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Environmental assessment to support ecodesign: from products to systems

A method proposal for heating systems and application to a case study

Calero Pastor, M., Mathieux, F. and Brissaud, D.

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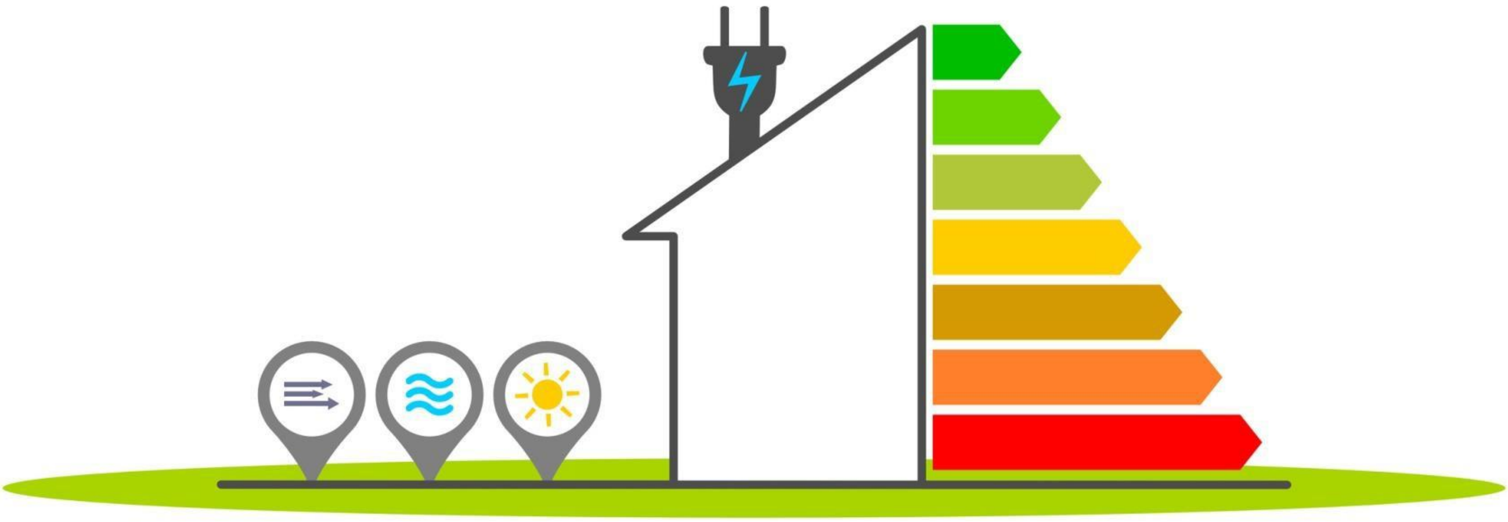

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Contents

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Abstract

Different policy instruments at the macro and micro level coexist with the goal of reducing the energy consumption of the building sector.

At the macro level, the Roadmap to a Resource Efficient Europe (EC, 2011c) and the Energy Efficiency Directive (EC, 2012a) highlight the importance of the building sector, which accounts for 40% of the total energy consumption in the European Union (EC, 2011a). Greater energy efficiency in new and existing buildings is crucial in order to reach the goal of the European Commission's energy roadmap for reducing the GHG emissions by 80-95% by 2050 compared to 1990 (EC, 2011b). The implementation of the Energy Performance of Buildings Directive (EPBD) 2002/91/EC (EC, 2010b) promotes the energy efficiency in the heating, cooling, lighting and operating appliances and the use of renewable energy in buildings. In particular, Heating, Ventilation and Air Conditioning (HVAC) systems account for 50% of the total energy consumption of buildings (Pérez-Lombard, L., et al., 2008). In 2012, half of the EU's energy consumption (546 Mtoe) facilitated heating and cooling, and much of this was wasted through insufficient insulation or inefficient equipment in buildings, among others (EC, 2016a).

At the micro level, product policies such as Ecodesign and Energy Labelling Directives, EU GPP and EU Ecolabel have the common goal of making the EU market more sustainable. Indeed, they have been very successful in improving the energy efficiency of building products, especially those involved in HVAC systems such as water and space heaters, coolers or air circulators. However, even greater saving potentials could be achieved when the focus is done at the system level rather than at regulating products alone. The issue is that here are huge methodological challenges regarding the definition of systems, the scope and boundaries of a system, the modelling of components that make up a system and its interactions, and the measurement of the energy flows within the system. Policy makers have already recognised the limitations of considering isolated products instead of product systems, and have proposed to move these product policies from components to packages or groups of products (e.g. Regulation 811/2013).

This report provides guidance towards bringing closer micro and macro scale policies at the building sector. The objective of the work presented in this report is to explore the methodological aspects of environmental assessments of systems at the design step, in order to get higher environmental benefits.

The procedure followed to develop the work of the present report began at analysing the system approach and environmental aspects at different product policies (Ecodesign and Energy Labelling Directives, EU GPP and EU Ecolabel) and the scientific literature (only on HVAC systems). As a result of this analysis and the comparison of both sources, some gaps were identified and general requirements were identified for a method supporting the design of good performing heating systems.

Product policies usually apply the extended product approach to include additional products, part of the system, that influence the overall performance of a group of products (packages). However, the system approach, i.e. including all the components is not widely applied, as it should be. Product policies focus on environmental performances during the use phase, including energy efficiency, although other aspects can also be considered (e.g. air emissions, sound levels or other technical requirements). On the other hand, the scientific literature uses the system approach and holistic environmental assessment such as LCA.

Then, the report proposes a simplified method and a calculation tool, to support the design process of good heating systems in residential buildings, based on the choice of the performance of its components. In the method, product performance figures provided by European sellers according to EU product policies are used when they are available. When product policy data is not available, designers are free to decide on which other tool to use to calculate the missing data. The method allows designers to

study the improvement potential and combination of products' performance levels and to achieve energy-saving targets at system level.

The method provides two new aspects that are not yet covered by the literature:

1- it allows the assessment of heating systems grounded on well-known and proven labelling schemes such as EU product policies, which are available at the early design stage and implemented by all manufacturers, and
2- it supports design activities at system level, providing informed decision-making on multiple design solutions based on different configurations of products with performance levels currently available on the market.

The method is also tested on a specific case study, simulating the re-design of two heating systems (a solar sanitary hot water system and space heating system) in a dwelling located in North Italy. The case study shows how the method can be applied using data of product policies when available, other tools and/or making assumptions. It also shows the quantitative results on the improvement potential of relevant components and on the combination of components with different performance levels. In addition, the package concept is applied to the case study. Despite the current limitations of the EU package concept (e.g. missing components and climate conditions, rough calculation, etc.), similar conclusions can be drawn from the EU package concept than from the method proposed, which shows the validity of the former. On the other hand, the method proposed is more complete, accurate and flexible and can therefore better support design activities.

The method represents a step forward on how to address better the system approach in environmental assessments and how this could be applied to ecodesign of product's systems. The report demonstrates that the method contributes at improving the task of building designers and regulators to easier achieve common and equivalent energy efficiency objectives.

1. Introduction and literature review

This report has been developed within the JRC Institutional project "Better Regulation Assessments for the Circular Economy: Supply Chains of Raw Materials and products" (BRACE-RMP), in the context of the work package "Single Market: supporting better regulation and circular economy through Life Cycle Assessment" (SMART-LCA) under Deliverable 20164 on "Environmental assessment: from products to systems".

This study aims at contributing to the improvement of sustainability of EU at various levels: micro scale (eg. products, services), meso scale (e.g. industrial sectors) or macro scale (eg. EU wide policy options). It provides guidance towards bringing closer micro and macro scale policies through the assumption that there are greater saving potentials when the focus is done at the system level rather than at regulating products alone.

However, there are huge methodological challenges regarding the definition of systems, the scope and boundaries of a system, the modelling of components that make up a system and its interactions, and the measurement of the energy flows within the system.

The Roadmap to a Resource Efficient Europe (EC, 2011) mentions that better construction and use of buildings in the EU would influence 42% of our final energy. This communication also brings out the importance to support research and innovation in areas such as smarter design. More recently (December 2015), the EU Circular Economy action plan (EC, 2015a) highlights the contribution of products to the circular economy. In this action plan, there is a particular focus on environmental performance assessment of buildings products. This report hence concentrates on building products and systems.

The system definition can include greater or smaller system boundaries. In this report, building systems are defined as a group of components present in a building with the common goal of fulfilling the same service. Then, building systems may include many energy-using products (EuP) and energy-related products (ErP) and sub-systems in charge of providing several services to users. These services can be shelter, food, HVAC (Heating, Ventilation and Air Conditioning), connectivity to internet and artificial light.

The work of this report is restricted to HVAC systems. HVAC systems account for 50% of the total energy consumption of buildings (Pérez-Lombard et al., 2008). In 2012, half of the EU's energy consumption (546 Mtoe) facilitated heating and cooling, and much of this was wasted through insufficient insulation or inefficient equipment in buildings, among others (EC, 2016a).

1.1 Product's systems in the building sector: policy framework

Several policies tackle the importance of reducing the energy consumption in the building sector. This sector accounts for 40% of the total energy consumption in the European Union (EC, 2011a). Greater energy efficiency in new and existing buildings is crucial in order to reach the goal of the European Commission's energy roadmap for reducing the GHG emissions by 80-95% by 2050 compared to 1990 (EC, 2011b).

The implementation of the Energy Performance of Buildings Directive (EPBD) 2002/91/EC (EC, 2010b) promotes the energy efficiency through the reduction of energy consumption used to maintain the indoor environment through heating and cooling, lighting and operating appliances and the use of renewable energy (RE) in buildings. The energy efficiency Directive (EC, 2012a) requires that 3% of the total floor area of heated and/or cooled zones of public bodies' buildings be renovated each year to meet at least requirements set in the EPBD.

Moreover, the Ecodesign and Energy Labelling Directives (EC, 2009; EC, 2010a) promote the production and consumption of more energy-efficient products. Typical Energy-using Products (EuP) used in buildings (e.g. boilers) have already been regulated for many years. The review of the Ecodesign Directive in 2009 extended its scope to include Energy-related Products (ErP), addressing other relevant building products (e.g. windows, taps, showers, insulation components). The main concern about product policies is that there are further great (energy and resources) savings potential when the focus is done at the system level instead of at the product level.

Some questions could be raised regarding the system approach in product policies. What would be the performance of a system composed of products affected by different product policies? For instance, one product with minimum Ecodesign requirements, another with an energy label B and a third product awarded by an EU Ecolabel. Are all the components influencing at the same rate the overall performance of the system? Which are the most influencing components in the system? Is it possible to outweigh the low performance of one product with the high performance of another one?

Although policies already co-exist at the macro- (i.e. buildings, through the EPBD) and micro- (i.e. building components, through the Ecodesign and Energy Labelling Directives) levels, there is still a technological gap between building designers and regulators that needs to be filled in order to ensure the achievement of overall energy efficiency objectives (Allouhi et al., 2015).

The originality of this report is to tackle the system approach in relation to product policies.

1.2 Current EU product policy initiatives on systems

The EPBD considers the building itself as the system for the purpose of analysis. In addition, defines the 'technical building system' as the technical equipment for the heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building or building unit. EPBD requires Member States to set system requirements in respect of overall energy performance proper installation appropriate dimensioning, adjustment and control for new, replacement and upgrading technical building systems.

This section focuses on four product policies: the Ecodesign and Energy Labelling Directives (EC, 2009; EC, 2010a), Green Public Procurement (GPP) (EC, 2008b) and the EU Ecolabel (EC, 2013a). The common goal of these product policies is to make the EU market more sustainable (EC, 2008a). According to these product policies, manufacturers and/or importers have to provide information regarding the performance of the products they put on the EU market.

Product policies initially addressed individual product. However, it was soon seen the importance of considering additional products or components that were greatly influencing the total energy efficiency. The **extended approach** in products' systems consists in extending the system boundaries in order to include other products influencing the performance of the product under study. The **system approach** considers all (or part of) the components and sub-systems needed to deliver a service.

However, BRE (2011) analysed the implementation of the system approach in product policies and identified the following risks:

- For developing robust system methodology, the length of the technical discussion by stakeholders might become too long.
- The system approach may become too difficult and this additional complexity might lead to higher costs and longer timescales.
- The system approach might not correspond to markets since industry operates at product or component level (unit of sales).

So far, product policies have dealt with the particularities of motor systems, lighting systems and heating systems. Next, current product policies on these systems are analysed from the product to the system approach and main environmental requirements are presented.

1.2.1 Electric motor systems

Motors systems may include a number of EuP, e.g. motors, drives, pumps or fans and their configurations and sizes are almost infinite. Simple motor systems can comprise a couple of components (e.g. an electric motor with variable speed drive) delivering a basic function such as turning a shaft at varying speed and torque; while there are larger systems (e.g. circulators or ventilation units) with many components fulfilling a function more easily recognised by an end user such as delivering air or water.

Initially, product policies focused on individual components (e.g. motors, pumps and fans). However, the evidence of the great saving potential of considering the motors systems as a whole gained importance and the system approach started to be implemented. For example in the case of pumps, while the improvement of the product alone can achieve savings of 4%, the extended product approach of adding adequate speed drives could achieve 30% savings and further system optimisation up to 45% of energy savings (BPMA, 2011). Thus, different components have been grouped into different categories allowing the addition of different components for specific applications. Figure 1 summarises how the product, the extended product and the system approach has been applied in EU product policies.

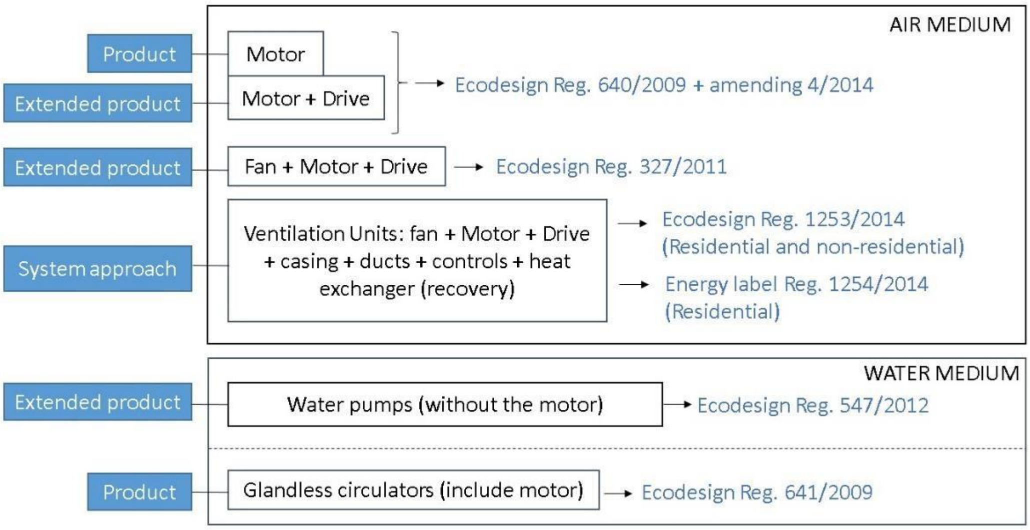

Figure 1. Overview of EU product policies on motor systems

Ecodesign of electric motors (Regulation 640/2009 and 4/2014) includes certain types of motors equipped with variable speed drives as well as motors integrated in other products. This regulation sets two different minimum (nominal) efficiency levels; IE2 for motors alone and IE3 for motors combined with a variable speed drive.

Ecodesign for fans driven by motors with an electric input power between 125 W and 500 kW (Regulation EC 327/2011) includes many fans used in combination with motors but not covered by Regulation (EC) No 640/2009. This regulation applies the extended approach including the fan to the system comprising motor and drive, set in the previous Regulation (EC) 640/2009. These types of fans integrated in other products such as ventilation systems in buildings are also under the scope of this regulation. Efficiency requirements are set for different types of fans.

Ecodesign of ventilation units (Regulation 1253/2014) include at least one impeller, one motor and a casing. They can also include heat recovery systems, ducted and not-ducted units, controls and motor with drive and also filters. Ventilation units may include fans covered by Regulation (EU) No 327/2011, but many ventilation units use fans not covered by it. This regulation defines two different types of measurement standards according to residential ventilation units and non-residential ventilation units. It sets minimum requirements on the energy consumption and sounds levels and on the use of drives, by-pass facilities and filters, depending on the type of ventilation unit (unidirectional or bidirectional).

Energy label of ventilation units (Reg. 1254/2014) only include the residential applications. This regulation defines different classes of energy consumption and provide information on flow rate and sound level.

In the case of water pumps, they can be a component of larger motor systems but they are regulated separately. Ecodesign of water pumps (Regulation 547/2012) sets minimum requirements for the hydraulic performance of water pumps without the motor. However, water pumps integrated in other products are also included in the scope of this regulation. It is set minimum efficiency indexes for different types of water pumps.

According to Europump (Europupm, 2014) it is important to distinguish between the "extended product" and the "extended product approach". The "extended product" (water pump without the motor, e.g. Reg. 547/2012) consists of physical components while the "extended product approach" (motor + water pump) a methodology to calculate the energy efficiency index of an extended product, which incorporates load profiles and control method. This last term "extended product approach" is not applied yet in regulations and it is under discussion in standardisation developments.

Ecodesign of glandless standalone circulators and glandless circulators integrated in products (Regulation EC 641/2009) includes glandless impeller pump used primarily for central heating systems or in secondary circuits of cooling distribution systems. Glandless means the shaft of the motor coupled to the impeller and the motor immersed in the pumped medium. This regulation set maximum energy efficiency index.

1.2.2 Lighting systems

The EPBD requires lighting systems to be taken into account in national calculation methodology as well as for determining cost-optimal levels for requirements on technical building systems including lighting for non-residential buildings.

The system approach in lighting ensures that not all the components but also other aspects influencing the illumination are considered. Luminaires are often sold with incorporated or accompanying lamps. The luminaire of a lamp is influencing the performance of the lamp itself. Thus, including both products (lamp and luminaire) in the analysis is a way of including their interaction. Nevertheless, additional aspects should be regarded such as that the illumination is appropriate for the application. For instance, LED lighting are very efficient themselves except when they are hot, so its use in enclosed fitting might be inappropriate (Littlefair and Graves, 2010). The high pressure sodium lamps are also highly efficient, but take time to warm up when turned on thus their use with occupancy sensors might not be a good solution. Likely, LED may be more efficient when they are switched on and off repeatedly unlike other lamps (Young et al, 2011). These examples show there are many system aspects that can influence the functionality of lighting.

The importance of the system approach in lighting is demonstrated even with emerging technologies such as LED lighting. While the use of LEDs can achieve 50% energy savings, the use of LEDs in combination with lighting controls (e.g. illumination zoning optimisation, occupancy control, daylight control) in a warehouse space, can reach 93% (Mutmansky and Berkland, 2013).

In the case of the Ecodesign implementing Directives affecting lighting firstly, isolated products were regulated with an initial tendency of distinguishing between the type of application (domestic/tertiary and directional/non-directional). Figure 2 summarises the EU product policies on lighting systems and when the product, the extended product or the system approach have been applied.

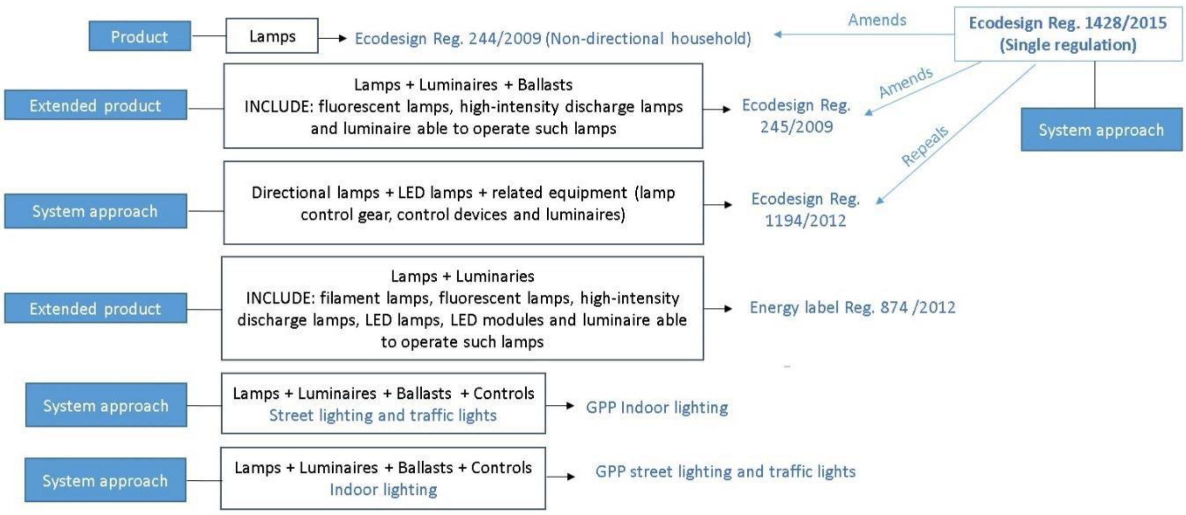

Figure 2. Overview of EU product policies on lighting systems

In the Ecodesign Regulation 244/2009, on non-directional household applications, only lamps are included. The efficacy (the amount of light given divided by the power that consumes) of the lamp is not the only parameter regarded. Other functionality requirements are set up related to maintenance, durability and failures aspects among others.

Ecodesign Regulation 245/2009 includes lamps, luminaires and ballasts, in particular fluorescent lamps without integrated ballasts, high intensity discharge lamps and lamps and luminaire able to operate such lamps. Different Ecodesign requirements are set up for each of these products individually but there are some interactions among them. Minimum requirements on efficacy of lamps are established as well as other lamp performance requirements (e.g. certain colour rendering index, maintenance factors, survival factors). Ballasts energy performing requirements are measured through the energy efficiency index which is a function of the lamp power. In addition, minimum requirements are included for ballast efficiency and energy consumption of fluorescent lamp ballasts. Luminaire energy performance requirements include compatibility with certain ballasts and limitations on the power consumption of incorporated ballasts.

Ecodesign Regulation 1194/2012 focus on directional and LED lamps and related equipment (lamp control gear, control devices and luminaires) for the installation of such lamps. The energy efficiency requirements of directional lamps are measured through an energy efficiency index. Other requirements on functionality (e.g. color rendering, color consistency), durability (e.g. lamp survival factor), maintenance (lumen maintenance) and failure (e.g. number of switching cycles before failure) are also set for directional lamps and LED lamps. For the equipment designed for the installation between the mains and these type of lamps, this regulation establish requirements on compatibility with certain energy efficiency index and on their power consumption. Generic requirements are set (and implemented by harmonised standards) making new lighting equipment more compatible with energy-saving lamps, and energy-saving lamps compatible with a wider range of lighting equipment. Product information requirements on lighting equipment assist users in finding matching lamps and equipment.

In conclusion, different EU Regulation on Ecodesign of lighting have been co-existing. While some of these regulations (Regulation 244/2009) have considered isolated products (lamps), other (Regulation 245/2009) have included different products (e.g. lamps, ballasts and luminaires) with interactions among them. Regulation 1194/2012 included additionally to directional and LED lamps, the compatibility of the related equipment for their installation. The experience on the implementation of all these regulations has facilitated to move forward a common single regulation (Regulation

1428/2015 that amends Regulation 244/2009 and Regulation 245/2009 and repeals Regulation1194/2012) to optimise reductions in energy consumptions.

In the case of the Energy Labelling on lighting (Regulation 874/2012), the scope has been on electrical lamps and luminaires mainly for household and professional applications. It includes filament lamps, fluorescent lamps high-intensity discharge lamps, LED lamps, LED modules and luminaires designed to operate such lamps. This piece of regulation provides not only the information on the energy efficiency classes of the lamp (included in the luminaire) but also on the compatibility of the luminaire with energy-saving lamps.

EU GPP criteria for indoor lighting (EC, 2012b) and for street lighting and traffic signals (EC, 2012c) set benchmark criteria for procurement of these types of lighting systems focused on purchasing resource and energy efficient lamps, design of a new lighting system or renovation of the existing lighting system and installation work.

1.2.3 Heating and cooling systems

These systems are usually regulated according to the service they deliver (sanitary hot water, space heating or space cooling), the energy source they use (liquid, gas or solid fuels, electricity, etc.) or their specific features (water-based or not).

The product approach is dominant in product policies of these systems, so that individual heaters or coolers are regulated separately (Figure 3). There are also regulations such as Ecodesign 814/2013 that cover more than one product, in this case, water heaters and storage tanks, both part of the heating system but with different sub-functionalities and thus, assessed with different performance methods. Regulation 813/2013 includes equipment designed to deliver one (space heaters) or two functions (combination heaters that deliver sanitary hot water and space heating). Regulation 812/2013 sets Energy Labelling requirements for packages of water heaters with storage tank and solar device once they have been installed together (extended product approach).

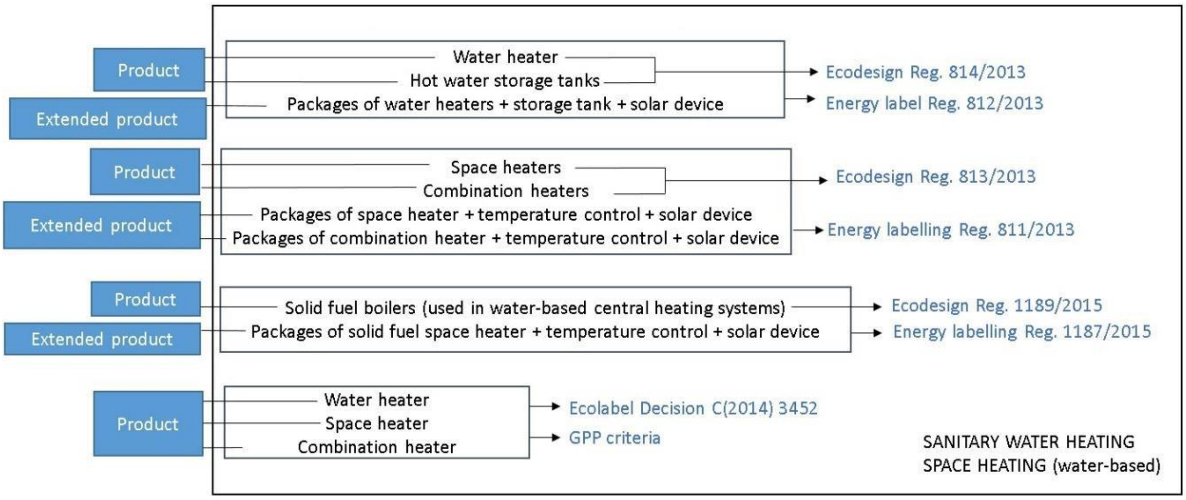

Figure 3. Overview of EU product policies on water-based heaters

Regulations 814/2013, 812/2013, 813/2013 and 811/2013 have different product scope but they use similar parameters to assess the performance of their products. The water energy efficiency is assessed in water heaters that deliver sanitary hot water according to different load profiles set under real test conditions (tapping patterns). In the case of space heaters, the main parameter assessed is the seasonal energy efficiency. In combination heaters both functions (sanitary water heating and space heating) are assessed separately. In storage tanks, Ecodesign requirements set maximum storage volumes and standing losses. Other performance parameters assessed in these regulations are sound power levels or nitrogen oxides emission (in fossil fuel water heaters). In addition to these parameters, Regulation 1189/2015 on the Ecodesign of solid fuels boilers (sanitary water heating and/or space heating and/or electricity generation), set maximum levels of organic gaseous compounds and carbon monoxides. Energy Labelling of solid fuel boilers (Regulation 1187/2015) include also packages of a solid fuel boiler, temperature controls and solar devices (extended product approach). EU Ecolabel (EC, 2014a) and GPP criteria for water-based heaters (EC, 2016b) are on high energy efficiency, low air emissions (GHG, refrigerants, NO_x, CO, OGC, PM and other hazardous substances) and low noise emissions, among others.

With regard to local space heaters (Figure 4), similar parameters to the previous one are assessed for Ecodesign of solid fuel local space heaters (Regulation 1185/2015), Ecodesign of local space heaters different of solid fuels (Regulation 1188/2015) and the Energy Labelling for local space heaters including solid fuels and excluding electricity (Regulation 1186/2015). All these regulations follow the product approach.

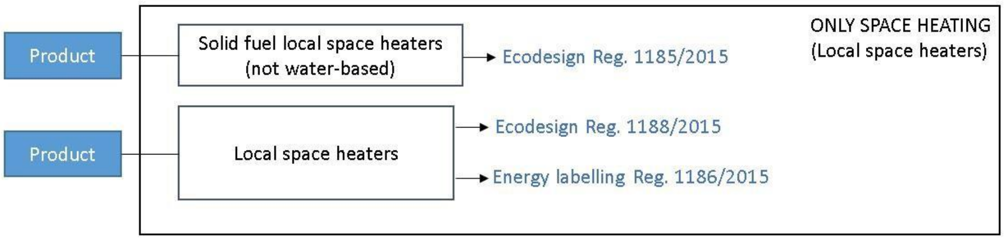

Figure 4. Overview of EU product policies on local space heaters

Equipment design for space cooling functions (Figure 5), usually may provide additional functions such as space heating, ventilation or de-humidification; however with a product approach. Ecodesign requirements for air conditioners and fans (Regulation 206/2012) are set for minimum energy efficiency, maximum electricity consumption and sound power levels. In addition, the type of refrigerant used may penalize (or not) the total energy efficiency. Energy Labelling on air conditioners (Regulation 626/2011) set energy classes for different types of air conditioners according to the cooling and/or heating function and for different climate zones.

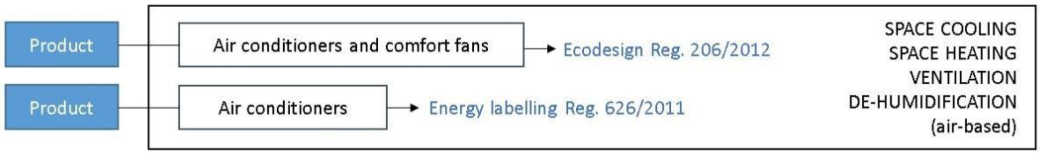

Figure 5. Overview of EU product policies on air conditioners

To sum up, some of the heating and cooling policies include different products in the same piece of regulation (e.g. water heaters and storage tanks in 814/2013), products which are part of the same system but with independent performance assessments (e.g. energy efficiency in water heaters and standing losses in storage tanks). The energy performance of packages is common practice in some heating systems with solar devices and/or storage tank and/or temperature controls, and the performance of the package is assessed through the extended product approach and under installed conditions. The system approach is not widely used in product policies. However, due to the particularity of some equipment, more than one function may be assessed in the same product.

1.2.4 HVAC systems in EU product policies: a summary

Heat, Ventilation and Air Conditioning systems may deliver more than one function and this is covered in some EU product policies (Table 1). Cogeneration heating systems which have the additional function of providing electricity are also included.

Table 1. Services delivered by HVAC systems regulated by EU product policies

SERVICE DELIVERED /PRODUCT GROUP	Sanitary hot water	Space heating	Space cooling	Ventilation	Electricity
Water heaters and hot water storage tanks (ED, GPP and EU Ecolabel) and packages of water heaters and solar device (ED and ELD)	X				
Space and combination heaters (ED, GPP and EU Ecolabel) and packages of space heaters, temperature control and solar device and packages of combination heaters, temperature control and solar device (ED, ELD, GPP and EU Ecolabel)	X	X			X
Solid fuel boilers and packages of solid fuel space heaters and temperature control and solar device (ED, ELD, GPP and EU Ecolabel)	X	X			X
Solid fuel local space heaters (ED)		X			
Local space heaters (ED and ELD)		X			
Air conditioners (ED and ELD) and comfort fans (ED)		X	X	X	
Ventilation units (ED) and residential ventilation units (ELD)		X		X	
Glandless standalone circulators and glandless circulators integrated in products (ED)		X	X		

Table 2 shows which products are in the scope of each of these product policies (including products alone and as part of a package). The package could be considered as a sub-system since they include a group of components or products but not all of them. Product policies allow making fair comparisons of products. Two products could be compared, only if they are equivalent products. Similar products could be considered equivalent if they deliver the same function within the system. Then, from the analysis of the types of products covered by product policies, the authors decided to classify them according to the function they deliver inside the HVAC system (CEN, 2006); generation of the service, storage, distribution or control (Table 2).

Table 2. Products covered by EU product policies (per function in the system)

PRODUCT FUNCTION/ EU PRODUCT POLICY	GENERATION OF THE SERVICE	STORAGE	DISTRIBUTION	CONTROL
Ecodesign (Regulation 814/2013) and Energy Labelling (Regulation 812/2013), EU GPP of water-based heaters and EU Ecolabel Decision 3452/2014	Water heaters (hot water)	Storage tanks (independent from water heaters)	-	-
In addition, Energy Labelling (Regulation	Packages of water heaters and solar device (hot	Storage tanks (as part of the	-	-

812/2013)	water)	package)		
Ecodesign (Regulation 813/2013) and Energy Labelling (Regulation 811/2013) EU GPP[4] and EU Ecolabel Decision 3452/2014	Space heaters (space heating)	-	-	-
	Combination heaters (sanitary hot water and space heating)	-	-	-
In addition, Energy Labelling (Regulation 811/2013), GPP[4] and EU Ecolabel	Packages of space heaters +solar device + supplementary heater (space heating)	Storage tanks (as part of the package)	-	Temperature control (as part of the package)
	Packages of combination heaters + solar device + supplementary heater (sanitary hot water and space heating)	Storage tanks (as part of the package)	-	Temperature control (as part of the package)
Ecodesign (Regulation 1189/2015) and Energy Labelling (Regulation 1187/2015) EU GPP[4] and EU Ecolabel Decision 3452/2014	Solid fuel boilers (space heating, sanitary hot water, electricity)	-	-	-
In addition, Energy Labelling (Regulation 1187/2015) EU GPP[4] and EU Ecolabel Decision 3452/2014	Packages of solid fuel boiler + solar device + supplementary heater (space heating, sanitary hot water, electricity)	Storage tanks (as part of the package)	-	Temperature control (as part of the package)
Ecodesign (Regulation 1185/2015)	Solid fuel local space heaters (space heating)	-	-	-
Ecodesign (Regulation 1188/2015) and Energy Labelling (Regulation 1186/2015)	Local space heaters (space heating)	-	-	-
Ecodesign (Regulation 206/2012) and Energy Labelling (Regulation 626/2011)	Air conditioners (space cooling, space heating and ventilation)	-	-	-
Ecodesign (Regulation 1253/2014) and Energy Labelling (Regulation 1254/2014)	Ventilation units (ventilation and space heating)	-	Ducts (part of the system)	Controls (part of the system)
Ecodesign (Regulation 641/2009)	-	-	Glandless standalone circulators	-

Table 2 shows that the majority of the products affected by product policies have the function to generate a HVAC service. This makes sense since most EU regulations aim at reducing the energy consumption. However, since products with other functions within the system also have an influence on the final energy consumption, product policies consider some of them as part of a package. The only product group that is regulated alone, and not as part of a package, are storage tanks.

Table 3 summarises the environmental aspects included in product policies of HVAC systems. Since almost all the products are ErP, these product policies focus in the use phase, either in the energy efficiency or in the energy consumption. For each product policy and product, a different methodology to calculate the energy efficiency is applied.

In addition to the environmental aspects mentioned in Table 3, there are information requirements which contribute to a proper use, maintenance, repair and disposal of the products.

Table 3. Summary of environmental aspects included in EU product policies of HVAC systems

ENVIRONMENTAL ASPECT/ PRODUCT POLICIES	Energy efficiency	Energy consumption (or energy losses)	Air emissions	Technical requirements influencing environmental aspects	Presence of hazardous substances	Sound power level
Regulation 814/2013 on Ecodesign of water heaters and storage tanks.	Water heating energy efficiency in water heaters	Auxiliary electricity consumption included in the water heating energy efficiency in water heaters. Maximum standing losses in storage tanks.	Nitrogen oxides in water heaters using liquid and gaseous fossil fuels.	Minimum volume of water mixed at 40C in water heaters. Maximum storage volume in storage tanks.	No	In water heaters
Regulation 812/2013 on Energy Labelling of water heaters, hot water storage tanks and packages of water heater and solar device	Water heating energy efficiency in water heaters. Standing loss in storage tanks. Energy class according to the energy efficiency in packages ofwater heaters, storage tank andsolar device)	Auxiliary electricity consumption included in the water heating energy efficiency in water heaters. Annual electricity consumption in water heaters. Standing loss in storage tanks.	No	No	No	In water heaters
Regulation 813/2013 with regard to Ecodesign requirements for space heaters and combination heaters	Seasonal space energy efficiency class in space heaters. Seasonal space energy efficiency and water heating energy efficiency class in combination heaters.	Auxiliary electricity consumption included in the seasonal space heating energy efficiency.	Nitrogen oxides (NO_x) in space heaters using liquid and gaseous fossil fuels.	No	No	In heat pump space heaters and heat pump combination heaters

ENVIRONMENTAL ASPECT/ PRODUCT POLICIES	Energy efficiency	Energy consumption (or energy losses)	Air emissions	Technical requirements influencing environmental aspects	Presence of hazardous substances	Sound power level
Regulation 811/2013 Energy Labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device	Seasonal space energy efficiency in space heaters. Seasonal space energy efficiency and water heating energy efficiency class in combination heaters. Standing loss in solar hot water storage tanks, if part of a solar device.	Auxiliary electricity consumption included in the seasonal space heating energy efficiency.	No	No	No	In all the products in the scope of the regulation
GPP and EU Ecolabel for water-based heaters	Water heating energy efficiency. Seasonal space heating energy efficiency		Greenhouse gases (GHG), NOx, organic monoxide (CO), organic gaseous compounds (OGC), and particulate matter (PM) emissions in heaters using liquid and gaseous fossil fuels.	Plastic parts	Refrigerant and secondary refrigerant in heat pumps. Hazardous substance s and mixtures	In fuel-driven, electrically-driven heat pump heaters and cogeneration space heaters
Regulation 1189/2015 on Ecodesign of solid fuel boilers	Seasonal space heating efficiency	Auxiliary energy consumption included in the seasonal space heating efficiency	Seasonal space heating emissions of PM. OGC, CO and NO_x in heaters using liquid and gaseous fossil fuels.	No	No	No
Regulation 1187/2015 on solid fuel boilers and packages of a solid fuel boiler, supplementary heaters, temperature controls and solar devices	Energy efficiency index (EEI)	Auxiliary energy consumption included in the EEI	No	No	No	No

ENVIRONMENTAL ASPECT/ PRODUCT POLICIES	Energy efficiency	Energy consumption (or energy losses)	Air emissions	Technical requirements influencing environmental aspects	Presence of hazardous substances	Sound power level
Regulation 1185/2015 with regard to Ecodesign requirements for solid fuel local space heaters	Seasonal space heating efficiency	Auxiliary energy consumption included in the seasonal space heating efficiency	PM, OGC, NO_x in heaters using liquid and gaseous fossil fuels.	No	No	No
Regulation 1188/2015 with regard to Ecodesign requirements for local space heaters	Seasonal space heating energy efficiency	Auxiliary energy consumption included in the seasonal space heating efficiency	NOx in heaters using liquid and gaseous fossil fuels.	No	No	No
Regulation 1186/2015 with regard to the Energy Labelling of local space heaters	Energy efficiency index (EEI)	Auxiliary energy consumption included in the EEI	No	No	No	No
Regulation 206/2011 with regard to Ecodesign requirements for air conditioners and comfort fans	Energy efficiency	Power consumption in off-mode and standby mode	Certain GHG penalize the energy efficiency	No	No	Indoor sound power level
Regulation 626/2011 with regard to Energy Labelling of air conditioners	Seasonal energy efficiency ratio and seasonal coefficient of performance (all air conditioners except double and single ducts). Rated energy efficiency ratio and Rated coefficient of performance for double and single ducts air conditioners.	Hourly energy consumption	No	No	No	Indoor sound power level

ENVIRONMENTAL ASPECT/ PRODUCT POLICIES	Energy efficiency	Energy consumption (or energy losses)	Air emissions	Technical requirements influencing environmental aspects	Presence of hazardous substances	Sound power level
Regulation 1253/2014 with regard to Ecodesign requirements for ventilation units	Thermal efficiency Fan efficiency	Specific energy consumption	No	Multi-speed drive or variable drive (except in dual use units). Thermal by-pass facility in bidirectional ventilation units. Filter equipped with visual change warning signal. Heat recovery system in non-residential ventilation units.	No	Sound power level
Regulation 1254/2014 with regard to Energy Labelling of residential ventilation units	Specific energy consumption	Maximum flow rate	No	No	No	Sound power level

Table 3 shows that Ecodesign regulations on HVAC systems set minimum thresholds mainly on energy efficiency, air emissions, sound power levels and other influencing technical requirements. On the other hand, the Energy Labelling just provides information on aspects such as the energy class, the annual energy consumption of the sound levels among others. On the other hand, GPP and EU Ecolabel have been defined aside the Ecodesign and Energy Labelling Directives and this is mainly due to their voluntary basis. Then, their product groups have different scope than those in Ecodesign or Energy Labelling since these product policies aim at rewarding the best products in the market (which could be very different from being obsolete or needed to be updated). GPP and EU Ecolabel criteria give importance not only to the use phase, but also the manufacturing or end-of life (EoL) phases and additional environmental criteria such as content in hazardous materials.

1.3 Environmental assessments in HVAC systems: scientific literature review

In this section, the results of the analysis of 17 scientific papers with regard environmental assessments in HVAC systems are presented.

The environmental assessments of these papers are all carried out at the system level and they cover different building services (Table 4).

Table 4. Services delivered by HVAC systems in the scientific literature

Scientific paper	Sanitary hot water	Space heating	Space cooling	Ventilation	Electricity
Yang et al, 2008		x		x	
Shah et al, 2008		x	x		
Becalli et al, 2012		x	x		
Koroneos et al, 2012	x	x	x		x
Debacker et al, 2013	x	x		x	
Prek, 2004		x			
Qu et al. 2010		x	x		
Hang et al, 2012	x				
Abusoglu et al, 2013		x			
Zambrana-Vasquez et al, 2015	x				
Blom et al, 2010		x		x	
Mikko et al, 2005				x	
Ucar et al, 2006		x			
Morrison et al, 2004	x	x			
Chyng et al, 2003	x	x			
Heikkila, 2006			x		
Heikkila, 2004			x		

From Table 4 it can be concluded that only few of the considered HVAC systems deliver only one service.

The top-down analysis (from systems to products) has delivered a number of components of each of the HVAC systems analysed in the literature review. Components are classified according to their function (Table 6), since equivalent products are those fulfilling the same function. This is consistent with the analysis carried out in Table 2 with product policies. Analysing the function of components one by one of all the papers, additional sub-functions (Table 5) were identified. Hence, it was possible a more detailed classification of components, according to their sub-function in the system (Table 5).

Table 5. Functions and sub-functions identified in HVAC systems of the literature review

FUNCTION	SUB-FUNCTION
PRODUCTION OF THE SERVICE	Harvest of energy
	Storage of energy carrier
	Conversion/transfer energy
	Storage of the medium or the service
	Evacuation/exchange of gases
	Protection
DISTRIBUTION	Distribution of the medium or the service
DELIVERY	Delivery of the end-use service
CONTROLS	System controls

Table 6 shows the detail of the analysis of only 6 references. HVAC systems from the analysed papers are very heterogeneous with regard of the type of components they include. Papers considering passive services i.e. those which do not use energy were not included in the analysis. Then, all the systems analysed in the journal papers include a component which produces the service, either by generating and/or harvesting the energy. Distribution components are mostly considered in the papers when they are present in the system. Delivery components and controls were mentioned but not included (losses and/or savings) in the journal papers analysed; however, other papers exist only focused on these components (e.g. Rhee and Kim, 2015).

The task of classifying every component of each system/s found in the journal papers (Table 6) proved that all the sub-functions proposed are needed. Likely, it also was shown that any component of a HVAC system (at least of those 17 journal papers analysed) could be classified in one of the sub-functions proposed.

Table 6. Components of some HVAC systems in the scientific literature

SCIENTIFIC PAPERS		**COMPONENTS' FUNCTIONS**								
		PRODUCTION of the service						**DISTRIBUTION**	**DELIVERY**	**CONTROL**
Reference	COMPONENTS SUB-FUNCTIONS/ SYSTEMS INCLUDED	Harvest of energy	Storage of energy carrier	Conversion/ transfer of energy	Storage of medium or the service	Evacuation / exchange gases	Protection	Distribution of the medium or the service	Delivery of end-use service	Controls
Yang et al, 2008	1. Two-pipe hot water heating (boiler) system with mechanical ventilation	-	-	Boiler Heat recovery ventilator	-	-	Expansion tank	Pipes and fittings (water) Circulating pump	Radiators	-
	2. Forced air heating (furnace with blower) system.	-	-	Furnace	-	-	-	Ducts (air)	Diffusers	-
Shah et al, 2008	1. Central natural gas furnace heating and conventional central air-conditioning	-	-	Furnace Air conditioner	-	Chimney	-	Duct network (cold and warm air)	Fan coil (air conditioner)	-
	2. Natural gas powered hydronic heating and conventional central air-conditioning	-	-	Boiler Condenser unit	-	-	-	Pipe network (water) Ducts (air)	Radiators Fan coil	-
	3. Electric air–air heat pump for heating as well as cooling.	-	-	Heat pump	-	-	-	Ducts	-	-
Becalli et al, 2012	Solar heating and cooling system	Evacuated tube solar collector field		Absorption chiller Auxiliary gas boiler	Hot water storage tank	Wet cooling tower		3 pumps	2 pipe fan coil units	
Koroneos et al, 2012	1. Solar heating system	Solar collector Geothermal pipes	-	Solar heat exchanger Geothermal heat exchanger	Hot water storage tank	-	-		In-floor pipe system (water)	

	2. Domestic hot water system	Solar collector Geothermal pipes	-	Solar heat exchanger Geothermal heat exchanger Electric resistance	Hot water storage tank	-	-	pipes	-	-
	3. Solar cooling system	Solar collector	-	Absorption chiller Auxiliary electric resistance	Cold water storage tank. Hot water storage tank	Cooling tower	-	-	In-floor pipe system (water)	-
	4. PV system	PV panels	-	-	-	-	-	-	-	-
Debacker et al, 2013	1.Space heating services (different generators)	-	-	Gas boiler Heat pump Oil boiler Pellet furnace	-	-	-	-	Panel radiator (steel plate) Floor heating	Manual valves Clock control Room thermostat Outside temperature
	2.Domestic hot water services (different systems)	-	-	Geyser (gas boiler) Electric boiler Oil boiler Heat pump Pellet furnace Solar boiler	Different capacities of hot water storage tank	-	-	-	-	-
	Ventilation	-	-	Single exhaust ventilator Supply ventilator	-	-	-	-	-	-
Qu, 2010	Solar thermal absorption cooling and heating system	Linear parabolic through solar	-	Double effect absorption chiller Heat recovery heat exchanger Auxiliary gas boiler	-	Cooling tower	Expansion tank Three-way valve	Pump	-	-

Table 7 summarises the type of methodologies to assess environmental performance of HVAC systems found in the scientific literature.

Table 7. Types of environmental assessments on HVAC in the scientific literature

Scientific paper	PERFORMANCE ANALYSIS	ENVIRONMENTAL ASSESSMENT
Yang et al, 2008	Coefficient of Performance of the HVAC system. Expanded cumulative exergy consumption.	Life-cycle energy use: pre-operation + operation phases (not LCA methodology). GWP of embodied impacts.
Shah et al, 2008	-	SimaPro 5.0 software. Franklin and ETH-ESU databases. Impact 2002+ method: 14 midpoint categories.
Becalli et al, 2012	Global Energy Requirement, NRE, energy return ratio. Primary energy consumption.	SimaPro software. Ecoinvent database. Cumulative Energy demand (CED) and EPD 2008 methods.
Koroneos et al, 2012	Exergy analysis (use phase)	SimaPro and Gabi (software and databases). 8 impact categories. Only manufacturing phase.
Debacker et al, 2013	-	Ecoinvent database, among other sources. Craddle to grave.
Prek, 2004	-	Eco-indicator 95 method
Qu et al. 2010	System performance (+system optimisation). RE use	-
Hang et al, 2012	-	SimaPro 7.1 software. Ecoinvent database. CED. Cradle to grave. Carbon footprint.
Abusoglu et al, 2013	Energy and exergy analysis	SimaPro 7.1 software.Ecoinvent database. Impact 2002+ (14 mid-point environmental aspects)
Zambrana-Vasquez et al, 2015	-	SimaPro 7.3.2 software. Ecoinvent 2.2 database. CML2 baseline 2000 V2.05 method. 10 impact categories. CED.
Blom et al, 2010	-	Ecoinvent, Idemat and EcoQuantum databases. CML 2000. 9 impact categories.
Mikko et al, 2005		LCA
Ucar et al, 2006	Exergoeconomic analysis. Optimisation.	-
Morrison et al, 2004	Seasonal performance	-
Chyng et al, 2003	COP (Coeficient of Performance)	-
Heikkila, 2006	-	LCA. EPS Design System 4.0. 4 impact categories.
Heikkila, 2004	-	LCA. EPS Design System 4.0. Weighting (EPS 200 default method).

Life Cycle Assessment (LCA) is used in 12 of the 17 scientific papers analysed. Performance analysis is also common (8 of 17) in terms of energy consumption, exergy or energy performance. In addition to the use phase, most of the papers consider the manufacturing phase. However, as expected, results of the analysis carried out in the journal papers show that most of the environmental impacts concentrate in the use phase. Exergy analysis is undertaken in 4 papers in order to include the efficiency of the production of the energy sources used by the HVAC systems.

1.4 Aims and scope of the report

The objective of the work presented in this report is to explore the methodological aspects of environmental assessments of systems at the design step, in order to get higher environmental benefits.

The procedure followed to develop the work of the present report began at the product level because the starting point were product policies (Ecodesign and Energy Labelling Directives, EU GPP and EU Ecolabel). Indeed, some product policies have recently broadened the boundaries from isolated products, to groups of products into what is called "packages". However, it was not possible to find scientific evidences which assessed systems in the direction from products to systems. Therefore, it was needed to explore the other direction, i.e. from systems to products. To do so, this report first addresses the policy framework including current policy initiatives on product's systems (section 1.2). Secondly, a scientific literature review is presented on environmental assessments of HVAC systems (section 1.3). Form the analysis of the system approach and environmental aspects on product policies and the scientific literature, and other practical aspects, general requirements are identified for a method supporting the design of good performing heating systems (section 2).

Then, the report proposes a simplified method and a calculation tool, to support the design process of good heating systems in residential buildings, based on the choice of the performance of its components (section 3). It focuses in heating systems since most HVAC systems in residential buildings provide only water and space heating (Perez-Lombard et al., 2011). In addition, Ecodesign and Energy Labelling requirements for space and water heaters are expected to bring annual energy savings of 600 TWh and CO_2 emission reductions of 135 million tonnes by 2030 (EC, 2016b). These savings and CO_2 reductions could be even greater using the system approach. In the method, product performance figures provided by European sellers according to EU product policies are used. The method is also tested on a specific case study, simulating the re-design of a solar sanitary hot water and space heating system in a dwelling located in North Italy.

The method has been developed to support design of heating systems. The method for the moment considers that new designs or improvements in the system are only achieved through choices in the technology of the components composing the system (as considered in EU product policies). The method only regards energy aspects (see section 3.1) at the use phase as part of the environmental assessment.

A real case study composed with a sanitary hot water system with solar devices and a space heating system is used to illustrate the implementation of the method and the calculation tool (section 4). Section 5 discusses the method presenting its added value and its limitations.

2. Identification of method requirements

The aim of this section is to summarise the findings of the literature review in order to identify requirements for a method that could be used by designers of heating systems. With this purpose, this section provides:

1. discussion on the review of the EU policies and scientific literature on environmental assessment on HVAC systems (section 1).
2. other practical method features found in the scientific literature, useful to identify the method requirements.

2.1 Discussion on the literature review

The analysed scientific literature focuses mostly in holistic environmental assessments such as LCA. Usually, all the phases of the life cycle of HAVC systems are considered, although results demonstrate that the use of energy during the use phase is by far the most important impact of these systems. Instead, EU product policies focus only in the use phase, and they have developed specific methods for analysing the energy performance of different product groups. Anyhow, the energy performance figures delivered by the product policies seem to be representative (as demonstrated in the scientific literature review) enough of the environmental impacts of HVAC products.

Some methods used by product policies to calculate the performance of the HVAC products may include very different technologies as is the case of the water heaters run with different types of fuels (EC, 2013b; EC, 2013c). This might cause a loss of accuracy in the figure provided, but on the other hand, it helps consumers to make fair comparisons between different products providing the same service. In addition, customers and users are provided with homogenous and easy-to-understand ratings methods. The methods used to measure the performance and the associated thresholds (updated regularly) of the product groups are usually developed during the 'Preparatory Studies', taking into account the currently or soon-to-be available technologies on the European market. These methods might not be purely scientific but they have been agreed and recognised by stakeholders (industry, government, consumer organisations, etc.) involved within the product group under study.

Although not all types of products, especially the innovative ones, have developed EU product policies through specific product groups, EU product policies cover the most share and the most important types of HVAC systems. Then, we could say that the majority of the products generating HVAC services on the market can be classified in some of the product groups in the scope of the product policies.

The four product policies (the Ecodesign and Energy Labelling Directives GPP and the EU Ecolabel) have facilitated the disclosure of very relevant information regarding product performance (Calero-Pastor et al., 2014). While the Ecodesign Directive sets minimum performance thresholds, the different energy classes reflect the variety of product performance levels currently available on the market, and GPP and the EU Ecolabel represent excellence in the performance of products. Thus, this batch of EU product policies could be seen as a mirror of the current market characteristics. Indeed, they have been very successful in improving the energy efficiency of building products, especially those involved in HVAC systems such as water or space heaters, coolers or air circulators.

On the other hand, the rapid evolution of technology hinders the dynamic and up-to-date knowledge of markets by designers. When technology evolves very quickly, some products are improved as others become obsolete over a short period of time. Building designers therefore need to be continuously updated on the current market availability of products. The use of these four product policies in a method could aid designers to choose the product performance levels currently available in the EU market.

Nevertheless, the common extended product approach considered in the product policies is less appropriate than the one considered in the scientific literature. This is mainly for two reasons. Firstly, this is because there are system components which cannot be considered as isolated products but as sub-system (i.e. distribution components in a HVAC system), and it is unlikely that they could be ever regulated by product policies in the near future. Thus, the extended product approach of product policies are susceptible of excluding some system components. The second reason is that product policies will hardly consider interactions between system components if some components could be left aside. In conclusion, the approach "from systems to products" considered in the scientific literature is more appropriate and could be easily integrated in a design method. Once the system has been defined, this approach is still compatible with the use of product policies at product level, as claimed before. Then, different levels of product performance levels could be combined to obtain an optimal solution at system level.

To sum up, the valuable information that EU product policies provides on the energy efficiency of ErP products could help to

- lean on a reliable and agreed scheme that is already available and easily accessible at the design step and useful in making fair comparisons of products,
- assess system performance based on the different performance levels of products currently available on the market, and
- analyse the possible alternatives regarding the combined performance of the products that make up the system.

Therefore, when possible, the method must use EU product policies information (at product level). When this is not possible, designers would be able to choose alternative tools to calculate the performance of the system components.

2.2 Other practical method features

The design of efficient HVAC systems is a huge challenge since buildings are complex systems, composed of many, very heterogeneous, materials and devices that interact with each other, the outside environment and their inhabitants (Peuportier et al., 2013). The performance of such systems greatly depends on the decisions made in the design phase (Annunciata et al., 2016), and in particular on the components chosen for the system. When designing HVAC systems, the choice of the performance of the products to be installed is usually made with regard to load calculations (Harish and Kumar, 2016). The optimisation of building design is still a topic of research and has yet to be implemented in engineering (Attia et al., 2013). Thus, in order to improve the energy performance of residential buildings, the building needs to be considered as a whole rather than as its individual components, and the solutions should be more flexible and user-friendly than those currently used (De Boeck et al., 2015). The usual design procedure of HVAC systems focuses mainly on satisfying heating demands, while system optimisation is considered secondary (Randaxhe et al., 2015; Attia et al., 2013). System optimisation can be achieved at two different levels, in terms of energy efficiency performance and of low-emission performance (Fesanghary et al., 2012). The low-emission performance does not include the energy input from renewable sources in order to give credits to these types of installations. Optimisation at system level should be then regarded as a key aspect of a method capable to be used by engineers and building designers.

Simulation tools have been used in the past forty years to integrate multiple aspects of system design (Colledani et al., 2014; Ellis and Mathews, 2002) based on technical and usage performance (Cor et al., 2014) or on energy consumption (Bonvoisin et al., 2013), among others. Building simulation tools can precisely model HVAC systems but fail when they cannot be fed with enough and adequate data in the early design stages, and deliver useful results quite late in the design process. These tools require product parameters that often are not supplied by manufacturers. They are time consuming and some are expensive. In addition, despite the increased number of and improvements in simulation tools, there can still be up to 40% difference between predicted and real energy consumption in buildings (Trčka and Hensen, 2010). Thus, some loss of accuracy might be acceptable if the design process could be sped up. Simplified tools such as conceptual system design or the use of simple equations require less input data, lower user expertise and yield more easily interpreted results. Trčka and Hensen (2010) stated that a combination of HVAC simulation tools with conceptual design could be useful in system modelling since the advantages of the former match well with the flexibility of the latter. Simulation tools could be accompanied by simplified design tools earlier in the design process, to be able to give useful and quicker information for practical decision-making. The combination of complex and simple tools is often used in the environmental impact assessments of different HVAC solutions (Zambrana-Vasquez, 2015; Yang et al., 2008). Therefore, the method can be simplified and still support the design activities.

But how to know if a HVAC system is well designed or not? Is it better or worse than other equivalent systems? Energy benchmarking of systems engineering consists in comparing the energy performance of a system against a common metric that represent the optimal performance of a reference system (Ke et al., 2013). Product policies use benchmarking in order to set which is the average performance level of the majority of products in the EU market. This is needed in order to set thresholds (e. g. Ecodesign Directive) able to be fulfilled by most manufactures. Once the market is known, the bad players can be eliminated through the Ecodesign Directive, the Energy Labelling Directive can pull the market towards the better products and the GGP and EU Ecolabel can award the best performing products. Thus, the benchmarking of systems could help to know how good a system design is.

2.3 Summary of method requirements

The requirements of the method can be summarised as:

- uses easily accessible product information from EU product policies (whenever possible);
- allows engineers to use their preferred alternative methods when appropriate;
- facilitates decisions to optimise performance at system-level from product performance information available on the market;
- is useful in the design phase, so that it should be a simplified method; and
- establishes the reference benchmark system with which compare solutions.

3. Designing good performing heating systems: method and calculation tool proposal.

The main aim of the method is to support the design of good performing heating systems in residential buildings throughout the right combination of the performance levels of the systems components. Not only the technology included in the components of the heating system is considered in the method but also the climate conditions, the building envelope and the user behaviour.

The method is based on energy benchmarking of systems. The benchmark system is defined in this report as the system that uses components with average performance levels. Then, a good performing system is a system that is behaving better than a benchmark system. The method consists firstly, in estimating the performance of one reference heating system (the benchmark in the case of a new design or the current system in the case of a re-design). Secondly, several improved alternatives are proposed and compared with the reference heating system. The designer is then able to choose among the different solutions provided.

The method uses data of different product policies of the ErP composing a heating system. Then, for instance, a system component with just Ecodesign minimum requirements might be combined with other components with a certain energy label or compliant with GPP or EU Ecolabel criteria. In principle, the method assumes that the performance of one component is independent from the performance of another component. However, the method is flexible enough to consider possible interdependencies at the system level.

The implementation of method in the design or re-design of a heating system will allow to:

- quantify the relative importance of individual components with different performance levels in the overall system energy performance;
- determine how good a heating system is;
- deliver combinations (design alternatives) of different levels of components performance for specific saving targets.

The estimation of the system performance in the method is done through a calculation tool that assess the energy performance parameters.

3.1 Energy performing parameters

The method relies in the analysis at system level of four performing parameters interrelated among each other. The definition of these parameters are:

- ✓ Energy heating demand (E_{Demand}): is the energy useful for delivering sanitary hot water or space heating. In order words, it is the output energy provided by the system;
- ✓ Non-renewable energy (NRE) consumption ($E_{NRE\ Consumption}$): is the NRE consumed or lost by the different components of the system needed to provide the service. It is the input energy (only the non-renewable) entering the system;
- ✓ Energy losses of the system (L): are the sum of the energy losses of each component of the system;
- ✓ Low-emission energy efficiency (η): is the ratio between the energy heating demand and the NRE.

They are calculated with the calculation tool (section 3.3).

The main objective of the design of a good or optimised heating system is to minimise the NRE consumption. This could be done either by reducing the energy demand or the energy losses, or by increasing the input of RE or the energy efficiency of the components.

Then, it could happen that components were performing poorly from an energy efficiency point of view when using high amount of RE. The analysis of the energy losses provides additional information on the behaviour of the system components regardless the type of energy used (renewable or non-renewable). Thus, it is also important to minimise the components' energy losses. This way, the practice of using mainly RE sources in order to compensate low performing components can be avoided. Even in the case of using only NRE, the analysis of the relative importance of energy losses of components into the overall losses of the system is useful to identify components with the highest contribution to losses.

The minimisation of the energy heating demand might be also achieved through the use of certain technology such as components abled to save energy at the user point. This would allow minimising also the overall energy consumption.

In conclusion, the aim of a good heating system design is to minimise the NRE consumption, but the analysis of the energy losses and energy efficiency of the components is also important to understand how the system behaves. In addition, components which are able to modify the energy demand should be also regarded. These four parameters are used to analyse the system at the three steps of the method which will allow designers to take decisions on which parameter to optimise more or less.

3.2 Steps of the method

The assessment method uses a calculation tool to obtain the energy demand, energy losses, NRE consumption and the energy efficiency of the heating system from the performance figures of its components. It focuses on the components composing the system and the best configuration of components in order to optimise the system performance. The method includes five steps of assessment (Table 8) divided in two main phases, the diagnostic of the initial system and the improvement phases. The calculation tool is used in each step of the method, except in step 1.

Table 8. Overview of the method

METHOD		CALCULATION OF	OUTCOMES
Phase 1: Diagnostic of the initial system	Step 1. Set of the global context and system modelling	Definition of the geographical context, the building features, the user behaviour and the heating system	A particular global context is defined and the heating system is modelled (types of components and their interactions are set).
	Step 2. Estimation of the performance of the initial system (the benchmark in the case of a new design or the current system in the case of a re-design).	✓ Energy heating demand ✓ NRE consumption ✓ Energy losses ✓ Low-emission energy efficiency	Referencesystem with which compare next results.
	Step 3. Study of the influence of relevant individual components in the overall system.	✓ NRE consumption of the system when improving one by one (independent) component.	System improvement potential – savings in kWh/y of individual components. Components with the highest system improvement potential.

Phase 2: Improvement: investigation of a better performing system	Step 4. Analysis of the worst, benchmark and best systems.	✓ Energy heating demand ✓ NRE consumption ✓ Energy losses ✓ Low-emission energy efficiency ...Of worst and best alternatives	Combination of components' performance levels with the worst and best feasible solutions. Comparison with the benchmark and the current design systems. How good is my initial system?
	Step 5. Analysis of other alternatives	✓ NRE consumption ...Of different solutions	System NRE consumption of combination of different components' performance levels. Multiples solutions for the several energy saving's target.

3.2.1 Phase 1. Diagnostic of the initial system

3.2.1.1 Step 1. Global context and system modelling

The performance of a heating system depends on the performance of its components, its interactions with the building, the geographic context (climatic data, local conditions of the building, etc.), and user behaviour. The geographic context, the building envelope and user behaviour define the demand for energy services. The method recommends that all these variables be accurately taken into consideration.

The purpose of the heating system is to provide sanitary hot water or space heating to the dwelling. The heating system is composed of components with different sub-functionalities (CEN, 2006): the energy generation, the storage, the distribution, the delivery of the service and the controls.

Figure 6 summarises the global context and the system modelling.

Therefore, firstly, the global context is detailed and secondly the heating system is modelled through the description of the system's components, how they are or can be connected, their sequence and main heat flows among them.

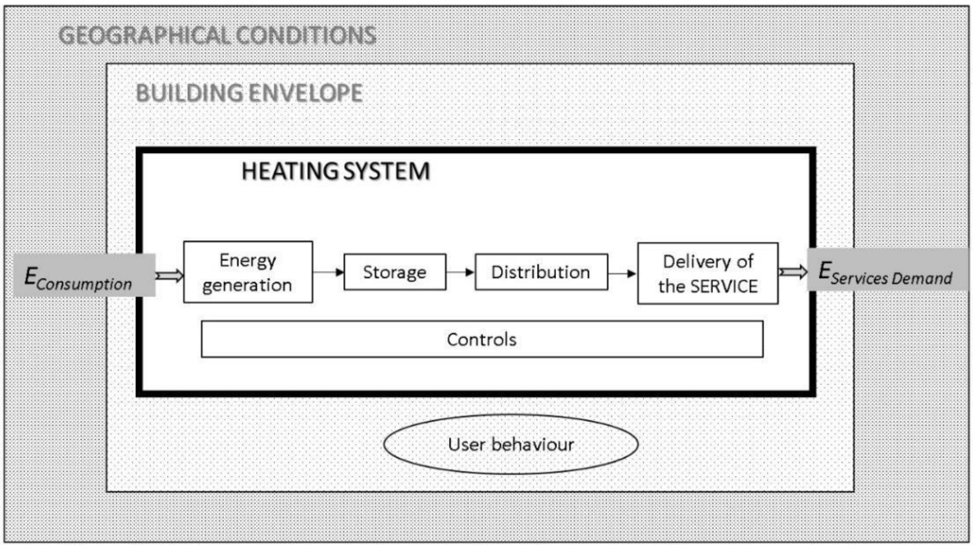

Figure 6. Heating system within the global context

3.2.1.2 Step 2. Estimation of the performance of the initial system

The objective of this step is to estimate the performance of a reference heating system that will be used to compare with the improved solutions assessed at next steps.

In a new design, the initial system analysed will be the benchmark system. The benchmark system is created using average performance levels of the components composing the system. In a redesign, the current performance of the components of the system are used for determining the initial system.

In this step, the calculation tool is used for the first time. Results of step 1 deliver the figures of the energy heating demand, NRE consumption, energy losses and low-emission energy efficiency of the initial system. Parameters calculated at this step 2 are used to compare those ones calculated at the next steps.

3.2.1.3 Step 3. Study of the influence of relevant individual components in the overall system.

The aim of this step is to identify the relevant (i.e. having significant and feasible improvement potential) components and the most influencing components.

In this step firstly, relevant and non-relevant components of the system are identified. Relevant components are those ones that have a significant and feasible improvement potential. This should be assessed by the designer according to the specific options and limitations of the heating system under study. The non-relevant components will be excluded for further analysis.

Secondly, the range of performance levels of each relevant component is analysed (from best to worst) according to the EU product policies affecting the component. Ideally, the best components are represented by performance levels of GPP and EU Ecolabel criteria or by the highest energy classes. Intermediate performance levels of components would be defined through the different Energy Labelling classes. Finally, the worst components performance level would be that one regulated by minimum Ecodesign requirements or the lowest energy label. In the case a component in the system is not affected by any European regulation, other regulations could be used or even it could be set up the range of performance according to assumptions made by the designer. This analysis will deliver the performance ranges of each component under study (Table 9), available in the market.

In principle, the type of technology of each component is assumed to be equivalent (the same sub-function inside the system) at each performance level, so big changes in technologies which could make change the way the system has been initially modelled (step 1) are not contemplated.

Table 9 shows how the performance ranges are set for a generic component i, with a maximum performance level A and a minimum performance level H. IS stands for Initial System and represents the performance level of the initial system assessed in the previous step (step 2, section 3.2.1.2).

Table 9. Performance ranges of a component i

LEVEL OF PERFORMANCE (from best to worst)	Component i
EU Ecolabel or highest energy label (A)	= η_{1A} or L_{1A}
GPP or energy label (B)	= η_{1B} or L_{1B}
Energy label (C)	= η_{1C} or L_{1C} (IS)
…	= $\eta_{1…}$ or $L_{1…}$
Ecodesign requirements or lowest energy label (e.g. H)	= η_{1H} or L_{1H}

Examples of specific components performance ranges can be found in Table 20, Table 21, Table 22, Table 23, Table 24. However, not all the components may have the same number of performance levels (Table 10).

Table 10. Example of performance ranges of n components assessed at step 3

	LEVEL OF PERFORMANCE							Number of performance levels
Component 1	A	B	C (IS)	D	E	G	H	$m_1 = 7$
Component 2	A	B (IS)	C	-	-	-	-	$m_2 = 3$
Component 3	A (IS)	B	C	D	E	-	-	$m_3 = 5$
Component n	A	B	C	D (IS)	-	-	-	$m_n = 4$

Once the performance ranges of each relevant component is set, the calculation tool is run for each performance level identified of each component of the system. The performance level is modified one at a time and the rest of the components performances are left as in the initial system (step 2, section 3.2.1.2). Equation 1 shows the total number of combinations or systems created (SC) of each performance level of each component, where mi the performance level of component i.

Equation 1:

$$SC\ (Step\ 3) = \sum_{i=1}^{n} mi$$

In the example shown in Table 10, the total number of systems created would be 19 (7+3+5+4).

Results of step 3 show the influence of individual components (for all their performance levels identified (from worst to best) in the overall system, in terms of energy improvement potential in kWh, where zero improvement is equal to the initial system assessed at step 2 (section 3.2.1.2). Thus, components with the highest improvement potential in terms of NRE are identified.

3.2.2 Phase 2. Improvement: investigation of a better performing system

The objective of this phase is to aid the designer to choose improved solutions by analysing how different combination of components performance levels can optimise the system.

3.2.2.1 Step 4. Analysis of the best, benchmark and worst systems.

The objective of this step is to determine how good the initial system is and to quantify the improvement potential at system level.

Worst, benchmark (in case it is not the initial system) and best systems are proposed through the combination of components performance levels according to results of step 3. The best system is estimated choosing the best feasible performance levels of relevant components. The benchmark system is estimated choosing average performance levels of relevant components. The worst system is estimated choosing the worst performance levels of relevant components. The calculation tool is used to generate results of best, benchmark and worst systems.

Results of this step 4 deliver the figures of the four performing parameters (section 3.1) for the best, benchmark and worst feasible alternatives. Then, best benchmark and worst combination of components performance levels are compared with the initial system obtained at step 2 (section 3.2.1.2).

3.2.2.2 Step 5. Analysis of other alternatives.

This step aims at analysing several configurations of components performance levels not studied in the previous steps.

At this step each better (than the initial system) and feasible level of performance identified at step 3 for each relevant component are combined one-by-one within the different components and assessed with the calculation tool.

Table 11 shows an example of how the number of performance levels is reduced by choosing only the better and the feasible (e.g. performance level A for component n is not feasible) performance levels.

Table 11. Example of performance ranges assessed at step 5

	LEVEL OF PERFORMANCE							Number of performance levels (Step 3)	Feasible and better performance levels (Step 5)
Component 1	A	B	C (IS)	D	E	G	H	$m_1 = 7$	$l_1 = 3$
Component 2	A	B (IS)	C	-	-	-	-	$m_2 = 3$	$l_2 = 2$
Component 3	A (IS)	B	C	D	E	-	-	$m_3 = 5$	$l_3 = 1$
Component n	-	B	C	D (IS)	-	-	-	$m_n = 4$	$l_4 = 3$

Equation 2 shows the total number of combinations of performance levels of different components (systems created), where l_i is the total number of feasible and better performance level of component i.

Equation 2:

$$SC\ (Step\ 5) = \prod_{i=1}^{n} li$$

In the example shown in Table 11, the total number of systems created would be 18 (3·2·1·3).

Results of this step 5 show the different performing parameters of all the selected combinations of components performance levels. Then, for a certain saving or energy efficiency target, many alternative solutions might be possible.

3.3 The calculation tool

A calculation tool to support the deployment of the method has been developed. It aims at guiding the calculation of the performing parameters: energy demand, NRE consumption, energy losses and the energy efficiency at system level.

The main features of the calculation tool are:

- considers the system level based on components performance levels;
- uses easily accessible product information, mainly from EU regulations; and
- allows engineers to use their preferable sub-methods when adequate.

The tool consists of a simplified procedure to calculated the energy parameters of heating systems, based on the performance levels of its components using data coming from EU product policies or other regulations/sources.

The tool for calculating the performing parameters has three steps:

1. Calculation of energy heating demand (E_{Demand});
2. Calculation of energy losses (L) and NRE consumption ($E_{NRE\ Consumption}$):
   a) Compilation of components performance ranges. Use available figures of EU product policies and/or if necessary calculate them with other tools;
   b) Calculation of the energy flows of the system;
3. Calculation of the low-emission energy efficiency (η).

Firstly, the variables set in step 1 of the method (climate conditions, building envelope, user behaviour) are used to calculate the energy demand. Next, the energy losses are assessed and the NRE consumption calculated from the figure of the energy demand throughout the modelled system (step 1 of the method). Finally, the low-emission energy efficiency is calculated based on the energy demand and the NRE consumption figures.

The sequence of the calculation tool proposed is not different from these applied in other building simulation tools. What is different is the use of the valuable information EU product policies provide on the energy efficiency of such components.

The use of data coming from EU product polices, allows running assessments with different performance levels of components currently available in the market (step 3 of the method). It allows to analyse the possible alternatives regarding the combination of performance levels of the components composing the system (step 5 of the method).

The calculation tool is run as many times (Table 12) as systems are created (SC). Table 12 summarises main systems assessed with the calculation tool according to each step of the method. In Table 12, n is the number of components in the system, IS refers to the performance level of the components of the initial system, m is the number of performance levels (from the best A to the worst H) of a component and l is the number of feasible and better performance levels of a component. System 1A means that component 1 has a performance level A and the rest of the components remain the same as in System I.

Table 12. Use of the calculation tool in the method

METHOD	SYSTEM	COMPONENTS PERFORMANCE LEVEL	TIMES THE CALCULATION TOOL IS RUN (Systems created)
Step 2: Estimation of the performance of the initial system			
First assessment with the calculation tool	Initial System (IS)	Comp. 1 = η_{1IS}	1
		Comp. 2 = η_{2IS}	
		…	
		Comp. n = η_{nIS}	
Systems at Step 2 =			**1**
Step 3: Study of the influence of relevant individual components in the overall system			
Influence of Comp. 1 in the overall system.	System 1A	Comp. 1 = η_{1A} Rest comp = System I	m_1

Only the performance of component 1 is changed, the rest of components stay as the initial system.	System 1B	Comp. 1 = η_{1B} Rest comp = System I	
	System 1H	Comp. 1 = η_{1H} Rest comp = System I	
Influence of Comp. 2 in the overall system.	System 2A	Comp. 2 = η_{2A} Rest comp = System I	m_2
	System 2B	Comp. 2 = η_{2B} Rest comp = System I	
	System 2H	Comp. 2 = η_{2H} Rest comp = System I	
Influence of Comp. n in the overall system.	System nA	Comp. n = η_{nA} Rest comp = System I	m_n
	System nB	Comp. n = η_{nB} Rest comp = System I	
	System nH	Comp. n = η_{nH} Rest comp = System I	
Systems created at Step 3 =			$\sum_{i=\square}^{n} mi$
Step 4: Analysis of the best, benchmark and worst systems			
Best performance	Best system (1A, 2A, nA)	Comp. 1 = η_{1A} Comp. 2 = η_{2A} Comp. n = η_{nA}	1
Benchmark performance (average performance of components)	Benchmark system (1B, 2B, nB)	Comp. 1 = η_{1B} Comp. 2 = $\eta_{2\ B}$ Comp. n = $\eta_{n\ B}$	1
Worst performance	Worst system (1Z, 2Z, 3Z)	Comp. 1 = η_{1H} Comp. 2 = η_{2H} Comp. n = η_{nH}	1
Systems created at Step 4 =			**3**
Step 5: Analysis of other alternatives			
Alternative 1	System 1A, 2B, nA	Comp. 1 = η_{1A} Comp. 2 = η_{2B} Comp. n = η_{nA}	l_1
Alternative 2	System 1B, 2B, nA	Comp. 1 = η_{1B} Comp. 2 = η_{2B} Comp. n = η_{nA}	l_2
Alternative 3	System 1H, 2B, nA	Comp. 1 = η_{1H} Comp. 2 = η_{2B} Comp. n = η_{nA}	l_3
Alternative 4	System 1A, 2H, nA	Comp. 1 = η_{1A} Comp. 2 = η_{2H} Comp. n = η_{nA}	l_4
Systems created at Step 5 =			$\prod_{i=1}^{n} li$

Thus, the total number of systems assessed with the calculation tool would be:

Equation 3:

$$TOTAL = 1 + \sum_{i=1}^{n} mi + 3 + \prod_{i=1-h}^{n} li$$

3.3.1 Calculation of the energy heating demand of the dwelling

The calculation tool allows the practitioner, to choose the most convenient instrument (simulation software, simple equations, rules of thumb, etc.) for calculating the energy demand. Simulation tools (eQUEST, DesignBuilder, SEAS3, etc.) are able to model the building envelope (closures, thermal bridges, etc.), the climatic data of the location and the user behaviours to obtain the energy services demand of a dwelling. Simple equations could refer the energy demand to, for instance, floor area, number of inhabitants or consumption patterns. Another option is to use available figures on the energy demand of the dwelling, for example the energy certifications of buildings according to the EPBD (EC, 2010b).

3.3.2 Calculation of the energy losses and the non-renewable energy consumption

The calculation of the energy losses and the NRE consumption is done through the analysis of the energy flows of the system. However, firstly, information about the components is needed.

a) Compilation or calculation of the performance of every component or sub-system.

The collection of data is time consuming in all the steps of the design process. When data is not available, the estimation might be more or less accurate depending on the time and effort the designer is willing to invest. Information on components covered by EU product policies such as the Ecodesign and Energy Labelling Directives, the GPP or the EU Ecolabel is available to designers. Technical information about products is available either in such regulations or through the technical documentation of the product provided by the manufacturer. Once the dataset is available, rules of thumb and simple equations provide results from very few macro data. Simulation software needs more detailed and numerous data but facilitates results that are closer to reality and can estimate the effects of innovative solutions where local knowledge is missing.

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Firstly, components performance figures from EU product policies are compiled; either from real products (manufacturer's technical information) or from the regulations affecting the target product (implementing regulations on the Ecodesign or supplementing regulations on the Energy Labelling Directives, the EU GPP or the Ecolabel for specific product groups). If a component or sub-system does not fall within the scope of such product policies, then its performance can be calculated using other tools such as simulation tools, simple equations or rules of thumb.

Table 13: Components' performance figures can be collected or calculated using EU product policies or other instruments.

SYSTEM COMPONENT	PERFORMANCE CALCULATION INSTRUMENT	COMPONENT PERFORMANCE FIGURE
Component 1	1st. EU PRODUCT POLICIES • Ecodesign Directive • Energy Labelling Directive • EU GPP • EU Ecolabel	= η_1 or L_1
Component 2		= η_2 or L_2
…		…

	2^{nd}. OTHERS • Simple equations • Rules of thumb • Simulation software	
Component n		$= \eta_n$ or L_n

b) Calculation of the energy flows of the system

This calculation is done based on the energy demand obtained previously (section 3.3.1). The energy efficiency of each component (ηComp) can be used in Equation 1 to calculate the energy losses of such component (L_{Comp}) in Equation 5 or the other way around. The energy losses of all components are aggregated to the E_{Demand} in the opposite direction of the energy flow (Figure 7) to calculate the (Equation *6*) L_{SYSTEM} and $E_{Consumption}$ (Equation 7).

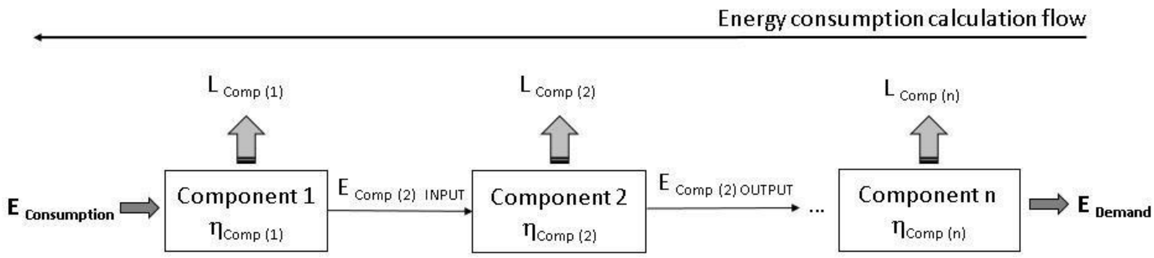


Figure 7. Energy flows of the system.

Where:

Equation 4:

$E_{Comp\ (i)\ OUTPUT} = E_{Comp\ (i)\ INPUT} \times \eta_{Comp\ (i)}$

Equation 5:

$L_{Comp\ (i)} = E_{\mathrm{Comp\ (i)\ OUTPUT}} - E_{Comp\ (i)\ INPUT}$

Equation 6:

$L_{SYSTEM} = \sum L_{Comp\ (i)}$

Equation 7:

$E_{NRE\ Consumption} = \sum L_{Comp\ (i)} + E_{Demand}$

3.3.3 Calculation of the low-emission energy efficiency

The low-emission energy efficiency of the system is defined as:

Equation 8:

$\eta_{SYSTEM} = E_{Demand} / E_{NRE\ Consumption}$

Where E_{Demand} is the energy useful for the service to be delivered and $E_{NRE\ Consumption}$ is the energy that is consumed by the heating system and its different components to provide the service.

Only the NRE consumption is considered since building-related policies are oriented towards low-emission designs. Thus, when a RE source is used in the system, it is accounted only the NRE for the calculation of the $E_{NRE\ Consumption}$. In this case, the energy efficiency indicator Equation 8 aims at minimising the NRE consumption, which is also called the low-energy efficiency.

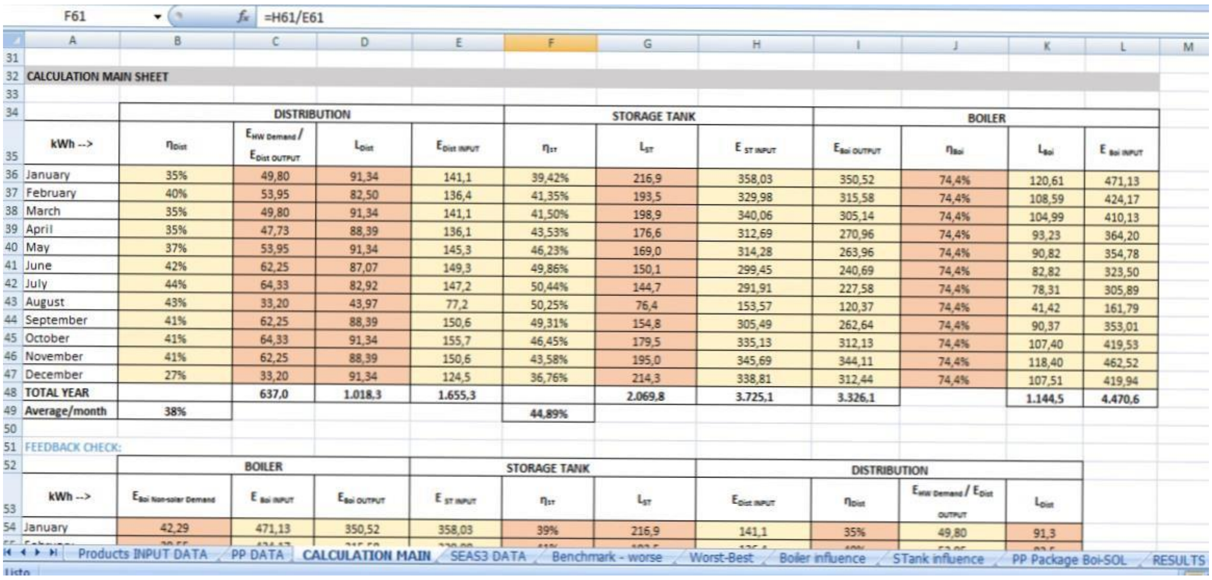
4. A case study: re-design of solar sanitary hot water and space heating systems in a dwelling

The method proposed was tested in a real case study that provides sanitary hot water and space heating. The method is applied in parallel to the sanitary hot water system and the space heating system since they have different functionalities, although they both share a condensing boiler. In this section, the heating systems are redesigned in order to identify their most significant improvement potential.

4.1 Implementation of the method on the case study

4.1.1 Phase 1: Diagnostic of the initial system

For this particular case study, a calculation tool has been created in an Excel file in order to facilitate the multiple calculations on all the created systems. This Excel file contains several sheets to introduce the data from the products systems, according to product policies (when available), software, etc. It also has some sheets to make calculations and others which give overall results. Figure 8 shows the appearance of this Excel file. Note that in this case, calculations have been made per month.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CALCULATION MAIN SHEET

	DISTRIBUTION				STORAGE TANK			BOILER			
kWh -->	η_{Dist}	$E_{HW\ Demand}$ / $E_{Dist\ OUTPUT}$	L_{Dist}	$E_{Dist\ INPUT}$	η_{ST}	L_{ST}	$E_{ST\ INPUT}$	$E_{Boi\ OUTPUT}$	η_{Boi}	L_{Boi}	$E_{Boi\ INPUT}$
January	35%	49,80	91,34	141,1	39,42%	216,9	358,03	350,52	74,4%	120,61	471,13
February	40%	53,95	82,50	136,4	41,35%	193,5	329,98	315,58	74,4%	108,59	424,17
March	35%	49,80	91,34	141,1	41,50%	198,9	340,06	305,14	74,4%	104,99	410,13
April	35%	47,73	88,39	136,1	43,53%	176,6	312,69	270,96	74,4%	93,23	364,20
May	37%	53,95	91,34	145,3	46,23%	169,0	314,28	263,96	74,4%	90,82	354,78
June	42%	62,25	87,07	149,3	49,86%	150,1	299,45	240,69	74,4%	82,82	323,50
July	44%	64,33	82,92	147,2	50,44%	144,7	291,91	227,58	74,4%	78,31	305,89
August	43%	33,20	43,97	77,2	50,25%	76,4	153,57	120,37	74,4%	41,42	161,79
September	41%	62,25	88,39	150,6	49,31%	154,8	305,49	262,64	74,4%	90,37	353,01
October	41%	64,33	91,34	155,7	46,45%	179,5	335,13	312,13	74,4%	107,40	419,53
November	41%	62,25	88,39	150,6	43,58%	195,0	345,69	344,11	74,4%	118,40	462,52
December	27%	33,20	91,34	124,5	36,76%	214,3	338,81	312,44	74,4%	107,51	419,94
TOTAL YEAR		637,0	1.018,3	1.655,3		2.069,8	3.725,1	3.326,1		1.144,5	4.470,6
Average/month	38%				44,89%						

FEEDBACK CHECK:

	BOILER			STORAGE TANK			DISTRIBUTION			
kWh -->	$E_{Boi\ Non\text{-}solar\ Demand}$	$E_{Boi\ INPUT}$	$E_{Boi\ OUTPUT}$	$E_{ST\ INPUT}$	η_{ST}	L_{ST}	$E_{Dist\ INPUT}$	η_{Dist}	$E_{HW\ Demand}$ / $E_{Dist\ OUTPUT}$	L_{Dist}
January	42,29	471,13	350,52	358,03	39%	216,9	141,1	35%	49,80	91,3

Figure 8. Screenshot of the MS Excel file created for the case study

4.1.1.1 Step 1. Global context and heating system modelling

The house is located in the North of Italy and the dwelling has a surface of 61 m^2. The house and its heating systems were refurbished in 2012.

Firstly, all the data required for the calculation of the energy services demand is collected. In this case study, it was used the simulation tool SEAS3 (ENEA, 2014), recommended by the Italian Energy Agency. It facilitates the calculation of the energy demand of the dwelling according to the geographical conditions (climate zone E according to Italian regulations), the characteristics of the building/dwelling (surroundings, orientation, height, thermal bridges, windows, etc.) and the user behaviour (presence during the year, opening of the closures, etc.).

The dwelling includes a solar sanitary hot water system and a space heating system which share the same boiler (Figure 9). The solar sanitary hot water system consists of the boiler, a solar panel (2.06 m^2) with a glycol pump, a sanitary water pipe network, a storage tank with two coils, three taps and one shower. The space heating system includes the boiler, the distribution components, the underfloor heating and the controls. There are also components such as two expansion vessels, a mixer valve and a safety valve but they are considered in the analysis since their energy losses are considered to be negligible.

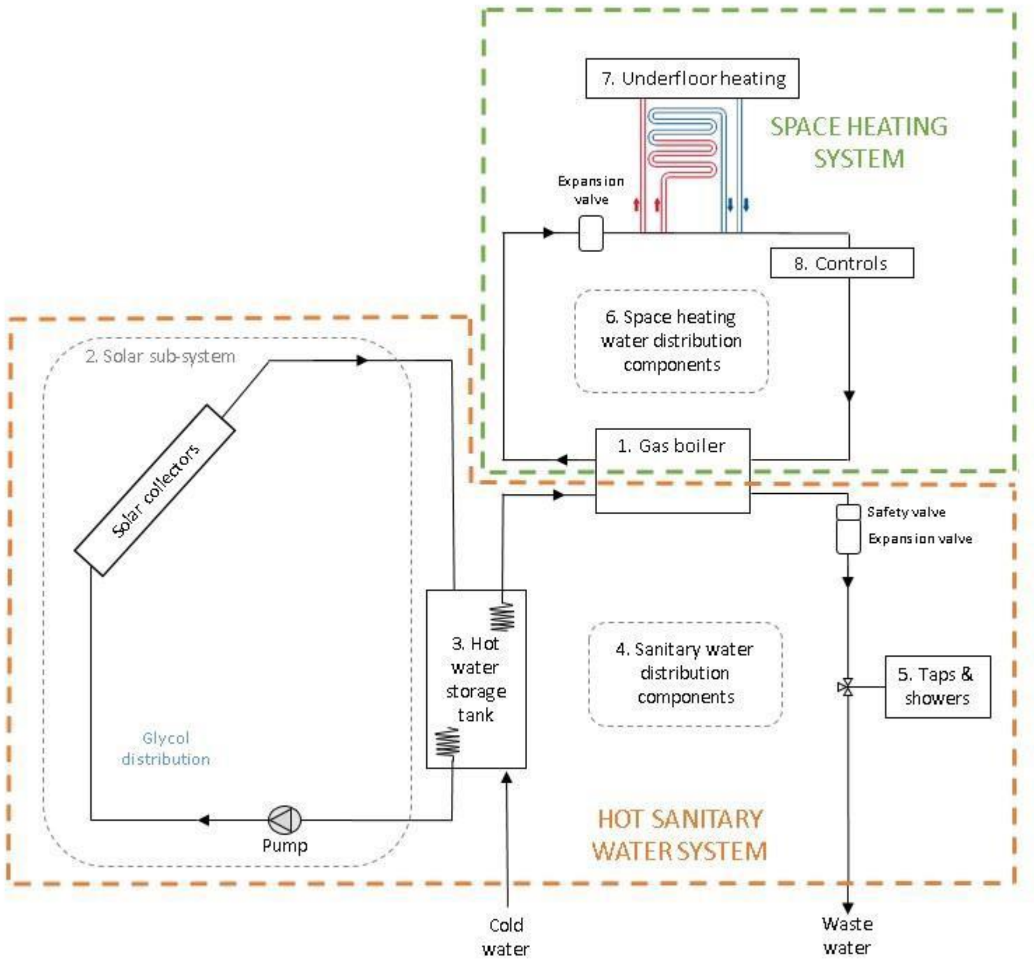


Figure 9. Heating systems of the case study.

In Figure 9 and Figure 10, the heating components (numbered from 1 to 8) are grouped according to their function in their overall system. The solar sub-system includes the solar panels the distribution components of the glycol and the solar pump and has the function of generating RE. Note that the boiler is the same for providing both sanitary hot water and space heating services.

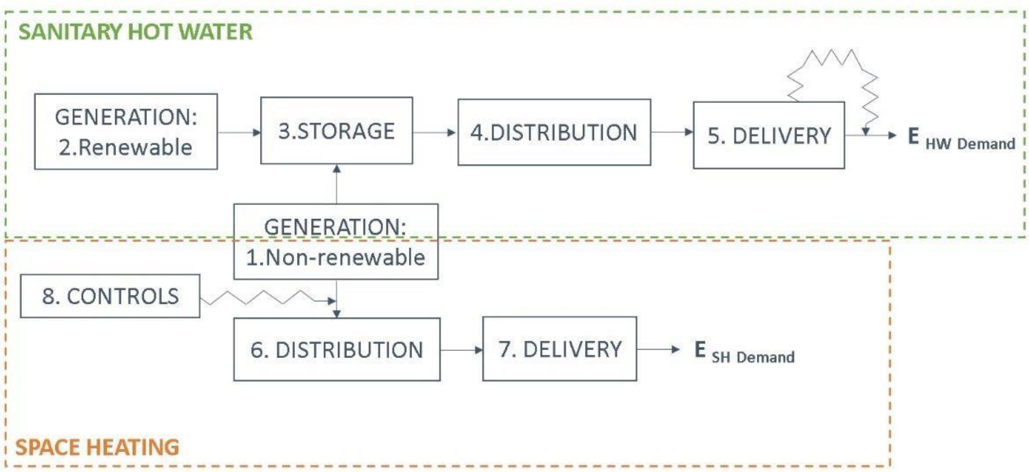


Figure 10. System modelling of the case study

According to EC 811/2013 (EC, 2013e), the boiler that provides both sanitary hot water and space heating is called combination heater. Thus, these types of heaters are labelled twice since the energy efficiency is calculated through two different formulas; one for each function that deliver (sanitary hot water and space heating). This case study follows the same reasoning so that both functions are not interrelated.

The delivery (taps and showers) and control (temperature control) components will be not be considered as components directly involved in the energy flows of system (see zig-zag arrows in Figure 10). In the taps and showers, this is because these components modify the energy heating demand (see case study assumption on Table 24 and not significantly the previous energy flow from the distribution. In the case of the temperature control of the space heating system, the reason is that it is a component that has an indirect role in the system (the hot water used for space heating does not go through the controls).

4.1.1.2 Step 2. Estimation of the performance of the initial system

At step 2 the calculation tool is used for the first time for calculating the performing parameters of the current design system.

<u>Calculation of energy heating demand</u>

The energy demand of the case study has been calculated trough SEAS3 according to the data collected previously (step 1) for the sanitary hot water system and the space heating system.

The annual energy demand in the sanitary hot water system ($E_{HW\ Demand}$) is 637kWh. It has been calculated from the number of dwelling inhabitants (2 people) and considering an average consumption of 50 L/person/day (assumption of SEAS3). The monthly average solar contribution is 65% of the $E_{HW\ Demand}$ which corresponds to 399kWh/y, based on climatic data (calculated with SEAS *solare,* complementary software to SEAS3). From these figures, the non-solar energy demand can be calculated; amount of energy that the boiler has to provide ($E_{HW\ Boi\ Non\text{-}solar}$) which corresponds to 238kWh/y (monthly accumulation).

The annual energy demand for space heating ($E_{SH\ Demand}$) is 18,085kWh (calculated with SEAS3) and takes into account the climate conditions and the energy losses from the building envelope and the user behaviour. From May to September, the space heating is off.

Table 14 summarizes figures energy demand, solar and non-solar energy demand for the current design of the sanitary hot water and the space heating systems.

Table 14. Energy demand, solar and non-solar energy demand (kWh/y) of the current design of the case study.

SANITARY HOT WATER SYSTEM			SPACE HEATING SYSTEM
$E_{HW\ demand}$	$E_{Sol\ OUTPUT}$	$E_{HW\ Boi\ Non\text{-}sol}$	$E_{SH\ Demand}$
637	399	238	18,085

<u>Calculation of the energy losses and NRE consumption</u>

The energy losses of the system is the sum of the losses of the components of the system (Equation *6*). The NRE consumption is the energy that needs to enter the boiler for covering both services independently: sanitary hot water and space heating.

a) Compilation or calculation of the performance levels of every component or sub-system.

Sanitary hot water system components

Manufacturers declare that the boiler has an energy label A (for sanitary water heating) with a water heating energy efficiency of 74.4% according to energy label of combination heaters (EC, 2013e). The water heating function of the boiler has a load profile M according to tapping patterns described in Regulation 814/2013 (EC, 2013c) for combination water heaters.

The storage tank has an energy label G (226W of standing losses) according to EC (2013b). The annual energy losses of the storage tank are calculated through SEAS3 based on the figure of the thermal dispersion declared by the manufacturer (5.03W/K) and climate data.

The solar device is indirectly regulated by Energy Labelling of combination heaters (EC, 2013e), so that it is added (giving credits in % of solar contribution) to a water heater in what is called package in this Regulation 811/2013.

The energy losses of the distribution are not regulated through EU product policies so that, they were assessed through SEAS3 based on data compiled from the installed technology (length of pipes and isolation material).

Taps and showers have a direct influence on the sanitary hot water energy demand. This product group is only regulated by EU Ecolabel and GPP criteria and lacks of Ecodesign nor Energy Labelling Directives' requirements so this makes difficult to benchmark the market products. The taps and showers used in the dwelling correspond to average market products thus, it is assumed that no significant energy losses or savings occur.

Table 15. Performance of the components of the current design of the sanitary hot water system of the case study.

SUB-SYSTEM AND COMPONENTS	PERFORMANCE (Current design)	PERFORMANCE CALCULATION
1.Boiler	Water heating energy efficiency ($\eta_{Boi\ HW}$): (load profile M) 74.4%.	Compiled from manufacturer's product sheet according to energy label A (EC, 2013e)
2.Solar sub-system	Solar contribution: 64.5%	Calculated with SEAS3 (solare) (ENEA, 2014)
3.Storage tank	Standing losses: 226W	Calculated from the figure of the thermal dispersion declared by the manufacturer. The standing losses corresponds to an energy label G (EC, 2013b).
	Total losses (L_{ST}): 2,070 kWh/y	Calculated with SEAS3 (monthly calculation according to climate data)
4.Distribution components	Losses ($L_{HW\ Dist}$): 1,018 kWh/y	Calculated with SEAS3
5.Taps & Showers	No energy losses, no savings on the $E_{HW\ Demand}$	Case study assumption

Space heating components

The boiler has a seasonal space heating energy efficiency of 92% (energy label A for space heating), according to the manufacturer.

The losses from the distribution of the water for space heating have been assessed by SEAS3 according to length and isolation of the tubes which connect the boiler and the underfloor heating.

The efficiency of the underfloor heating is 97%, default value given by SEAS3 for this type of space heating delivery. This efficiency has not been calculated with real data of the case study since there are not agreed calculation methods and for time constrains.

The temperature control of the case study is indirectly included through the Energy Labelling of space heaters (EC, 2013e). It is a control type V and contributes to 3% of the seasonal space heating efficiency of packages of space heaters and solar device. It is assumed that the same 3% is achieved as savings from the energy output of the boiler.

Table 16. Performance of the components of the current design of the space heating system of the case study.

COMPONENTS	PERFORMANCE (Current design)	PERFORMANCE CALCULATION
1.Boiler (the same boiler as for the sanitary hot water system)	Seasonal space heating energy efficiency ($\eta_{Boi\ SH}$): 92%	Compiled from manufacturer's product sheet according to energy label A (EC, 2013e)
6.Distribution components	Losses ($L_{SH\ Dist}$): 38 kWh/y	Calculated with SEAS3
7.Underfloor heating	η_{UFloor} = 97%	Data taken from SEAS3 (efficiency set up by default)
8.Controls	Temperature control: Type V: 3% of savings (S_{Cont})	Assumption based in information included in Energy Labelling (EC, 2014b).

b) Calculation of the energy flows of the system

Figure 11 shows the energy flows from one component to the next. Energy inputs and losses of every component (Table 17 and Table 18) are calculated according to Equation 4 and Equation 5 respectively in the opposite direction of the energy flows.

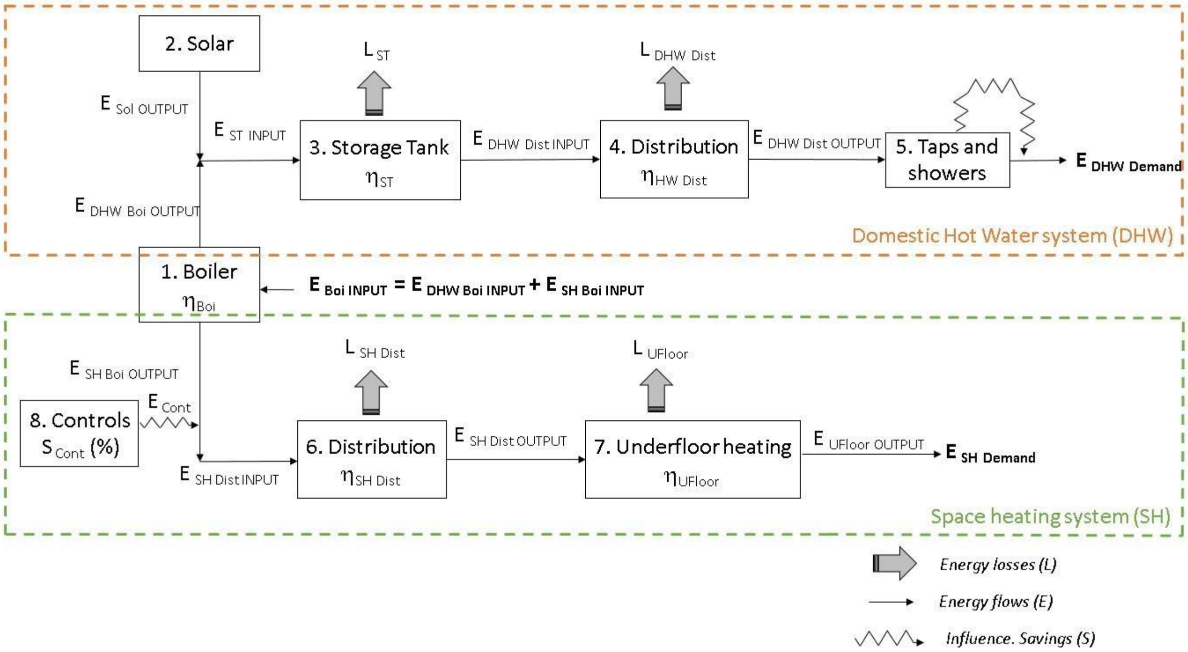


Figure 11. Energy flow chart of the heating systems of the case study.

In the sanitary hot water system, since no losses or savings are assumed in the installed taps and showers, in the current design $E_{Dist\ OUTPUT}$ = $E_{HW\ Demand}$ = 637 kWh/y (Table 14). In addition, as mentioned in section 3.1 since the RE is not accounted, the energy provided by the boiler ($E_{HW\ Boi\ OUTPUT}$) is the energy not covered by the solar sub-system ($E_{Boi\ Non\text{-}sol}$) plus the energy losses of all the components (Equation 9). Then, NRE consumption is $E_{Boi\ INPUT}$ and it is calculated using Equation 4.

Equation 9:

$$E_{HW\ Boi\ OUTPUT} = E_{ST\ INPUT} + E_{Sol\ OUTPUT}$$

Table 17. Figures (kWh/y) of the energy flows of the current design sanitary hot water system of the case study.

DISTRIBUTION COMPONENTS (HW)		STORAGE TANK		BOILER HW FUNCTION	
$L_{HW\ Dist}$ (Table 15)	$E_{HW\ Dist\ INPUT}$ (= $E_{ST\ OUTPUT}$) (Equation 2)	L_{ST} (Table 15)	$E_{ST\ INPUT}$ (Equation 7)	$E_{HW\ Boi\ OUTPUT}$ (Equation 6)	$E_{HW\ Boi\ INPUT}$ (Equation 1)
1,018	1,655	2,070	3,725	3,326	4,471

In the space heating system, the energy demand is satisfied only through the boiler (Equation 8). Table 18 summarises the losses and energy flows of the heating system.

Equation 10:

$$E_{SH\ Boi\ OUTPUT} = E_{Dist\ INPUT}/(1\text{-}S_{Cont})$$

Table 18. Figures (kWh/y) of the energy flows of the space heating system of the current design case study.

UNDER FLOOR HEATING		DISTRIBUTION COMPONENTS SH		CONTROLS	BOILER SH FUNCTION	
L_{UFloor} (Equation 2)	$E_{UFloor\ INPUT}$ (Equation 1)	$L_{SH\ Dist}$ (Table 16)	$E_{SH\ Dist\ INPUT}$ (Equation 2)	E_{Cont} (Table 16)	$E_{SH\ Boi\ OUTPUT}$ (Equation 8)	$E_{SH\ Boi\ INPUT}$ (Equation 1)
545	18,630	38	18,668	560	18,108	19,683

The importance of the energy losses of each component aids at having an overview on how every component behave within the overall system (Figure 12), regardless the type of energy used (natural gas or solar energy). The sum of the losses of the sanitary hot water and space heating systems, make the boiler the component with the highest losses (43%), despite its rather good performance (see Table 15 and Table 16). The storage tank is the second component with highest losses (32%) due to its poor performance (see Table 15). The distribution losses represent 17% and the underfloor heating 8% of the total energy losses. In conclusion, according to results of Figure 12 the components to be upgraded would be, in order of relative importance; the boiler, the storage tank, the distribution components and the underfloor heating.

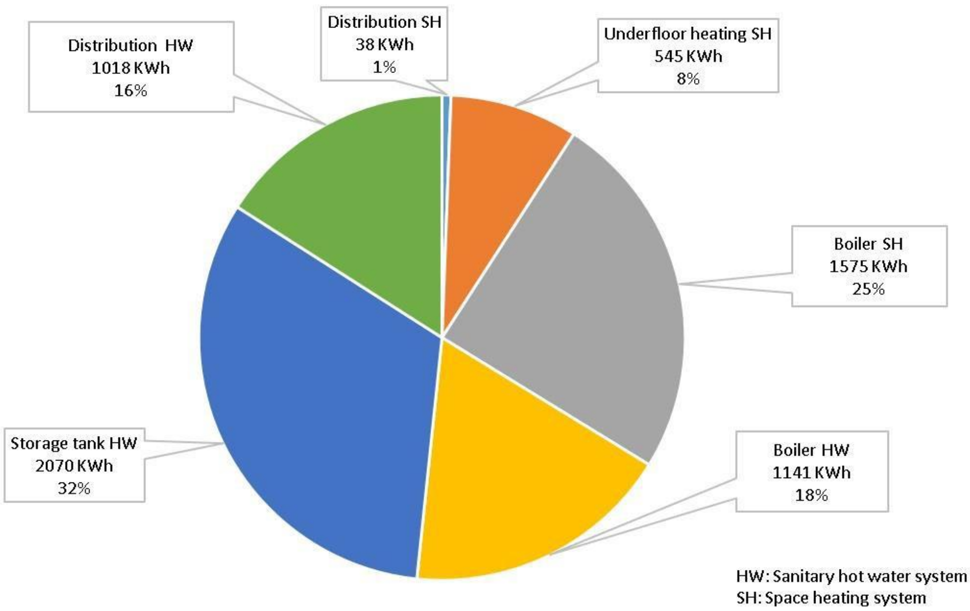


Figure 12. Contribution of each component to the overall energy losses of the current design heating system.

<u>Calculation of the low-emission energy efficiency</u>

The energy efficiency indicator of the heating systems of the case study is then defined as the ratio between the sanitary hot water or space heating demand ($E_{HW\ Demand}$ or $E_{SH\ Demand}$) of the dwelling and the energy input ($E_{WH\ Boi\ INPUT}$ or $E_{SH\ Boi\ INPUT}$) needed in the boiler:

Equation 11:

$\eta_{WH\ SYSTEM} = E_{HW\ Demand}/E_{HW\ Boi\ INPUT}$

Equation 12:

$\eta_{SH\ SYSTEM} = E_{SH\ Demand}/E_{SH\ Boi\ INPUT}$

Table 19. Energy performance parameters of the heating systems of the current design case study.

SANITARY HOT WATER SYSTEM			
$E_{HW\ Demand}$ (Table 14) (kWh/y)	$E_{HW\ Boi\ INPUT}$ (Table 17) (kWh/y)	$\eta_{HW\ SYSTEM}$ (Equation 5)	$E_{HW\ Losses}$ (Equation 3) (kWh/y)
637	4,471	14.2%	4,233
SPACE HEATING SYSTEM			
$E_{SH\ Demand}$ (Table 14) (kWh/y)	$E_{SH\ Boi\ INPUT}$ (Table 16) (kWh/y)	$\eta_{SH\ SYSTEM}$ (Equation 5)	$E_{SH\ Losses}$ (Equation 3) (kWh/y)
18,085	19,683	91.9%	2,158

The energy efficiency of the heating systems of the case study, according to the method proposed is 14.2% for the sanitary hot water system and 91.9% for the space heating system (Table 19). Looking at the figures of the low-emission energy efficiency and the total losses, the sanitary hot water system has a higher improvement potential than the space heating system. However, although the good performance of the space heating system versus the one of the sanitary hot water system, the energy demand of the former is much greater. Therefore, it might happen that improving the space heating system could bring higher energy savings in absolute values. Next section analyses the improvement potential of individual components of both systems in terms of kWh/y of savings (Figure 13).

4.1.1.3 Step 3. Study of the influence of relevant individual components in the overall system

In this step, the improvement potential of individual components is studied in terms of energy savings potential (kWh/y) on the overall system (in both sanitary hot water and space heating systems).

The gas boiler of the case study is regulated under the product group "combination heaters" by Ecodesign (EC, 2013d) and Energy Labelling (EC, 2013e) Directives. The boiler is also regulated by EU Ecolabel (EC, 2014a) and GPP (EC, 2016b) under the product category "water-based heaters". The gas boiler of the case study has an energy label A for both the water heating (74.4%) and the seasonal space heating functions (92%), the maximum class for boilers alone (Table 20 and Table 21). Higher classes can be achieved only at package level if solar devices are used jointly with the boiler. However, in this section results will be displayed per component; the boiler and the solar sub-system separately. Phased out energy classes and classes that can only be achieved with solar devices are not considered for further analysis.

Table 20. Performance ranges of the water heating efficiency of the boiler.

Energy Labelling (EC, 2013e)		Other product policies
Energy efficiency class	Minimum water heating energy efficiency (Profile M)	
A+++	$\eta_{WH} \geq 163$	In theory, these energy classes can be only achieved in packages of boilers with solar devices (van Amerongen, 2015)
A++	$130 \leq \eta_{WH} < 163$	
A+	$100 \leq \eta_{WH} < 130$	
A	$65 \leq \eta_{WH} < 100$	74.4% Case study 65% EU Ecolabel (EC, 2014a)
B	$39 \leq \eta_{WH} < 65$	-
C	$36 \leq \eta_{WH} < 39$	We assumed 38% to be average products in the market (benchmark)
D	$33 \leq \eta_{WH} < 36$	-
E	$30 \leq \eta_{WH} < 33$	30% - minimum Ecodesign requirements (EC, 2013e)
F	$27 \leq \eta_{WH} < 30$	Phase out
G	$\eta_{WH} < 27$	Phase out

Table 21. Performance ranges of the seasonal space heating efficiency of the boiler.

Energy Labelling (EC, 2013e)		Other product policies
Energy efficiency class	Minimum seasonal space heating energy efficiency	
A^{+++}	$\eta_{SH} \geq 150$	In theory, these energy classes can be only achieved in packages of boilers with solar devices and temperature control.
A^{++}	$125 \leq \eta_{SH} < 150$	
A^{+}	$98 \leq \eta_{SH} < 125$	
A	$90 \leq \eta_{SH} < 98$	98% EU Ecolabel (EC, 2014a) 92% Case study (benchmark) 90% GPP (EC, 2016b)
B	$82 \leq \eta_{SH} < 90$	86% - minimum Ecodesign requirements (EC, 2013d)
C	$75 \leq \eta_{SH} < 82$	Phased out
D	$36 \leq \eta_{SH} < 75$	Phased out
E	$34 \leq \eta_{SH} < 36$	Phased out
F	$30 \leq \eta_{SH} < 34$	Phased out
G	$H_{SH} < 30$	Phased out

Regarding the solar devices, three options have been assessed with SEAS *solare* (complementary software to SEAS3):

1. No solar devices: 0% solar contribution.
2. One solar panels (2,06 m^2): 65% solar contribution on the energy demand (as the initial system of the case study)
3. Two solar panels (4,12 m^2): 99% solar contribution on the energy demand.

The storage tank is included in the same product group of the same pieces of regulations than water heaters under the name "storage tank" regarding Ecodesign (EC, 2013c) and Energy Labelling (EC, 2013b). Standing losses for each energy efficiency class (Table 22) are calculated with the storage volume (160L) according to the methodology set out in the Energy Labelling (EC, 2013b).

Table 22. Performance ranges of the storage tank.

Energy Labelling (EC, 2013b)		Other product policies
Energy efficiency class	Standing losses (W)	
A+	0 ≤ SL < 30	In theory, these energy classes can be only achieved with innovative insulation concepts such as evacuated systems or aerogel (Van Amerongen, 2015)
A	30 ≤ SL < 41	
B	41 ≤ SL < 57	
C	57 ≤ SL <80	We assumed that 69W are average products in the market (benchmark)
D	80 ≤ SL < 100	-
E	100 ≤ SL <130	Minimum Ecodesign requirements in September 2017 (EC, 2013c)
F	130 ≤ SL <158	-
G	≥ 158	226W Case study

The temperature control and solar devices are not directly regulated under the corresponding product groups but as additions to the packages space heaters, temperature control and solar device, through the Energy Labelling (EC, 2013e). Different control classes are defined for each type of temperature control (EC, 2014b). As mentioned above, the assessment of temperature controls in this case study assumes to have the same % in terms of savings on the energy output of the boiler.

Table 23. Performance ranges of the temperature control.

Definition of temperature control classes (EC, 2014b)		Contribution to seasonal space heating energy efficiency of packages
Class I	On/off Room Thermostat	1%
Class II	Weather compensator control, for use with modulating heaters	2%
Class III	Weather compensator control, for use with on/off output heaters	1.5%
Class IV	TPI room thermostat, for use with on/off output heaters	2%
Class V	Modulating room thermostat, for use with modulating heaters	We assumed 3% are average products in the market (benchmark)
Class VI	Weather compensator and room sensor, for use with modulating heaters	4%
Class VII	Weather compensator and room sensor, for use with on/off output heaters	3.5%
Class VIII	Multi-sensor room temperature control, for use with modulating heaters	5%

Regarding taps and showers, although being regulated by EU Ecolabel and GPP criteria, these product policies do not provide a quantifiable measure of the energy consumption associated with these components. Instead, the Swedish Standard 820000:2010 (SIS, 2010) provides an energy classification for different levels of energy use for mechanical basin and mixing valves. We use the Swedish Standard 820000:2010 (SIS, 2010) to generate better and worse scenarios of the case study, modifying the energy demand (Table 24). It is assumed that taps and showers below the average products (current design) generate energy losses and taps and showers above average products generate energy savings on the energy demand.

Table 24. Performance ranges of the taps and showers.

Swedish Standard 820000:2010 (SIS, 2010)		Case study assumption
Energy efficiency class	Measured energy use (kWh)	
A	≤ 1.6	53% savings
B	$1.6 \leq E < 2.2$	35% savings
C	$2.2 \leq E < 2.8$	18% savings
D	$2.8 \leq E < 3.4$	We assumed they are average products (no losses, no savings)
E	$3.4 \leq E < 4.0$	18% losses
F	$4.0 \leq E < 4.6$	35% losses
G	< 4.6	53% losses

The distribution components of the sanitary hot water and space heating are not specifically regulated by any product policy. Distribution cannot feasibly be improved especially when the house is new or has been recently refurbished. In the sanitary hot water system, the design of the building and the location of the boiler (next to the radiant tubes and far away from the tapping points) hinders the possibility of using less tubing. On the other hand, the current isolation of the tubing is acceptable in terms of width (1.5 cm for the sanitary hot water system and 2.2 cm for the space heating system) and material (polyurethane). Thus, the distribution components for both the sanitary hot water system and the space heating systems have a low feasibility and hence, they are not included in Table 25. In Table 25, the energy losses of the distribution are the ones of the current design ($L_{HW\ Dist}$ =1,018 kWh/y for the sanitary hot water system and $L_{SH\ Dist}$ = 38kWh/y for the space heating system).

Similarly, the underfloor heating recently installed in the dwelling of the case study makes not feasible its improvement. In addition, this type of delivery component of the space heating is not regulated by any product policy and the accounting of its losses has not been yet agreed. These facts make the underfloor heating difficult to be modified and thus, it is consider as not relevant and hence, not included in Table 25. In Table 25, the efficiency of the underfloor heating is the one of the current design (η_{RFloor} = 97%).

Table 25. Data of the improvement potential analysis of individual components of the sanitary hot water and space heating systems.

VARIABLES (Component parameters)	CURRENT DESIGN	POSSIBLE VALUES	SOURCE/COMMENTS
SANITARY HOT WATER SYSTEM			
Solar panels (number of panels)	1 (2.06 m^2)	0, 1, 2 solar panels	Same characteristics of the one already installed.
Boiler (energy class/water heating energy efficiency)	A (74.4%)	E (30-33%), D (33-36%), C (36-39%), B (39-65%), A (65-100%)	Energy Labelling (EC, 2013e), Ecodesign (EC, 2013d) and EU Ecolabel (EC, 2014a). See Table 19.
Storage tank (energy class/ standing losses)	G (226W)	G (>158W), F (158-130W), E (130-100W), D (100-80W), C (80-57W), B (57-41W), A (41-30W), A^+ (<30W)	Energy Labelling (EC, 2013b) and minimum Ecodesign requirements (EC, 2013c). See Table 21.
Taps and showers (energy losses/savings on energy demand)	0% losses 0% savings	-53%, -35 and -18% losses 18%, 35%, 53% savings	Assumption based on Swedish label SS 820000:2010 (SIS, 2010). See Table 23.
SPACE HEATING SYSTEM			
Boiler (energy class/ seasonal space heating energy efficiency)	A (ηSH Boi 92%)	B (82-89%), A (90-96%)	Energy Labelling (EC, 2013e) and Ecodesign (EC, 2013d) and EU Ecolabel (EC, 2014a). See Table 20.
Controls	Type V: 3% savings	No controls (0% savings), class I (1% savings), class III (1.5% savings), class II and IV(2% savings), class VII (3.5% savings), class VI (4% savings), class VIII (5% savings)	Assumption made based on Energy Labelling (EC, 2013e). See Table 22.

Figure 13 has been built based on every performance level of each individual component (Table 25). The performance level is modified one at a time and the rest of the components performance levels are left as in the current design. Thus, Table 13 shows results of 38 heating systems: 26 (3+9+7+7) sanitary hot water systems and 12 (4+8) space heating systems.

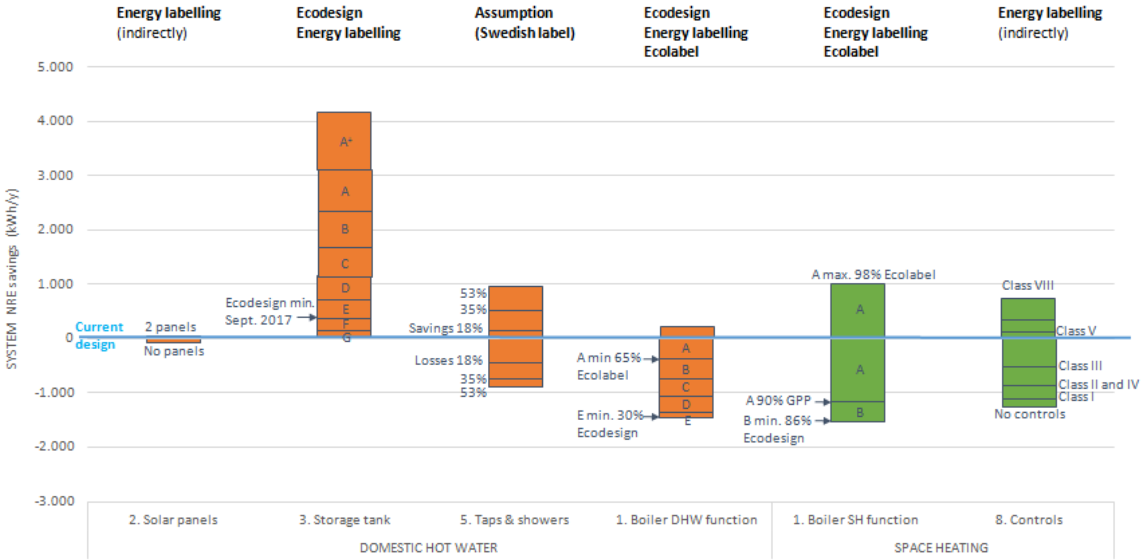


Figure 13. Results of the improvement potential analysis of individual components.

Results of Figure 13 show, for each component, the system potential for improvement expressed in energy savings (kWh/y). Improvement would be negative if for example, the current boiler (labelled A) were replaced by a worse technology (energy classes from B to E). Therefore, upgrading the storage tank to the maximum energy class (A+) could bring the highest energy savings to the sanitary hot water system (up to 4,162 kWh/y). An upgrade of the space heating function of the boiler could lead to energy savings of 1,012 kWh/y in the system. Efficient taps and showers could lead to savings of 985 kWh/y in the DHW system. Using controls of class VIII could lead to savings of 748 kWh/y. The sanitary hot water function of the boiler (243 kWh/y) and the solar panels (48 kWh/y) have less significant potential for improvement.

Note that the relationship of some of the component performance levels (i.e. boiler and storage tank) and the energy efficiency of the system is not linear (Figure 13). This happens because higher energy classes are more difficult to reach.

It can be concluded that the storage tank performance influences much more the system than the rest of components of the system.

4.1.2 Phase 2. Improvement: investigation of a better performing system

This section aims at searching improved solutions with regard the initial system.

It is assumed that the components used in the following alternatives are fulfilling the same function as the reference heating system and that they are located in the same place. Thus, the only changes in the system are done at the performance of the components. New components and/or technology could be added only if the system modelling made at step 1 of the method is still valid. If it is not valid, the "new" system has to be modelled first.

4.1.2.1 Step 4. Analysis of the best, benchmark and worst systems

The worst case is set according to information of minimum Ecodesign requirements and/or lowest energy class. In the case of the storage tank the lowest standing losses (226W) are assumed to be high enough to be considered the worst case.

The number of solar panels is considered constant (equal to 1 solar panel) since their improvement potential is very low (Figure 13). The number of solar panels, the distribution and the underfloor heating are considered the same as the reference case study and their best or worst options are not studied.

Table 26 shows the details of the best and worst scenarios proposed for the sanitary hot water and the space heating systems.

Table 26. Best and worst combination of components' performance levels.

Component	WORST	BENCHMARK (average products in the market)	CURRENT DESIGN (case study)	BEST
SANITARY HOT WATER SYSTEM				
Boiler	Energy label class E (30%)	Energy label class C (38%)	Energy label A (74%)	Energy label A (100%)
Storage tank	Energy label class G (226W)	Energy label class C (69W)	Energy label class G (226W)	Energy label class A+ (14W)
Taps and showers (on energy demand)	Swedish energy class G. Energy losses: 53%	Swedish energy class D. Energy savings/losses = 0	Swedish energy class D. Energy savings/losses = 0	Swedish energy class A. Energy savings: 53%
SPACE HEATING SYSTEM				
Boiler	Min. Ecodesign or Energy label class B (86%)	Energy label class A (92%)	Energy label A (92%)	Energy label A max. (97%)
Temperature controls	No controls	Class V (savings 3%)	Class V (savings 3%)	Class VII (savings 5%)

Results obtained with calculation tool deliver the figures of the performing parameters of the best, benchmark, current design and worst alternatives (Table 27). Note that the best alternative assumes a low energy demand thanks to efficient taps and showers and that the worst one considers high energy demand due also to inefficient taps and showers.

Table 27. Performing parameters for the best, benchmark, current design and worst alternatives of the sanitary hot water system.

	NRE consumption (kWh/y)	Energy losses (kWh/y)	Energy demand (kWh/y)	Low-emission energy efficiency
WORST	11,623	11,224	974	8.4%
BENCHMARK	5,018	4,780	637	12.7%
CASE STUDY	4,471	4,233	637	14.2%
BEST	1,190	1,290	299	25.2%

Figure 13 shows how the energy efficiency of the current design of the sanitary hot water system of the case study is slightly better than the benchmark and that the improvement potential to the best case is 11%.

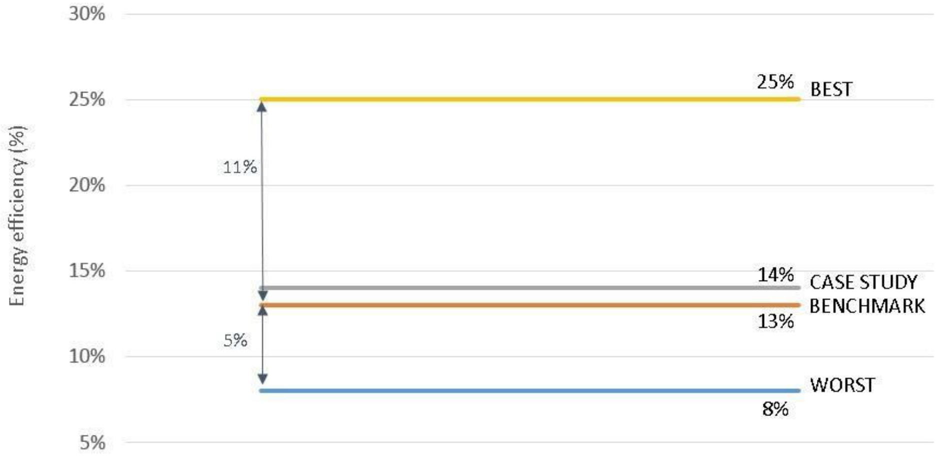


Figure 14. Energy efficiency of the best, benchmark, current design and worst combination of the sanitary hot water system.

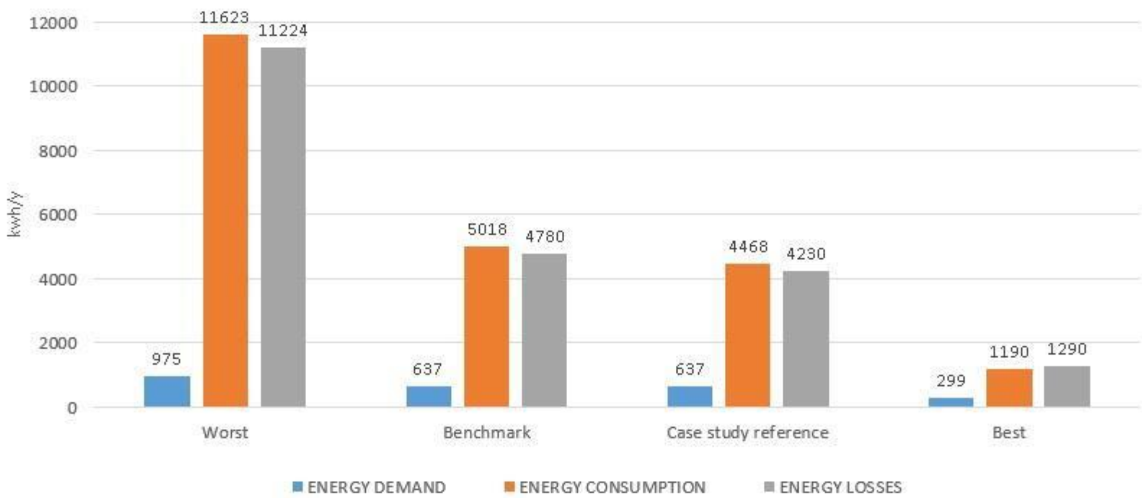


Figure 15. Energy demand, consumption and losses of the best, benchmark, current design and worst combinations of the sanitary hot water system.

Regarding the space heating system, the case study is the benchmark system and the improvement potential up to the best alternative proposed is only 5%.

Table 28. Performing parameters for the best, benchmark, current design and worst alternatives of the space heating system.

	NRE consumption (kWh/y)	Energy losses (kWh/y)	Energy demand (kWh/y)	Low-emission energy efficiency
WORST	21,707	3,622	18,085	83.3%
CASE STUDY/ BENCHMARK	19,683	2,158	18,085	91.9%
BEST	18,096	945	18,085	97.0%

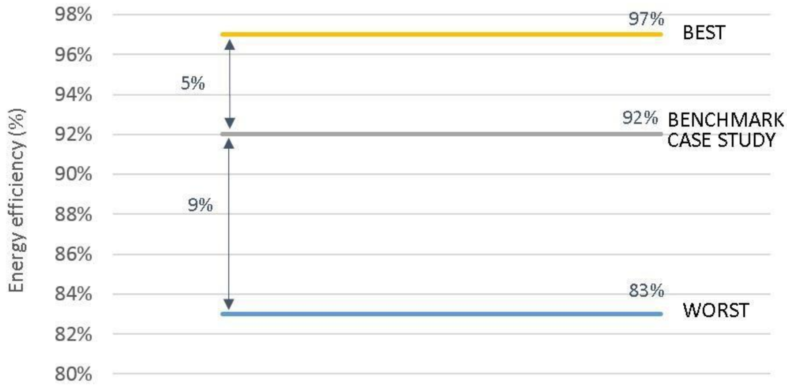


Figure 16. Energy efficiency of the best, benchmark, current design and worst combination of the space heating system.

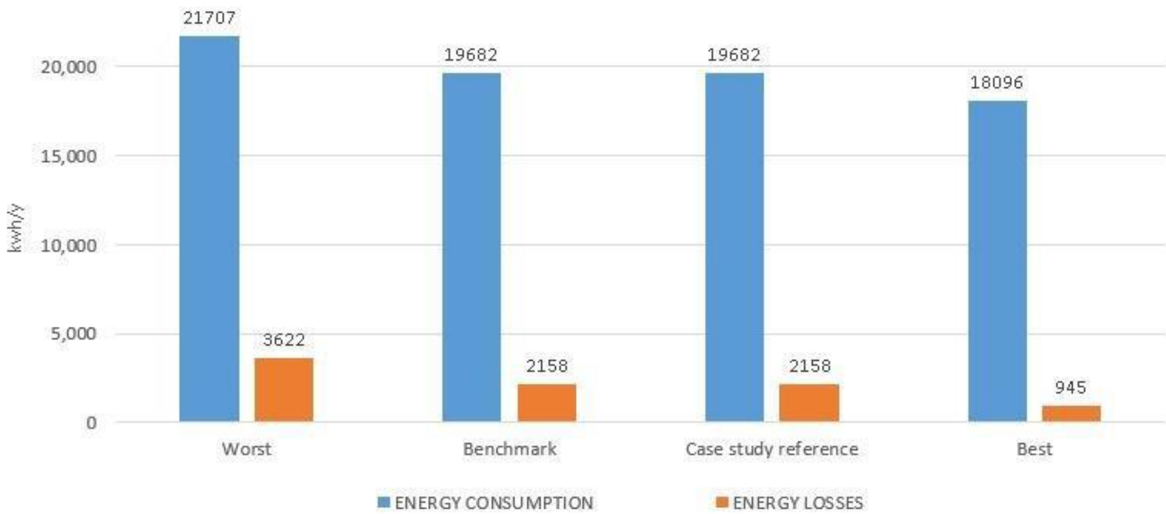


Figure 17. NRE consumption and losses of the best, benchmark, current design and worst combinations of the space heating system.

Even if the improvement potential up to the best alternative is only 5% in absolute terms the value is not negligible, being equal to 3,611kWh/y. It is slightly higher than the potential savings from the hot water production system, evaluated in 3,281 kWh/y. The sum of the two contributions could bringing a reduction of the NRE consumption equal to 28.8%.

4.1.2.2 Step 5. Analysis of other alternatives

Sanitary hot water system

For the sanitary hot water system, it is analysed how the combination of different levels of performance of the components affects the NRE consumed by the boiler. Assumptions have been made to generate design options:

- As the number of solar panels has poor potential for improvement (Figure 13), only one panel is considered in the following;
- The water heating energy efficiency of the boiler could be improved up to 100%. Two A-labelled boilers are considered (74% and 100% respectively);

- The storage tank could be easily improved up to the minimum value of energy class B (57W), since this class represents the average products in the market (Van Amerongen, 2015). Six energy classes are considered: G (current design 226W), F, E, D, C, B;
- Regarding taps and showers, four levels have been considered (0%, 18%, 35% and 53% of savings on the E_{HW} Demand).

Given these assumptions, there are 48 possible sanitary hot water system design options (2*1*6*1*4). Fig. 6 shows the NRE consumption for 32 (2*1*4*1*4) design options; for simplification of the figure, two levels of performances for the storage tanks (C and B) are not presented. Each quartet of bars represents a combination of a boiler (74% and 100% of water heating energy efficiency) and a storage tank (from G to B energy class). The colour of each bar corresponds to the four different levels of efficiency of the taps and showers considered (0% savings in blue, 18% savings in orange, 35% savings in grey and 53% savings in yellow).

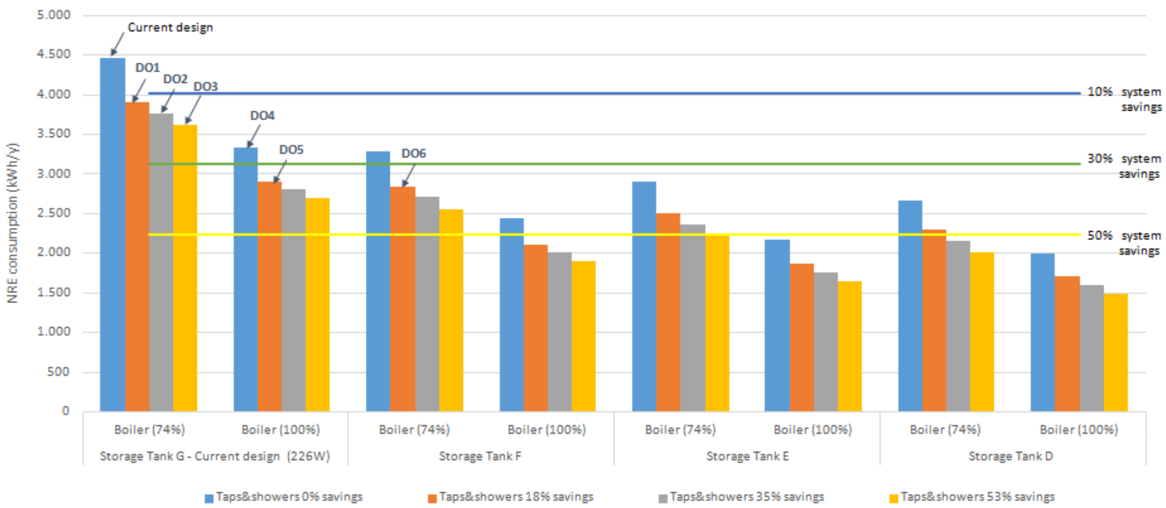


Figure 18. Alternative solutions based on combining products with different levels of in the sanitary hot water system.

According to Figure 18, for an energy-savings system target (with respect to the current design) the designer could choose among various design options (DOs) or combinations of products with different performance levels. For instance, achieving a system's energy saving of at least 10% to 30%, the taps and showers need to be replaced by ones that lead to 18% energy savings on the energy demand (DO1). Other options include choosing more efficient taps and showers (DO2 and DO3) or replacing the boiler by one with 100% of water heating energy efficiency (DO4). To achieve system savings of at least 30% to 50%, the boiler must be substituted by one with 100% of water heating energy efficiency, and taps and showers must be replaced by others that lead to 18% savings on energy demand (DO5). Another option could be to upgrade the storage tank to an F energy class and replace the taps and showers by ones that save 18% of the energy demand (DO6).

In addition, Table 29 shows the results of the performing parameters of the six selected solutions. The first column only shows the modifications to the current design case study.

Table 29. Results of the analysis of the alternatives of the sanitary hot water system

ALTERNATIVES OF IMPROVEMENT modifying:	NRE consumption (kWh/y)	Energy losses (kWh/y)	Energy demand (kWh/y)	Energy efficiency (%)	Savings (kWh/y) and (%)
1. Taps and showers C	3,905	4,088	522	13.4	566 (12.7%)
2. Boiler 100%	3,235	2,997	637	19.7	1,236 (27.6%)
3. Boiler 100% + taps and showers C	2,905	3,088	522	18.0	1,566 (35.0%)
4. Storage tank F + taps and showers C	2,844	2,208	522	18.4	1,627 (36.4%)
5. Storage tank E + taps and showers A	2,222	2,497	299	13.5	2,248 (50.3%)
6. Boiler 100% + storage tank E	2,166	1,927	637	29.4	2,305 (51.6%)

Space heating system

In the case of the space heating system, only the combination of the performance levels of the boilers and the controls is analysed since they are the relevant components which have potential for improvement.

- The space heating energy efficiency of the boiler could be improved up to 98%. We consider two A-labelled boilers, but with different energy efficiency indexes: 92% and 98%;
- Regarding the controls, 4 options are considered; class V (3% savings), class VII (3.5% savings), class VI (4% savings) and class VIII (5% savings).

The rest of components (distribution of the space heating and underfloor heating) are kept with the same values as step 1 of the method (see Table 16). Therefore, there are 8 possible combinations (2*4). Figure 19 shows the NRE consumption for each combination.

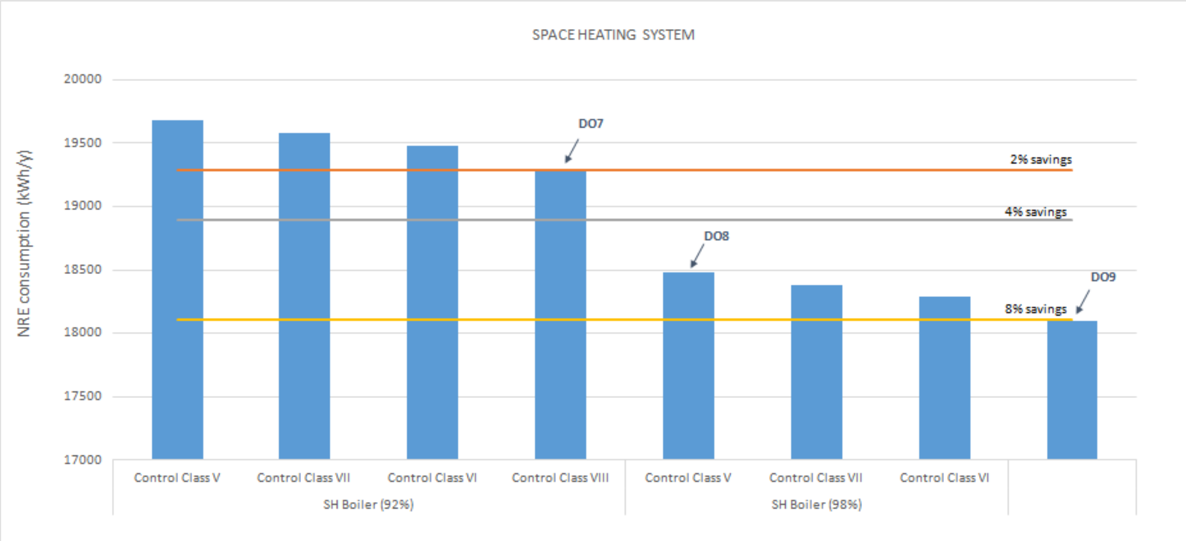


Figure 19. Alternatives solutions from the combination of different components performance levels of the space heating system.

Saving targets are set up at 2%, 4% and 8% and 3 solutions from Table 30 are chosen for a more detailed analysis.

Table 30. Results of the analysis of three selected alternatives for the space heating system.

ALTERNATIVES OF IMPROVEMENT modifying:	NRE consumption (kWh/y)	Energy losses (kWh/y)	Energy demand (kWh/y)	Energy efficiency (%)	Savings (kWh/y) and (%)
DO7 = Boiler 92% + Control class VIII	19,277	2,135	18,085	93.8%	406 (2.1%)
DO8 = Boiler 98%	18,477	953	18,085	97.9%	1205 (6.1%)
DO9 = Boiler 98% + control class VII	18,096	945	18,085	99.9%	1,586 (8.1%)

In conclusion, three main results can be drawn from the case study. Firstly, the influence of the performance ranges of individual components (Figure 13) on the system can be studied with the proposed method. A second result is that proposing a feasible benchmark for the products' performance levels (Figure 14, Figure 15, Figure 16 and Figure 17), it can be quantified if the current design of the case study is above or below the benchmark system. The third type of results helps designers to study and compare various alternatives (system configurations) combining different component performance levels and simulating their system performance (Figure 18 and Figure 19). It is then possible to reach a certain energy efficiency target through combining different performance levels of the installed devices. This could be done either through simple modifications to the current devices or through the substitution by a better device.

4.2 Application of the EU package concept to the case study.

As described at section 1.2, some product polices have recently broaden the boundaries from isolated products to groups of products into what is called "packages". This has been usually done through the extended approach which consists of extending the boundaries of the system in order to include other products which influences the performance of the product under study.

In case of Regulation 811/2013, the package concept was introduced very late in the development policy process (only 7 months before the publication of the regulation) during the consultations prior to the adoption of the delegated act (EC, 2013f). Suppliers of solar devices and temperature controls (often SMEs and consumer organisations) were not able to communicate the benefits of their products by only providing information on their products in an isolated manner (as part of the product fiche of heaters) for the following reasons: their products are usually placed in the market by their clients (dealers or installers) and thus, consumers do not have easy access to this information; the interesting information on savings of these devices can be only understood when used together with heaters. On the other hand, end-users lacked information at the point of sale to make informed choices on the overall efficiency of packages of heaters combined with solar devices and/or temperature control (EC, 2013f). The provision of information on solar devices and temperature control to consumers was initially too limited and to overcome this market barrier, the package concept was introduced (EC, 2013f). The package label and fiche allows the independent provision of information by suppliers and dealers. Then, the dealer can make up the package label according to separated product fiches provided by suppliers of heaters, solar devices and temperature controls.

Regulation 811/2003 (EC, 2013e), includes two types of packages: packages of a space heater, temperature control and solar device; and packages of a combination heater, temperature control and solar device. This last package is the one affecting the case study since the heater is a combination heater and thus, provides both sanitary hot water and space heating. However, the installation of the heating systems of the case study in the dwelling was done before Regulation 811/2013 entered into force (September 2015) and hence the labelling of the package was not available. Indeed, this regulation would oblige nowadays to set an energy class to the package/s of combination heater with storage tank, temperature control and solar device of the case study.

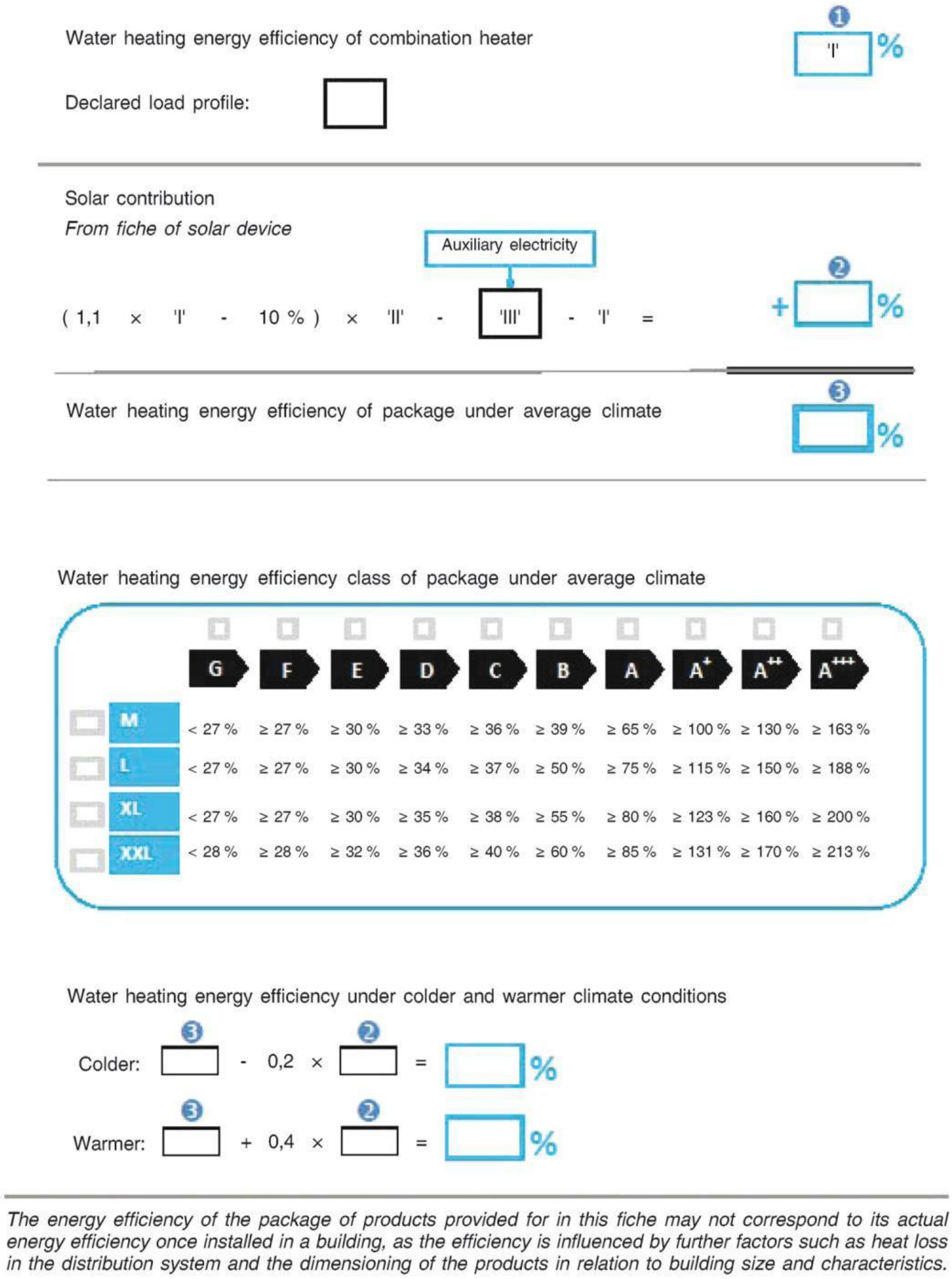
This section implements this product policy to the case study and analyses the differences with the method proposal of section 3.

4.2.1 Analysis of existing EU package relevant for the case study

Since the sanitary hot water system and the space heating system only share the combination heater, two different packages are analysed one for each of the functions of the heater (water heating or space heating). These two packages need to be labelled according to 811/2013 (EC, 2013e) and are:

- Package 1: the combination heater, the storage tank and the solar panel, in the sanitary hot water system.
- Package 2: the combination heater (the same as for package 1) and the temperature control, in the space heating system.

In the package 1, Regulation 811/2013 in its *Figure 5* (EC, 2013e) establishes the fiche for a package of combination heater, temperature control and solar device indicating the **water heating** energy efficiency of the package offered.



Water heating energy efficiency of combination heater ❶ 'I' %

Declared load profile:

Solar contribution

From fiche of solar device

Auxiliary electricity

(1,1 × 'I' - 10 %) × 'II' - 'III' - 'I' = ❷ + %

Water heating energy efficiency of package under average climate ❸ %

Water heating energy efficiency class of package under average climate

	G	F	E	D	C	B	A	A+	A++	A+++
M	< 27 %	≥ 27 %	≥ 30 %	≥ 33 %	≥ 36 %	≥ 39 %	≥ 65 %	≥ 100 %	≥ 130 %	≥ 163 %
L	< 27 %	≥ 27 %	≥ 30 %	≥ 34 %	≥ 37 %	≥ 50 %	≥ 75 %	≥ 115 %	≥ 150 %	≥ 188 %
XL	< 27 %	≥ 27 %	≥ 30 %	≥ 35 %	≥ 38 %	≥ 55 %	≥ 80 %	≥ 123 %	≥ 160 %	≥ 200 %
XXL	< 28 %	≥ 28 %	≥ 32 %	≥ 36 %	≥ 40 %	≥ 60 %	≥ 85 %	≥ 131 %	≥ 170 %	≥ 213 %

Water heating energy efficiency under colder and warmer climate conditions

Colder: ❸ - 0,2 × ❷ = %

Warmer: ❸ + 0,4 × ❷ = %

The energy efficiency of the package of products provided for in this fiche may not correspond to its actual energy efficiency once installed in a building, as the efficiency is influenced by further factors such as heat loss in the distribution system and the dimensioning of the products in relation to building size and characteristics.

Figure 20. Calculation method of energy efficiency of package 1 of the case study according to Regulation 811/2013

According to Regulation 811/2013 (and other regulations), not only the solar collector is included under the solar device definition but also the solar hot water storage tank or the pump of the collector loop (EC, 2013e). Thus, the "solar contribution" section of Figure 20 (and Figure 21) includes parameters of the solar panels (collector area, efficiency, etc.), the storage tank (nominal storage volume, energy class or standing losses, etc.) and the pump (electricity consumption, standby consumption, etc.) of the solar circuit.

Where (formulas from Regulation 811/2013):

- I' is the water heating energy efficiency of the boiler,
- II' = (220*Qref)/Qnonsol
- and III' = (Qaux*2.5)/(220*Qref);

and:

- Qref is the reference energy set through each load profile,
- Qnonsol is the annual non-solar contribution defined as the annual contribution of electricity and/or fuels to the useful heat output of a package of combination heater, temperature control and solar device, taking into account the annual amount of heat captured by the solar collector and the heat losses of the solar hot water storage tank (EC, 2013e),
- and Qaux (=III') is the auxiliary energy consumption.

All these variables are defined in detail in 811/2013 (EC, 2013e).

In the package 2, Regulation 811/2013 in its *Figure 1* (EC, 2013e) establishes the fiche for a package of combination heater, temperature control and solar device indicating the **seasonal space heating** energy efficiency of the package offered.

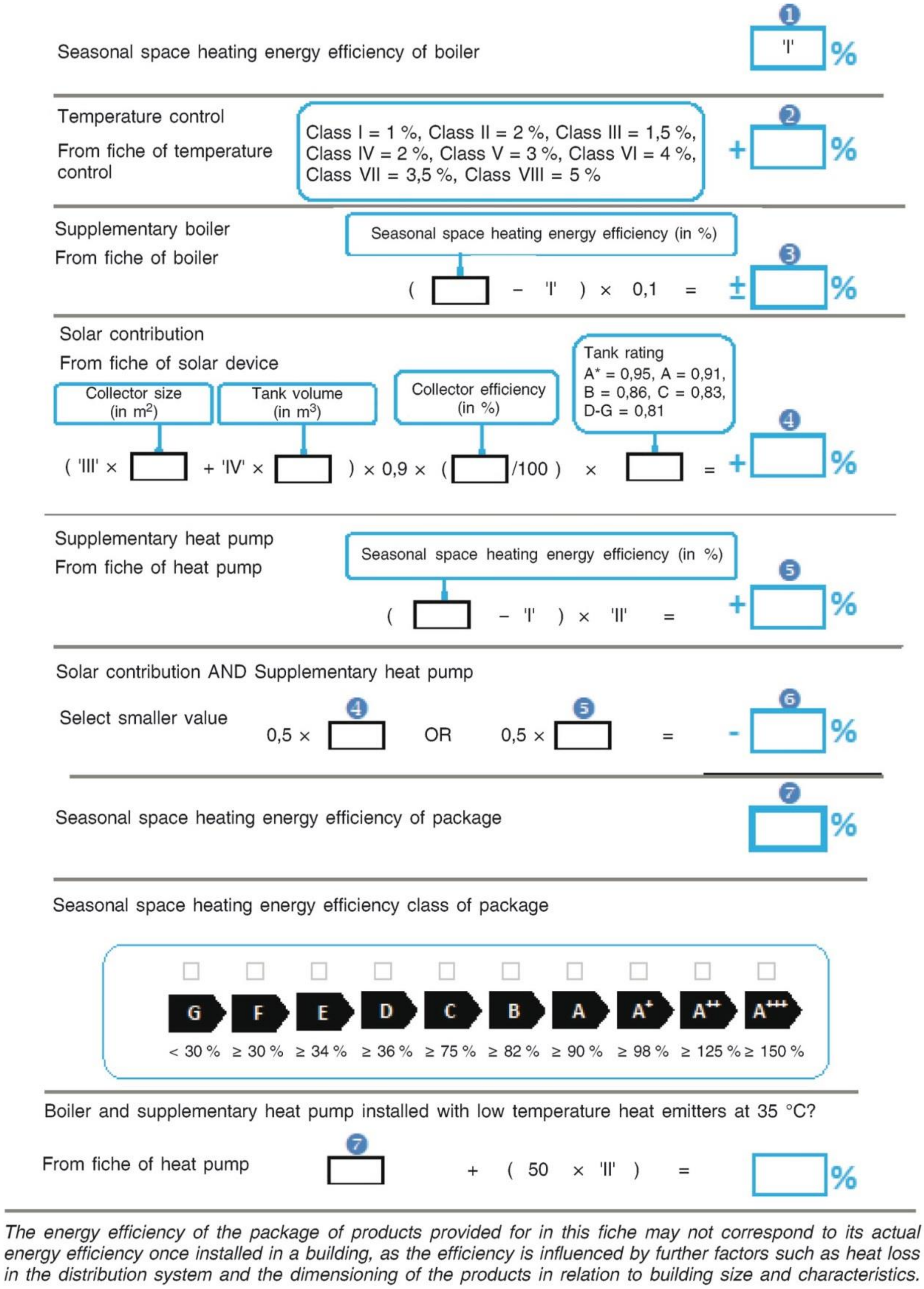


Figure 21. Calculation method of the energy efficiency of package 2 of the case study according to Regulation 811/2013

As shown in Figure 20 and Figure 21, results of the energy efficiency of the package according to the Energy Labelling affecting the packages (Regulation 811/2013) of the case study are obtained by adding efficiencies of the different products which compose the package. Then, the Efficiency provided by the manufacturer of the solar device or controls can be easily combined with the efficiency provided by the heater manufacturer.

This way it is avoided the discrimination of configurations offered by dealers/installers consisting of parts that were placed in the market individually compared with identical configuration offered by a single supplier/dealer (EC, 2013g).

These calculations are simple (not based on energy balances as in the method proposed in section 3) because the aim of these packages is to account the benefits somehow of using renewable energy sources and controls together with heaters.

This "modular approach" is complementary but very different from the "system approach" under the EPBD where the entire installation is considered and the losses from the building, and where the heat demand and required heating capacity are relevant as well (EC, 2013g).

Indeed, the footnotes of Figure 20 and Figure 21 inform about some limitations on the results of the package energy efficiency. It is stated that the efficiency of the package might be influenced by further factors such as the distribution losses and the dimensioning of products according to the size and characteristics of the building. The authors of this report also note that other components are neither taken into account, such as the delivery components (in the case study, the taps and showers and the underfloor heating). In addition, neither climate conditions nor the losses due to the building characteristics are considered, which could have a great influence in the energy services demand of the dwelling.

4.2.2 Implementing EU packages in the case study

<u>Package 1</u>

The water heating energy efficiency of the boiler is 74.4% (I') according to the manufacturer and its load profile M (Qref = 5.845). Qaux is 56 kWh/y. The Qnonsol has been calculated with SOLCAL (vA Consult, 2016) and is 1523kWh. SOLCAL is an online free software used in some documents of the European Commission (EC, 2012d and EC, 2015b) to calculate the non-solar energy needed in the package and includes several technical parameters from the solar collector and the storage tank. It does not include climate conditions.

Following formulas of Regulation 811/2013 (see previous section):

- I' = 74.4%
- II' = (220*Qref)/Qnonsol; (220*5.845)/1523 = 0.844
- and III' = (Qaux*2.5)/(220*Qref); (56*2.5)/(220*5.845) = 0.109
- Solar contribution: (1,1 x I' - 10%) x II' – III' – I'; (1.1 x 74.4% - 10%) x 0.8844 – 0.109 – 74.4% = -24.63%
  This negative value is due to the Qnonsol calculated with SOLCAL which includes also the solar storage tank. Indeed, the low efficiency (class G) of the storage tank is responsible for the negative number of the solar contribution. This means that all the heat provided by the solar panels is lost in the storage tank. This negative value is penalizing the bad efficiency of the solar subsystem (solar collector, solar pump and solar storage tank). It is probable that such a negative value would not be obtained if a more recent system and storage tank was considered.
- Water heating energy efficiency of package under average climate: I'+solar contribution = 49.8%, class B.

Table 31. Package results on the sanitary hot water heating system of the case study.

	Package 1
Water heating energy efficiency of the package under average condition	49.8%
Package energy class	B

Figure 22 shows the influence of each component on the improvement of the overall energy efficiency of package 1. The highest possible energy class of the storage tank is A^+ with no standing losses (SL=0); however, in this analysis we consider SL=14W. Then, nine storage tanks are considered, one per each performance level based on their standing losses (SL); G of the case study (SL=226W), G maximum (SL=158W), F (SL=130), E (SL=100), D (SL=80), C (SL=69), B (SL=57), A (SL=30W) and A^+ (SL=14W). The heater already has the highest energy class A, but its water heating efficiency could increase up to 100%, thus two heaters are considered (74.4% and 100%). Only 1 and 2 panels are considered since two panels achieve already a 99% of the energy demand (see section 4.1.1).

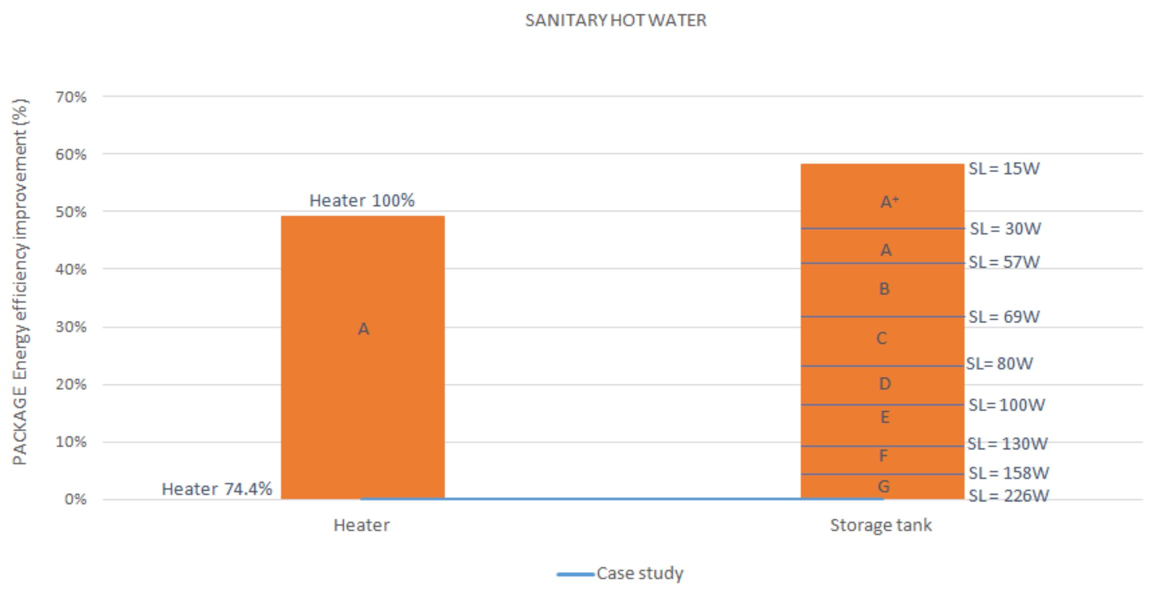


Figure 22. Contribution of individual components on the energy efficiency improvement of package 1 according to Regulation 811/2013

Package 1 has a low energy class mainly due to the high losses of the storage tank. Regarding the number of solar panels, if two solar panels are considered instead of one, the package energy efficiency remains the same. Therefore, in this system, the solar panels per se have no improvement potential at the package level if other components (the storage tank or the heater) are not improved. The storage tank could achieve the highest improvement (58%) on package 1 as shows

Figure 22 using a storage tank with an energy class A+ (SL=14W). Improvements of 4%, 9%, 17%, 23%, 32%, 41% and 47% could be achieved by increasing the energy class of the storage tank from the case study (G, SL=226W), to G maximum (SL=158W), F (SL=130), E (SL=100W), D (SL=80W), C (SL=69W), B (SL=57W) and A (SL=30W), respectively. Although the already good heater of the case study (class A, 74.4%), the potential for improvement (49%) of the package is very high with a water energy efficiency of 100%.

In conclusion, the storage tank alone could achieve the highest package energy efficiency (108%). The heater alone has also a relevant influence but its improvement potential is smaller than the one of the storage tank. The number of solar panels has the least potential for improvement in this system. These results are in line with those obtained in section 4.1 of the report in which the method proposed is applied to the case study, in which the storage tank and the heater have the most influence on the overall system, while the increase of solar collectors is not relevant.

Figure 23 shows results of combining different components improvements to package 1 under the same assumptions of Figure 22.

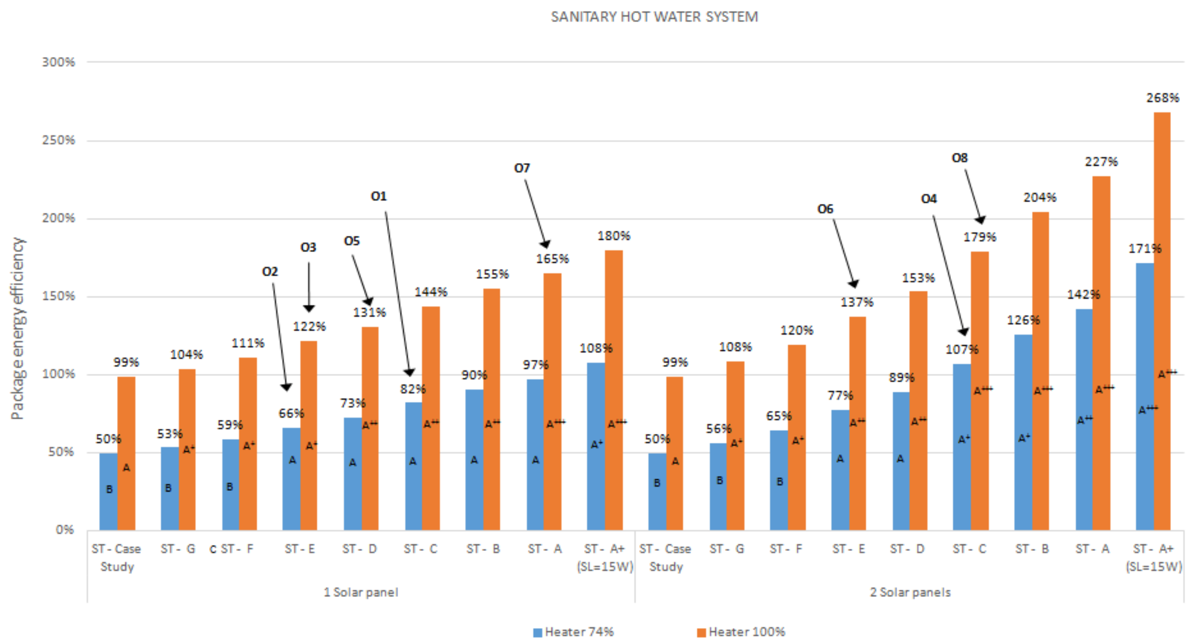


Figure 23. Combined options to improve package 1.

As mentioned above, the parameter solar contribution in the package formula of Regulation 811/2013 (Figure 20) is a negative value (-24.63%) since it is assumed that the solar panels are not able of covering the great losses of the storage tank. The solar contribution starts to be a positive value when using a storage tank with an energy class C (SL=69W). With this storage tank the package label is A (Option 1). However, Ecodesign minimum requirement set for September 2017 is that the storage tank should have at least a class E (in the case study SL=100W). Therefore, the first component to improve should be the storage tank up to at least an E class (SL=100W) (Option 2). Starting from this basis, other components could be also improved in order to improve the package label.

To increase the package energy class from A to A^+, the easiest options would be: to improve the storage tank from up to class E and to increase the water heating energy efficiency of the heater up to 100% (Option 3) or; to use a storage tank class C and two solar panels (Option 4). For achieving a package energy class A^{++}, either the storage tank improves up to class D and the heater up to 100% (Option 5) or; the storage tank improves up to E, the heater up to 100% and two solar panels are used (Option 6). The maximum package efficiency (A^{+++}) could be achieved through: a storage tank class A and a heater with 100% of water heating energy efficiency (Option 7) or; two solar panels, a storage tank with a class C and a heater with 100% of water heating energy efficiency (Option 8).

The drawback of options 6 and 8 is that imply to modify three components. Option 7 uses a storage tank A, and according to Amerongen (2015), this class would be reachable only by applying innovative insulation concepts such as evacuated systems or aerogels, which would not be suitable for a 60m^2 dwelling. Therefore, we discard options 6, 7 and 8. Table 32 shows results of 5 design options according to the package concept of Regulation 811/20013.

Table 32. Options of the package 1 label improvement according to Reg. 811/2013

OPTIONS OF IMPROVEMENT, modifying	Package label	Package energy efficiency	Improvement (on the package energy efficiency)
1. Storage tank C	A	82.0%	32.2%
2. Storage tank E	A	66.4%	16.6%
3. Storage tank E + heater 100%	A$^+$	122%	72.2%
4. Storage tank C + 2 solar panels	A$^+$	107%	57.5%
5. Storage tank D + heater 100%	A^{++}	131%	81.0%

Regarding section 4.1 of the report in which the method proposed is applied to the case study, different alternatives for improvement are proposed in Table 29 according to energy savings at system level. Although different criteria (energy savings in Table 29 and package label in Table 32) are used to generate design alternatives, there is one coincident design alternative: to modify the storage tank up to an E class and to use a heater with 100% of water heating energy efficiency. At both analysis, the improvement would be quite significant: 51.6% of energy savings in the first case (Table 29) and 72.2% package efficiency improvement in the second one (Table 32). It should be highlighted that design alternatives identified in Table 29 also considers other components of the system, such as taps and showers.

<u>Package 2</u>

The space heating energy efficiency of the heater is 92% according to the manufacturer. The control class of the temperature control is V so that it contributes 3% to the seasonal space heating of this package.

Table 33. Package results on the space heating system of the case study

	Package 2
Space heating efficiency of the package	95%
Package energy class	A

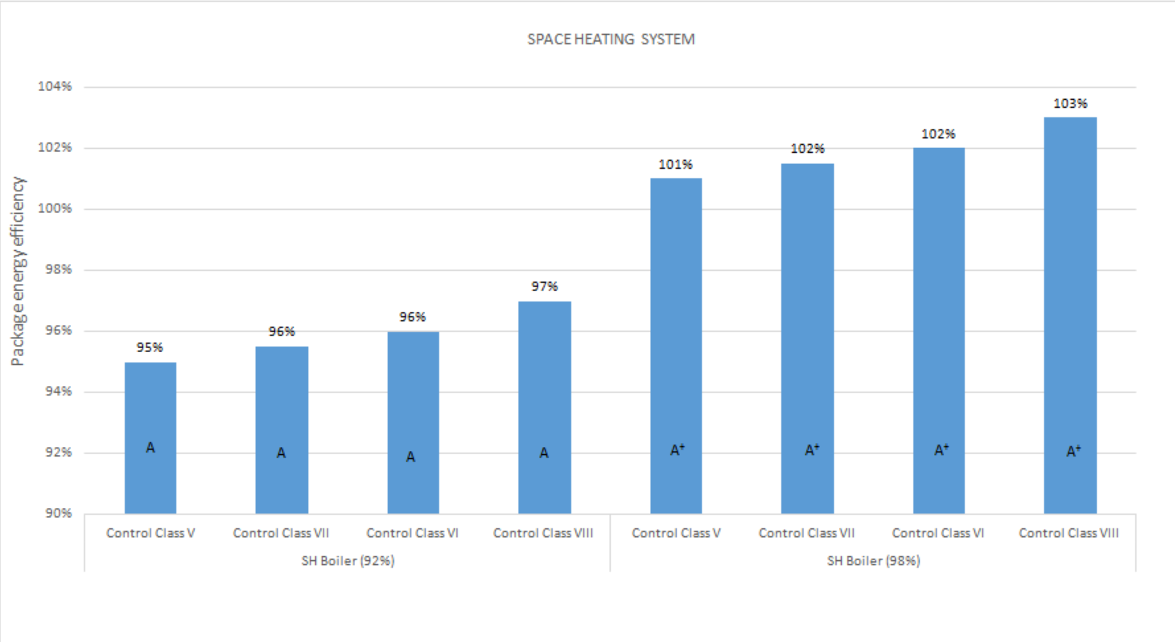


Figure 24. Influence of the heater and the controls on package 2

The heater has a greater influence in the package efficiency than the controls. Improving the heater space heating energy efficiency from 92% to 98%, the package would increase its efficiency from 95% (A) to 101% (A^+). However, improving the controls up to its maximum, the package efficiency would increase only up to 97%. Similar conclusions can be drawn when applying the method proposed to the space heating system (see section 4.1).

The design method proposed in section 3 of this report goes beyond the current EU package approach since it takes into account the specific global context (climate conditions) and the component configuration (including every element and their energy flows), and is therefore more realistic in terms of the geographical conditions, building envelope and heating system.

5. Overall discussion on the method, added value and limitations

<u>About the method</u>

The method proposed estimates the energy performance of a heating system based on the performance of its elements (components and sub-systems), using data from EU product policies. The use of product policies in a design method contributes to filling the technological gap among building designers and regulators (Allouhi et al., 2015) to achieve energy savings targets.

The **simplified method proposed helps designers** to take informed decisions to better achieve energy-saving targets. In fact, the most interesting feature of the method for designers relies on the results of the improvement potential and combination of products' performance levels, as demonstrated in the case study (section 4).

The method provides three new aspects that are not yet covered by the literature:

1. it allows the assessment of heating systems grounded on well-known and proven labelling schemes such as EU product policies, which are available at the early design stage and implemented by all manufacturers,
2. it supports design activities at system level, providing informed decision-making on multiple design solutions based on different configurations of products with performance levels currently available on the market, and
3. it allows to know how good or bad a heating system is throughout setting the worst, the benchmark and the best system (and thus, the improving potential). This is not a novelty for instance at product or building level, but it is at the heating installation level.

Data from EU product policies have the advantage of being based on homogeneous calculation methods and ratings for a particular product group. This is useful since the performance of components comes from an agreed evaluation process that makes it easier to compare products. These figures are available either from the regulations themselves or from manufacturers' technical documentation. In addition, as these product policies are continuously reviewed in order to adapt to market dynamics, performance calculation methods and thresholds are regularly updated. Designers, according to these product policies, can study the performance range (i.e. energy classes) of a component before choosing the product (available in the market) to be installed. However, the calculation methods applied in product policies might have some limitations in the accuracy of the performance figures they provide, and nowadays face the additional challenge of dealing with product systems. The method proposed is based on simplified methods which could be useful for decision making at the early steps of design, and thus, it is secondary if it does not provide very accurate performance figures. In addition, the method is flexible enough to allow designers to decide on which other calculation tool to use, when product policy data is not available.

The method proposes the **decomposition of the system** into elements and the aggregation of the performance of each element. Theoretically, the granularity of the decomposition does not matter – all that is required is the possibility to link each element with its performance. In practice, the decomposition is an expert task undertaken by a senior designer. The proposed method adapts to the most appropriate level of decomposition to manage interdependencies among elements. However, in reality the behaviour of the system is not a simple combination of the behaviours of its elements. The proposed method is valid only if the behaviour of each element is quasi-independent of the others; thus, the aggregation is a simple approximate function. More investigations will be made in the future to detail dependencies and synergies among elements and consequently, the aggregation function will be accurate.

Regarding the **procedure of the method**, the global context and system modelling is done once at step 1. The boundaries, the assumptions, the user behaviour and the building envelope losses are initially assessed at step 1 and remain constant throughout the next assessment steps. Therefore, everything but the changes due to technological aspects of components of the system will remain the same in steps 2, 3, 4 and 5. The addition of new components would also need a redefinition of step 1. However, the method is flexible enough to restart the method redefining parameters at step 1, if the global context or the system modelling losses change. The calculation tool facilitates this, reassessing easily the energy flows. The addition of new components and/or technologies would have to be studied further to check the applicability of the method.

<u>How the method links to EU package concept</u>

EC regulators have already recognised the limitations of considering isolated products instead of product systems, and have proposed to move their product policies from components to groups of products, giving data on performance at system level. This has already been done, for example, through the aggregation of some products' performance in 'packages', such as the packages of water heaters and solar devices (EC, 2013b; EC, 2013c). This is a first attempt to benchmark HVAC systems through product policies. The energy benchmarking of systems engineering involves comparing the energy performance of a system against a common metric that represents the optimal performance of a reference system (Ke et al., 2013). Once the energy labels of packages are well established and documented (they came into force only in September 2015), comparisons among different systems will be possible and it is expected that this will lead to higher energy savings.

However, this package is not the whole system; it is a coherent set of components of the system, and is a candidate to be regarded as a single element (as sub-system) in the decomposition of the real system, with an associated level of performance. Implementing the package concept to the case study in accordance with Regulation EC 811/2013 (EC, 2013b), two packages could be labelled according to the different services delivered (see section 4.2): the group of the heater, the solar panel and the storage tank (sanitary hot water) and the group of the heater and the temperature control (space heating system).

The energy efficiency package is calculated by summing the performance of different product parameters. The energy flows from one component to the next are not addressed with such a package approach, as they actually are in the method proposed in this report. In addition to this package (heater, solar panel and storage tank), distribution components, the taps of showers and the underfloor heating should be also included (as done in section 3), since they are part of the system. The method proposed in section 3 includes the losses of all the components of the heating system (distribution and delivery components) and the global context (climatic conditions, building characteristics, and user behaviour). Thus, the method proposed (section 3) is more complete than the EU package concept in terms of number of components.

However, when analysing the improvement potential of packages in the case study, similar conclusions are achieved than with the method proposed. The storage tank has the highest improvement potential, the boiler is relevant although its already good performance, and the number of solar panels has a small influence on the results on the package and the system according to the method. The fact that similar conclusions can be drawn from results from the EU package concept and the method proposed (in section 3) shows that although the limitations of the EU package concept (e.g. missing components and climate conditions, among others), the latter still gives correct outcomes. An advantage of the EU package concept in contrast with the method proposed is that its application is easier and more straightforward.

The design method proposed in section 3 of this report hence tries to go beyond the current EU package approach since it takes into account the specific global context and the component configuration, including every element, and is therefore, more realistic in terms of the geographical conditions, building envelope and heating system (it includes the energy demand and system energy losses). In addition, the energy balance applied in the method is more accurate than the simple addition of parameters applied in the EU package regulations and thus, it gives a more precise performance figure. On the other hand, the method proposed allows changes in the configuration of the system in a more approximate way than the EU concept package does.

6. Conclusions and perspectives for the future

This report explores and addresses some methodological challenges of the environmental assessments (especially concerning energy efficiency) of systems at the design step. An analysis of the system approach and environmental aspects on product policies and the scientific literature and other practical aspects is carried out in order to identify requirements for a method supporting the design of good performing heating systems.

The review on product policies (Ecodesign and Energy Labelling Directives, the GPP and the EU Ecolabel) on systems shows that these regulations usually apply the extended product approach to include additional products, part of the system, that influence the overall performance of a group of products (packages). The system approach, i.e. including all the components is not widely applied, as it should be. Product policies focus on environmental performances during the use phase, including energy efficiency, although other aspects can also be considered (e.g. air emissions, sound levels or other technical requirements). On the other hand, the scientific literature uses the system approach and holistic environmental assessment such as LCA. The method proposed in the report is an initial answer to this discrepancy.

According to the requirements identified as a result of the literature review, a simplified method is proposed to assess the design of efficient heating systems in residential buildings using data from EU product policies. The design method helps calculating the energy performance of a good heating system according to the performance of its components. It facilitates the selection of the performance of each product that make up the system and the combination of these to obtain an optimised solution at system level.

The performance levels of products used are those of the EU product policies (the Ecodesign and Energy Labelling Directives, the EU GPP and the EU Ecolabel), when available. When EU product policy data are not available, the method is flexible enough to allow designers to decide on which other calculation tool to use. As alternatives to EU product policy data, rules of thumb and professional software such as computational simulation tools can be used to assess product performance. The method can be used to enable the assessment of solutions, the comparison of alternatives and optimisation of the energy performance of the system at various stages of the design process, especially in the early stages. It also helps guide design activities towards energy-saving targets.

The method was applied to a real-life case study, and the fictive redesign of two heating systems (sanitary hot water system and space heating system). It is shown how the steps of the method are applied, which data is used and which results are produced. A calculation tool is created in Excel to facilitate multiple analyses. Two main results can be drawn from the case study. The first result shows the quantification of the influence of the performance of individual components currently available on the market in the overall system. A second result is that the proposed method helps designers to study and compare various alternatives (up to 6 design options are analysed in detail), combining different product performance levels and simulating their system performance. This could be done either through simple modifications of the current devices or through the substitution by a better device.

In addition, the package concept set in Regulation 811/2013 (EC, 2013e) is studied and implemented in the same case study. Although the limitations of the EU package concept (e.g. missing components and climate conditions, rough calculation, etc.), similar conclusions can be drawn from the EU package concept than from the method proposed, which shows the validity of the former. On the other hand, the method proposed is more complete, accurate and flexible, and hence has the capacity to better support design activities. Future work will have to improve the robustness of the method in order to extract the main drivers of design for system optimisation. The method could be applied to systems in which new technologies are added (by redefining step 1) and to new designs (the case study is a re-design) to check its applicability. Further applications of the method changing the global context (location, user behaviour, etc.) would be useful to strengthen the method under different global conditions (not technological dependent). On the other hand, additional sets of experiments on air conditioning, ventilation and different combinations of services would contribute to consolidate the method and to provide general conclusions on influent design parameters on HVAC systems. This could also include systematic analyses of synergies among system elements to help adjust the decomposition/aggregation process. Thus, even though the method has been developed and tested only on the design of heating systems, it could also be extended to support all HVAC systems, and possibly generalised to any other type of system for which product policy data are available.

The method represents a step forward on how to address better the system approach in environmental assessments and how this could be applied to ecodesign of product's systems. It improves the task of building designers and regulators to easier achieve common and equivalent energy efficiency objectives. In addition, to be able to design a system according to a certain energy efficiency target is a preliminary stage in the benchmarking of the energy efficiency of heating systems. Benchmarking is needed for regulating products and systems so that it gives relative information based on the average market characteristics. For designing, benchmarking is also relevant, especially for optimisation purposes.

While macro policies (i.e. EPBD, Energy Efficiency Directive) set global (by country, by sector, etc.) energy targets, micro policies (such as Ecodesign or Energy Labelling Directives) set specific energy targets (by product groups). Ideally, these two approaches should be somehow aligned. The work presented in this report contributes to bringing closer macro and product policies in which heating products are involved. However, it is a method created to be used by building designers and although it is a simplified method, it could not be directly used in product policies as it is. The findings of the report could help in the future to better set up a product rating schemes for heating systems and other HVAC systems.

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List of definitions

Boiler: *a space or combination heater which generates heat using the combustion of fossil fuels and/or biomass fuels, and/or using the Joule effect in electric resistance heating elements* (Reg. 811/2013).

Combination heater: *a space heater that is designed to also provide heat to deliver hot drinking or sanitary water at given temperature levels, quantities and flow rates during given intervals, and is connected to an external supply of drinking or sanitary water* (Reg. 811/2013).

Energy performance : in the context of the work of this report, it describes how well a product/component or system behaves in terms of energy consumption or losses.

Heater: *a space heater or combination heater* (Reg. 811/2013).

Heating system: is a group of products or components, physically connected aim at delivering sanitary hot water or space heating into a dwelling.

Package : in the context of the Ecodesign and Energy Labelling Directives, means a group of particular products specified by these product policies and offered to the end-user as a whole.

Product/component: is a manufactured unit that can be sold in the market. When a group of products can be sold as a single unit they are also called product or component. In this report, it may also be called system component or system product.

Service: is the function delivered by a system. Examples of services delivered by buildings are: hot sanitary water, space heating, space cooling, ventilation, lighting, etc

Space heater: a *device that provides heat to a water-based central heating system in order to reach and maintain at a desired level the indoor temperature of an enclosed space such as a building, a dwelling or a room and is equipped with one or more heat generators* (Reg. 811/2013).

Sub-system: referrers to a smaller group of products than the system, physically connected and aiming at fulfilling the same sub-function. An example would be a solar sub-system composed of the solar panels, the solar panel and the distribution of the medium (e.g. glycol).

Sub-function: is the specific function a product, group of products or sub-systems inside the system. For example, the solar sub-system has the sub-function of providing solar energy to the whole system.

System: is a group of products or components physically connected and with the common goal of fulfilling the same function or delivering the same service.

Water heater: *a device connected to an external supply of drinking or sanitary water, generates and transfers heat to deliver drinking or sanitary hot water at given temperature levels, quantities and flow rates during given intervals, and is equipped with one or more heat generators* (Reg. 812/2013).

List of abbreviations

CEN	European Committee for Standardisation
E	Energy
EC	European Commission
ED	Ecodesign Directive
ELD	Energy Labelling Directive
EU	European Union
EuP	Energy-using Products
ErP	Energy-related Products
EPBD	Energy Performance of Buildings Directive
GPP	Green Public Procurement
L	Energy losses
HVAC	Heating, Ventilation and Air Conditioning
HW	Sanitary hot water system
NRE	Non- renewable energy
S	Energy savings
SL	Standing losses
SH	Space heating system
RE	Renewable energy

List of figures

List of tables

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