke

Large Energy Savings by Sorption-assisted Dishwasher

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Abstract

BSH developed and introduced a new technology aimed at reducing the energy consumption of dishwashers. A conventional dishwashing cycle needs two heating phases, one for heating water during the cleaning phase, the other for heating water at the beginning of the drying phase to heat up the dishes. During the drying phase the dishes evaporate water by means of their heat capacity.

Introducing an open cycle adsorption technology called Zeolite®-Drying, BSH could omit the second heating phase and save the energy expanses for that phase. The dishes are dried by a hot air flow, circulated through a packed bed of microporous adsorbents such as zeolites, removing the moisture from the air and heating it up.

Using the Zeolite®-Drying technology BSH achieves about 20% lower energy consumption and an excellent drying performance, especially of dishes of low heat capacity, such as plastic items.

The application of this open adsorption process in dishwashers is the first of its kind in commercial use in domestic appliances world wide.

Principle of the Technical Innovation

The principle of an open adsorption cycle is shown in Figure 1. In desorption phase hot air is blown through a packed bed of microporous adsorbent pellets. Water adsorbed at the inner surface of the adsorbent is released to the air and removed from the packed bed. This process, called desorption, needs energy, which is taken from the hot air. The air cools down and leaves the packed bed very humid at moderate temperatures. About two thirds of the heat of desorption used to produce the hot air can be recovered by condensing the water vapour from the air at any medium which needs heating at moderate temperatures. After the desorption phase the adsorbent is energetically charged, energy is stored in the adsorbent.

In an adsorption phase humid air is blown through a charged adsorbent bed, water vapour is adsorbed at the adsorbent, the heat of adsorption is released and the air is heated. The air leaves the adsorbent bed hot and dry and can be used for any heating purpose, e.g. for drying dishes.

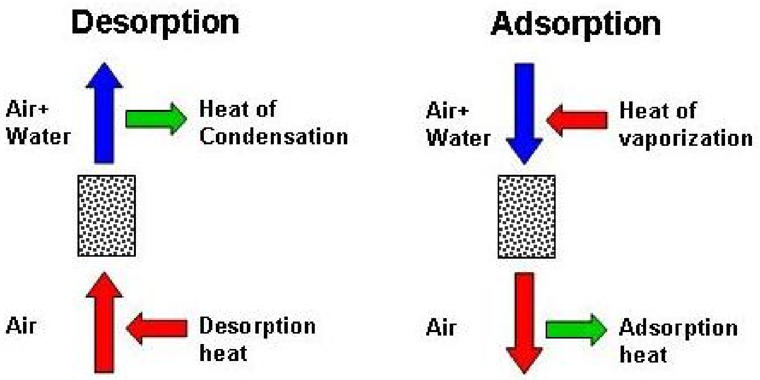

Figure 1: Schematic of an open cycle adsorption process

Practical Application to Dishwashers

In cooperation with the Bavarian Center for Applied Energy Research (ZAE Bayern), a well know center of expertise in this field of research, BSH implemented an open adsorption cycle in a dishwasher. Figure 2 shows the principle.

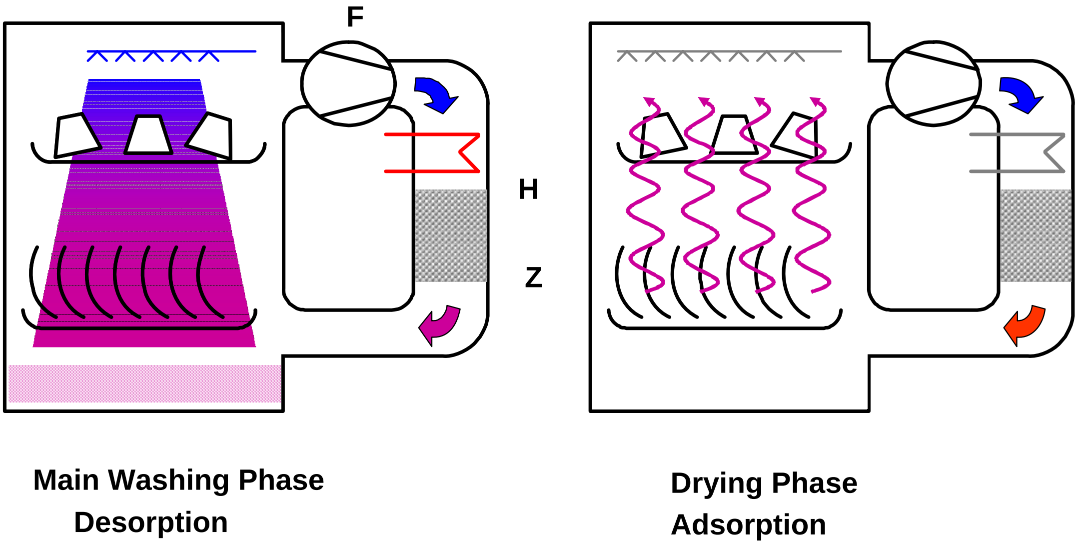

Figure 2: Schematic of a dishwasher with an open cycle adsorption drying system, using the components Fan (F), Electrical Heating Element (H), Zeolite Container (Z)

At the beginning of the main washing phase air from the tub is blown by a fan through a container with a packed bed of Zeolite pellets, which is used as adsorbent. The air is heated to temperatures of about 220 °C before it enters the Zeolite bed. The hot air desorbes water from the Zeolite and enters the tub at temperatures of about 60 °C. The water vapour of the humid air condenses at the rinsing water and the dishes, heating it up. After desorption the zeolite is charged and an additional electrical heater heats the rinsing water to the washing temperature.

In the drying phase humid air from the tub is blown through the Zeolite bed. The moisture from the air is absorbed by the Zeolite and the air is heated to about 60 °C. The hot air dries the dishes. The heat capacity of the dishes does not matter.

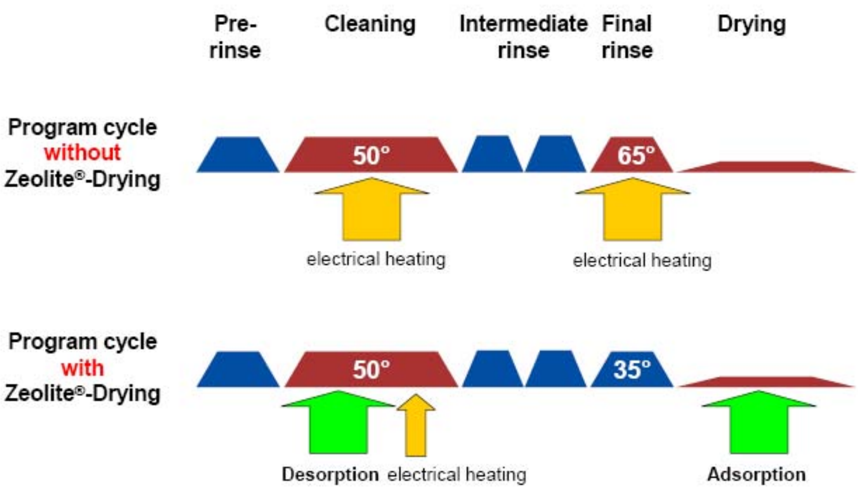

Figure 3: Energy flow diagram of a conventional washing cycle and a washing cycle with Zeolite®-Drying sorption technology

The differences in energy flow of a conventional washing cycle and washing cycle with Zeolite®-Drying sorption technology are shown in Figure 3.

In the pre-rinse phase no heating is required. In the main cleaning phase the conventional cycle heats the water directly by an electrical heater. The sorption technology cycle provides the main part of the heating by humid air produced by desorption of the Zeolite. In the intermediate rinse phases no heating is needed. In the final rinsing phase the conventional cycle heats the water and the dishes electrically to provide heat for the following drying phase. This is not necessary when using the Zeolite®-Drying technology. In the drying phase the conventional cycle uses heat from the heat capacity of the dishes to evaporate the remaining water from the dishes. The Zeolite®-Drying technology uses hot air produced by adsorption of the evaporated water vapour, which gives excellent drying results even in the case of dishes with low heat capacity, e.g. plastic items. Main advantage of the Zeolite®-Drying technology, however, is the removal of a second heating during the final rinse phase.

Energy Saving and Market Potential

With the integration of the Zeolite®-Drying sorption technology in a dishwasher, the reduction of the energy consumption for the standard washing programme[1] is about 0.20 kWh. Compared to conventional systems using specific heat drying, the energy savings easily reach 20%.

This is the first world-wide commercial use of an open sorption process in the home appliances industry (white goods). It demonstrates the readiness of BSH to supply energy efficient products, in order to save resources and contribute to environmental protection. This innovative drying technology is already on the market.

Today, almost all manufacturers of dishwashers offer energy-efficient-class A appliances; however, with the prospective revision of the EU Energy Label, BSH expects to be the benchmark in new energy requirements.

[1] according to EN 50242, for a 12 place settings machine with an energy efficiency class A and an energy consumption of 1.05 kWh

Cold Appliances

Relevance of consumer real life behaviour in cold storage on energy consumption

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Abstract

Since 1994, all cooling appliances offered for sale, hire or hire-purchase in Europe have to be labeled with the EU Energy Label which shows the appliance energy consumption as well as other useful information for consumers. But the standardised test conditions applied to measure this energy consumption are very different from the real life conditions in consumer homes. Especially the ambient temperature, the refrigerators air temperature, the refrigerators charge and the door opening behaviour as well as the addition of heat load (such as warm food and drinks) is not reflected by what is defined in the standard.

With the objective of documenting the real life conditions for refrigerators in private homes, a web-based survey with a total of 1000 participants was carried out in four European countries (Germany, United Kingdom, France and Spain) in autumn of the year 2007.

The results of the consumer survey as well as the consequences in terms of energy consumption of domestic refrigerators will be presented.

Introduction

Since 1994 all cooling appliances offered for sale, hire or hire-purchase in Europe have to be labeled with the EU Energy Label which shows the appliance energy consumption as well as other useful information for the consumers. The measurement of the refrigerators energy consumption is based on EN 153 and the directive 94/2/EG. Energy consumption is measured at an ambient temperature of 25 °C for all climatic classes (Sub Normal (SN): +10 °C to +32 °C; Normal (N): +16 °C to +32 °C; Sub Tropical (ST): +16 °C to 38 °C) except the Tropical class T (16 °C to 43 °C). The latter is tested at an ambient temperature of 32°C. These climatic classes define the ambient temperature range under which the appliance should be operated. The energy tests are carried out at a temperature of 5°C for the fresh-food storage compartment. The fresh food compartment does not contain test packages during the test, it is empty. The energy consumption is measured for 24 hours while operating with a closed door.

The standardised test conditions in EN 153 differ substantially from real life conditions. In real life the refrigerator usually contains many goods and these are loaded and unloaded in irregular intervals. To do this it is necessary to open the door which will cause cold air to be replaced by air of ambient conditions. Storage temperatures in the refrigerator may vary from consumer to consumer, but the temperature selected will have large influence on the amount of energy needed to maintain this condition. Furthermore, in the household, the ambient temperature in the room where the refrigerator is placed seldom is constant at 25 °C.

All these factors have a more or less high influence on refrigerators energy consumption. For example it is clear from basic physics and also reported that the consumer can save energy reducing the ambient temperature[1] whereas an increasing ambient temperature results in an additional consumption[2].

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[1] Böhmer T. & Wicke L. (1998): “Energiesparen im Haushalt“, Deutscher Taschenbuchverlag

[2] Stiftung Warentest (1994): “Umwelt geschont - Strom gespart“, *Test* 3, p. 36-39

According to Lepthien[3] also the internal temperature adjustment has a considerable impact on the energy consumption of a refrigerator. A raise of the internal temperature can save energy whereas the energy consumption rises with a temperature reduction.

Regarding the door openings both Alissi[4] and Grimes et al.[5] found that the energy consumption increases proportionally to the number of door openings. In most cases door openings are associated with loading or unloading of food. These activities can additionally increase the refrigerators' energy consumption.

To be able to assess the effect of real life consumer behaviour on the energy consumption of refrigerators a detailed knowledge of the consumer behaviour is necessary. In order to document consumer real life conditions in European households, a web-enabled survey was carried out in autumn 2007.

Material and Methods

Sample

The 1011 participants of the web-based survey were obtained by a German market research company (ODC Services GmbH, Munich) which also hosted the survey. The survey was carried out in equal shares in four European countries (France, Germany, Spain and Great Britain). With the objective of seeing differences between different household types five segments of equal size were generated (singles younger than 30 years, singles older than 55 years, couples, families with 3 or 4 persons and extended families with 5 or more persons). It was always the person purchasing and preparing the food in the household who was asked to complete the questionnaire.

Questionnaire

The questionnaire contains 43 questions covering general information about the refrigerators like age and configuration, ambient conditions (temperatures and position near any heat source), internal temperature setting, consumer charging, discharging and door opening behaviour and demographics and socioeconomics characteristics of the participants respectively. The results are therefore based on estimations of the consumer when entering the answers. Care was taken by the market research company to ensure only qualified answers are recorded.

Results

Participants

About one third of the 1011 participants were male, two-thirds female. The distribution of the household sizes conforms to the predetermined quotation. The age distribution of the respondents is given by figure 1. The largest age group is between 26 and 30 years (24,5 %) and between 18 and 25 years (14,5 %).

[3] Lepthien K. (2000): "Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt", Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik

[4] Alissi MS. (1987): "The effect of ambient temperature, ambient humidity and door openings on household refrigerator energy consumption", MSME thesis, Purdue University, Indiana; p. 1–168

[5] Grimes JG, William PEM, Shomaker BL. (1977): "Effect of usage conditions on household refrigerator–freezer and freezer energy consumption", ASHRAE Trans 1977;83(1): p. 818–28

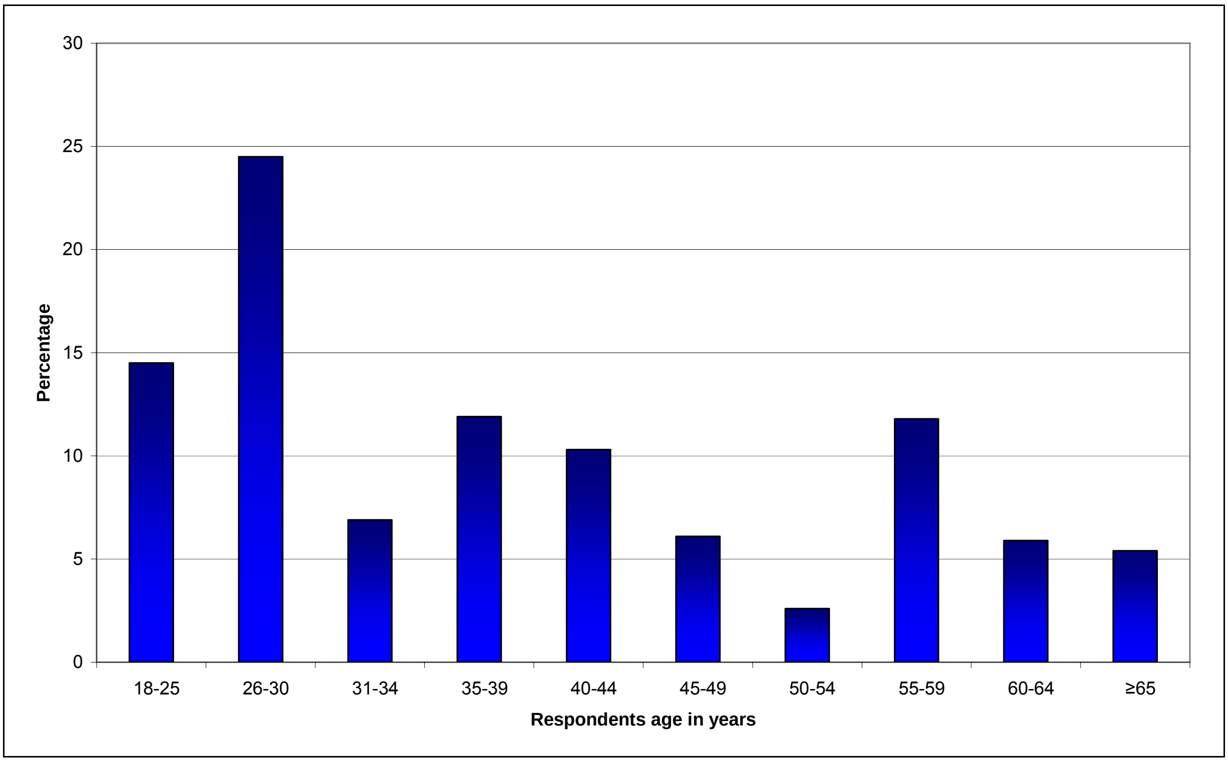

Figure 1: Age distribution of the respondents

Ambient temperature

The participants were asked about the maximum, minimum and normal ambient temperature in the room, where the refrigerator is placed. The statistical analysis of the answers of all participating households (n=1011) shows that the average maximum ambient temperature in the room where the refrigerator is placed is about 24,5 °C. In most of the households (62,5 %) the maximum ambient temperature is within the range 20 °C to 31 °C but reaching values of over 43 °C, especially in Spain (1,2 %) (figure 2). Considering all countries a total of 15,1 % of cooling appliances are operating out of the upper range of the climatic classes SN and N (ambient temperatures higher than 32 °C). 1,4 % of the appliances are placed in a room with a temperature higher than 39 °C and consequently operate out of the upper range of the class ST. The upper range of the climatic class T is exceeded by 0,5 % of the participating households.

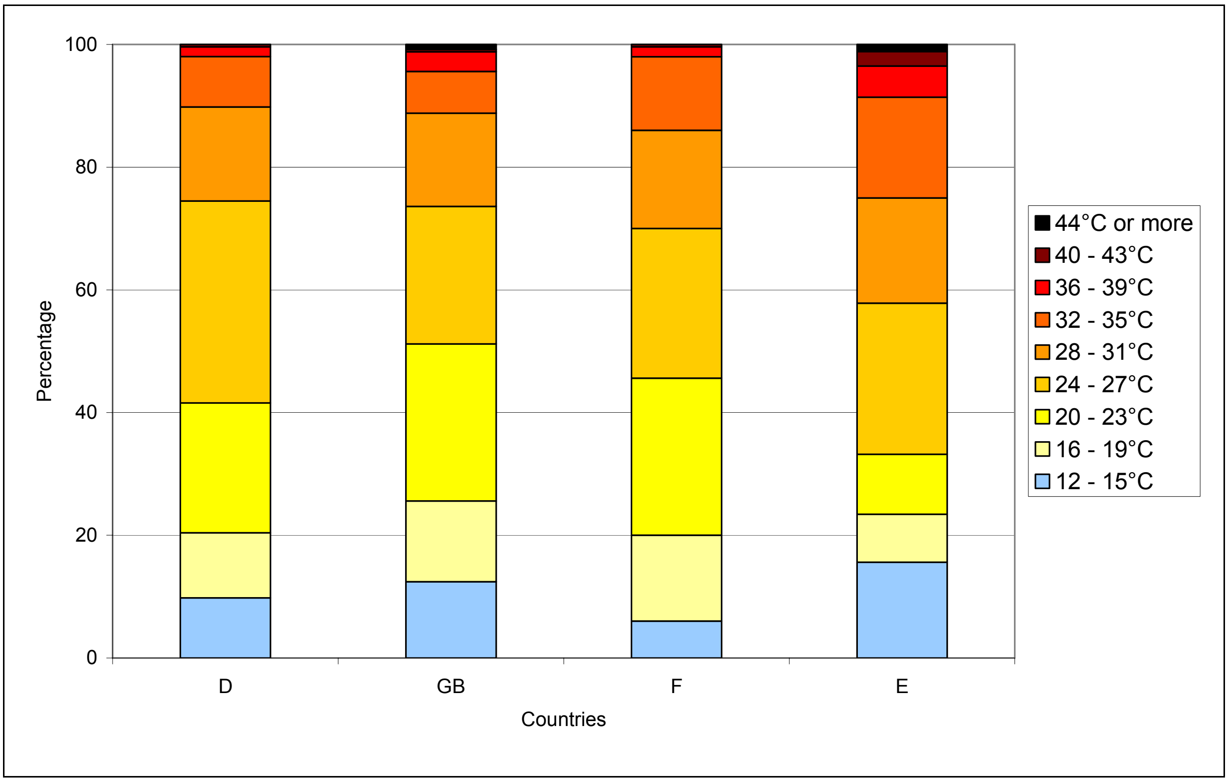

Figure 2: Maximum ambient room temperature per country

The average minimum ambient temperature in the room where the refrigerator stands is about 12,5 °C. Many of the participating households (49,1 %) have a minimum ambient temperature between 12 °C and 19 °C. But on average, approximately 42 % have a minimum ambient temperature of under 12 °C, especially in Great Britain (54,4 %) and Spain (56,6 %). According the respondents, in 31,2 % of the households in Great Britain and in 34,3 % of the Spanish households the minimum temperatures lies at less than 8 °C (figure 3) well outside the temperature range defined in the climatic classes.

The average normal ambient temperature in the room where the refrigerator is placed is 18,3 °C. Approximately 75 % of the interviewed persons indicated that the normal ambient temperature is within the range 16 °C to 23 °C. On average 8,6 % of the households have normal temperatures less than 12 °C and in 4,6 % of the households the normal temperature reaches values of 24 °C up to 32 °C and more (figure 4).

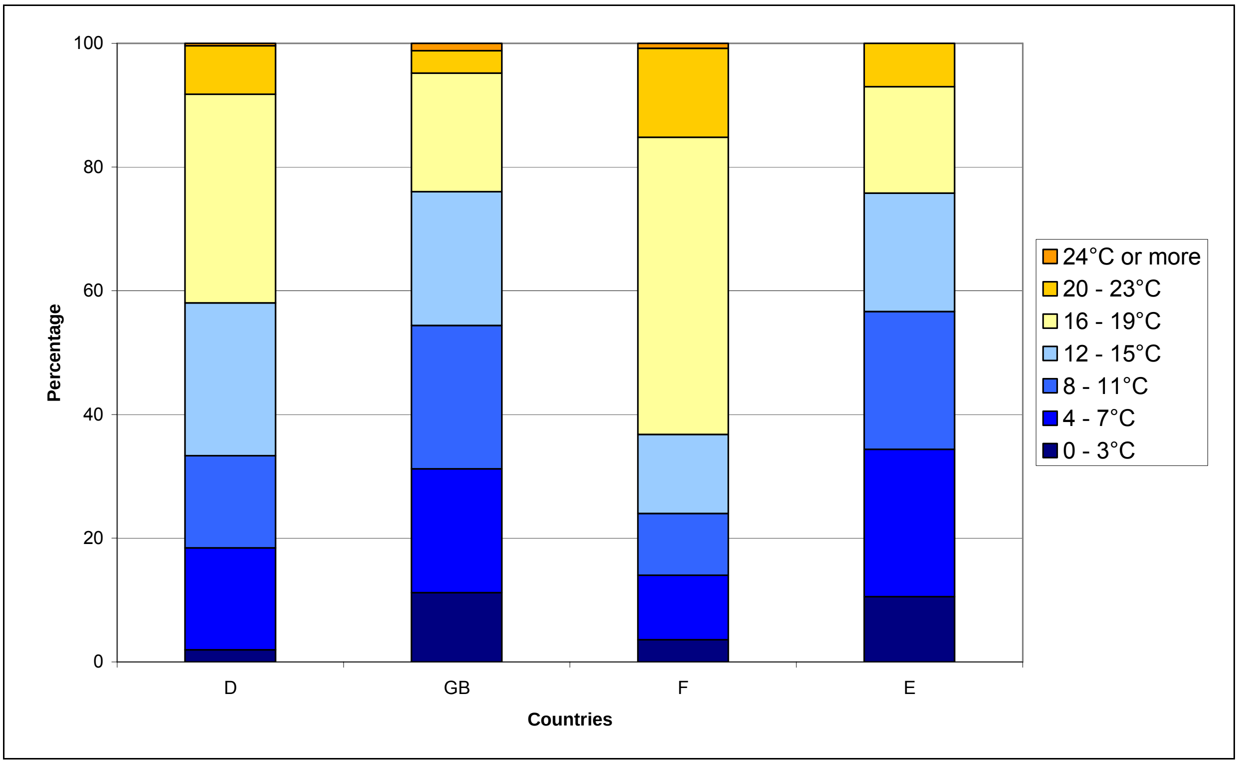

Figure 3: Minimum ambient room temperature per country

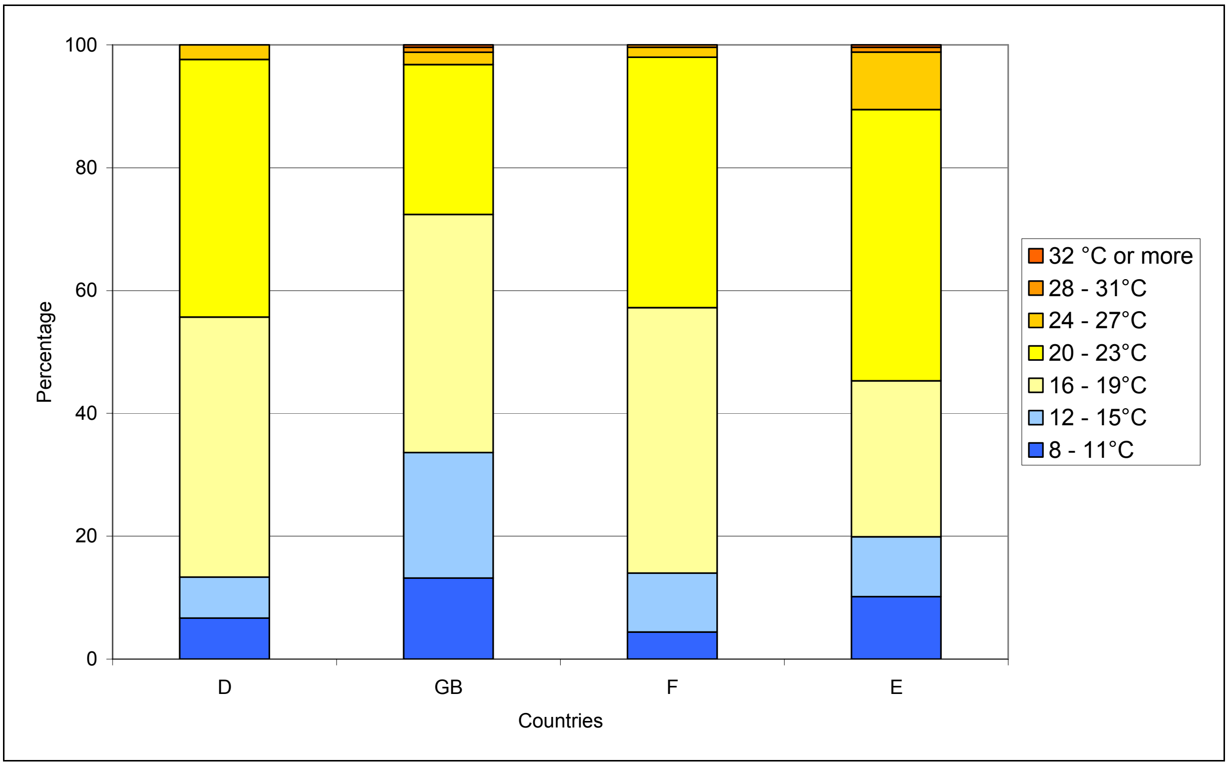

Figure 4: Normal ambient room temperature per country

Temperature setting

There are two different ways to adjust the internal temperature in the refrigerator, the adjustment in degree Celsius and the numbered setting adjustment. Because of that the participants were asked about their adjustment possibilities. The respondents with numbered setting adjustment additionally were asked to indicate the number of adjustment levels. But a high share of these participants (18,8 %) don't know the number of their adjustment levels. Consequently, these answers could not be analysed and in the following only the results of the consumers which can adjust their refrigerator by degree Celsius are presented. These consumers were asked about their general temperature adjustment.

These participants (n = 326) have an average actual temperature setting of 4,5 °C. About two-thirds (66,2 %) of the respondents with degree Celsius adjustment choose an internal temperature between 3 °C and 6 °C (figure 5). 20,9 % of the participants adjust their refrigerator to temperatures from 7 °C up to 12 °C and 12,9 % choose a temperature adjustment between 0 °C and 2 °C. Especially in Great Britain the interviewed persons have low internal temperatures (average 3,9 °C) whereas in Germany the respondents favour higher temperatures. The average internal compartment temperature in Germany is at 5,8 °C.

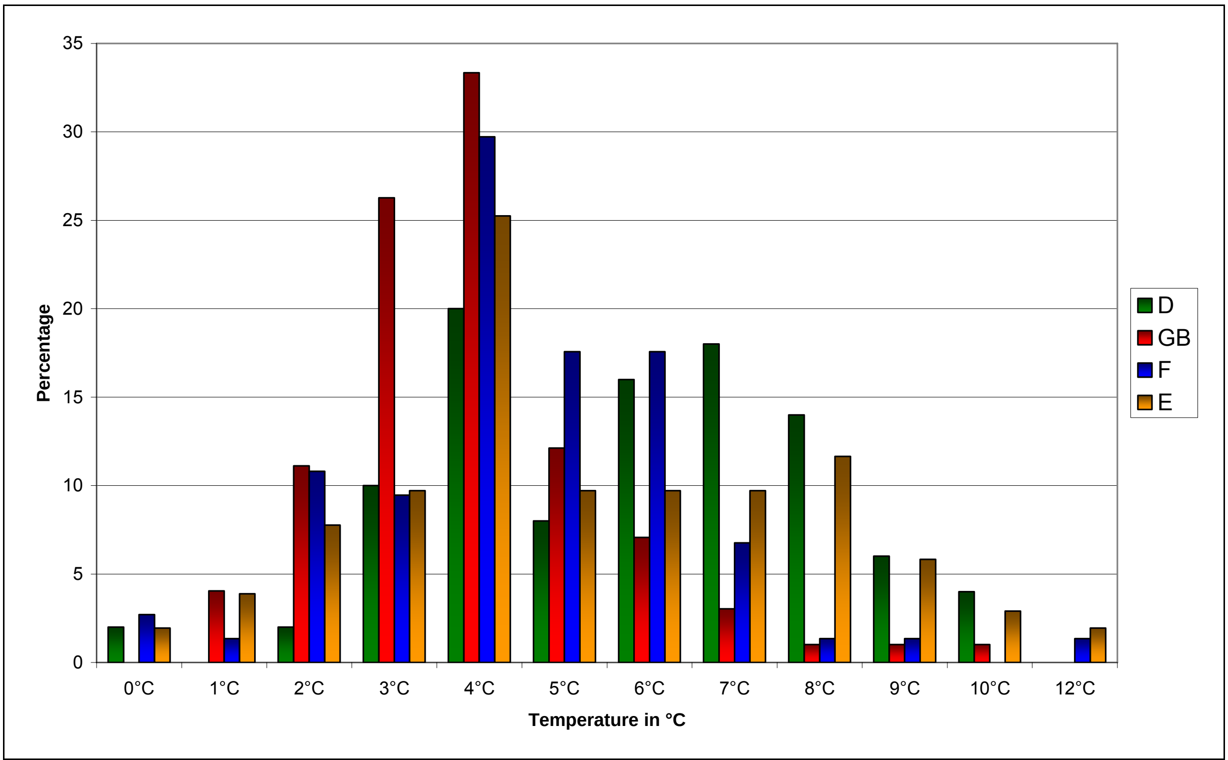

Figure 5: Refrigerators internal temperature adjustment in °C

Position near any heat source

Approximately 34 % of the refrigerators in the participating households are positioned near a heat source. In Spain, 59 % of the refrigerators have such a position. In most cases, the heat source is a cooker (41,9 %) or a combined cooker and oven (22,1 %). Furthermore, 12,4 % of the refrigerators are exposed to direct sunlight.

Door opening

The participants were asked to estimate the number of their refrigerators door openings per day. Most of the respondents calculate a door opening frequency of 6-10 times per day (35,8 %). The distribution of the frequencies is shown in figure 6.

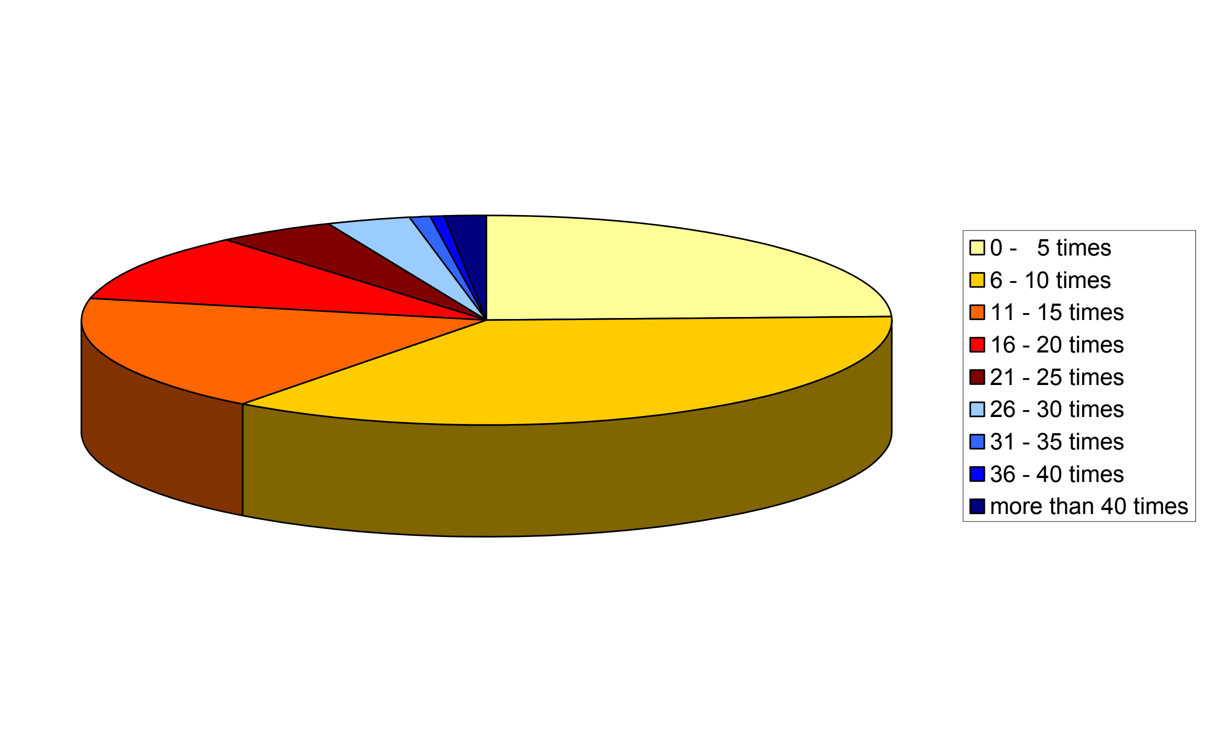

Figure 6: Frequency of door opening per day

Insertion of hot items

The participants were asked if they cool down prepared food before putting it in the refrigerator. On average 71,6 % answered that they always cool down their prepared food before the insertion while only 49,6 % of the French respondents agree with this statement. Even 17,9 % of the participating households in France stated that they never cool down hot food before putting it in their refrigerator. In the other three countries only 1,4 % of the respondents have an agreement with this answer (figure 7).

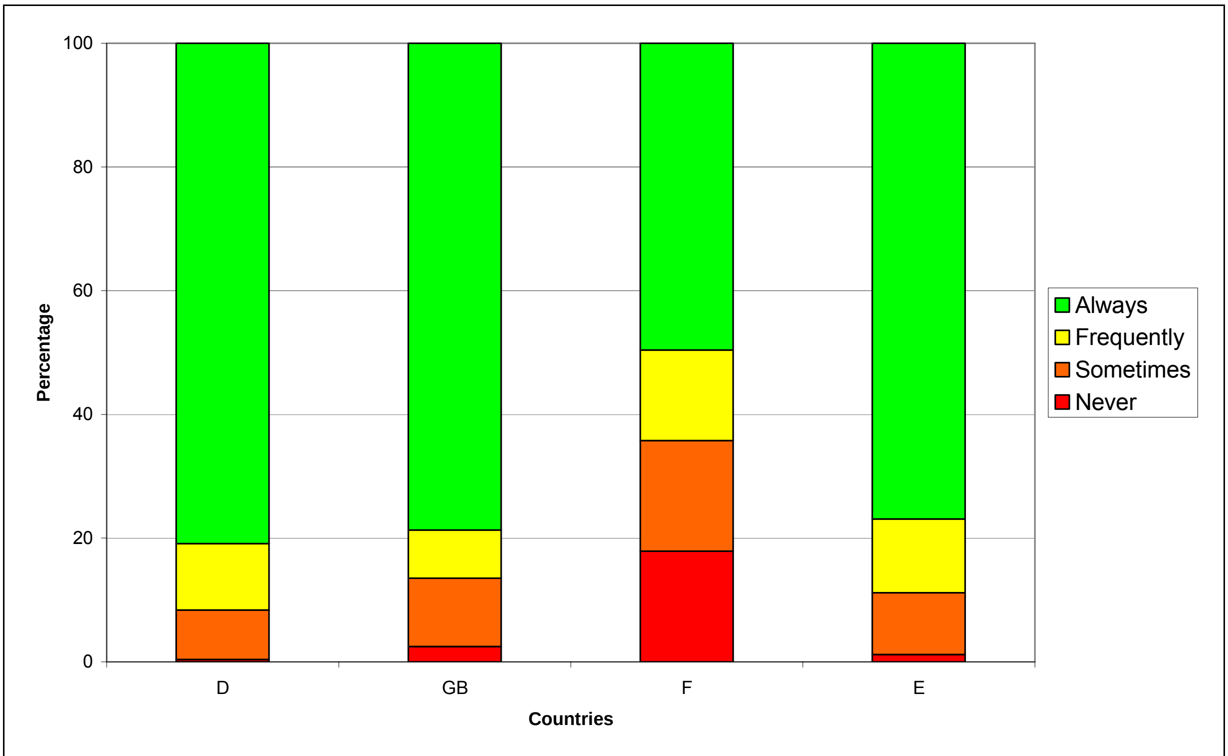

Figure 7: Cool down prepared food before insertion

Discussion

The present study has revealed many differences between the European countries regarding the refrigerator handling. Especially the outside influences like ambient temperature and place of installation of the refrigerators vary a lot.

A detailed analysis of the ambient temperatures shows that the countries with the largest share of maximal ambient temperature (Spain and Great Britain) also have the largest share of minimal ambient temperatures whereas in France and Germany most households have a relative constant ambient temperature. These findings fit in with the results of the EuP LOT 13 study[6]. The differences can probably be ascribed to the place of installation of the cooling appliance: it can be placed in a heated room, where the temperature is extensively constant over the year, or in an unheated room where the temperature follows the ambient temperature. A high share of participants stated that they have a normal ambient temperature of about 20 °C and that there are temperature differences of only 0 to 8 K (43 %) in the room where the refrigerator is placed (figure 9). That means that the ambient temperature is close to the temperature used in the energy consumption test (25 °C). Concerning the energy consumption large ambient temperature differences can be seen as problematic. 4,4 % of the respondents, especially in Great Britain (5,6 %) and Spain (10 %), answered that there are differences of at least 28 K in the ambient of their refrigerator (figure 8). Both high and low extreme values can negatively influence the energy consumption of the cooling appliance. Conduction of the cabinet walls causes 60-70 % of the total heat load in the refrigerator and it is proportional to the differences between ambient and internal compartment temperature[7]. According to the findings of Stiftung Warentest[8] an ambient temperature of 40 °C instead of 25 °C will cause a duplication of the energy consumption.

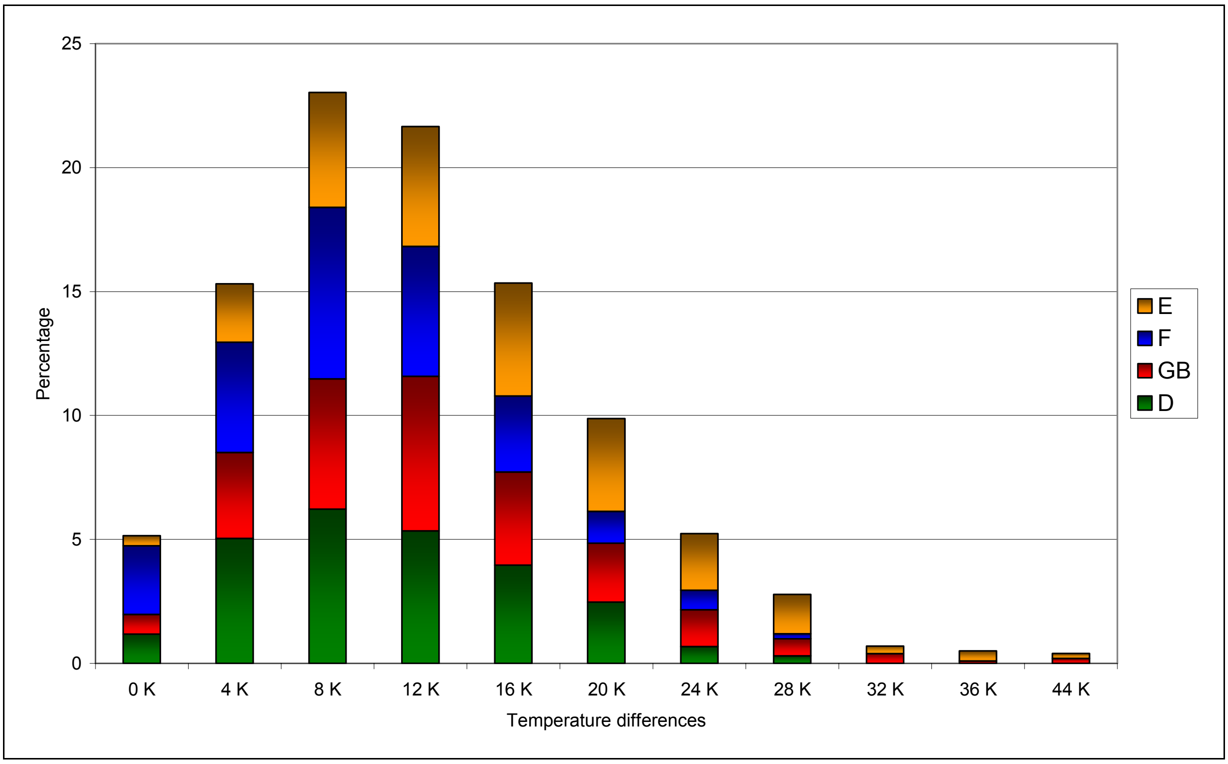

Figure 9: Ambient temperature differences over the year

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6 Stamminger 2007: “Preparatory Studies for Eco-Design Requirements of EuP, LOT 13: Refrigerators and Freezers”, http://www.ecowet-domestic.org/, p. 288-289

7 ASHRAE Handbook (equipment): “Household refrigerators and freezers”, Atlanta (GA): ASHRAE, 1988

8 Stiftung Warentest (1994): “Umwelt geschont - Strom gespart“, *Test* 3, p. 36-39

Temperatures lower than 25 °C in the air around the refrigerator can reduce the energy consumption to a certain extent. Böhmer & Wicke[9] for example calculated a reduction of 8 % per K with decreasing ambient temperature. But if the ambient temperature falls below 16 °C, the owner of an appliance with only one compressor and one thermostat risks to store their perishable food under inadequate conditions. Because of the low difference between the air temperature around the refrigerator and the internal fridge compartment temperature the compressor operates rarely and consequently the required freezer compartment temperature can not be maintained. A solution for this problem is offered by the so called "winter switch"[10]. It activates a small heater, for example the light bulb in the refrigerator, which heats the fridge compartment and consequently starts the compressor. But this small heater consumes additional energy, 192 Wh per day for an 8 watt light bulb and 360 Wh per day for a 15 watt light bulb.

Additionally, the ambient temperature rises if the refrigerator has a position near an external heat source. The results of the present study show that in 34 % of the participating households the refrigerator is located near a heat source, in most cases near a cooker or an oven. Lepthien[11] investigated the influence of a nearby operating oven on the energy consumption of a cooling appliance. She stated that a localisation near such a heat source only has a marginal impact on the refrigerator's energy consumption, an increase of 0,9 – 1,3 % can be observed.

Another factor, which has an impact on the refrigerators energy consumption, is the internal temperature setting. The recommendations for safety food storage are around 4 °C[12] to 5 °C[13]. According to the results of the present consumer survey 27,6 % of the participants choose a temperature adjustment less than 4 °C. This fact offers a chance for saving energy, because a refrigerator with a lower temperature setting consumes much more energy than an appliance with a temperature setting of 5 °C[14].

Furthermore, the number of door openings per day influences the refrigerators energy consumption. When opening the door, warm and moist air pours in the cabinet and mixes with the cool air inside. When the door is closed the warmth has to be transported out of the compartment. In this study an average number of door openings of 11 times per day was found. This result, which based on guesses of the participants, agrees with the finding of Thomas[15]. She measured the number of daily door openings in 34 European households and found that the most frequent number of door openings per day was 13. According the calculation of Alissi[16] and Grimes et al.[17] there is only a small additional consumption per day coming from this effect, as the heat capacity of the exchanged air is quite low. But in most cases door openings are associated with loading or unloading of food. These activities can additionally increase the refrigerators' energy consumption. The insertion of hot goods

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[9] Böhmer T. & Wicke L. (1998): "Energiesparen im Haushalt", Deutscher Taschenbuchverlag

[10] Stamminger 2007: "Preparatory Studies for Eco-Design Requirements of EuP, LOT 13: Refrigerators and Freezers", http://www.ecowet-domestic.org/, p. 313

[11] Lepthien K. (2000): "Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt", Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik

[12] Kreyenschmidt J. (2003): "Modellierung des Frischeverlustes von Fleisch sowie des Entfärbeprozesses von Temperatur-Zeit-Integratoren zur Festlegung von Anforderungsprofilen für die produktbegleitende Temperaturüberwachung", Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Agrimedia Verlag

[13] Baumgart J. (1994): Mikrobiologische Untersuchung von Lebensmitteln, Behr's Verlag

[14] Lepthien K. (2000): "Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt", Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik

[15] Thomas S. (2007): "Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa", Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik

[16] Alissi MS. (1987): "The effect of ambient temperature, ambient humidity and door openings on household refrigerator energy consumption", MSME thesis, Purdue University, Indiana; p. 1–168

[17] Grimes JG, William PEM, Shomaker BL. (1977): "Effect of usage conditions on household refrigerator–freezer and freezer energy consumption", ASHRAE Trans 1977;83(1): p. 818–28

for example causes an increasing energy consumption of cooling appliances because its warm need to be taken out and will add to compressor workload. On average 17,1 % of all respondents answered that they never (5,4 %) or only sometimes (11,7 %) cool down hot food before they put it into the refrigerator. Especially in France, 35,8 % of the participants sometimes or never cool down their hot items before the insertion. The heat load, which is caused by the insertion of hot food, is a function of mass, product type and the temperature difference between the temperature of the food before and after cooling. In the present study, there are no data gathered concerning the aforementioned parameters. Consequently it is impossible to estimate this additional energy consumption. However, Masjuki et al.[18] conducted several experiments by placing fresh water of 24-25 °C into the refrigerator and freezer compartment. Per kg water an additional energy consumption of 90 Wh was found.

Conclusion

A web-enabled study was carried out in four European countries in order to identify the impact of the consumer behaviour on energy consumption of household refrigerators. The results show that in average real life energy consumption may be a bit lower than the energy consumption measured according to the standard, as the average ambient temperature is significant lower as the temperature used in the standardised test procedure. But additional energy is used due to the effect of door openings which are not considered in the present standard. Looking on the individual refrigerator our results have shown that the consumers not always follow the recommendations to save energy. The insertion of hot goods or the internal temperature adjustment for example are significant factors influencing the energy consumption. Another important factor is the ambient temperature, which shows high individual differences. About 25 % of the appliances in the participating households are even operating out of the temperature ranges given by the climatic classes. So an accurate operation of the refrigerators is not ensured. This fact can result in increasing energy consumption as well as in inadequate food protection.

References

[1] Böhmer T. & Wicke L.: *Energiesparen im Haushalt*, Deutscher Taschenbuchverlag, 1998. ISBN 3423508132.

[2] Stiftung Warentest*: Umwelt geschont - Strom gespart.* In: Test 3, pp. 36-39

[3] Lepthien K. *Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt*, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik, 2000.

[4] Alissi MS. *The effect of ambient temperature, ambient humidity and door openings on household refrigerator energy consumption*. MSME thesis, Purdue University, Indiana, pp. 1-168, 1987.

[5] Grimes JG, William PEM, Shomaker BL. *Effect of usage conditions on household refrigerator-freezer and freezer energy consumption*, ASHRAE Trans, 83(1), pp. 818-828, 1977.

[6] Stamminger R.: *Preparatory Studies for Eco-Design Requirements of EuP, LOT 13: Refrigerators and Freezers*, 2007, p. 313. Can be downloaded at: http://www.ecowet-domestic.org/

[7] ASHRAE Handbook (equipment): *Household refrigerators and freezers*, Atlanta (GA): ASHRAE, 1998. ISBN 1883413540

[8] Stiftung Warentest*: Umwelt geschont - Strom gespart.* In: Test 3, pp. 36-39

[9] Böhmer T. & Wicke L.: *Energiesparen im Haushalt*, Deutscher Taschenbuchverlag, 1998. ISBN 3423508132.

[18] Masjuki HH., Saidur R., Choudhury IA. Mahlia TMI, Ghani AK, Maleque MA. (2001): "The applicability of ISO household refrigerator-freezer energy test specifications in Malaysia", *Energy* Vol. 26 No. 7, pp. 723-737

[10] Stamminger R.: *Preparatory Studies for Eco-Design Requirements of EuP, LOT 13: Refrigerators and Freezers, 2007*, p. 313. Can be downloaded at: http://www.ecowet-domestic.org/

[11] Lepthien K. *Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt*, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik, 2000.

[12] Kreyenschmidt J.: *Modellierung des Frischeverlustes von Fleisch sowie des Entfärbeprozesses von Temperatur-Zeit-Integratoren zur Feststellung von Anforderungsprofilen für die produktbegleitende Temperaturüberwachung*, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, 2003. Agrimedia Verlag. ISBN 3-86037-223-8

[13] Baumgart J.: *Mikrobiologische Untersuchung von Lebensmitteln* , Behrs Verlag, 1994. ISBN 3-86022-160-4

[14] Lepthien K. *Umweltschonende Nutzung des Kühlgerätes im privaten Haushalt*, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik, 2000.

[15] Thomas S. *Erhebung des Verbraucherverhaltens bei der Lagerung verderblicher Lebensmittel in Europa*, Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn, Institut für Landtechnik, Abteilung Haushaltstechnik, 2007

[16] Alissi MS. *The effect of ambient temperature, ambient humidity and door openings on household refrigerator energy consumption*. MSME thesis, Purdue University, Indiana, pp. 1-168, 1987.

[17] Grimes JG, William PEM, Shomaker BL. *Effect of usage conditions on household refrigerator-freezer and freezer energy consumption*, ASHRAE Trans, 83(1), pp. 818-828, 1977.

[18] Masjuki HH., Saidur R., Choudhury IA. Mahlia TMI, Ghani AK, Maleque MA. *The applicability of ISO household refrigerator-freezer energy test specifications in Malaysia*, Energy Vol. 26 No. 7, pp. 723-737, 2001.

Cool Carbon

Thomas Grammig

GTZ-Proklima

Anne Arquit Niederberger

Policy Solutions

Sam Shiroff

BSH Bosch and Siemens Home Appliances GmbH

Abstract

The rationale for a Public-Private Partnership between Bosch und Siemens Hausgeräte (BSH) and GTZ-Proklima is outlined, comprising a new Kyoto Protocol Clean Development Mechanism (CDM) Methodology and a Programme of Activities CDM Project to replace old household refrigerators. It is suggested that CDM projects in general can extend global emissions trading and support the costs of accelerating the diffusion of energy efficient appliances. CDM projects undertaken by or via utility companies in particular have the potential to lead to a new generation of Demand-side Management. The Partnership implements a PoA project in Brazil and the results obtained will allow to upscale such CDM projects for household refrigerators worldwide.

The Kyoto Protocol and Household Appliances

Using less energy does not necessarily have to mean sacrifice on the part of the consumer. Demand-side Management (DSM), which can generate "negawatts" in lieu of generation capacity to meet the demand for energy, can be encouraged by and has been successful under some regulatory regimes [[1] p.12]. In some circumstances, this requires habit changes on the part of businesses and individuals – such as using appliances during off-peak hours, or changing shifts for energy-intensive operations so that demand does not outstrip supply. For instance, such DSM measures are currently used out of necessity by South African Eskom to reduce the daily power outages due to rapid growth in energy demand having overtaken supply. Another example involving more structured management is Stadtwerke Hannover and Freiburg's use of DSM in their Integrated Resource Planning as a long-range option for the past 10 years. Rather than ask customers to change habits, they have been carefully crafting subsidies for efficient refrigerators, light bulbs, insulation and other energy savers that allow consumers to enjoy similar or even better services while consuming less energy. This leads to happier customers, lower energy bills, more easily managed power demands and reduced impacts on the environment. In other words, Demand Side Management can bring significant benefits to all stakeholders.

The Kyoto Protocol and carbon markets, more broadly, have the potential to lead to a new wave of utility DSM and other end-use efficiency activities. The first critical mass of residential Clean Development Mechanism (CDM) projects are those that substitute Compact Fluorescent Light bulbs (CFLs) for incandescent light bulbs, typically providing the same lumen output using 75% less electricity. In Mexico, India and Senegal the documents for registering CDM projects, with around 35 million light bulbs, have already requested registration from the Kyoto Protocol authority, the Clean Development Mechanism Executive Board. The idea is simple: end-users are provided with efficient CFL bulbs free of charge (or at a reduced price) in exchange for the inefficient incandescent bulbs. The programs are paid for by revenues from sales of carbon credits, called "certified emission reductions" or CERs (and from sales of CFLs, depending on the design of the program). Thus the entity that implements the program covers the bulk of the up-front capital cost of the more expensive CFLs and is paid back over the lifetime of the CFLs, as CERs are generated and sold, eliminating the up-front capital cost barrier to the end-user. As a result, households have lower energy bills, the market for CFLs is stimulated, utilities can better manage peak demand (without the need to build additional power plants just to satisfy peak demand) and increase grid reliability, local pollutants and greenhouse gas emissions are reduced, and the national economy of energy importing countries is strengthened by conserving scarce foreign exchange.

In the residential sector, lighting and refrigerators/freezers account for the bulk of electricity demand and mitigation potential. It is estimated that there are more than one billion refrigerators in the world that are over twelve years old. Technological advances mean that energy savings of up to 75% (and more with older refrigerators) can be achieved simply by exchanging these old refrigerators for new ones. Also, although a fridge exchange involves higher expenditures than light bulbs, the energy savings are much easier to predict. People switch light bulbs on and off, but refrigerators generally stay plugged in all the time – thus a reduction in their consumption leads to a clearly predictable reduction in base-load: something quite valuable for an energy utility.

Moreover, collecting and recycling old refrigerators and replacing them with the most modern, new units, provides additional benefits that other appliances cannot, such as the avoidance of the release of highly potent greenhouse gases in the form of fluorinated gases as refrigerant and blowing agent for insulation material (HFCs have a global warming potential (GWP) of more than 1300, i.e. 1 kilogram of HFC contributes as much to climate forcing as would 1300 kg of carbon dioxide, and CFCs have a GWP of as much as 10,000). Moreover, CFCs are also an Ozone Depleting Substance; although their manufacture has been banned by the Montreal Protocol, CFCs are still found in old refrigerators around the world, posing a long-term threat to both the ozone layer and the climate system. There are 1.2 to 1.5 billion domestic refrigerators currently in service, representing an estimated bank of 100,000 tons of CFC-12, for example, and approximately 75% of their service refrigerant demand continues to be CFC-12 [2]. Thus there are compelling reasons to dispose of old refrigerators containing these substances as quickly as possible. As a result, several Brazilian utility companies have started to exchange light bulbs and refrigerators in pilot schemes to gather data and operational experience.

Given the significant energy savings and the tremendous environmental added value of replacing old refrigerators, it would appear that refrigerator exchange and recycling programs would be an ideal candidate for the Kyoto Protocol's Clean Development Mechanism, which is designed to accelerate such beneficial action. However, the CDM framework requires a complicated process involving the creation of a methodology, designing of monitoring metrics and the implementation of a project.

Opening Household Refrigeration to the Clean Development Mechanism

In order to accelerate this process, BSH Bosch and Siemens Home Appliances GmbH (BSH) and the German Organization for Technical Cooperation (GTZ) have joined forces to overcome several barriers to open household refrigerators to global carbon markets. The Brazilian context is well suited to demonstrate such CDM projects and to replicate them in all other developing countries that have significant numbers of old refrigerators.

Brazil began some of its first DSM pilots after the power outages in 2001. The projects included a combination of awareness-raising and light bulb and refrigerator replacement. The average household in Brazil uses 20.4% of its electricity consumption for refrigeration, 20.6% to heat water, 12.1% for light and 8.7% for air-conditioning [3]. In a recent testing campaign conducted in the context of the GTZ/BSH partnership, we found that refrigerators in Brazilian favelas (slums) are nearly five times less efficient (871 kWh/year) than the model considered for use under a CDM program (180 kWh/year), even though households struggle to pay their electricity bills (Figure 1). Replacing old refrigerators with energy efficient ones reduces consumption for refrigeration by 80%, and replacing the average new refrigerator with the most energy efficient one by 40%.

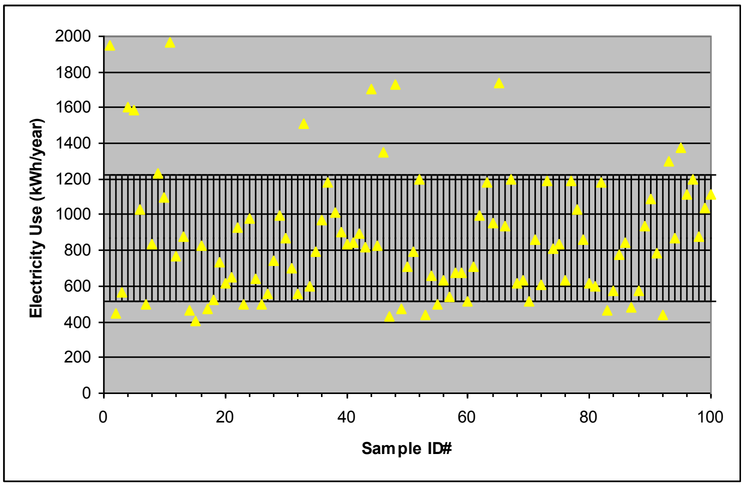

Figure 1. Electricity use of old refrigerators from Brazilian favelas

The average (mean) for the refrigerators tested is 871 kWh/year, with a standard deviation of +/- 352 kWh/year. Over one-quarter of these refrigerators use more than 1000 kWh/year, whereas none use less than 400 kWh/year (more than double the demand of the refrigerator to be used under the project activity).

Four types of barriers exist and each one is being addressed with suitable innovations:

First, the carbon accounting requires foolproof, universal, controllable and low-cost blueprints, so called CDM methodologies, which prescribe exactly how a kilowatt-hour saved is converted into tons of carbon dioxide. This barrier is the most important one because one cannot claim carbon credits unless the CDM Executive Board has approved a suitable and viable methodology. As a centerpiece of the Kyoto Protocol's accuracy and integrity, judgment of a methodology is public and under intense scrutiny. Moreover, the hurdles set by the methodology itself are often decisive in terms of its eventual use.

A blueprint for refrigerators, eloquently dubbed "AMS III.X" was developed by GTZ and BSH and has recently been approved. It allows use of the most widely known refrigerator testing protocol both for the old and the new refrigerators and minimizes the number of tests required. Furthermore, no measurements during the lifetime of the new refrigerators are required. Therefore, the carbon accounting is relatively inexpensive, and it credits all "suppressed demand". In other words, the carbon avoided includes kWh that household physically didn't consume because they switched the refrigerator off to reduce their electricity bill. This is a sometimes overlooked principle in the Kyoto Protocol; essential demand such as refrigeration can be satisfied and the full difference between old and new technology under full service demanded is accountable. By definition, suppressed demand only appears in low-income households. This adds a significant social dimension to CDM by allowing for improvement and development in people's lives. In this case, via improved refrigeration, fewer trips to the grocery store or less spoiled cartons of milk.

Second, management of the refrigerator exchange, including their accounting procedures, needs clear documentation. Whereas this is not the core-business of a utility, BSH is in the position to offer this as a service to the utilities as part of the exchange and the CDM process. The greatest energy savings and with them the largest amount of carbon credits are possible when the oldest refrigerators are exchanged. In the Brazilian context, these are used in households in low-income neighborhoods, such as in Brazilian slums (known as favelas). Brazilian utilities are under pressure from the government to improve service provision in favelas and act as effective conveyors of social policy for these households. Low-income households get subsidized electricity rates, but only if they use less than 100 kWh per month. Often, the old second- or third-hand refrigerators in these households use more than this amount – meaning that the subsidy is out of reach and paying the full cost of electricity impossible. As a result, many families illegally tap into the electric lines in a manner that is dangerous, highly inefficient and costly to the utilities. Providing them with new refrigerators, lowers their consumption, brings them under the 100 kWh cap and allows them to receive and pay an electricity bill, which in Brazil also opens the door to other social benefits. While exchanging refrigerators in Favelas is complex, it also brings great advantages to the utilities, which reduce theft and transmission losses, as well as to the residents, who enjoy social and economic advantages. Age and poor refrigerator maintenance add to the suppressed demand and both translate into customer regularization and better household services. Now, with the reward from carbon credits, improved services to low-income households are directly connected with global carbon reduction demand.

Third, taking old refrigerators out of use is incomplete unless there is assurance that they are disposed of without new environmental impact. Because refrigerators contain environmentally harmful gasses, the recycling process requires special equipment to ensure they are not released into the atmosphere. Unfortunately, this equipment is not always readily available. The reality is that recycling capacity needs to be created in all developing countries and this requires large investments. BSH is working in partnership with local actors to bring such a recycling plant in Brazil into operation. Combined with this will be measures to establish the carbon accounting necessary for the crucially important fluorinated gases in old refrigerators.

CFC-11 and CFC-12 have been the main destroyers of the ozone layer and old household refrigerators are the largest remaining banks of these gasses globally. CFCs, which are covered by the Montreal Protocol, are not eligible under the Kyoto Protocol but may be eligible for voluntary credits under the Voluntary Carbon Standard (VCS)[1]. As for the energy consumption reduction, this accounting needs to be foolproof, universal, controllable and cheap. The recycling plant is the location where the carbon accounting for CFCs is demonstrated. It is hoped that the income from Verified Emission Reductions (VERs) can cover the investment costs for the facilities, thereby paving the way for investments in many developing countries. Furthermore, AMS III.X requires a 90% recovery of all CFCs, in a so-named "eligibility criteria" (3.I), so the benefits of carbon credits are possible only when non-Kyoto gasses are reduced as well, thereby enlarging the environmental integrity ("conservativeness of a methodology") of the Kyoto Protocol. Imposing the threshold of Greenhouse Warming Potential (GWP) < 15 from the EU Directive 2002/96/EC's as maximum allowed for the refrigerant and foam blowing agent in new refrigerators, the eligibility criteria in AMS III.X, further strengthen this integrity.

Fourth, BSH will establish the first so-called Programme of Activities (PoA) CDM project for refrigerators. This is a new opportunity in the CDM. All CDM projects approved so far are fixed in scale during their lifetime and this imposes that each extension requires the entire transaction cost of at least 15,000 €. The fixed scale has prevented more distributed emission reductions from being realised. PoA is a new mode of CDM implementation, permitting sustained programs, rather than just individual projects, to be pursued by a managing entity. Although the PoA concept was specifically designed to facilitate programs to provide incentives for dispersed, small-scale actions such as end-use efficiency [[4]], it has gotten off to a slow start since it was introduced about two years ago. So far, nine PoAs are undergoing validation – and some have been at this stage for more than a year – but none registered. In addition to methodological challenges facing all end-use efficiency activities under the CDM, crucial market actors have been reluctant to embrace PoA – for example, DOEs are concerned about liability implications – and some DNAs have not created the legal framework to make it possible for them to issue letters of approval for PoA. Furthermore, potential PoA managing entities lack the necessary capacity. The CDM Executive Board is still considering ways of addressing the key barriers to PoA implementation, such as those noted by market actors in the Call for Public Input on PoA that was undertaken in September 2008 and will consider approving a revised version of the "Procedures for registration of a Programme of Activities as a single CDM project activity" at its May 2009 session. Not surprisingly given the scope and impact, the initial residential PoA proposals are for solar water heaters and light

[1] In contrast, the Gold Standard unfortunately does not even allow crediting of reductions in the Kyoto gas HFC-134a, despite the fact that this is included in the approved CDM methodology AMS III.X. and that the methodology is only applicable to projects that include a refrigerator replacement program to improve energy efficiency. Similarly, the Gold Standard for VERs will not allow the resulting non-Kyoto CFCs to be credited, either.

bulbs. BSH and GTZ have identified the best format for a PoA on exchanging refrigerators across Brazil and will submit the documentation for the approval of a PoA where step by step, new cities can be added. Utilities find the possibility attractive to start in a part of their concession area and then extend the coverage.

CDM Project Innovations State-of-the-Art

Each of the four barriers requires efficient technology and regulatory experience. BSH's main contributions are a refrigerator that is 40% more energy efficient than the best currently available (which is also produced by BSH), and the business strategy of managing the implementation of a CDM project – the logistics of moving appliances. GTZ brings knowledge and experience with the Montreal and Kyoto Protocols, defining the contribution to sustainable development of household appliances in low-income households as well as a strong global reputation for high-quality, diligent and transparent development work. GTZ has also brought in leading external energy efficiency and CDM experts to support methodology development and program design.

When it comes to determining whether the CDM provides a sufficient financial incentive, the capital and transaction costs associated with generating carbon credits relative to CER revenues over time are critical. The primary question is the cost of "producing" the credit i.e. how much do you have to spend to get a CER? Profitability thus depends on key program design choices, such as the cost and performance of the technology employed, how the program is financed, whether CERs are sold via forward contracts or on the spot market, or the cost of complying with the monitoring hurdles created by the chosen methodology.

In terms of cost-benefit, refrigerators and light bulbs are the most relevant appliances for low-income households in Brazil and many other developing countries. In other places, building insulation and heating are more relevant as initial steps. Unfortunately, the latter two, while achieving high leverage, are particularly difficult to implement because of the accounting complexities in the methodologies. Therefore, the successful BSH - GTZ public private partnership will assure that refrigerators are the second appliance after light bulbs to be connected to global carbon trading; accelerating the pace toward even greater efficiency while offering consumers the same (if not better) services for lower cost.

The CDM has seen rapid quantitative growth to over US $100 bn traded Certified Emissions Reductions (CERs) in 2008. However, the slow process of defining CDM methodologies has limited qualitative growth. Among 125 approved methodologies, only 17 are used in more than 40 CDM projects, and the UNFCCC secretariat recently compiled a list of 93 methodologies that had been used in 5 or fewer projects that had passed the validation stage[2]. In addition, more than 50% of the methodologies originally proposed (132 proposals) were rejected by the CDM Executive Board for being insufficiently rigorous to comply with the CDM modalities and procedures. Certain sectors, such as energy efficiency, transport and building, are underrepresented and the problems of methodology development have played a large role. For the case of AMS III.X, the time between first submission and approval was 134 days compared to an average for all approved methodologies of 305 days. The first barrier was thus overcome with exceptional speed. The quality of AMS III.X will be visible by the number of CDM projects applying it.

The Brazilian Ministry of the Environment estimates there are 30 mio. refrigerators with CFCs in Brazil, all older than 10 years. If the sampling and testing done by BSH reflects the country average (see Figure 1) and all were replaced with BSH refrigerators, then using AMS III.X to replace them represents 6.5 mio. tons of carbon dioxide, or CERs annually, based on the electricity consumption avoided. This technical potential is theoretical because the subsidies available to utility companies are smaller. In Brazil, there are currently 353 CDM projects of all types at different stages of approval with 34 mio. CER annually. Only seven of these concern energy efficiency and >80% of the CER arise in landfills (methane), bagasse (sugar mills) and hydropower. This bias to single site and large scale is even stronger in Brazil than in India or China. The Brazilian utilities have so far only engaged in small hydropower CDM projects in a

[2] EB 47 Proposed Agenda – Annotations (Annex 1)

few cases and only with minority stakes. International Independent Private Power companies have been more active there.

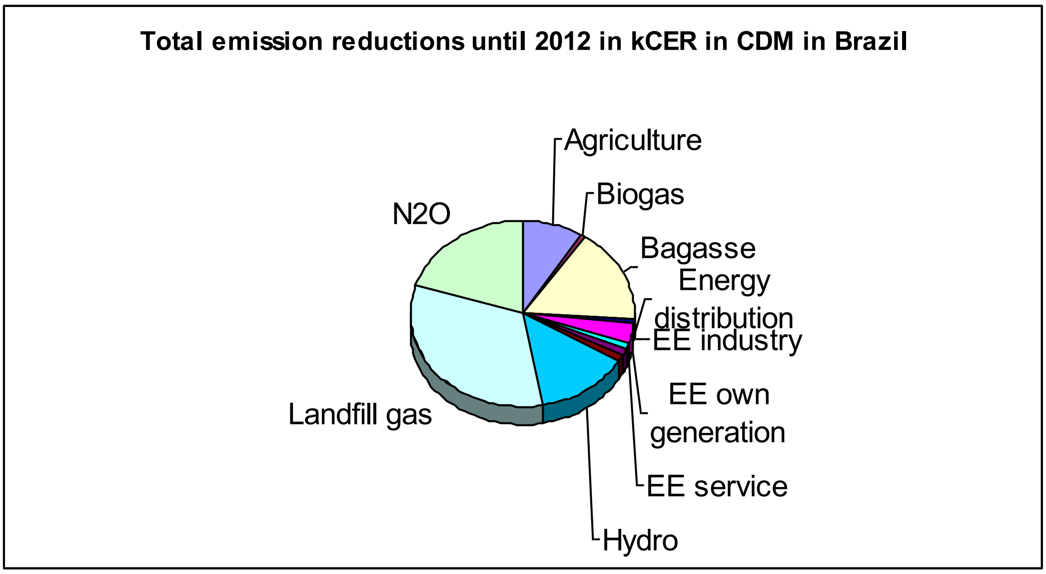

Figure 2. Types and size of registered CDM projects in Brazil

Source: www.cdmpipeline.org accessed on 11-02-09

The technical potential for refrigerator exchange is larger than the current CDM types, but it is more expensive than the single generation sites with no fuel costs. Light bulbs and water heaters represent a multiple of the potential for refrigerators. It is unknown how large the economic potential in this technical potential for refrigerators is because the benefits to utilities besides the avoided electricity are unknown just as the specific costs of large-scale refrigeration exchanges are uncertain. Furthermore, the tariffs for Brazilian utilities are revised every five years and no adjustments for productivity are possible in between. Some utilities would reduce losses when low-income households' consumption declines below the level where governments pay the bills. It is thus necessary to distinguish the customer classes and define particular refrigerator exchange terms. The economic potential is certainly sensitive to the additional income from global emissions trading. The influence of accounting in utilities is not reflected in the incremental cost curves for emission reductions often cited in policy papers.

Furthermore, the avoided emissions of CFCs are as important as the avoided carbon dioxide emissions from electricity generation. Assuming that half of these old refrigerators have stone wool insulation and half Polyurethane with CFC-11 as foam blowing agent, the recycling of these old refrigerators represents 20.2 mio. tons CO_2e as voluntary carbon reductions out of CFC-11. GTZ has provided advice to the "Gold Standard" and the "Voluntary Carbon Standard", the leading voluntary carbon schemes, to assure that a recycling methodology uses a life-cycle approach to account for the impact of recycling, because only a credible methodology will allow voluntary carbon reductions to be valued at a sufficient price level for recycling capacity investments to become feasible. VCS will soon issue such guidance for CFC methodologies in this standard, whereas CFCs from refrigerator recycling are not eligible under the Gold Standard for VERs.

Programme of Activities (PoA) are intended to be the chosen format for distributed emission reductions such as in household appliances. PoAs for CFL exchange in Mexico and Senegal have been submitted to the U.N.-FCCC and the differences illustrate the different options. In Senegal, it is run by a governmental body (the so-called PoA operating entity) with support from the World Bank buying CERs on behalf of the Italian government (World Bank estimates for Africa as a whole 13.27 mio CERs/year from CFLs, from 17.3 GWh/year saved or 5.28 % of electricity generation in the continent). In contrast in Mexico, the CFL exchange PoA is managed by a private company via retail chains across the country and in competition to government-run CFL programmes (FIDE and CONAE). PoAs for solar water heaters are also prepared by a government agency (Tunisia) and by a private company (South Africa). The correct application of the methodology is the only precondition: otherwise, operational functions in a PoA CDM project can be freely divided between organizations. Who receives the proceeds from the sale of CERs is not defined in a PoA so that risk and rewards can be divided as suitable.

In standard single site CDM, the site operating companies carry most responsibility and reward, but in PoA CDM projects a technology supplier, retailer, or utility has a bigger role and can use different means to reach households. Different PoA CDM projects for the same or overlapping regions will be in a "channel conflict". BSH's mastery of the refrigerator methodology is a competitive advantage and combines well with the logistics of moving refrigerators or with the billing and PR by utilities. A PoA design reflecting the refrigerator cost and the recycling can set a trend.

Concerning the accounting and volume of units barrier, all Brazilian utilities are obliged by law to invest 0.5 % of their income in low-income communities or in energy efficiency R&D. With a partially implemented privatization of utilities, these regulations for utilities are not well established. Some utilities prefer the fines rather than offering assistance to low-income communities. The results obtained in the PoA CDM project by BSH, in terms of carbon certificates achieved, operational costs and impact on corporate reputation, will undoubtedly be well visible for the other 30 utilities in Brazil.

Another aspect of this second barrier is the role of the Brazilian climate authority, the so-called Designated National Authority (DNA) that is located in the Brazilian Ministry of Science and Technology. Under the international CDM rules, the DNA of the respective country must approve each CDM project or program. Among the DNA in all developing countries, the Brazilian one has the reputation of being the most competent and thorough. This enhances the demonstration effect of implementing the refrigerator CDM in Brazil, but surely the DNA's demands have to be met. Of course, offering a CDM project with exceptional social and environmental benefits to the Brazilian DNA, BSH would get particular attention. The Stakeholder Consultation process is a standard part of a CDM projects and the Brazilian DNA has unique demands on the conditions of this process. It is well possible that the Brazilian DNA will also be the only DNA that issues PoA CDM specific regulation.

CDM Projects as a Format of Global Technology Transfer

Scientists around the world are citing increasing concern about the rapid rise in CO_2 concentrations in the atmosphere. Achieving a maximum level of 500ppm (some say only 350ppm) is imperative to avoiding potentially catastrophic increases in global temperature above 2° Celsius. This will not be achieved by emission reductions in the industrialized world alone. As a result, pressure is mounting on the large developing countries like Brazil, China and India to accept commitments to stabilize and eventually reduce their greenhouse gas emissions. Concurrently, the desire and need for developing nations to provide their citizens first with access to modern forms of energy and subsequently with increasingly higher standards of living remains as strong as ever. As a result, there is enormous pressure to find fast, efficient and large-scale solutions for "leap-frogging" the dirtier period of development. This will require cleaner and more efficient ways to produce electricity on the supply-side. However, it will also require serious thinking and incentive mechanisms that allow for dramatic and continuous improvement in efficiency.

The next Conference of the Parties to the UN Framework Convention on Climate Change and Meeting of the Parties to the Kyoto Protocol in Copenhagen in December 2009 is expected to lay the ground for the future global climate policy regime, which may or may not include an additional commitment period within the context of the Kyoto Protocol. Since climate change is a challenge faced by all people in all countries, providing consumers with the right motivation and economic incentives to make environmentally responsible choices will be a valuable component to the overall effort. The Brazilian DNA is keen on showing the potential of PoA CDM projects to contribute to emission reduction commitments, see a public comment on [5]. With large hydropower, Brazil can benefit from global emissions trading more on the demand side, which may prove the better option. Refrigerators have consistently been one of the largest energy-consuming devices owned by individuals. They are also one of the first items that emerging consumers purchase. The impact of replacing the oldest units with the most efficiency can prove an enormous global contribution. BSH and GTZ are continuing to work to ensure the necessary infrastructure is in place to make this happen.

All leading technology suppliers gain a competitive advantage by adding CDM to their marketing as they offer the highest emission reduction. This is an indirect outcome of emissions trading which depends on suitable CDM methodologies and these suppliers learning how to shape CDM projects. Furthermore, helping utilities undertake large DSM programmes is an important form of Transfer of Technology, a key issue in the Bali Action Plan. Only the methodology and the recycling barriers are the same for all countries, and the other two barriers, the adaptation of the exchange to households and the design of PoA, require new solutions in each country.

References

[1] Arquit Niederberger, A., Scaling up energy efficiency under the CDM. In Holm Olsen, K., and J. Fenhann (eds.), *A Reformed CDM, Including New Mechanisms for Sustainable Development*. Perspectives Series 2008. Copenhagen: UNEP Risø Centre, pp. 127-145, December 2008.
Arquit Niederberger, A., *Overview of Policies and Measures to Promote Household Equipment Efficiency*, Background Paper, United Nations Forum on Energy Efficiency and Energy Security: Taking Collaborative Action on Mitigating Climate Change (Seoul, Republic of Korea), 17-18 December 2007.

[2] UNEP/TEAP, *2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee*. Nairobi: UN Environment Program, 2006.

[3] Schaeffer R. *The potential for electricity conservation and carbon dioxide emission reductions in the household sector of Brazil*, Energy Efficiency 2/2: 165 – 178, 2009.

[4] Hinostroza, M., Cheng, C.-C., Zhu, X., Fenhann, J., Figueres, C., and F. Avendaño, *Potentials and Barriers for End-Use Energy Efficiency under Programmatic CDM*, UNEP Riso CD4CDM Working Paper Series, 3, September 2007.

[5] http://cdm.unfccc.int/public_inputs/2009/cdmimprov/cfi/QMUPAX7ICIGXIVH0E1FW83KSW13E2G

A New Global Test Procedure for Household Refrigerators

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Abstract

There is a significant amount of trade in household refrigerators around the world. World production of refrigerators was estimated to be 90 million units per annum in 2008. Refrigerators are an important energy consuming appliance in the residential sector, and to some extent in the commercial sector. Internationally, there are about 60 countries world wide that have some sort of program to regulate the energy efficiency of refrigerators[1] and separate freezers, mostly in the form of mandatory comparative energy labeling and minimum energy performance standards (MEPS).

Despite being a product that is widely traded internationally, refrigerators have poorly aligned test procedures. Most current test procedures determine the energy consumption at a single ambient temperature. Ironically, ambient temperature has the largest single impact on the energy consumption of a refrigerator. Another attribute which is not quantified in most current test procedures is processing load – this occurs from door openings and the cooling of food and drinks. Processing efficiency can vary by a factor of four across models.

The IEC took over the responsibility of household refrigeration with TC59 (household appliances) in 2006. This paper outlines the latest in the development of a new global test procedure for refrigerators which will quantify the key relationship between ambient temperature and energy consumption and should include the quantification of a load related (usage) factor which can be scaled up (or down) to reflect actual usage in different parts of the world. If achieved, this will facilitate the identification of, and trade in, highly efficient models and will ensure that energy labeling and MEPS systems correctly rank and regulate refrigerators on the basis of their actual energy consumption for typical use.

Market Overview for Refrigerators

By any benchmark, global production and trade in refrigerators is massive, hence the energy impacts are also large. Global production of refrigerators was estimated to be 73 million units per annum in 1992 [20] while production within APEC was estimated to be nearly 40 million units in that year, or nearly 60% of world production. Current world production of refrigerators is now estimated to be close to 90 million units per annum, with China now becoming increasingly important on the world manufacturing stage [3]. Production in Asia is currently about 45 million units a year (China accounts for more than 30 million units) while total pan-European production is around 25 million units and North and South America about 20 million units a year, with little production elsewhere. The prevalence of different configurations varies considerably by region, but at a global level, top freezers are the most common (nearly 40%), bottom freezers are next at about 33% and side by side are about 13%. The remaining types are mostly single door refrigerators or other configurations including separate freezers.

Refrigerators are an important energy consuming appliance in the residential sector and, to some extent, in the commercial sector. In developed countries, ownership rates are either stable or growing slowly, varying from 0.9 to 1.5 units per average household (plus additional separate freezers). In developing countries, ownership is highly varied but in most cases is rapidly increasing as living standards increase [18]. Given the relatively long life of refrigerators (up to 20 years in developed countries), the world stock could be well over 1 billion units in operation at the moment, although data on this statistic is scant. The IEA estimate that the stock of refrigerators in the OECD was over 500 million in 2000 [19].

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[1] Refrigerators include refrigerators and refrigerator-freezers. The term freezers refers to separate stand alone freezers. However, the term refrigerators in this paper generally means household refrigeration appliances, which includes all of these products.

Refrigerators are one of the few appliances that remain “on” continuously and as such consume a significant amount of electricity during normal use. Electricity consumption of refrigerators typically range from 100 to 1000 kWh or more per annum, depending on the design, size, features and efficiency. This constitutes a significant share of household electricity consumption in most countries. In Australia, household refrigerators account for about 12% of residential electricity consumption, or some 26 PJ per year (7.2 TWh/year) in 2008 [1].

Given that refrigerators are significant users of electricity, it is hardly surprising that they are the focus of attention of many programs that aim to reduce electricity consumption and greenhouse gas emissions associated with power generation. There are nearly 60 countries that have some program to regulate the energy efficiency of refrigerators (includes EU25) [2]. The most prevalent programs are mandatory comparative energy labeling and minimum energy performance standards (MEPS or efficiency standards). A majority of countries use both of these program measures in parallel. There are also a number of endorsement style labeling programs in operation around the world.

While refrigerators are now a product with a large international trade, different countries have poorly aligned test procedures. There are at least half a dozen different test procedures in force around the world and there are many national and regional variations to these predominant test procedures.

A traded product must generally comply with mandatory requirements in all the markets where it is sold and authorities in each market will usually ask for evidence that it does so. This means that a refrigerator exporter will need to have each model tested several times (or many times) to demonstrate that it complies with the relevant performance requirements as well as MEPS and/or energy labeling in each of the markets where it is sold. This can restrict the availability of many energy efficient products in many markets.

The cost and time needed to comply with different energy efficiency programs can add significantly to the cost of traded refrigerators and can constitute a barrier to trade, especially if local testing is mandated as a pre-requisite for importation. This is also an operational nightmare for larger producers that want to trade in many markets.

Origin of Different Test Procedures

Many national and regional test procedures for performance for refrigerators (excluding safety, which is mostly standardized within IEC except for the USA) have been around for many decades. The main focus of these test procedures was originally the maintenance of suitable internal temperatures for the safe storage of food. This is usually assessed at different ambient temperatures to ensure that the refrigerator is capable of operating correctly in a normal range of household conditions. This assessment of operation at different ambient temperatures is still a key focus of many current test procedures and is core to the energy service which is provided by refrigerators. While many refrigerators were tested to assess their temperature performance, energy consumption measurements were not part of this assessment.

The first country to bring energy consumption to the testing forefront was Canada, which introduced mandatory energy labeling in 1978, followed by the USA in 1980[2]. The US reviewed their local test procedures and adopted an elevated ambient temperature (90°F which translates roughly to 32°C) to compensate for “normal use” such as door openings and the addition of warm food and drinks. The process by which this ambient was selected is unclear, but it has propagated into a number of other regional test procedures.

The various test procedures developed by ISO in the 1970s and 1980s settled on an ambient temperature of 25°C, which is somewhat warmer than normal use in Europe (thought to be about 20°C on average). Again, this higher than normal test temperature was probably intended to account for consumer use, although little documentation on its selection process is thought to exist.

Prior to 1999, Japan had a unique refrigerator test procedure that tested the product at two ambient temperatures (15°C and 30°C) and it included a sequence of door openings to simulate actual use

[2] Some European countries had voluntary energy labeling programs in the 1970s (eg France and Germany) [4] but these were not widespread or overly successful.

(JIS C9601)[13]. In an effort to harmonize test procedures, Japan adopted a local standard that was fully based on the ISO standard in 1999 (primarily ISO 8561 [12]) with test packages in the freezer and with no door openings. Within a year, Japan was unhappy with this test procedure and the associated energy results and added door openings to the test while keeping the ambient at 25°C. As a result of field trials during the period 2003 to 2006, which showed that energy consumption during normal use was considerably higher than the figures determined in the laboratory, Japan again changed its refrigerator test procedure back to the previous ambient temperatures with door openings, but now with the addition of warm drinks, warm test packages and ice making and the removal of ice during the energy test (defrosting energy is included in the test as well).

Korea and Taiwan have used an ambient energy test temperature for refrigerators at 30°C. These test procedures were in fact very similar to the early JIS test procedure but without door openings. Australia and New Zealand adopted a clone of the North American approach to energy testing in the mid 1980s (with the introduction of energy labeling) and used an ambient temperature of 32°C. Most other test procedures in the world are variants on these main approaches.

Critical Review of Energy Test Procedures for Refrigerators

The North American test procedure for energy consumption was separated from the performance tests at the time of government regulation. This is a desirable approach as assessing all elements of performance in a single test is not practical. AHAM[3], who owned the original test method, showed some vision and foresight into how frost free refrigerators operated. However, the North American energy test procedures, which are now incorporated in government legislation by direct reference, have changed little in the past 25 years, and this is presenting new problems (the US DOE regulations still reference the 1979 edition of the AHAM standard). There are some inconsistencies in the US approach: for example separate freezers (even frost free products) still retain test packages (moist sawdust, not ISO test packages) and the fresh food target temperature for energy tests on combination refrigerator-freezers is an alarmingly warm 7.22°C, which is highly dangerous in terms of food preservation. The poorly defined temperature requirements in the US test method in some cases has lead to the inclusion of inflexible user controls on low end products supplied to the local market, which tend to perform poorly from a temperature perspective (even if they are relatively efficient in accordance with the test method). Another issue is that the adaptive defrost algorithm, although admirable in its intent, gives quite ridiculous default values under some conditions, which results in unrealistically long defrost periods for energy consumption calculations.

Up to 2000, there was very little input into the ISO refrigerator committee from outside of Europe, so the ISO standards remained strongly oriented towards European style direct cooling products. An ISO standard to cover frost free (forced air) products was not published until 1995 (ISO 8561), and many frost free dominated countries outside of Europe resisted its adoption as there were significant problems in its use (partly arising from the inexperience of Europeans with this technology). A critical flaw in the ISO test has always been that it attempted to combine the energy test with the temperature performance tests. These tests specify freezers loaded with test packages (to simulate consumer loads) and therefore present huge problems for energy testing. Firstly, a large freezer load can take weeks to stabilize at each temperature setting, meaning that energy tests are very slow and potentially have poor reproducibility if full stability is not reached. The other fundamental problem was the definition of freezer temperature in the ISO test – this is defined as the warmest temperature of the warmest test package during the stable operation of the refrigerator. This temperature bears little relationship to the average temperature in the compartment, which is in fact the key thermodynamic driver for energy consumption. Energy testing of frost free products with a large freezer test package load presents another raft of testing related problems.

The new Japanese test procedure for refrigerators (JIS C9801-2006 [13]) is in many ways superior to most other test procedures because it subjects the refrigerator to a range of real processing loads to which the refrigerator has to respond in order to maintain internal temperatures. Another good aspect of the Japanese test procedure is the assessment of energy at both 15°C and 30°C ambient temperatures, which could be considered a typical range of normal use temperatures. Despite the many good elements to the Japanese test procedure, it has some significant drawbacks. Firstly,

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[3] Association of Household Appliance Manufacturers.

implementing door openings during an energy test presents a range of operational and strategic problems and most test labs are highly resistant to the prospect of having to instigate this regime during normal tests. The rate of door opening and the control of ambient humidity become critical. The other problem is that the heat load resulting from door openings and food/test packages (and ice making) in the JIS test is quite large and presents a significant "processing load" for the refrigerator during the energy test. While this in itself is not necessarily a problem, there are issues. The processing load varies somewhat depending on the product size and there are step changes in the loads added (multiples of 500ml bottles, multiples of test packages), which makes direct comparisons between similar products difficult. The other problem is that the loads are added during the recovery after a defrost period and many refrigerators are unable to fully recover from the effects of the added processing load before the next defrost, so it is not possible to separately assess the affects of the added processing load on the steady state energy consumption. The ability to do this is critical if the processing load is to be more generic so that it could be adapted for use in different countries.

In Australia and New Zealand, AS/NZS4474 has been developed on a continual basis over the past two decades and now contains many elements of test procedure best practice [11]. However, it is now understood that the energy test condition is not representative of normal use (see following section). While there is a desire to improve this element of the test procedure in AS/NZS, there is currently no international or regional test procedure that is an improvement over the current approach. For a small market like Australia and New Zealand, it is not realistic to develop a new test procedure from scratch, especially for global products such as refrigerators.

Changing test procedures and regulations is a slow process, especially for a high profile product like refrigerators, which are widely regulated. For a new test procedure to be adopted, regulators would need to be convinced that the procedure would deliver substantial long term advantages over their current approach. At this stage, no test procedure for refrigerators is suitable for global adoption.

A detailed review of many refrigerator test procedures can be found in [10]. Based on extensive analysis of refrigerator test data, it can be stated definitively that the use of an elevated temperature does not accurately compensate for heat loads during normal use. The reasons for this are explained in a later section of this paper. The approach of using an elevated temperature for energy tests is fundamentally flawed. The other observation is that products tend to have their energy consumption optimized for the test procedure to which they are designed [16]. While this is hardly surprising, it means that test procedures which can not estimate normal use will most likely provide a poor indication of efficiency and relative energy during normal use.

What Should a New Refrigerator Energy Test Procedure Deliver?

The objective of a product test method can be set out in general terms using some standard goals as stated by the IEC. Ideally a test procedure should be:

- Repeatable (same result on the same product in the same lab on retest): this is a combination of the test consistency and the product behaviour or consistency;
- Reproducible (same result on the same product in different labs): repeatability plus inter-laboratory differences;
- Technically simple but able to cope with new and emerging technologies;
- Inexpensive, avoiding the need for very expensive specialized equipment where possible;
- Quick as practicable;
- Reflective of consumer use and consumer relevant.

While all of these objectives are clearly desirable, some of these tend to be mutually exclusive for some products. This is especially so for refrigerators.

Understandably, regulators have focused on the issue of reproducibility, as this is a key element that underpins the enforceability and integrity of their programs. A test procedure that cannot be reproduced cannot be reinforced. So this been a fundamental requirement for all test methods.

In terms of simplicity and low cost, testing of refrigerators has never fulfilled these objectives. Tests have always been expensive, slow and complex. Refrigerators are a complicated thermodynamic product, the energy service is difficult to accurately assess, and accurate control and measurement of ambient and internal temperatures is required. However, the most up-to-date test procedures use sophisticated data logging equipment, which makes analysis more accurate and faster.

Unfortunately, historically little attention has been given to the issue of consumer relevance and accurately representing actual use. This is astounding for a product that accounts for such a significant share of household energy around the world. Part of the reason is that this is very difficult to do.

For technical programs that set an efficiency hurdle (such as MEPS), the need to reflect actual use is less important, as long as the relative value derived from the test method is reflective of the value derived in actual use. For energy labeling, where the energy consumption is declared and compared by consumers, it is more important to use a number that is closer to actual use where possible. At worst, the relative energy performance and ranking in the test procedure needs to be similar to the ranking in actual use.

Field data suggests issues with most of the current major test procedures in terms of both relative ranking and absolute energy consumption of products as shown on energy labels and as used. But analysis of field data is very complex as energy consumption is affected by both changes in ambient temperature inside the home and the amount of processing load (use) by the individual household. A review of in use energy consumption data for refrigerators shows:

- Australia, 1990 – 10 refrigerators measured in the lab at the start, after 1 year and after 2 years and used in typical homes between tests. Results: average in use energy was 80% of the label value (AS/NZS, 32°C ambient), but varied ±20% at a model level [5].

- Europe, 1998 – 100 refrigerators monitored in homes for 1 year. Results: average in use energy was 100% label value (EN153/ISO, 25°C ambient), but the standard deviation was ±18% at a model level [7].

- Sweden, 2006 – 13 refrigerators monitored in homes for 1 year. Results: average in use energy was 100% label value (EN153/ISO, 25°C ambient), but the variation was as much as ±50% at a model level [6].

- USA, 1990 – 209 refrigerators monitored in homes for 1 year. Results: average in use energy was 95% label value (AHAM HRF-1, 32°C ambient), but the variation for individual units was as much as ±60% from the energy label value for that model [8].

A household survey in Japan over several years was particularly interesting. When compared to the energy consumption in the laboratory (using the ISO test procedure or ISO with door openings) over the period 2001 to 2004 it was found that in use energy consumption could be as much as 300% (or more) of the labeled value. A selection of data is shown in Figure 1 [9]. Further investigations found that the single ambient temperature of 25°C was partly to blame, but it also became evident that some manufactures had programmed their refrigerators to recognize the test procedure and switch off various heaters and other energy consuming auxiliaries when it detected an energy test. This dramatic mismatch between laboratory and in use energy prompted changes to the JIS test procedure in 2006 as noted above, which reverted to two ambient temperatures plus door openings and added processing loads.

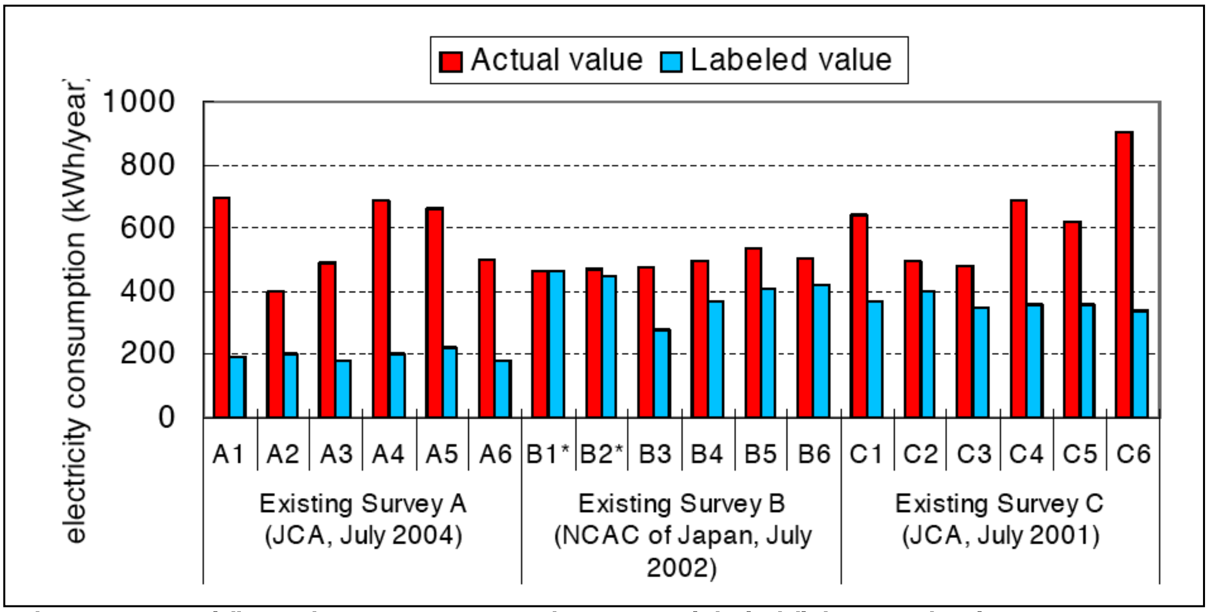

Figure 1: Actual (in use) energy consumption versus labeled (laboratory) values, Japan

With the advent of sophisticated electronics in many appliances, it is becoming increasingly difficult to stop or even detect circumvention (cheating) during an energy test. This suggests that test procedures need to be more realistic in nature (more like normal consumer use) in order to avoid these problems. With respect to refrigerators, the most common form of circumvention is switching off heaters (eg anti-sweat heaters or heaters associated with icemakers) during an energy test. But there are other strategies, such as the artificial delay of defrost periods during a test, which could deployed in order to obtain an unrealistically low energy consumption during an energy test.

The complication is that test procedures need to encourage and reward smart controls that save energy during normal use (eg anti-sweat heaters which are operated in response to ambient conditions, adaptive defrost controls that reduces defrost energy consumption during low use periods) but penalize, or at least not reward, controls that save energy only during the energy test. This is not as easy as it sounds, particularly if the test procedure is not close to normal use.

Energy Impacts of Normal Refrigerator Use

There are a number of factors that affect the energy consumption of a refrigerator. The most important of these are:

- Ambient temperature;
- Processing load from the addition of warm air and humidity through door openings and processing load from the addition of food and drink to be cooled (effectively, the efficiency of the refrigeration system);
- Internal compartment temperatures (user settings);
- Design and energy associated with the defrost and recovery (for defrost free products);
- Impact of additional internal humidity in terms of the response of the defrost system (including frequency of automatic defrost cycles) to remove this moisture;
- Additional user related features such as ice and water dispensers, additional doors, multiple compartments and special use zones;
- Possible longer term deterioration in energy performance with age (wear and tear, failure of components) – this factor has not been assessed in this paper.

Ambient temperature effect

Test data for nearly 100 refrigerators has been analyzed as part of the development of a new international test procedure. This analysis demonstrates that the ambient temperature effect has by far the largest influence on a refrigerators' energy consumption. The energy consumption of most refrigerators roughly doubles from an ambient temperature of 15°C to an ambient temperature of 30°C. However, the relative ranking in terms of energy consumption often changes across different ambient temperatures. This is illustrated by Figure 2 which shows the steady state power consumption[4] of six similarly sized bottom mount refrigerator-freezers at different temperatures. While the energy consumption response to ambient temperature is similar for all models, the relative ranking of units changes with temperature. It also illustrates that a test result at 32°C (or even 25°C) may bear little relation to actual or relative energy at 15°C. Even more interesting is an examination of the slope of the power curve in terms of power increase per degree C temperature rise as illustrated in Figure 3. This demonstrates that the slope can range from an increase with increasing temperature for some models to a decrease with increasing temperature from other models. Analysis of temperature response curves for 70 models show temperature response slopes ranging from 1% per degree C to 9% per degree C and slopes can increase, decrease or remain steady across different ambient temperatures [15]. This illustrates that energy measurement at a single ambient temperature may not provide a representative measure of energy use over typical ambient temperature changes. A famous engineer once said "you can't guess the slope of a line from a single point"; nor can you guess the shape of a curve. A full temperature response curve across all likely operating ambient temperatures would be ideal.

One of the largest underlying drivers for the lack of harmonization of refrigerator test procedures around the world is the basic understanding that ambient temperatures have a significant impact on the energy consumption. Tropical countries and those with hot climates are reluctant to embrace a test at a low ambient temperature and many other countries see a high ambient test temperature as irrelevant. The reality is that refrigerators are subjected to a range of ambient temperatures during normal operation and the median temperature will vary by climate (but it also depends on the climate conditioning in households). Only a new test procedure that can provide relevant energy performance data for all climates will be globally relevant.

Processing load

The second most significant influence on energy consumption of refrigerators is processing loads from door openings and the addition of warm food and drinks. The only test procedure to attempt to measure this impact is the Japanese JIS C9801. The door opening regime is 35 openings for fresh food and eight for the freezer per day, conducted at 8 minute and 40 minute intervals respectively. Load added is 125g of ISO freezer test packages for each 20L of freezer volume and 500ml of water in bottles for each 75L of fresh food volume. As an example, a refrigerator with a 100L freezer and a 300L fresh food compartment would have 625g of freezer test packages and 2000ml of water introduced during the test. Introduced loads are at the ambient test temperature.

Test data for ten Japanese refrigerators at 15°C and 30°C shows that the energy impact of the processing load, which includes the addition of warm drinks, test packages and door openings, ranges from 10% to 40% of the steady state energy consumption, depending on the particular model. While the variation is partly due to differences in JIS loads for different sized units, further examination found that the apparent marginal coefficient of performance (COP)[5] of a range of refrigerators varied from as low as 0.5 to as much as 2.0. Therefore the efficiency of processing loads varies by a factor of up to four between different models for the ten models evaluated. Even if their temperature response curves were the same, these units would display remarkably different energy consumption behaviour during normal use as the energy needed to process these loads would vary considerably.

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[4] Steady state power consumption in this case does not include any additional energy associated with defrost and recovery, the frequency of which can vary with changes in ambient temperature or usage.

[5] The apparent marginal COP is calculated as the ratio of the enthalpy change of the water placed into the refrigerator (to change it from ambient temperature to the operating internal temperature, including any phase change) divided by the additional energy required by the refrigeration system to remove this heat.

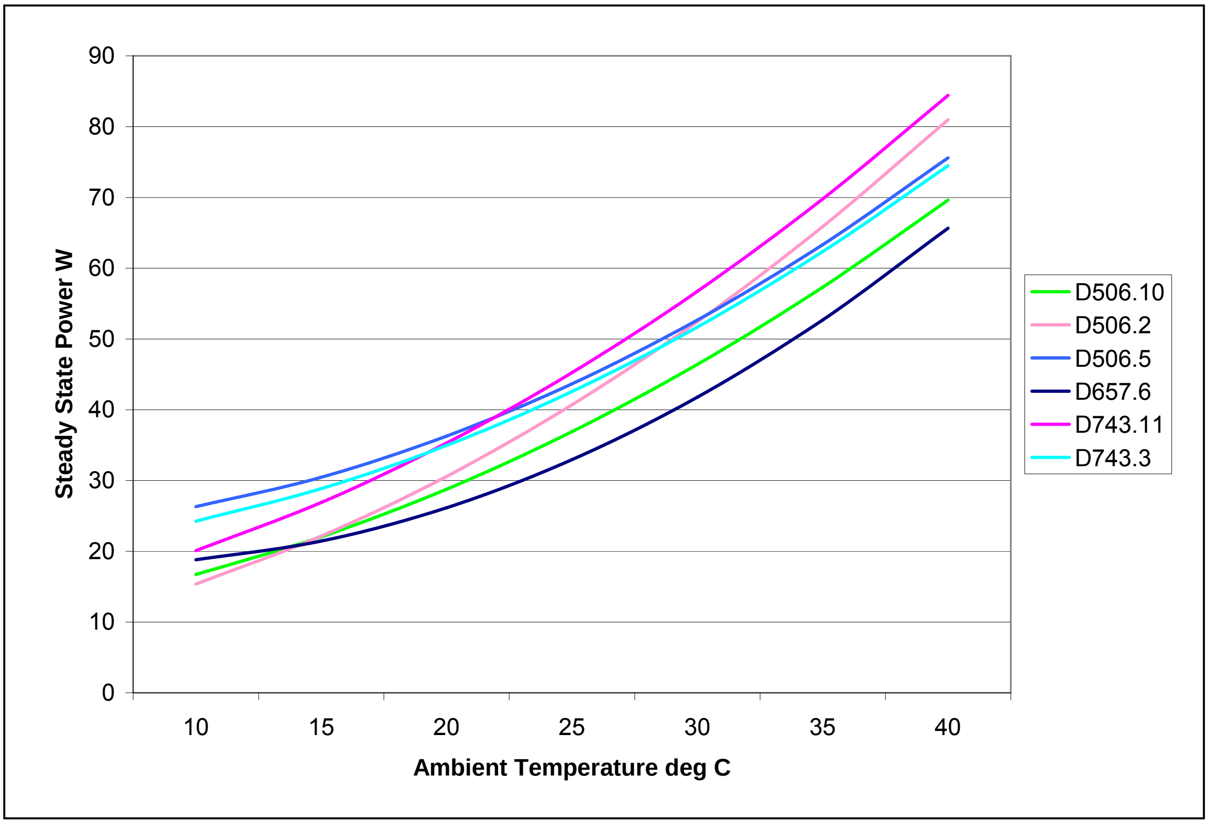

Figure 2: Energy temperature curve for 5 bottom mounted frost free refrigerators (<400L)

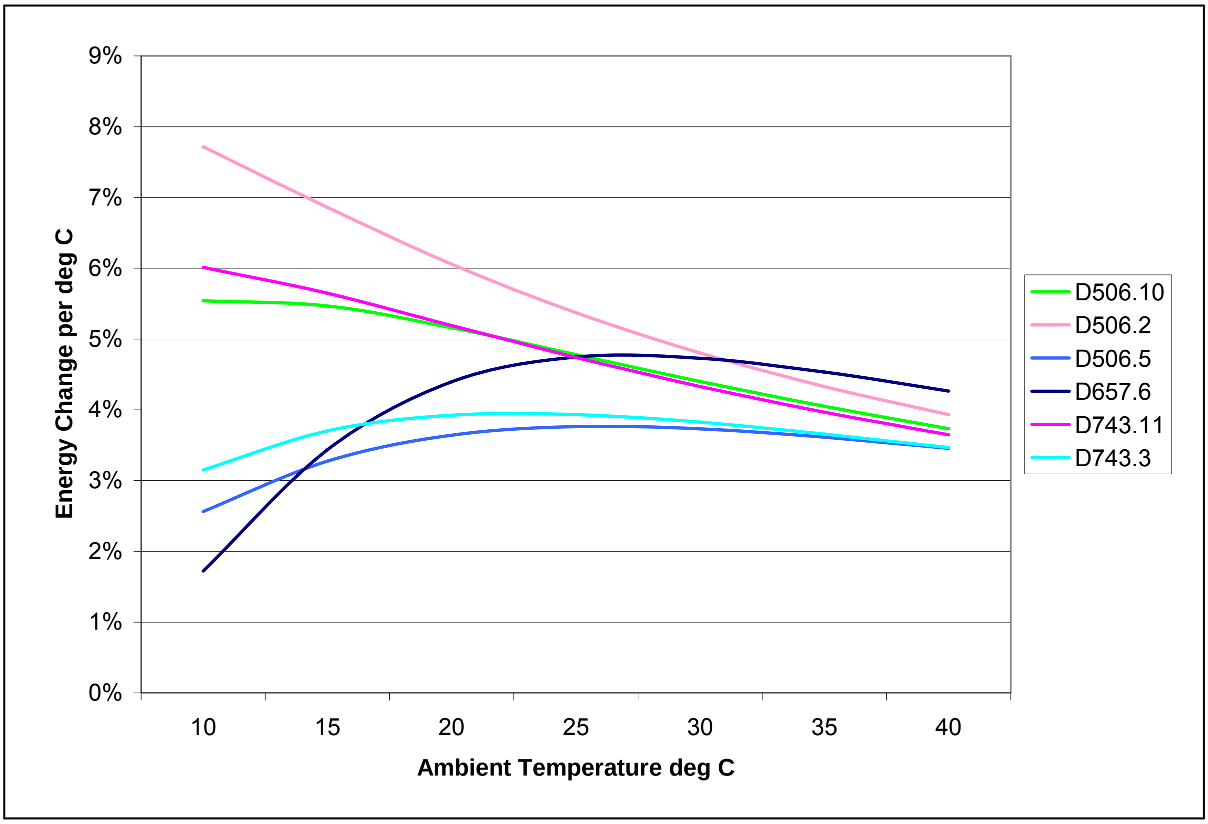

Figure 3: Energy temperature slope for 5 bottom mounted frost free refrigerators (<400L)

The problem with a test procedure that only assesses energy consumption without any processing load is that it skews designers towards insulation rather than improved refrigeration processing efficiency.

Detailed psychrometric calculations have been undertaken to quantify the relative impact of the different processing load elements in the JIS test procedure [15]. These processing loads are made up of:

- Sensible cooling of warm air introduced from door openings;
- Latent cooling of moisture introduced from door opening plus formation of condensate;
- Cooling of water (fresh food) and test packages (freezer);
- Making of ice (where an icemaker is present).

These are illustrated in Figure 4 at an ambient temperature 32°C and compartment temperatures of 4°C and -18°C. Typically, door openings account for more than half of the total processing load on the refrigerator while cooling of water makes up another 15% or so, meaning that fresh food loads are about 70% of the total load at an ambient temperature of 32°C. At an ambient temperature of 16°C (the proposed IEC lower ambient test temperature), the fresh food load share falls to about 50%. These calculations demonstrate that door openings are a significant usage element for refrigerators.

Most importantly, the refrigerator sees the entire processing load resulting from these elements as an internal heat load. The origin of a heat load should not really matter during a laboratory test (apart from the disposal of condensate during defrosting). So it may be possible to avoid a sequence of door openings (a major component) through alternative heat loads deployed during the test.

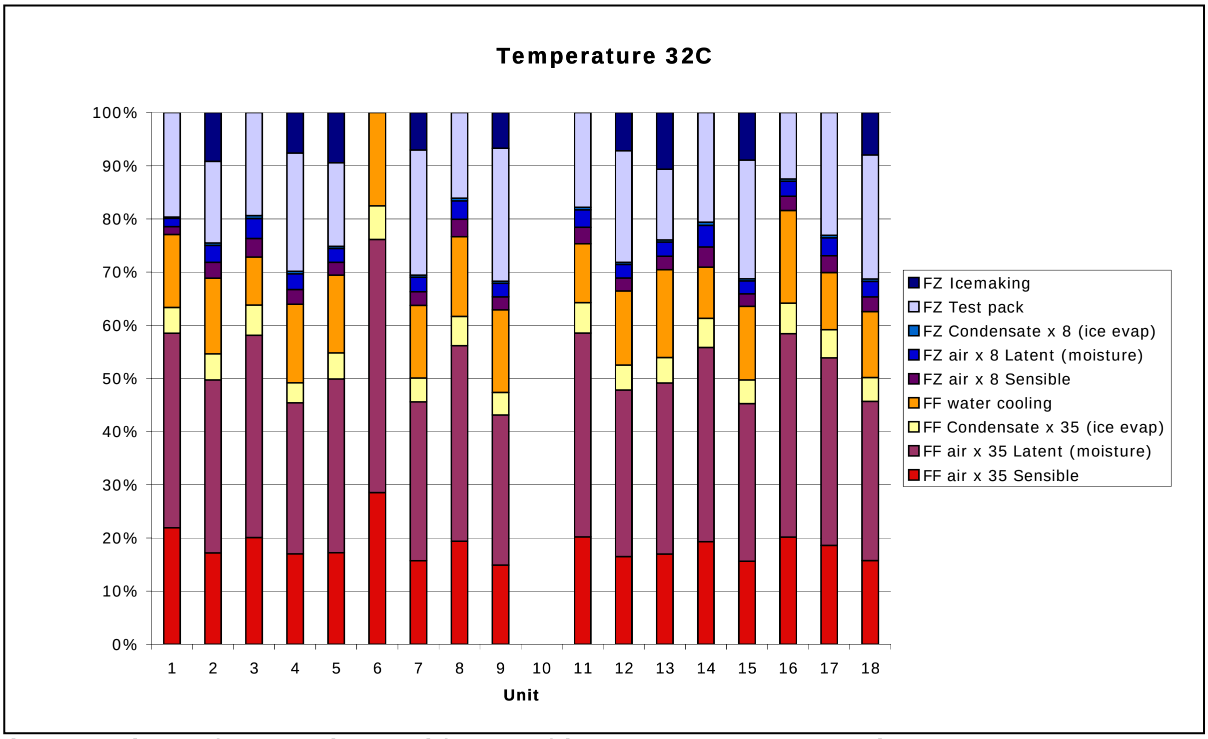

Figure 4: Share of processing load for 18 refrigerators, JIS test procedure

To accurately assess the impact of processing load during normal use, refrigerators must be monitored in people's homes. However, assessing the impact of processing load on energy consumption and separating this from ambient temperature effects and defrost frequency through end use measurements is complex. Ideally energy data is required at 1 minute intervals[6] as well as ambient temperature data adjacent to the refrigerator (this can be collected less frequently). To assess the processing load, an accurate temperature energy curve for the particular refrigerator being metered needs to be determined as well as the marginal efficiency of the refrigeration system. Unfortunately, these data are available for very few refrigerators and the analysis of in-use metering data to assess the processing load is complex. All field trials of refrigerators to date have measured total energy over a year and attempted to compare this to labeled or laboratory energy values. No previous field trials have attempted to quantify the impact of processing load or ambient temperature on total energy consumption.

How realistic are the JIS door openings? Data on door openings was obtained from 48 refrigerators in the USA, New Zealand and Australia over an average period of 243 days each (total 13,028 days of data). This evaluation showed that there were an average of 30.6 openings per day (SD=16) for the fresh food compartment and 4.5 (SD=3) for the freezer compartment (the statistical means for each country were similar), although the distributions for both of these values were quite wide [15]. This suggests that the JIS loadings are not so far away from typical use in some western countries.

Internal compartment temperatures

Another element that affects energy consumption of refrigerators is the user selected internal temperature. The impact of internal temperatures is significant in that some consumers may run their compartments colder or warmer than the recommended or standard value. Analysis of 30 refrigerators in Australia with separate controls for fresh food and freezer found that the typical energy impact of internal compartment temperature variations was about 3% to 4% per degree C for freezer temperature and 1% to 2% per degree C for fresh food temperature [17] when operating at an ambient of 32°C. The exact impact varies at a model level and depends on the system design and configuration. However, the potential maximum energy difference between individual units of the same model operating in the field is likely to be of the order of 10% or less for typical user selected internal temperatures.

Ability to operate in different ambient conditions

Another factor that can affect energy efficiency is any minimum performance requirements such as the ability to operate in extreme temperatures. For example, being able to maintain internal temperatures at an ambient temperature of 43°C requires a larger compressor when compared to a less stringent requirement (eg at an ambient of 32°C for temperate climates) – this larger refrigeration "capacity" means that operation during normal use (moderate ambient temperatures) will be somewhat less efficient unless a variable output compressor is used.

Defrost system design

The inherent design of the defrost system will determine the marginal energy impact of defrost and recovery. Some design strategies can minimize this impact. These include partial use of hot compressor gas in the defrost process and thermal isolation of the evaporator from the compartments. Isolation reduces leakage of any heat used for the defrosting operation into the storage compartments. Thermal isolation has two benefits. Firstly it reduces heat ingress into the compartments which has to be removed by the refrigeration system (resistive heating may therefore have a double energy penalty). Secondly it reduces any temperature rise during defrost which is important for food quality. Defrost operation is an inherent characteristic of each model and the user has only an indirect impact on the energy consumption associated with defrost and recovery (as a result of use and ambient conditions).

Ideally, there should be a way of estimating a typical defrost period during normal use. For single speed compressors that use compressor run time, this can be readily calculated under different ambient temperature regimes and use regimes. Similarly, defrost controllers that run on a fixed time

[6] 1 or 2 minute data allows the total energy consumption per compressor run cycle to be accurately determined, which is required to assess steady state power consumption (in order to separate ambient temperature effects from usage effects). Longer monitoring intervals result in a large error in the average cycle power due to inaccuracies in the cycle time. This is only applicable to single speed compressors. Inverter driven compressors require other techniques.

period (unusual, but they do exist) are simple as they do not change in response to any usage or ambient conditions. Adaptive controls are the most complex, as they respond to many variables in order to optimize the defrost period. Adaptive defrost controls are many and varied, but many use information such as compressor run time (or refrigeration output for inverters), ambient temperature and/or humidity, count of door openings and defrost heater time for the previous defrosts. Adaptive defrost controllers are good in that they theoretically minimize the frequency of defrosts for the particular usage of the appliance. However, this is an area where circumvention can be programmed into the product (eg if the product sees a stable specific ambient test temperature and no door openings, it is fairly easy to program a delay in the defrost – this can be hard to detect). While accurately estimating the defrost period in the field is desirable, it is important to note that a 100% error in this variable will typically result in a 5% energy error. So defrost period is important but is less critical than other parameters in terms of accurately assessing energy consumption during normal use.

A New Global Test Procedure for Refrigerators

A new globally relevant test procedure is needed. None of the existing national, regional or international standards for refrigerators assess the most important impacts of energy consumption, such as ambient temperature impact and processing load efficiency (apart from JIS, which has problems in terms of its global application).

After the publication of ISO15502 (now IEC 62552 [14]), ISO Working Group 2 agreed to start work on a new international test procedure to redress the shortcomings of the ISO standard. An additional goal was to make the test procedure more globally relevant in terms of its ability to deal with ambient temperatures and consumer use. In 2006, the responsibility for household refrigerator performance test procedures was moved from ISO to IEC at the request of IEC TC59. Working Group 12 under TC59 has been developing the new global test method since 2006, although progress has been slow. This is partly due to the complexity of the task, but is also due to resistance from some members as the new approach moves away from historical approaches. To some extent, this is understandable as manufacturers have invested heavily in designing their products to the current local test procedures and regulators regulate current products on the same basis. From 2006 to 2009, refrigerators did not have their own sub-committee within TC59 (now SC59M), so there has been a lack of leadership and guidance on development of this standard to date.

While there are many details still to be confirmed, the elements of a new global energy test method are being pieced together. The key elements where there has been at least some agreement are:

- General setup, instrumentation and tolerances – similar to AS/NZS4474.1-2007. Data recorded at 1 minute or faster, equal intervals.
- Fresh food air temperature sensors as per ISO, but some variants are under discussion in IEC. Freezer air temperature sensors as per AS/NZS.
- Internal compartment target temperatures for energy: -18°C (air average) for freezer, +4°C for fresh food, no test packages in the freezer (unloaded).
- Average temperature will be based on an average over the entire defrost control cycle.
- Test period starts at the beginning of a defrost period (once the steady state condition ceases: eg start of defrost heater or pre-cool before defrost) for frost free products.
- Internal temperatures – may calculate target temperatures by interpolation (triangulation or linear, depending on the number of controls).
- New volume measurement based on “what you see is what you get” (details being debated).

The agreement to average the temperature over the whole defrost control cycle is particularly important. This provides a strong penalty for products that allow excess heat to leak into the compartments during defrost and also offers a reward for pre-cooling of compartments prior to a defrost in order to maintain higher food quality by limiting temperature rises.

The debate over ambient temperatures for energy testing has been long and intense. Understandably, laboratory personnel want to minimize the combinations of requirements and fix temperatures at a point where they already test (16°C and 32°C are already used for European temperature operation tests). The use of fixed pre-defined points obviously simplifies testing. However, if the key output of the standard is a temperature energy curve for steady state conditions, then the ambient temperatures used to determine this curve are largely immaterial. In fact, given that all refrigerator responses are curves, it is highly desirable that 3 different ambient temperatures be used to determine the curve. The use of ranges of ambient temperature in the new standard (eg one point in the range 13°C to 18°C, one point in the range 22°C to 26°C, one point in the range 30°C to 34°C) would make it almost impossible for manufacturers to circumvent the test procedure as the refrigerator would be unable to work out whether it is under test. This is an important consideration.

An associated issue is that some refrigerators have heaters that operate in lower ambient temperatures or under some conditions. These heaters make the standard ambient temperature energy curve appear to have a discontinuity at the point where the heater operates. The operation of any such heaters needs to be taken into account when developing the temperature energy curve.

The working group is currently considering a proposal with the following elements:

- Determine P1 – power under steady state condition at particular ambient temperature and internal temperature setting (period between defrosts).
- Determine P2 – power of unstable period of defrost and recovery (expressed as additional energy in Wh over and above the P1 power level for the control setting).
- Determine P3 – power in response to a processing load added (expressed as addition energy in Wh over and above the P1 power level for the control setting).
- The processing load to determine P3 is a water load (at the ambient temperature) of 10g per litre of volume for fresh food and 3g per litre of volume for freezer: this is added to the compartment during steady state operation[7].

Detailed analysis of 70 refrigerators has found that the defrost and recovery energy is best characterized as a marginal energy consumption over and above the underlying steady state power consumption P1 for the particular ambient temperature and internal temperature setting. While there is a small random and usage associated element to the marginal defrost energy P2, the marginal energy is remarkably stable across all conditions of ambient temperature and internal temperature where expressed as energy consumption above P1. This means that data for two or three defrost and recovery periods are required to characterize this element of a refrigerator.

One area where there have been few concrete proposals to date is an approach to determine the time between defrosts during normal use. This is most critical for adaptive defrost systems that may use a number of use related parameters to adjust the defrost period. The most likely approach is the use of test data together with some specific tests or algorithms using manufacturer data to assess the response under more typical usage regimes.

An area that has not been discussed to any extent is the issue of assessing suitability of internal storage temperatures. While it is likely that a variant of the current ISO/IEC temperature storage test will be developed (with freezer test packages), the details are still open. It is widely agreed that assessment of storage temperatures for a refrigerator is a key performance element. An associated performance measure could be stability of internal temperatures over time and over different ambient temperatures (without the need for consumer intervention).

[7] The fresh food compartment load is added in open plastic containers 500g max each. The freezer compartment load is added as water in ice making trays. Load is added after the unit has fully recovered from a defrost period; recovery from the addition of the load should be complete before the next defrost.

Conclusions

Refrigerators represent an important energy using product in households and the commercial sector throughout the world, resulting in widespread energy regulation. While there is a significant world trade in refrigerators, different test procedures are used in many countries. The current test procedures, with the exception of the Japanese JIS, fail to take into account the two most important aspects of energy consumption of a refrigerator – the response to changes in ambient temperature and the efficiency of processing of heat loads arising from normal use. None of the current test procedures is suitable for adoption as a global test procedure.

Detailed data analysis for refrigerators shows that the energy consumption (and perhaps more importantly ranking) can vary under different conditions. This means that energy labeling and MEPS (efficiency standards) are probably discouraging or even excluding some products from the market that are more efficient during normal use and encouraging the use of products that are less efficient during normal use. Refrigerators are almost universally optimized to perform best under the energy test procedure under which they are regulated. While their temperature operation under normal use may be satisfactory, their energy performance may be less than optimum. A new test procedure is needed.

While good progress has been made on a new global test procedure within IEC, there is still some distance to travel before the methodology and details are settled. In particular, details of how to determine an ambient temperature energy response curve and the addition of a processing load is still open. The other area that requires detailed work is research on typical usage in different regions around the world and approaches on how the parameters measured in a new global test procedure can be adapted to reflect typical use in different regions. Data on internal dwelling temperature distributions by region is also lacking. A new global test procedure promises a more accurate and relevant ranking of refrigerating appliances to provide better consumer information and to set efficiency levels based on more realistic in-use performance. For manufacturers, even though a new global test procedure may be more complicated than each of the existing test procedures, it will ultimately reduce the total testing burden on suppliers if a single global testing regime can be agreed. A global test procedure will also allow the identification and trade of the most efficient products into all markets, which will help to drive down global energy consumption.

References

[1] EES 2008, *Australian Residential Sector Baseline Energy Estimates 1986-2020*. Prepared by Energy Efficient Strategies for the Department of the Environment, Water, Heritage and the Arts, Australia, June 2008. Available from www.energyrating.gov.au in the electronic library.

[2] Harrington L. and Damnics M. 2004, *Energy Labelling and Standards Programs Throughout the World.* Report commissioned and published by The National Appliance and Equipment Energy Efficiency Committee, Australia, Report 2004/04. Available from www.energyrating.gov.au in the electronic library.

[3] UN 2008. *UN Data, Industrial Commodity Statistics Database*, 25 July 2008.

[4] EES 1995, *Status of Energy Labelling for Household Appliances in Europe*. Report for the Office of the Chief Electrical Inspector, Victoria, Energy Efficient Strategies, February 1995.

[5] ACA 1990, ACA 1990, *Energy Consumption of Refrigerators and Freezers Used Under Normal Conditions of Use*, Australian Consumers' Association for NSW Department of Minerals and Energy, Sydney, November 1990.

[6] Bennich P. 2008, *private communication*, preliminary results from Swedish Energy Agency end use metering program.

[7] Sidler O. 1998, *private communication*. Information derived from the Cold II study monitoring data, France, Olivier Sidler, Enertech, France.

[8] Meier A. 1995, *Refrigerator energy use in the laboratory and in the field*, article in Energy & Buildings, Volume 22, pp233-243. Elsevier Press.

[9] Sasaki 2008, presentation to APP BATF HVAC-R WG/Household Refrigerator working group, Sydney, by Hiroshi Sasaki, Panasonic, September 2008.

[10] Harrington L. 2000, *Symposium on Domestic Refrigeration Appliances*. Background discussion paper – minimum energy performance standards, energy labelling & test procedures for APEC Project EWG 4/99T, Wellington New Zealand, March 2000. Available from http://www.energyefficient.com.au/APEC.html

[11] AS/NZS 4474.1-2007, *Performance of household electrical appliances-Refrigerating appliances Part 1: Energy consumption and performance*, Standards Australia.

[12] ISO 8561 *Household frost-free refrigerating appliances - Refrigerators, refrigerator freezers, frozen food storage cabinets and food freezers cooled by internal forced air circulation - Characteristics and test methods*. International Standards Organisation.

[13] JIS C9801-2006, *Household refrigerating appliances – Characteristics and test methods*, Japanese Standards Association.

[14] IEC 62552-2007 *Household refrigerating appliances – Characteristics and test methods*. Previously published ISO15502-2005. International Electrotechnical Commission.

[15] Harrington L. 2008, presentations to IEC TC59 WG12 (refrigerators), Munich, November 2008.

[16] Bansal P.K. 2000, *A Generic Approach To The Determination Of Refrigerator Energy Efficiency*, EEDAL Proceedings 2000, Naples. Paper by Pradeep K. Bansal, University of Auckland.

[17] Harrington L. 2007, *Impact of Changes in AS/NZS4474.1-2007 on Energy Consumption*, prepared for the Equipment Energy Efficiency Program, October 2007. Available from www.energyrating.gov.au in the electronic library.

[18] McNeil M.A. and Letschert V.E. 2005, *Forecasting electricity demand in developing countries: A study of household income and appliance ownership*, paper presented to ECEEE Summer Study, June 2005, Authors Michael A. McNeil and Virginie E. Letschert, Lawrence Berkeley National Laboratory. Available from www.eceee.org.

[19] IEA 2003, *Cool Appliances - Policy Strategies for Energy-Efficient Homes*, International Energy Agency, Paris. Available from www.iea.org

[20] Lebot B. and Waide P. 1995, *Refrigerators and Freezers: Market Characteristics, Energy Use and Standards Harmonization*. Ademe, Valbonne, France

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Highest energy efficiency in household refrigerating appliances

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Abstract

Reducing energy consumption and CO_2 emissions is the main goal of the new labelling layout directive (2009/xx/EC) and the EuP regulation (2009/yy/EC) on household refrigerating appliances.

One very special appliance in this range is the GTP 2356 chest freezer with an energy consumption of more than 26 % below the best current energy efficiency class A++. The overall improvement in energy consumption from 1994 to 2009 amounts to 72 % in total. In the same period the storage time during malfunction increased from 30 hours to 110 hours. These advances were achieved by insulation improvements, compressor improvements and mainly system optimisation.

Market acceptance and high sales numbers are proof of the necessity of such lighthouse appliances significantly better than A++.

The new labelling implementing measure is urgently needed to support the development and sales of more such very energy efficient appliances. The result would be a win-win-win situation: Cost reduction (due to reduced energy costs for customer), CO_2 reduction (environment) and job security (turnover > profit > jobs). Only with this "efficiency mark" can consumers be aware of, and compare, appliances better than today's best class. Market pull by the consumers will then automatically increase numbers of highly energy efficient appliances.

Chest freezer achieves 27 % better Energy Efficiency Class (EEC) than A++

We would like to explain the way we have gone to get cold appliances in production which are more energy efficient than today's best EEC A++. The GTP 2356 chest freezer has been chosen as an example. It is 27 % more efficient than the current EEC A++.

Background information on the situation regarding labelling in the field of household refrigerating appliances is required. On 30 March 2009 the EU delegations of the EELEP (Regulatory Committee on the Ecodesign and Energy Labelling of Energy-using Products) voted for a revised energy labelling directive and an implementing measure of the EuP directive. European Parliament adopted it on 6 May 2009. The said labelling directive is relevant for the highly efficient cold appliances from 1 January 2010 at the earliest and from 1 January 2011 at the latest. Figure 1 shows the situation today with an EEC range from A++ to G (best to worse). The corresponding EEI (energy efficiency index) shows the relation between the current energy label and the label from 1 January 2010. The left column shows that the new EEC A-60% marks a significant improvement in energy efficiency in comparison to today's best EEC A++. A 27 % improvement is necessary to achieve A-60%.

Relative improvement class to class	Today EEC	Today EEI	From 1.1.2010 EEI	From 1.1.2010 EEC
-50%			11	A-80%
-27%			22	A-60%
-29%	A++	30	33	A-40%
-24%	A+	42	44*	A-20%
-27%	A	55	55	A
-17%	B	75	75	B
	C	90	95	C
	D	100	110	D
	E	110	125	E
	F	125	150	F
	G	>125	>150	G

* moves to 42 on 1 July 2014

Figure 1: Current and future energy label classes for refrigerating appliances

All Liebherr appliances mentioned in the paper and all Liebherr home appliances sold in Europe use different mixtures of pentane isomers as a blowing agent and the natural gas isobutene as a refrigerant. Both gases have a GWP (global warming potential) of 3 [1], which is negligible in comparison to refrigerants containing flour.

If an appliance with significantly better energy efficiency than comparable appliances (regarding volume and configuration) is to be established successfully on the market, it needs to be optimised in a special way. This optimisation process is exemplified further on with the GTP 2356 chest freezer which is the appropriate appliance for this description. The development progress is shown from 1994 to 2009. Two appliances with identical net volume are compared.

The GTP 2102 chest freezer produced in 1994 with an EEC "D" and an energy consumption of 401 kWh per year was optimised in the past 15 years to become the GTP 2356 in EEC A++ (from 2010 A-60%) with an annual energy consumption of 113 kWh. This means a reduction in energy consumption of 72 %. In the same period, the ability to keep the storage temperature in the case of a power failure increased by 336 % from 30 hours in 1994 to 110 hours in 2009. See Figure 2 for details.

[1] DIN EN 378-1:2008-07; GWP CO_2 = 1

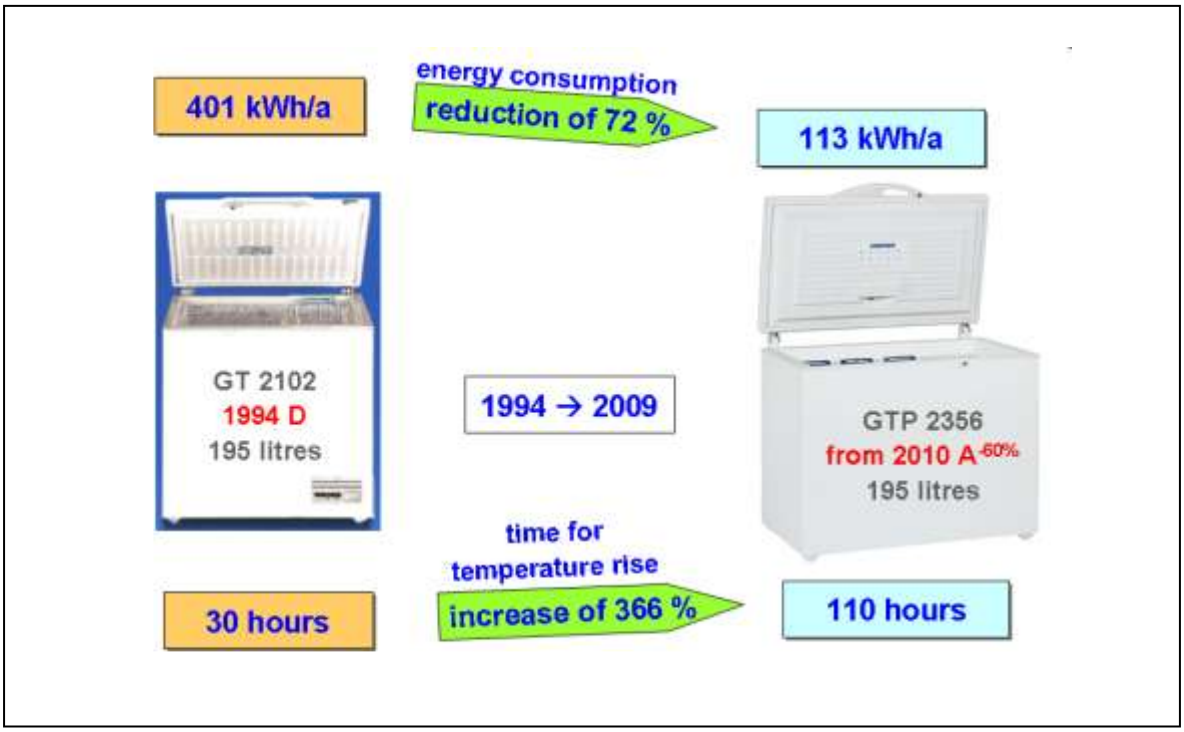

Figure 2: Comparison of chest freezers with same volume from 1994 with 2009

This GTP 2356 chest freezer has been available on the market since autumn 2008. The price is identical to the GTP 2626 chest freezer with the same outer dimensions, but with more storage volume (50 litres) and the EEC A++. Comparison with the GTP 2226 chest freezer with nearly the same storage volume but smaller outer dimensions results in a reduced price and also EEC A++. See Table 1 for a summary.

Table 1: Comparison of chest freezers

	GTP 2356	GTP 2626	GTP 2226	GT 2102
Year	**2009**	2009	2009	1994
EEC	**from 2010 A-60%**	A++	A++	D
Energy consumption	**113 kWh/a**	172 kWh/a	157 kWh/a	401 kWh/a
Storage volume	**195 L**	245 L	205 L	195 L
Temperature rising time	**110 h**	60 h	54 h	30 h
Dimensions h x l x w	**92 x 113 x 76**	92 x 113 x 76	92 x 100 x 76	81 x 84 x 63

Now let us take a closer look at the technological aspects in the comparison of the GTP 2356 (2009) to the GT 2102 (1994). The technological improvements which were used to achieve this increase in energy efficiency can be put into three main categories:

- Improvement in insulation
- Improvement in compressors
- System optimisation

The proportions of each category in the overall energy saving achieved in the 15-year observation period are shown in Figure 3.

The smallest category of 25 % is the improvement in insulation. It is divided into three separate points, two being closely linked together. First of all the thickness of the walls and the lid were increased on average from 63 mm to 120 mm. Increasing the thickness of the wall design is not the only important factor. The chemistry of the foam also has to be adapted so that the cure time does not increase linearly with the increase in thickness. If not taken into account, this would lead to higher production costs due to prolonged processing time.

In the same optimisation step the thermal conductivity of the foam was reduced to get better thermal insulation. At the same time there should be no loss in stability of the foam, as it gives the appliance its rigidity and the option of stacking in storage. A decrease in foam rigidity would reduce the possible stacking height and therefore again lead to increased product costs because more storage area would be required for the same quantity of appliances. Thermal conductivity and rigidity may be enhanced by increasing the foam density. However, this means more material and transport costs, leading to higher product costs which are unacceptable. Therefore all mentioned points must be achieved with the lowest possible increase in foam density if any. Close collaboration with the suppliers of the foam components is necessary to come up with an economical and ecological solution.

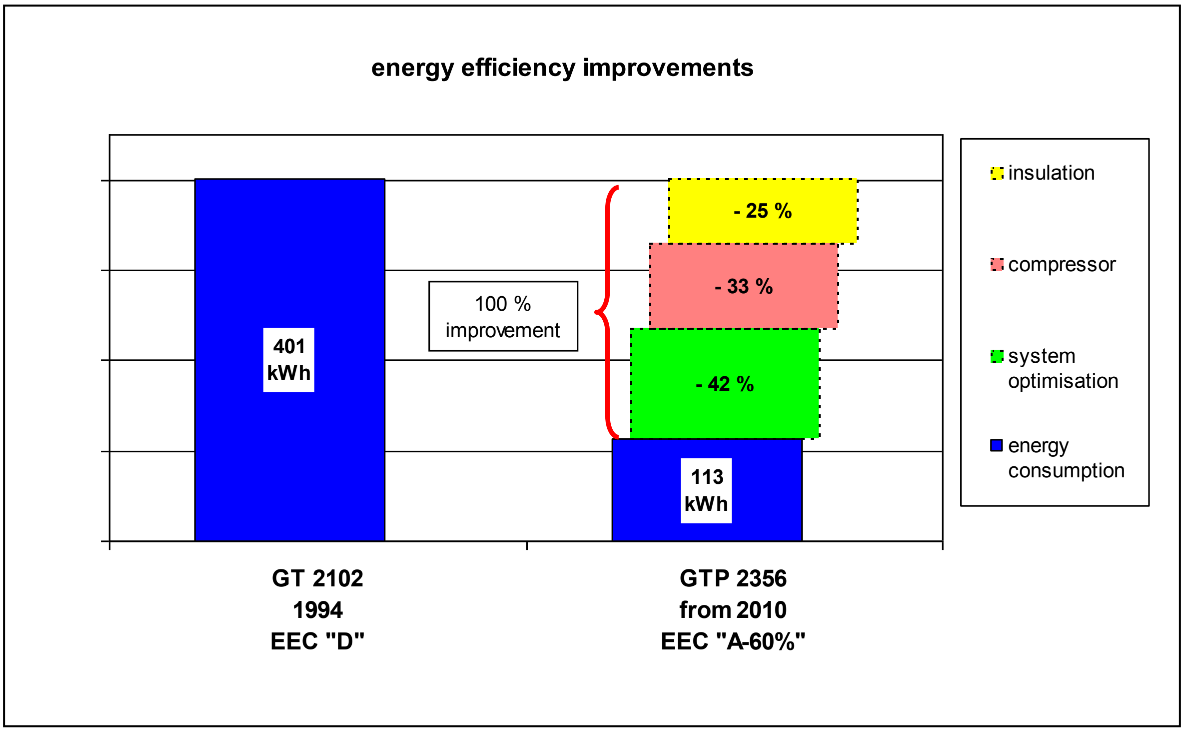

Figure 3: Proportions of the different technological improvements from 1994 to 2009

The third aspect of insulation improvement is the distribution of wall thickness. From a theoretical point of view the k-value and thus the heat flow of a wall does not decrease linearly with the increase in wall thickness, but with the ratio of k-value ~ 1/thickness (see Figure 4).

Thus it is important to adjust the wall thickness to achieve optimum thickness everywhere, relating to the temperature difference between outer and inner surface of the appliance. There is the additional difficulty of combining these theoretical wall thicknesses with the design requirements regarding usability for end-user and production costs, e.g. the use of as many common parts as possible without forgetting the aim of optimum insulation distribution.

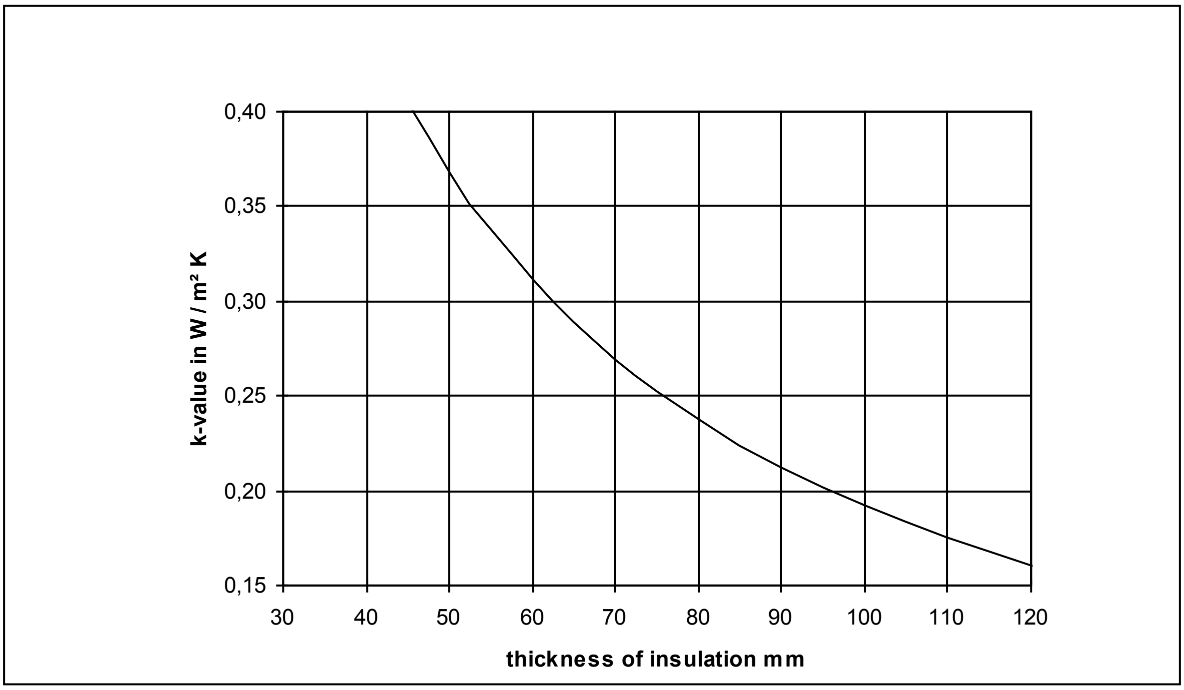

Figure 4: Relation between k-value and thickness of insulation

The second category of 33 % is the improvement in compressors. It is divided into two separate points. First, the indirect optimisation of compressors by improving the built-in situation within the compressor niche. The air duct around the compressor is optimised to achieve better heat dissipation from the compressor surface to the ducted ambient air. The compressor runs at a lower temperature, which leads to a better COP for the whole system.

Second, direct optimisation of compressors by compressor manufacturers. The main steps made by all compressor manufacturers are optimisation of electrical motor, lubricant and mechanics. The “new” technology of variable speed compressors, which results in the most efficient compressors on the market, does not need to be used in the GTP 2356. A “normal” high efficiency compressor is sufficient to reach the goal of 27 % better efficiency than EEC A++. The difference in cost between a high efficiency compressor and a variable speed compressor is approx. 80 %. It is more effective to spend this absolute value of money or less in the third category of energy optimisation.

The third category for optimisation is the main category in relation to proportion (42 %) and impact on production costs of the appliance. We divide it into three subsections. The very detailed technical information to reach the endmost points of efficiency is confidential and cannot be disclosed in this paper.

The change from back-wall to hot-wall condenser and the subsequent improvements to the refrigerant circuit are the main points in reaching highest appliance energy efficiency within an acceptable frame of production costs. The optimisation steps are made by simulation and iterative modelling and measurement of prototypes and samples.

Evaporator optimisation: The chest freezer of 1994 was already built with a coiled aluminium tube around the inner liner. The shape and size of the tube as well as the use of a heat conductive paste are optimised regarding energy efficiency and production costs. To achieve the shortest production time the characteristics of the adhesive tape needed to fix the tube to the inner liner must be optimised. The conditions, repeatability of the tube fixing process in production and the “15 year reliability” of the product must not be disregarded.

Heat exchanger from capillary to suction tube: Internal heat exchange in a capillary system is a very complicated interface in a refrigeration circuit. The thermodynamic interaction in the two-phase flow in the capillary is not yet fully understood by science. Though optimisation is done mainly by experiment, several percentage points of energy efficiency may be achieved

Accumulator: In household freezers the accumulator works as a liquid separator to protect the compressor from suctioning of liquid refrigerant. In the accumulator, liquid and gaseous refrigerant is present in dynamic variable composition. The parameters of the accumulator are adjusted to avoid sound generation due to this two-phase fluid flow while at the same time not causing a deterioration in energy efficiency

Interaction and feedback of components: A refrigeration circuit is a dynamic system where every component interacts with the others in a way that the optimum regarding energy efficiency can only be reached in an iterative process. Each component has to be optimised individually and the interaction of all components has to be adjusted by a further iterative process adjusting each component and the interface between the components. This calls for the special experience of our engineers and the use of confidential empirical values. This step by step process is time-consuming and needs to be restarted if one of the components is improved (e.g. compressor). This is particularly the case for an appliance which has more or less exhausted all technological possibilities regarding energy reduction and is sensitive regarding market price.

Electronic control instead of mechanical thermostat: Optimisation of an adjusted run-time and off-time of the compressor is fully flexible. The on and off switch conditions can be fixed in the above-mentioned iterative process. Parameters like frequency and duration of lid openings may be taken into account to optimise energy consumption in real use. At the same time, reduced temperature fluctuation optimises food storage quality.

Improvement of lid sealings: The lid sealing is made up of two sealings complementing one another. Looking at the sealings from the direction ambient temperature (25°C) to inside temperature (-18°C), the gasket is the first barrier for the incoming heat. This extruded PVC profile is composed of three parallel air chambers which reduce the heat flow into the appliance by insulation through reduction of convection and a nearly airproof sealing of the inner volume of the appliance from the atmosphere. The second level of sealing is designed through the gap between the lid and the upper part of the walls of the appliance body. It has a two-tiered shape – see Figure 5. Good insulation is achieved by the labyrinth which is 10 cm long.

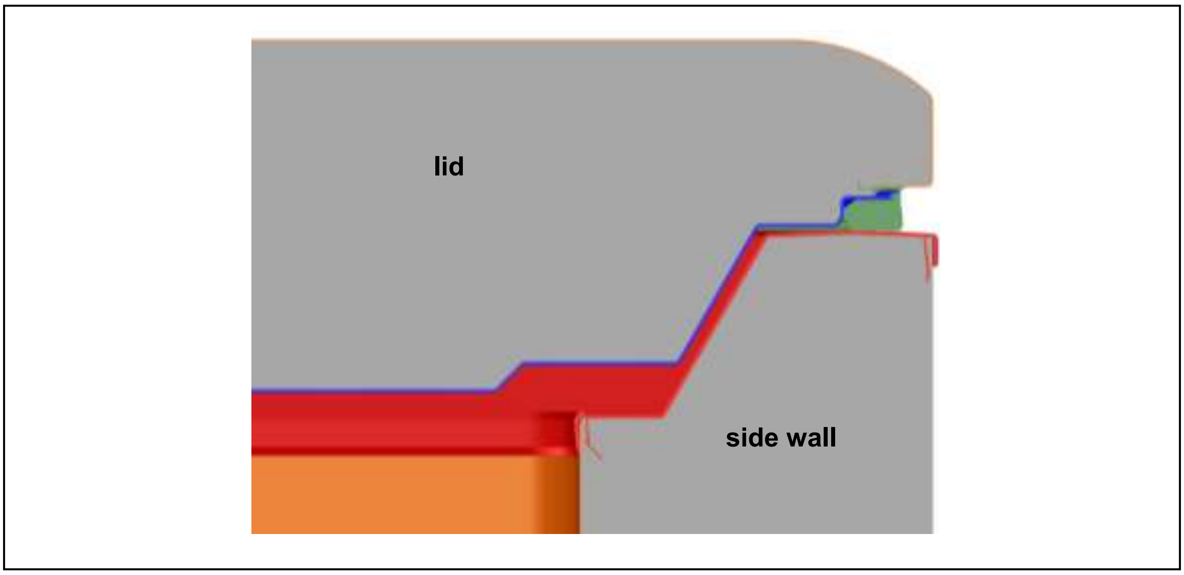

Figure 5: Sectional view of gasket and labyrinth sealing

Advances in Environmentally Sustainable Refrigerants and Blowing Agents

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Honeywell Internationall

Abstract

Novel refrigeration working fluids and polyurethane blowing agent insulating gases with attributes of high thermal performance and low environmental impact are in development stages approaching commercialisation. These materials exhibit very low global warming potential (GWP < 15), good thermal insulation or refrigeration performance, improved flammability characteristics compared to hydrocarbon materials, and are in conformance with the EU F-Gas Regulation (EC 842/2006). Utilisation of these materials in residential appliances / white goods offers the potential to improve energy performance. Chemical and physical properties, including thermodynamic data, for the various refrigeration and insulation applications will be compared and contrasted. A commercialisation perspective and timeframe will be outlined in the context of the varying industries' requirements.

Key Words: Sustainability, Low Global Warming Potential

Introduction

Amongst the numerous raw materials utilized in the manufacture of household refrigerator, refrigerator/freezer, and freezer industry, included are: 1) refrigerant gas, as the working fluid in the refrigerant circuit; and 2) blowing agent, as the insulation gas in the polyurethane foam insulation. The phase out of ozone depleting substances (ODS) in this industry has mandated the use of two categories of materials – hydrofluorocarbons (HFC) and hydrocarbons (HC). The use of HFC materials in this industry is particularly attractive due to a variety of desirable properties exhibited or imparted by HFC materials. HFC-134a (1,1,1.2-tetrafluoroethane) refrigerant gas has been widely favoured due to the high flammability characteristics of the alternative gas R-600a (isobutane). HFC-245fa (1,1,1,3,3-pentafluoropropane) blowing agent has gained wide acceptance due to the excellent thermal performance imparted to the polyurethane foam insulation, and the flammability characteristics of the alternative blowing agents (hydrocarbons). The only detriment to the heretofore iterated HFC materials is the concern of the global warming potential (GWP).

The household refrigerator industry has a hierarchy of attributes for refrigerants and blowing agents:

- good environmental properties, with preferred materials exhibiting zero ozone depletion potential (ODP), and low global warming potential (GWP)
- low order of toxicity
- high performance, specifically with respect to efficiency and capacity for refrigerant gases, and thermal performance for blowing agents
- non-flammable, or low flammability risk characteristics
- commercial availability on a global basis

All other attributes equal, the refrigerator OEM would necessarily choose the highest performance material, for a variety of reasons, however most importantly higher performance material use allows more freedom for an individual refrigerator energy platform design.

Honeywell embarked upon a research program to identify fourth generation fluorocarbon chemistry that would incorporate the desired environmental properties, that is, low global warming potential (GWP) with respect to climate change, while maintaining desirable properties and high performance characteristics. Meeting the requirements outlined in the EU F-gas regulation (for those applications specifically listed / regulated) requires GWP less than 150. Further, with respect to blowing agents in the context of end of lifetime management, embedded in the Waste Electronic and Electrical Equipment (WEEE) directive (2002/96/EC) is the concept of a GWP less than 15. These new high performance materials, whilst containing fluorine, are also by their chemical structure classified as olefins, and more specifically hydrofluoroolefins (HFO). Hydrofluoroolefins (HFO's) are a separate and distinct class of materials from the heretofore known HFC materials, primarily due to the olefin nature of the molecule and the relatively short lifetime in the atmosphere. HFO-1234ze(E), HFO-1234yf, and the new HFO chemistry under development and commercialisation by Honeywell is fourth generation fluorocarbon technology. More specifically, in IUPAC nomenclature: HFO-1234ze(E) is [trans-1,3,3,3-tetrafluoropropene], and HFO-1234yf is [2,3,3,3-tetrafluoropropene].

Air Conditioning and Refrigeration Applications

Two very low global warming refrigerants have been identified: HFO-1234yf and HFO-1234ze(E). HFO-1234yf has been proposed to replace R-134a in automobile air conditioning systems. HFO-1234yf has shown to be a close replacement to R-134a, and has been extensively studied in this application. In addition to the environmental, toxicity, and flammability characteristics discussed previously, a number of performance and risk assessments of this refrigerant have been completed. It can be concluded that this refrigerant (HFO-1234yf) offers superior environmental performance and is acceptable for commercial use in future vehicles that are designed for use of the new refrigerant.

EU has restricted (as of July 2008) the use of R-134a in one-component foam applications. For this application, another HFO has been developed and recently commercialised by Honeywell: HFO-1234ze(E). This fluid has potential efficacy in vapour compression applications. Therefore, this article discusses applications of these two molecules in stationary air conditioning and refrigeration systems.

Refrigerant Physical Properties

Depicted in Table 1 are some properties of both HFO-1234yf and HFO-1234ze(E), together with some refrigerants also proposed as replacements for R-134a in stationary applications. Note the boiling points of proposed fluids quite higher than carbon dioxide (R-744) and lower than isobutane (R-600a), in the range of the replaced fluid (R-134a). Additionally, both HFO refrigerants have critical temperatures consistent with R-134a. Also shown in Table 1 are Permissible Exposure Limits (PEL) and flammability limits (LFL and UFL). Both HFO fluids have very low order of toxicity and will likely be classified as "A" by ASHRAE. It is also important to note that HFO-1234ze(E) does not exhibit flame limits under standard test conditions of ASTM E-681 or EU A11. HFO-1234ze(E) does, however, exhibits flame limits at elevated temperatures (above 30°C).

Table1. Refrigerant Comparative Physical Properties

Refrigerant	GWP	Normal Boiling Point (°C)	Critical Temp. (°C)	PEL (ppm)	LFL / UFL (Vol%, 23°C)
R-134a	1410	-26	101	1000	-
HFO-1234ze(E)	6	-19	110	1000*	-
HFO-1234yf	4	-30	94	500**	6.2-12.3
R-600a	<5	-12	135	800	1.8-8.5
R-744	1	-78.4	31	4000	

* Honeywell internally adopted PEL, basis current toxicological assessment.
** HFO-1234yf WEEL = 500. American Industrial Hygiene Association (AIHA)

Figure 1 illustrates pressure -- temperature relationships for R-134a, HFO-1234yf, HFO-1234ze(E), and R-600a. Both R-134a and HFO-1234yf have very similar pressures. R-600a has the lower pressure among all fluids and HFO-1234ze(E) is correspondingly between R-134a and R-600a. All properties in this article were obtained using Refprop 7.0 models (Lemmon et al., 2002). All constants in these models were fitted using experimental data obtained in Honeywell research laboratory.

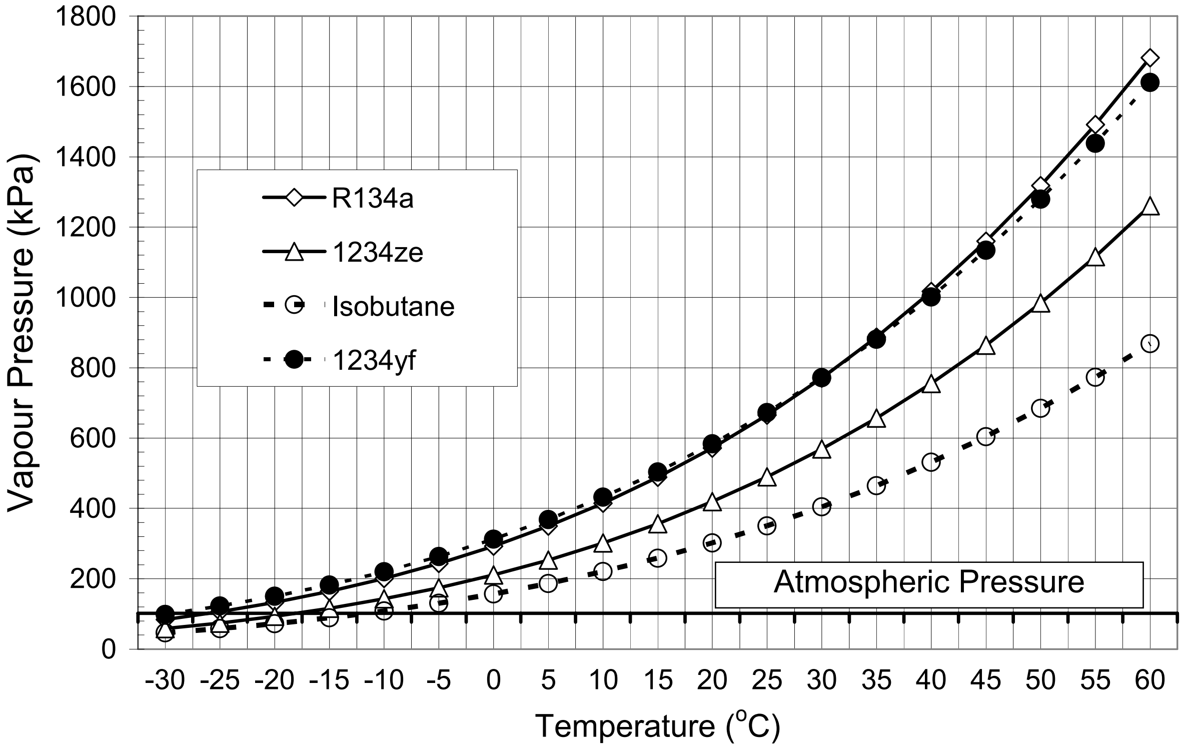

Figure 1. Refrigerant Pressure – Temperature Relationship

Vending Machines

Current vending machines systems use R-134a representative of medium level evaporation temperatures (usually -6°C). Since HFO-1234yf and HFO-1234ze(E) have boiling temperatures, respectively -30°C and -19°C, both fluids are suitable replacements for R-134a in this application.

An assessment of performance for both fluids was performed, employing a detailed simulation model "Genesym" (Spatz and Yana Motta, 2004), which accounts for thermodynamic and thermal characteristics (heat transfer and pressure drop) of these fluids. The test system, a beverage cooler tested by DeAngelis and Hrnjak (2005), was utilized. This beverage cooler refrigeration system was less than 1kW cooling capacity (640 cans). Further, the system employed tube-and-fin heat exchangers for the evaporator and condenser, reciprocating compressor, and a capillary tube as the expansion device.

Simulations were performed at steady state with a room ambient temperature of 32.2°C (50% RH), and a cabinet temperature of 2.2°C (50% RH). Table 2 summarizes the results comparative to R-134a (baseline). Drop-in evaluation of HFO-1234yf yielded capacity and efficiency values within 4% of the baseline. It is conjectured that with heat exchanger optimization, HFO-1234yf efficiency will compare equal to, or better than R-134a.

HFO-1234ze(E) exhibited 83% capacity under drop-in conditions, as expected due to its lower vapor density. The original system was modified for HFO-1234ze(E) by utilization of modern technologies in the heat exchangers (cross-grooved tubes, louver fins, optimized circuitries) and 5% larger heat transfer surface in the condenser. With these system modifications, no change in compressor displacement was required. Table 2 illustrates HFO-1234ze(E) performance in this application.

Table 2. Refrigerant Assessment in Vending Machine application

Refrigerant	Capacity kW	Efficiency -	Flow %	Suct. P %	Disch. P %	Charge %	Disch Temp. Change (ºC)
R134a	100%	100%	100%	100%	100%	100%	0.0
HFO-1234yf Drop-in	96%	96%	130%	109%	98%	101%	-24.8
HFO-1234ze(E) Drop-in	83%	87%	90%	79%	69%	92%	-3.6
HFO-1234ze(E) Modified	98%	97%	102%	86%	68%	89%	-9.9

Household Refrigerators

Similarly to vending machine assessment, thermodynamic simulations were employed; comparing HFO-1234yf and HFO-1234ze(E) to the existent R-134a. This cycle calculations were performed utilizing a Suction Line – Liquid Line heat exchanger, a common configuration practiced in domestic refrigerators.

Operating conditions employed were typical values as practiced in this industry:

- Evaporation temperature: -23°C
- Evaporator outlet superheat: 0°C (1°C increase of temperature in suction line)
- Compressor inlet temperature: 32°C
- Condensing temperature: 55°C (5°C sub-cooling at the outlet of condenser)
- Compressor Efficiencies: 70% Isentropic, 100% Volumetric

Table 3 confirms HFO-1234yf as a near drop-in replacement to R-134a exhibiting lower discharge temperature, which suggests enhanced durability of the compressor in this application. Considering typical long lifetime of household refrigerators, this performance attribute is important in this application.

HFO-1234ze(E) exhibits lower capacity, as expected due to its lower vapor density (i.e. lower mass flow). Utilization of HFO-1234ze(E) refrigerant will require a larger displacement compressor and possibly subtle redesign of the heat exchangers. Modifications of this nature should be consistent with adoption of R-600a, and IT is contemplated that R-600a system designs may be adaptable to HFO-1234ze(E) refrigerant. Further evaluation is indicated to support this case, however HFO-1234ze(E) low flammability risk provides motivation to pursue such studies.

Table3. Refrigerant Assessment in Household Refrigerators

Refrigerant	Capacity (%)	Efficiency (%)	Suction Pressure (%)	Discharge Pressure (%)	Disch. Temp. Change (°C)	Flow
R134a	100%	100%	100%	100%	0.0	100%
HFO-1234yf	102%	99%	115%	96%	-20.0	128%
HFO-1234ze(E)	72%	101%	70%	75%	-8.0	78%
R600a	56%	107%	54%	52%	-20.0	31%

Polyurethane Insulation Blowing Agents

Applications preference of blowing agent in polyurethane foams for the household refrigerator industry includes both gaseous and liquid materials. The preferences of the OEM result from refrigerator design, materials, specific performance characteristics, and processing equipment. In an effort to satisfy these broad requirements, both a gaseous blowing agent [HFO-1234ze(E)], and a liquid blowing agent designated as HBA-2 are under development. HFO-1234ze(E) blowing agent has been commercialized in the EU as of July 2008 to meet EU F-Gas restrictions in effect for one component foams industry. As discussed in this paper prior, HFO-1234ze(E) is also under development a LGWP refrigerant fluid Table 4 compares, in the context of polyurethane blowing agent application, the LGWP HFO material to other utilized materials.

Table 4. Comparative Blowing Agent Physical Properties

Property	**HFO-1234zeE**	isobutane	**HBA-2**	cyclopentane	HFC-245fa
Molecular Weight	**114**	58	**< 134**	72	134
Boiling Point (°C)	**-19**	-12	**Liquid**	49.3	15.3
Flashpoint (°C)	**None** (at ~ 23°C)	-83	**None**	-7 / 19.4	None
LEL / UEL (Vol%-air)	**None** (at ~ 23°C)	1.8 – 8.4	**None**	1.5 – 8.7	None
GWP (100 yr horizon)	**6**	<15	**<15**	<15	1000

HFO-1234ze(E) exhibits good performance as a blowing agent in conventional two component polyurethane foams, with foam thermal performance similar to HFC-134a in various formulations. Solubility of HFO-1234ze(E) across a spectrum of polyols generally suggests improved characteristics over HFC-134a. Those familiar with foamed polyurethane processes will observe that gaseous blowing agents are more easily incorporated utilizing third stream blowing agent addition prior to or directly at the foam head. HFO-1234ze(E) will find direct application in polyurethane applications wherein HFC-134a is dosed into the polyol stream, as a co-blowing agent, to enhance frothing characteristics and performance.

HBA-2 exhibits excellent properties as a blowing agent for polyurethane insulation foams. HFC-245fa performance and properties have been chosen as the baseline for comparison of HBA-2. Properties that are critical to use in polyurethane foams, namely boiling point and molecular weight are within reasonable proximity of HFC-245fa. A characterisation of HBA-2 physical properties is illustrated in Table 4, compared against HFC-245fa and cyclopentane. Hydrocarbon blowing agents, namely cyclopentane, has found use in some polyurethane applications, however exhibits less than preferred physical properties, and further, exhibits flammability characteristics.

Laboratory foam panels, utilizing a small high pressure foam machine were prepared and characterized for performance. The polyurethane formulation utilized was a commercial appliance (refrigerator) industry formulation, in which HBA-2 was equal-molar substituted for HFC-245fa. The conditions for processing these appliance type panels very nearly replicate the typical industrial parameters. The foams prepared were of excellent quality – uniform and small cell size, and absence of voids. As illustrated in Figure 5, HBA-2 exhibited similar insulation performance (lambda or k-factor) as HFC-245fa industry data. Figure 6 provides the lambda curve as might typically be used for assessing refrigerator insulation foam.

Further characterisation of the foams has shown initial and aged lambda to be similar to HFC-245fa foams. Foam ageing becomes important when the total energy consumption over the lifetime of the refrigerator is considered. As foam ages, blowing agent diffuses out of the cells, and corresponding other gases infuse into the cells, resulting in a deterioration of the insulation performance, and correspondingly, and increase in refrigerator energy consumption.

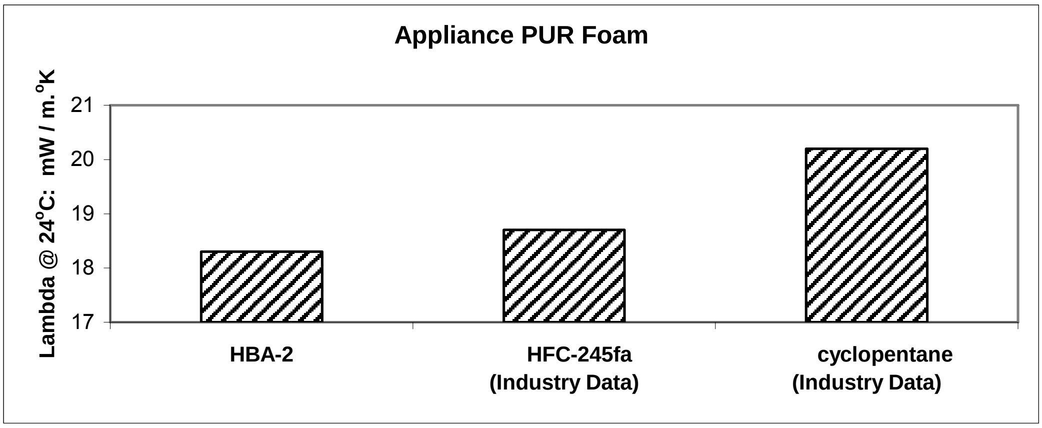

Figure 5. Initial Lambda Comparison of Liquid Blowing Agents in Appliance Foam

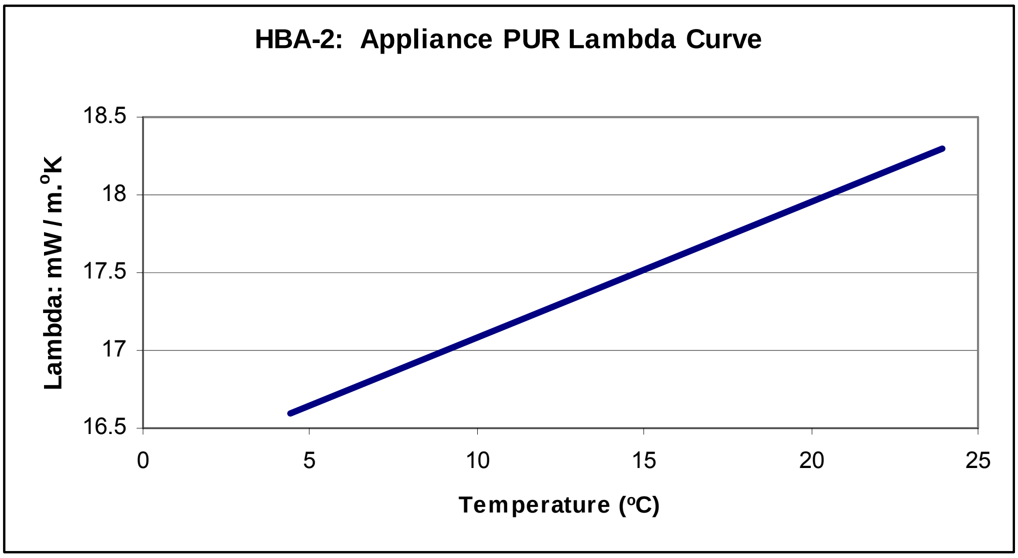

Figure 6. Appliance Foam Lambda Curve

EU chemical safety assessment synopsis

EU New Chemicals Notification Requirements – 92/32/EEC (7th Amendment to Directive 67/548/EEC [OJEC L 154 of 05.06.1992]) outlines i.a. toxicity assessment requirement of new chemicals to the levels (quantity) of manufacture in the EU, import into the EU, and use in the EU. HFO-1234ze(E), as of the writing of this paper, has been notified at the Annex VIII – Level 1, which allows for supply into EU of 1000 tonnes/annum or a cumulative of 5000 tonnes, before reaching the next notification level, i.e. Level 2. With respect to full commercialization of HFO-1234ze(E), EU notification at the Annex VIII-Level 2, which allows for supply of HFO-1234ze(E) quantities greater than 1000 tonnes/year or a cumulative of 5000 tonnes has been pre-empted and replaced by the REACH regulation.

HFO-1234yf has been notified at the Annex VII, which allows for supply in EU of 10 tonnes/annum or a cumulative of 50 tonnes. With REACH pre-emption, HFO-1234yf is considered as registered under REACH at the 10 tonnes level.

REACH regulation [Registration, Evaluation, Authorisation and Restriction of Chemicals, (EC) 1907/2006] has, effective June 1, 2008, replaced the notification provisions of directive 67/548/EEC. Under REACH each manufacturer or importer of a substance over 1 metric tonne per year is obliged to submit a registration file, and for volumes over 10 metric tones, a chemical safety report. For volumes over 100 and 1000 metric tonnes, additional data must be submitted. Moreover, for these volume bands, the registrant must submit proposals for animal tests needed to obtain certain (eco) toxicological data points. The goal of the latter provision is to prevent as much as possible (duplication of) animal tests. In many cases, waivers for such tests can be proposed.

The registration should indicate the intended uses for which the substance is notified. Use outside these registered uses is prohibited, unless a downstream user submits a separate registration file for that use. HFO-1234ze(E) has been notified for use in insulation foam and as an aerosol propellant.

The main effect of REACH is that legacy substances (which are on the EINECS, European Inventory of Existing commercial Chemical Substances) that were exempted from the notification obligations under Directive 67/548/EEC will have to be registered. For these phase-in substances, a transition period is applicable depending on the volume band and their classification.

Substances on the ELINCS, including HFO-1234ze(E) and HFO-1234yf, are considered as registered under REACH (article 24) for the volume band for which they have been notified. In the case of HFO-1234ze(E), this means that Honeywell can place up to 1000 metric tonnes on the European market without any further obligation under REACH.

Prior to exceeding the tonnage band, each registrant must submit an update to the registration file. Honeywell intends to submit an update for HFO-1234ze(E) and HFO-1234yf at the 1000+ metric tonnes status in the course of 2009. Within three weeks of receipt, the European Chemicals Agency (ECHA, based in Helsinki, Finland) must conduct a completeness check of the registration (update). This is a formal check if the registrant has fulfilled all the formalities under REACH, it is not an evaluation of the data provided. If the registration is considered as complete, the registrant may produce or import the substance in the quantities for which it has submitted the registration (update).

The evaluation of the registration file will be dependent on the characteristics of the substance and the intended uses. Toxic chemicals, or substances intended for emissive use by the general public will be given greater priority than substances that are notified for non-emissive, or professional/industrial use. Such an evaluation may lead to possible restrictions on use, labeling requirements or other measures intended to prevent undesirable exposure of humans and the environment.

Commercialization status

At the writing of this paper, Honeywell has successfully commercialised HFO-1234ze(E) in the EU coinciding with the implementation of the EU F-Gas Regulation constraints on the use of high GWP materials in one component foams industry. The manufacturing site is located at Buffalo, NY, USA, with inventory and terminal in both NA (for export) and the EU. Commercialisation in other regions of the world is dependent upon completion of notification and registration requirements for the respective regions.

HFO-1234yf is considered registered under REACH, and commercialisation in the EU is set to commence. At the writing of this paper, various application segments – automotive (mobile air conditioning) and stationary refrigeration – are progressing through system assessment and qualification.

HBA-2 is still early in application and commercial development. The toxicity assessments for this molecule is in the very early stages, however, the acute inhalation studies for this molecule are very promising. At the writing of this paper, HBA-2 is in the preliminary stages of a complete battery of toxicology assessment.

Conclusions

Recently developed low global warming molecules have potential applications in systems that currently employ medium pressure refrigerants and there is a need for this transition. A significant majority of automotive OEMs now support the use of HFO-1234yf where R-134a is scheduled for phase-out.

HFO (hydrofluoroolefin) technology offers significant promise for energy efficiency in household appliances (refrigerators). These advanced materials cross the spectrum of refrigerant gas and blowing agents in polyurethane insulation. Improvements in energy consumption may also be supported with ease of use and safety both within the manufacturing operation, as well as the consumer household.

HFO-1234yf and HFO-1234ze(E) have potential in applications such as small commercial and residential refrigeration systems where low global warming refrigerants are needed or desired. Unlike other fluids, comparable performance to existing refrigerants can be achieved without significant hardware modification. Further investigations for these applications include additional performance evaluations as well as flammability risk assessments where appropriate.

Disclaimer

Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve the user from the responsibility of carrying out its own tests and experiments, and the user assumes all risks and liability for use of the information and results obtained. Statements or suggestions concerning the use of materials and processes are made without representation or warranty that any such use is free of patent infringement and are not recommendations to infringe on any patents. The user should not assume that all toxicity data and safety measures are indicated herein or that other measures may not be required.

References

Spatz, M.W.S. and Yana Motta, S., *An evaluation of options for replacing HCFC-22 in medium temperature refrigeration system*, International Journal of Refrigeration, Vol 27, pp 475-483, 2004.

Lemmon, Eric W., McLinden, Mark O. and Huber, Marcia L., *NIST Reference Fluid Thermodynamic and Transport Properties* – Refprop Version 7.0, 2002

Johnson, Robert W and Bowman, Jim., *The Effect of Blowing Agent on Energy Use and Climate Impact of a Refrigerator*, EEDAL Conference 2003

Sondergaard, R., Nielson, D. J., Hurley, M. D., Wallington, T. J., and Singh, R., *Atmospheric chemistry of trans-$CF_3CH=CHF$: Kinetics of the gas-phase reactions with Cl atoms, OH radicals, and O_3*, Chemical and Physics Letters 443(2007), Elsevler Press, pp 199 – 204.

Preliminary measurement of energy consumption for residential refrigerators and refrigerator-freezers

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Abstract

The implementation program of energy efficiency standard and labeling of refrigerating appliances has been issued by the Government of Indonesia by the Directorate General of Electricity and Energy Development (DGEED) which is under the jurisdiction of the Ministry of Mines and Energy, Decree No. 238-12/47/600.5/2003 on the Procedure of Energy Efficiency Label Attachment. The Laboratory of Refrigeration and Air Conditioning of the Mechanical Engineering Department, Faculty of Engineering, University of Indonesia undertakes the task of testing the energy consumption of refrigerators.

The preliminary laboratory test on energy consumption of domestic refrigerators was conducted to monitor the used of its energy consumption according to Indonesian Standard Energy Labels for household appliances SNI 04-6710-2002. (Adopted from ISO 7371- 1995 (E)). The performance measurements were based on the yearly room temperature in the wet tropical humid climate at 30°C.

All of the tested refrigerators were brand new and there was no data on the energy consumption of the appliances from the manufactures. With the consideration of no recovery times or the door opening effect on storage temperature and the refrigerator's door is closed during the test, the results of monitoring and testing of 8 (eight) samples of domestic refrigerators with the range of capacity of 145 to 155 liters indicated that the energy consumption (kWh/24h) were between 1.52 to 1.85 kWh/24h. There are also differences in the compartment temperature, compressor power and running current between the manufacturer claims and the measurement results. The energy consumption measurements might be continued and be conducted in the next future according to the new version of standard test procedure and method.

1. Introduction

Whilst the energy labeling of refrigerating appliances has been issued by the Government of Indonesia by the Directorate General of Electricity and Energy Development (DGEED), most of the local manufactures of refrigerator and refrigerator freezer are waiting for the action and implementation of launching those program.

Typically, in the absence of new energy efficiency regulations, local manufacturers stated in their refrigerator and refrigerator freezer product only the volume, defrost system, compressor power and type of refrigerant. The detail technical specification with regard to the energy consumption was not included. The objective of the energy labeling program for residential refrigerator and refrigerator freezer is too encouraged to the customers to purchase the most energy efficient refrigerator to reduce their own electricity cost and also to make consumers aware of the advantages of energy efficient refrigerators and more willing to purchase them.

At the first stage, the government intends to encourage the local manufactures to implement the program by the voluntary action. After the test procedures have been agreed between manufacturers and the government, the labeling program has to be changed to mandatory program.

The preliminary test to measure energy consumption of the residential refrigerator and refrigerator freezer has already been conducted to support the energy labeling program which has been introduced by the government (Master plan of energy conservation program – RIKEN 2005).

The ISO 7371-1995 (E) was used to carry out the energy consumption test. The 145 to 155 liters domestic refrigerator of tropical class originally was taken for this preliminary energy consumption measurement.

2. Definition

Household refrigerator is an insulated cabinet of suitable volume and equipment for household use, cold by one or more energy consuming means and having one or more compartments intended for the preservation of food, one at least of which is suitable for the storage of fresh food.

According to the ISO 7371-1995 (E) the classification of the compartments is as follows:

1) **Fresh food storage compartment :** Compartment intended for the storage of unfrozen food which may be itself divided into sub-compartments, and in which the temperatures can be maintained in accordance with Table 1.

2) **Chiller compartment:** Compartment intended for the storage of particular foods or beverages at a temperature warmer than that of the fresh food storage compartment,

3) **Low temperature compartment:** compartment which may be either :
   - an ice-making compartment, or
   - a frozen food storage compartment.

4) **Ice-making compartment:** compartment intended specially for the freezing and storage of water ice-cubes.

5) **Frozen food storage compartments:** compartment intended specially for the storage of frozen food. They are classified according to their storage temperature, as follows:

   - "*one-star* " (*) compartment, compartment in which the storage temperature is not warmer than - 6 ^{o}C.

   - " *two-star* " (**) compartment, compartment in which the storage temperature is not warmer than - 12 ^{o}C.

   - "*three-star* " (***) compartment, compartment in which the storage temperature is not warmer than - 18 ^{o}C.

Table 1. Fresh food storage compartment temperatures (oC)

Climate Class	Ambient Temperature	Food Compartment Temperature	Fresh Food Compartment Temperature	Three Star (***)	Two Star (**)	One Star (*)	Chiller Compartment
		t_1,t_2,t_3	t_m, t_{max}	t***	t**	t*	t_{cm}
SN	+ 16 and + 32	$0 \le t_1,t_2,t_3 \le +10$	+ 5	≤ -18	≤ -12	≤ - 6	$+8 \le t_{cm} \le 14$
N	+ 16 and + 32						
ST	+ 18 and + 38						
T	+ 18 and + 43						

Note: SN : extended temperature class ; N : temperate class ; ST : sub tropical class ; T : tropical class.

3. Test facilities

3.1 Room test

The dimension of room test (Figure 1) is 3400 mm (L) x 3400 mm (W) x 2720 mm (H) with all the wall and ceiling thermal isolated using styrophore and aluminium plate coated with anti-corrosion material. The door consists of 100 mm rigid polyurethane foam and covered with aluminium plate and some insulation around the door to prevent the thermal losses.

It's also equipped with one pressure compensation valve and lighting 4 x 60 watt. A refrigerating machine with the 2 TR capacity completed with the control instrumentation is installed to maintain the room temperature under certain condition.

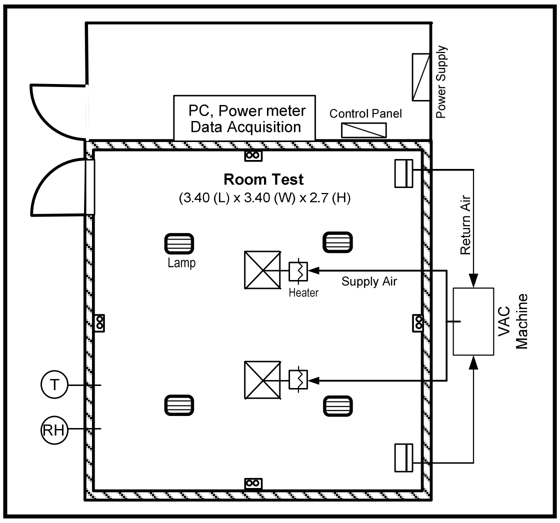

Figure 1. Room Test Layout

3.2 Instrumentation and devices

During the energy consumption measurements, the following instruments were used:

1) Watt-hour meter, with the accuracy ± 0.1 %.
2) Temperature measurement was conducted using thermocouple type K which connected to the data acquisition, accuracy ± 0.05 % of reading + 2 digits, completed with software.
3) Monitoring of the room temperature is done by thermocouple type K and connected to digital temperature recorder, and the wall mounted dial thermometer.

4. Test Procedure

1) Refrigerator classification: one door, manual defrost, and volume between 145 to 155 liter.

2) Room test condition to be maintained at temperature 30 ^{O}C ± 1 ^{O}C with the range of relative humidity between 50% ÷ 70%.

3) Refrigerator installation

- Refrigerator should be installed according to ISO 7171 -1995 (E), as shown on Figure 2.
- Refrigerator is placed on a wooden solid platform, black painted, has opening under the platform for free air circulation purpose. The top of the platform is 30 cm above the test room floor (Figure 2.).
- Two black painted vertical partitions are placed on the sides of refrigerator and fixed on the platform, 30 cm from the sides of the refrigerator. One wooden partition is arranged to the rear of the refrigerator at a specific distance with the height at least 30 cm above the top of the refrigerator.
- Minimum air velocity surrounding the refrigerator should be less than 0.25 m/s.

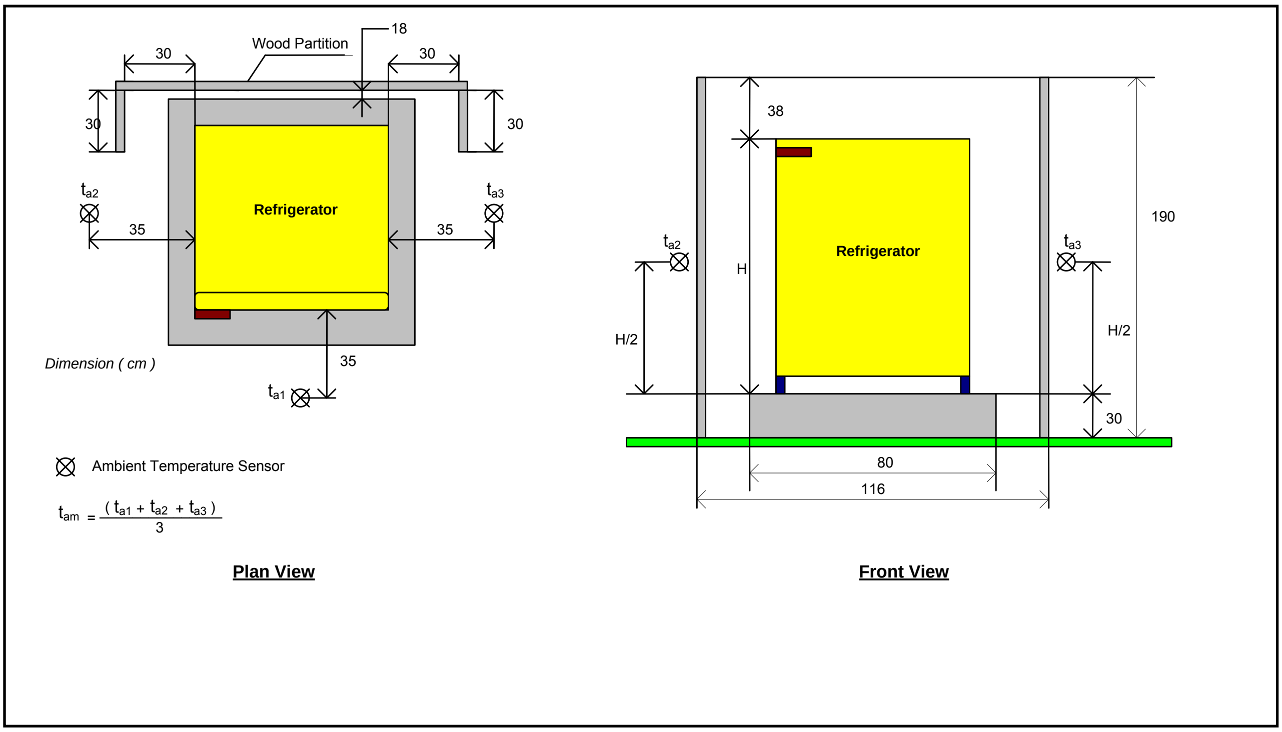

Figure 2. Refrigerator plan and temperature points of measurement

4) Measurement
   - Temperatures has been measured with the K type thermocouple and located according to Figure 3.
   - One thermocouple inside the freezer compartment (t_f).
   - Three positions of thermocouple inside the food storage (t_{c1}, t_{c2}, t_{c3})
   - Three positions of thermocouple located outside the refrigerator (t_{a1}, t_{a2}, t_{a3})
   - Thermocouples are inserted in the centre of a tinned solid cooper cylinder, having mass of 25 g, and has outer dimension of diameter and height 15.2 mm.

5) The measurement is carried out under continuous and cycling operating modes at no load condition.

6) The refrigerator door is closed during the test.

7) The test period was 24 h and is measured after a steady state condition is obtained.
   At the test room condition, temperatures and electrical energy consumptions of the refrigerator are recorded at each setting point of the thermostat: low, medium and high. The start and stop of operating time has also been recorded.

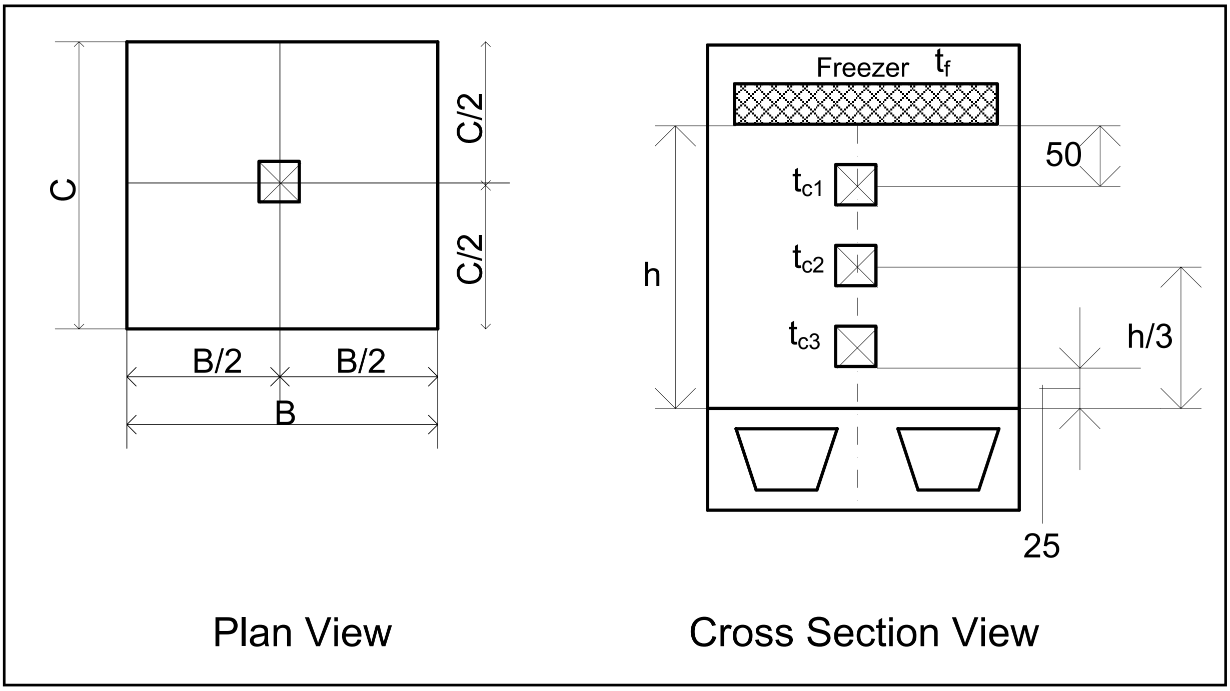

Figure 3. Temperature sensor positions

5. Energy consumption test

Temperature and energy consumption measurements have been conducted to 8 (eight) sample of local manufactured, one door, manual defrost, 140 – 150 liter capacity refrigerator.
Energy consumption is calculated based on the one temperature condition as shown on Figure 6. ISO 7371-1995 (E) using the interpolation method of the two values, i.e. lowest and highest temperature has been attained during the test period.

6. Results and discussion

Table 2 shows the result of measurement and calculation of energy consumption

Eight refrigerators were tested, which had not previously been tested for energy label consumption. Instead of the test standard ambient temperature of 32°C, refrigerators were tested at 30°C and also subjected to a door-closed regime.

Table 2. Measurements and calculation result

Produk	R1	R2	R3	R4	R5	R6	R7	R8
Ambient Temperature (^oC)	30.1	30.2	30.1	29.9	30	29.8	29.7	29.8
Volume (ltr)	145	155	145	155	145	155	150	150
Current (Ampere)								
Starting	1.25	1.45	1.44	0.965	1.12	0.98	1.11	1.12
Running	0.72 ± 0.01	0.68 ± 0.012	0.68 ± 0.012	0.64 ± 0.01	0.65 ± 0.01	0.56 ± 0.01	0.57 ± 0.01	0.58 ± 0.01
Voltage, Volt	220 ± 10	220 ± 10	220 ± 5	220 ± 5	220 ± 5	220 ± 10	220 ± 5	220 ± 5
Cosφ	0.49	0.51	0.50	0.49	0.50	0.51	0.50	0.49
Refrigerator temperature (^oC)								
1. Food Compartment	4.30	3.90	3.80	3.00	3.20	2.80	4.00	3.50
2. Freezer	-12.50	-9.60	-11.70	-12.10	-10.20	-12.10	-13.50	-11.80
Compressor Power (W)	72.37	77.17	74.33	69.83	72.30	64.00	63.50	64.00
Energy Consumption (kWh/24h)	1.74	1.85	1.78	1.68	1.74	1.53	1.52	1.54

Refrigerator R2 as indicated on Table 2.requires a highest energy consumption of 1.85 kWh/24h and refrigerator R7 has a lowest energy consumption of 1.52 kWh/24h.

The starting current of most refrigerators has approximately two times of the running current which has a range of 0.56 – 0.72 Ampere.

Refrigerator R1, R4, R6 and R7 have the lowest freezer compartment temperatures (< –12 ^oC) and will classified to two star (**), and the others are confirmed to one star class (*) refrigerator.

The power consumption of refrigerator R6, R7 and R8 are 64.0 W, 63.5 W and 64.0 W respectively and Refrigerator R7 has a lowest power consumption of 63.5 W.

1) Compartment temperatures

During the measurement, it is recorded that the variation of test room temperatures are between 29.8 ^oC to 30.2 ^oC and the temperatures in the freezer compartment are from – 9.6 ^oC to -13.5 ^oC. The food compartment temperatures are in the range of 2.8 ^oC to 4.3 ^oC.

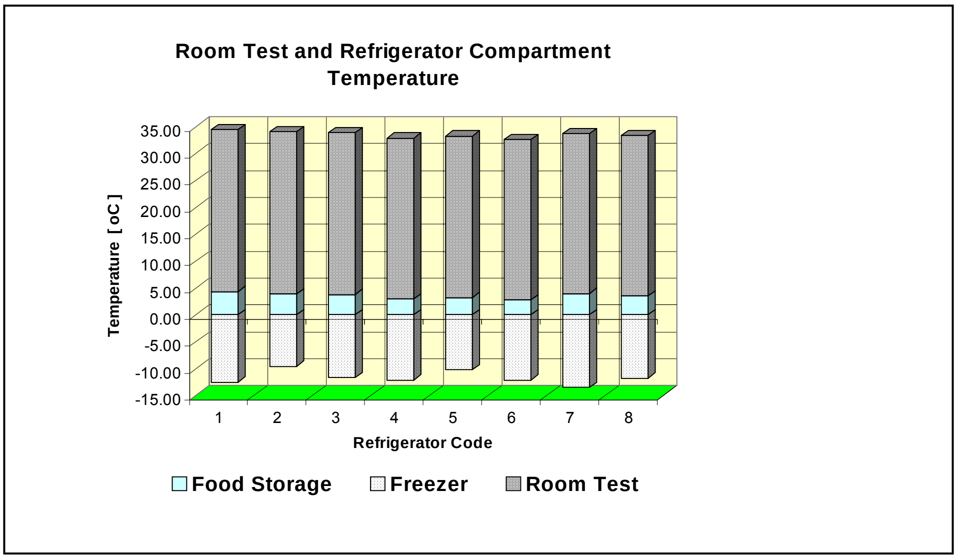

Figure 4. Room and Refrigerator Compartment Temperature

2) Power and energy consumption

It was observed and as shown on Table 2. that there was a closed relation between the power consumption and volume of refrigerator. The increasing power consumption shown a strong correlation with the refrigerator volume. It was merely depend on the art of fabrication from the manufacturer.

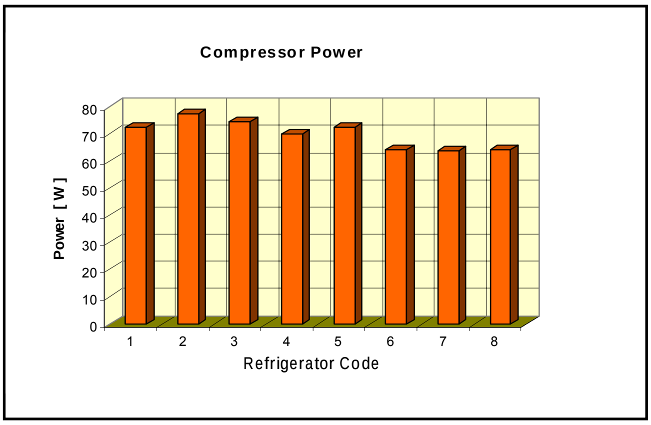

Figure 5. Compressor Power Consumption

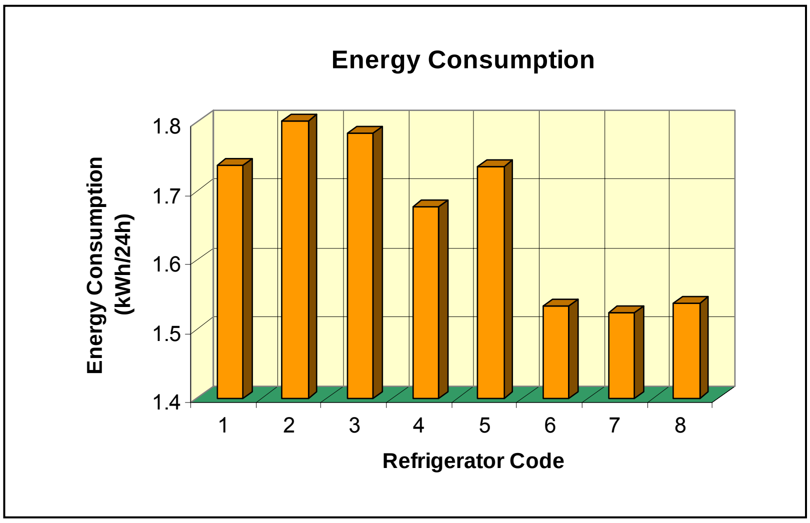

Figure 6. Energy Consumption

7. Conclusion

1) It was found that refrigerators has a power factor (cos φ) in the range of 0.6 – 0.7. It means that the refrigerators consumed more current from the electrical circuit. Such information has never been informed by the manufacturer to the customer.

2) Freezer temperature of all refrigerators could not reach to the final temperature -18 ^{o}C. Thus, all of the refrigerators could not achieve three star (***) class.

3) The issues of the energy labeling program and energy consumption test for household/domestic refrigerator has to be implemented and should be endorsed by the government to protect the consumer from misleading to choose the most energy efficient refrigerator.

4) Manufacturer has obligation to inform the energy label in their new product. The labels containing energy efficiency information has to be affixed to the refrigerator models of participating brands. By selecting energy label for household refrigerator will help the customer to select energy efficient models to save electricity and reduce their electricity bills.

5) Due to the lack of information with regard to the energy consumption report from the manufacturer, these energy consumption test report could not be compared to the manufacturer's standard.

8. References

1) BS EN 153 : 1990 : Measuring the energy consumption of electric mains operated household refrigerators, frozen food storage cabinets, food freezers and their combinations, together with associated characteristics.

2) CFR - 10 Energy , DOE - 1994 : Part 430 Energy Conservation Program for Consumer Product Sub Part B Test Procedure, Appendix A : Uniform Test Method for Measuring the Energy Consumption of Electric Refrigerators and Electric Refrigerator -Freezers.

3) ISO 7371 – 1995(E) : Performance of Household Refrigerating Appliances Refrigerators with or without Low Temperature Compartment.

4) JIS C 9607 - 1986 : Household Electric Refrigerators, Refrigerator-Freezers and Freezers.

5) *Final Report on Implementation of Energy Labeling-Household Electrical Appliances*, Center of Energy Study University of Indonesia, 2002

Improving Energy Efficiency of Product Use: An Exploration of Environmental Impacts of Household Cold Appliance Usage Patterns

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Abstract

This report presents the findings from a qualitative study investigating how product design can be used to change consumer behaviour to reduce the household energy consumption. A fundamental aspect of this aim is to fill the gap in existing research by understanding the product use behaviour and its impacts on the environment. Household cold appliances were chosen as a case to explore the capacity of designer-conducted user studies to identify unsustainable aspects of product use. User-centred research techniques [1, 2] including questionnaires, semi-structured interview and Product-in-Use observations were used to collect information about the “actual” and “assumed” needs, the diversity in use context, the unsustainable and sustainable use patterns and the hidden factors behind the usage. Eighteen British families were involved in this qualitative study. This paper presents the methods and process for extracting design oriented information from the behaviour study in the early phases of energy efficient products development. It concludes that usage patterns study can offer resources to assist manufacturers and designers minimise environmental impacts product use. Also it discusses the implications for the future design of household cold appliances.

Introduction

During the use phase, a significant proportion of a product’s energy demand is determined by the consumer’s behaviour. In studies from the United States, the Netherlands and the UK, cited by Wood and Newborough [3], it is estimated that resident’s behaviour is responsible for 26–36% of in-home energy use. Therefore, in addition to improving the technological efficiency of domestic appliances, a fundamental change in user behaviour is required to achieve the reduction in residential energy consumption. Product manufacturers and designers are ideally placed to plan and to shape the way in which operation occurs: how these appliances are perceived, learned, and used. A better understanding of what users do and how they interact with products as well as the hidden factors behind daily decision-making process should be gained in order to encourage more sustainable daily actions.

In the home, there are very few pieces of equipment that use energy 24 hours a day 365 days a year. Fridges and freezers are two such products and account for around one-fifth of domestic energy consumption [4] and 25% of the average household bill [5]. The Energy Saving Trust [4] estimated that in the UK, “households spend £1.2 billion on electricity every year on cooling and freezing food and drinks” which is equivalent to the electricity consumed by all office buildings [5]. The UK Government Energy White Paper [6] identified the need for further reductions in the energy used by cold appliances [7]. To reduce environmental impacts in this cold sector, most solutions have focused on technological innovations. However, about half the efficiency gains have been offset by the “rebound effect” [4]. The rebound effect is liked to the supply side. Manufacturers are providing bigger volume cold appliances. According to the Environmental Change Institute [8], the average size of cold appliances on the market was increased by 15% between 1995 and 2001. This has resulted in the fact that revealed that manufacturers are not selling appliances with lower overall energy consumption [9]. On the demand side, it is reported that every household at least own one cold appliance often with two or more [8]. A survey by Mintel [10] shows that in 2007, the sales in this sector grew by 8% compared with 2005. Recently, consumers are enthusing about larger and more energy hungry appliances, such as, American style fridge freezers containing integrated LCDs or ice producers. Over the lifetime, an American style fridge and freezer consumes 1800 KWh more than the typical average sized A-rated appliance. Increasing consumer expectation for comfort, convenience, speed and security as well as the social and psychological contexts within which cold appliance consumption behaviours exist are challenging the energy gains of technological improvements of reducing the impact of product use. The current energy label test is criticised by consumer bodies and experts for not reflecting actual energy consumption of home use. In research of the real-life usage, the consumer surveys on actual energy consumption have given the following results (see Table 1). These studies from different countries provide interesting data on the real-life of fridges and freezers, but they are generally concerned with the end result of quantitative data collection, not the use process. Fridges and freezers, the 'must-have' products in the household, are widely used by a variety of user groups in a range of habitual use behaviours and routine activities. Research to date indicates that the everyday product use behaviour and its evnrionmental impacts have not yet been clearly addressed.

Table 1, difference in electricity consumption of fridge and/or freezer between actual and the label provided by research from different countries [7, 11, 12, 13, 14].

Energy Consumption Research community	Effects of actual energy consumption
Food Refrigeration and Process Engineering Research Centre (FRPERC) report	The effect of door opening is 1-2% The influence of warm food is 4-10%
Mennink et al. (1998) tested a 200 litre refrigerator	The effect of door opening is 8% (2.2W) The influence of Adding food at room temperature is 11% (3.1W)
Refrigerators and Freezers, product case 5, Methodology Study Eco-design of Energy-using Products (MEEUP) for European Commission	Ice-up of the evaporator deteriorate the efficiency by 10-20% 1°C difference in temperature causes a 4% difference in energy consumption.
ECUEL project SAVE (1999) in France used metered appliances in around 98 households for one month between January and July 1998 to monitor	Keeping a cold appliance in a non-heated storeroom rather than a kitchen gives an average energy saving of 36%. On average, freezers were operating at 3.1°C colder than the recommended temperature (-18°C), leading to 17.6% more energy use.
In Japan, the surveys on Actual Energy Consumption of Top-Runner Refrigerators of Jyukankyo Research Institute (2006) monitored over 100 refrigerators in household for one year	Average annual actual electricity consumption was 65% larger than the JIS test value (Japan Industrial Standards test in 1999)

Rather than a quantitative energy monitoring study, the qualitative study of the fridge and freezer use provided an insight into the type of information required by designers to reduce the energy consumption in operating the product. To collect qualitative information about the "actual" and "assumed" needs, the diversity in use context, the unsustainable and sustainable use patterns and the hidden factors behind the usage across a broader sample, a combined research techniques have been conducted in eighteen British families. By analysing the use of the fridge and freezer, the areas with the potential for achieving improvements by energy efficient product design were identified. The final section discusses the implications for future design of household cold appliances. Some design briefs are outlined as an example of how design solutions can be used to change consumer behaviour to reduce the household energy use.

Data Collection and Analysis

To be eligible for the study, participants needed to do food shopping and cooking regularly, be the owners of the fridges and freezers and live within easy travelling distance of the researcher. Table 2 summaries the composition of the households involved in this study.

Table 2 the composition of the participants involved;

Age	Had owned fridge/ freezer for	Family Size Person/ Household	Single	Two	Three	Four	Five
25-65	4months - 16years		1	4	3	7	5

Methods of study

Qualitative methods would be applied to uncover and understand what lies behind the everyday use of the fridge and freezer in order to “give the intricate details of phenomena that are difficult to convey with quantitative methods” [15]. As shown in Table 3, a combination of user-centred research techniques [4, 5] was employed for this study to capture opportunities for design to help consumers to use their fridge and freezer more efficiently.

Table 3 Research methods used for the main study

Research Activity	Time	Equipment	Participant	Aim (h=hour, m=minute)
Questionnaire: User profile; Participant Information Sheet; Informed Consent Form	10m		Wife and/or Husband	To brief the research, its significance, the use of the data & their right to withdraw from this study; To gather the basic information from the potential participants; To enable participants to get familiar with the study & the researcher.
Observation: Food Unpacking Recording	15-30m	Hand-held digital camcorder	Wife and/or Husband	To uncover the habits &principles of unpacking grocery shopping.
Observation: Fridge & Freezer Use Condition, Use Environment	10m	Digital camera and digital camcorder	Researcher	To gain insight of the fridge and freezer use and reasons for particular use behaviour
Observation: 24 Hours Behaviour Record	24.5 h	Fixed camera, laptop & motion detected software	Family member(s)	To adequately capture a range of behaviours related to the everyday use of fridge & freezer,
Post-intervention Questionnaire	15m		Wife and/or Husband	To identify individual’s knowledge & attitudes towards energy & resource efficiency & eco-friendly purchasing &performance of environmental behaviour; To ascertain the links between intentions & daily use behaviour of the fridge & freezer.
Semi-structured Interview, Explanations to 24-hour record	30-40m	Voice recorder	Wife and/or Husband	To discover the attitudes in relation to environment & energy use of fridge & freezer; To entice users’ true opinions & promote substantive discussions about the reasons for their particular behaviour, the users’ environmental responsibility & the changes that should be made to the fridge & freezer design.

Observation

Miles and Huberman [16] identified that focusing solely on individual behaviour without attending to contexts runs a serious risk of misunderstanding the meaning of events. The visual recordings enable researchers to capture people’s behaviour in real-life contexts [1] and to look at the interaction between people and their environment [17], offering more detailed and more accurate source of daily practices and routines [18]. It is an interactive and naturalistic [1] method to record behaviours which people may not be able to articulate when asked [19]. Also it helps the observer to identify true opinions and actions as people often say one thing but think or do another [20]. As Daut commented, video enables the researcher to capture both visual and audible information providing a rich source of data about people’s ordinary lives [21].

In this study, the interaction between the user and the product assessed the environmental consequences from three stages - before use (selection and purchase), mid-use (operation and maintenance) and after use (disposal or recycle). Mid-use is broken down into five parts – getting started, use, sequence of use, context of use and life of usage. Considering the household fridge and freezer and their central relationship to food preparation and consumption, the use activities around the fridge and freezer were arranged into three related groups including condition and environment of product in use, food shopping unpacking and food preparation. Correspondingly, three observations of Product-in-Use were conducted.

Questionnaire and Semi-structured Interview

It was felt that no technique used independently can give a representative picture of fridge and freezer use, but multiple methods built a sufficient profile of users' values and intentions behind the daily practice. Self-completion questionnaires and semi-structured interviews clearly offered an advantage in supplementary data collection. These two techniques were used to investigate what consumers thought about their fridge and freezer and the environmental impacts of their use. They helped to reduce the risk that the conclusion would reflect any limitations of a specific method.

A self-completion questionnaire, a series of pre-established questions with a limited set of response categories, was designed for respondents to evaluate themselves. The results allow the assessment of current respondents' environmental attitudes and action in different environmental subject areas, including energy efficiency and waste recycling. The use of open ended questions provides respondents with an opportunity to respond to the "like" and "dislike" issues about cold appliance in more detail. The face to face interviews resulted in insightful information about users, which consisted mainly of descriptions of the routine practice ingrained in the fridge and freezer use patterns. The face to face interview provided the opportunity to modifying the enquiry according to the real situation, since some of the questions have not been predetermined, but asked in an open-ended manner to discuss not only "what have people done" but also "why have people done it" [22]. Using a pre-prepared agenda of issues enabled discussions around specific issues, avoiding irrelevant or useless content and making the comparisons of responses with other interviewees' easily. All the activities conducted in this study were recorded by notes, photos and video recordings which assisted more detailed analysis to extract, compare and collate similarities and differences.

Data Analysis

The qualitative nature of the data collected throughout the study has informed the data analysis process. Three main analysis methods, coding, matrix and mapping and clustering, were adopted, undertaking three analysis activities data reduction, data display and conclusion drawing and verification [16]. The coded information was compressed into maps, to enable reviewing and unscrambling of the research data. Themes were drawn from the data. Finally, the objects that had similar characteristics were clustered to build theory [16].

Results

Through analysing the data of the real use of domestic cold appliances, the householders' real needs and its environmental impacts were identified and divided into five themes: Use scenarios of the household fridge and freezer; Fridge and freezer in use and design; Kitchen plans; Life of usage and lifestyle of user; Food packaging. The first two of these are outlined in more detail in the following sections

Use Scenarios of the Household Fridge and Freezer

The video footage illustrated the flow, order and disorder of "everyday life" in eighteen households regarding the use of cold appliances. It exposed that the use impacts with the refrigerator are closely tied to the temporal routines of food preparation and consumption. Bouts of intensive activities that took place around unpacking grocery shopping and meal time characterised the typical scenarios for use of the domestic refrigerator. The analysis was focussed on three areas of intensive work with the fridge and freezer: "morning", "evening meal" and "unpacking grocery shopping" to identify the sequence of routinising use. In this paper only morning activities will be discussed.

Morning

In the households where members were out at work or school during the weekday, a flurry of activities conducted with the fridge needed to be done for the day ahead in the early morning. Unsustainable use patterns of 15 fridges during the breakfast preparation in a normal weekday were selected as samples. It revealed two most damaging behaviours of fridge use in the morning: “high frequency of door opening” and “left door open”. Combined with the demographic information from user profile questionnaires, a more detailed analysis of the factors influencing the fridge use was produced. It suggested that “rushers” were heedless of the time of opening of the fridge door, as all the tasks got achieved with the largest amount of conveniences and the least amount of effort.

This “rush” was embodied in the high frequency of the fridge door opening for the food preparation. The more family members, the more variety of food needed from fridge, the more times door opened. The detailed description of the observed behaviour below illustrated the various agents that affected the times of door opening:

- Number of family members: In a 5-person household, fridge opened 20 times to prepare breakfast and lunch boxes for the children and 18 times within 24 minutes (MUS-F18); while in the observational studies 2-person families only opened it 5-6 times mainly for a drink during breakfast.
- Age of children: adults got up early to prepare and had breakfast with their younger children; while in the family with the teenage children, older children had independent breakfast and the fridge was used more.
- Time of breakfast preparation: in some of the households, the husband was the first one to appear in the video and often organised and ate his own breakfast in the early weekday morning. So the same food for breakfast, such as, milk, always was taken out repeatedly.
- Different types of drinks: the variety of drinks for breakfast increased the number of times doors were opened. Also, if two of family members drank different juices, in the behavioural records, they usually opened for two kinds of drinks out and back in (MUS-F0*5).*
- Food variety: compared with all childless and in full-time employment, families with children at home consumed more vegetables, fruit and yogurts had more proper breakfasts and used the fridge more*.*
- The preparation of the fruit bags and lunch boxes for work and school.

It can be found that “rushers” often intended to get “quick tasks” done with the door opening, such as, checking expired date of the items, pouring drinks for breakfast (Figure 1), searching for vegetables in the bottom drawers, making lunch boxes and fruit bags and transferring items between worktop and fridge one by one. For example, *the wife spent 68s transferring foods for breakfast between worktop and fridge and the son left door open for 70s to make sandwiches (MUS-F04)* (see Figure 2).

Figure 1: pouring milk for breakfast with door open (MUS-F17)

Figure 2: left door open for 70s to make sandwiches (MUS-F04)

Householders who were knee-deep in morning chaos failed to be organised during the breakfast preparation. Firstly, they were not planning in advance. The wife opened the fridge 5 times for her and her husband’s breakfast, but 4 times within 1 minute (MUS-F16). Secondly, they opened the fridge for making breakfast without thinking about all family members. Milk was taken out 4 times by 4 different family members during breakfast time (MUS-F15); and twice in 2 persons household within 5 minutes (MUS-F02).

Fridge and Freezer in Use and Fridge and Freezer Design

The findings from the Product-in-use observations and interviews indicated that there existed a variety of use patterns of fridge and freezer performed with or without intentions which contributed to the creation of many environmental stresses. The results discussed below presented the gap between product design and their real requirement.

Use content

The interviewees pointed out that the main functions of the domestic refrigerator were to: prevent bacteria multiplying; keep food fresh; maintain and chill food and drink as well as provide a sensible storage for the food and drink. The divergences in the opinions lay egg storage and individual preference for cold food and drinks. Some of the participants stressed the need for chilling certain food and drinks. In some households there was a second fridge particularly for keeping wine cool. Load conditions also affected the energy efficiency can be seen in the following three aspects: having the refrigerator overcrowded or too empty and placing food in a mess represented in Figure 3. There are several issues influencing overfilling including: having parties or visitors, the frequency of shopping affected by work patterns and the distance between the shops/supermarket and home, the life stage of the users affected by having children and having a healthier diet. Going on holiday is the time for users to use up or throw away the food to ensure the fridge as empty as possible. Leaving the empty fridge running then became one of the harmful use behaviours which should draw the designers' concerns.

Figure 3: overfilled fridge; "empty" fridge; food placed in a mess

Linking the interview and the observation, the data showed that consumers also located items because of: "Frequency of the use" - for easy access; "Routinising practice", habitual place; "Where there is space"; "Fridge design". On reflection, these examples strongly supported the argument for three perceptive elements of daily practice model [23]. When householders interacted with the refrigerators, they oscillated between:

1. Keeping in control with intentions and understandings constituted through a more or less conscious assessment of existing practice, for example, "frequency of the use" and knowledge learnt from past experience and others, such as, family home, friends and media including magazines, cookery magazines, TV and radio.

2. Routinising behaviour without awareness - a habit that is "highly automated" [24] as immediate responses to specific cues, operating outside awareness with a minimum of deliberation or little cognitive effort. In the observation, it could be seen that users maintained a certain degree of routine to operate the refrigerator while they could not make themselves clearly for why they do in that manner in the interview.

3. Lacking of principles without plans - letting things go in a disorganized manner. No standard routine related to locating items into the refrigerator was one of the contributory factors for the increase of the open time. This was certainly confirmed by locating principle of "Where there is space" and interestingly "fridge design" might offer the possible solutions to this problem caused by user behaviour.

Another issue about environmental intentions and actual behaviour is evident in the user study. Users who considered themselves environmental friendly could not integrate energy conscious behaviour into every part of their daily routines. Whilst element 1 of the daily practice model embodied the agreement among the real action and intention and desire for “being green people”, element 3 symbolised “being out of control” and “lock-in the daily practice”. Observing routines indicated practitioners' shift from element 1 to element 3. For instance, MUS-F02's daily interaction with the fridge, such as, placing food inside the fridge, food preparation, was a lot more “relaxed” than putting away her grocery shopping.

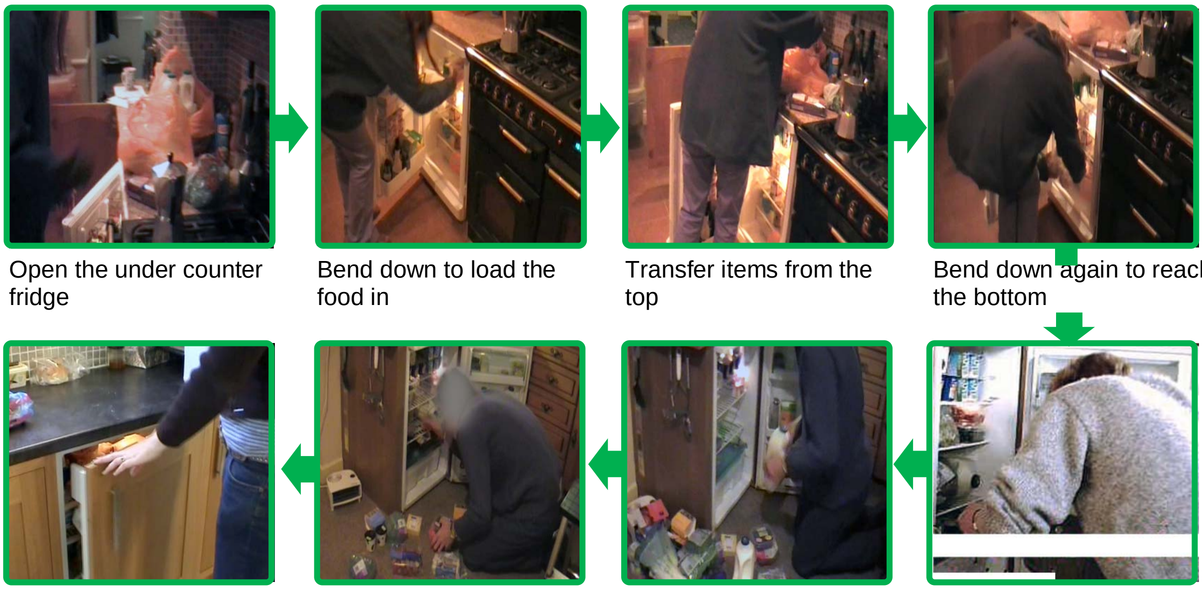
Fridge and freezer design and use behaviour

“If I have got room, I just put everything in the fridge, because it is easier. Because I do not know where to put…” (MUS-F09). The fridge and freezer afforded such convenient food storage solutions that some of participants expressed their preference for a much bigger fridge and thought about the American style fridge and freezer when they purchased or would purchased in the future. However, it was reported that the space left for the refrigerator was the main restriction of the purchase of American side by side style or bigger size refrigerator.

Observing use routines of the fridge and/or freezer exposed how these were tied up with bodily movement, with the design of the appliance and users' capability of adaptation to the design as well as with the use impacts on environment. The following sections illustrated the typical refrigerator behaviour scenarios for identifying the relationship between the mundane practice and the product design:

- Issues related to style of the fridge and/or freezer:

The users of under counter fridge had to always bend, squat or kneel down to reach the back and bottom of the fridge for search for the desired item and sort out content. Figure 4 illustrates this in more detail.



Open the under counter fridge | Bend down to load the food in | Transfer items from the top | Bend down again to reach the bottom

Stand up to close the door | kneel down lower to look at back of the narrow shelf | kneel down to make space and sort out the contents | Squat down to search the back

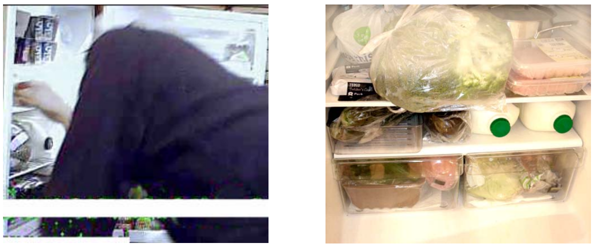
Figure 4: routines of movement when using the under counter fridge

- Issues related to interior design of the fridge and/or freezer:

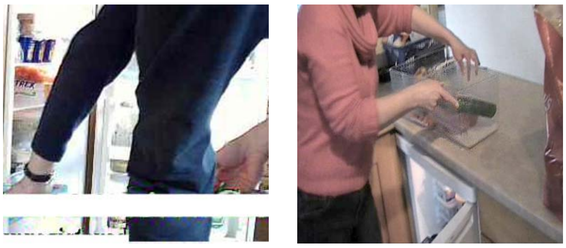
There is time wasted, when the door is open, for the user to search for the desired item and to shuffle food stuffs around to make them fit when restocking the shelves, doors and drawers. The participants also exhibited how they designed and rearranged their fridge to meet their individualised needs as tasks could get achieved with a degree of effortlessness. Table 4 gives some examples of this.

Table 4: daily interaction with the shelves and drawers

The top shelf is too high to reach; “things on the top may be the things that you do not pull out very open. It is just storage” (MUS-F07).



Kneel down to search back of the narrow shelves; Rearrange narrow shelves as storage according to the size of food packaging. Additional container is added to remove items at back easily.



It is hard to sort the content out at the bottom. “Drawers never seem to open wide enough to get larger packet in. I end up emptying a drawer to be able to fill it again” (MUS-F14); “When I put the shopping away, if I have a lot of things to put in, then I take the drawer out … I put the fresh, new items at the bottom, I can reorganized the drawer” (MUS-F10).

Observing routines showed that users often take drawers or containers out of fridge to load food in on the near floor or the worktop far away from the fridge with the door open.

- Issues related to the accessories of the fridge and/or freezer:

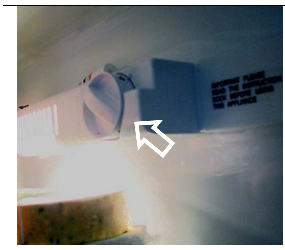
Product-in-use observation not only captured flaws in product performance and highlighted design limitations of the accessories and functioning parts in the fridge and/or freezer but also uncovered the latent customer needs and ways in which users adapt products to better suit their needs. Combined the findings of observation and the interview, the gaps between the consumers’ “actual” versus “assumed” needs were identified, some examples are given in table 5 below.

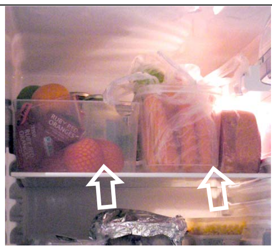
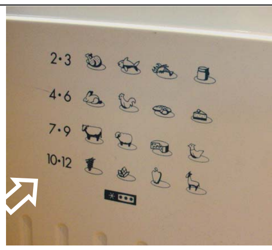
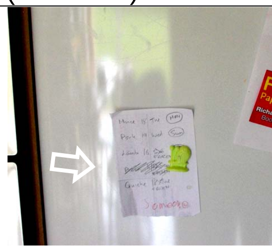
Table 5: use condition of the accessories of the fridge and/or freezer

Poorly designed door vs. user’s arrangement of the shelf–“the door compartments are difficult to arrange for cartons and bottles” “We took out egg tray out here (to make the space high enough for keep the big bottle)” (MUS-F03).

Poorly designed can holder-“This is space for cans but it just wastes space. We have hardly ever put cans” (MUS-F07).

Poorly designed temperature control panel-inside the door, users have to open the door to check or adjust the setting.



Poorly designed temperature adjuster - Hard to understand	Poorly designed temperature setting - Hard to read	Poorly designed ice-cube tray	Use condition of egg trays - most of the participants do not use the egg tray
 User's way of storing eggs - "we put eggs into the fridge with box since there is date on the box" (MUS-F01).	 User's way of storing eggs - keep eggs with boxes on the egg tray (MUS-18).	 User's adaptation to design - Butter is stored on the egg tray, while the egg box is on the top shelf (MUS-02)	 Poorly designed egg tray - if user has eggs in, it wastes a lot of space on the top and second shelves (MUS-F15).
 Use condition of bottle racks (MUS-F08)	 Underlying needs – additional containers to keep cheese, fruit and vegetables.	 Poorly designed instruction	 Underlying needs "food calendar" - note of expired date of food on the fridge

Discussion

The results of the main user study clearly illustrated that the different usage patterns of household fridges and freezers resulted in unnecessary energy consumption. Analysis of the routine use of household electronic appliances proved that the three perceptive elements of the daily practice model [23] existed between which users swung. It explicitly suggested the behaviour in terms of the use of household cold appliance is complex and informed or restricted by a range of internal and external factors. There is a gap between environmental intention and real action as well as issues arising from the routine practice performed automatically with little deliberation ingrained in our use patterns of the fridge and freezer. It was also found that how the household appliance and kitchen infrastructure came together with the purpose of directing and influencing people to behave in a specific way. "We know that those will fit into the door, so I do not buy three 4 pints of skimmed milk. I do not buy what would not fit in the door. So I may modify what I buy" (MUS-F07). However, due to the complexity of motivations for shifting behaviour, different levels of interventions need to be designed accordingly to ensure behavioural and habitual change.

The following sections presented a few examples of the how design-led interventions can facilitate user behaviour change to improve the energy efficiency of the fridge and freezer. Based the discussion, the suggestions were divided into four levels: product design, system design, service design and food packaging design.

Changing user behaviour through sustainable product design

Firstly, the results show there is a lack of consumer awareness of the link between their personal behaviour and the direct impact on the environment and energy use. Design-led interventions would need to build on energy conversation to guide a behavioural change. Designing an effective way of communicating makes sure consumers know how to use the product efficiently through a range of design interventions through providing information, choice, feedback or behaviour spur [23], such as, to inform the most energy efficient temperature of the fridge, “I have no idea what it is at the right temperature or wrong temperature” (MUS-08). For example, some kind of scale is for users to see how efficient they are, advisedly; in term of cost because that is what people understand. Also as MUS-03 suggested, a counter was to set on the door to count the door opening times, “when you know you open the door a lot, maybe you try to reduce that (MUS-03).

A few design features could limit behavioural energy waste of the fridge and/or freezer, such as, separate temperature drawers and shelves and “more doors” to reduce the cold air exploration when the door was open. Making good use of space inside the fridge was also raised. “The design means you must be careful to leave about 4 inches unfilled at the front of each shelf” (MUS-F09). Reducing the intervals between the shelves and pulling out the shelves like a drawer could be useful to get things at back easily and to make much more useful room in fridge. Additional, rather than dictated by the fridge manufacturers, the fridge could “be modular”. A more adaptable interior and a kit of compartments, for example, to provide sufficient adjustability of shelves would enable individuals to decide the food location and to create the optimum arrangement of their food and drinks in the fridge. To reduce door opening times, designers could create internal structures for organising food for children use or for the temporal routines of food preparation and consumption including morning breakfast and evening meals and special milk and butter/margarine storage solutions for making quick meals and drinks, as in the case of through-the-door ice dispenser. What is more, designing to display the contents better would reduce the opening time for seeking items inside the fridge or even seeing the foods without opening the door. For instance, using shallow drawers or software to keep a food shopping record can provide consumers with a clear view of the food inside the fridge and freezer decreasing food waste and the amount of time with the door open.

Influencing user behaviour through sustainable system design

The modern kitchen design restricted operating condition of the fridge and freezer. “We have got it (under counter fridge) next to the cooker, which is stupid, but we did not design the kitchen” (MUS-F06). It needs to be a good advice for people when they are designing their kitchen, if they do by themselves, they need advice; if the kitchen suppliers design it, they need to be forced to consider that. Taking the food storage, preparation, fridge and freezer design and kitchen design as a whole into consideration, designing a food system in the kitchen could encourage sustainable energy and food consumption behaviour, such as, to reduce the energy losses of transferring items and the food waste. Furthermore, kitchen infrastructures would be designed for the user to operate electronic appliances at ease and get tasks achieved with deftness and effortlessness. For accessing the items inside easily, the fridge might be placed at the suitable height and location for the practitioners to reduce the time waste for bodily movements.

Facilitating change in user behaviour through sustainable service design

As discussed the loads in the fridge and freezer had links with having parties or visitors, the frequency of shopping, going on holiday, having a healthier diet, having children, growing vegetables in garden, living in friendly community as well as whether they ordered a food delivery online. To address these changes in loads in the fridge and freezer during all the stages in the family’s life, providing consumers with options through service design could encourage them to think about their use behaviour and take responsibility for their actions. This may be achieved by designing a flexible modular system with separate temperature settings, and supplying a modular service with the customer to meet their needs during their different life stages. For example, when they harvested the vegetables or had visitors, an additional fridge or freezer module can be switched on; when their grown-up children left home, the fridge unit could be dissembled and the needless parts could be collected by the manufacturers. Or a local community services may be set up to reduce the energy and food waste during the food life cycle from growing, storage, consume, give away leftover or needless purchase to the end of food disposal. Moreover, considering the life cycle of the fridge and freezer, more services should be provided by manufactures including supplying more choices of the accessories kit, such as the compartments, shelves and drawers, detailed DIY repairing tips and other measurements to encourage the user replace older machines with newer, more efficient ones. This would avoid unnecessary replacement, usage of a second cold appliance and unnecessary energy consumed by more than ten-year-old mode.

Assisting change in user behaviour through sustainable food packaging design

According to the type and shape of the food or food packaging, more behaviour constraints and affordances [23] can be designed to lock the location of the food quickly. And the label on the packaging needed to be read easily in order to transmit the information better and to reduce the time for user to check the expired date or look for the desired item with the fridge door open.

Conclusion

This paper concludes that usage patterns studies can offer rich resources to assist manufacturers and designers in minimising environmental impacts product use. The qualitative data uncovered the way in which the product is used and its unnecessary energy use, the gap between environmental awareness and real action, and the reasons for such a gap. It also identifies the critical role of product design plays in daily routines. By understanding the limitations with current designs and the affects they have on user behaviour, a real potential was identified to enable design to create "better" user behaviour. The suggestions presented are some examples of design ideas that could be drawn from the behaviour study. The next step will be to create some 'behaviour changing' product ideas from each suggestion and test them with users to evaluate their effectiveness. In addition it is the intention to demonstrate how design can lead to overall reduced energy use by modifying user behaviour.

References

[1] Evans, S., Burns, A. and Barrett, R., *Empathic Design Tutor*, Cranfield University, UK, 2002

[2] Maguire, M. *Methods to support human-centred design*, International Journal of computer studies, 55, 2001,pp. 587-634.

[3] Wood, G. and Newborough, M., *Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design,* School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, Scotland, UK. 2003

[4] Energy Saving Trust, *The rise of the machines. A review of energy using products in the home from the 1970s to today*. June2006. Can be downloaded at: www.est.org.uk/uploads/documents/aboutest/Riseofthemachines.pdf .

[5] CAT. *Cool It!* Tipsheet, Centre for Alternative Technology. Retrieved March 25, 2007, from http://www.cat.org.uk/catpubs/pubs_content.tmpl?sku=PUBS_20/08&key=ts_cool

[6] BERR, *Energy White Paper, Section Two. The Low Carbon Economy, Chapter 3: Energy Efficiency*, 2003, from http://www.berr.gov.uk/files/file21192.pdf.

[7] MTP., *Domestic: Cold Appliances, Market Transformation Programme, Supporting UK Government policy on sustainable products*, 2007, from http://www.mtprog.com/SelectProductStrategy.afspx?intSelection=1&intSector=1

[8] Environmental Change Institute. *40%house*, Oxford University, Oxford, UK, 2005

[9] Lockwood, M. and Murray, R. *RED Future Currents: Designing for a changing climate*. 2005

[10] Mintel, *Fridges and Freezers - UK - March 2007 Market Intelligence Essentials, Marke Intelligence: UK*, 2007

[11] Mennink B.D. and Berchowitz D.M.,*Development of an Improved Stirling Vacuum Super Insulated Fridges with Thermal Store and Photovoltaic Power Industrialized and Developing Countries*, IIR Conference - New Applications of Working Fluids in Refrigeration and Air Conditioning, Hanover, Germany. 1994

[12] VHK. *Refrigerators and Freezers, product case 5*, Methodology Study Eco-design of Energy-using Products (MEEUP) for European Commission,final report, Delft, 2005, from http://www.vhknet.com/download/MEEUP_Methodology_fin.pdf.

[13] Takahiro Tsurusaki, Yumiko Iwafune, Yoshiaki Shibata, Chiharu Murakoshi, Hidetoshi Nakagami *Actual Energy Consumption of Top-Runner Refrigerators in Japan*, Jyukankyo Research Institute, Inc., Japan, 2006

[14] MTP., BNC11: *Domestic refrigerator test standard vs. real-use energy consumption*, 2007 http://www.mtprog.com/ApprovedBriefingNotes/PDF/MTP_BNC11_2007May2.pdf

[15] Strauss, A., and Corbin, J., *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Sage Publications Ltd, USA, 1990

[16] Miles, M. B., and Huberman, A. M. *Qualitative data analysis: an expanded sourcebook* (2 Ed.). Thousand Oaks: Sage Publications. 1994

[17] Sanoff, H. I*ntergrating programming, evaluation and particiation in design: A theory Z approach*. Hants Ashgate.1992

[18] Knoblauch, H., Schnettler, B., and Raab, J. *Video Analysis. Methodological Aspect of Interpretive Audiovisual Video-Analysis in Social Research*. In Knoblauch, H., Schnettler, B., Raab, J. and Soeffner, H. (Eds.), Video Analysis: Methodology and Methods, Oxford: Peter Lang. 2006

[19] Lofthouse, V. A. and Lilley , D. *What they really, really want: user centered research methods for design*, International design conference–design 2006, Croatia, May 15-18, 2006

[20] Kelley, T. *Innovation Begins with an Eye, the Art of Innovation ,*IDEO.Doubleday Publishing, 2001

[21] Daut, T. *Recording the "Habitus"*. In Pole, C.(Eds.) Seeing in Believing? Oxford: Elsevier. 2004

[22] Berger, A. A. *Media Research Techniques* (2 Ed.). London: SAGE, 1998

[23] Tang, T. and Bhamra, T. *Changing Energy Consumption Behaviour through Sustainable Product Design*, international design conference-design2008, Croatia, May 19-22, 2008.

[24] Jackson, T. *Motivating Sustainable Consumption; A review of evidence on consumer behaviour and behavioural change* In: A report to the Sustainable Development Research Network as part of the ESRC Sustainable Technologies Programme Centre for Environmental Strategy, University of Surrey, Guildford. 2005

[25] Siegle, L. *Your home may be hurting the planet Guardian Unlimited*, June 8, 2006, Can be downloaded at: http://observer.guardian.co.uk/shellenergy/story/0,,1793286,00.html

Other Appliances

Strategies to Enhance Energy Efficiency of Coffee Machines

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Abstract

Coffee machines use large amounts of electricity for permanent ready (keeping hot) and standby modes. With relatively simple measures as auto-power-down, better insulation of boilers and low standby the energy efficiency can be strongly enhanced. The energy saving potential of an efficient versus a typical espresso machine is about 120 kWh per year. High efficiency coffee machines only have a consumption of about 50 kWh per year, capsule machines even below 40 kWh. The entire EU stock of coffee machines (estimated 100 Mio) thus holds a saving potential of up to 12'000 Mio kWh per year.

Conventional espresso machines usually have higher electricity consumption than A-class ovens or A++ refrigerators. Regarding the great differences between products and the high saving potentials, it is strongly recommended to take measures.

In the framework of the IEE-project “Euro-Topten” a measuring method for coffee machines was developed. The Blue Angel (der Blaue Engel) now follows a new cluster approach. As part of this approach it has launched a climate protection label (Klimaschutzzeichen). Thereby Euro-Topten and the Blue Angel coordinated their procedure and harmonized the measurement method. The criteria are applied for the label the Blue Angel and for the selection of best products of Europe on www.topten.info. The Euro-Topten measuring method is suggested for a labeling directive and might be incorporated into the IEC 60661 standard (Methods for measuring the performance of electric household coffee makers), respectively.

Particularly an EU-energy label for coffee machines and an appropriate application of the new European MEPS for standby (including auto-power-down) would be very effective measures to raise the efficiency of coffee machines, which should be covered by the preparatory study for ecodesign on coffee machines, Lot 25.

Already today, diverse high efficiency models of several important brands of coffee machines are available on the European market. They are presented on www.topten.info and – from June 2009 – can be labeled with the Blue Angel. An EU-energy label would be appropriate and would give important incentives to trade and industry to develop and offer more energy-efficient coffee machines.

European Market Situation of Coffee Machines

According to GfK more than 18 million coffee machines are sold in Europe every year, thereof 10 million traditional filter coffee machines and 8 million espresso and filter-pad machines (see table 1).

Sales coffee machines 2006/2007

Sales coffee machines (in 1000)	**2006**	**2007**	**Increase**
Filter	10'076	10'072	0.0%
Filter-pad	3'546	3'410	-3.8%
Espresso portioned	1'647	2'356	43.1%
Espresso fully automatic	824	870	5.5%
Espresso piston hand-operated	1'358	1'246	-8.2%
Combi Espresso-Filter	312	284	-8.9%
All Coffee Machines	**17'763**	**18'238**	**2.7%**
All Espresso- and Pad-Machines	**7'375**	**7'882**	**6.9%**

Table 1: Total sales figures of coffee machines of 18 European countries (AT, BE, CH, DE, FR, GB, ES, IT, NL, PT, SE, DK, FI, GR, PL, HU, CR and SR) according to GfK [1]

Traditional filter coffee machines still have the highest market share (55%). For comfort and quality reasons there is a strong trend towards espresso fully automatic and an extremely strong trend towards espresso portioned machines. Low-comfort and low quality machines such as filter-pad machines, espresso piston hand-operated and combi espresso-filter are losing market share. The (most energy relevant) espresso machines and filter-pad machines have a market share of 43% and a considerable growth of 6.9% (table 1).

However, according to private communications from producers it is known that national markets differ strongly. In some countries such as Italy, Switzerland or Portugal espresso machines have a huge market share of over 70%, while in other countries the share of espresso machines is still below 20% (e.g. Belgium, Germany or the Netherlands). In Belgium or the Netherlands filter-pads are quite popular with a market share of about 40%.

Furthermore it is interesting to have a look at the monetary value distribution of the markets. Because espresso machines are more expensive than filter-pad machines and especially filter coffee machines the impression is quite opposite to that of mere units: espresso machines (espresso portioned, fully automatic, piston hand-operated) are strongly dominating the market in value.

High Energy Saving Potentials of Coffee Machines

Coffee machines account for a significant proportion of the electricity consumption in more and more European households and offices. Most conventional coffee machines account for higher electricity consumption than A-class ovens or A++ refrigerators.

According to the research project "Standby consumption of household appliances" by the Swiss Agency for Efficient Energy Use (S.A.F.E.), Espresso and filter-pad machines use large (unnecessary) amounts of electricity for permanent ready (keeping hot) and standby modes [2]. According to measurements and tests by Topten [3], energy consumption of a typical espresso machine is about 170 kWh per year. With relatively simple measures as auto-power-down (auto-off), better insulation of boilers and low standby the energy efficiency of coffee machines can be strongly enhanced. High efficiency espresso machines only have a consumption of about 50 kWh per year, capsule machines even below 40 kWh. The magnitude of the energy saving potential of an efficient versus a typical espresso machine is about 120 kWh per year.

The stock of coffee machines in the EU is estimated 100 Mio units, consuming 17'000 Mio kWh per year and causing electricity costs of about 2'500 Mio Euro. Roughly 20 Mio coffee machines are sold per year. If in the next years these 100 Mio coffee machines in Europe could be replaced by energy-efficient models, 12'000 Mio kWh or 1'800 Mio Euro electricity costs could be saved yearly.

Appropriate technologies for high efficiency exist and have been introduced on the market. According to Topten a number of high efficiency models of several important brands of coffee machines are available on the European market (see www.topten.info) [4].

The Blue Angel

The Blue Angel is the world's oldest and most well-known eco-label. The German Federal Environment Ministry, the German Federal Environment Agency and the Environmental Label Jury decided to increasingly focus the Blue Angel on climate protection: From the beginning of 2009 the Blue Angel will also award to particularly energy-efficient and climate-friendly products and services. This is an important attribution for climate protection [5], [6].

The new climate label advises consumers which products are particularly energy-efficient and climate-friendly. To enable consumers to spot the best products more easily the new Blue Angel logo will provide corresponding additional information to visibly express this message in the logo itself.

The Blue Angel – A Climate Protection Label

The new label will, for a start, be available for ten product groups in a first phase, and further 90 product groups in phase 2 (2009–2012). The first new Blue Angel were passed by the Environmental Label Jury in April 2009 in Berlin, one of them being espresso machines.

The requirements for espresso machines (RAL-UZ 136) were elaborated by Oeko-Institute (Freiburg, Germany) [7]. The energy-relevant award criteria for coffee machines were developed by Euro-Topten.

Topten

Topten is a voluntary, non-profit international project to create a dynamic benchmark for the most energy-efficient products on national markets and to work in partnership with market actors to stimulate market demand for the highest-efficiency devices. The successful concept was first started in Switzerland (www.topten.ch) and Germany (www.ecotopten.de) in 2000.

Topten is a transparent system to continuously identify the best products available in each product category, with energy efficiency a key criterion. Topten makes the regularly updated results freely accessible via a user-friendly Internet interface. To each product category, selection criteria and comprehensive recommendations are available.

Topten is coordinated by the Topten International Group TIG (Paris, France).

"Euro-Topten" is a project supported by the European Commission Intelligent Energy – Europe IEE and national funding. So far, Topten is online in 12 European countries. Until 2010 it will be expanded to 16 European countries and include 20 partners (budget: 1.7 million €).

For coffee machines Topten has developed:

- Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for household use
- Criteria for energy-efficient Coffee Machines
- Recommendations for policy design

Euro-Topten Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines

In the framework of Topten, the IEE-project "Euro-Topten" and the Swiss Agency for Efficient Energy Use (S.A.F.E.) have developed a measuring method to identify the energy consumption for the typical use of a coffee machine.

A first version of the Euro-Topten "Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for household use" [8] was developed within the scope of a Swiss research project and presented at EEDAL conferences in Torino 2003 [9] and in London 2006 [10]. Since then the method has been optimized and harmonized with the Blue Angel. As an essential advancement it is now possible to consider the effective time lag of auto-power-down according to actual factory settings instead of using a fixed value of one hour.

It is of prime importance to choose appropriate measurement methods. The experiences of Topten over several years indicated that key features as auto-power-down with short preset delay and insulated boilers have to be included carefully. On the other hand, effects as energy consumption for producing coffee or vapor, which look important at a first glance showed to be of little relevance but would cause measurement methods to become unreasonably complex and ineffectual in praxis. The production of coffee and vapor is not measured, but is accounted for with a standard value, as it requires relatively little energy and the difference from one machine to another is minimal (details see [11]). In fact, the "keeping warm" energy consumption exceeds the consumption for coffee and vapor production by far, even with short auto-power-down delays below 1 hour.

The aim of the measuring method is to identify the annual energy consumption. In the same way as for all devices and appliances with different modes and usages, the annual energy consumption has to be determined for uniform – i.e. standard – usage. The measuring method is based on a "standard use", for which a typical number of "coffee periods" and the electricity consumption for coffee and vapor production (no measurement, standard value) are assumed. The typical "standard use" was investigated within the scope of the Swiss research project "Standby consumption of household appliances" [2].

The measuring method covers the operating modes ready (water is kept at temperature for an immediate cup of coffee), standby (water is not kept at temperature) and off. Coffee machines with flow-type heater entered the market newly; as they have no regular ready mode, the measuring method has been extended. For these machines coffee productions are a condition for activating from standby; therefore measured and normalized production energy consumption replaces the standard value otherwise used. Optional energy saving modes that are not activated in the factory setting can be included in an additional measurement. If a machine has accessory heating elements that can be switched off (e.g. heated cup trays, steamer), additional programmable modes can be measured next to the factory setting. The electricity consumption can be measured for coffee machines both with and without auto-power-down function.

The measuring method includes amongst others definitions, tolerances and control methods, instructions, measurement report, standard use and calculation of electricity consumption.

Criteria for Energy-efficient Coffee Machines of the Blue Angel and Topten

The Blue Angel and Euro-Topten have defined criteria for energy-efficient coffee machines. In order to be labeled by the Blue Angel and to be displayed on www.topten.info coffee machines must particularly meet the following technical criteria:

- Include an auto-power-down function switching off the permanent heating of the water after a certain time lag to standby or off.

- The time lag of the auto-power-down (auto-off) according to factory setting must not exceed 1 hour for fully automatic and piston hand-operated machines and 30 minutes for capsule machines.

- Power consumption in the standby (or sleep) mode following the auto-power-down must not exceed 1.0 W.

- The machine must have a mains switch (power consumption less than 0.3 W).

- Electricity consumption in the ready mode period defined by the Topten measuring method (E_{ready}) must not exceed 35 Wh for fully automatic and piston hand-operated machines, and 30 Wh for capsule machines. The Topten ready mode period is very simple: heating up from cold, re-activate after 30 minutes, reactivate again after 30 minutes, wait for auto-power-down.

Methods

- According to Euro-Topten "Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for household use" [8].

- Tolerances and control methods according to "Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for household use".

Explanatory notes

- Typical coffee machines without auto-power-down use about three quarters of their total electricity consumption for the permanent keeping hot (ready) and in standby mode. Therefore assessment criteria must cover auto-power-down as well as the power consumption in ready and standby mode. Taking into account all three aspects guarantees that models with auto-power-down, but generating electricity losses in ready and standby mode higher than the savings, cannot be selected.

- The time lag to standby mode is a crucial factor and must not be based on generalized values. The time lag has to be included into the measurement the way it works in real usage situations. Otherwise, the measuring result of the major loss of electricity is incorrect. Especially if the time lag in reality is shorter than generally assumed, or with innovative approaches such as flow-type heaters the assumption of a typical value leads to incorrect results.

- As soon as there is a sufficient range of energy-efficient coffee machines on the market, the criteria regarding power consumption in the ready mode will be tightened (see recommendations below).

- The following aspects are not relevant for the electricity consumption and mainly depend on the consumers' individual preferences: pump pressure (preparing a "real" espresso requires at least around 8 bars), flavor of the coffee, noise and a machine‘s handling properties such as how it is switched on, how the coffee is received, how to clean or to decalcify it.

- It has been assumed that for coffee machines the electricity consumption during the use phase is environmentally more relevant than the production and the disposal phases, as it is the case in other electrical products with a high power consumption such as cooling appliances and freezers (e.g. EuP-studies cooling appliances [12]. A comprehensive analysis will be realised within the EuP study regarding coffee machines).

- Furthermore for the Blue Angel there are requirements concerning lifetime, material and consumer information [7].

Impact and Experiences with the Euro-Topten Measuring Method for Coffee Machines

The Euro-Topten measuring method for coffee machines is applied at:

- Best Products of Europe: Presentation of the most energy-efficient coffee machines on the European market (www.topten.info, 5 models, May 2009). Best Products of Europe is an aggregation of all national Topten-projects and displays the very best products all over Europe.
- Topten Switzerland: Presentation of the most energy-efficient coffee machines on the Swiss market (www.topten.ch, 24 Models, May 2009). The selection criteria on national Topten sites are still less stringent than on the European site www.topten.info.
- Austrian Energy Agency AEA: Presentation of the most energy-efficient coffee machines on the Austrian market (www.topprodukte.at, 16 Models, May 2009). The selection criteria on national Topten sites are still less stringent than on the European site www.topten.info.
- Most important Swiss retailers: Coop bases its label “Oecoplan” for high efficiency coffee machines on Euro-Topten selection criteria and measuring method. As from summer 2009 Migros is distinguishing Topten-Coffee machines at the point of sale as Topten-products.
- Over 30 energy consumption testings of coffee machines by order of retailers, environmental organizations and producers of coffee machines.
- German Energy Agency (dena): International competition and award of the most efficient coffee machines at the Domotechnica/Koelnmesse, February 2008 [13].
- European Commission: Award of the most efficient coffee machine at the Klagenfurt Fair in the framework of the “Euro-Topten Product Exhibition and Competition”, September 2008.
- Promotion programs of Swiss electrical utilities to increase the market share of high efficiency coffee machines: Zurich Municipal Electric Utility (ewz, since autumn 2007 [14]), Berne Municipal Electric Utility (ewb, June 2009), Electric Utility Tamins (ewt, since 2008), Basel Municipal Electric Utility (iwb, during spring 2008).

Strategies to Enhance Energy Efficiency of Coffee Machines

Unlike many domestic appliances, a coffee machine’s electricity consumption is not required to be declared up to date. Regarding the great differences between products and the high saving potentials by known simple technologies such as an auto-power-down function, better insulation of boilers and low standby consumption, an EU-energy label for coffee machines would be a very effective measure to raise efficiency of coffee machines. It would give incentives to trade and industry to develop and offer energy-efficient coffee machines. There are several initiatives aiming at defining criteria regarding the energy efficiency of coffee machines:

- In the framework of the IEE-project “Euro-Topten” and together with the Blue Angel a measuring method and calculation formula for the electricity consumption of coffee machines have been developed. Furthermore, criteria regarding the energy efficiency of coffee machines have been defined. Both measuring method and energy efficiency criteria are being applied successfully (see above).
- At EU-level, energy efficiency of coffee machines is being studied, and policy measures will be dedicated. In the frame of the Ecodesign of Energy using Products (EuP) preparatory study Lot 25 [15] the introduction of standards, the obligation to declare electricity consumption, an energy label and minimum efficiency requirements will be taken into account.
- The German Federal Environment Ministry, the German Federal Environment Agency and the Environmental Label Jury have linked the Blue Angel to the global warming discussion and introduced an eco-label “Blue Angel for climate-relevant products”. The project is conducted

by Oeko-Institute covering ten product groups in a first phase (finished in april 2009), one of them being coffee machines [5], [6], and further 90 product groups in phase 2 (2009-2012).

Recommendations for Policy Design

The market of coffee machines in European countries is still extremely disperse. However, in all countries there are strong trends to higher sales figures and towards high end products (real espresso- and filter-pad machines instead of traditional filter systems). It is a great challenge to introduce energy efficiency measures in a country before a boom of first equipment acquisition.

The following aspects are recommended to be considered thoroughly in the EuP Lot 25 study:

- Minimum Energy Performance Standards (MEPS) based on the Blue Angel and Euro-Topten constraints:
    - Ready mode: 35 Wh (coffee fully automatic, piston hand-operated) respectively 30 Wh (capsule and pad machines) (tier 1). More stringent criteria should be foreseen for tier 2 (according to market development).
    - Standby: 1 Watt
    - Standby consumption is regulated already in tier 1 of the EuP Standby Directive (Lot 6 [16]), while auto-power-down is covered in tier 2 (the appliance must go into standby as quickly as possible).

      However, it is very important that both functions – standby and auto-power-down – are also included in this horizontal measure for coffee machines. (Euro-Topten uses both terms auto-power-down and auto-off synonymously).

      An auto-power-down automatically terminates the heating of a machine after a certain time of inactivity. This time lag should not exceed 1 hour.
- Efficiency potentials:
    - Better insulation of boilers
    - Optimizing of the auto-power-down
    - Low standby: see above
    - Standby and auto-power-down actually are covered by the EuP Standby Directive, Lot 6. Nevertheless it is crucial to include for coffee machines both modes in the horizontal measure.
    - Solution with continuous-flow heaters
- Profiting from the preliminary work done by Euro-Topten and the Blue Angel. Technical design standards for coffee machines on the basis of Euro-Topten measurement methodology and a standard usage pattern are suggested and might be incorporated into the IEC 60661 standard (Methods for measuring the performance of electric household coffee makers 2003-03) [17]).
- Introduction of an EU-Energy Label for coffee machines.
- Coffee machines could be included in the EcoLabel as well. The EU EcoLabel informs consumers that appliances meet certain ecological requirements during its entire life cycle (Legal base: regulation No. 1980/2000 (EC) on a revised Community Ecolabel award scheme, ec.europa.eu/environment/ecolabel/index_en.htm).
- Promotion programs are important to increase the market share of high efficiency coffee machines. Possibilities are rebate programs, information campaigns, or bonus-malus systems addressing producers.

References

[1] GfK Group, Nuremberg, Germany, www.gfk.com

[2] Nipkow, J., Bush, E.: *Stand-by consumption of household appliances*, Swiss Agency for Efficient Energy Use S.A.F.E. on behalf of the Swiss Federal Office of Energy SFOE, Berne 2003. Download from: www.electricity-research.ch (search: appliances)

[3] Euro-Topten and Topten International Group TIG (Paris, France): www.topten.info

[4] Topten-Selection of high efficiency coffee machines (Super Automatics, Capsule Espresso Machines, Selection criteria): www.topten.info

[5] German Federal Environment Ministry (BMU), German Federal Environment Agency and Environmental Label Jury: *The Blue Angel – Active in Climate Protection. Labelling of particularly energy-efficient and climate-friendly products.* Joint press release from 19. 11. 2008, Berlin.

[6] The Blue Angel: *Eco-Label and Climate Protection – Blue Angel for Climate-Relevant Products – Information Paper.* Press release from 19. 11. 2008.

[7] RAL-UZ 136: Espressomaschinen / Kaffeemaschinen mit hohem Druck. Vergabegrundlage für Umweltzeichen. Ausgabe June 2009. *Previously unreleased.*

[8] Euro-Topten and Swiss Agency for Efficient Energy Use S.A.F.E.: *Measuring Method and Calculation Formula for the Electricity Consumption of Coffee Machines for household use*. 2009. Download: www.topten.info

[9] Swiss Agency for Efficient Energy Use S.A.F.E., Nipkow, J., Bush, E.: *Stand-by consumption of household appliances*, Presentation at EEDAL 2003 Conference, Torino.

[10] Swiss Agency for Efficient Energy Use S.A.F.E., Nipkow, J., Bush, E.: *Energy label for Coffee Machines*, Presentation at EEDAL 2006 Conference, London.

[11] Topten International Group TIG (Paris, France), Nipkow, J., Bush, E.: *Coffee machines: recommendations for policy design.* Download: www.topten.info

[12] Preparatory studies for Eco-design Requirements of EuPs (Tender TREN/D1/40-2005). Lot 13: Domestic Refrigerators & Freezers.

[13] German Energy Agency (dena), Award on the most efficient coffee machine: *Ausgezeichnete Kaffeevollautomaten. Strom sparen beim Kaffeetrinken.* Press release.

[14] Ewz: Rebate and promotion program of Zurich for high efficiency coffee machines. More information: www.topten.ch

[15] Bio Intelligence Service: *Non-tertiary coffee machines.* Preparatory studies for Eco-design Requirements of EuPs (TREN), Lot 25.

[16] Ecodesign of EuP Products. Preparatory Studies Lot 6: Standby and OFF-mode Losses of EuPs.

[17] IEC. *Methods for measuring the performance of electric household coffee makers*, international standard IEC 60661, Ed. 2.2, 2006-02.

Energy Implications of Appliances in Cars

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Abstract

The average European spends several hundred hours per year in cars. For many, this exceeds the time they spend in all buildings except for their primary residence. It is not surprising then that vehicles are being equipped with an increasing number of appliances and services commonly found in homes, including lighting, heating, cooling, audio equipment, DVD players, and computers. New appliances, such as refrigerators, are appearing in Japan and the United States. Some new vehicles are available with high voltage outlets, suggesting that future appliances will be moved between home and vehicle. Vehicle-based devices have different usage patterns than those in residences and sometimes have different designs. Their total energy use is poorly documented but still appears to be less than a few hundred kWh. On the other hand, the price of generating electricity to operate these devices is much more expensive--often over € 0.67 /kWh--because the prices of petrol and diesel are so high. Thus, the economics of improved energy efficiency for vehicle-based appliances are very different.

Introduction

Europeans spend roughly an hour a day in cars. [1] The principal role of a vehicle is to move from one location to another but the driver and other occupants also accomplish other tasks while in their vehicles. For many people, cars are the second most frequently occupied "building" (after homes). For this reason, the energy consumed inside cars to provide services and amenities should be treated as another sector, similar to commercial buildings, schools, or hospitals.

Many activities performed in cars are similar to those in buildings: the occupants listen to audio entertainment, drink, eat, communicate with friends on the telephone, and watch videos. Sometimes the vehicle behaves as an extension of an office with a computer, display, and printer. All of these activities traditionally occurred inside buildings and have either shifted or expanded to mobile use. Similarly, appliances that once resided solely in buildings are now becoming common in vehicles or being moved from one to the other.

These trends suggest that the automobile has become an extension of the residence and office. It is therefore important to understand the energy implications of the appliances within cars and their relationship to other buildings.[1] What are the major appliances in cars? How much energy do they use? Finally, what are the prospects for future energy use and savings?

Energy Supply Systems in Cars

Cars transform petrol or diesel fuel into mechanical drive, heat, and electricity. Waste heat from the engine is applied to heating the car's interior, defrosting windows, and tempering cool air from the air conditioner. Electricity is generated from the engine's crankshaft through a generator or alternator. If the engine is switched off, then a battery supplies the electricity. Electricity is typically supplied as 12 Volt Direct Current (DC).

The conversion system is relatively inefficient, especially when supplying electricity. In the worst case, the electricity is generated, used to charge the battery, and then discharged to supply the load. Each step involves losses. In a few cases, the resulting low voltage DC is further transformed to 115/220V AC power, resulting in further losses. The conversion losses and inefficiencies are summarized in Figure 1.

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[1] During heat waves, people sometimes "escape" their uncomfortably hot homes by driving in their air conditioned cars.

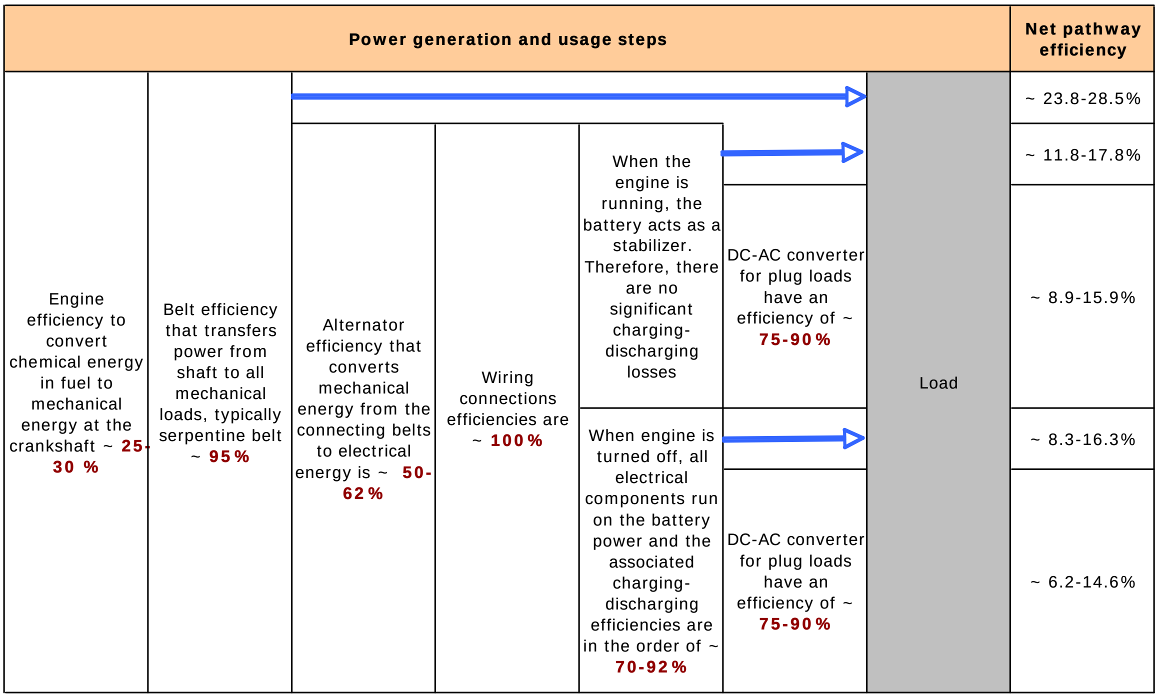


Figure 1. Conversion efficiencies in cars (from Thomas et al. [2])

Thus, efficiencies for most paths of electricity generation range from 10 – 20%.

Long-haul trucks often have separate, fuel-powered, generators to operate while idling. These devices are used to operate refrigeration equipment, cabin heaters, air conditioners, and electronics. The impetus for these units has been both environmental—to reduce emissions and noise—and economic.

Hybrids and other advanced technologies sometimes employ different designs. For example, hybrids typically power the air conditioner through an electric motor. Electric cars use heat pumps to provide heat because the electric motor cannot supply enough waste heat. In these cases the economics shift radically because delivering heat becomes expensive.

The combination of low efficiencies and high fuel prices means that the cost of supplying a kilowatt-hour of electricity is very high: about € 0.67/kWh, assuming 15% efficiency and 1.1 €/litre of petrol. This is at least 5 times the typical prices of electricity supplied to domestic or commercial customers attached to the grid. The high cost of generating electricity on board makes photovoltaic-supplied electricity—at about € 0.50/kWh-- surprisingly economic. Toyota will begin offering an integrated photovoltaic panel in the roofs of 2010 Toyota Priuses. [3]

What Appliances are Present In Cars?

A car resembles in many ways a small home. The car has a building envelope, with walls, windows—lots of them— doors, and air infiltration. Like a building, a car is heated, cooled, and ventilated. The modern car offers its occupants illumination, a range of consumer electronics, and food-related services. A partial list of the appliances found in cars is found in Table 1. These are all familiar end uses in buildings. Cars are also experiencing a growing problem related to standby power use. The consequences are more severe, however, because cars are unable to start after periods of inactivity. Manufacturers are installing larger batteries to handle these loads. The energy devoted to propelling the car is *not* considered buildings-related (and still represents the overwhelming majority of energy consumption of vehicles).

Table 1. Services and appliances found in cars

Service	Remarks
Space heating	Generally provided by waste heat but electric vehicles use heat pump
Air conditioning	Traditionally the AC has been one-speed and blended with waste heat to maintain desired temperatures, but new designs use variable output ACs.
Ventilation	Fans, drawing either outside air or recirculating conditioned air
Powered windows	Motors
Lighting	Cabin lights
Radio	Primarily over-the-air but satellite and internet appearing
CD player	
MP3 player	This may have an on-board hard disk or include a removable source (e.g., ipod)
DVD player	Typically delivers video to back seats
Video display (GPS, DVD)	Some vehicles already have more than three displays
Refrigerators	With volumes less than 5 litres, cooled (or heated) with Peltier-effect thermoelectric system
Computers	This refers to user-operable computers; most cars have one or more on-board computers controlling vehicle operation
Powered speakers	
Security system and video surveillance (for back up)	
Transformers (low voltage to 115/220 VAC)	These are sometimes used to provide emergency power to homes
Assistance to disabled persons	Wheelchair hoists
Cup warmers	

This list continues to grow as the vehicles evolve to provide additional services. These devices appear earliest in the vibrant after-market, especially for mobile offices, trucks, and recreational vehicles. The end uses are described below, as well as the energy they consume. Examples of strategies to reduce fuel consumption are also included.

Heating and Cooling Appliances

Automotive heating systems typically use waste heat from the engine and electrically operated fans (blowers) to distribute the warm air. Cooling systems in cars run about 80% on shaft power and 20% on electricity. The fans draw 150 – 400 W depending on size and setting. [4] The operating hours will depend on the climate but will most likely be between 100 and 1000 hours/year. At 200 hours/year and 200 W average operating power, a fan will consume roughly 40 kWh/year in the heating mode.

Air conditioning is a more energy intensive service because the motor must operate a compressor to remove heat and a blower to distribute the cool air. Until recently, air conditioners in cars drew power from the crankshaft and therefore varied output depending on engine speed. Waste heat was blended with the cold air to obtain the desired temperature. (This process is functionally identical to "terminal reheat" used to control temperatures in some air conditioned buildings.) This design is thermodynamically wasteful but technically the simplest to manufacture and control.

Air conditioners in cars have more extreme design constraints than found in typical homes. They must be sized so as to rapidly lower the temperature of a dangerously hot (over 70°C) vehicle interior down to a comfortable temperature. [5] The cooling capacity is typically around 6 kW, which is similar to that needed to cool a house. The air conditioner is thus drastically oversized for most conditions. The typical system COP for an auto air conditioner is about 1.6 [6] but test conditions differ from residential units—the blower contribution is not included, for example--so this value is only indicative [7].

Air conditioning is well known to add a significant penalty to fuel consumption. In the United States, air conditioning is responsible for 5.5% of vehicle fuel consumption. [8] Air conditioning in cars consumes about 40% of the primary energy required to cool U.S. residential buildings. Vehicle-based air conditioning energy use is high after taking into account the small “floor area” in vehicles and the relatively few hours of occupancy. In Europe, vehicle-based air conditioning energy use probably exceeds that used in European homes (because air conditioning in homes is still relatively rare).

Measures to conserve vehicle air conditioning fuel use resemble those used in buildings, that is, reducing thermal loads and increasing the efficiency of the cooling equipment. Cars face unusual constraints, however, because the conservation measures cannot interfere with driving. Thus, shading, overhangs, window placement, and insulation opportunities are limited. Nevertheless, highly reflective paints and coatings, roof insulation, and better control of air circulation offer many savings opportunities. Improvements in compressor efficiencies—beginning with variable capacity systems—offer additional savings. One new vehicle includes more intelligent controls that optimizes use of re-circulated air. Rooftop photovoltaic collectors have also been investigated as a means of cooling vehicle cabins while the car is parked [5] and will appear in at least one vehicle in 2010. [3]

Lighting

Lighting energy consists of interior and exterior lighting. The IEA [9] estimated the electricity consumed by each external light function based on the power and number of hours of operations. The data are summarized in Table 2. Headlights could be considered as either a driving-related energy consumption or, like buildings, as “exterior lighting”.

In 1995, the typical car had four interior lights. In 2001 the average had already climbed to 15 lights [10] Some are rated as high as 10 W but a shift to 1 – 5 W LEDs is underway. The estimates in Table 2 assumed eight 3-watt bulbs in the average vehicle and that lights were operated for 3 minutes/day, which might occur as a result of door opening and closing (see Table 2). However, some lights may stay on while the car is moving or occupants may deliberately keep some lights switched on while the car is stationary; including these activities could easily double energy consumption. In any event, the electricity consumed by cabin lights is small.

Table 2. Lighting use in cars (adapted from IEA [9]**)**

Light	Operating Time (hours/year)	Typical Power for Incandescent Design (W)	Annual Energy Use (kWh/year)	Est. percent time in operation (based on 480-580 hrs driving/year)
Headlamps (high beam)	24	65	1.6	4-5%
Headlamps (low beam)	115	55	6.3	20-24%
Rear tail lamps	115	7	0.8	20-24%
Daytime running lamps	141	40	5.6	24-29%
Interior lights	146	20	2.9	25-30%
Brake lamps, turn signals	5	not estimated		
Dashboard lights	5	not estimated		
Total			17.3	

Auto manufacturers have gradually applied more efficient lighting technologies. Their principal target has been to improve efficiency of headlamps. However, a kind of "rebound effect" has occurred. Most of the savings have been converted into brighter lights rather than lower power. This is not the case for hybrids, where improvements in efficiency are usually translated into greater driving range. The 2010 Prius, for example, switched to LED low-beam headlights to principally to save power. Brake lamps and turn signals are gradually converting to LEDs. The impetus has been increased reliability rather than energy savings.

Consumer Electronics

Cars host an increasing number of consumer electronics. Some products are unique to cars (hands-free telephone, GPS, etc.) but most are modifications of products already present in homes, such as audio equipment, hard disk drives, and DVD players. A third category, mobile devices, are frequently carried between the home and the car; these include mobile telephones, mp3 players, ipods, laptop computers, etc. A popular option now is a USB plug, which allows even more devices to charge or operate through the auto's power system. These devices draw relatively little power but may become a significant vehicle load when many of them are in use. In the United States, occupants in a large vehicle could easily be simultaneously operating a GPS screen, two DVD screens (and players), and audio equipment. Furthermore, many of the devices draw standby power if not completely shut down. For this reason, the controls and logic need to be carefully designed to avoid draining the battery after the engine is switched off. (Mobile devices designed for use in homes are particularly likely to have uncontrolled standby power.)

Microsoft and Apple (and others) offer operating systems to coordinate many of these devices. This feature adds another power burden on the car while operating and (sometimes) even while the engine is off.

Another new option is mains power outlets in cars. This appears as both an option in new cars and as a retrofit. An inverter converts 12 VDC to 115/220 VAC with an output range of 50 – 250W. The presence of mains power in cars means that nearly any appliance can also be used in a car. Many inverters are equipped with USB ports, too. A third application for the inverter is as a back-up power supply in case the home experiences a power failure. The Prius has already been used to provide emergency power to the home during black-outs in the United States. This feature may be encouraged by utilities so as to reduce peak power demands (although the peak power benefits of these systems would need to be larger to be economic).

Computers will be used more frequently in cars. The computers will be used for work-related needs and as a source of music, audio books, and other information. Other computers are being specifically designed for installation in cars. Busses and some vehicles already have internet access with wireless service; this feature is likely to become more popular in cars. Examples of modifications are displayed at mp3cars.com. These are mostly custom-made modifications but demonstrate the kinds of equipment that are technically feasible to install.

Until recently there has not been much pressure to design more efficient electronics for use in cars. However, electric vehicles need to conserve electricity wherever possible so as to extend range. These new constraints have encouraged electronics manufacturers to re-examine efficiency options. Bose Electronics, for example, recently announced a new audio system that draws 50% less power than its predecessors which is specifically designed for use in the 2010 Chevy Volt. The system is also 30% smaller and 40% lighter. General Motors estimated energy savings from the Bose system was comparable to removing twenty kilograms of mass from the vehicle. Similar efforts will no doubt be applied to designing more efficient displays, which have not been significantly modified for mobile use.

Refrigeration and Heating Appliances

Fuel-powered stoves and refrigerators have long been used in campers and other recreational vehicles. Now, small refrigerators and heating devices are appearing in ordinary vehicles. Most refrigerators rely on 12 V power and exploit the thermoelectric effect for cooling. A typical unit draws 40 W. This is not an especially efficient thermodynamic process but requires no moving parts or flammable chemicals. Manufacturers have little incentive to improve efficiency because they compete almost entirely on first cost and buyers are unable to see differences in energy use. As a result, manufacturers still rely on foam insulation rather than, say, vacuum insulation panels to reduce heat gain.

The same thermoelectric system can also provide heat to keep beverages warm. Cup warmers are also becoming popular for commuters. Others rely on power from a USB connection (though it’s unclear how effective they actually are).

Consumers will carry appliances from their homes into their cars when the cars have 115/220V power. These appliances’ electricity consumption will probably be small because the number of operating hours is limited by the number of hours they occupy the vehicle. The chief problem will be dealing with standby power consumption after the engine has been switched off.

Conclusions

Europeans spend roughly an hour a day in cars. For many people, cars are the second most frequently occupied “building” (after homes). For this reason, the energy consumed inside cars to provide services and amenities should be treated as another buildings sector, similar to commercial buildings, schools, or hospitals. The number of appliances in a typical car is increasing as cars becomes extensions of the office, living room, and dining room.

With the exception of air conditioning, appliance energy use in cars is always much smaller than in homes. The total electricity use is probably less than a few hundred kilowatt-hours per year. However, the cost of that energy may still be significant because car-generated electricity often exceeds € 0.67/kWh, which is several times higher than typical domestic tariffs. A roof-top photovoltaic unit may be cost-effective.

Power inverters also make it possible to operate mains-voltage appliances in the car, so consumers will move them from one building to another as needed. Their energy consumption is likely to be modest.

Standby power consumption will be a more serious technical problem in cars than in homes. Uncontrolled standby power demands—though small--will quickly drain a battery. New management schemes will be needed to handle the diverse equipment and services found in cars. A partial solution will be the incorporation of photovoltaic panels on the roof which will be able to offset standby power consumption.

Acknowledgements

This paper draws heavily on an earlier paper by Thomas et al. [2] but has been revised and updated with new information and discussion.

References

[1] Brundell-Freij, K., *Travel demand – trends and driving forces*. 2008, WSP Analys & Strategi.

[2] Thomas, V., et al. *Appliance Energy Use in America's Second Home – The Automobile*. in *ACEEE Summer Study on Energy Efficiency in Buildings*. 2008. Pacific Grove: Ameridan Council for an Energy-Efficient Economy.

[3] Karin, J. *2010 Solar Roof Prius* TFOT (The Future of Things) 2009 February 20, 2009; Available from: http://thefutureofthings.com/pod/6252/2010-solar-roof-prius.html#.

[4] Siemens VDO. *Siemens VDO Produces 200 Millionth Air-Conditioning Blower Motor*. 2005 [cited 2009 February 15]; Press Release]. Available from: http://www.vdo.com/press/releases.

[5] Rugh, J., et al. *Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and New Solar-Reflective Glazing*. in *SAE World Congress*. 2007. Detroit: SAE.

[6] Gado, A.E.-S.A.E.-D., *Development of a Dynamic Test Facility for Environmental Control Systems*, in *Department of Mechanical Engineering*. 2006, University of Maryland: College Park.

[7] Hendricks, T. *Multi-Variable Optimization of Electrically-Driven Vehicle Air Conditioning Systems Using Transient Performance Analysis*. in *SAE Vehicle Thermal Management Systems*. 2003. Detroit.

[8] Rugh, J., V. Hovland, and S.O. Andersen. *Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioners*. in *15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit*. 2004. Washington, D.C.

[9] International Energy Agency, *Light's Labour's Lost*. 2006, Paris: IEA.

[10] Murphy, P. *Spotlight on Automotive Interior Lighting*. Machine Design.com 2001.

Energy savings potentials in domestic ventilation products and the necessary technologies

Abstract

Standard kitchen ventilation products use traditional technology. In the beginning hot air with low density from cooking was forced through a hole or a chimney system to extract smoke, fumes and odours to the outside. Since the electrification, this is done by fan driven chimney hoods that incorporate also lighting systems. With the rising sensitivity towards energy consumption all the electrical consumers are in focus. Adequate, high efficient solutions for the direct consumption of chimney hoods are easily to name: ec-motors instead of condenser or shaded pole motors, LEDs for lightings and low standby technologies. A soon to come energy label will specially focus on fan efficiency.

The major energy waste though usually comes from the installation and usage of the hood in extraction mode rather than operating the hood in recirculation mode. So the energy content, given by temperature differences between inside and outside temperature, of the air volume that is extracted to the outside must be considered. We call that the indirect energy consumption. For countries with domestic heating and/or cooling systems this amount of energy tops the direct energy consumption.

Zero emission homes combine chimney hoods with central ventilation installations and thus use heat exchangers also for kitchen fumes on the cost of considerably lower extraction performance for the hoods. For standard installations this is not applicable.

The extraction mode still has a much better acceptance and ranking among consumers. Industry has found good working solutions for oil and grease filtering, but for odour reduction, a basic demand for recirculation, there is no solution that comes close to just extracting the air to the outside. But there are some promising approaches for improving the efficiency of a hood by measuring and improving the steam catch rate. Flexible systems with combinations of extraction and recirculation are possible. Optimizing fan speeds and with it the extracted air volume by monitoring the air pollution is available. Also combinations of common and new technologies could be a way to significantly enhance odour reduction. A simple way is to enlarge filtering area using the well known charcoal. Odour binding and destruction can be a possible field for research and development. In industrial surroundings, technologies against germs are already in use.

To take energy efficiency serious industry has to add solutions for better energy efficiency to its performance specifications so that the consumer gets a real choice.

The kitchen ventilation

Ventilation systems have a long history since mankind uses fire for heating and cooking in closed surroundings. In the beginning it was just a guide for fresh air and fumes by natural ventilation but its character changed now to more flexible, active, fan driven systems. With it the main task also changed to keep a good kitchen climate while cooking by extracting oil and grease, odors and humidity and, of nearly similar importance, to light the hob working area. All of the tasks are related to energy consumption and thus in the focus of the considerations to follow.

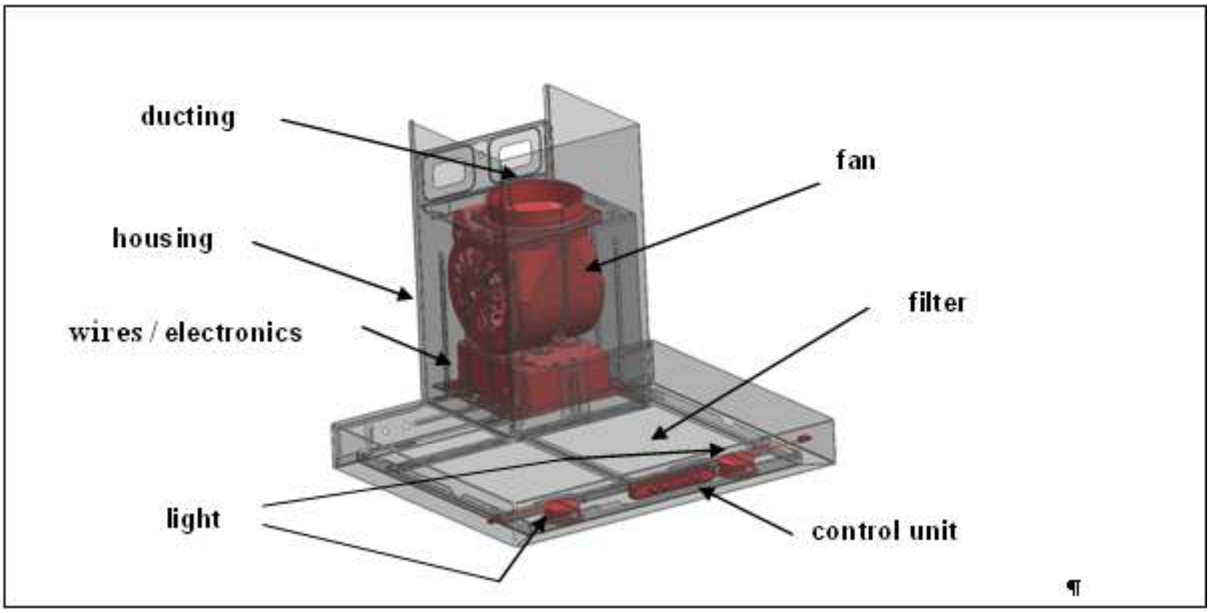
World wide the usage of kitchen ventilation products, so called hoods, is common in developed countries' households with access to electrical energy and the evolving trend to built-in kitchens. The main tasks and system architectures of hoods worldwide are similar, but design and usage vary according to local cooking preferences and market demands.

Unlike other kitchen appliances, hoods are not only a plug and play solution with a given size and volume, but form a system of the appliance and the ducting, which is planned and installed not by the hood manufacturer. In common, ducting either extraction or recirculation plays a major role in system performance and energy consumption. Historically, kitchen ventilation systems only used extraction and still do in some countries. Recirculation has a common performance disadvantage and is mostly used for cost reasons (e.g. in vented spaces) or the lack of allowance to modify walls. But rising energy costs and tight houses (passive houses) force the industry to find new solutions to fill the performance gap.

The European market sums up to approx. 8.8 million hoods sold per year with a slight growth tendency.

State of the technology

A common hood comprises of the following main components:



Main components of a hood

The fan

The task of the fan is to establish a fluid flow through the hood. Thus it creates a low-pressure area under the hood to catch the upturn vapors from the underneath hob cooking area, guide the vapors through a filter system and transport it through the ducting.

Low-pressure cannot be directed, so the air suction is shaped half-spherical underneath the hood and transports the cooking vapors and a high fraction of the so called auxiliary air volume.

Hood fans comprise radial forward or backward curved impellers with single- or double-sided air inlets. The possible air volumes range from 150m³/h up to 1000m³/h. A calculation scheme for the selection of a hood's air volume bases on the fact that there is a by pass for the cooking vapors and thus the hoods cannot catch the all vapors in the first cycle. So more than one filtering cycles are necessary, expressed by the so called air exchange rate of approx. 8-12 times per hour the kitchen air volume. For a kitchen of 20m² this gives an air volume of approx.: 10/h * 20m² * 2,5m = 500m³/h. For comparison, a common house size in Western Europe has a free air volume of approx. 500m³/h. So, theoretically a hood fan is capable of exchanging the air content of a house once per hour. Given a room size of 50m², as is becoming popular with open kitchens the air volume according to the above calculation already needed to be 1250m³/h.

A second important factor to the customer's selection of a hood and fan system is the noise level for the standard use declared in the catalogues. The noise level is given in dB (A) re 1pW.

Motors of hoods are of the asynchronous type and have usually 3-4 speed settings for balancing the needed air volume and the noise level. The speed is adjusted by several motor windings rather than by resistive or leading edge controls.

The most popular motor technology of a hood fan is the shaded pole motor. Due to its low manufacturing costs it is used in approx. 62% appliances of the yearly European sales, followed by the condenser motor, which is used practically in the rest of the sales volumes. Shaded pole motors are usually found in low performance hoods whereas condenser motors are found in medium to high class and performance hoods.

The lighting

The second important task for a hood is to light the working area of the hob. Commonly incandescent light bulbs and low-voltage halogen lamps are used, rarely also fluorescent lamps. For a good light distribution the amount of light, the direction and the uniformity of the light is necessary. The performance of this is measured according to the standards. Costumer also chooses according to light color as for cooking natural lighting colors are preferred to make the food look fresh and healthy.

The energy efficiency of fluorescent lamps is the highest followed by the halogen lamps and the worst efficiency have the incandescent lamps.

The electronic and the control

The low cost, high sales volume products usually have mechanical switches with 3-4 steps. These solutions do not have significant stand-by or operating losses. The functionality is rather simple and allows the user only to choose the air volume and whether the light is on or not. Medium and high class hoods usually have an electronic control with additional comfort and performance features. The highest speed setting there has a timer driven fall-back option to the second highest setting for noise comfort reasons. The highest setting then is called a booster mode. Other options like displays, colored switches, timers, filter cleaning cycles and so on occur. The air volume can usually also be chosen in 3-4 steps.

The electronics do have low operating losses that are of minor importance compared to the light and fan demands, but have stand-by losses which we will analyze.

The (oil & grease) filter

The filter is the most important part of the hood for the execution of its main task. Filters are made of meshed metal baffles out of aluminum. Locally there are other filter systems due to historical reasons and cooking habits. So in the United States so called baffle filters are demanded by the customer for its professional look, although the performance is minor compared to that of mesh filters. In China there are very low performing filters on the market due to high volumes of low viscose of oil while cooking.

Filter efficiency of European hoods is usually very high and ranging for the best performing hoods in the area of 95%. On the other side we can see also performances of as low as 60-65% especially with exotic or not well designed filters.

The housing

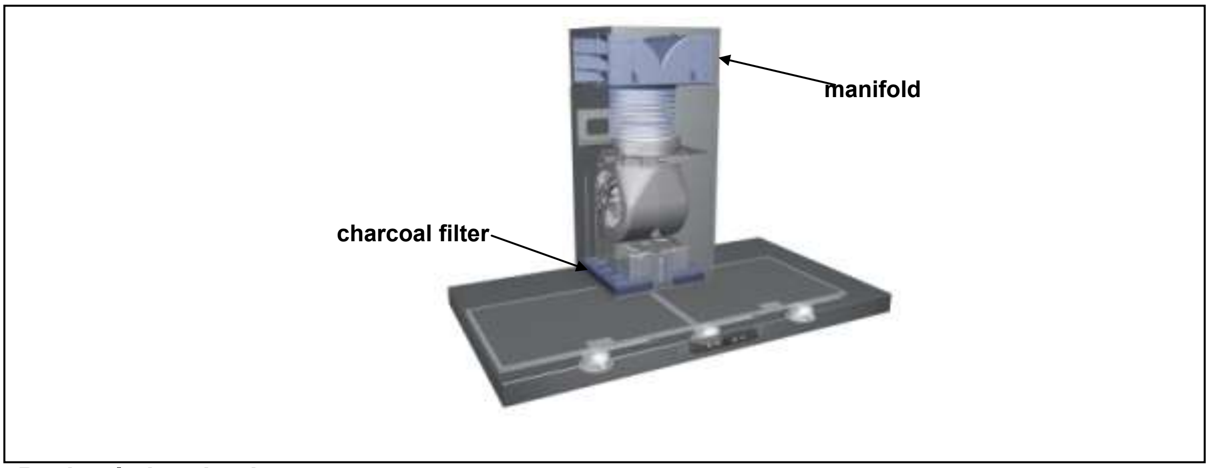
The housing nowadays plays a major role for the customer as it is perceived as design issue. Nevertheless it's inner and it's outside shape, its dimensions, it's height above the hob and a lot of other factors, like the vapor catch rate, influence the performance of a hood. Other than the width, these factors usually are not considered when buying or designing a kitchen ventilation system.

The most common design today is the standard hood that is hidden under the kitchen furniture. On the opposite the so called chimney hood is getting more and more popular. All of these are wall mounted appliances that are located over the hob. With the change of housing style to bigger rooms and open kitchens island hoods, hanging from the kitchen ceiling, are becoming familiar. Especially in the United States down-drafts, hoods that are located in the floor cupboard and extracting the air from the back or the side of the hob working space are well known.

The ducting

It is of great importance, that a hood is one of the only appliances in the kitchen that are not only plug and play, but form a complete system by needing a ducting for the inlet and the outlet. The performance is highly dependent on the ducting, but the manufacturers only have limited or no access to this and the customers choice and installation.

There are 2 main ducting styles, the extraction and the recirculation. The extraction simply is a tube system guiding the air through a hole in the wall to the outside. For a proper system design the inlet air volume and the extraction air volume needs to be the same, but this fact is not always considered in the planning phase. Together with small ducts this can limit the system performance significantly. The recirculation has an additional charcoal filter to reduce odors and then guide the air back to the kitchen again by a manifold.

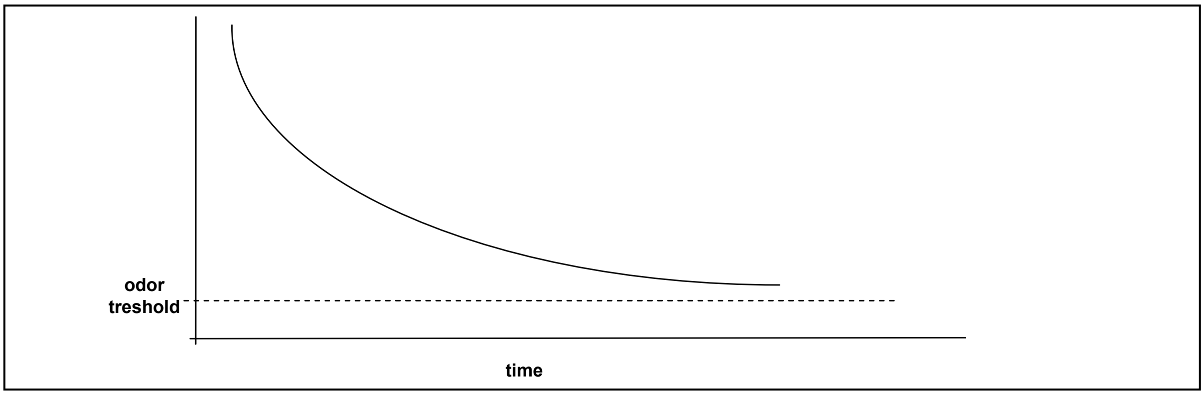


Recirculation ducting

In Western Europe both are found in nearly equal distribution, although there is no exact market data available.

In Asia and the United States mainly extraction is common, as is also, if possible by the house or apartment circumstances, mostly in warm countries. In China with its high oil quantities charcoal filters, and thus recirculation, cannot be used as the filter would block very fast due to the low oil filter performance.

The answer to the question why the costumer prefers extraction, even if he needs a ducting system and a hole in the wall, is easy. European style hoods have a very good performance in filtering oil and grease out of the cooking vapors – but not the odors. In addition the charcoal filter reduces the air volume (up to. 30%) and increases the noise level significantly. Not to forget that charcoal filters need replacement every 6 months. Manufacturers all rely on charcoal filter and may vary the base material, size and thickness to show performance differences. Nevertheless the performance is low as is shown in the following chart as even with "good" performing charcoal filters the threshold of the odor that the human nose can detect is lower than the resulting odor concentration even after a longer filtering time with diverse filter cycles.



Odor reduction curve for standard charcoal filters

Other known technologies for odor reduction, as high temperatures or chemical reactions, cannot be used due to the high air volume, the open system design and the costs.

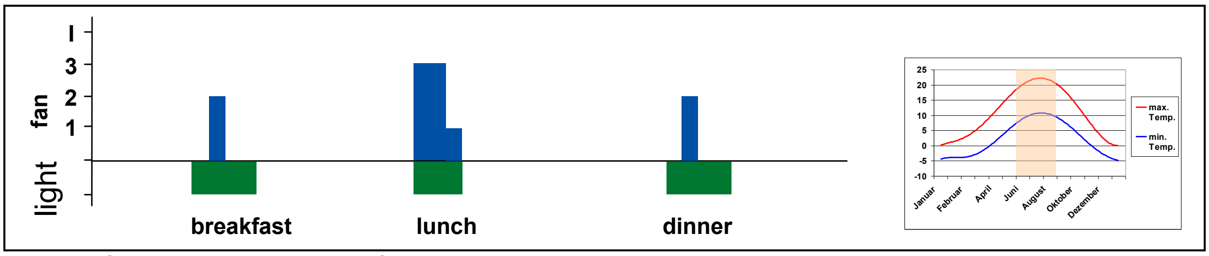
Humidity, that is produced while cooking, is not of significant importance today that needed special attention in the design and the usage of a hood.

Today’s energy consumption of hoods

The following chart gives an overview over the energy consumption of a hood. We divided the energy consumption in 3 segments:

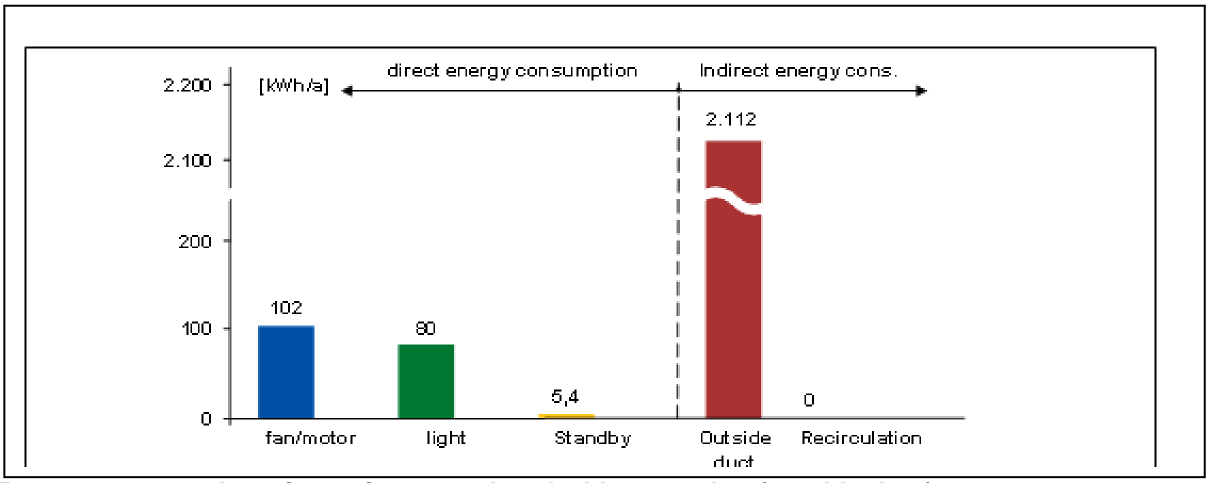
- Direct energy consumption, as a result of the electrical consumer like fan and lighting
- Indirect energy consumption, as a result of the ducting
- Performance losses (or gains) as a result of hood system design

For the direct energy consumption we use a high performance hood with 1000m³/h and 80W of halogen lights. For the calculation of the indirect energy consumption we take the city of Fulda as climate reference. The usage profile highly influences all aspects of the energy consumption. We use an average profile that can be found in any country.



User profile and climate chart for energy consumption calculation

Under the term of performance losses we subsume diverse approaches, so there is no clear classification scheme for the terms. The performance losses cannot be expressed in total amount and therefore we only name them in the latter without values. Energy reduction targets in some cases on the direct energy consumers, but mostly on the complete system.



Energy consumption of a performance hood with extraction (outside duct)

The charts show that the relation of energy consumption for the fan and the lights are balanced, but the indirect energy consumption outperforms the direct energy consumption by a factor 10! Here the lost heating energy in autumn, winter and spring lead to these figures. A similar picture could be drawn if we considered lost cooling energy of an air conditioner in summer time. Standby losses are of no high importance.

The figures show that it is preferable to improve also the indirect energy consumption.

Technological improvements

We will discuss some improvements of all 3 energy consumption segments as stated before.

Improvements of the direct energy consumers

For the fan technology and the lighting there are better technologies available.

Condenser motors instead of shaded pole motors

A shaded pole motor has the least energy efficiency and is outperformed by a factor of 2 by the condenser motor. The condenser motor is widely used in middle and high performing hoods, but in the low performing area with a market sales volume of 62% of the yearly sales in Europe the shaded pole motor is dominant.

The European Commission has started actions to reduce energy consumption in home ventilation systems with a study covering also hoods. The study focused on direct energy consumption of the fans in hoods (for the hoods part of the study). Ducting and, with it, indirect energy consumption are not considered. All calculations base on the European sales of approx. 8.8 million units per year.

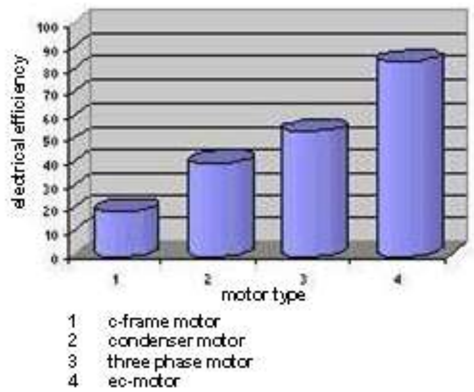
In the study it could be shown, that a cut-out of all shaded pole motors in 2 steps until 2016 could reduce the yearly energy consumption by 260GWh in 2020 and the following years. As a constraint, the shaded pole motors are assumed to be exchanged by condenser motors with the same performance.

Manufacturing on-costs in average pay off for the consumer and are compensated by lower lifetime energy costs, so that there is a win-win situation for the consumer and the environment.

Ec-motors

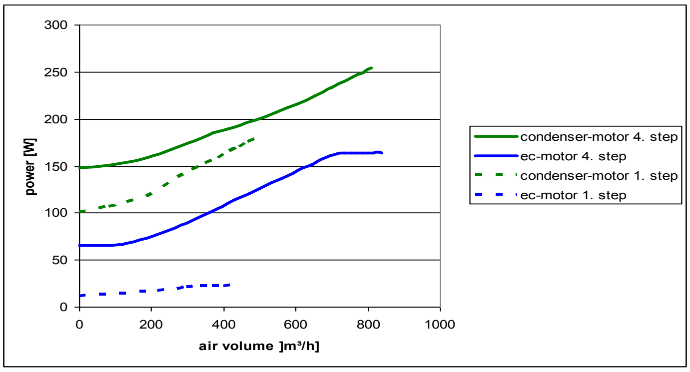
The best energy efficiency has the electronic commutating motor, the ec-motor. It is approx. 2 times more efficient than a condenser motor. The high energy efficiency is a direct result of the fact that ec-motors only have one winding system, and with it only one time the losses, compared to condenser motor. The opposite side is formed by a permanent magnet. A second advantage is that due to exact control, the magnetic fields match the torque demands better and thus losses can be reduced. As this technology relies on and needs an additional electronic control it is not cost effective today, which means that the comparison of additional manufacturing costs cannot be compensated by the gains of energy efficiency and lower energy consumption over the lifetime.

An additional positive effect for the ec-motor comes from the fact that the torque of that motor is significantly higher than that of e.g. the condenser motor and so it can cope better with higher counter pressures, as are given with recirculation systems or low diameter ducts. The standard electronic control is, without extra efforts, capable of variable speed. That could be used for adaptive systems.



Energy efficiency comparison (source EBM, Mulfingen); example of a condenser motor fan

Ec-motors consume in part load, as is in low speed usage, significantly less energy compared to the other motor types. The energy efficiency is relatively stable over the speed range, whereas the energy efficiency of shaded pole or condenser motors worsens in average in lower speeds, thus using only little energy less compared to full speed.

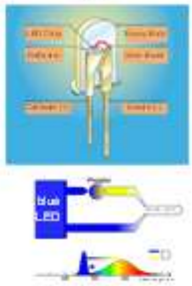


Comparison of energy consumption of ec-motor and condenser motor in part load

Lighting systems

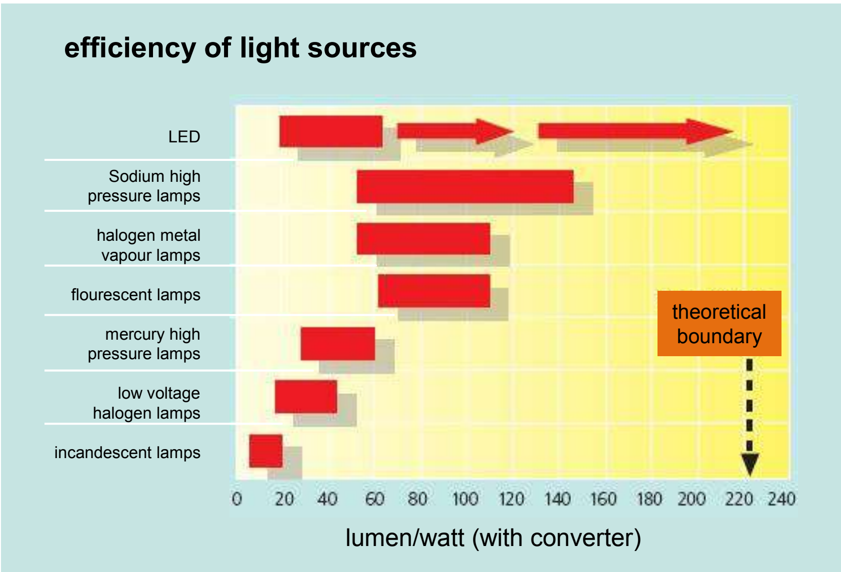
Fluorescent lamps have the highest efficiency in light technology today. But LEDs are expected to outperform this – and they are accepted more by the customers due to modern appearance and its modern light color style.

With the EU directive and other national bans of incandescent lamps, the lighting industry worldwide is forced to develop new and more energy efficient alternatives solutions under the constraints and demands of consumers to keep the existing sockets, ambience, temperatures and, if possible, light colors, as there are countless numbers of lights installed. The following table gives an overview over existing and future lighting systems for hoods.

type:	incandescent lamps	high voltage halogen lamps	low voltage halogen lamps	energy savings lamps	LED
					
principle:	thermal emitter	thermal emitter with inert gas	thermal emitter with inert gas	gas discharge with low temp. plasma and fluorescence	elektroluminescence (with color conversion)

Lamp types used in hoods

In the following there is a comparison of energy efficiencies of important actual and future solutions.



Energy efficiency of lamp types

The inefficiency of incandescent and also halogen lamps are easily explained by the active principle of making light. The latter create light just by thermal radiation and thus only little of the needed energy is used for the wanted light. For incandescent lamps the ratio is approx. 5% of light yield compared to 95% of (heating) losses. For halogen lamps this ratio is better but the principle is the same. Fluorescent today have the best energy efficiency, but lack of acceptance due to very low band widths of light colour frequencies of cheap, low quality products, making it a rather artificial light compared to the warmth of daylight or incandescent light. The same is true for LED lights as the principle of creating the white light has similarities. On fluorescent lamps the white light is created by a phosphoric layer at the inside of the glass tube which is stimulated by high energetic stages in the plasma phase. For the most common LED technology for white lights an original blue LED light is used. To get a white light the complimentary colour yellow needs to be added. This is created by an electroluminescent layer in the LED similar to the fluorescent lamps principle. The mixture of the blue and yellow colour gives the desired white. Light colours can be chosen by the combination of LED wavelength and the electroluminescent layer.

Today’s LED solutions don’t meet all expectations as there are: high costs, not the highest efficiency and the sensitivity towards temperature. All of these criteria are expected to be improved in the coming years due to massive R&D efforts worldwide. An advantage already given is that the life span of LEDS is far higher than that of all other popular light technologies. So LEDs already have an obvious advantage because of the lower waste expenses and the savings of otherwise needed replacement of light bulbs.

Using a similar approach as was done for the EuP study LOT10 on hoods fan motors we can derive that a change to more energy efficient light systems will also have a major reduction on energy consumption in households. The calculation base is not prepared as the necessary data of usage, given by the consumers using habits, the current distribution of lights used in hoods and the trend towards new lighting solutions is not given. But by looking at the numbers of the energy reduction potentials of the fans, also changing the light technology can have a noticeable impact on European energy consumption.

Improvements at the indirect energy consumption

As we saw in the energy consumption comparison the indirect energy outperforms the direct energy consumption by a very high factor. This is valid for extraction only, but with an estimated ratio of 50% of all hoods sold and installed in Europe it has the greatest effect on energy consumption. As these energy losses are part of the heating (or cooling) system of a domicile, it is not thought of naturally in link with the hoods energy consumption. Also, customers do not have a tangible idea of the amount of energy as there is no reference to them. Even Architects and e.g. the norms for energy efficiency of buildings, like the EnEV in its subsequent versions in Germany, do not, and cannot, deal with this matter directly. Indirectly the leak proof of domiciles is of rising importance, and with it, the issue of extraction is touched also.

A second problem is that there are no popular satisfactory technical solutions for odor reduction on the market. So we will discuss existing, but not commonly known solutions and also fields for future improvements and research.

Improved charcoal filters

Existing charcoal filters are made of granulated charcoals or charcoal foams. Due to service reasons, the filters usually must fit in the given space in the base of a hood. This limits the possible performance as the square, a significant factor for the performance, is very limited. Thus common odour filters lack of performance. To overcome this, the system had to be expanded for the use of bigger, external charcoal filters. There are solutions on the market but not common yet. But still we cannot expect a completely satisfying performance.

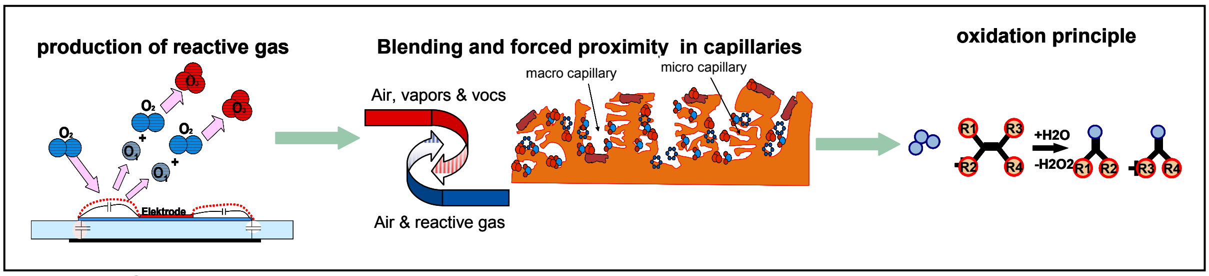
What, in all solutions, needs to be considered is the so called fluid shortcut. That is, that if the circulated air outlet is close to the inbound air section, we see that the air takes the shortest way between the outbound and inbound section. Thus fumes that spread out into the room are hardly caught by the ventilation system again, leading to areas with higher odour concentration in the kitchens not directly accessible by the ventilation system.

Plasma technology

Other possible technologies for odor reduction are limited due the high air volume and the open system. Thus e.g. thermal solutions cannot be considered. A technology that is newly on the market deals with plasma and radicals to destroy odors by chemical oxidation.

The plasma is created by a dielectric barrier discharge, a technology similarly known from plasma TV sets. A flat dielectric material is covered by 2 appropriate electrodes on either side. The electrodes are set under pulsating direct current of about 3kV peak. With the plasma also ozone and as a result reactive gases are created. If the system is in the outbound air flow of the hood, the reactive gases and the already filtered vapors mix. The oxidative reaction needs time so it was an advantage to timely “store” the mixture into micro and macro capillary structures. As also ozone is produced we have to prevent safely that these unwanted components spread out of the system. The easiest way to combine both tasks is to use a charcoal layer that surrounds the system completely. Ozone recombines in the charcoal layer and the surface structure is an ideal haven for the mixture of reactive gases and the vapors.

With the given, but usually not known, parameters of air volume, humidity and amount and structure of the VOCs it is not easy to design and balance the system to have a good odor reduction performance and to limit the production of reactive gases to the only necessary limit. In advance, all additional filters, as given by the charcoal filter, limit the hoods performance as the air volume drops and the noise level rises.



Principle of odor reduction by reactive gas approach with plasma

Even as there are systems on the market, the technical and also cost problems are not in a state to let the plasma solution take over bigger market shares in the near future. But it seems to be the best approach yet as it showed significant better performance in odor reduction compared to standard charcoal filters and in some cases is close to the odor reduction performance of extraction hoods.

One problem still remains. Odors produced while cooking are highly complex. So it is not easy (or even impossible) to detect, classify and properly measure all different VOCs as the human nose can do it. So all laboratory studies with odor reducing systems need to rely on one or a few organic VOCs for performance verification – but the result and with it the satisfaction of the costumer is only judged by the nose.

If industry can design a well performing system that, in the eyes of consumers, is accepted, trusted, reliable and not too costly, this system could have a major impact on indirect energy savings of kitchen ventilation systems.

Hybrid ducting systems

One of the most interesting solutions for reduction of the indirect energy consumption is the so called hybrid ducting system. It simply combines the advantages of extraction solutions with that of recirculation solutions. So there is no new technology and, what also is of great importance, no significant change in user habits and experience, necessary given if combined with an automated control. On the other hand the hybrid ducting system needs additional investments in space and money.

The hybrid ducting system has an extraction and also a recirculation system. To link the two there is an air flap that might chose between extracted or circulated air. The flap may operate exclusively in one mode or work continuously between extraction and recirculation mode, giving interesting possibilities.

If there is only a manual choice between the two modes the consumer can use extraction when he thinks that the odor concentration is too high for the charcoal filters. That is usually in the beginning of a cooking process, whilst if the first period is over usually, less odors are produced. In this case the user can choose recirculation mode and thus save indirect energy. The amount of savings is directly dependent on the performance of the recirculation performance and on the sensitivity and needs of the user.

Performance improvements

In the previous chapter we saw some solutions to directly reduce indirect energy consumption of hoods. In this chapter we shortly want to discuss some technologies that could support the efforts of reducing direct and indirect energy consumption. The idea behind it is simple: the better or more targeted one function operates, the better the system might operate and thus needs less energy.

Introduction of a catch rate

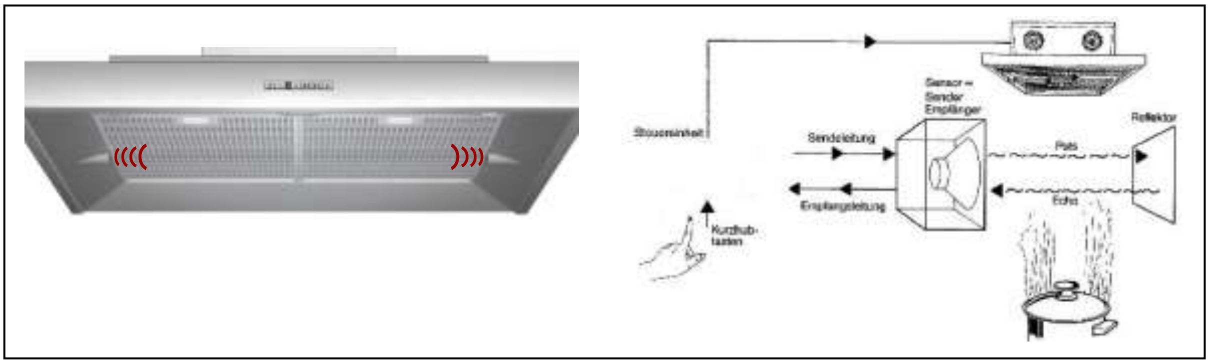
Today the performance of a hood is judged by the air volume, the more, the better. More air volume means that a bigger ratio of vapor is caught by the hood in the first pass. But there are other options that could improve the first pass result, that is, if the design of the hood and e.g. the distance to the hob is optimized.

For a judgment of performance we needed a measurement principle to know the ratio of cooking vapors that go through the hood in the first pass and the fraction that evaporates in the room and is caught later. We call the ratio of caught vapors in the first pass and the total vapors produced while cooking the catch rate. Actually experts discuss a measurement principle able to be taken over by international standards.

Adaptive controls

Another idea to improve system performance is to adapt the air volume to the minimum needed demand for best performance. Tests show that it is possible to measure the load of vapors, described by the amount of particles, VOCs, humidity and temperature.

A successful approach uses ultra sonic waves to measure the vapor concentration. The ultra sonic waves are created by a sound system that directs its waves through the inlet area of a hood. The waves reflect at a mirror and the sound system, now used as a microphone, measures the strength of the signal. An electronic control always adapts the fan speed to a lowest possible, but good performing, value automatically and readjusts if the vapor concentration changes. If no significant concentration can be found it shuts the fan off.



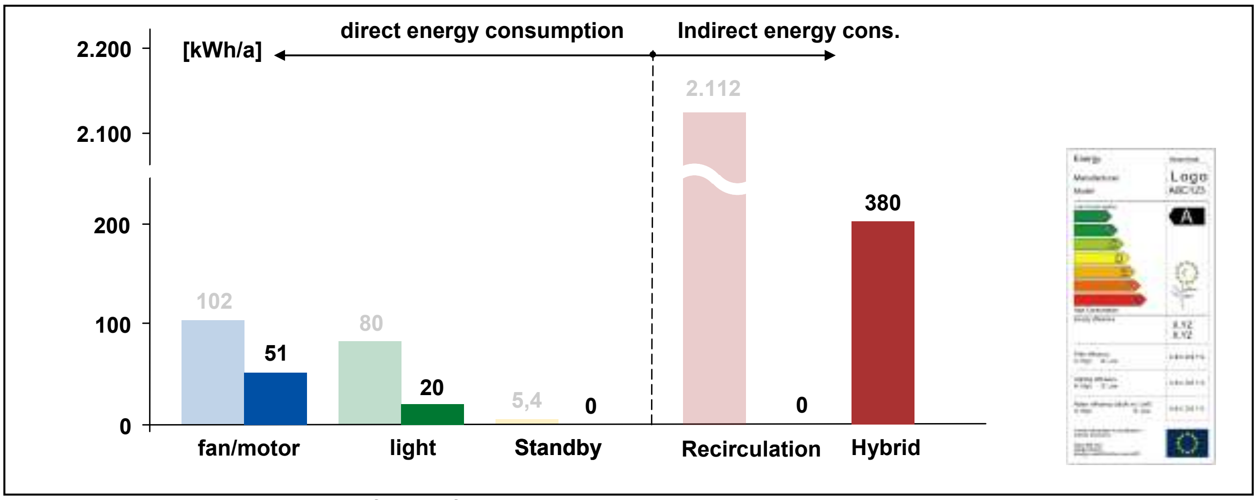
Adaptive control by ultrasonic vapor detection

Future's energy consumption of hoods

If we adopt all existing and future technologies to hoods we can reduce the direct energy consumption of fans by approx. 50% by using ec-motors instead of condenser motors. If compared a shaded pole motor to a condenser motor, the average gain in energy efficiency also is approx. 50%. This was studied in a test of the major hoods manufacturers in Europe to support the current effort of the European Commission to introduce a energy label scheme for hoods. The figures may vary dependent on the original fan size. For the lighting we assumed change from 20W low voltage halogen lamps to 3W high power spot LEDs. Current LED spots have a higher focus, thus a smaller angle of light distribution, so we assume the usage of approx. 1,5 LEDs spots to replace one 20W halogen lamp. For standby losses there are technologies, like solar assistance, available to reduce the demand to zero.

The biggest gain appeared if we can completely eliminate extraction, thus reducing the indirct energy consumption to zero and, in addition, use the heating energy of a cooking process completely for ambience heating if needed.

For the hybrid ducting system we assume to only use about 10% of the average using time for extraction. As in this scenario, naturally, the speed setting is higher than that of the rest of the usage time, we gain only around 82% of the maximum.



Future energy consumption of a performance hood with recirculation or hybrid ducting; proposal of an energy label for hoods

Conclusion

We discussed the different energy consumptions of kitchen ventilations systems, also known as hoods, and divided them into 3 segments: the direct energy consumption and the indirect energy consumption and performance losses. The direct part is given by the electrical energy consumed by the fan and the lighting, whereas the indirect part is given by the energy content of the ambient air transported from the inside of the house to the outside. The latter is for extraction hoods, which make approx. 50% of the market, by far the highest value but the market is not sensitive to that fact due to a lack of information and technology.

We showed several possibilities to sustainably reduce energy consumption on hoods. For the direct energy the usage of existing technologies like ec-motors and LED lights can highly contribute to the improvement of the consumption. For the indirect energy consumption new approaches are needed, to convince consumers of better odor reduction possibilities and with it, to move from extraction to recirculation. A hybrid ducting system could be a timely solution until good performing odor reduction systems are available. As a mixture on the impact on direct on indirect energy consumption better measurement principles and adapted fan air volumes, and thus, better performance of hoods can contribute to direct and indirect energy consumption.

Labelling and Standards for Domestic Gas Cooking Appliances in Brazil - Improving Energy Efficiency and Safety

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Abstract

In the middle of the 80's, Brazil began the implementation of a comparative labelling programme for energy consumption domestic appliances. This programme has been coordinated and ruled by INMETRO - Brazilian Government Institute for Metrology, Standardisation and Industrial Quality. For electric appliances such as refrigerators and air conditioners this programme has been conducted in partnership with PROCEL, the Brazilian Government Programme for Electric Energy Conservation. By the end of the 90's, in partnership with CONPET, the Brazilian Government Programme for Rational Use of Petroleum Derivatives and Gas, sponsored by PETROBRAS – Brazilian Petroleum Company, INMETRO decided to extended the energy labelling programme to domestic gas appliances, in a voluntary mode. The use of the energy comparative label became mandatory for all domestic gas cooking appliances in 2003, due to an agreement with local manufactures to promote safety and efficiency. Since then, all products must be tested, approved, classified and labelled before commercialization. The laboratory tests follow a Brazilian Standard, based on the European Standard test for performance, safety and rational use of energy of domestic cooking appliance burning gas. For market surveillance and control, a sample of the production models is selected every year to be retested by INMETRO's accredited laboratories network. In order to highlight the most efficient gas energy labelled products to the customers, CONPET has introduced in 2005 an efficiency endorsement label, a distinction mark like Energy Star. The updated data base list of the gas labelled models of cooking appliances, with their characteristics, efficiency levels and the indication of the most efficient ones endorsed by CONPET, is available to customers at the Internet. In 2006, a new safety mandatory requirement was established by INMETRO for all gas cooking ovens. In 2008, after a negotiation with the manufactures, the levels of efficiency in the energy label classifications were raised, therefore more efficiency became necessary for CONPET gas energy endorsement label. Also in 2008, due to the regulation of the federal government energy efficiency law, a new Minimum Energy Performance Standard (MEPS) was requested for the products. Further requirements for energy efficiency and safety are planned for next years. All these initiatives and government policies lead to continuous improvements on domestic gas cooking appliances used in Brazil.

Introduction

There are many energy labelling programmes in the world for electric consumption appliances. Some countries have gas energy labels for heaters but very few have comparative labels for gas cooking appliances. Brazil has implemented for domestic gas ranges, cooktops and ovens, an unique combination of national test standards and voluntary conformity rule (since 2000), mandatory comparative energy labelling (since 2003), voluntary energy efficiency endorsement label (since 2005) and Minimum Energy Performance Standard (MEPS) regulated by a federal law (since 2008).The graph of Figure 1 shows that gas energy usage has almost the same proportion of electric energy usage on the residential sector in Brazil. Most Brazilian homes have a refrigerator, a TV, and a gas cooking stove fuelled with Liquefied Petroleum Gas (LPG). Only on the more concentrated urban areas there is a Natural Gas (NG) distribution network and, on rural areas, firewood is also used for cooking. Almost all of the above 4.5 millions gas cooking appliances units sold each year are for LPG use and conversions for NG can be made after sale.

Part of the LPG, as well as part of the NG, still has to be imported to supply the whole country market. Emissions and safety requisites should also always be considered when using gas. This paper describes the Brazilian Labelling Programme and the regulation policy that have the aim of bringing energy efficiency and the attendance of safety standards for all domestic gas cooking appliances commercialized in Brazil.

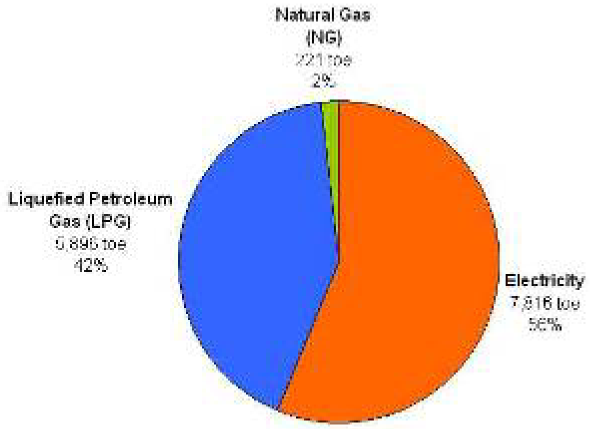


Figure 1: Residential Use of Electricity and Gas in Brazil - 2007

The Brazilian government energy saving programmes

Brazil has two major Government Energy Saving Programmes linked to the Ministry of Mines and Energy – MME: PROCEL - National Programme for Electrical Energy Conservation, created in 1985 and developed by Brazilian state-run power holding ELETROBRAS, and CONPET - National Programme for Rational Use of Petroleum Derivatives and Natural Gas, established in 1991, sponsored and developed by PETROBRAS, Brazilian main petroleum company.

The national institute of metrology, standardization and industrial quality – INMETRO

INMETRO was created in 1973, to support Brazilian enterprises, to increase their productivity and the quality of goods and services. Linked to the Ministry of Development, Industry and Foreign Trade – MDIC, some duties of INMETRO are: to maintain the national measurement standards in the country; to coordinate the compulsory and voluntary certification of products, processes and services; to plan and carry out the activities of accreditation of calibration and testing laboratories; to foster the presence of Brazil in the international activities related to metrology and quality. INMETRO conducts and rules the Brazilian Program for Conformity Assessment for products and services, which can be implemented by different mechanisms such as: Certification, Declaration of Conformity by the supplier, Labelling, Testing and Inspection.

The Brazilian labelling programme and the national energy conservation label

The Brazilian Labelling Programme – PBE began in 1982 and is now part of INMETRO's major Programme for Conformity Assessment. With partnership of PROCEL for electricity consumption products and CONPET for oil and gas consumption products, INMETRO implemented the National Energy Conservation Label – ENCE. INMETRO Energy Label compares similar products in terms of energy consumption or energy efficiency and informs customers about the energy use and other technical specifications. Depending on the product, the label also means attendance to other conformity requisites for safety or quality. Energy labelling is already implemented in a voluntary or mandatory mode for several products sold in the country such as: refrigerators; freezers; air conditioners; washing machines; gas cooking appliances; gas, electric and solar water heaters; photovoltaic systems; electric motors; ceiling fans; fluorescent lamps and ballasts; TV standby; light vehicles and buildings. The energy comparative labels used in Brazil are similar to energy labels used in Europe and other countries in the world. Figures 2 and 3 are examples of INMETRO Energy Label with PROCEL and CONPET partnership:

Figure 2
INMETRO / PROCEL Electric Washing Machine Label

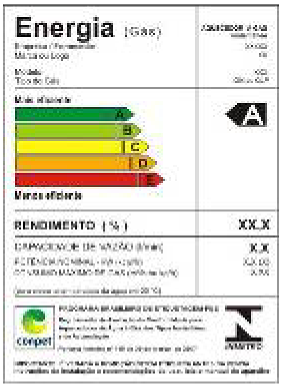


Figure 3
INMETRO / CONPET Gas Water Heater Label

Energy saving and efficiency endorsement labels

A 1993 Federal Decree created the Green Energy Label to award the best energy efficiency equipments. Since then, the PROCEL Energy Saving Endorsement Label shows the customers the products with the best electricity efficiency within each category. The CONPET Energy Efficiency Endorsement Label was only introduced in 2005 as a distinction mark to highlight the most efficient gas household cooking appliances and water heaters. The idea of the CONPET Label was to follow the success already obtained by the PROCEL Label, using a similar lay-out. This strategy was based on consumers and sellers previous knowledge of PROCEL Label, in order to have a faster and easier visual association (the red one for electricity and the blue one for gas usage efficiency). The Energy Efficiency Endorsement Labels are shown on Figures 4 and 5:

Figure 4:
PROCEL Electric Energy Saving Endorsement Label

Figure 5:
CONPET Gas Energy Efficiency Endorsement Label

Both PROCEL and CONPET labels act like the Energy Star Label. They are of voluntary use and can only be applied to selected INMETRO energy labelled models that complies the award requisites each year. These requisites are based on the whole information of INMETRO Energy Label to distinguish the smarter choices for the customers. A washing machine for example, besides having low electricity consumption, must also have high washing and centrifugation efficiency and low water usage to receive the PROCEL Label. In order to use CONPET Label, a gas stove with an oven must have high efficiency on the cooking table hob and also low gas consumption on the oven. An official ceremony is organized every year by ELETROBRAS/PROCEL together with PETROBRAS/CONPET to award manufactures or importers of more efficient appliances with a trophy and a diploma, as recognition of the Brazilian

Government. Receiving PROCEL and/or CONPET Labels became a marketing aid for the companies and a target for the products.

Brazilian standards for domestic cooking appliances burning gas

The Brazilian Association for Technical Standards – ABNT is the entity responsible for standardization in Brazil. The Brazilian Standard for laboratory test of domestic cooking appliance burning gas, ABNT NBR 13723 Part 1 (Performance and Safety) and Part 2 (Rational Use of Energy), published in 1999 and revised in 2003, was based on the European Standard CEN EN-30. The test standard applies to all construction specifications of the domestic cooking appliances such as gas circuit linkage, stable structure, combustion system, flame stability, surface external temperatures, emissions, gas consumption, cooking table efficiency. Gas cooking appliances with electrical components also must be tested for electrical safety based on another standard: NBR NM IEC 335-1:1998. Today there are 5 independent laboratories accredited by INMETRO to test gas appliances in Brazil. Two located in Rio de Janeiro, two in São Paulo and one in Rio Grande do Sul state. Other 10 manufactures of domestic gas cooking appliances have laboratories authorized to test their own products.

Labelling programme for domestic gas cooking appliances

By the end of the 90's INMETRO in partnership with CONPET started the steps for the implementation of the National Energy Conservation Label for Domestic Gas Cooking appliances. The laboratories tests were based on the just published Brazilian Test Standard ABNT NBR 13723 for domestic cooking appliance burning gas. At the initial tests only a few models in the market were able to be approved by the new standard including performance and safety requisites. On the majority models tested at this time, the energy efficiency of the cooking top table burners was close to or even below the minimum value of 52% required by the standard. After an adaptation period to introduce the new rules, the manufacturers, represented by their association, ELETROS, agreed to change the specifications of all their domestic gas cooking appliances models for better energy efficiency and consumer safety. The proposition was that the label should not only compare the products for energy use but also certify the attendance of minimum efficiency and safety requirements of the Brazilian standard, becoming mandatory in a few years. For a gas stove with cooking top table burners and an oven the label would have two classifications, one to compare the cooking table efficiency and the other to compare the gas consumption of the oven relative to its volume. The labelling programme began in a voluntary mode in 2000 to become mandatory for all domestic gas cooking in the market by 2003.

The individual efficiency η_i *(%)* of a burner (only the ones with power above 1.16 kW are measured) on the cooking table is calculated boiling water in a standard pan over the burner and can be defined as:

*η_i (%) = 100 * (measured heat absorbed by the water in a standard pan) / (thermal energy theoretically available to be absorbed by the water on the gas fuel burn due to its Calorific Power).*

The efficiency index adopted in the energy label to compare cooking tables was the arithmetic mean of the efficiency measured in all burners.

η (%) = $\sum \eta_i$ (%) / number of burners (above 1.16 kW)

For example, a cooking table with 5 burners and 4 above 1.16 kW, the mean efficiency η *(%)* would be the sum of the individually measured efficiency of the 4 burners above 1.16 kW divided by 4.

For the ovens, a gas consumption index was created in order to compare different sizes of ovens. This index called *Ic* (%) was defined in the labelling rule published by INMETRO using the following equation:

*Ic (%) = 100 * (measured gas consumption for oven temperature maintenance) / (maximum admissible gas consumption for oven temperature maintenance calculated by the standard)*

The oven maintenance temperature considered is 210 ºC measured at the empty oven geometric centre. Using the equation of the test standard for an oven internal volume V with a measured gas consumption C, *Ic (%)* can also be calculated as below:

$Ic\ (\%) = 100 * (C / 0.0726) / (0.93 + 0.035 * V)$ for Liquefied Petroleum Gas (LPG):

$Ic\ (\%) = 100 * (C / 0.0903) / (0.93 + 0.035 * V)$ for Natural Gas (NG):

Where V is the oven internal volume in litres and C is the gas consumption in kg/h for LPG or in m^3/h for NG.

The comparative classification levels of the energy label were first established in 2000 using the statistical distribution of the models tested at this time. Table 1 shows the values of the classes used for the mean energy efficiency of the burners on the cooking table, *η (%)*, and for the oven temperature maintenance gas consumption Index, *Ic (%)*:

Table 1: Cooking Table and Oven Energy Classification Levels in 2000

Cooking Table Burners Mean Efficiency *η* (%)	Label Classification Levels	Energy Efficiency	Oven Gas Consumption Index *Ic* (%)	Label Classification Levels
≥ 61.0	A	More Efficient	≤ 53	A
≥ 58.2	B		≤ 64	B
≥ 56.1	C		≤ 69	C
≥ 54.1	D		≤ 75	D
≥ 53.0	E		≤ 81	E
≥ 52.5	F		≤ 87	F
≥ 52.0	G	Less Efficient	≤ 100	G

The levels of Table 1 were valid in the voluntary phase (2000 - 2002) and also used in the mandatory phase initiated in 2003. In 2006, after 3 years running as a mandatory labelling programme, almost no more cooking appliances models were found in the "F" and "G" classification levels and. these levels were extinguished and incorporated in the "E" level. After the introduction of CONPET Energy Efficiency Endorsement Label in 2005, CONPET and INMETRO initiated a negotiation with manufactures to review and raise the efficiency classification levels of the energy label to be valid in 2008. This revision was necessary because of two factors: excessive number of models in the "A" to be awarded by CONPET Label and the regulation of the Energy Efficiency Law number 10,295 defining new Minimum Energy Performance Standard (MEPS) for gas cooking appliances. The new values for the classes increased the efficiency in at least 1% for cooking table and at least 2% for the ovens with an equal separation between classes .They also introduced the new efficiency levels for CONPET Label and new MEPS required by law (as described further in this paper on Tables 3 and 4). Table 2 shows the classification levels since 2008:

Table 2: Cooking Table and Oven Energy Classification Levels in 2008

Cooking Table Burners Mean Efficiency *η* (%)	Label Classification Levels	Energy Efficiency	Oven Gas Consumption Index *Ic* (%)	Label Classification Levels
≥ 62.0	A	More Efficient	≤ 51	A
≥ 60.0	B		≤ 55	B
≥ 58.0	C		≤ 59	C
≥ 56.0	D		≤ 63	D
≥ 52.0 *	E	Less Efficient	≤ 67	E

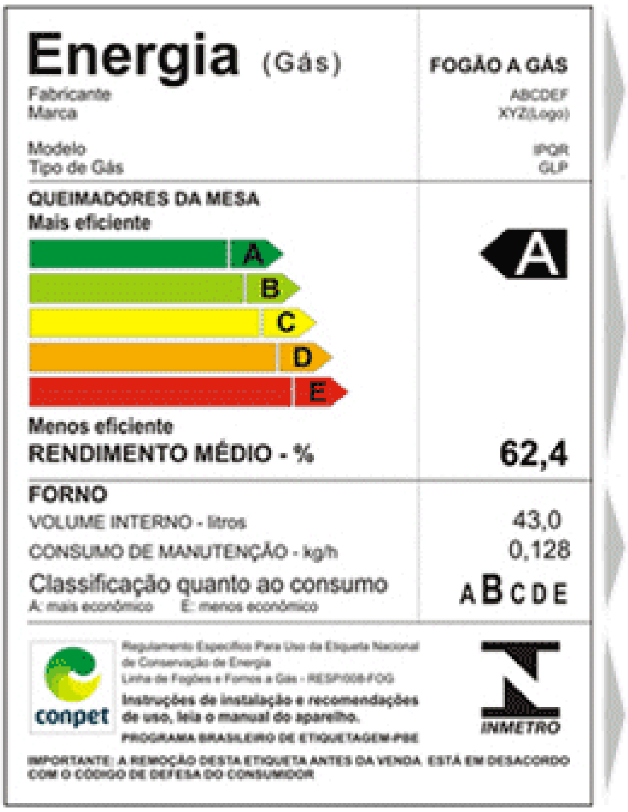
* The "E" level can be applied only to cooking tables with one single burner

Actual information about INMETRO labelling of domestic gas cooking appliances can be found at: www.inmetro.gov.br/consumidor/produtospbe/fogoes.asp .

The energy comparative labels for domestic gas cooking appliances

The most used residential gas cooking appliance in Brazil is a gas range with 4, 5 or 6 burners on the cooking table and an incorporated gas oven, running on LPG. The normal food preparation in this stove by the Brazilians families has usually the following time sharing: 85 % of the time cooking on the top table burners and 15 % of the time baking using the oven. This fact was considered on how to display the energy efficiency classification levels information in INMETRO Energy Label design. Three types of Labels are used. Figure 6 shows and explains the most common one used for a gas range with an oven, Other two similar labels are used for a gas cooktop (without oven) and other for a single gas oven.

Energy Label for a Stove with Cooking Table and Oven



Description

Type of product.
Manufacturer or Supplier's name.
Brand name or logo.

Model name or code.
Gas Type: LPG or NG.

Cooking Table energy efficiency classification level. **"A"** is the more efficient and **"E"** is the less efficient.

The mean efficiency value of the Cooking Table burners:
η (%)

Oven internal volume in liters.
Oven temperature maintenance gas consumption in kg/h for LPG or m^3/h for NG.
Oven classification using the Consumption Index (***Ic)***.
"A" means less gas consumption and **"E"** means more gas consumption related to the oven volume

CONPET and **INMETRO** logos.
Label rule number.
Advice to sellers to not remove the label.

Figure 6: Gas Stove INMETRO Energy Label Explanation

CONPET energy efficiency endorsement label criteria

The CONPET Energy Efficiency Label criteria are defined by a commission formed by government representatives, suppliers associations and consumers defence entities. These criteria are based on the information and the classification level of INMETRO Energy Label. They can be reviewed every year and may periodically induce the revision of the "A" classification levels, and consequently the "B" to "E" levels, acting like pulling them at the top for higher efficiency. Table 3 shows the efficiency levels required for CONPET Label since 2008:

Table 3: CONPET Energy Efficiency Label for Gas Cooking Appliances Endorsement Criteria since 2008

Product	Classification Level in the Energy Label	Energy Efficiency Criteria
Domestic Gas Stove with Cooking Table and Oven	Cooking Table and Oven simultaneously classified in the **"A"** Level	Mean Efficiency of the Cooking Table Burners $\eta \geq 62.0$ % Oven Gas Consumption Index $Ic \leq 51\%$
Domestic Gas Cooking Table without Oven	Cooking Table Burners classified in the **"A"** Level	Mean Efficiency of the Cooking Table Burners $\eta \geq 62.0$ %
Domestic Single Gas Oven	Oven classified in the **"A"** Level	Oven Gas Consumption Index $Ic \leq 51\%$

More information about CONPET Energy Efficiency Endorsement Label can be found at the following link: www.conpet.gov.br/projetos/selo_01.php?segmento=corporativo .

The Energy Efficiency Law

Since 2001, the Energy Efficiency Law number 10,295 is in force establishing that all equipments commercialized in Brazil should have minimum energy efficiency or a maximum energy consumption indexes. An Inter-Ministerial Commission presided by MME was created to specify those index based on the work of technical groups of each specific equipment coordinated by PROCEL or CONPET and INMETRO. The Brazilian Labelling Programme was chosen by this Commission as the instrument to provide these indexes. Electric motors had its mandatory minimum energy efficiency indexes established since 2003, Compact Fluorescent Lamps in 2006, Air Conditioners and Refrigerators in 2007 and. Gas Water Heater in 2008. The Minimum Energy Performance Standard (MEPS) for the gas cooking table burners and for gas ovens were defined in 2007 to be valid from 2008. The Energy Efficiency Law also determines that periodically new target efficiency minimum indexes should be established for the equipments and may periodically induce the revision of the "E" classification levels, and consequently the "D" to "A" levels, acting like pushing them at the bottom for higher efficiency. Table 4 shows the MEPS defined by the Law since 2008:

Table 4: Minimum Energy Performance Standard (MEPS) for Gas Stoves and Ovens since 2008

Equipment or Part of the Equipment	Minimum Energy Efficiency or Maximum Consumption Index	Value	INMETRO Energy Label Classification Level
Gas Cooking Table with more than one burner	Mean Efficiency of the burners (η)	$\eta \geq 56.0$ %	**"D"**
Gas Oven	Oven Gas Consumption Index (Ic)	$Ic \leq 67$ %	**"E"**

Although not included in the Law, the Cooking Table with a single burner is still regulated by the mandatory labelling programme with a minimum efficiency of 52 % required in the test standard for an individual burner. They are the only gas cooking appliance allowed in the "E" classification level of INMETRO Energy Label.

New safety requirements for domestic gas ovens

INMETRO established a new safety rule for all domestic gas cooking ovens commercialized after June of 2006. By this rule all ovens should be equipped with a flame supervision system, a gas cutting device to actuate in case of flame extinguish. This system avoids gas leakage and accidental explosions due to the gas accumulation inside the oven, especially dangerous when using LPG (heavier than air). Because of the safety system, the procedure to light up the ignition of the new ovens had to change. All manufactures had to adapt their models and provide new instructions for their customers. INMETRO is also studying with the manufactures a new rule to reduce gas stoves maximum external surface temperatures. Temperatures allowed by the Domestic Gas Cooking Appliances Test Standard are being considered too high for the country hot regions. Lowering external temperatures will force the use of a better isolation in the ovens, avoiding excessive outside heat dissipation and therefore improving safety and also the efficiency.

Gas cooking appliances data and customer information

The cooking appliances updated data base is available at the Internet and shows the suppliers (manufacturer or importer) main name; brand; model name or code; type of product (cooktop, stove or oven); type of gas; number of burners on the cooking table; mean efficiency of the cooking table burners; cooking table classification; oven volume; oven gas consumption; oven consumption index; oven classification and endorsement of CONPET Energy Efficiency Label (highlighted on light green lines). A complete list of models is published at INMETRO site at: www.inmetro.gov.br/consumidor/pbe/fogao_forno.pdf. Table 5 shows a translated sample of how this list is displayed:

Table 5: Example of Gas Cooking Appliances Data

592 Models Labeled by INMETRO - 362 Stoves; 205 Cooktops; 25 Ovens December 2008
345 Models Awarded with CONPET Label (58%)

Supplier	Brand	Model	Type of Product	Type of Gas	Number of Burners on the Cooking Table	Cooking Table Burners Mean Efficiency (%)	Cooking Table Classification	Oven Volume (liters)	Oven Maintenance Consumption LPG (kg/h) NG (m^3/h)	Oven Consumption Index (%)	Oven Classification	CONPET Energy Efficiency Label
ABC	ABC	Domino 2	Cooktop	NG	2	63.5	A	\	\	\	\	YES
CBA	DEF	Especial 4	Stove	LPG	4	62.1	A	46.0	0.101	55	B	NO
CBA	DEF	Especial 5	Stove	LPG	5	61.3	B	107.0	0.155	45	A	NO
CBA	DEF	Especial 6	Stove	LPG	6	62.3	A	107.0	0.155	45	A	YES
XYZ	KWL	Gold 90	Oven	LPG	\	\	\	88.30	0.115	39	A	YES

To facilitate customers search for the most efficient cooking appliances, CONPET also launched in 2008 a consulting application to allow the selection of desired models at: www.conpet.gov.br/consultafogoes (the name in Portuguese means “consultingstoves”). In this site customers can choose to view only the models with CONPET Label. They will also find an explanation of the INMETRO Energy Label and can download the electronic version of CONPET booklet: “Hints for economy and safety on the use of your gas stove”.

Market surveillance and control

All domestic gas cooking appliances, locally manufactured or imported, should be tested and labelled before commercialization. The results of laboratory data have to be submitted to INMETRO and CONPET. INMETRO has subordinated official agencies in all Brazilian states to check the stores for the correct use of the Energy Label. Every year INMETRO makes a selection, sampling some models of each supplier, to be retested in one of the 5 independent accredited laboratories. If there is any discrepancy of the declared data or nonconformity for model’s safety the supplier must correct the label information and/or the product. INMETRO also hear consumers complaints and intercepts to solve the related problem or to improve the products with manufactures.

Conclusion

The strategy of government policies implemented with the industry and society collaboration has been successful in Brazil. This strategy includes voluntary to mandatory labelling for energy consumption and safety, award for energy efficiency and avoidance of inefficient products in the market. The top pulling effect of CONPET Label in the “A” efficiency classification level combined with the bottom pushing effect in the “E” level of the Energy Efficiency Law facilitate periodical revisions of INMETRO Energy Label levels, leading to more efficiency. After almost 10 years the Labelling Programme for domestic gas cooking appliances is bringing an estimated economy of 20% on gas consumption and much more safety on using gas for food preparation in Brazilian homes. By the end of 2008 there were almost 600 models labelled, more than three times of the number of models labelled at the voluntary beginning before 2002. The picture in Figure 7 shows the use of INMETRO Energy Comparative Label and CONPET Energy Efficiency Endorsement Label on Domestic Gas Cooking Stoves in a Brazilian store display for the customers:

Figure 7 Labelled Cooking Stoves in a Brazilian Store

The mean efficiency of the cooking table burners, close to the test standard minimum of 52% in the past, is now above 60% in almost all models and no model with more than one burner can have mean efficiency below 56%. The new ovens have a lower risk of gas accidents and also have a maximum consumption index limited to 67% instead of the unlimited previous value of 100%. When the new higher efficiency levels were proposed to the manufacturers in 2006, to be in force in 2008, only 17% of the models in the market would be able to keep using CONPET Energy Efficiency Endorsement Label. Knowing this, manufactures improved their products to avoid losing the “A” classification on the cooking tables and ovens, as shown by Figure 8 with a comparison of 2006 X 2008 models. The chart brings class “A” distribution, (1) in 2006, (2) with the new “A” criteria applied to 2006 models and (3) in 2008. For this reason, even with the new energy efficiency criteria launched in the beginning of 2008, 58% of the models were still awarded with CONPET Label at the end of this year. Figures 9 and 10 bring the classification distribution on INMETRO Label in 2008.

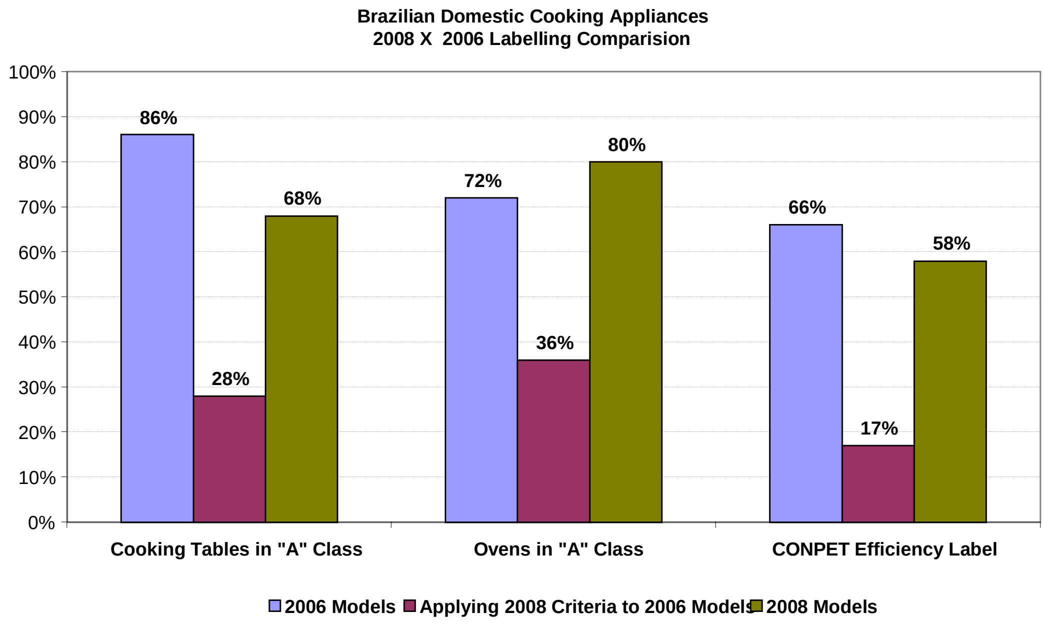


Figure 8: Cooking Tables Classification Level Distribution by the end of 2008

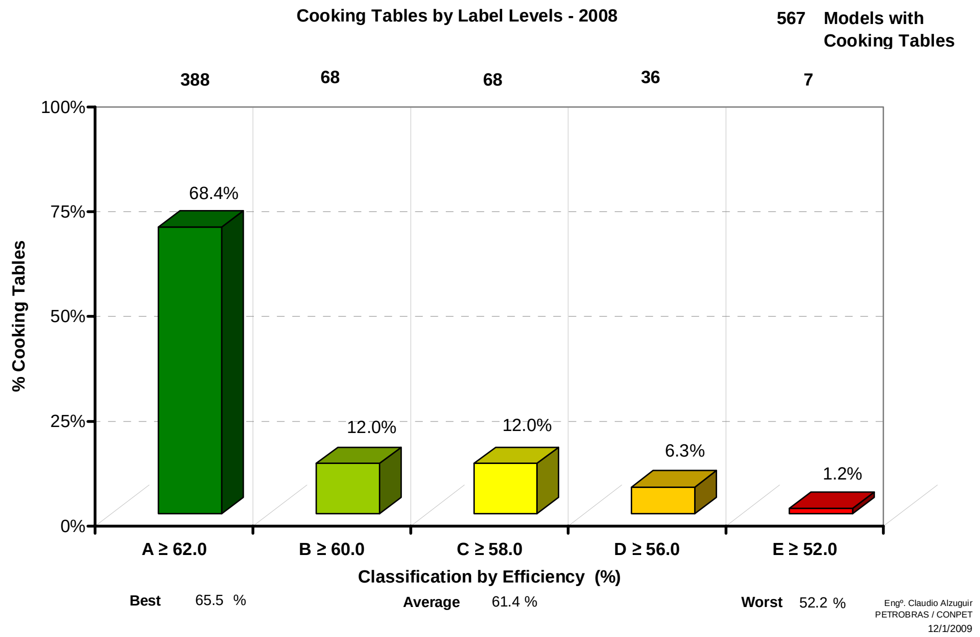


Figure 9: Cooking Tables Classification Level Distribution by the end of 2008

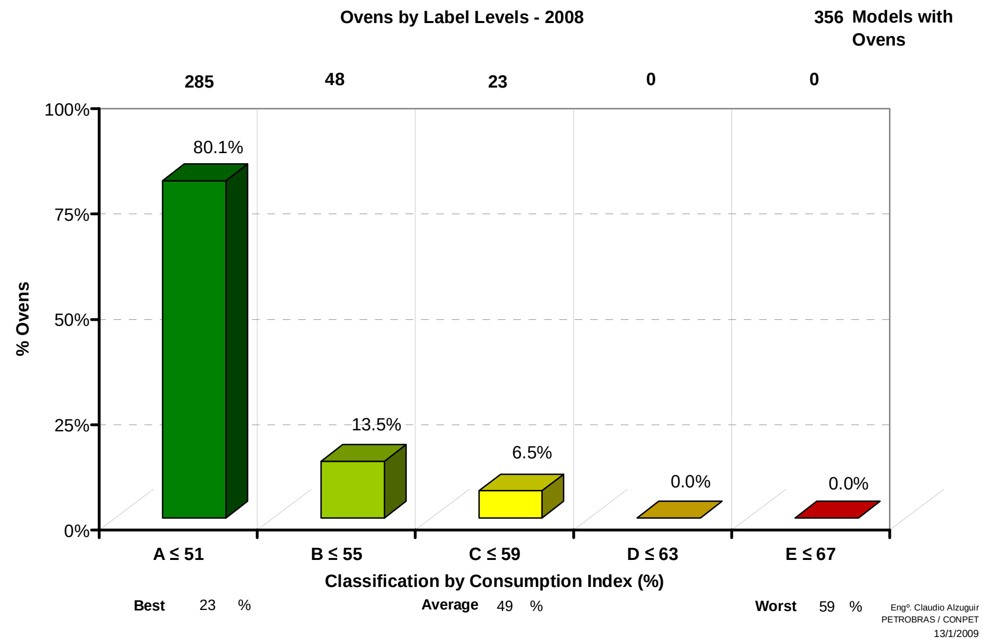


Figure 10: Ovens Classification Level Distribution by the end of 2008

The classification levels of the Energy Label are periodically (usually in 3 to 5 years) revised to raise the “A” to “E” scale. Higher energy efficiency and other safety requirements are now being negotiated with the suppliers to be in force in 2011. All these initiatives and government policies lead to continuous improvements on domestic gas cooking appliances used in Brazil.

References

[1] CONPET - Programa Nacional da Racionalização do Uso dos Derivados do Petróleo e do Gás Natural *(National Programme for Rational Use of Petroleum Derivatives and Natural Gas):* www.conpet.gov.br

[2] PETROBRAS - Petróleo Brasileiro S.A. *(Brazilian Petroleum Company):* www.petrobras.com.br

[3] INMETRO - Instituto Brasileiro de Metrologia, Normalização e Qualidade Industrial *(National Institute of Metrology, Standardization and Industrial Quality):* www.inmetro.gov.br

[4] PROCEL – Programa Nacional de Conservação de Energia Elétrica *(National Programme for Electrical Energy Conservation):* www.eletrobras.com.br/procel

[5] MME – Ministério de Minas e Energia *(Ministry of Mines and Energy):* www.mme.gov.br

[6] MDIC – Ministério do Desenvolvimento, Indústria e Comércio Exterior (*Ministry of Development, Industry and Foreign Trade*): www.mdic.gov.br

[7] ABNT – Associação Brasileira de Normas Técnicas *(Brazilian Association for Technical Standards):* www.abnt.org.br

[8] ABNT NBR 13723 – Aparelho Doméstico de Cocção a Gás Parte 1 Desempenho e segurança, Parte 2 Uso Racional de Energia *(Brazilian Standard for Laboratory Test of Domestic Cooking Appliance Burning Gas, Part 1 Performance and Safety and Part 2 Rational Use of Energy).*

[9] Claudio Alzuguir, Luiz Carlos Cipriano, Carlos Felício, Rosana Novais and Telma Villela: *Deduction of the equation for oven gas consumption index, Ic (%), from ABNT NBR 13723 oven maximum power calculation using oven internal volume and measured gas consumption.*

[10] ELETROS – Associação Nacional de Fabricantes de Produtos Eletroeletrônicos *(National Association of Eletroeletronic Products Manufactures):* www.eletros.org.br

[11] INMETRO – Programa Brasileiro de Etiquetagem – PBE *(Brazilian Labelling Programme):* www.inmetro.gov.br/qualidade/eficiencia.asp

[12] INMETRO – Informações para Etiquetagem de Fogões e Fornos Domésticos a Gás *(Labelling Information for Domestic Cooking Appliances):* www.inmetro.gov.br/consumidor/produtospbe/fogoes.asp

[13] INMETRO – Portaria n°. 73 – Instituição da Etiquetagem Compulsória de Fogões e Fornos Domésticos a Gás *(Regulation n°. 73 - Establishment of Mandatory Labelling for Domestic Cooking Appliances):* www.inmetro.gov.br/legislacao/rtac/pdf/RTAC000761.pdf

[14] INMETRO - Regulamento de Avaliação da Conformidade para Fogões e Fornos a Gás (*Rule for Conformity of Domestic Cooking Appliances):* www.inmetro.gov.br/consumidor/produtospbe/regulamentos/Portaria018_2008.pdf

[15] INMETRO - Tabela de consumo/eficiência energética para Fogões e Fornos Domésticos a Gás *(Data base list of labelled domestic cooking appliances):* www.inmetro.gov.br/consumidor/pbe/fogao_forno.pdf

[16] CONPET – Informações sobre o Selo de Eficiência Energética *(Energy Efficiency Endorsement Label Information):* www.conpet.gov.br/projetos/selo_01.php?segmento=corporativo

[17] CONPET – Regulamento do Selo de Eficiência Energética *(Energy Efficiency Endorsement Label Rule):* www.conpet.gov.br/download/pdf/regulamento_selo_conpet.pdf

[18] CONPET / PETROBRAS – Consulta de Aparelhos Domésticos a Gás *(Domestic Cooking Appliances Data Consulting):* www.conpet.gov.br/consultafogoes

[19] CONPET – Dicas de Economia e Segurança no Uso do seu Fogão a Gás *(Hints for economy and safety on the use of your gas stove):* www.conpet.gov.br/dicasfogoes

[20] Governo Brasileiro - Decreto de Instituição do CONPET *(Brazilian Government - CONPET Creation Decree):* www.planalto.gov.br/ccivil_03/DNN/Anterior%20a%202000/1991/Dnn213.htm

[21] Governo Brasileiro - Decreto de Criação do Selo Verde de Eficiência Energética *(Brazilian Government - Green Energy Efficiency Label Creation Decree):* www.planalto.gov.br/ccivil_03/DNN/Anterior%20a%202000/1993/Dnn1931.htm

[22] Governo Brasileiro – Lei n°. 10.295 - Política Nacional de Conservação e Uso Racional de Energia *(Brazilian Government Law n°. 10,295 - National Policy for Conservation and Rational Use of Energy):* www.planalto.gov.br/ccivil_03/LEIS/LEIS_2001/L10295.htm

[23] Governo Brasileiro – Decreto de Regulamentação da Lei n°. 10.295 *(Brazilian Government - Law n°. 10,295 Regulation Decree):* www.planalto.gov.br/ccivil_03/decreto/2001/D4059.htm

[24] MME – Portaria Interministerial n°. 363 – Regulamentação Específica para os Índices Mínimos de Eficiência Energética de Fogões e Fornos a Gás *(Inter-ministerial Specific Regulation n°. 363 for Minimum Efficiency Indexes of Domestic Cooking Appliances):* www.mme.gov.br/download.do?attachmentId=12953&download

[25] MME – Balanço Energético Nacional - BEN (*National Energy Balance*): www.mme.gov.br/site/menu/select_main_menu_item.do?channelId=1432

[26] CLASP – *Collaborative Labeling and Appliances Standards Program*: www.clasponline.org

Topten.info: Market Pull for High Efficiency Products

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Abstract

Topten is a voluntary, international, non-profit project aiming at stimulating market demand for efficient products by creating a dynamic benchmark for the most energy efficient products on national markets and working in partnership with the most relevant market actors. This paper updates the international community on the evolution of Topten since the launch of the Swiss system in 2000, highlighting achievements and challenges. The paper presents new analysis of lessons learned with respect to topics such as:

- Institutional arrangements and prerequisites – cooperation and synergies with energy agencies and existing government programs
- Resource requirements – struggle to raise funding for the Topten "public service" to consumers; "business models"
- Cooperation with stakeholders – all the way on the market chain from manufacturers to end-users, R&D people to retailers, large scale buyers and public procurers, utilities and ESCOS
- Topten market functions and value added to various market actors
- Analysis of Topten impacts – status, plans and challenges (performance indicators, contribution to market transformation processes)
- International benchmarking and quality assurance – Topten will soon be present in 16 countries, allowing for powerful data cross-checking, inquiries to global manufacturers as well as policy recommendations
- Prospects for expanding Topten to additional countries.

The planned addition of more European countries but also of TopTen USA and China to the international Topten family brings a new dimension to this originally European program.

Introduction

Existing energy efficiency benchmarks can be used to eliminate the worst products from the market (e.g., mandatory minimum energy performance standards), encourage timely replacement and steer consumers to better than average products (e.g., voluntary energy star label cut-offs), but there is no incentive for manufacturers to go beyond these existing benchmark levels and innovate at the cutting edge of efficiency – and no easy way for large buyers and end users to seek out the highest efficiency models.

If we are to rise to the challenge of cutting greenhouse gas emissions significantly to levels currently under serious political discussion, it will be essential to speed the innovation and market transformation process to take maximum advantage of low-lifecycle cost end-use efficiency opportunities. Topten responds to this need [1-4].

Topten is coordinated by TIG, the Topten International Group. Topten is a transparent system to continuously identify the 10 "best" products available in each product category (with energy efficiency a key criterion) and to make the results freely accessible via a user-friendly Internet interface (www.topten.info). For each product category, the Internet site provides the following elements:

- Data displays for each of the approximately 10 products that make the selection cutoff, as well as for a representative "inefficient" product (to aid comparison)

- Selection criteria
- User advice, including background information and purchase/use tips
- Policy recommendations, for example, regarding appropriate levels for mandatory and voluntary standards or the design of incentive schemes
- Downloads and links to publications, standards, labels, and organizations external to Topten

By updating the product lists on review cycles that ensure that the most current products are always reflected on the site, national Topten Websites showcase highly efficient new products soon after they become available.

Topten relies on declarations of existing labels and schemes (e.g. EU-energy label, energy star), for which some tests are undertaken by authorities, consumer organizations and Topten carries out spot checking in the test center S.A.L.T. (www.salt.ch).

Achievements to Date

Establishment of a High-Efficiency Benchmark

Overview on categories

Thematically, the focus is put on electricity with mass produced equipment in household, SME and commercial buildings, as well as on cars (Figure 1).

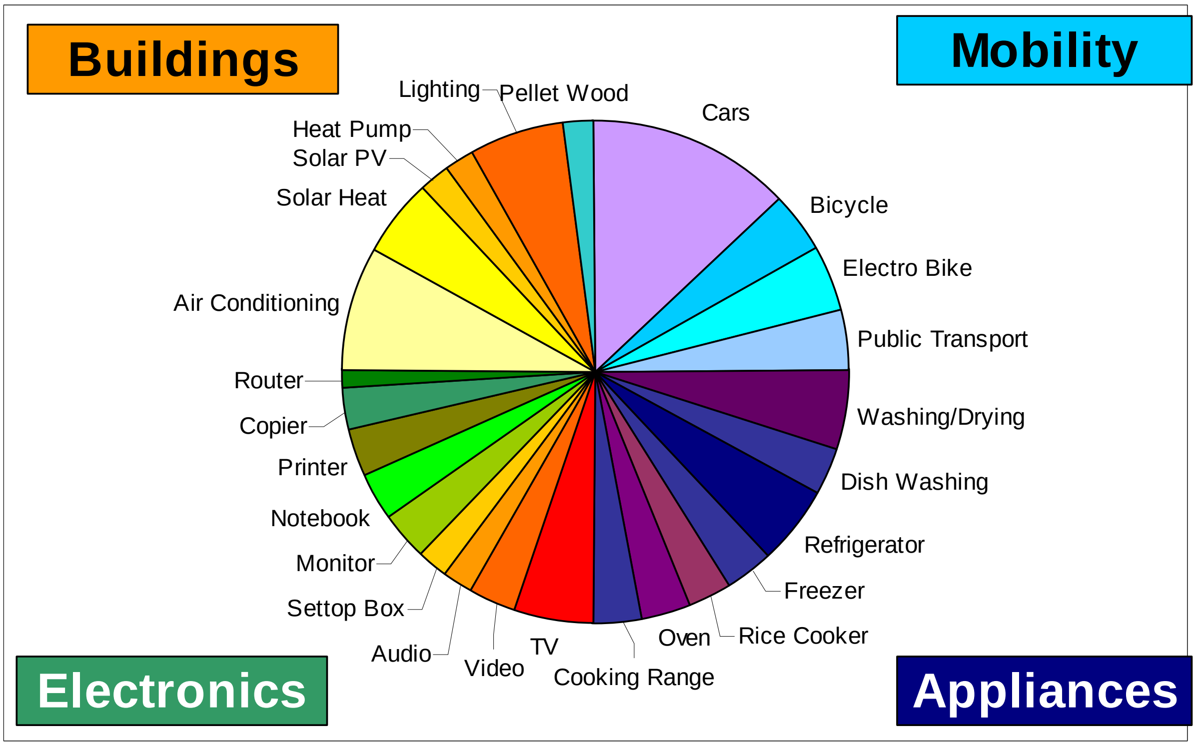

Figure 1: Overview on conceivable categories

Topten Benchmark Function

Topten offers the most stringent national benchmark to differentiate a wide range of product, equipment and vehicle categories based primarily on their energy efficiency. The dynamic nature of the selection criteria limits the product offerings to only the approximately top 10 performers, so Topten continuously pulls the market toward higher levels of efficiency. By working with various market actors to incentivize manufacturers toward innovation at the leading edge of efficiency, Topten promotes competition among manufacturers and ensures that tomorrow's "business as usual" products are radically more energy efficient than today's.

Approach and impact mechanisms

The over-all goal of Topten is to stimulate market transformation towards more energy efficient products and to contribute against climate change (Figure 2). The main concern is to lower barriers to find best available energy efficient products. Topten is one synergetic instrument of the strategy for energy efficient equipment. Topten focuses on the market pull of new efficient products, main stream products are covered by instruments as energy labelling and timely replacement whereas low end products need to be removed by market access limitations. The strengthening of transparency on high efficiency products for all actors is key. Market transformation takes place when producers can be stimulated to offer better products and consumers to ask for them.

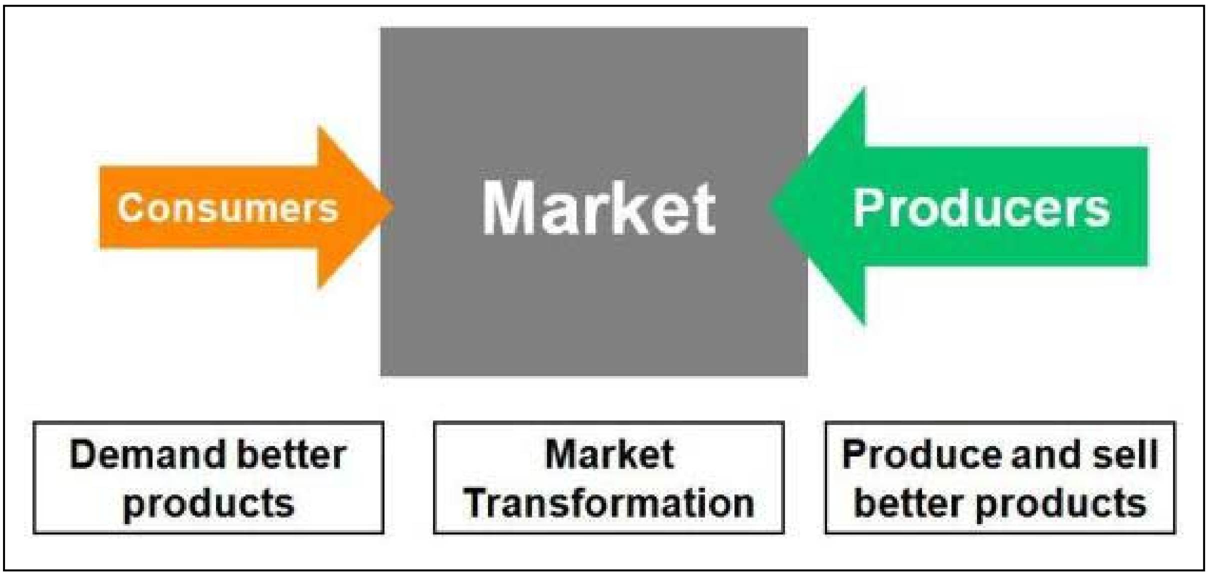

Figure 2: Impact mechanisms of Topten

Value Proposition

Topten plays a range of market functions that add value for the full range of market actors, both up- and downstream (Table 1). Topten's energy efficiency benchmarking function offers value through a commitment to educating purchasers, building markets for emerging technologies, blazing a trail for voluntary and mandatory efficiency programs, and conducting third-party testing to verify product performance.

Beyond its use to manufacturers, the general public and policymakers, Topten is a tool for utilities, procurement programs and other stakeholders to incorporate into efficiency programs, driving further energy savings. Such integration will link product purchases and installations to quantifiable energy savings. This integrated approach with the market will produce long-term reductions in carbon emissions and create positive environmental impact, while reducing energy costs, demand and waste.

Table 1. Range of market functions by Topten

Market Actor	Topten Value Proposition
Manufacturers	• Support market introduction of new high efficient products • Provide independent, objective marketing of products • Increase demand for innovative products

Retailers	• Identifies best products to optimize range of products • Increases sales of high end products • Position retailer as competent in energy efficiency and quality
Consumers	• User-friendly interface to identify most efficient products and access incentives (e.g. by electrical utilities) • Inform consumers on total life-cycle cost (purchase price plus energy bill). Communicate benefits of efficient products for climate protection
Large Buyers and Procurement Officers	• Support formulation of procurement specifications • Reduce operating costs to enhance competitiveness
Policy makers	• Provide real-time market data on the "best" products, with energy efficiency as a key criterion • Pave the way for new and more stringent standard & label specifications and minimal energy performance standards (MEPS)
Utilities	• Continuously identify the highest-efficiency products • Provide Topten benchmark for rebate programs • Include products for which standards/labels are not available
Media	• Serve as credible, independent source of information • Issue regular updates

Source: Adapted from a more comprehensive table in *TopTen USA 2009-11 Development and Funding Plan*

Market Introduction of Innovative Products

Heat Pump Dryers

Drying laundry with laundry dryers is becoming more and more popular. Electricity consumption by dryers will therefore increase considerably in the near future. The promotion of energy efficient heat pump dryers helps to strongly lower this effect. Heat pump dryers cut energy consumption of conventional dryers in half and exceed the energy label A threshold by far. According to market data from 2008, heat pump dryers did not reach the break through yet and achieved a market share of less than 4% in most European countries. The situation in Switzerland however is promising: the market share of heat pump dryers has grown continuously since 2004, and reached 15,6% in 2008. Also the product range is growing: today there are 11 models for residential and 3 for semi-professional use on the Swiss market. The introduction to the Swiss market was mainly facilitated by Topten and its partners, among them the City of Zurich, which could be convinced to launch a procurement program for heat pump dryers as well as rebate programs [6,7].

Coffee Machines

Annually, more than 18 million coffee machines are sold in Europe. The trend goes clearly towards espresso and filter pad machines (comfort and quality reasons); by now those account for about 45% of total sales, while the rest is mainly traditional filter coffee machines [8,9].

Espresso and filter pad machines use large amounts of electricity for permanent pre-heating and standby modes. According to measurements by Topten, energy consumption of a typical espresso machine is about 170 kWh per year. With relatively simple measures as auto-power-down, better insulation of boilers and low standby the energy efficiency of coffee machines can be strongly enhanced. High efficiency espresso machines only have a consumption of about 50 kWh per year. The entire EU stock of coffee machines (estimated 100 Mio) thus holds a saving potential of up to 12'000 Mio kWh per year.

In the framework of the IEE-project "Euro-Topten" a measuring method for coffee machines was developed. This methodology is suggested and might be incorporated into the IEC 60661 standard (Methods for measuring the performance of electric household coffee makers) and a labelling directive, respectively. Euro-Topten and the label Blue Angel [10] coordinated their procedure and harmonized their measuring methods. It is applied for the selection of best products on www.topten.info and for the Blue Angel.

Conventional coffee machines usually have higher electricity consumption than A-class ovens or A++ refrigerators. Regarding the great differences between products and the high saving potentials, it is strongly recommended to take measures. Particularly an energy-label for coffee machines and an appropriate application of the new European MEPS for standby (including auto-power down) would be very effective measures to raise the efficiency of coffee machines, which should be covered by the preparatory study for eco-design on coffee machines (lot 25).

Already today, diverse high efficiency models of several important brands of coffee machines are available on the European market. They are presented on www.topten.info. Energy labels for coffee machines would be appropriate and would give incentives to trade and industry to develop and offer more energy-efficient coffee machines.

Geographical Expansion

Europe

So far, Topten is online in 12 European countries. The launch was funded by the European Commission (IEE-project Euro-Topten, 2006-08) and national funding [1-4]. With the IEE-project Euro-Topten Plus (2009-11) it will be expanded to 16 countries and include 20 partners (budget: 1.7 million €). New Topten sites will be launched in Norway, Greece, Romania and Lithuania. Best of Europe is an aggregation of all national Topten-projects and displays the very best products all over Europe. The launch has been funded by WWF and Oak Foundation (2007- mid of 2009). For the follow-up and extension new funding will be required.

In addition to updating existing websites and creating 4 new ones, the project will focus on household appliances, office equipment, cars and work with large buyers on procurement.

The impact of Topten Europe is summarized in the report 2009 [1] and in Table 2. Within the market transformation tool box, Topten is considered as a "soft measure", a measure that definitely impacts the market on crucial aspects: it is a market shifter, a facilitator, an education tool, a decision making aid.

Table 2. Key Results of Euro-Topten 2006 – 2008

12 websites presenting continuously updated selections of best appliances, recommendations for users and selection criteria
Information available in more than 10 languages
166 product categories scanned in the 12 countries, broken down into more than 600 market segments to stick to consumers' preferences
More than 9,5 million visitors over the three years of the project, 4,3 millions in 2008.
A large media coverage, reaching over 150 million readers, viewers and listeners, worth over 2,1 million € (this is a conservative statement as it only concerns the 6 countries which were able to quantify their media coverage)
"Best of Europe": the only review of the supply of efficient appliances on the European market (BAT, policy analyses)
An open Topten platform: new organizations can join at any time
Differentiated impact on numerous target groups: tailored information delivered to consumers, procurement officers, policy makers, NGOs and institutions, support to utilities, support and recognition to product manufacturers and retailers investing in energy efficiency.

The resulting number of saved kWh could be best quantified in the framework of a structured and comprehensive evaluation project. Topten covers a wide range of activities, from detailed market and technical studies to dissemination to various target groups including the general public. This versatility offers many keys for evaluation. A city modifies its procurement policy; a utility decides on a rebate programme; policy makers favour ambitious regulations; NGOS communicate on energy savings in homes in order to link individual behaviour and climate change issues; retailers chose to adopt energy efficient positioning and revise their range selection; manufacturers develop new efficient models and strongly market them; consumers' demand for efficient models grow – Though these decisions depend on the strategies stakeholders decide to adopt, Topten may weight, more or less explicitly, in all of these decisions transforming markets. Topten brings about three major positive impacts which all together contribute to save energy.

- Visitors get to know very quickly and simply about best appliances
- The portal www.topten.info has enabled the Topten partners to develop synergies and create a new activity called "Best of Europe" which identifies best available technologies and present the status quo on efficient products
- Through their daily activities, the Topten teams generate substantial positive impact and play a range of market functions that add value for the full range of market actors: consumers, manufacturers, retailers, procurement officers, policy makers, utilities, the media, NGOs.

United States

The potential energy (and related energy cost) savings and greenhouse gas emissions reductions that could be achieved by implementation of Topten in the United States – coupled with a lack of an energy efficiency benchmark more ambitious than ENERGY STAR and the promise of significant energy efficiency funding in the context of economic stimulus incentives – have created great enthusiasm for bringing the Topten system to the US market, particularly among energy efficiency program administrators (Table 3).

Table 3. TopTen USA Savings Potential

Product	U.S. Unit sales/yr (millions)	Avg. lifetime energy use (in kWh)	Est. % savings from TopTen	One year CO_2 reduction for 10% TopTen market share (tons)	One year CO_2 reduction for 100% TopTen market share (tons)
Screw-Based Lamps	1,400	60	80%	5,376,000	53,760,000
Televisions	36	6,000	60%	10,368,000	103,680,000
Computers	50	2,040	70%	5,712,000	57,120,000
Monitors	45	270	60%	583,200	5,832,000
Room Air Conditioners	10	7,540	25%	1,508,000	15,080,000
Clothes Washers	9.5	5,093	75%	2,903,010	29,030,100
Clothes Dryers (electric)	6.4	10,800	45%	2,472,768	24,727,680
Refrigerators	11	7,280	35%	2,242,240	22,422,400
Freezers	2.2	4,884	30%	252,014	2,520,144
Dishwashers	7.3	4,670	60%	1,625,160	16,251,600
Vehicles	17	7,212*	27%	32,470,000	324,700,000
Total	**1,594.4**			**65,512,392**	**655,123,924**

Source: TopTen USA 2009-11 Development and Funding Plan

The mission of TopTen USA is to create a dynamic benchmark for the most energy efficient products on the U.S. market and work in partnership with market actors to stimulate market demand for the highest-efficiency devices. Following a series of initial enquiries and preparatory efforts beginning in 2007, serious work on TopTen USA began with initial seed funding from WWF USA in April 2008 (Figure 3). Since then, an independent TopTen USA corporation was formed, the TopTen USA Executive Board was constituted, funding to hire an Executive Director and undertake the initial benchmarking work was secured from foundations, based on the *TopTen USA 2009-11 Development and Funding Plan*, and work on an initial set of product categories has been launched.

	Initial Concept	Preparatory Phase	Start-Up I	Start-Up II
Description	Informal consulta-tions to guage interest/feasibility	Secure startup funding and build organiza-tional capacities	Nonprofit startup and strategic alliances	Market research, Web and product development
Time Period	2007 - 2008 ➔	2008 ➔	January - June 2009 ➔	July - December 2009
Funding	In kind only	$200 k (WWF USA)	$350 k (Sea Change Foundation, Energy Foundation)	Budget of $1.3 m
Key Institutions	Interested expert consultancies	• Interim Management Team • Ad Hoc Advisory Panel (ACEEE, NEEA, NEEP, NRDC, PG&E, WWF USA)	TopTen USA Institutions: • Executive Board • Advisory Panel • National Consultative Group	Same as Phase I, plus establish relationships with: • Efficiency program administrators • Media partners • Retailers
Milestones		• TopTen USA Executive Board and corporation formed • 2009-11 Development and Funding Plan • Funds secured for Start-Up Phase	• Hire Executive Director and retain contractors • Preliminary lists for at least four categories of TopTen USA products • Convene Advisory Panel & National Consultative Group • Funds secured Phase II	• Complete initial product lists • Create web design & content • Obtain TIG Accreditation • Establish relationships with market actors • Funds secured Phase III

Figure 3. History and Plans for TopTen USA Development

TopTen USA is fortunate to have a powerful coalition of enthusiastic stakeholders represented in its Board, including the American Council for an Energy Efficient Economy; environmental non-profits (WWF USA and the Natural Resources Defense Council); regional energy efficiency program administrators (Northeast Energy Efficiency Partnerships, Inc. and Northwest Energy Efficiency Alliance); and Pacific Gas & Electric, which serves a liaison function with other California utilities.

Market research, product benchmarking, Web development, relationship building, and fundraising will continue in 2009, with a view to launch TopTen USA in 2010. TopTen USA has consulted extensively during its development phase with the founding Board members of the Topten International Group to benefit from lessons learned in Europe and will soon join the TIG Board.

Topten China

The Topten China project was started in early 2009 with seed money from WWF Switzerland and Swiss government REPIC funds. It is coordinated by Topten International Group (TIG) with technical support by Topten International Services (TIS). The Topten China Project Management Team (PMT) was built up in WWF Beijing China Policy Office and is developing the necessary partnerships with Chinese NGO's, governmental agencies and market stake holders. The PMT of Topten China project has introduced the Topten concept to the related Chinese government and got positive feedback, while technical matters, co-funding and communication partners are still under discussion. In order to built-up the partnership at the inception phase and kick-off the Topten China website development a partner mobilizing meeting, which will involve both international partners (TIG, TIS and WWF Switzerland) and Chinese agencies (governmental officials, technical experts, representatives of NGO's etc) will be held in June 2009.

Within a three year period the Topten China project will prepare (year 2009), launch (year 2010) and start to continuously operate the Topten China website (year 2011). The build-up of the Chinese information platform will be made visible in electronic (internet, supported by radio and TV activities) and print media (newspapers, magazines and journals). In the preparatory phase, national market research in China will lead to identify priority products and select the most energy efficient equipment.

In parallel research on the respective Chinese testing standards and performance criteria for the selection of the top ten products in each sector is planned.

The Topten China project has to deal with the characteristics of a huge market supply of and demand for Chinese energy efficient products. For each specific product category there are a lot of available and rapidly updated Chinese and international brands with top level of energy efficiency. For example, there are at present (CNIS: registration for Energy label 2008) 3199 refrigerator types in the market, and 76% of these products have the Chinese efficiency Class 1 [11].

Challenges

Documenting Topten Impacts

Analysis and assessment of national Topten systems and their impacts are necessary to:

- provide feedback and information needed to continuously improve processes and services, maintaining Topten's market position as the premier benchmark and resource guide to the most efficient equipment, products and services, thereby enabling Topten to succeed in its mission
- provide information needed by sponsors and funders to maintain their support for Topten as a strategy and tool to increase energy efficiency (i.e. regulated energy efficiency program administrators in the US must be able to demonstrate that TopTen USA positively impacts the market adoption of high efficiency products leading to energy savings)
- document the role that Topten can play in sustainable development efforts (e.g., poverty alleviation, climate change mitigation, energy security), including quantification of related impacts, as well as lessons learned to enhance the effectiveness national Topten systems.

In Europe the focus is put on sets of performance indicators, annual reporting and analysis of impact. In USA funders are rather demanding for independent evaluations. As a result, TIG has yet to issue guidance on Topten performance analysis and evaluation approaches.

Securing Sustained Funding, while Maintaining Independence

The effectiveness of Topten depends to a large extent on its credibility as a trusted high-efficiency benchmark for all market actors, which requires independence from industry (manufacturer) influence with respect to product selection. This has let to a strict funding firewall between manufacturers and Topten. Yet securing sufficient and sustained funding for both national Topten systems and the work of the Topten International Group has proven challenging.

The European Topten system systems still involve a lot of *pro bono* effort. Many national programs are struggling with only a few staff to develop, launch and fundraise for their programs. As Topten has had an organic development in Europe, these teams have done as much as possible with the limited resources available to demonstrate Topten, and are now slowly moving towards more sustained funding models. Core budgets in Europe have typically been in the range of about EUR 100 to 250 thousand per year. Although each national Topten system has pieced together its own mosaic of funding sources, the most common have been the following:

- Public government funding (federal, state, city) has typically been the initial source of seed funds – providing start-up funding to establish national Topten sites before there is a "product" to sell. In Switzerland (funded by Federal SwissEnergy program, electrical utilities and WWF) and the EU (funded through the Intelligent Energy Europe program and national partners), the government continues to be a major funding source. In the case of the new Euro-Topten Plus project, which runs from 2009-11, IEE pays 75% of the EUR 1.7 million budget and national programs secure the rest. Some state and city governments are also interested in direct cooperation in procurement programs and have funded specialized product testing as well as development of specifications for public tenders organized for best products (like copiers, office lighting, etc.). The results were usually transported into mandatory buying rules of the city for the time after the first purchase.
- Environmental non-profit organizations constitute the second major funding source, providing grants as well as in-kind support, especially on specific testing of products. Consumer advocacy organizations have shared the cost of product testing (they do regular tests on all

kinds of products, not involving energy, whereas, Topten pays for the additional energy testing, according to an agreed annual plan). These relationships have also included agreements on publication in their media, which have great value to Topten. In many cases they negotiate media products (like billboards in the streets or small Topten booklets delivered in journals) for much lower cost than a commercial enterprise would have to pay. These organizations also provide in-kind qualified marketing and partnership development support. For instance, WWF Switzerland launched the "Climate Group" inviting large enterprises to sign a charter for environmentally friendly behaviour in many fields. WWF used Topten as a follow up tool to support decisions about the energy efficiency of the range of products that the charter signatories manufacture or sell.

- Utilities have provided core budget support and/or have funded specific projects (e.g., product tests, design of rebate schemes). Topten works with utilities to establish selection criteria for rebate/discount schemes and assists with determining an appropriate level for rebates (particularly for innovative products that have a higher up-front purchase price, such as A++ fridges or heat pump dryers). Usually, utilities provide strong support in communication as they are in direct contact with their customers.
- Private foundations are another source of funding for Topten, which have been crucial to launching the US effort. Since many European Topten systems are not independent entities, many are not directly eligible for grant funding and work through their NGO partners to obtain grants. The Oak Foundation, for example, channelled some funds via WWF Switzerland to the European Topten effort.
- Media are another potential source of funds (e.g., fees for Topten assistance with producing articles and shows (print, TV, radio, web, etc.). However, Topten has not received relevant revenues from this source to date.
- Pro bono work has been a key ingredient. A committed group of experts continue to donate their services to Topten out of personal commitment and dedication to the causes of energy efficiency, climate change mitigation, emission reduction, and nature. This international network of friends and colleagues in the "Topten family" - which includes several industry insiders (many of which now have an internal group dedicated to innovate best products) – is regarded as a key factor in Topten's success and ability to move fast into new fields (e.g., heat pump dyers, new generation of high-efficiency LED lights to substitute low voltage halogen lamps in domestic areas).

Early on, TopTen USA will explore the potential to generate market-based revenues through agreements with retailers to use the TopTen USA brand to promote listed products. For example, web-based retailers such as Amazon - as well as standard retail merchants - might use TopTen USA messaging and branding to demonstrate their commitment to energy efficiency by carrying the most efficient products available. In doing so, TopTen USA must position the TopTen USA brand as a complement to the well-established Energy Star label (e.g., in many cases, TopTen USA listed products will be the most efficient options that meet specific Energy Star product specifications). TopTen USA will also explore "fees for services" as another possible revenue strategy (e.g., charge retailers for the service of connecting their stores to the TopTen USA website through a zip-code based retail store locator for TopTen USA listed products).

National Topten teams in Luxembourg and Switzerland have already begun to develop licensing relationships with retailers that allow them to use the Topten logo at the point of sale. This is a time-consuming process and it is too early to know whether these efforts will be successful as a significant new source of funding.

Although TIG has advised against requiring manufacturers to pay for independent testing as a criterion for product listing, TopTen USA will also investigate the potential to establish a set fee schedule to help cover the cost of product testing. It is routine for US-manufacturers to test products through third-party laboratories on a fee-for-service basis. In addition, manufacturers pay fees to certification organizations such as Green Seal and Scientific Certification Systems (SCS), models similar to potential TopTen USA testing. This model would likely depend on TopTen USA's success in creating sales for high-efficiency products.

Manufacturer and retailer revenues are potential funding options only at this time. It is important to note that, while the European Topten includes retailer licensing fees, it does not include funding from manufacturers. If TopTen USA expands funding to include testing fees from manufacturers, careful consideration must be given toward avoiding conflicts of interest and the protecting Topten's position as an independent resource for information regarding efficient products. Currently, TIG does not support any financial arrangement with manufacturers for TIG members.

International Benchmarking – Best of the World

TIG currently maintains the "Topten – Best of Europe" regional benchmarking system (www.topten.info), which draws on data from participating national Topten systems. With the planned addition of non-European countries to the Topten family, it is TIG's ambition to expand its benchmarking efforts to "Best of the World", but this simple concept presents significant methodological challenges, such as differences in:

- Testing procedures (e.g., standard driving cycles used to determine the fuel economy of cars)
- Electrical voltages and frequencies (e.g., refrigerators in Europe and Asia run on 230V at 50 Hz, whereas in the US they operate on 110 V at 60 Hz), which can affect the relative efficiency of equipment
- Equipment characteristics across markets (e.g., the US market has the tendency to demand significantly larger appliances and cars with more features than the European market)

Given these challenges, TIG intends to undertake joint European-US-Asia research on the best way forward, one option being to first develop additional regional benchmarks, such as for Europe, North America or Asia. The IEA Implementing Agreement 4E Project will launch an Annex on " Mapping & Benchmarking" that will provide an overview of policy measures and compare sales weighted average and best performance of products put on the market (like: domestic cold appliances, integrated home networks, TVs, water heaters, domestic laundry, domestic lighting, domestic air-conditioners, computer displays, laptop computers) in different countries. The Topten research can certainly benefit from 4E activities.

Organizational Development to Accommodate Growth

Topten International Group TIG

The Topten International Group (TIG) was formed in 2006 to launch, support and coordinate national Topten projects. The organization adheres to the Topten Charter and TIG Rules of Procedure and is operated largely via the part-time, *pro bono* efforts of its three founding board members. Up to now, TIG has mainly supported the Euro-Topten efforts, but thanks of the geographical development, TopTen USA and China will be received in the TIG Board soon.

National Topten Systems

In contrast to TopTen USA, national Topten organizations in Europe have been "structured" following funding opportunities, in particular, the Euro-Topten project within the framework of the EU Intelligent Energy Europe subsidy program. In most countries, Topten is a "project" or an "activity" undertaken by an organization (which carries out other projects) – and has no separate organizational structure. That these projects were carried out from the start exclusively by either public bodies or NGO explains why Topten projects have not (yet) grown into independent structures. For public bodies, as long as their government is happy and provides funding, there is no reason to change. For NGOs it seems difficult to start a project and then transform it into something independent which might compete for fundraising. This experience suggests that it is preferable to begin with a private, independent, non profit from the start – as is the case for TopTen USA and Switzerland.

Knowledge Management

Another issue is to ensure that the Topten International Group can meet the growing demands on the institution to fulfill its quality assurance, oversight/support, coordination, and policy roles. The main part of technical knowledge is public and online on topten.info. However, there is a large pool of operational knowledge in the Topten family. This “institutional memory” lies in publications, workshop-documents and in individuals’ know-how. Guidance and periodic workshops on strategies applied and lessons learned in various countries should be strengthened.

Future Evolution

The Board of the Topten International Group will be expanded in 2009 to include representatives of TopTen USA and Topten China. Collaborative efforts for 2009-10 will be agreed at the TIG Board meeting in 2009 and may include items such as:

- Development of a common evaluation framework for Topten
- Terms of Reference for a TIG knowledge management system
- Brainstorming on a mechanism for routinely transferring high efficiency product developments between Europe, China and the USA
- Exchange of experience on building relationships with retailers and large buyers
- Clarification of the TIG accreditation process to facilitate TopTen USA accreditation in 2009
- Develop a Work Plan for research to support the development of “Topten – Best of the World”

References

[1] Euro-Topten Coordination Team. *Click your way to energy savings - Find out the most efficient products in Europe with a simple click on Euro-Topten websites*. Report 2009. Can be ordered from www.topten.info

[2] Bush Eric, Sophie Attali, Conrad U. Brunner, Anne Arquit Niederberger. *Topten - Best of Europe: How do best products perform and why aren't they sold across Europe?* Proceedings of the eceee Summer Study (La Colle sur Loup, June 2007). Can be ordered from www.eceee.org.

[3] Bush Eric, Sophie Attali, Conrad U. Brunner, Anne Arquit Niederberger. *Topten.info: Fast selection, best choice*. EEDAL Conference on Energy Efficiency in Domestic Appliances and Lighting, London. 2006

[4] Attali Sophie, Eric Bush. www.topten.info goes European - *How to get Mr. Smith hooked to energy efficient appliances*. Proceedings of the eceee Summer Study (Mandelieu, June 2005). Can be ordered from www.eceee.org.

[5] www-ecodryers.org, website of the Ecodesign Lot 16 team: Ecobilan, PricewaterhouseCoopers (in cooperation with CODDE and KERP). 2009

[6] Bush Eric, Jürg Nipkow: *Tests and promotion of energy-efficient heat pump driers*. EEDAL, London, 2006

[7] Nipkow Jürg, Bush Eric: *Promotion of energy-efficient heat pump dryers*. EEDAL, Berlin, 2009

[8] Nipkow Jürg, Eric Bush (S.A.F.E.). *Energy label for coffee machines*, EEDAL, London 2006

[9] Eric Bush, Jürg Nipkow, Barbara Josephy, Susanne Heutling, Rainer Griesshammer. *Strategies to Enhance Energy Efficiency of Coffee Machines*, EEDAL, Berlin 2009

[10] Topten International Group TIG. *Measuring Method and Calculation Formula for the Electrical Consumption of Coffee Machines* (2009). Can be downloaded from www.topten.info

[10] Umweltbundesamt und RAL, Dessau. Umweltzeichen *Der Blaue Engel.* www.blauer-engel.de

[11] Zhang Xin (CNIS): *Chinese standards and labels for energy efficient products*, Motor Summit 2008, Zurich Switzerland. Can be downloaded from www.motorsummit.ch

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Abstract
This book contains the Proceedings of the 5th International Conference on Energy Efficiency in Domestic Appliances and Lighting, Berlin (DE), 16-18 June 2009. The EEDAL'09 conference has been very successful in attracting an international audience, representing a wide variety of stakeholders involved in policy implementation and development, research and programme implementation, manufacturing and promotion of energy efficient residential appliances and lighting. The international community of stakeholders dealing with residential appliances and lighting gathered to discuss the progress achieved in technologies and policies, and the strategies to be implemented to further this progress.
EEDAL'09 has provided a unique forum to discuss and debate the latest developments in energy and environmental impact of residential appliances and installed equipment, and lighting. The presentations were made by the leading experts coming from all continents. The presentations covered policies and programmes adopted and planned in several geographical areas and countries, as well as the technical and commercial advances in the dissemination and penetration of energy efficient residential appliances and lighting.

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