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Methods to capture actual energy savings due to the implementation of minimum energy performance standards (MEPSs) under the EU Ecodesign

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Contents

Abstract

Ecodesign and Energy Labelling measures contribute to improve energy efficiency of products on the European market by setting minimum efficiency requirements and by providing a clear indication of the performance to consumers. The 2020 European Court of Auditors (ECA) Ecodesign audit, with respect to the ecodesign impact accounting (EIA) model used by the EC to evaluate the impact of its Ecodesign and energy labelling policies, recommended to 'assess the scope for evaluating the results of the policy using sample-based methodology to measure actual energy consumption by end users with a view to improving the accuracy of the model'. The main goal of this report is to make the link between in-situ measurements and assessment scenarios, identifying suitable methods to capture actual energy savings due to the implementation of minimum energy performance standards (MEPSs) under EU Ecodesign. In the study the necessary general conditions to implement appliance energy monitoring campaigns at European level are described in details, including technical and organisational aspect, e.g. stakeholder roles, sample size, recruitment procedure, budget needs etc. These different aspects have been then tailored into practical concrete field monitoring methodologies, to collect and analyse real-life energy data use and market trends, for three product groups: televisions (ENER lot 5), domestic refrigerators/freezers (ENER lot 13) and gas boilers (ENER lot 1).

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1 Introduction

With an increasing focus on energy efficiency and carbon emissions reductions there is a great need to have actual measured data to understand how energy is being used and thus support the development of robust Energy Transition Policies.

In the case of household equipment, user behaviour is usually an important factor affecting actual appliance electricity consumption. However, there are rather poor data and little understanding in this area. In-situ measurements can provide valuable data on usage patterns and information on the typical range of "normal" use across households. Specific drivers can also be inferred. But only a few end-use metering programmes have been carried out so far and their results rapidly become outdated. Nobody knows precisely how the current electricity consumption of an average European household is broken down or at what time of the day it is consumed [1].

Ecodesign and Energy Labelling measures contribute to improve the energy efficiency of products on the European market by setting minimum efficiency requirements and by providing a clear indication of the performance of appliances to consumers. The European Commission monitors and reports on their impact, with a view to improve its understanding over time and to fine-tune forecasting and reporting. The 2020 European Court of Auditors (ECA) Ecodesign audit [1] formulated the following recommendation with respect to the ecodesign impact accounting model that is used by the European Commission to evaluate the impact of its Ecodesign and energy labelling policies[2]:

2(b) assess the scope for evaluating the results of the policy using sample-based methodology to measure actual energy consumption by end users with a view to improving the accuracy of the impact accounting model.

In order to fulfil this recommendation, it is necessary to identify suitable methods to capture actual energy savings due to the implementation of Minimum Energy Performance Standards (MEPSs) under the EU Ecodesign and of the provision of a clear indication of the performance of appliances to consumers with energy labelling. In other words, it could be beneficial to evaluate the results of the Ecodesign and Energy labelling policies using sample-based approach to estimate the actual energy consumption of appliances in Europe. Energy savings estimated with ex-ante and bottom-up engineering approaches are often different to average real savings. Bottom-up engineering approaches are usually based on the consumption difference between the baseline appliance (average in the market before the MEPS) and the average appliance in the market after the MEPS has been enforced, by using manufacturer declared consumption values calculated with the EU harmonised test methods. The difference could be caused by:

The degree of representativeness of the test method of the <u>average</u> real-life usage of the appliance, which depends on many factors like for example the variability in users' behaviour, the installation of appliances, and the potential exploitation of measurement conditions and regulatory loopholes;

- The deterioration of the performance of some equipment over time (e.g. dust accumulation on the refrigerators heat exchanger);
- Other effects such as change in climate conditions.

[1] https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=52828
[2] https://ec.europa.eu/energy/studies_main/final_studiesecodesign-impact-accounting_fr

To this end in some projects, ex-post assessment methods of savings have been introduced for example based on metered data or a combination of metered data and engineering models. In these methods, sampling is common, due to the prohibitive costs of monitoring each implementation.

In this context, the first goal of this report is to make the link between in-situ measurements and assessment scenarios. Once the usefulness of monitoring campaign is proven, the necessary conditions to implement monitoring campaigns of appliances at European level will be described, including technical and organisational aspects.

These different aspects have been then tailored into practical concrete field monitoring methodologies, to collect and analyse real-life energy data use and market trends, for three product groups: televisions (ENER lot 5), domestic refrigerators/freezers (ENER lot 13) and gas boilers (ENER lot 1).

2 In situ measurements: which purposes and benefits?

Calibrate and improve policy assessment scenarios and models

The Ecodesign Impact Accounting study[3] presents every year the updated results of a comprehensive accounting of the assumed impacts of Ecodesign and Energy Labelling measures, in particular on energy consumption in the EU. It draws notably on Ecodesign Preparatory and Impact Assessment Study models and scenarios. The level of details of the assumptions differs from one product group to another. All these assessments have in common the use of stock models that simulate the way the stock of products in the EU changes annually based on past market data and assumptions on the evolution of product sales, ownership rates, and/or product lifetime. They also use assumptions on the average product usage (number of cycles, duration of use, settings, etc.). As for any model, calibration is highly beneficial, and the more calibration points are available and precise, the higher the probability that the model delivers accurate assessments. Impacts models used in Ecodesign and Energy Labelling deliver theoretical assessments and involve past data that may be relatively old, partial, or with high uncertainties. Table 1 provides an idea of such uncertainties for key modelling parameters for a typical product group.

Table 1. Uncertainties for key modelling parameters for a typical product group

Parameter	Typical data sources used as input to the stock model	Typical issues
Annual sales by performance (energy class, size, etc.)	- More or less recent and detailed market monitoring data sets (when available) - Model distributions in manufacturer product databases as proxy of sales	As there is no systematic market monitoring in the EU, data may be partial and old, or not fully representative.
Average ownership rates	- Collection of national (more or less precise) data in Member States, often extrapolated to the EU - Results from surveys	Surveys are not always trustworthy, and they rarely go into the details of product subcategories.
Product lifetimes	- 'Typical' values provided by manufacturers (possibly theoretical) - Assumptions suggested by other stakeholders, that may be contradictory or not based on identical lifetime definitions	Getting accurate and consensual values for average product lifetime poses methodological and data challenges
Product usage	- In situ measurement campaigns, when they exist (and only in specific countries) - Behavioural surveys and studies, on samples that may lack representativeness	Experience shows that surveys often provide inaccurate and uncertain results. They are also limited in the level of details they can access to.

Source: Authors' analysis

[3] European Commission, Directorate-General for Energy, Ecodesign impact accounting annual report 2021: overview and status report, Publications Office, 2021, [Ecodesign impact accounting annual report 2021 - Publications Office of the EU (europa.eu)]

Just as an illustration: to prepare Ecodesign and Energy Labelling requirements for dishwashers that entered into force in 2021, the 2017 preparatory study[4] estimated the average EU ownership rate based on a previous 2014 JRC study, itself based on a Euromonitor estimate from 2012. The study also revealed that variations between data obtained from surveys could be huge, e.g., a 2015 survey in selected EU countries found an ownership rate of 49% in Poland while the aforementioned Eurobarometer source found 20% for this country.

Box 1. Case study: stock modelling vs in situ measurement in France

The French electricity grid authority RTE has used for many years appliance stock modelling to forecast specific electricity needs in households in future years. The model uses mostly data from market monitoring institutes and surveys about product usage. This modelling approach can be compared against the results of in situ measurement campaigns.

In 2015, a measurement campaign has been carried out in France on domestic cold and wash appliances in a sample of 107 households [2]. The table below compares the average unitary electricity consumption for the appliances as calculated by the RTE modelling and as found in the measurement campaign.

Appliance	2014 consumption in RTE model (kWh/unit)[5]	2015 consumption in situ campaign (kWh/unit)[6]	Deviation
Fridge	350	359	+3%
Standalone freezer	370	354	-4%
Washing machine	200	92	-54%
Dishwasher	280	170	-39%

Source: Dupret et al. [2] and RTE. Add the following study in the references RTE, Bilan prévisionnel de l'équilibre offre-demande d'électricité en France, 2015

Whereas modelling seems to provid good results for cold products (where the impact of user behaviour is limited), it is far less convincing for the other appliances for which huge deviations were observed.

These results were taken into account by RTE to recalibrate their modelling. More recently, another more thorough in situ campaign was launched in France on a fairly representative sample of 100 French households and has delivered data for 2019 [3]..

The table below compares once more the RTE modelling for that year[7] and the results of the PANEL ELECDOM measurement campaign[8]. It shows again substantial variations for some appliances (also non negligible ones for products already measured in 2015).

[4] JRC (2017), Ecodesign and Energy Label for Household Dishwashers - Preparatory study Final report

[5] Source: RTE, Bilan prévisionnel de l'équilibre offre-demande d'électricité en France – Edition 2015

[6] Source: ADEME, Campagne de mesures des appareils de production de froid, des appareils de lavage et de la climatisation

[7] Source: RTE, Bilan prévisionnel de l'équilibre offre-demande d'électricité en France – Edition 2021 – Annexes Techniques

[8] Source : ADEME, PANEL ELECDOM - Consommations électrodomestiques françaises basées sur des mesures collectées en continu dans 100 logements

Appliance	2019 consumption in RTE model (kWh/unit)	2019 consumption in PANEL ELECDOM (kWh/unit)	Deviation
Fridge	260	302	+16%
Standalone freezer	320	288	-10%
Washing machine	120	101	-16%
Dishwasher	190	162	-15%
Main TV set	170	187	+10%
Oven	140	146	+4%
Kitchen hobs	200	131	-35%
Lighting (all lamps)	260	147	-43%

Source: Enertech [3] and RTE. Add the following study in the references RTE, Bilan prévisionnel de l'équilibre offre-demande d'électricité en France, 2019

Provide additional insights to better inform policy-making and policy assessment

Results from in situ measurement campaigns can also be useful to analyse a number of key implementation and design aspects of Ecodesign and Energy Labelling regulations, notably:

1- Identifying ex-post aspects that may have been overlooked or underestimated in the ex-ante policy preparation and in policy assessment models (e.g. in terms of technologies, rebound effects, unsuspected regulatory consequences, aging of products, etc.)
   - ➢ Are there important biases and missing aspects in the models?

2- Giving potential evidence on circumvention and non-compliance issues
   - ➢ Are there clear indications of improper regulation implementation, which may jeopardise policy success?

All these aspects are relevant to reinforce the robustness of policy evaluations.

Assess the actual impact of generic and other regulatory requirements

Beyond specific Ecodesign requirements and Energy Labels that directly influence the energy efficiency of product sales, in situ measurement campaigns can also deliver information on the impacts of other more generic regulatory requirements that have been adopted in the past.

As those only concern the share of products that have been placed on the market after the date of entry into force of the requirements, there might not be enough of them in the measured sample to make statistically representative quantifications. However, interesting observations should be possible, that may provide useful lessons about regulatory intervention.

As an illustration, here are a few examples of the types of questions that may be investigated during an in-situ campaign with respect to Ecodesign and Energy Labelling:

- Has the removal of exaggerated correction factors for refrigerating appliances tackled past distortion effects?

- Has the obligation to include a cold wash programme on all washing machines increased cold wash?

- Has the by default extinction of screens after 4 hours of inactivity had any impact on total usage time?

- Is the total usage time assumed in the impact accounting realistic? To what extent is the standardised power consumption representative of the average power consumption (energy consumed / hours of operation)?

As samples may be not large enough to be able to draw robust conclusions, the purpose will not only be to make quantitative extrapolations, but rather to draw attention on potential issues. To this end, in order to be relevant, it will be necessary to measure not only the power/energy consumption of products but also other characteristics (e.g. the way products are used. See section 5.4.3).

3 Inventory of major end-use measurement programs

End-use metering campaigns provide invaluable information on how, where and when electricity and gas are used in households. Despite these clear benefits, there is a general lack of available metering data. Table 2 and Table 3 summarise the programs on this subject that have been found in the literature. The list is not intended to be exhaustive. Table 2 gives a short overview of the main end-use metering campaigns completed in Europe for the last 30 years. Table 3 goes more into details for five recent international programs (one includes the follow-up of gas boilers). It shows the main characteristics of each project.

The two tables will form the basis for the critical description of the main features of a monitoring campaign detailed in this report.

Table 2. Summary of electricity end-use measurement studies [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14]

Name	Country	Date	Number of households	Subject	Metering length	Data collection time intervals
Nutek	Sweden	1992	66	Main domestic appliances, except lighting	Several months	overall electricity consumption over the
Ciel	France	1995	114	All domestic appliances, except	1 month	10 minutes
Ecodrôme	France	1996	20	All domestic appliances	2 years	10 minutes
Ecuel	France	1998	98	Cooking and cold appliances	1 month	10 minutes
EDF100	France	1999	100	All domestic appliances and electric	1 year	10 minutes
Eureco	Denmark, Greece, Italy,	2000-2001	400 (100 per MS)	All domestic appliances	1 month	10 minutes
Eclairage 100	France	2003	100	lighting (bulbs were 100 %	1 year	10 minutes
Piscines	France	2006	20	Swimming pools	4 months	10 minutes
Remodece	Portugal, France, Germany, Denmark, Norway, Bulgaria, Czech republic, Greece, Romania, Belgium, Hungary,	2008	1300	Audiovisual, IT, cold, washing/drying appliances, air conditioning	2 weeks	10 minutes
Sweden	Sweden	2005-2008	400	All domestic appliances	1 month (40 for 1	10 minutes
Fraunhofer ISE – Wärmepumpen	Germany	2007-2010	110	Heat pumps	3 years	
Aktion Brennwertcheck	Germany	2011	996	Gas condensing boilers	1.5 months	
Italy	Italy	2013	20	Cold appliances and washing	5 weeks	1 day
Cuisson	France	2014-2016	102	Cooking appliances (electricity and	1 year	1 hour
Froid lavage	France	2015	107	Cold, washing/drying appliances, air	1 year	10 minutes
Verbraucher messen	Germany	2015	48	Cold, washing/drying appliances, TVs	3 months	overall electricity
HESCA	Italy	2017	28	Main TVs and Connected	2 weeks	1 day
Chauffe-eau	France	2018	20	Electric water heater	1 year	10 minutes

Source: Authors' analysis

Table 3. Detailed description of 5 recent or ongoing end-use measurement studies [3], [15], [16], [17], [18], [19]

Name	Country	Date	Sample design			
			Methodology	Size	Characteristics	Recruitment process
SPAHOUSEC	Spain	2011	6 samples statistically representative of 3 climatic zones and 2 types of dwellings (flat and one-family house). Snowball samplng of 200 dwellings (min. 150 and max. 250) with quota on the type of dwelling.. Extrapolation to the national level according to the weight of the total population in each zone.	600	Selection in areas with a GDP per inhabitant equivalent to the national average justified by the relation between the energy consumption and the purchasing power. (Bias : areas with low- or high- income populations left out.) Quotas on flats and one-family houses to keep a relation close to a ratio 3 to 1, in correspondence with the information available from the Spanish Statistics Institute	Access to the dwelling facilitated through the collaboration with students from universities, corresponding to each climate zone. Their involvement in the project was stimulated with the help of an informative letter of IDAE. Likewise, the dwellings were encouraged to participate by offering them the possibility to receive an energy diagnosis of their dwellings.
HEMS	United states	2018-2023	Quota method for Ductless heat pumps, ducted heat pumps, heat pump water heaters, central air conditioning, forced air furnaces, baseboard heaters. When possible, the same sample pool from the previously completed NEEA residential building stock assessment (RBSA) is used for the metering sample, providing a broad information base about the home. The sample is selected from a four-state region: Oregon, Washington, Idaho, and western Montana.	400	No selection criteria other than for priority end uses mentioned	Initially postcards and telephone calls. Later, a web survey that asks if interested in participating in the study.
HEEP2	New Zealand	sept 2021 - sept 2023	Sample size is based on budget constraint and estimates of the sample sizes need to be confident that certain things observed will be statistically significant.	280	Partnership with Stats NZ, the national statistics body. One of the aims is to have an overall sample that adequately represents the whole of New Zealand. Participants in the study come from the Household Economic Survey (HES) which is carried monthly by Stats NZ.	Participants of HES are asked if they are interested in taking part in the HEEP2 Project. Each month, Stats NZ communicate a list of households who have consented to be contacted about the study. They then go through a staged recruitment process, beginning with an initial phonecall to see if they are happy to find out more the project. If they are, they are sent a full information pack. This random sampling should according to statistic laws be representative of New Zealand geographically, and hopefully in terms of typology (apartments and non-apartments) and tenure (rentals vs owner occupied).
Panel Elecdom	France	May 2019 - Ongoing	Random sampling in 10 zones with pre-selection criteria (geographic, residential structures -urban, peri-urban and rural area, average ressource level)	100	No selection criteria	Invitation sent via an online Internet Panel in the 10 specified geographical zones
Intertek	England	2010-2011	Quota sampling based on life-stage (single pensioner household, single non-pensioner household, multiple pensioner household, households with child/children, multiple person households with no children living at home) in 16 areas scattered all over England. Territory divided into 3 regions (North, Midlands, South) : additional and main quota set to have the same number of units in each territory independantly from the propulation distribution in order to make comparisons between the outomes of each territory.	251	Quota sampling based on life-stage (single pensioner household, single non-pensioner household, multiple pensioner household, households with child/children, multiple person households with no children living at home)	Recruitment was carried out among a regionally and nationally representative panel called Capibus of 2000 British adults who have agreed to take part in future research and who are interviewed every week.

Name	Country	Date	Data capture				
			Monitoring techniques	**Measured parameters**	**Data collection time**	**Data storage**	**Metering length**
SPAHOUSEC	Spain	2011	• 600 wattmeters (appliances on plug up to 3kW). Each technician was provided with 10 wattmeters, with the objective of taking measures of one household each week (4 days from Thursdays to Sundays). • in each type of dwelling (flat or one-family house) and climate zone (six in total), an electricity consumption register equipment (connected to the main switchboard) (during 10 months).	• Electrical service of heating: reversible and non-reversible heat pumps, electrical heaters, electrical convectors, electrical radiators and electrical boilers. • Electrical service of water heating: electrical heaters of water. • Refrigeration: air conditioning and reversible heat pumps • Cookers: electrical; glass ceramic hob and induction. • Household electrical appliances: refrigerators, freezers, washing machines, washing machines-dryers, dishwashers, TVs, dryers, ovens, PCs and rest of electrical equipment.	• overall costs and energy consumed over the period chosen for measurements for wattmeters. • 1 hour for electricity consumption register	-	9 months (spring season was assimilated to autumn because of the similarity of temperatures and energy demands)
HEMS	United states	2018-2023	Metering at the circuit panel by circuit	Electricity and temperature sensors for indoor temperature, fireplaces, and woodstoves. Gas is not a part of this study..	1 minute	Stored in the cloud, transmitted from the meter via a cellular modem	5 years
HEEP2	New Zealand	sept 2021 - sept 2023	Metering at the circuit panel by circuit	• Electricty use (each circuits of the electrical panel - no measure directly on appliances) • Gas use (total flow of gas into the house and then trying to separate out the different amounts for heating and hot water by looking at the pattern of usage) • Hot water use (temperature at the inlet and outlet of the cylinder, the flow of water into the cylinder, the total water used in the home) • Indoor and outdoor condition, relative humidity, levels of carbon dioxide, atmospheric pressure, light levels), building and appliance survey, householder survey	1 minute	The encrypted data is transmitted back to the secure BRANZ database over a provided wifi network.	1 year
Panel Elecdom	France	May 2019 - Ongoing	Goal : explain at least 90% of the total electricity consumption of each household. Metering at the circuit panel by circuit and directly on plugs. 25 measuring points on average for each dwelling	Electricity uses and ambient temperature/humidity	10 minutes	Data transmitted everyday to the secure Enertech server via GPRS network	Ongoing for 3 years
Intertek	England	2010-2011	Metering at the circuit panel by circuit and directly on plugs	Electricity uses and ambient and extrernal temperature	10 minutes	Data stored in the data logger and downloaded at dismantling	26 units - 1 year 225 units - 1 month

Name	Country	Date	General organisation of the program		Miscellaneous			
			Priority among appliances	Onsite Inventory + questionnaire	Update of the monitoring program	Link with other sources	Personal data management	What are the collected data used for?
SPAHOUSEC	Spain	2011	-	Questionnaire addressed to the equipment, their technical characteristics and pattern of use, differentiating working days and festivities. The questionnaire included a request on information based on the electricity invoices corresponding to the last 12 months	Pioneer project for Spain	-	-	• Determine the total energy consumption by energy sources, end-uses and services in household sector. • Build validated and harmonised methods for the determination of energy consumption
HEMS	United states	2018-2023	• The six appliances mentioned • As far as possible it was tried to meter all other circuits and the main circuit.	The questionnaire from the NEEA Residential Building Stock Assessment has an onsite inventory.	A smaller metering study was completed in 2012. Individual appliances, like heat pumps, heat pump water heaters, and televisions are monitored more frequently. More information can be found on NEEA's website.	The Residential Building Stock Assessment (RBSA) and national weather service data	The data is stored in a secured site. The data contains no personally-identifying information.	It is used for energy efficiency measurement, load forecasting, transmission and distribution planning, integrated resource planning, demand response potential assessment, and financial planning.
HEEP2	New Zealand	sept 2021 - sept 2023	All the circuits of the electrical board	Building and appliance survey provides information on the physical characteristics of the dwelling	HEEP project started in 1995 with a pilot study and progressed to detailed data collection in 400 houses throughout New Zealand. The sample included households from large and small cities, urban and rural areas and both the North and South Islands from Kaikohe to Invercargill. Each house was monitored for about 11 months. Data collection was completed in 2005.	The information collected by BRANZ in HEEP2 will be linked with the Household Economic Survey dataset	Data collected is encrypted, do not identify individuals or households in published statistics or research, keep information for as long as it has statistical or research value. All data collected in HEEP2 is stored securely on the BRANZ network. Only approved researchers can access the data. Name, address and contact details will be completely removed from BRANZ records once the study is complete. Data available in Stats NZ Data Lab	The Household Energy End-Use Project (HEEP) is a long-term study with the objective to measure and model the way energy is used in New Zealand households. The model will be used to understand current and future national household energy requirements, and as a tool to evaluate the implications of building and appliance performance changes. The HEEP2 data will allow researchers to answer a whole raft of questions, with the aim of understanding how to enable and motivate people to affordably create healthy home environments, in ways that contribute to a low-emissions economy.
Panel Elecdom	France	May 2019 - Ongoing	Order of priority has been defined to guarantee a monitoring rate of 90% with a limited number of meters	Questionnaire addressed to the electrical appliances, their technical characteristics and pattern of use	Several previous monitoring campaigns in France	-	The data is stored in a secured site. The data contains no personally-identifying information.	It is used for various research projects, in particular by the sponsors (ADEME and RTE)
Intertek	England	2010-2011	Order of priority has been defined empirically to measure the most consuming appliances.	Questionnaire on life-stage, background information of the household regarding climate change issues and a detailed list of electrical appliances owned.	-	-	-	Assess the potential electricity savings in the residential sector

Source: Authors' analysis

4 Sample design

To date it is not feasible to survey the whole population of appliances throughout a country and even less at the European scale[9]. So, sampling is necessary. The method of sampling should be documented as precisely as possible in order to consolidate the credibility of the outputs of the study and in order to meet the international publication standards.

Sampling methods

Much of the statistical theory on sampling is based on probability sampling (simple random sampling and its derivatives, like stratified sampling). Interviewees are drawn randomly from a census database containing detailed socio demographics characteristics, with the assumption that all drawn individuals will answer the survey. This latter assumption is very stringent: there is no such thing as survey with a 100% response rate. National statistical agencies rely on two different processes to offset this issue:

Coming back to a respondent, with missing answers, drawn from the database at various days and hours to collect his/ her answers. This is costly and takes time. Only national statistical agencies can in general afford the added cost and delay.

Estimate the individual missing answers, using the individual information in the sampling database. This data is only available to national statistical agencies. Moreover, this missing values estimation is based on the observed characteristics of the interviewee, while there is a chance that the non-response to a survey is linked to other characteristics, non-observed in the census data.

For other agencies, there is a need to address the non-response issue, and to do that at the aggregate level, not by estimating individual missing answers. This is usually done, before the data collection stage, by imposing quotas, or after that, by weighting the answers to calibrate the distribution of the main socio demographics on values derived from the census. Any non-probability[10] sampling approach would need to use either or both of these approaches.

4.1.1 Probability sampling

The most common techniques among Probability Sampling are the Simple Random Sampling, and the Stratified Sampling[11.]

4.1.2 Simple Random sampling

In simple random sampling, one starts by identifying a complete list or enumeration of all of the population elements (e.g. people, houses, phone numbers, etc.). Each of these is assigned a unique identification number[12], and elements are selected at random to determine the individuals to be included in the sample. As a result, each element has an equal chance of being selected, and the probability of being selected can be easily computed. This sampling strategy is most useful for small populations, because it requires a complete enumeration of the population as a first step.

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9 With self-monitoring and reporting appliances, this should at least in theory nearly become feasible in due course

10 Non-probability sampling is a method of selecting units from a population using a subjective (i.e. non-random) method

11 https://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_probability/bs704_probability2.html

12 According to the Regulation (EU) 2016/679, the EU new General Data Protection Regulation (GDPR). See section 7

4.1.3 Systematic sampling

Another way to choose randomly the respondents is by Systematic Sampling. Systematic Sampling also begins with the complete sampling frame and assignment of unique identification numbers. However, in systematic sampling, subjects are selected at fixed intervals, e.g., every third or every fifth person is selected. The spacing or interval between selections is determined by the ratio of the population size to the sample size (N/n). For example, if the population size is N=1000 and a sample size of n=100 is desired, then the sampling interval is 1000/100 = 10, so every tenth person is selected into the sample. The selection process begins by selecting the first person at random from the first ten subjects in the sampling frame using a random number table; then the 10^{th} subject is selected.

With systematic sampling like this, it is possible to obtain non-representative samples if there is a systematic arrangement of individuals in the population.

4.1.4 Stratified sampling

If some previous information on the measured variable is available, it is worthwhile to consider sampling methods which will produce more precise estimators than simple random sampling. This is the case of Stratified Sampling. In Stratified Sampling, the population is split into non-overlapping groups or strata (e.g. men and women, people under 30 years of age and people 30 years of age and older), and then sample is selected within each stratum. If the variance of the measured variable is smaller in each stratum than it is globally, the precision of an estimator based on stratified sampling will be better than the precision of an estimator based on random sampling. Adequate representation of subjects in each stratum should be ensured. Sampling within each stratum can be by simple random sampling or systematic sampling. For example, if a population contains 70% men and 30% women, and we want to ensure the same representation in the sample, we can stratify and sample the numbers of men and women to ensure the same representation. For example, if the desired sample size is n=200, then n=140 men and n=60 women could be sampled either by simple random sampling or by systematic sampling.

Whatever the exact technique used with probability sampling, the main issues are (i) to have close to zero non-response (ii) the capability to estimate the individual missing values from individual data on non-respondents. When these conditions are not met, methods akin to quota sampling should be used.

4.1.5 Quota sampling

In quota sampling, we determine a specific number of individuals to select into our sample in each of several specific groups. This is similar to stratified sampling in that we develop non-overlapping groups and sample a predetermined number of individuals within each. For example, suppose our desired sample size is n=300, and we wish to ensure that the distribution of subjects' ages in the sample is similar to that in the population. We know from census data that approximately 30% of the population are under age 20; 40% are between 20 and 49; and 30% are 50 years of age and older. We would then sample n=90 persons under age 20, n=120 between the ages of 20 and 49 and n=90 who are 50 years of age and older.

The formula used to calculate the precision of estimators obtained with quota sampling is similar to the one used for stratified sampling [20].

Sample size

Within all studies gathered on energy consumptions in households based on onsite monitoring (see chapter -), none explains the choice of the sample size in regards to the expected precision of the outcomes.

Israel [21] sums up the most commonly used equations to determine the sample size needed to reach a certain degree of precision[13]. Energy consumption within a population is characterised by a mean value and a standard deviation. Assuming that the sample is reasonably large (n_0 greater than 80), the following equation applies:

$$n_0 = \frac{Z^2 \sigma^2}{e^2}$$

Where n_0 is the sample size, Z is the abscissa of the normal curve that cuts off an area α at the tails, e is the half length of the confidence interval, and σ^2 is the variance (both e and σ^2 are expressed in the same unit of measure as the measured variable) in the population which size N is considered as much greater than n_o (this applies for National or European level assessments).

Z depends on the chosen level for the confidence interval. This parameter is set at 95% according to most authors. This means that there is a 95% chance that the actual population average attribute is within +/- e of the average calculated with the sample. With a 95% confidence level, Z equals 1.96.

The Panel Elecdom project [3] provides the yearly electricity consumption of major household appliances for 100 representative French dwellings. Based on these data, it is possible to calculate the minimum sample size for the main devices in French households (Table 4).

Table 4. Minimum sample size with regard to expected accuracy based on Panel Elecdom data

	# Units in Panel Year 1	Equipment Rate*	Estimated french stock	Mean consumption Y1 (kWh)	Standard Dev Y1 (kWh)	Expected accuracy				
						2%	5%	10%	15%	20%
Total household consumption	101	100%	29 500 000	4792	3450	4 978	796	199	88	50
Lighting	101	100%	29 500 000	147	122	6 569	1 051	263	117	66
Fridge	28	118%	34 810 000	166	75	1 973	316	79	35	20
Fridge-Freezer	87			346	147	1 746	279	70	31	17
Freezer	56	60%	17 700 000	288	181	3 793	607	152	67	38
Washing machine	100	91%	26 845 000	101	76	5 438	870	218	97	54
Dishwasher	72	58%	17 110 000	162	106	4 135	662	165	74	41
Dryer	31	30%	8 850 000	301	240	6 106	977	244	109	61
TV	114	155%	45 725 000	162	164	9 843	1 575	394	175	98
TV Set-top Box	75	74%	21 830 000	87	38	1 813	290	73	32	18
Laptop	91	118%	34 810 000	22	33	22 556	3 609	902	401	226
Oven	65	56%	16 520 000	146	89	3 511	562	140	62	35
Boiler	45	44%	12 980 000	173	254	20 655	3 305	826	367	207
Internet Set-top Box	99	86%	25 370 000	96	52	2 798	448	112	50	28

*: the equipment rate is derived from a survey on 4000 households (EDF R&D, 2016). It can be greater than 100% because there can be more than on appliance per household. *Source*: Enertech [3] and author analysis

[13] It is assumed that behaviour does not vary between countries. This is a simplification, because it is not always the case. This aspect needs to be better investigated in further studies

Table 4 shows that the required number of investigated appliances for a same accuracy depends on the device type: while a sample of 70 appliances would give an outcome with +- 10% precision for fridge-freezers, 152 households would be necessary for freezers and even 218 for washing machines; for a precision of +- 5%, the required sample size is about 4 times greater than for +- 10%.

These figures derived from this French in-situ measurement program can be used for surveys in other countries as well. But in any case, the actual accuracy of the outcomes will have to be recalculated based on the measured variance compared to the forecast.

In the above approach, it is assumed that the sampling design is a simple random sample. But more complex designs leading to greater precision (for example stratified random samples) will be useful in some situations. In order to calculate the precision of the estimate with such designs, the variances of subpopulations, strata, or clusters must first be calculated. Thus, the Department of Economic and Social Affairs of the United Nations recommends in its Practical Guidelines for Designing Household Survey Samples [22] the use of a "design effect d"[14] from 1.5 to 2 for the sample size unless it can be computed more accurately using the gathered data. We report later the "design effect" for the cluster approach of the Panel Elecdom project (see section 4.3.1).

Application to energy consumption of electrical appliances

Regarding energy consumption of electrical appliances, the issue faced by most stakeholders is that there is not usually an access to the whole population. In other words, there is no register at national level with the name, address, telephone of each citizen. Nowadays more and more people are no longer registered in the telephone book which was before the most complete source of contacts. Moreover, the rate of success of such a recruitment has become very low, people having got exasperated by unwanted solicitations. Therefore, Simple Random Sampling is in practise not feasible. Different techniques of sampling can be used to draw a representative sample of the whole national population out of a more limited panel of owners. Five examples are presented in paragraph 3 and two of them focused on the main domestic electrical appliances are highlighted below.

4.1.6 Case study 1: Panel Elecdom in France

The sample of the Panel Elecdom project has been chosen among a panel of 500 000 households in France provided by an online panel company. For budget issues, the project had been designed to monitor in details the electricity consumption of the major appliances in 100 households[15], which corresponds to an approximate accuracy at appliance level of +/- 10 to 20% as shown in Table 4.

Three influencing factors have been used to build a first sample of 500 households scattered among 10 sites (50 households per site):

- Geographic: clusters within 50 kms radius to optimize travel costs and scattered all over France for a good geographical representativeness (climatic, cultural, daylight…). The 5 following areas have been chosen: North, East, West, South and Mountain

[14] The design effect is an adjustment made to find a survey sample size, due to a sampling method (e.g., cluster sampling or stratified sampling) resulting in larger sample sizes than expected with simple random sampling (SRS). The design effect is the ratio of the actual variance to the variance expected with SRS.

[15] The Panel Elecdom project is still ongoing. Its initial implementation (i.e. selection and recruitment of the sample, purchase and installation of the monitoring equipment in 100 households, maintenance and analysis of the data for the first year) costed around 500 000 euros.

- Household median income: 3 types of areas have been investigated (high revenue per household > 22 k€/year; medium around 20 k€/year; low < 18 k€/year) in order to address heterogeneous profiles

- Dwelling types and location: 3 types of housing (rural -dispersed-, urban -collective- and suburban)

The 3 factors are crossed in order to obtain 10 different zones (different combination of the 3 factors[16]).

A web questionnaire has been addressed to all participants of the panel within the given areas. There were 2 750 respondents. From these 50 respondents have been drawn randomly in each of the 10 sites in order to create a first stage sample of 500 units.

The representativeness of the panel versus national statistics regarding income, number of people per household, dwelling type (apartment vs. single family house) has been checked. Outliers were discarded.

Then 12 participants have been drawn for each of the 10 sites. The 120 candidates have then been called to check their commitment to participate to this long-term project. Any panellists resigning before the measurement process were replaced by new randomly drawn candidates from the 10 x 38 = 380 left. The panel was slightly oversized (120 versus a goal of 100) to take into account drop outs during the implementation of the in-situ measurement. The chosen panel is illustrated in Figure 1.

Figure 1. Location and characteristics of the ten recruitment zones (centred on Roubaix, Guingamp, Paris/Lyon, Rambouillet, Nancy, Besançon, Limoges, Chambéry, Aix-en- Provence, Toulouse)

Source: Enertech [3]

Ex post, the representativeness of the household sample has been compared to the national statistics in terms of number of people, tenure, type of housing, average surface (m²), revenue, equipment rate, willingness to buy new appliances within a year, sensitiveness to environmental issues.

Overall, the discrepancy versus the national population lies in a slight overrepresentation of families of four. The project stakeholders decided neither to correct the sample definition nor to redress the outcomes. Although the sampling of the survey is not strictly a probability one, the design is similar to a cluster survey, where first clusters of homes are drawn from a database, and then individuals are drawn from each cluster. With the available data, it is possible to calculate the design effect d, i.e., the ratio of the variance of the

[16] Not all the possible combinations have been considered, but only 10. See figure 1

estimate resulting from this design to the variance that one would obtain in a probability sampling (with no cluster) framework. The calculation of the design effect d is based on the following formula [23]:

$$d = \frac{Var(Estimate_{Clustering})}{Var(Estimate_{Probability})} = \frac{\frac{\sum_{i=1}^{m}(Y - y_i)^2}{m\ x\ (m-1)}}{\frac{\sum_{j=1}^{N}(Y - Y_j)^2}{N}}$$

where N is the size of the whole sample, Y is the overall estimator, Y_j are the N individual values of the sample, y_i is the estimator in each cluster i, m is the number of clusters in the sample, n is the average size of the clusters. The number of possible clusters is considered to be very large with respect to the number of clusters m in the sample. The design effect d is to be used as multiplying factor to compute the sample size needed to achieve the same precision as a random sample or to recalculate the accuracy of the estimate.

In Table 5, the estimates of this design effect can be found for the various categories of the Panel Elecdom project.

Table 5. Estimates of the design effect for the main appliances of the Panel Elecdom project

Category	Design effect (d)
Overall energy consumption	2.5
Lightning	1.1
Fridge- freezer	4.2
Freezer	2.6
Laundry washing machine	1.4
Dishwasher	1.5
Dryer	1.6
TV	0.36
Oven	5.4
Boiler	0.52
Refrigerator	4.4
TV set top box	1.8
Internet set top box	1.7
Laptop	3.1
Water heater	3.6

Source: Panel Elecdom project and author analysis

In order to minimise the design effect in a cluster survey (i.e., d as close as possible to 1), it is recommended that the averages of the variable of interest be as close as possible across clusters. Of course, this is mostly assessed a posteriori. In Table 5, the fact that boilers have a design effect below 1 probably comes from the fact that the region was an important variable to determine the clusters. Thus, for boilers, the cluster design of the survey allowed a better accuracy versus a probability one, while on the contrary, it was by far less precise for fridge-freezers, although they had the lowest variance within the panel.

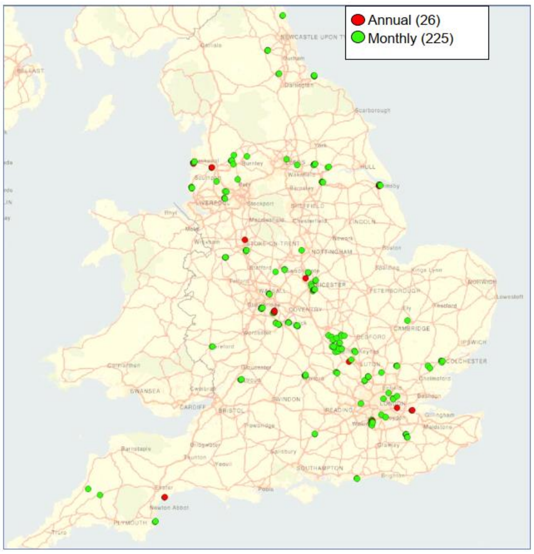
The value of the design effect is the result of a complex mix of factors (social, geographical, economical etc.) that should be investigated ex-ante if a cluster sampling framework is chosen. Nevertheless, the above design effect calculation could serve as a guidance for a future study. Two important facts should be kept in mind however, before applying automatically these coefficients to a new survey: (i) there is a confidence interval around these design effects[17] (ii) other profiling variables could be used to make the clusters more homogeneous. Therefore, it is recommended to calculate the confidence interval around the design effect with specific statistical techniques, e.g. “bootstrap methods”[18] and analyse the available data to uncover new profiling variables.

4.1.7 Case study 2: Household Electricity Survey in England

The Household Electricity Survey [23] surveyed 251 households in England, monitoring the electrical power demand and energy consumption over the period May 2010 to July 2011 (see Table 3). The project was funded by the Department for Environment, Food and Rural Affairs, the Department of Energy and Climate Change and the Energy Saving Trust[19]. The recruitment was carried out by the company IPSOS among a regionally and nationally representative panel called Capibus of 2 000 British adults who have agreed to take part in future research and who are interviewed every week.

The Sample has been divided in sub-samples of about 80 people gathered/stratified by their geographic location belonging to one of the 3 Government Office Regions (Figure 2). For each sub-sample demographic quotas have been set only on life-stage (single pensioner household, single non-pensioner household, multiple pensioner household, households with child/children, multiple person households with no children living at home). When not all quotas were reached in a sub-sample, new candidates were sought in the same area using the snowballing technique (i.e., “do you know someone in your area who could match following criteria?”). Overall quotas have been set to represent equally the 3 Government Office Regions and then to represent the distribution of life-stage in each subsample.

Figure 2. Location of participating households of English Electricity Survey



Source: Household Electricity Survey [19]

[17] The confidence interval will depend on the dispersion of the variable under study and therefore on an ad hoc calculation

[18] The bootstrap method is statistical procedure for estimating quantities about a population by averaging estimates from multiple small data samples. It can be used to calculate the mean, the standard error, construct confidence intervals and perform hypothesis testing. See also https://en.wikipedia.org/wiki/Bootstrapping_(statistics)

[19] This project costed around 370 000 euros (this includes the rental of the monitoring equipment, training of the electricians in charge of installing the monitoring equipment in the households, analysis of the data, but not the cost related to the work of the electrician neither the selection and the recruitment of the sample)

Ex-post, the representativeness of the households' sample has been compared to the social grade, life-stage, number of people, property age and working status. Life stage and number of people of the household of the sample fit very well with the national statistics, while discrepancies appear for the other factors.

4.1.8 Sample design final recommendations

Except for the study HEEP2 in New-Zealand (see Table 3) for which the recruitment is carried out by the public Statistical body (Stats NZ) through a monthly survey proposed to all citizens during census, all the most recent large scale monitoring samples have been based on representative panels provided by private companies. Using existing online panels (from a public body or from a private company) seems to be the most effective way to recruit a representative sample for a future assessment of the energy consumption of household appliances. To avoid biases and to make the outcomes credible, the representativeness of the panel should be well (and more than in the available studies) documented.

Recruiting the participants through an online panel can be cost effective and offer a certain guarantee of homogeneity across countries. Access Panels are the standard tool, used by all large companies, to survey consumers and reach specific targets, combining good data collection quality and cost effectiveness. It should be noted that the participation rate will be impacted by different factors:

A respondent who has accepted to install the meter might finally not install it, or the meter might not work after installation,

There will be some attrition in the panel: panellists moving home, meter uninstalled or broken down.

A-priori assumptions on these dropout rates, drawn from previous experience, will be needed to evaluate the feasibility of using online panels for this measurement. Derived from previous programs it can be estimated that:

In around 5% of the households, no data at all will be collected (respondents will not or badly install the meter at the beginning);

- In around 15%, less than one year of data will be available (datalogger unplugged or broken during the monitoring campaign). But it is highly dependent on the type of appliances (less dropout for fridges for example than for computers).

It is recommended to select participants well scattered within the territory in order to ensure a good geographical representativeness (climatic, cultural, daylight…). The sample characteristics should be compared to national statistics and outliers should be discarded after comparison with the following possible influence factors (list to be adapted to the type of appliance):

- Owner occupant status;
- Number of occupants in the home;
- Single-residential versus multi-residential;
- Household size;
- Geographical location;
- Heating type;
- Electricity consumption;
- Income levels or other socio-economic variables.

Geographical clustering might be required to meet budget constraints when the monitoring infrastructure has to be installed by a qualified technician. In this case, participants should be drawn randomly within the subsamples. The sampling framework should be designed with a preliminary assessment of the design effect in order to set an appropriate sample size and clustering strategy. The final sample should be compared to the national statistics and should be cautiously either corrected (replacement) or redressed (weighted) when significant discrepancies occur.

Lastly, one should always remember that, when using non-probability sampling the calculation of the error margin depends on more assumptions than in the theoretical probability sampling framework. Therefore, the results ought to be accompanied by a description of how the sample has been obtained so that readers can evaluate the credibility of the results.

Evaluation at the European level

The assessment of the electricity consumption of domestic appliances subject to the Ecodesign/Energy labelling regulations requires to choose samples and check their representativeness at national level. In order to optimize the costs, the surveys could be implemented only in a few European countries representing most geographical, cultural and living standards. The number of domestic appliances is first dependant on the number of households and for some of them secondarily dependant on the number of inhabitants per household, on the surface area of the dwelling. Table 6 shows that the 8 countries with the greatest number of households per country represent 76.5% of the European population (77.5% of the households) and a good geographical spread. Table 6 also shows that all 4 empirical geographical zones (centre, east, north, south) are rather homogeneous in term of standard of living. These 8 countries could serve as sampling frame (i.e. Germany, France, Italy, Spain, Poland, Netherlands, Romania, and Sweden).

TO BE NOTED: In the case of gas boilers, a similar methodology, combining representativeness of UE households and geographical spread, have been used. In this case the 8 countries of the sample would be Germany, Italy, France, Netherlands, Spain, Poland, Romania and Denmark. According to our estimates, they represent 84% of the EU boiler stock

Table 6. EU-27 countries – Demographic, economic and geographic features

Country	Number of households 2020[20]	Number of inhabitants 2021[21]	Median standard of living in the EU (2019, in EUR)[22]	Zone (empirical classification)
Germany	40 556	83 155 031	23 460	CENTRE
France	30 304	67 439 599	21 726	CENTRE
Italy[23]	26 079	59 257 566	17 165	SOUTH
Spain	18 794	47 394 223	16 043	SOUTH
Poland	14 733	37 840 001	8 022	EAST
Netherlands	7 936	17 475 415	25 801	CENTRE
Romania	7 518	19 186 201	4 267	EAST
Sweden	5 564	10 379 295	24 700	NORTH
Belgium	4 882	11 566 041	25 672	CENTRE
Czech Republic	4 839	10 701 777	10 627	EAST
Greece	4 388	10 682 547	8 777	SOUTH
Hungary	4 126	9 730 772	6 478	EAST
Portugal	4 069	10 298 252	10 800	SOUTH
Austria	3 987	8 932 664	26 555	CENTRE
Finland	2 749	5 533 793	25 490	NORTH
Bulgaria	2 710	6 916 548	4 612	EAST
Denmark	2 413	5 840 045	30 681	NORTH
Slovakia	1 920	5 459 781	8 703	EAST
Ireland	1 878	5 006 907	26 250	CENTRE
Croatia	1 461	4 036 355	7 892	EAST
Lithuania	1 348	2 795 680	8 606	EAST
Slovenia	914	2 108 977	14 774	EAST
Latvia	861	1 893 223	8 827	EAST
Estonia	619	1 330 068	12 228	EAST
Cyprus	334	896 005	16 704	SOUTH
Luxembourg	261	634 730	37 844	CENTRE
Malta	213	516 100	16 240	SOUTH
Total	195455	447 007 596		

[20] Eurostat, lfst_hhnhwhtc serie, last update 02.06.2021
[21] Eurostat, Demographics and gross rates [demo_gind], last update: 05-07-2021
[22] Eurostat (extraction from december 2021) - https://www.insee.fr/fr/statistiques/2830158#tableau-figure1_radio1
[23] Data on Median standard of living from 2018

5 Data acquisition and management

In order to improve the knowledge of energy consumption and usage in households, it is necessary to monitor it at appliance-level. Different techniques are currently available to this end. In the following paragraphs, each is described and illustrated with examples of solutions available on the market. This chapter also addresses the measurement of explanatory parameters that allow to specify the operating conditions of household appliances (temperature, humidity and weather data). Then it explains how to control, clean, store, display and process the data.

Data collection and transfer

5.1.1 Data loggers

A data logger is a device consisting of a sensor, a sensitive part (temperature, humidity, electrical energy, pulse counting, etc.) and an on-board memory for recording measurements. These measurements are usually made at regular time steps (measurement rate or integration period). Data are not available remotely. They need to be downloaded from the internal storage of the data loggers at the end of the measurement period. Thus, there is no maintenance which is easier and cheaper than for communicating measurements.

In addition to the selection criteria common to all sensors (accuracy, size, robustness, etc.), the main criteria for choosing a data logger are the size of its memory (in terms of the number of storable points) and its autonomy if it is battery-powered.

In the case of event-based measurements (switching a light on or off, for example), the autonomy is not known a priori because it depends on the use that is done of the appliance. The use of on-board memory measurement is particularly efficient in a "mobile fleet": this consists of purchasing a “fleet” of data loggers that are successively installed in different homes according to measurement needs. This optimal use makes it possible to limit the number of purchased data loggers while limiting data generation to the exact needs of the measurement campaigns. They also can be sent by post and installed by the participants themselves (no need of certified electrician) which makes the organisation of monitoring campaigns easier.

Advantages	Drawbacks
- Ease of installation (no need of certified electrician) - Limited maintenance - Reliability (no complex communication components, limited risk of failu	- limited size of the internal memory - No possible control of the data during the monitoring program (need to anticipate a data loss rate)

5.1.2 Measurement systems with communication function

Box 2. Glossary: some common vocabulary in the field of communicative measurement:

Gateway: A device installed between two networks with different protocols, that provides a translation between the different languages. In practice, the same object can be called a hub ora gateway.

Concentrator or Hub: A device that gathers data from a set of sensors. It is usually also a gateway.

Bus: A wired link that can be shared by several elements. NB: it is different from pulse meter that requires dedicated links (which cannot be shared) from each meter to the concentrator.

Communication protocol: A system of rules that allows different components of a communication system to transmit information.

Measurement systems with communication function have been expanding rapidly in recent years, so that it is very difficult to have an exhaustive overview of all the players and technical solutions available on the market. Communicating measurement is more expensive than on-board memory measurement and is generally less robust as communication problems come on top of any other possible failures. On the other hand, communicating measurement allows dynamic data to be monitored in real time and therefore it helps react quickly, which can be essential in certain cases, such as to see the immediate effects of setting changes on an equipment or on the behaviour of a user. Communicative measurement requires the development of a specific data communication architecture. There are many different communication protocols. Usually, a complete infrastructure is composed of different sub-networks, each with its own protocol.

Some protocols are dedicated to transmit simple information (e.g., temperature or index at the transmission time) and allow basic equipment (sensors, meters, etc.) to be connected locally. These are typically fieldbuses (Modbus, M-bus, KNX). These protocols are used for communication within a building. Others are suitable to the transmission of more complex information (typically historic time series over a certain period) between more advanced equipment (computers or PLC) over distances that may exceed the scale of a building. Some "high level" protocols are used only within a building (BACnet, Bluetooth, KNX, etc.) and others can be used to transfer data from a building to an external server (GPRS, TCP/IP, etc.). Some of these protocols are for wired communication (i.e. Modbus, KNX, Bacnet, TCP/IP), others for wireless (i.e. Bluetooth and GPRS), M-bus for both. Switching from one protocol to another requires a gateway so in order to avoid complexity it is necessary to limit the number of different protocols for the different sensors of the monitoring infrastructure.

The most common communication protocols are (non-exhaustive list) [24]:

- M-bus for heat meters (transmission of energy, volume, and temperatures) and flow meters.
- Modbus for electricity meters; also used for heat and flow meters. It is now the de facto standard for basic communications.
- KNX for the control of electrical equipment.
- BACnet, LON for controllers and some heating or ventilation equipment.
- TCP/IP/Ethernet for all "high-level" communication. This is the protocol generally used to transmit data outside a building or to an in-house computer.
- Wi-Fi: wireless link using deregulated frequency bands (which anyone can use without special authorisations). It requires at least one access point (Wi-Fi router type)
- GPRS: Wireless link using the GSM (mobile phone) network. It requires a SIM card and a dedicated subscription. Note that mobile phone networks are not available everywhere.
- LORA or LoRaWAN: long range radio protocol with low power consumption.
- ZigBee: "high level" radio protocol for short distance optimised for very low power consumption.
- Z-Wave: low-rate radio protocol for indoor uses.
- Bluetooth: short-range wireless technology standard.

- Sigfox: proprietary radio protocol for long distances.
- EnOcean: radio technology with ultra-low power consumption. There is no battery in the sensors, thanks to the energy harvesting[24].

Table 7 provides an overview of the most common protocols and their applications.

Table 7. Most common protocols and their applications

In-house protocol		Both	Home <-> Server protocol
• M-bus • Modbus • KNX • BACnet • LON	• Wi-FI • ZigBee • Z-Wave • Bluetooth • EnOcean	• TCP/IP • LORA	• GPRS • Sigfox

Source: authors' analysis

Monitoring techniques for electrical uses

5.1.3 Smart electric metering

The Smart Metering deployment in the European Union aims at monitoring electricity consumption in real time and through this helping to reduce it. So far, it is not possible with smart meter data to precisely disaggregate consumption into specific individual appliance loads, even with powerful Non-intrusive Load Monitoring (NILM) algorithms (see section 0). Moreover, the administrative procedures to obtain these data can be tedious (protection of personal data, see section 7).

Figure 3. Examples of smart meters

TELEGESTORE from Italy	LINKY from France	SGM 1100 from Spain
		
Source : https://isplc2007.ieee-isplc.org/docs/keynotes/rogai.pdf	Source : https://fr.wikipedia.org/wiki/Linky	Source : https://www.aclara.com/products-and-services/smart-meters/sgm-residential/sgm1100/

[24] EnOcean's patented energy harvesting technology, works by obtaining energy from light (https://www.enocean.com/en/technology/energy-harvesting/)

5.1.4 Electric meter socket (at the plug level)

For monitoring plugged-in household equipment, it is possible to use measuring devices that are placed directly between the equipment to be monitored and its power supply.

This type of meter has the advantage of being simple to use. It comes with installation instructions and can be installed directly by the owner of the equipment without the intervention of a technician.

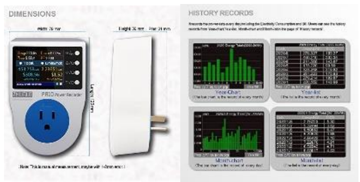
They generally accept a maximum load up to 3600W, making it possible to use them to monitor almost all domestic electrical appliances (except electric cooking)

The two different types of devices (devices with display and data logging devices) are described in the following paragraphs.

5.1.5 Devices with display

There are a large number of devices available on the market that display the instantaneous power and the cumulative energy (over the entire monitoring period) directly on the meter or via an interface (smartphone, PC). More advanced models allow a reading of the monthly, weekly or daily total. It is not possible to download data from this type of device.

Figure 4. Examples of plug-in energy monitors without internal memory

NZR SEM 16+	ZHURUI PR10-E US15A	AWOX SmartPlug Plus
		
Source : https://www.testoon.com/nzr-sem16-p-77599	Source : https://fr.aliexpress.com/item/32695358611.html	Source : https://www.leroymerlin.fr/prise-connectee-bluetooth-awox-

5.1.6 Data logging devices

A few plug-in devices allow the recording of active, reactive and/or apparent energy consumption, etc. at a time range (or integration period) from 10 minutes to 1 hour. With this kind of monitoring devices, it is possible to study the operating cycles, power demand levels and standby consumption. It should be noted that although all loggers offer more or less the same time steps, their capacity to store recorded data can vary greatly.

For example, for a 10 minutes time step, the GREENPRIZ system has a storage capacity of 26 days, compared to 97 days for the SEM16+USB or 455 days for the Enerplug from OMEGAWATT.

Figure 5. Examples of plug-in energy monitors with internal memory

GREENPRIZ wall socket and master module	NZR SEM 16+ USB	OMEGAWATT Enerplug micro logger
		
*Source : https://*www.kallysta.com/greenpriz/	Source : https://www.testoon.com/nzr-sem16usb-p-77600	Source : http://shop.omegawatt.fr/micrologger/63-micro-logger-

Table 8 provides an overview of the characteristics of different available solutions to measure energy consumption directly on an appliance.

Table 8. Main characteristics of different solutions to measure energy consumption directly on an appliance

	Integration period	Data capture	System with communication function	Advantages	Drawbacks
Display power meter (NZR SEM 16+; ZHURUI PR10)	Between 1 and 30 days	Direct reading	No	* Low cost * Easy to use * Reliability	* Manual data collection per meter * Limited level of analysis * Difficulty in reading the
"Smartplug (AWOX SmartPlug Plus)	Between 1 and 30 days	Display on a smartphone application (Bluetooth)	No	* Easy to read data	* Manual data collection per meter * Installation of an application * Manual data collection per meter
Wattmeter recorder (NZR SEM 16+ USB)	1 to 60min.	Display and download on PC (USB)	No	* 97 days of data storage at 10min. * Data extraction capability * Detailed level of analysis	* Requires a PC + software * 97 days of data storage at 10 minutes. * High cost
Wattmeter recorder (OMEGAWATT Enerplug micro logger)	1 to 60min.	Read and download on a PC (infrared)	No	* 455 days of data storage at 10min. * Data extraction capability * Detailed level of analysis	* Requires a PC + software * High cost

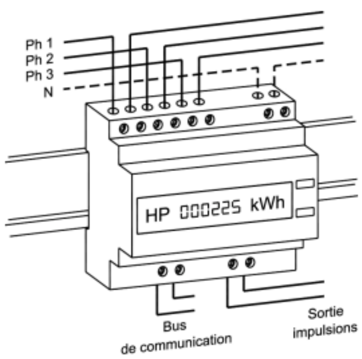
"Smartplug" recorder (GREENPRIZ)	15min. in visualization 1 hour in extraction	Display and download on PC (Bluetooth)	Yes	* Easy to read data * Possibility of data extraction *Can be connected to a communicating infrastructure	* Requires a PC + software * Installation of software * 40 days of data storage * Integration period not modifiable (15min.)
Wattmeter recorder (OMEGAWATT Enerplug LoRa logger)	1 to 60min.	Read and download on a PC (LoRa dongle)	Yes	* Detailed level of analysis *Can be connected to comm. infrastructure	*Requires an integrator for storage *Requires a PC + software * High cost

Source: authors' analysis

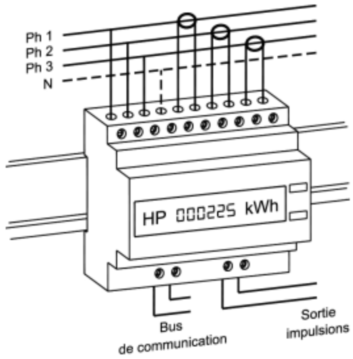
5.1.7 Circuit-level electricity monitoring (in the electrical panel)

Some household equipment is plugged directly in the electrical panel, such as the oven, ventilation, air conditioning, electric heaters, boilers and lighting. They should be monitored directly at their electrical outlet. There are two types of meters: those with direct connection and those with current transformers.

Figure 5b. Examples of direct three-phase connection (in series) and with current transformer



Direct three-phase connection (in series)



With current transformer (CT)

Source : RAGE Guide https://www.programmepacte.fr/sites/default/files/pdf/guide-rage-compteurs-capteurs-points-de-mesure-2015-07.pdf

5.1.8 Direct connection meters (in series)

They are used to monitor single and three phase feeders and must be installed by a qualified electrician. Their installation is not particularly difficult and their cost is relatively low, but there must be space available in the electrical cupboard. Most of these meters are limited to a display (mechanical or LCD) of the total consumed energy and a flashing indicator. Some meters have a pulse output or a Modbus or MBus output. The main drawback of this type of meter is that it requires a meter for each electrical outlet.

Figure 6. Examples of circuit-level energy monitors without internal memory

Counter with flashing meter indicator	Counter with pulse output	Meter with Modbus output	Meter with MBus output
iEM210 from Schneider 	General Electric MT+D1i32 	MM100LMOD from Polier 	PRO1MB by Polier 
Source : https://electgo.com/se_a9mem 2010	Source : https://www.elkjop.no/product/tjen ester-og-tilbehor/diverse-tilbehor/maler-digital-1-fas-1-mod-32a-it-d1i32-ge/39321	Source : https://www.domomat.com/39 000-compteur-modulaire-monophase-100a-modbus-affichage-lcd-polier-	Source : https://www.electrissime.fr/com pteur-electrique-modulaire-monophase-45-a-m-bus-certifie-mid-pro1mb-

5.1.9 Meters with current transformers

The current transformer (CT) meter consists of one or more current transformers (current clamp) and an integrator/concentrator. This type of meter has the advantage of being able to monitor several single-phase or three-phase feeders at the same time. Unlike direct connection meter, it requires special attention during the installation and configuration of the measurement channels: direction of the CTs (negative intensity); CT transformation coefficient; phase matching between voltage taps and intensity measurements (in three-phase). It should be noted that if only one of these points in any of the three phases followed is not fulfilled, the calculation of the total consumption will be erroneous and unusable.

Current transformers meters

There are 3 categories of current transformers meters: closed cores, separate cores (clamps) and flexible cores. Each of these three categories has different clamp sizes and transformation coefficients depending on the current intensity levels (Amperes) tolerated. The choice of clamps to use depends on the size and intensity levels of the departures to be monitored. It is important to note that with closed cores current transformers, it will be necessary to switch the whole electric system power off and to unscrew the wires in order to install the sensors. It is a more complicated, but more secure and reliable installation than separate clamps toroid systems.

Figure 7. Examples of current transformers

Closed clamps current transformer meter	Separate toroid current transformers	Flexible current transformers
LEG412004 from Legrand 	9TR06-00600 from SIREA 	SOCOMEC TF model 
Source : https://www.rexel.fr/frx/Cat%C3%A9gorie/Distribution-et-gestion-de-l%27%C3%A9nergie/Gestion-de-l%27%C3%A9nergie/Compteur-d%27%C3%A9nergie/Transformateur-de-courant-ferm%C3%A9-63A/LEG412004/p/70868275	Source : https://www.sirea.shop/produit/tore-ouvrant-100mv-monophase-modbus/	Source : https://www.socomec.fr/fr/p/capteurs-tf

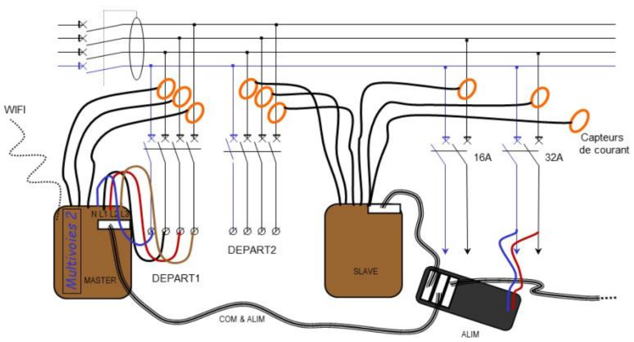
Integrators

Some integrators only display the index of the total consumption. Some models can also provide more information about the operation of the monitored appliance (instantaneous and maximum power, power factor, active, reactive and apparent energy, etc.). If some integrators are equipped with an integrated display, others (less expensive) need a smartphone or a computer as remote display. Some integrators can also be equipped with LoRA, WiFi, Mbus, ModBus or any other communication protocol. A very few systems are equipped with on-board memory, which considerably secures data acquisition and avoids the risk of communication problems. As an example, the OMEGAWATT MV2 system has a 64GB internal storage for current, active, reactive and apparent power, voltage, frequency and grid voltage events at an adjustable time step of 1 second, 3 seconds, 1 minute, 10 minutes and 2 hours.

Figure 8. Examples of integrators

Remote reading equipment		
EmonTx 	CURB  	IoTaWatt 
Source : https://guide.openenergymonitor.org/technical/emontx/	Source : https://ideaing.com/product/curb-home-energy-monitoring-system	Source : https://i.gzn.jp/img/2021/03/01/iotawatt/00.jpg

Direct readout equipment		
Wizer EM5 from Schneider Electric 	Squid EnOcean from EWATTCH  	Legrand eco-meter 
Source : https://www.elecdirect.fr/compteurs-d-energie-schneider/5398-schneider-compteur-rt2012-5-entrees-230v-mono-wiser-em5-5-tores-eer39000-3606480568695.html	Source : https://www.domadoo.fr/fr/suivi-energie/2859-ewattch-squid-sous-compteur-electrique-enocean-12-entrees-3770002148045.html	Spource : https://www.legrand.fr/pro/catalogue/41492-ecocompteur/pack-ecocompteur-modulaire-standard-compose-dun-ecocompteur-reference-412030-et-de-3-tores-fermes-60a-reference-412008

Embedded memory hardware
OMEGAWATT's Multichannel2  

Source : https://mv.omegawatt.fr/doc/notice_multivoies_fr5.pdf

5.1.10 Lampmeters

For specific monitoring of lighting electricity consumption, one solution consists in monitoring it directly from the specific outlets of the electrical panel.

This solution has two drawbacks: it requires the intervention of a qualified electrician and a single electrical outlet supplies most of the time several light circuits making it impossible to differentiate them.

Another solution that is simple to implement and allows monitoring by lighting circuit and/or by light point is to use a photosensitive resistor placed near the light source to follow.

Please note that this sensor is not an energy meter since it only records the date, time and duration of each change of state (on/off) of a light point. To obtain energy consumption, it is necessary to know the total power of the circuit. The risk is that a bulb is changed or broken during the measurement period, which can create a measurement error.

Lampmeters are not communicating systems.

Figure 9. Examples of light dataloggers

Stand-alone devices		Remote power and memory device
ENERTECH meter lamp 	UA-002 from HOBO 	LM 393 from RQG 
Source : ENERTECH	Source : https://www.onsetcomp.com/products/data-loggers/ua-002-64/	Source: https://electronicsinfra.com/product/ldr-sensor-module/

5.1.11 Alternative methods to estimate electricity consumption

Apart from the described dedicated amperemeters measurement methods, the electricity consumption of heatpumps can be also estimated from mapping it as a function of the rotation speed of the compressor.

Monitoring techniques for thermal applications

5.1.12 General information on the case of an individual gas boiler

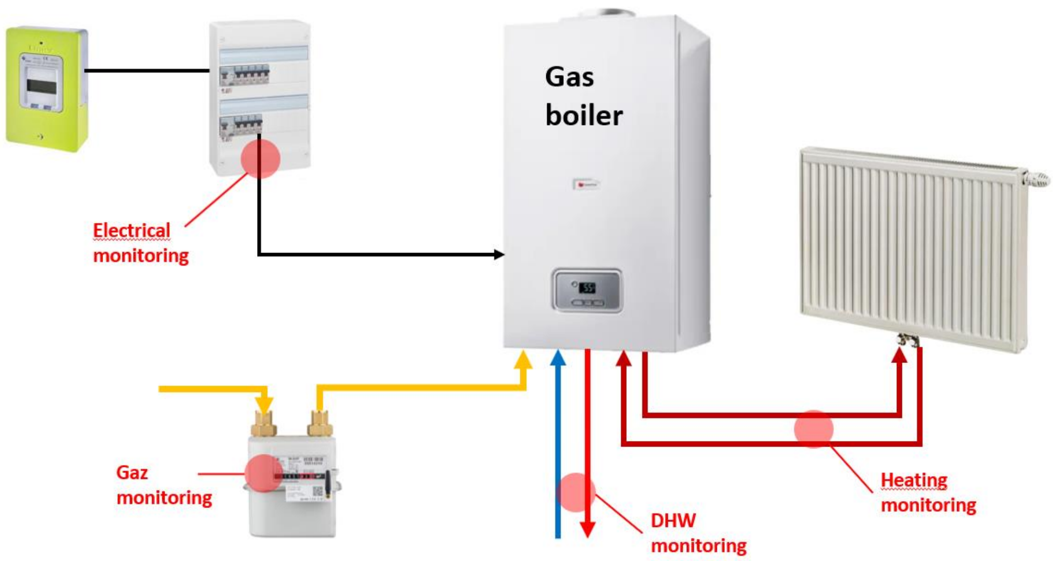
The monitoring infrastructure necessary to evaluate energy consumption and efficiency of a gas boiler is complex. It requires the following measurement points (Figure 10):

- The electrical consumption of the boiler taken at the electrical panel or directly at the boiler plug by a power meter. This measurement allows in particular to understand the operating cycles of the auxiliaries (burner, pump, etc.) and to be able to detect the operation of the boiler when there are several uses of the gas (for example cooking).

- The gas consumption of the dwelling. It represents the heat consumption in final energy (the average conversion coefficient of gas in kWhgas/m3 being given by the gas provider or obtained thanks to the gas invoices of the household).
    - NB: Be aware that in case gas is also used for other purposes such as cooking, an assumption will be necessary to extract the boiler use from the gas measurement. This is generally not a problem as major gas uses are heating and DHW, but it may affect the accuracy of the approach (Figure 11).
    - The estimation of the cooking consumption can be based on existing (seldom) measurement campaigns or be calibrated on gas data gathered in the dwelling when the boiler is off.
    - It is also possible to target only dwellings that do not have other gas uses than the boiler.

- The consumption of Domestic hot water (DHW) in useful energy, which is obtained by installing a heat meter at the boiler outlet, on the DHW network.
- The heating consumption in useful energy, which is obtained by installing another heat meter at the boiler outlet, on the heating network.

Figure 10. Monitoring infrastructure to evaluate energy consumption and efficiency of a gas boiler



Source: Authors' analysis

Measuring the efficiency of a boiler requires measuring its gas consumption as well as the thermal energy supplied at the output[25]. Several recent French measurement campaigns [25],[26] have shown that the annual efficiency measured in the field differs greatly from the values given by the manufacturers (lab tests). The difference is around 10-15% which is significant[26] (seasonal efficiency as defined for the Energy Label is

[25] Other simplified methods are also possible (e.g. estimate the gas consumption monitoring the boiler fan speed)

[26] It represents a gap of 2 classes of the Energy label

given at 90-95% on Gross Calorific Value -GCV- while the first feedbacks from measurement campaigns are rather around an average value of 77-82% on GCV).

This main difference between the claimed and measured performance could be mainly due to:

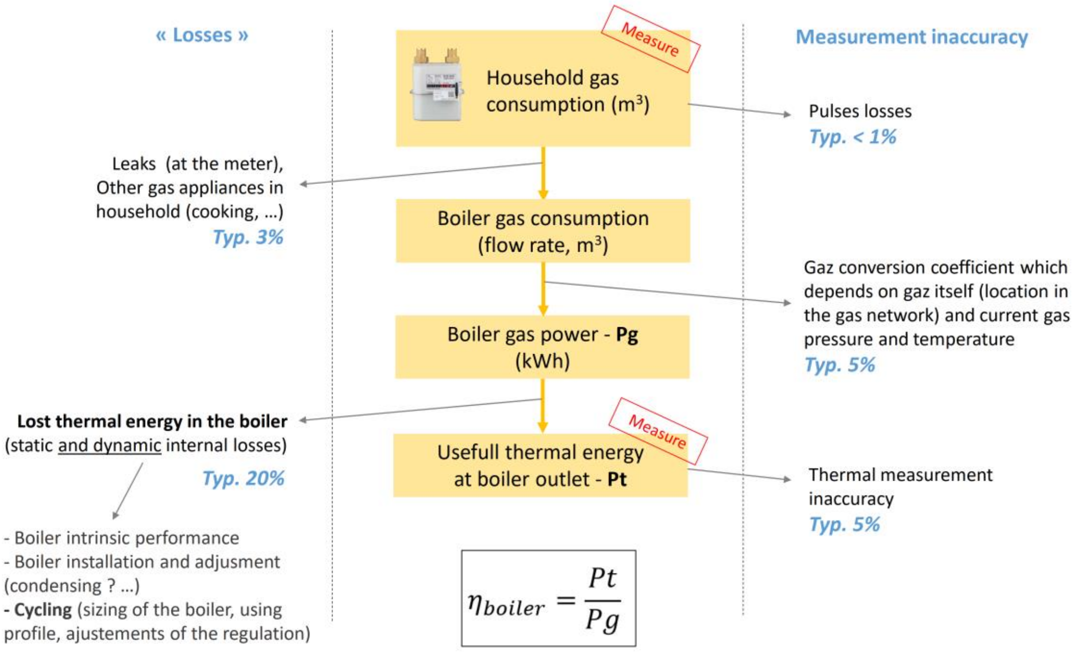
1. Boiler implementation conditions: flue gas condensation does not systematically occur for condensing boiler (because of the flow temperature setting, the circulator sizing, the type of terminal regulation, the installation balancing, etc.). More generally, combustion does not necessarily benefit from such fine adjustments as in a lab.

2. Heat demand profiles that very often present "cycling" phenomena that have the effect of increasing heat losses. The main effect is dynamic because it is linked to the heating of the boiler body at each warm-up period, which is not simulated by manufacturers when they give an efficiency at nominal or partial load, since claimed performances are measured in steady state.

3. Oversizing of the boilers, which increases the effects of point 2.

A major issue related to measurement of boiler thermal performances in households is the accuracy of the measured efficiency. Indeed, there are some unavoidable measurement errors due to complex monitoring infrastructure and field reality (very different from a lab). The measurement inaccuracies (gas conversion coefficient, thermal energy...) can reach 10 to 20% if the installation or the type of sensors are badly chosen (Figure 11).

Figure 11. Thermal losses and measurement issues involved in a boiler thermal performance monitoring.



Source: Authors' analysis

However, a compromise can be found between the cost of metrology, field constraints and the stated goals. The use of accurate heat meters (see section 5.1.16) and the choice of dwellings that do not have gas cooking should make it possible to evaluate annual and seasonal performances with a margin of error of about ± 5-10%, which can already provide valuable results for a large sample size, given the magnitude of the phenomena intended to be observed.

In the following paragraphs, the different components of the necessary monitoring infrastructure are described.

5.1.13 Gas meter

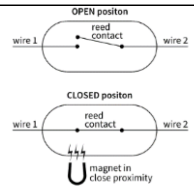
Unlike heat meters, household electricity meters, water meters and gas meters can only provide pulse information [27] (as opposed to ModBus or MBus output that provides an index). Since 2000 in France, gas meters are legally required to have a pulse output.

This point is important because it conditions the in-situ measurements:

- In case of failure of the datalogger that records the pulses, the information is lost for the duration of the failure (unlike an index recording, which at least allows to "save the sum of the consumption" that took place during the data gap).
- An index reading of the meter display at the beginning and at the end of the campaign is needed to guarantee the total amount of final energy consumed during the monitoring period.

Inside the gas meters there is usually a magnet located in the penultimate or last drum of the mechanical totalizer. It is this magnet which, when it passes through, switches on, for example, a magnetic reed contact NO (Normally Open) of a pulse emitter. The weight of the pulses depends on each individual gas meter. Generally, residential gas meters allow one pulse per dm^3.

Figure 12. Example of gas meter

 Principle of the pulse reader	 Example of pulse weight (magnet on penultimate drum-> 1 ipulse = $0.01m^3$)

Source: Authors' analysis

5.1.14 Pulse reader/transmitter

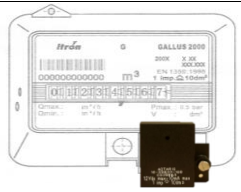
Pulse emitters are not supplied with the gas meter and there are many different types of emitters depending on the model and manufacturer of the gas meter. There are two main types of pulsers: those with a diameter of 4 or 6mm terminal block and those with a binder connector.

A few manufacturers also offer wireless transmitters (such as NAS LoRaWAN pulse reader).

In Belgium the new digital meters allow the reading and logging of gas (and electricity consumption) with a dongle attached to the so called "P1 port". The 30€ dongle comes with an app for the end user.

[27] A pulse output in a meter represents a defined amount of flow passing through the meter (gas, water heat or electricity meter). As one pulse equals one turn of the wheel, one pulse is equivalent to the amount of flow that caused that turn of the sensor wheel, like a turn on a dial in front of the meter.

Figure 13. Examples of pulse transmitters

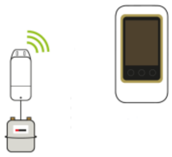
Terminal block transmitter	Binder connector transmitter	Wireless transmitter
		

Source : https://www.compteur-energie.com/gaz-emetteurs-impulsions.htm

5.1.15 Pulse recorder

Once the right pulse reader/transmitter has been associated with the gas meter, it is possible to record and store the data over the requested integration period. Both a stand-alone logger or a wireless interface can be used as a gateway to an integrator (radio) or an external server (LoRaWAN).

Figure 14. Examples of pulse recorders

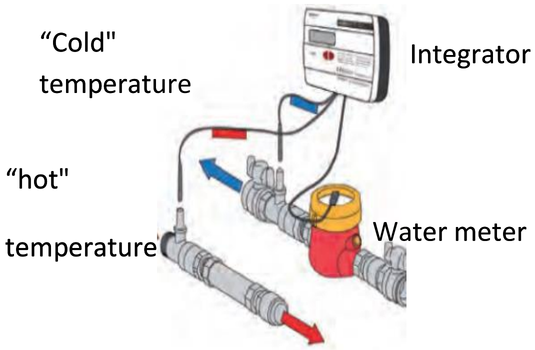
OMEGAWATT pulse recorder	Sensing LAB's LoRaWAN interface	TYWATT 5100 from DELTADORE
		
Source : https://mv.omegawatt.fr/doc/notice_wirelesslogger7.pdf	Source : https://sensing-labs.com/lorawan-devices/sl-tester-commissioning/	Source : https://www.deltadore.fr/domotique/suivi-consommations/accessoires/tywatt-5100-ref-6110029

5.1.16 Heat meter

A heat meter consists of the following components (see Figure 15)

- a water meter (or flow meter);
- a "hot" temperature sensor;
- a "cold" temperature sensor.

Figure 15. Schematic representation of a heat meter.



Source: ENERTECH

In addition, an integrator computes these three parameters into thermal energy and displays the measured, calculated and stored data.

Note that if one of these three metering devices is wrongly positioned or wrongly calibrated, inaccurate or defective, the conversion into thermal energy will be erroneous and unusable, hence installation of the heat meters should be done with great care in order to make sure that the collected data are correct.

In the following paragraphs each component of a heat meter is detailed.

Figure 16 : Examples of heat meters

Mechanic		Static	
Hydrocal M3 	Microclima Coax 	Skarky 774 	Multical 303 
Source : https://www.bmeters.com/fr/produits/hydrocal-m3/	Source : https://www.maddalena.it/en/product/microclima-u/	Source : https://www.diehl.com/metering/fr/produits-services/comptage-de-lenergie-thermique/sharky-774-compact-fr/	Source : https://www.kamstrup.com/fr-fr/solutions-chauffage/compteurs-chauffage/meters/multical-303

5.1.17 Water meter

There are 2 different categories of water meters:

- "Mechanical" (propeller and turbine),
- "Static" (ultrasound and electromagnetic).

The first category has the advantage of being less expensive but it requires a clean liquid (no mud). Beyond the cost and the cleanliness of the flow, the choice of the water meter must take into account:

- The needs regarding the nominal, minimum and maximum flow rate in relation to the actual flow rate of the installation
- The constraints of space and condition of implementation of the meter in relation to the constraints of the hydraulic installations to be monitored.

Most water meter installations require the intervention of a plumber/heating specialist as it is necessary to integrate them into the existing hydraulic manifold.

There are also non-intrusive ultrasonic flowmeters (clamp on) which do not require service interruption or the hydraulic installation to be modified. Although the installation of these meters is rather simple, there are many constraints to be taken into account and the integrator must be accurately set in order to obtain a reliable measurement.

Figure 17. Examples of non-intrusive heat meters

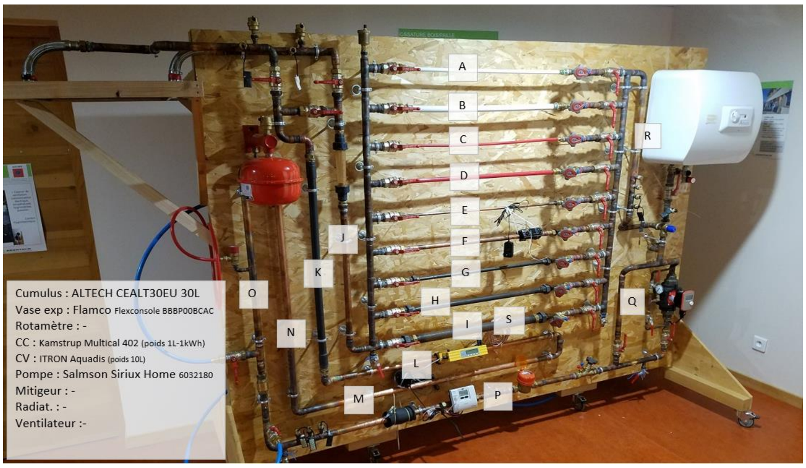
KEYENCE FD-Q	MICRONICS U1000	SITRANS FST020
		
Source : https://www.keyence.fr/products/process/flow/fd-q/	Source : http://www.micronicsdebitmetres.com/docs/Micronics-U1000-French-Issue%202.1.pdf	Source : http://www.siemenstransmitter.com/product/SITRANS-FST020-clamp-on-ultrasonic-flowmeters/1514

Intrusive flow meters (i.e., requiring the intervention of a plumber, for the installation of the flowrate measurement and the temperature probes) are generally more accurate than non-intrusive meters (Table 9).

We only know one non-intrusive product (flow meter FD-Q from Keyence) that has comparable accuracy and compactness to intrusive solutions. It is especially fitted for DHW measurement as it can be precisely calibrated by drawing water and measuring volume from the tap.

The addition of a calibration phase on a test bench (Figure 18) enables the use of non-intrusive Keyence FD-Q flow meters for heating energy consumption of a boiler with an accuracy of ± 5-10%.

Figure 18. Enertech test bench for flow meters.



Source: Enertech

5.1.18 Temperature sensors

Some heat meters are pre-equipped with temperature sensors and an integrator that calculates power directly. In some cases (e.g., KEYENCE FD-Q and SITRANS FST020), temperature sensors must be added to the water meter in order to determine the power using the following formula:

P = qv × 1.16 × ΔT   with

- P in [kW]
- qv in [m³/h]
- 1.16: Product of density and heat capacity of the water in [kWh/m³.K] at specific water temperature
- ΔT: Temperature difference received or lost by the water in [K]

Surface and immersion temperature sensors can be found on the market.

While surface probes have the advantage of being non-intrusive, they have the drawback of being sensitive to stratification and disturbance. Beyond the constraints of installation and location, the choice of temperature sensors must include consideration of the useful temperature range in relation to the theoretical temperature of the circuit being monitored and the level of accuracy.

Immersion probes must be installed by a plumber or a heating specialist.

Figure 19. Examples of temperature probes (surface and immersion)

Surface temperature probes		Immersion temperature probes	
THERMASGARD ALTF1 	THERMASGARD ALTF2 	*Kit DGSF50* 	EFET-PT100-50-2L Kit 
Source : https://ses-automation.fr/_catalogue/_fiche/ALTF1.pdf	Source : https://ses-automation.fr/_catalogue/_fiche/ALTF02.pdf	Source : https://www.girpi.com/produit/kit-sonde-pt100-doigt-de-gant/	Source : https://www.thermatec-shop.fr/destockage-sondes/829-pt100-avec-doigt-de-gant-inox-12-g-x-50-mm.html

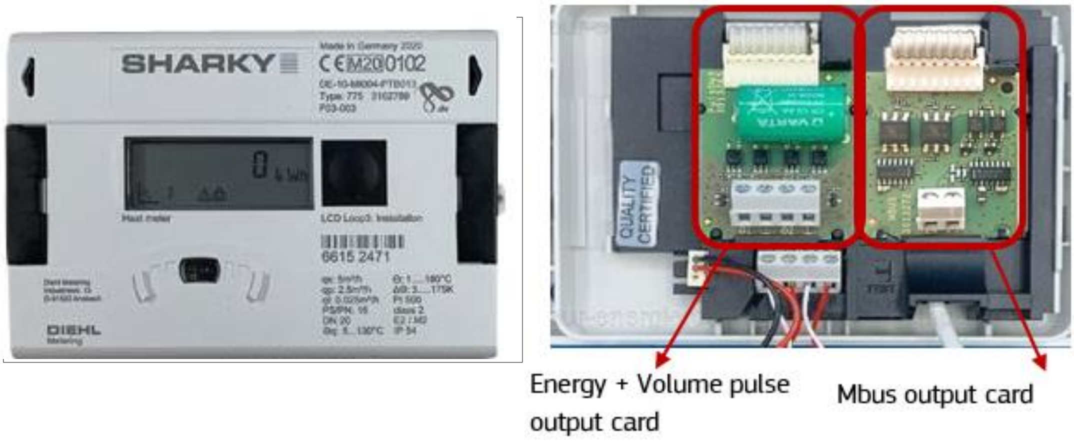
5.1.19 Integrators

Integrators are either mains-operated or battery powered. They are fitted with communication modules (pulse outputs, MBUS, ModBus, LON, etc.) or simply with a display without the possibility of downloading data. These last models only allow a monthly index storage over a year.

Communication modules facilitate the centralisation and automation of data collection. These modules, often optional, must be carefully chosen according to:

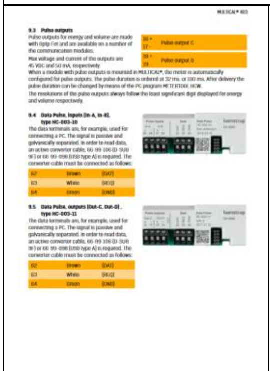
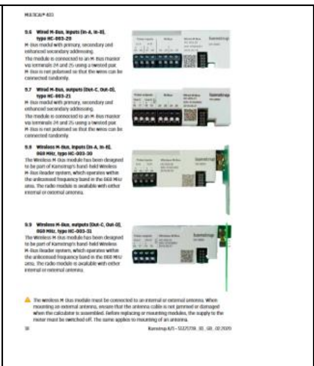
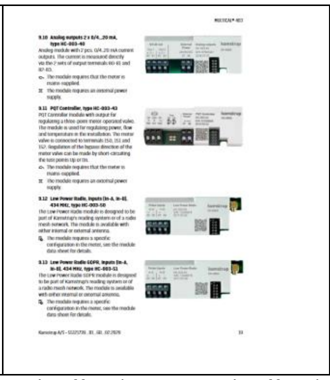
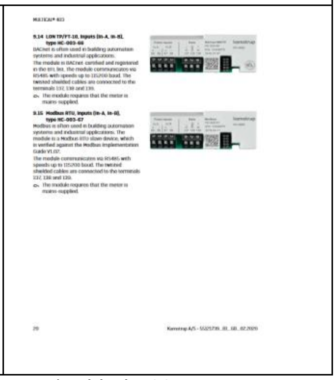
- The required data (energy/volume/temperature/other),
- The data resolution (1kWh/0.1kWh/0.01kWh/...)
- The desired communication protocol.

Figure 20a. Example of integrator



Source : https://www.diehl.com/metering/fr and ENERTECH

Figure 20b. Example of an integrator for heat meter

Communication module for Multical 403, 603 and 803			
			

Source: https://www.kamstrup.com/fr-fr/solutions-chauffage/compteurs-chauffage/meters/multical-403

As for gas meters, the data from heat meters will be recorded thanks to a pulse recorder (see section 0).

5.1.20 Summary of heat metering solutions in dwellings

Table 9 summarises the main characteristics of intrusive and non-intrusive solutions suitable for heat metering.

Table 9. Summary of the main characteristics of two solutions for heat measurement in households.

Heat meter	Accuracy for heating	Accuracy for DHW	Risk associated to the installation (leak, etc.)	Compa-city	Output	Indicative Approxima-tive cost supplied/ installed	Retrieval at the end of the meas. camp.
Intrusive ultrasonic heat meter with submerged probes	< 3%	< 3%	YES	Compact	Pulse (heating, flow) or index (modbus)	500€[28]	NO
Non-intrusive heat metering Keyence FD-Q + surface probes	< 15% without calibration < 5% with calibration on test bench	< 3% with calibration on field	NO	Very compact	Pulse only (flow)	350€[29]	YES

Source: authors' analysis

Non-intrusive heat metering has many advantages over intrusive metering (simplicity of installation, minimization of the risk of leakage, recovery after campaign, etc.) provided the right choice of sensor and its calibration on a test bench to reduce the measurement error.

Monitoring techniques for other types of data

5.1.21 Temperature, humidity

There are a large number of devices available on the market for displaying and/or recording the temperature and indoor humidity. There are several technologies to download the measurement data (Bluetooth, infrared, USB, SD card, etc.)

Beyond the price, it is the technical characteristics of the device that will make the difference between them, such as the level of precision, resolution, measurement rate, internal memory capacity, power autonomy, communicating abilities, etc.

[28] Without taking into account the time needed to discuss with the plumber/heating specialist.

[29] Purchasing cost of the sensor 800€ with amortisation over 4 years + 1 hour installation/deinstallation time + temperature probes.

Figure 21. Examples of temperature monitoring solutions

SHT31 from SENSIRION	RHT-Air from NOVUS	THB 40 of PCE	WATH by OMEGAWATT	174H from Testo
				
Source : https://sensirion.com/products/catalog/SHT31-Smart-Gadget/	*Source :* https://www.novusautomation.com/site/default.asp?Idioma=33&TroncoID=090617&SecaoID=611135&SubsecaoID=801146&Template=../catalogos/layout_produto.as	*Source :* https://www.pce-instruments.com/french/instruments-de-mesure/mesureur/thermohygrom%C3%A8tre-pce-instruments-thermohygrom%C3%A8tre-pce-thb-40-det_173769.htm	*Source :* http://shop.omegawatt.fr/wirelesslogger/51-capteur-sans-fil-amplifie-temp-hygro-interne.html	https://www.testo.com/fr-FR/mini-enregistreur-de-temperature-et-d%27humidite-testo-174-h/p/0572-6560

5.1.22 Weather data

Meteorological data can provide direct explanations for changes in operation and behaviour or even changes in consumption. Weather stations can include more or less sensors (temperature, humidity, irradiance, wind speed and direction, rainfall, atmospheric pressure and pollutant, ultraviolet, etc.). The necessary level of information should be defined prior searching for a weather station in order to avoid the multiplication of costly measurement points.

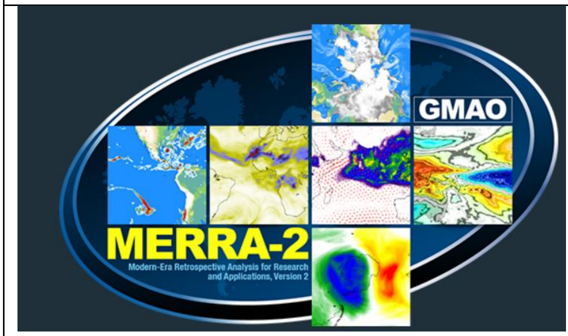
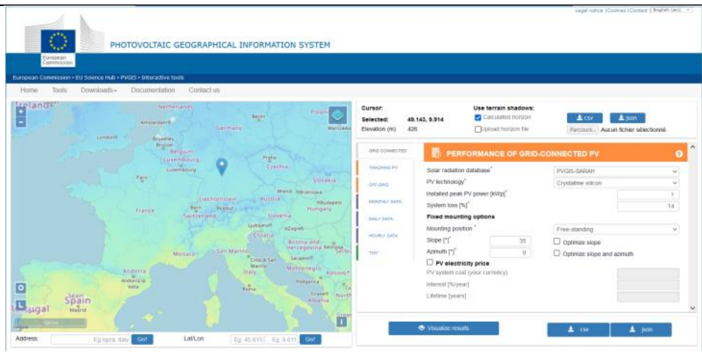
The installation of a weather station with sensors will be all the more complicated as there will be measurement points. If the weather station contains a temperature probe, it has to be installed in the shade, between 1.5 and 2 meters above the ground (preferably above a vegetated ground) or in a shelter located in full sun as well as away from an element with high thermal inertia (concrete slab). For a rain gauge, the station should be placed away from buildings or trees. For an anemometer, the station must be installed more than 2 meters above the ground (if possible 10 meters) and avoid proximity to any obstacle that could disrupt air circulation.

Figure 22. Examples of weather stations

Individual weather station	
WS-2902C from Ambient Weather	Vantage Vue from DAVIS
	
Source : https://ambientweather.com/ws-2902-smart-weather-station	*Source :* https://www.davisinstruments.com/products/vantage-vue-wireless-weather-station?variant=39619860758689

Another much cheaper (or even in some cases, free) solution to collect weather data relies on obtaining meteorological data files, via the meteorological services of each country (DWD in Germany, Météo-France or Météociel in France) or by meteorological database like MERRA which provides many meteorological data from all over the world for free .Note that PVGIS offers real solar data but only from 2005 to 2016.

Figure 23. Examples of meteorological database services

<table>
<tr><td colspan="2">Meteorological database services</td></tr>
<tr><td>MERRA 2 from the NASA</td><td>PVGIS from EU science HUB</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>*Source :* http://www.soda-pro.com/web-services/meteo-data/merra</td><td>*Source :* https://re.jrc.ec.europa.eu/pvg_tools/fr/tools.html</td></tr>
</table>

5.1.23 Other parameters

It could be valuable to be able to monitor other explanatory parameters that allow to specify the operating conditions of household appliances like:

- The selected program (washing-machines, dish washers, tumble driers, ovens, hobs, range hoods),
- The thermostat setting of a refrigerator/ a freezer/a boiler/a water heater,
- The amount and the type of laundry that is washed/dried, food that is cooked/stored in a fridge,
- The settings that are selected for a television or a computer

There is currently no way to automatically measure them precisely, but we know that manufacturers are already collecting data from smart appliances (IoT); some of these information could be recorded by the user (e.g. with a logbook or a survey), but with a low reliability. Data collection time intervals

The first monitoring campaigns were made with one single cumulative measurement over the total monitoring period. It was still the case with quite recent programs like Spahousec (2011, see Table 3) or "Verbraucher messen nach" (2015, see Table 2). The reason of this choice is the ease of installation and the low cost of the measurement systems (see section 5.1.4). Later, data were recorded every 15, 30 minutes or 1 hour ("Cuisson" 2014-2016, see Table 2). Between 2000 and recent years, almost all programs have been made at a 10 minutes time step (see table 3) which is the time step chosen by the French Electricity supplier EDF in France. 10 minutes is a good compromise between precision and necessary data storage. It allows to study not only the total electricity consumption of an appliance but also its power demand at least for appliances with reasonably long operating cycle.

As shown in Table 3, the most recent programs are mostly done at a 1-minute time step. It is made possible thanks to the improvement of monitoring systems (increase of the data storage capacity) and data analysis (big data analytics). It allows to go even further in the knowledge of end-uses, for example analysing more accurately the operating cycles and the power demand. But 1 minute time step does not still offer the opportunity, for example to analyse transient at compressor start-up which would require a 1 second recording rate. This would be useful in Non-intrusive load monitoring (see section 5.8).

The smaller the time step the more accurate but also the more data to collect, to store or to transmit and of course to analyse.

Control of the data collection

A communicating infrastructure is likely to malfunction at the beginning and over time. It is therefore essential that someone (internally or an external company) maintains it. Data quality insurance and quality control is only possible through a regular and thorough inspection of all incoming metering data. With communicating meters, a control procedure needs to be continuously operated in order to guarantee the consistency of the data. Three steps of verification need to be implemented:

- Initial checks (at installation of the metering devices),
- Daily checks,
- Longer-term checks.

As an example, the control procedure applied in the project Panel Elecdom [3] is detailed in Table 10.

Table 10. Data control procedure applied in the project Panel Elecdom [3]

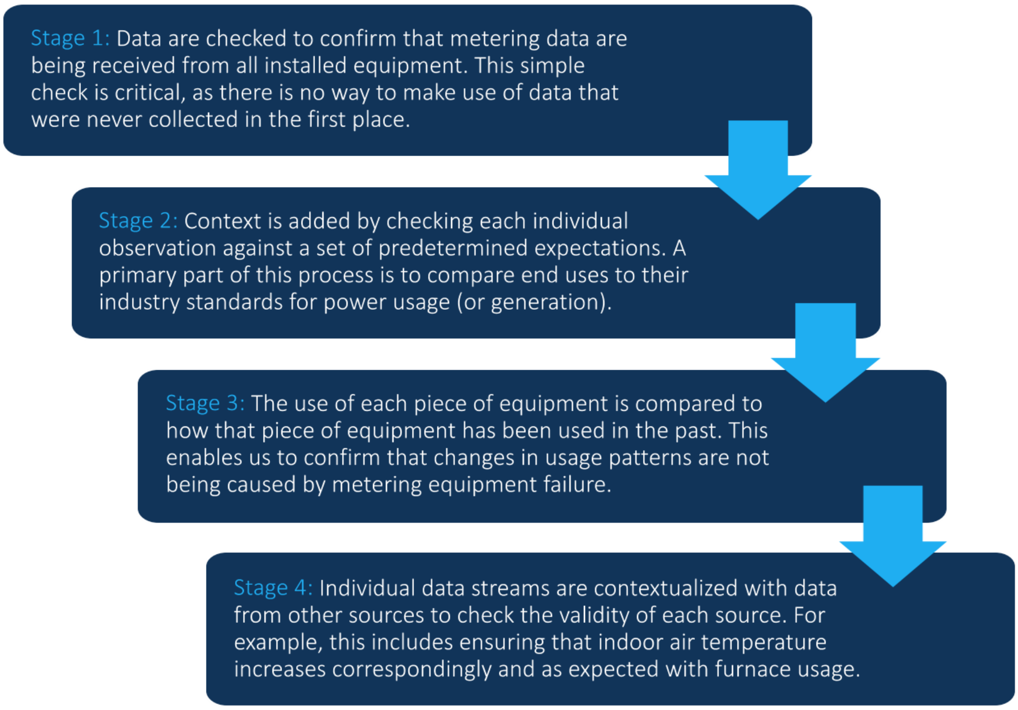
	Initial checks	Daily checks	Longer-term checks
When?	Within 24 hours of instrumentation (Ideally on site)	Every day (automatic)	Every 6 or 12 months
Checkpoints	Review the collected first data to avoid possible meters failure Consistency manually checked Check for time synchronisation	No data during the last 24 hours “Holes” in the data Presence of 0 for a use that is supposed to be permanently on (or on temperatures)	Check of the battery level of the metering device Check of the clock
Action	Modification/Change of the metering devices	Generation of an alert and a corrective action if necessary	Battery change and time resynchronisation to compensate if necessary

Source: Enertech [3]

A second example of quality assurance process is given in

Figure 24. This 4-stage approach is employed in the HEMS project [17].

Figure 24. Data quality control process of the HEMS project



Source: HEMS project [17]

Cleaning of the data files

The collected data undergo the following consecutive steps to get them ready for the analysis:

1. Collection of raw data: raw data are received from the meter measurement, possibly via concentrator and data platform, for example in CSV or TSV format.

2. Plausibility and consistency check via visualization. This step enables checking whether the data are coherent to what they measure. When a meter sends aberrant data, it should be deleted. Usually, this step is done manually.

3. In the rare cases where data gaps are significant, interpolation (using a method appropriate to the use concerned) can be performed.

4. The resulting clean data are suitable for the final stage of analysis.

Data storage, display and processing

5.1.24 Database software

In order to easily access, process and graphically display the data, it is necessary to create a database from the original data files. The different actions on the database (writing data or selective reading) can be done via:

- the SQL language which is the most common and proven standard, used by numerous data scientists,
- NoSQL languages which are more recent; they have been developed by database software providers to cover their specific needs.

Many database formats exist, each with their own specificity in terms of ease of installation, use and performance (in writing and reading). They can be generalist or for example specific to time series, which are the format of the in-situ measurement data. Table 11 provides a list of the most popular generalist and time series database software.

Table 11. Most popular generalist and time series database softwares (in alphabetical order)

Generalist database software	Time series database software
• Elastic search: https://www.elastic.co/elasticsearch/ • MariaDB: https://mariadb.org/ • Microsoft Access: https://www.microsoft.com/en-us/microsoft-365/access • Microsoft SQL Server: https://www.microsoft.com/sql-server/ • MySQL: https://www.mysql.com/ • Oracle Database : https://www.oracle.com/database/ • PostgreSQL: https://www.postgresql.org/ • SQLite: https://www.sqlite.org/index.html	• Graphite: https://graphiteapp.org/ • InfluxDB: https://www.influxdata.com/products/ • OpenTSDB: https://opentsdb.net/ • Prometheus: https://prometheus.io/ • TimescaleDB: https://www.timescale.com/

Source: authors' analysis

The generalist database software has the advantage of being accessible by a larger number of users than specific time-series database software. Furthermore, they allow to store not only time series but also other types of information, like maintenance operations, appliance characteristics, answers to questionnaires, etc. On the other hand, time-series database software is optimised for this particular use and therefore more efficient.

In summary, data scientists will first go for the software they are used to work with. However, if there is a very large volume of data with demanding applications (real time display for example), one should use time-series databases. If there is a lot of other non-temporal information to be stored, the best choice will be generalist databases. Another option could be to manage two databases in parallel (one for each type of data).

5.1.25 Data display and processing

Data display and processing can be done with in-house developed software or through the use of existing tools like (non-exhaustive list)

- Chronograf (pour InfluxDB) : https://www.influxdata.com/time-series-platform/chronograf/
- GNU Octave: https://gnu.org/software/octave/
- Grafana: https://grafana.com/grafana/
- Julia: https://julialang.org/
- Kibana (for Elastic search): https://www.elastic.co/products/kibana
- Matlab: https://www.mathworks.com/products/matlab.html
- Microsoft Excel : http://products.office.com/en-us/excel

- Scilab: https://www.scilab.org/
- Scipy: https://scipy.org/

The choice of the software first depends on the data scientist preferences. Chronograf, Grafana and Kibana have been designed to display data in a web browser while GNU Octave, Julia, Matlab, Scilab and Scipy are scientific programming languages of which one of the features is data visualization. Excel is the simplest but the most limited solution which makes it possible both display and processing without the need for programming.

Metered data associated with engineering models (NILM)

The previously described methods to monitor individual end uses are intrusive to the building and rather expensive to implement. Non-intrusive load monitoring (NILM) technologies are an alternative which have the potential to offer a low-cost, scalable method for acquiring end-use data. Several comprehensive literature reviews of the research and development of NILM technologies have been presented in the literature [27].

NILM consists of measuring electricity consumption using a smart meter or a dedicated device (usually placed in the panel board) and patented algorithms. It relies on a single point of measurement; no extra equipment is necessary. In a house, there are a broad range of household appliances and many of them can behave very similarly from an electrical point of view. The general electricity consumption corresponds to the overlap of many signatures of appliances and in order to get the contribution of single appliances, they need to be separated. Discerning the most relevant and informative features is crucial for any NILM application whose performances depend on the household appliance signature uniqueness [28]. In the field of NILM, performance evaluation can be conducted on real-world aggregate signals (provided by smart meters for example) or artificial superpositions of individual load signals (denoised aggregates)[30]. Load disaggregation algorithms provide significantly better performance on denoised aggregate signals for all types of appliances mainly due to the fact that the signal is less complex. Complexity in real-world aggregate signals increases with the number of unknown or untracked loads [29]. NILM vendors currently face significant challenges with identifying and inferring energy consumption of single end uses. Monitoring of individual end uses thanks to NILM technology has not proven so far to perform at the levels desired for relevant use cases [30],

As an example, the American Pacific Gas and Electric Company launched in 2015 a five months' test to assess and compare the current analytical capability and accuracy of three different electricity disaggregation products [31]. In this test, data from NILM products were compared to direct measurements of electric end-uses in six homes (see Figure 25). The conclusion is disappointing: the three products mis-estimated by more than a factor of two for a large number of significant end-uses. The accuracy of NILM systems at appliances' level is today still not proven. In any case, it varies from one appliance to another.

Most disaggregation vendors do not publicly publish their accuracy statistics, and often have little incentive to participate in third-party studies if the results are to be made public. Apart from the above-mentioned study, the only other organisation who have performed such comparisons is the Electric Power Research Institute (EPRI). But their recent reports are not publicly available free of charge. Due to this lack of relevant proof of accuracy, it is necessary to run more field tests of NILM systems in real houses before any massive roll-out. This technology is still maturing. Product advances are still needed to improve performance.

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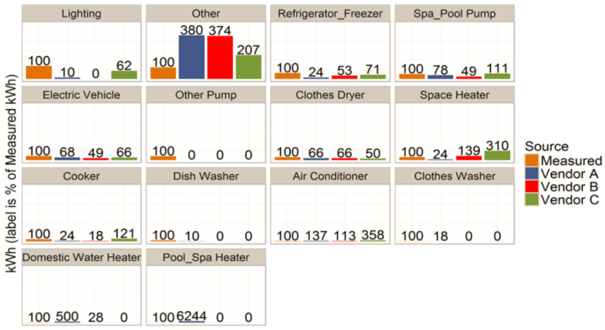
[30] Artificial superpositions of individual load signals (denoised aggregates), is a data analysis technique that finds the right combination of concurrently active appliances that minimizes the difference between aggregate signal and the sum of power demands. In this way, it can be estimated which appliances are operating at the same time and extrapolating their energy consumption (see also https://arxiv.org/pdf/2008.10985v2.pdf)

Figure 25. Percent of Measured by End Use (all Test Sites -December 2014 thru April 2015) of the NILM American Pacific Gas and Electric Study



Source: NILM American Pacific Gas and Electric Study [31]

Furthermore, as the most accurate solutions require higher frequency input data, data provided by utilities at large time intervals (15, 30, 60 minutes) are not suitable for capturing precise electricity consumption data at appliance level. The User port of the smart meter (P1, S1) could be a promising solution in the future as it requires no installer. However, the resolution of the provided data have to be sufficiently high. It seems that it could be the case with Belgian smart meters as they are quite recent, but it is not the case with other older concept EU smart meters, e.g. the French Linky smart meter. Linky "standard" serial port provides apparent power (VA) - not active power (W) - and cumulative energy given in Wh. With this resolution, a power of 3600W during 1 second is needed to "see" 1 Wh which does not match NILM prerequisite. It means that with such a low resolution it is impossible to detect low-power appliances, i.e., the majority of the household appliances Furthermore, current research done on NILM often uses data resolution below one second in order to identify the start-up peaks (fridges, heating devices, water heaters…). It can be concluded that using the user port of the smart meter for NILM products is a promising solution on a next generation of smart meters if the necessary prerequisites (data resolution) are imposed. Thus, until then, the intervention of a certified electrician would in any case be necessary to install the dedicated high frequency meter and gateway to collect and transmit the data. Considering this information, it seems still wiser to install sub-metering systems that are more mature technologies[31].

[31] Confirmed by an email exchange with Oliver Parson Senior Data Scientist – NILM expert (18/12/21)

6 General organisation of in situ-measurement programs

Metering length

In the previous end-use measurement programs (see Table 2 and Table 3), there are globally two different strategies regarding metering length:

- One full-year or more (HEEP2, HEM, Panel Elecdom), which is the optimum as it is possible to capture seasonal variations, it is expensive (as it requires a large number of monitoring devices), but would be necessary for heating applications;
- Around one month (Remodece, "Werbraucher messen nach", HESCA), which allows a greater number of households to be covered in a shorter time period. It also limits the number of monitoring devices needed, thus the cost, by using the same monitoring equipment for several households.

Some programs (Sweden, Intertek, SPAHOUSEC, Eureco) are a hybrid version with most households monitored over a short period and a small sub-sample monitored for a full-year. Correction factors are then applied based on the long duration measurements.

Monitoring strategy

The study objective is to elaborate a methodology for single products but different strategies could be drawn up to reduce the overall cost and to ease the organisation of in-situ measurements. To this end, it should be possible to monitor several appliances in a same household either at the same time or one after another (in order to limit the number of necessary monitoring equipment). The idea behind is to use the same sample to cover several household appliances.

On site Inventory and questionnaire

Meter data collection should in any case be accompanied by information about the household, the equipment features, its usage and the building. It is necessary to add at least an inventory of features of the surveyed appliances and a questionnaire compiling household specific information (demographics, attitudes, etc). The list of relevant information should be tailored for single appliance. Here are some examples of data to be collected (non-exhaustive list):

- Household
    - Number of occupants
    - Age of the occupants
    - Occupancy pattern
    - Income or profession or socio-professional category
    - Level of energy-awareness ?

- Appliance features (should be accompanied by pictures of the appliance in its environment, control panel and its dataplate)
    - Brand
    - Model
    - Purchase year[32]

32 Asking householders, the age of appliances is much less reliable, as respondents tend to provide superficial estimates that exaggerate ages like 5 or 10 years. Asking the year of purchase allows people to think of events that occurred at the same time (e.g., age of kids, moving, getting married etc), which is

    - Energy label information (if available), including EPREL reference if available
    - Technical features (volume, size, technology, connected object)
    - Settings (thermostat, brightness, energy saving mode, spin speed…)
    - Location within the house/flat - heated room-non heated room- (kitchen, basement, living room…)
    - Installation: built in, next to a cooking appliance…
- Building and electrical installation
    - Type (flat/house)
    - Living area
    - Electrical installation (contract power, smart meter)
- For gas boilers
    - Building envelope characteristics
    - Type of heating transmitters
    - Building energy class (e.g. kWh/m2*y)
    - Degree days
- Usage:
    - Program(s) used

These data are of course essential to analyse the electricity consumption of the appliance itself but they will also be very useful to give a clear overview of what appliances are really on the field and in this way to take a critical look to the parameters (assumptions) fed into the models (like Ecodesign Impact Accounting, see section 0). A lot of information about household data collection can be found in the Australian Residential End Use Monitoring Program [33]. An example of additional features to record taken from this report is given in Table 12.

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generally a lot more accurate. The year of purchase is required in order to 'get a feel' for the age of these devices (which can influence energy consumption), and also to help cross-matching of the appliance (in order to obtain accurate energy labelling information).

Table 12. List of standard additional features to record by appliance type

Appliance	Feature No. (see Attributes 16-20 for Appliances in Table 4)	Options/Data Type
AC	1. Rated Output (W) 19. Energy Label CEC Cool 20. Energy Label CEC Heat 21. Serial Number	1. Number 2. Number 3. Number 4. Text
Clothes Dryer	1. Capacity (kg) 22. Energy Label CEC 23. Serial Number	1. Number 2. Number 3. Text
Clothes Washer	1. Capacity (kg) 24. Energy Label CEC 25. Water Label (L/Wash) 26. Serial Number 27. Technology	1. Number 2. Number 3. Number 4. Text 5. Drum/vertical axis/twin tub/other
Computer – Box/Home Entertainment Box	1. Network Connection	1. None/LAN/Wifi/3G
Computer – integrated/Laptop/ Tablet (eg iPad)	1. Screen Size (cm) 28. Network Connection	1. Number 2. None/LAN/Wifi/3G
Computer Monitor	1. Screen Size (cm) 2. Technology	1. Number 2. LCD/CRT
Dishwasher	1. Capacity (place settings) 2. Energy Label CEC 3. Water Label (L/Wash) 4. Serial Number	1. Number 2. Number 3. Number 4. Text
Freezer	1. Group 2. Energy Label CEC 3. Serial Number	1. 6U/6C/7 2. Number 3. Text
Games Console (ALL)	1. Network Connection	1. None/LAN/Wifi
Printer (ALL)	1. Link Type	1. Parallel/Serial/LAN/Wifi
Radio	1. Technology 2. Network Connection	1. Digital/Analogue 2. None/LAN/WiFi
Refrigerator	1. Group 2. Energy Label CEC 3. Usage Ranking 4. Serial Number	1. 1/2/3/4/5T/5B/5S 2. Number 3. Primary/Secondary 4. Text
Television (ALL)	1. Screen Size (cm) 2. Technology 3. Network Connection 4. Usage Ranking 5. Serial Number	1. Number 2. CRT/LCD/LCD(LED)/Plasma/OLED 3. None/LAN/Wifi 4. Primary/Secondary (n^{th} TV) 5. Text

Source: [32]

7 Personal data management

Regulation (EU) 2016/679, the EU new General Data Protection Regulation (GDPR), regulates the processing by an individual, a company or an organisation of personal data relating to individuals in the EU[33]. It came into force in May 2018. It is very protective and provides every person free control over his or her personal data, under certain conditions. Data is essential material for scientific work and personal data is part of this material. Such data need to be protected as much as they need to be used, reused or disseminated according to the organisational and operational principles of scientific research and in compliance with all regulations on the protection of privacy [33].

What are personal data for in situ measurement program?

Personal data means any information that makes it possible to identify a living person directly or indirectly (Article 4 of the GPDR):

- Directly identifying data: surname, forename, address, etc.
- Indirectly identifying data: a telephone number, or cross-referencing information.

Energy consumption measurements can be used for guessing the data subject habits, creating a personal behaviour profile, deducing personal and socioeconomic information, or guessing the presence, absence or current activity of the residents. Therefore, they can be considered personal data in the meaning of the article 4 of the GDPR [34].

Personal data can be managed in different manners:

1- Data pseudonymization: it consists in separating directly identifying data (for example surname and forename) from other non-identifying data (for example, by assigning numbers to persons thus avoiding disclosing their surname, but by keeping a correspondence table to trace the identity of the person).
2- Anonymised data: this irreversibly removes the link with personal data. If the identification of a person is no longer possible the GPDR does no longer apply.

In principle, the processing of personal data must have a fixed period of time, in relation to the fulfilment of the purpose for which they have been collected. The GDPR states that this data storage period is set at the «strict minimum», at the end of which normally the data must be archived in accordance with the regulations on public archives. Nevertheless, the GDPR also sets out that data may be kept for longer periods of time when they are processed «for archiving purposes in the public interest, for scientific [...] research, or statistical purposes» (Article 5 of the GDPR).

In case of in-situ measurements personal data will first be pseudonymised. Indeed, they need to be available until the end of the analysis process (in order to be able to contact participants to get potential additional information). They will then be stored in an anonymous form (GDPR no longer applies).

It would be key that the EPREL[34] registration number of the model is among the data logged for each appliance, to be able to compare the recorded parameters, including efficiency, to the standardised one

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[33] https://ec.europa.eu/info/law/law-topic/data-protection/reform/what-does-general-data-protection-regulation-gdpr-govern_en

[34] EPREL Public website (europa.eu)

What are the responsibilities of the different stakeholders?

The controller responsible for processing is the person that determines the purpose and means of the processing operation (Article 4 of the GDPR). Each controller shall maintain a record of processing activities under its responsibility (article 30 of the GDPR). It is required to keep track of:

- The purposes of the processing operation
- The categories of data subjects and related data
- The recipients of the data
- Information on the use of data, their storage and the rights of the data subjects
- The names and contact details of the controller and the Data Protection Officer.

The subcontractors who are « natural or legal persons, public authorities, agencies… which processes personal data on behalf of the controller » (Article 4 of the GDPR) must provide appropriate safeguards to protect the security and confidentiality of the data, specified in particular in the binding contract between the controller and the subcontractors. This contract shall also specify their respective commitments for data processing.

The European Regulation applies to data processing operations in the context of activities carried out by an establishment located on EU territories.

Content of the GDPR documents

When a research project involves personal data, it is necessary to address the following items in a consent form and/or an information notice:

- The lawfulness of the processing, which is the basis of the processing (the person must consent to the processing of his or her data -article 6 of the GDPR-)
- The purpose of the processing operation
- The relevance and proportionality of data
- Data security and protection (security mechanisms should be provided at all stages of the project)
- Limited data storage (the data may only be stored for a predefined and limited period. At the end of the processing operation, the data shall be either anonymised or stored for subsequent reuse for scientific research purposes only.)
- Transparency of information about the use of data

The GDPR has extended the rights of individuals in the following ways:

- Precise information on the processing, purpose, use of the data, storage period is provided to the participants. This information must be transparent and easily accessible (article 12 of the GDPR). It must be transmitted directly to the data subjects.
- Right of access to one's data (article 15 of the GDPR)
- Right to be informed of a data breach when there is a significant risk for the data subjects
- Right to objection (article 21 of the GDPR): a person may object, on legitimate grounds, to the use of his or her personal data unless the processing complies with a legal obligation. A derogation makes it possible to reject such a request where the processing is based on the performance of a task of public interest.
- Right of rectification (article 16 of the GDPR): a person may ask to modify his/her data.
- Right to erasure (article 17): a person may request access to his/her data and request erasure. The request may not be granted, if exercising this right is likely to make impossible or seriously impair the achievement of the processing objectives

- Right to portability (article 20): a person may ask to receive his/her data in a structured and machine-readable format and to transmit them to another controller. This right shall not apply to processing necessary for the performance of a task in the public interest or in the exercise of official authority vested in the controller.
- Right to a restricted use of one's data (article 23)

8 Methodologies to collect and analyse relevant real-life energy use data: Televisions (ENER lot 5)

Within the framework of this study, the different aspects to take into account when designing in-situ measurement campaigns have been identified as:

- Sample design with a special focus on statistical representativeness;
- Data acquisition (different metrological possible solutions) and management;
- General miscellaneous questions as metering length, information to collect on site to better describe the appliance of interest, personal data management.

In the following report sections, these different aspects will be tailored into practical field methodologies for the following product groups:

- Televisions (ENER lot 5);
- Domestic refrigerators and freezers (ENER lot 13);
- Gas boilers (ENER lot 1).

This section addresses specifically televisions[35] (screens larger than 100 cm²). All other electronic displays (computer monitors, digital signage displays, projectors) are excluded. It provides a methodology to collect and analyse relevant real-life energy use data. It explicitly details the organisational aspects and the role of the different stakeholders when launching a European in-situ measurement program.

Parameters to monitor

In order to improve the knowledge about real-life energy use of televisions and the impact of regulatory requirements it is not only necessary to monitor their electricity consumption but also to analyse the parameters that influence this consumption.

8.1.1 Parameters influencing the electricity consumption of a television

The main parameters that influence the electricity consumption of a television are the following [34]:

- Technological aspects
- Screen size;
- Picture settings (e.g., screen brightness, backlight, Picture modes (e.g. "standard", "natural", "gaming", "dynamic"), auto-brightness control, contrast, gamma correction etc.);
- Power consumption of the processor;
- Resolution and picture enhancement features (e.g., HDR);
- "Smart" features (integrated Internet and interactive Web 2.0 features), affecting also the standby consumption;
- Presence detection.
- Behavioural aspects
- Viewing time,
- Type of standby mode/start function (e.g., paired with a home assistant, quick start function, black screen mode),
- Type of viewed content (TV channels, SVOD, video game, etc.).

[35] The Regulation (EU) 2017/1369 defines a 'television' as an electronic display designed primarily for the display and reception of audiovisual signals and which consists of an electronic display and one or more tuners/receivers.

8.1.2 Overview of the regulation requirements for televisions

Ecodesign and Energy Label regulations – Regulations: (EC) 642/2009 and (EU) 1062/2010

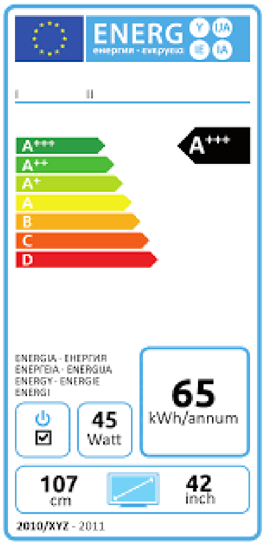
The first set of regulations was adopted in 2009 and 2010 and covered only televisions[36].

The energy efficiency index calculation to set minimum requirements and labelling classes was a relatively linear function of the screen area, with a base allowance differentiated between television sets and television monitors, and a bonus for full HD resolutions (which were still pioneer technology at that time).

Power limits in standby and off mode were also set. An auto-power down provision required all televisions to switch by default to standby mode after 4 hours of inaction.

The regulations stipulated that products shall be tested in the 'home-mode' configuration that is advised to the user on initial activation.

Figure 26. Illustration of the first TV Energy Label



Source: Regulation (EU) 1062/2010.

Revised Ecodesign and Energy Label regulations - Regulations (EU) 2019/2021 and (EU) 2019/2013

The latest version of "electronic displays" Ecodesign and Energy Label regulations has entered into force on March 2021[37]. The scope has been extended to all 'displays' (i.e., televisions, computer monitors, signage displays).

[36] Ecodesign regulation (EC) 642/2009 and energy labelling regulation (EU) 1062/2010

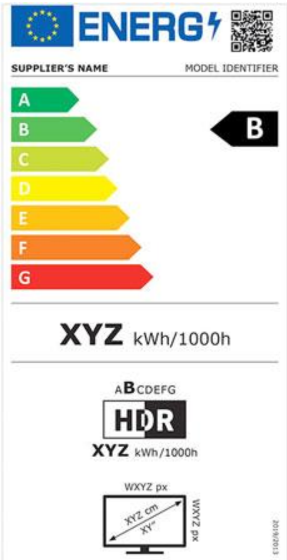
[37] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/televisions_en

The calculation formula to set minimum requirements and labelling classes has been changed to introduce a less linear and more asymptotic relationship between power limits and screen size. This better represents the state of technologies and efficiency potentials according to the size. It also means a reinforcement of requirements for larger screens. The energy label has been rescaled to A to G, with the top classes empty in the beginning.

The requirements and labelling scales are also now differentiated according to the type of content viewed (Standard or High Dynamic Range – SDR/HDR[38]).

Moreover, the new regulation further tightens the maximum allowed power consumption when the television is in off or in standby, and smart televisions must have the so-called network standby disabled in their default configuration to better save energy when the television is not in use.

Figure 27. Illustration of the current display Energy Label (since 2021)



Source: Regulation (EU) 2019/2013

The revised regulations notably specify among other things that:

- As before, the products shall be tested in the 'normal configuration' that is advised to the user on initial activation;
- Products equipped with an auto-brightness control feature set by default, persisting in other configurations, and reducing smoothly the power use by up to 20% at least in the darkest ambient light, can get a 10% discount on the measured power;
- Televisions shall by default switch to standby mode after 4 hours of inaction;
- No software update is allowed to make a product non-compliant with Ecodesign requirements.

[38] a product when it shows content in HDR can consume twice as much energy as other settings.

Benefits of the project to improve and inform EU policies

The results of a European monitoring campaign of televisions will be very useful for both the evaluation of the EU regulatory process (e.g., Ecodesign Impact Accounting study) and to inform future improvements of the Ecodesign and Energy Label Regulations for displays. It would bring considerable added-value to the Ecodesign preparatory studies. The results and lessons learned may also be used in several other ways.

The benefits have already been described in the previous sections. In this paragraph we apply our general conclusions to the specific case of televisions.

8.1.3 Information expected from the field data collection

The following information could be derived directly or indirectly from the in-situ measurement program (non-exhaustive list):

- What is the average daily/annual electricity and power consumption of TVs?
- What is the average daily on-time use?
- Is this average on-time use typically shorter on recent models with auto-power down and presence detection features?
- What is the standby power demand / energy consumption?
- What are the main determinants influencing the total energy consumption or the power demand (year of purchase, technology, resolution, energy class, screen size, brightness and backlight settings including picture modes, smart features…)?
- What is the daily load curve? Does it vary throughout the year?
- Does the electricity consumption depend on the season?
- What is the average power demand per screen area (W/dm^2), overall and by energy class of the products?
- How has this parameter changed across the years (by comparing TV sets of various ages)?
- Are there explained or unexplained trends jeopardising the impact of Ecodesign and Energy Labelling regulations?
- Are there some key factors that are not sufficiently or not well enough covered by the regulations?

8.1.4 Ecodesign Impact Accounting

The in-situ measurement campaign will provide a highly-welcome calibration point for the Ecodesign Impact Accounting calculations that estimate theoretically the benefits of Ecodesign and Energy Labelling. It will also allow to better understand the determinants of energy use of televisions and improve the modelling of impact assessments.

8.1.5 Provide a first calibration point

In-situ monitoring campaign will give a precise picture, in a given year, of:

- The average constitution of the stock of televisions in households (in terms of ownership rate, models, energy class, screen size, etc.), that can be confronted to the theoretical stock models based on sales data and assumptions used in Ecodesign Impact Accounting and resulting in potential data corrections and improvements;
- The average usage behaviour, leading to substantial improvements of the typical imprecise assumptions that are used at EU level;
- Comparing the theoretical energy consumption calculations against a field measurement, allowing for questioning the sources of potential deviations and identifying the main sources.

Such a calibration point is precious to improve the modelling data and factors taken into account, and ensure the accounting modelling delivers credible impact assessments.

8.1.6 Improve the level of details of the assumptions

The calculations in the Ecodesign Impact Accounting for displays are based on a limited number of factors on which assumptions are made: evolution of screen area and power per area (W/dm^2) for new sales broken down in two simplified subcategories (HD and UHD/3D/HDR), viewing time, standby time and standby type ('standard', 'HiNA', 'LoNa'). Data is largely theoretical, in the absence of reliable data sources.

The rich data and correlations gathered in the in-situ measurement campaign will allow to assess whether this level of simplification is accurate or whether it overlooks key technological and behavioural aspects that would deserve to be better reflected in the modelling. It will also highlight on which aspects the assumptions have been the most uncertain, and how to reduce this uncertainty by improving the modelling parametrisation or the precision on certain parameters.

8.1.7 Provide insights on the impact of Ecodesign and Energy Labelling

A measurement campaign gives information for a given year, so in theory it is a relatively static picture making it difficult to depict trends over the years.

However, in a sample of hundreds of households there will be product models of various ages. By classifying them by purchase date and streamlining and harmonising as much as possible the measured energy performance (e.g., W/dm^2), some historical comparison may be drawn. There will be obviously statistical uncertainties and limits to take into account, but we are confident that useful information may be obtained this way on trends in efficiency progress over the years.

Distinguishing the impact of regulation from other natural technological developments is of course very challenging, and the in-situ campaign will not answer on this, yet it might highlight aspects where the regulation objectives have been hampered by detrimental trends.

8.1.8 Informing the revision of Ecodesign and Energy Labelling Regulations

Television is a fast-changing technological product, and Ecodesign and Energy Labelling regulations have to be updated often to follow pace. The next review is already planned for the end of 2022.

In-situ measurements could provide valuable insights on several aspects of the regulations to prepare future reviews, including:

- the appropriateness of the energy label and efficiency index formulas to drive market change in the right direction;
- the level of consideration of recent technological developments;
- Opportunities to further influence key behavioural aspects of product usage;
- The credibility of test methods to reflect real-life use;
- Other aspects currently overlooked in regulations.

8.1.9 Additional benefits and opportunities

On top of informing Ecodesign and Energy Labelling regulations, the results of the measurement campaign would have many other benefits, such as:

- Improving all energy demand models at EU and national levels, with better quality data on televisions;

- Providing useful quantitative information for awareness raising and educational campaigns on sustainable behaviours and energy saving tips;
- Feeding other initiatives, reports, and projects on product efficiency covering televisions;
- Supporting national authorities in charge of monitoring and surveying markets;
- Raising public, media and opinion leader awareness on sustainability challenges with digital products;
- Improving NILM or deep neural network systems: e.g. it could be very useful to test NILM algorithm on the field (not only on set of existing data) in order to improve them.

Monitoring strategy

8.1.10 Monitoring plan

In order to improve the knowledge of electricity consumption of televisions at European level, two strategies could be implemented depending on the goals:

1. Monitor all the televisions of each household in the sample: it allows to get the full picture of what constitutes the electrical load related to televisions today on the field (not only the main screen typically located in the living room, but all the other secondary devices in other rooms).
2. Monitor only the main television of each dwelling: it allows to get a good indication of what the largest, often most recent, and most used screens installed in households consume.

-

Box. 3 Example of France (Panel Elecdom project [3])

In a representative sample of French metropolitan households recently measured, 91% have at least one TV set but in equipped household, the average total number of sets is 1.7.

The average electricity consumption of the main TV set is 187 kWh/year (on 6h46 per day), and 58 kWh/year (2h52 viewing time per day) for the secondary ones. The standard deviation is much larger for secondary televisions, reflecting a higher variability of models and of usages.

The French example reveals that secondary sets weight much less in terms of annual energy use. Besides, they may be less and less used in the future as alternative devices (smartphones, tablets, etc.) get more and more commonly used to access TV content. Last, they are usually older and do not represent the latest technologies. In this report we consider both strategies.

8.1.11 Side Information to be collected

As already explained in the bibliography section, meter data collection should be in any case accompanied by information about the household, equipment features, and their usage. A questionnaire tailored for televisions will be submitted to each participant. It will compile the following information (non-exhaustive list):

- Household
    - Number of occupants
    - Age of the occupants
    - Occupancy pattern
    - Income or profession or socio-professional category
    - Number of televisions frequently used (at least once a week for example)
- Building and electrical installation
    - Type (flat/house)
    - Living area (m²)
    - Electrical installation (contract power, smart meter)
- Appliance features

- Brand
- Model
- Purchase year
- Energy label information (if available)
- Technical features and settings (technology, resolution, smart features, refresh rate, quick start function, ambient light sensor, blank screen function, energy saving mode, sleep timer)
- Location within the house
- Reception mode (Internet, digital terrestrial television, cable)

- Usage, habits:
  - Connection to other appliances
  - Estimated viewing time per day
  - Usage of the television: watch live program, replay program, listening to music, playing video game
  - Other screen type used to watch program/video: computer, smart phone, tablet.

Participants will also be requested to take some pictures of their televisions in their environment, the dataplates (where useful technical information is gathered), and the menu screens where the settings are visible (brightness, contrast, eco-mode, etc.).

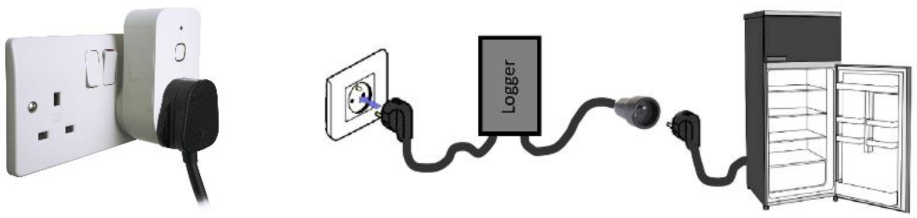
Measurement system

In the case of television, only electricity consumption will be measured. All influential variables will be audited thanks to the questionnaire (see section 8.1.11).

The electricity consumption of a television can only be monitored with a plug-in energy datalogger as, most of the time, there is no dedicated line for this specific appliance in the electrical board.

Plug-in energy datalogger can be installed by the participants themselves as it is an easy operation. They simply must be plugged between the appliance to monitor and the electrical socket (Figure 28). There is no need of a certified electrician.

Figure 28. Example of plug-in energy monitors and its installation mode



Source: Internet picture and authors' analysis

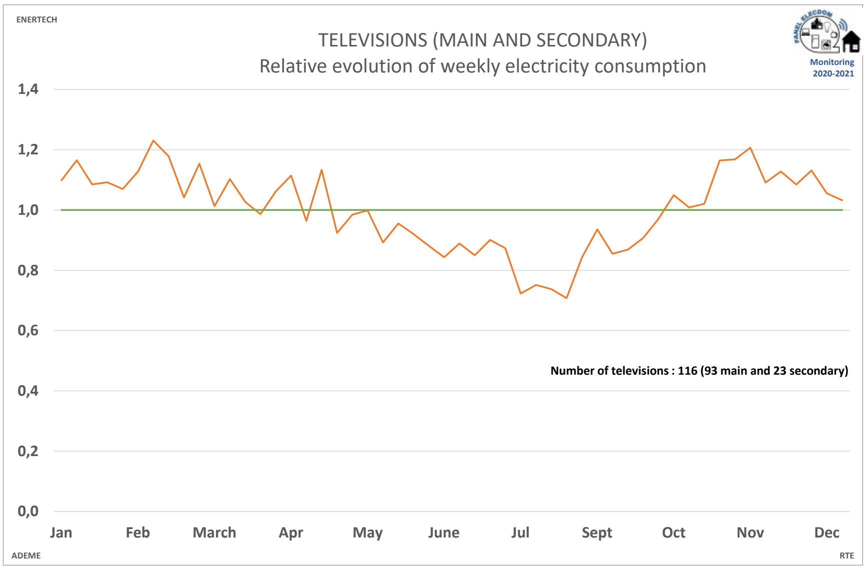
They can be sent by post/shipping service which makes the organisation of the monitoring campaign easier and cheaper. Another benefit is that, unlike the case of dedicated teams installing the dataloggers, there are no geographic constraints to build the representative sample of households in each country.

The use of models with on-board memory is recommended. Ideally a data collection time interval of 1-minute should be chosen as it allows to get a very fine knowledge of the use of the appliance, for example analysing more accurately the operating cycles and the power variation.

Monitoring duration

The electricity consumption of televisions has never been monitored during one whole year at European level. Indeed, in the only European-wide in-situ residential measurement campaign (Remodece project [6]), the metering equipment was installed in each household only for about a month. Figure 29 gives the evolution of the electricity consumption of the televisions over the seasons for France (Panel Elecdom project). There is no important seasonal effect but the consumption slightly decreases during spring and summer.

Figure 29. Televisions - Relative evolution of weekly electricity consumption over the year



Source: Enertech[3]

So, as the seasonality has not been precisely addressed yet, we recommend to monitor the electricity consumption of the televisions during a whole year in each household.

Monitoring strategy

The objective of the study is to elaborate a methodology for single products, but different strategies could be drawn up to reduce the overall cost and to ease the organisation of in-situ measurements[39]. To this end, it should be possible to monitor several types of appliances in the same household either at the same time or one after another (in order to limit the number of necessary dataloggers). The idea would be to use the same sample of dwellings to cover several electric household appliances. This is the case of plug-in monitoring (e.g. TVs, refrigerators, washing machines), but an electrician would be needed for products that are plugged directly in the switchboard (e.g. lighting, ovens etc) and a plumber would be necessary in case of gas boiler monitoring. In the latter cases, both organisation and costs are different and the cost savings of a multi-product campaign are thus reduced.

[39] it is difficult to give a precise % cost savings as the size of the sample should be adjusted to be representative for the different appliances (different criteria are used for the sample selection)

Selection of the sample of households

8.1.12 Geographical localisation of the sample

As indicated in the literature review (paragraph 4.4), we propose to implement the in-situ measurements only in few European countries representing most geographical, cultural and living standards in order to optimize the costs. We suggest to use as sampling frame the 8 countries with the greatest number of households per country. They cover all 4 empirical geographical zones (centre, east, north, south) and are rather homogeneous in terms of standard of living.

These 8 foreseen countries are: Germany, France, Italy, Spain, Poland, Netherlands, Romania, Sweden.

Figure 30. Location of the 8 foreseen countries for the European end-uses monitoring campaign

Source: Authors' analysis

8.1.13 Sample size

The sample size is a compromise between representativeness and cost. In this study we will evaluate 3 different sizes: 100 (110 with 10% security margin), 150 (165) and 200 (220) televisions in each of the 8 countries. Two strategies are considered:

- Strategy 1 (S1): Only the main TV is monitored in each household
- Strategy 2 (S2): Main and secondary TVs are monitored in each household. As the ownership rate of main and secondary TVs is not known for each country, based on the results of the Panel Elecdom project, we make the assumption of an average ownership rate of 1.7 appliances per equipped household.

In both cases, the number of monitored appliances is the same. The difference will be in the number of considered households:

- S1: 110/165/220 households per country

- S2: 65/98/130 households per country (assumption for television ownership rate = 1.7).

Table 13 and Table 14 give respectively the expected accuracy for strategies 1 and 2, based on "Panel Elecdom" project results for televisions.

NB: the actual accuracy of the outcomes will have to be recalculated during the data processing phase based on the measured variance compared to the forecast.

Table 13. Expected accuracy as a function of the sample size for strategy 1 (only main televisions monitored) based on Panel Elecdom data

Scale	Main TV Mean consumption Y1 (kWh)	Main TV Standard Dev Y1 (kWh)	Number TV case 1	Number TV case 2	Number TV case 3	Expected Precision case 1	Expected Precision case 2	Expected Precision case 3
COUNTRY	**187**	**169**	**110**	**165**	**220**	17%	14%	12%
EU-27	**187**	**169**	**880**	**1 320**	**1 760**	6%	5%	4%

Source: Elecdom project And authors' analysis

Table 14. Expected accuracy as a function of the sample size for strategy 2 (main and secondary televisions monitored) based on Panel Elecdom data

Type of TV	Scale	TV Mean consumption Y1 (kWh)	TV Standard Dev Y1 (kWh)	Number TV / *(households)* case 1		Number TV / *(households)* case 2		Number TV / *(households)* case 3		Expected Precision case 1	Expected Precision case 2	Expected Precision case 3
All TVs	**COUNTRY**	**163**	**164**	**110**	*(65)*	**165**	*(98)*	**220**	*(130)*	**19%**	**15%**	**13%**
	EU-27	**163**	**164**	**880**	*(520)*	**1 320**	*(784)*	**1 760**	*(1040)*	**7%**	**5%**	**5%**
Main TVs	COUNTRY	187	169	65	*(65)*	98	*(98)*	130	*(130)*	22%	18%	16%
	EU-27	187	169	520	*(520)*	784	*(784)*	1 040	*(1040)*	8%	6%	6%
Secondary TVs	COUNTRY	58	86	45	*(45)*	67	*(67)*	90	*(90)*	43%	35%	31%
	EU-27	58	86	360	*(360)*	536	*(536)*	720	*(720)*	15%	13%	11%

Source: Elecdom project And authors' analysis

The accuracy of both strategies is very similar, varying between 4 and 7% at European level as a function of the sample size and the monitoring strategy. Logically, the precision is slightly better for main televisions with strategy 1 but in this case no information is collected concerning secondary televisions. The choice of the strategy to select depends on the final goal:

- Strategy 1: collect a lot of very precise information on the most recent and used televisions of each equipped household
- Strategy 2: get a better representation of an "average" television at European level by taking into account almost all of the televisions in actual use of each equipped household.

8.1.14 Selection criteria

The following influencing factors, at household level, have been identified for televisions at this preliminary stage:

- Household income or socio-professional category
- Dwelling types and location: 3 types of housing (rural -dispersed-, urban -collective- and suburban)
- Housing type: house or flat
- Household composition: single, couple (young and old), family with child(ren).

As the participants will install the dataloggers by themselves, it will be possible to get a sample well scattered within the selected countries in order to take into account a good geographical representativeness (climatic, cultural, daylight…). The pre-sample characteristics will be compared to the national statistics and outliers will be discarded.

The selection criteria will have to be confirmed by the future contractor at the beginning of the mission.

8.1.15 Selection mode

For this project it is necessary to find participants in 8 European countries that satisfy the previous described selection criteria. We propose to subcontract this mission to an Online Panel Provider (OPP) which has the capabilities to target appropriate audiences thanks to its panel of thousands of profiled consumers. Online panels are groups of pre-recruited individuals who have agreed to take part in surveys, focus groups, or in-depth interviews. To get recruited into a panel, individuals share a large amount of household data, demographic data, and behavioural characteristics during the registration phase. Sharing this information makes segregation and recruitment easy for future research studies. People are recruited from various channels (Internet, social media and email). Many OPPs reward their panelists in the form of gift coupons.

Project organisation

In order to complete this challenging project, a very qualified Project Manager (PM) should first be appointed. This company will be in charge of supervising the whole project, choosing and managing the subcontractors.

8.1.16 Preparation of the in-situ measurement campaign

Selection and purchase of the monitoring equipment

The metering equipment to be used is described in section 0. A call for tender should be launched at the beginning of the project in order to find the appropriate product at the best price.

NB: due to the current electronic component shortage the delivery time could be very long (at least 6 months).

Recruitment of the Online Panel provider

In parallel, the OPP should be recruited by the PM. This company should be selected with great care as it will play a key role in the project. It will be the direct contact of the participants. Ideally, it should be an international firm with offices in the 8 countries; otherwise, it could be a company with contracts with researchers in the 8 countries able to provide direct contact with the participants. It will not only provide the sample but also performs different tasks as document translation, hotline (see following sections for a more detailed description).

Preparation of the different documents

The different necessary documents are described in the following paragraphs. They will all be:

- Developed by the PM
- Translated and coded (when necessary) by the OPP.

<u>Recruitment tools (advertising and pre-recruitment questionnaire)</u>

In order to enrol participants, a short, clear and user-friendly description of the project should be written. The text should also explain what is expected from the applicant (install a datalogger on his/her main television (S1) or all the televisions (S2) for one year and fill in a questionnaire related to each appliance) and what will be the reward.

It will be accompanied by a short pre-recruitment questionnaire. The following questions could be asked (non-exhaustive list):

- How many televisions have you got? (If the answer is none, the applicant is rejected[40])
- Do you plan to change at least one of your television(s) during the year to come? (If the answer is yes, the applicant is rejected)
- Do you plan to move out during the year to come? (If the answer is yes, the applicant is rejected)
- Socio professional category
- Housing type (house or flat)
- Household composition (single, couple (young and old), family with child(ren))
- Address
- Email address
- Phone number

These documents will need to be translated in the different languages and to be coded for later Internet broadcast.

Household questionnaire that goes with in-situ measurement

A technical and behavioural questionnaire will be developed in order to collect the information described in section 8.3.2. The participant will also be asked to upload some pictures (dataplate, television settings…).

Monitoring equipment installation guidelines and procedure

The datalogger will be shipped with paper-based installation guidelines.

GDPR form

As personal data will be collected during the project, a GDPR form needs to be filled in by the participants at the beginning of the project. Its creation will be sub-contracted to a GDPR consultant. If legally possible, the form will be filled in and sign online (for example after answering the household questionnaire). The GDPR consultant will be in charge of the whole GDPR strategy of the project i.e., the content of the different GDPR documents.

8.1.17 Recruitment of candidates

The validation of the representativeness of the sample will be sub-contracted to a Statistical Consultant (SC). This company will validate the relevance of the selection criteria that are proposed (see section 8.1.14) and will assist the OPP at each step of the recruitment process.

Pre-recruitment of the potential candidates (online)

The OPP will send the online advertising and the pre-recruitment questionnaire to its panelists that meet the selection criteria.

Validation of the consistency of the sample

Based on the positive answers, the OPP assisted by the SC will build a first sample.

[40] However this information is relevant to understand overall stock of TVs

Initial contact with participants (phone)

By experience we know that some candidates that first declare online their willingness to participate will then withdraw from the study when they receive the monitoring devices. In order to avoid this situation, the OPP will call each respondent to re-explain the project and confirm his/her consent. During this call, he/she will confirm his/her coordinates. The SC will closely follow this process as the sample characteristics will probably be continuously modified.

8.1.18 In situ End-use measurements

Questionnaire and GDPR form

Once the oral agreement has been reached, the online household questionnaire (see section 8.1.11) will be sent to the participant. Its last part will contain the GDPR consent form.

Parcel preparation and shipping

The PM will centralise the final list of candidates of the 8 countries that have fulfilled the household questionnaire and the GDPR form. It will then send the monitoring device(s) with the installation guidelines to each household.

Installation support for the monitoring equipment

Participants will have to install the plug-in energy datalogger(s) on their television(s). A dedicated hotline (mail and phone number) will be available in each country in order to help with troubleshooting. It will be managed by the OPP assisted by the PM if necessary.

Validation of the correct installation

The confirmation of the correct installation will be validated by a picture sent by the participant to the OPP. This picture will show the datalogger plugged between the electrical socket and the television. At the end of this stage, the participant will receive a first gift card.

Hotline during monitoring campaign

A hotline, managed by the OPP and the PM, will remain available throughout the measurement period.

Return of the monitoring equipment

After one year, participants will receive a pre-paid return label in order to send the datalogger back to the PM. They will be sent a second gift card, once the data are downloaded.

8.1.19 Data processing

The PM will first clean the data files. Then, statistical adjustment will be made by the SC in order to correct improprieties or limitations in observed data and to remove the influence of nuisance variables. Afterward, the PM will process the data and will be able to answer the questions listed in section 8.1.3.

8.1.20 Summary of the tasks and the key actors

Table 15 summarises the actors of the project and their tasks. The Project Manager has the central role and must be multi-skilled. The second key-actor is the Online Panel Provider. Several companies have been contacted to build this methodology. The best solution would be to find an Online Panel Provider that can do all the described tasks. If it is not possible, it will be necessary to find local contacts in every 8 countries for the hotline assistance (installation phase, monitoring period, return of the dataloggers).

Table 15. Summary of the actors of the project and description of their tasks

Actors	Tasks
Project Manager (PM)	- Selection and purchase of the monitoring equipment - Recruitment of the Online Panel Provider, the Statistical Consultant and the GDPR Consultant - Design of the different documents (advertising, pre-recruitment questionnaire, household questionnaire, installation guidelines, GDPR form, document describing the return procedure for the datalogger) - Parcel preparation and shipping - Assistance for the hotline during the installation phase et throughout the measurement period
Online Panel Provider (OPP)	- Translation of the different documents (advertising, pre-recruitment questionnaire, household questionnaire, installation guidelines, GDPR form, document describing the return procedure of the datalogger) - Coding of the questionnaires and GDPR form - Recruitment process (online pre-recruitment, initial contact by phone, household questionnaire, GDPR form) - Hotline during the installation phase et throughout the measurement period - Management of the return of the monitoring equipment
Statistical Consultant (SC)	- Validation of the representativeness of the sample at each step of the recruitment process (validation of the selection criteria, continuous validation of the consistency of the sample during its building) - Assistance in data processing (statistical adjustment)
GDPR Consultant	- Development of the GDPR strategy

Source: Authors' analysis

Estimated budget of the different TV monitoring strategies

This section estimates budget for the different TV monitoring strategies. Table 16 recalls the hypothesises of the six different strategies that have been proposed.

Table 16. Summary of the different strategies

Strategy	Monitoring strategy	Number of households	
		Per country	EU (Sample: 8 MS)
S1	Monitor only the main television of each household	110	880
S2		165	1 320
S3		220	1 760
S4	Monitor all the televisions of each household	65	520
S5		98	784
S6		130	1 040

Source: Authors' analysis

Table 17 gives the cost breakdown between the different contractors and sub-contractors for the 6 different strategies.

Table 17. Cost breakdown between the different contractors and sub-contractors for the 6 different

Strategy n°	Main/ All TVs	Number of households / country	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers purchase& shipping- (€)	Total costs (€)
S1	Main	110	86 400	254 510	8 175	10 000	106 302	465 387
S2	Main	165	107 200	368 090	8 175	10 000	159 453	652 918
S3	Main	220	128 800	481 310	8 175	10 000	212 604	840 889
S4	All TVs	65	80 800	163 520	8 175	10 000	98 815	361 310
S5	All TVs	98	99 200	232 616	8 175	10 000	148 306	498 297
S6	All TVs	130	118 400	299 330	8 175	10 000	197 630	633 535

Source: Authors' analysis

The cheapest strategy is S4 which consists in monitoring all the televisions of a limited number of households (65 households per country, 110 main and secondary televisions per country) in 8 representative countries. It lies to an expected precision of:

- 7% for all televisions at European level (8% for the main TV and 15% for the secondary ones)
- 19% for all televisions at country level (22% for the main TV and 43% for the secondary ones)

If the focus is to be on the main television of each household, a sample of 110 households (strategy S1) provides a good accuracy (6% at European level and 17% at country level) for an acceptable budget.

IMPORTANT NOTE: due to the current unprecedented crisis on electronic components, there is an important uncertainty on prices and delivery time of the dataloggers. Therefore, the costs given in this report (also for domestic refrigerators and gas boilers monitoring strategies) are only indicative.

Detailed costs for each strategy

In Annex 2.1, the budget for each strategy is broken down between the different tasks and actors. Costs are only indicative as they can be changes depending on the selected dataloggers, the ownership rate of secondary televisions in the different countries, the length of the document to translate, the incentives proposed by the Online Panel Provider.

9 Methodologies to collect and analyse relevant real-life energy use data: Refrigerators and freezers (ENER lot 13)

This section addresses specifically fridges (1 and 2 doors) and freezers (upright and chest) (Figure 31). It provides a methodology to collect and analyse relevant real-life energy use data. It explicitly details the organisational aspects and the role of the different stakeholders when launching a European in-situ measurement program.

Figure 31. Examples of the different types of cold appliances

Refrigerator	Refrigerator with ice-box	Fridge freezer	Upright freezer	Chest freezer
				

Source: Author's analysis

Parameters to monitor

In order to improve the knowledge on real-life energy use of fridges and freezers and the impact of regulatory requirements it is not only necessary to monitor their electricity consumption but also to analyse the parameters that influence this consumption.

9.1.1 Parameters influencing the electricity consumption of a fridge or a freezer

The main parameters that influence the electricity consumption of domestic fridges and freezers are the following [37]:

- Technological aspects
- Insulation material and thickness
- Compressor efficiency
- Temperature controller
- Quality and ageing of the door gaskets
- Automatic defrosting and other special features (ice-maker, etc.)
- Smartness features (e.g., integrated screen, internet connectivity, etc.)
- Built-in or free-standing appliance
- Behavioural aspects
- Ambient temperature and product placement
- Internal temperature (thermostat set point)
- Volume
- quantity/temperature/humidity of products placed in the appliance
- Frequency of door openings
- Maintenance (manual defrosting, dusting, etc.)

9.1.2 Overview of the regulation requirements for cold appliances

Ecodesign and Energy Label regulations (2010-2021)

Household refrigerating appliances have been covered by relatively complex regulations. The functioning of these appliances is quite basic, but decision-makers and manufacturers were eager to take into account various parameters in the approach.

Ecodesign limits and energy labelling classes were set using an energy efficiency index (EEI), calculated by comparing the measured energy consumption against the 'standard energy consumption' of a product model. The standard consumption is obtained through a formula involving parameters and correction factors that differ according to the product category and features.

10 different categories of appliances were considered:

1. Refrigerator with one or more fresh-food storage compartment
2. Refrigerator-cellar, cellar and wine storage appliances
3. Refrigerator-chiller and refrigerator with a 0-star compartment
4. Refrigerator with a 1-star compartment
5. Refrigerator with a 2-star compartment
6. Refrigerator with a 3-star compartment
7. Refrigerator-freezer
8. Uprigth freezer
9. Chest freezer
10. Multi-use and other refrigerating appliances

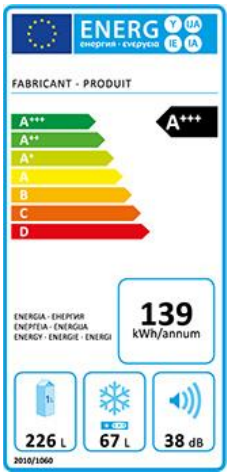
Correction factors included:

- The 'Climate class', providing a 10 to 20% bonus on the EEI calculation for appliances designed to work in especially warm climatic conditions (tropical and subtropical classed appliances)
- The 'Frost-free' factor, giving a 20% bonus for appliances that automatically defrost the freezer compartment,
- The 'Built-in' factor, providing again a 20% bonus for appliances built in integrated kitchens
- The 'Chill compartment', representing 50 kWh/year of extra allowed energy use for appliances with a chill compartment greater than 15 litres.

It is to be noted that the setting of these category parameters and correction factors was not entirely science-based but rather reflecting the state of the market at the time of discussing the regulations. Over time, they have led to increasing market distortions (favouring certain types of categories over others) and windfall effects (e.g., encouraging manufacturers to claim the too-generous correction factor bonuses)[41].

[41] This has been documented in e.g., 'Assessment of the applicability of current EC correction factors and tolerance levels for domestic refrigerating appliances' (Intertek 2012)

Figure 32. Illustration of the first Energy Label for cold appliances



Source: Regulation (EU) No 1060/2010

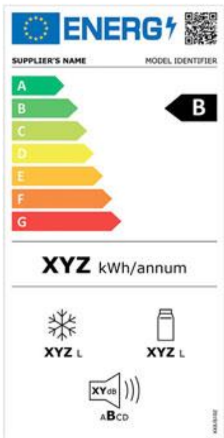
Ecodesign and Energy Label regulations (since 2021)

An effort has been made in the review of the regulations to design a more science-based approach and revisit the number and level of correction factors. The resulting new energy efficiency index (EEI) formula adopts a compartment-based approach, but remains relatively complex. 10 types of appliance compartments are still defined (fresh food, chill, cellar, frozen, etc.), with differentiated parameter values. Correction factors still cover:

- The ‘auto-defrost’ factor, reduced to 10%
- The ‘built-in’ factor, reduced to 2 to 5%
- A new ‘multi-door’ factor, from 2 to 5% for multi-door models

The new energy label has been substantially rescaled. The majority of models are currently in the E and F classes.

Figure 33. Illustration of the current Energy Label for cold appliances



Source: Regulation (EU) 2019/2016

Benefits of the project to improve and inform EU policies

The results of a European monitoring campaign of fridges and freezers will be very useful for both the evaluation of the EU regulatory process (e.g., Ecodesign Impact Accounting study) and to inform future improvements of the Ecodesign and Energy Label Regulations. It would bring considerable added-value to the Ecodesign preparatory studies. The results and lessons learned may also be used in several other ways.

The general benefits have already been described in section 2. In this paragraph we apply our general conclusions to the specific case of cold appliances.

9.1.3 Information expected from the field data collection

The following information could be derived from the in-situ measurement program (non-exhaustive list):

- What is the average daily/annual electricity and power consumption of fridges and freezers?
- What are the average operating conditions for fridges and freezers (ambient and internal temperatures)?
- What are the main determinants influencing the total energy consumption or the power demand and the differences between installed products (ambient temperature, internal temperature, age, defrost technology, energy class, volume, other features...)?
- What is the daily load curve? How does it vary throughout the year?
- How does the electricity consumption vary along the seasons?
- Are there explained or unexplained trends jeopardising the impact of Ecodesign and Energy Labelling regulations?
- Are there some key factors that are not sufficiently or not well enough covered by the regulations?
- Can detrimental or inappropriate effects of the parameters and correction factors in the regulations be spotted and analysed?

9.1.4 Ecodesign Impact Accounting

The in-situ measurement campaign will provide a highly-welcome calibration point for the Ecodesign Impact Accounting calculations that estimate theoretically the benefits of Ecodesign and Energy Labelling. It will also allow to better understand the determinants of energy use of fridges and freezers and improve the modelling of impact assessments.

Provide a first calibration point

In-situ monitoring campaign will provide a precise picture, in a given year, of:

- The average constitution of the stock of fridges and freezers in households (in terms of ownership rate, models, energy class, number of compartments, special features, etc.), that can be confronted to the theoretical stock models based on sales data and assumptions used in Ecodesign Impact Accounting and resulting in potential data corrections and improvements;
- The average usage behaviour and the effect of product ageing, leading to potential improvements of the typical theoretical assumptions that are used at EU level;
- Comparing the theoretical energy consumption calculations against a field measurement, allowing for questioning the sources of potential deviations and identifying the main sources.

Such a calibration point is important to improve the modelling data and factors taken into account, and ensure the accounting modelling delivers credible impact assessments.

Improve the level of details of the assumptions

The impact of Ecodesign and Energy Labelling regulations is currently estimated in the Ecodesign Impact Accounting through distinguishing 5 categories of appliances (simple refrigerators, fridge-freezers, wine cellars, upright freezers, chest freezers), looking at the sales-weighted average efficiency indexes in 2015 and guessing how this would change in the future (based on assumptions on the sale trends by energy classes), then by deriving the electricity consumption from the efficiency index values. Several theoretical assumptions and simplifications are applied during these steps, in terms of e.g., the repartition of sales by product categories in the future, the potentially differentiated evolutions of sales by energy class, the pace of adoption of special features and evolution in appliance sizes and number of doors, etc. The assessment also does not take into account the impact of real-life usage conditions and ageing.

The rich data and correlations gathered in the in-situ measurement campaign will allow to assess whether the overall approach and the various simplifications along the theoretical calculations provide an accurate-enough estimate. It will also highlight on which categories and aspects the assumptions have been the most uncertain, and how to reduce this uncertainty by improving the modelling parametrisation or the precision on certain parameters.

Provide insights on the impact of Ecodesign and Energy Labelling

A measurement campaign gives information for a given year, so in theory it is a relatively static picture making it difficult to depict trends over the years.

However, in a sample of hundreds of households there will be product models of various ages. By classifying them by purchase date and streamlining and harmonising as much as possible the measured energy performance (e.g. the energy consumption per litre of cold/frost volume during a summer day of comparable ambient temperature, and special features taken into account), some historical comparison may be drawn. There will be obviously uncertainties and approximations, but we are confident that useful information may be obtained this way on trends in efficiency progress over the years and in real-life conditions.

Distinguishing the impact of regulation from other natural technological developments is of course very challenging, and the in-situ campaign will not answer on this, yet it might highlight aspects where the regulation objectives have been hampered by detrimental trends.

Informing the revision of Ecodesign and Energy Labelling Regulations

The current regulations have to be reviewed by the end of 2025.

The in-situ measurement could provide valuable insights on several aspects to prepare the future reviews, including:

- The appropriateness of the regulations and efficiency index formulas to drive market change in the right direction, as well as avoid unwanted or unexpected detrimental effects
- The level of consideration of recent technological developments in the regulatory requirements
- Opportunities to further influence key behavioural and non-behavioural aspects
- The credibility of standardised test methods to reflect real-life use and capture the relevant aspects
- Other aspects potentially overlooked in regulations.

Additional benefits and opportunities

On top of informing Ecodesign and Energy Labelling regulations, the results of the measurement campaign would have many other benefits, such as:

- Improving all energy demand models at EU and national levels, with data of better quality on refrigerating appliances
- Providing useful quantitative information for awareness raising and educational campaigns on sustainable purchase and energy saving tips
- Feeding other initiatives, reports, and projects on product efficiency covering refrigerating appliances
- Supporting national authorities in charge of monitoring and surveying markets
- Raising public, media and opinion leader awareness on sustainability challenges with appliances
- Improving NILM or deep neural network systems

Monitoring strategy

9.1.5 Monitoring plan

In order to improve the knowledge of electricity consumption of fridges and freezers at European level, two strategies could be implemented depending on the goals:

1- Monitor all the cold appliances of each household in the sample: it allows to get the full picture of what constitutes the electrical load related to cold appliances today on the field (not only the main fridges and potential main freezer, but all the other secondary devices often located in basement, cellar, garage…).

2- Monitor only the main fridge and possible main freezer of each household: it allows to get a good indication of what the largest, often most recent, and most used cold appliance(s) installed in the households consume.

In this report we will consider both strategies.

Box. 4 Example of France ("Panel Elecdom" project [3])
In a representative sample of French metropolitan households recently measured, 100% have at least a fridge (1 or 2 doors) and 47% at least a freezer. In equipped households, the average total number of appliances is 1.15 for fridges and 1.23 for freezers. The average electricity consumption is 302 kWh/year for fridges (1 or 2 doors) and 288 kWh/year for freezers.

9.1.6 Side Information to collect

As already explained in the bibliography section, meter data collection should be in any case accompanied by information about the household, equipment features, and their usage. A questionnaire tailored for fridges and freezers will be submitted to each participant. It will compile the following information (non-exhaustive list):

- Household
  - Number of occupants
  - Age of the occupants
  - Occupancy pattern
  - Income or profession or socio-professional category
  - Number of fridge(s) (1 and 2 doors) and of freezer(s)
  - Origin: bought new or second hand

- Building and electrical installation
    - Type (flat/house)
    - Living area (m²)
    - Electrical installation (contract power, smart meter)

- Appliance features
    - Brand
    - Model
    - Volume
    - Number and type of compartments
    - Climate class
    - Built-in or free-standing
    - Purchase year
    - Energy label information (if available)
    - Settings (thermostat set point)
    - Location within the house (heated/non heated room)

Participants will also be requested to take some pictures of their fridges and freezers in their environment, the dataplates (where useful technical information is gathered), and the thermostat settings.

Measurement system

In the case of fridges and freezers, the following parameters will be measured:

- Electricity consumption
- Internal and ambient temperatures.

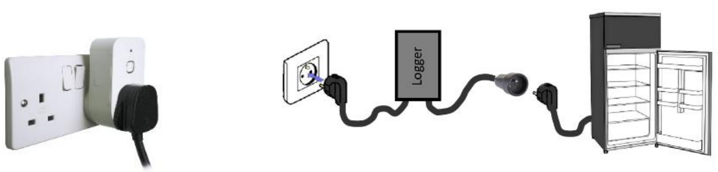
The other influential variables will be audited thanks to the questionnaire (paragraph 6.3).

9.1.7 Measurement of electricity consumption

The electricity consumption of fridges or freezers can only be monitored with a plug-in energy datalogger as, most of the time, there is no dedicated line for this specific appliance in the electrical board.

The plug-in energy datalogger can be installed by the participants themselves as it is an easy operation. They simply must be plugged between the appliance to monitor and the electrical socket (Figure 34). There is no need of a certified electrician.

Figure 34. Example of plug-in energy monitors and its installation mode



Source: Internet picture and author analysis

The use of models with on-board memory is recommended. Ideally a data collection time interval of 1-minute should be chosen as it allows to get a very fine knowledge of the use of the appliance, for example analysing more accurately the operating cycles and the power variation.

9.1.8 Measurement of ambient and internal temperatures

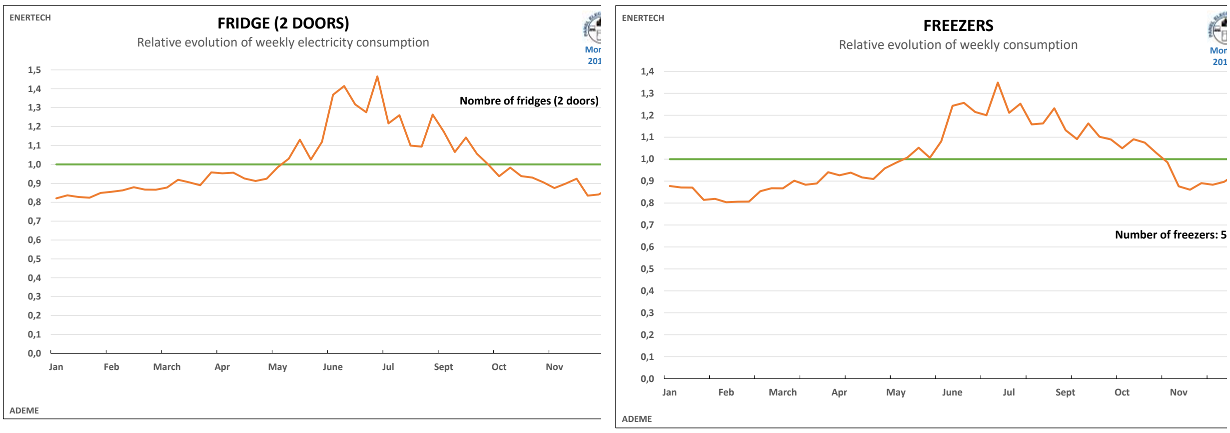
Ambient and internal temperatures can be monitored thanks to temperature loggers (Figure 35) that can withstand cold temperatures (up to -30°C for freezers). Their internal memory capacity should be large enough to be able to store data at 10- or 30-minutes time step during one year. Indeed, the intention is to monitor steady-state conditions thus 1-minute time step is not necessary. Their battery should also be sized to fulfil these requirements.

All the dataloggers (plug-in energy and temperature dataloggers) can be sent to participants by post/shipping service which makes the organisation of the monitoring campaign easier and cheaper. Another benefit is that, unlike the case of dedicated teams installing the dataloggers, there are no geographic constraints to build the representative sample of households in each country.

Monitoring duration

The electricity consumption of fridges and freezers have never been monitored during one whole year at European level. Indeed, in the only European-wide in-situ residential measurement campaign (Remodece project [4]), the metering equipment was installed in each household only for about a month. Figure 35 shows that the electricity consumption of the fridges and freezers is highly seasonal (Panel Elecdom project).

Figure 35. Fridges and freezers - Relative evolution of the weekly electricity consumption over the year



Source: Enertech [3]

So, as the seasonality has not been precisely addressed and seems to be very important, we recommend to monitor the electricity consumption of the fridges and freezers during a whole year in each household.

Monitoring strategy

The objective of the study is to elaborate a methodology for single products but different strategies could be drawn up to reduce the overall cost and to ease the organisation of in-situ measurements (see paragraph 8.6).

Selection of the sample of households

9.1.9 Geographical localisation of the sample

As indicated section 4.4, we propose to implement the in-situ measurements only in a few European countries representing most geographical, cultural and living standards in order to optimize the costs. We suggest to use as sampling frame the 8 countries with the greatest number of households per country. They cover all 4 empirical geographical zones (centre, east, north, south) and are rather homogeneous in terms of standard of living.

These 8 foreseen countries are: Germany, France, Italy, Spain, Poland, Netherlands, Romania, Sweden.

Figure 36. Location of the 8 foreseen countries for the European end-uses monitoring campaign

Source: Authors' analysis

9.1.10 Sample size

The sample size is a compromise between representativeness and cost. In this study, two strategies are considered:

- Strategy 1 (S1): only the main fridge and freezer (if there is one) are monitored in each household.
- Strategy 2 (S2): All Fridges and freezers are monitored in each household. Ownership rate of the secondary cold appliances is not known for most of the countries. Based on the results of the French Panel Elecdom project, we make the assumption of an average ownership rate of 1.15 for fridges and 1.23 for freezers per equipped household.

In both cases, the number of monitored appliances is the same. The difference will be in the number of considered households:

- S1: 110/165/220 households
- S2: 96/144/192 households (assumption for fridge ownership rate = 1.15).

Table 18 and Table 19 give respectively the expected accuracy for fridges and freezers, based on "Panel Elecdom" project results for cold appliances.

NB: the actual accuracy of the outcomes will have to be recalculated during the data processing phase based on the measured variance compared to the forecast.

Table 18. Expected accuracy as a function of the sample size for fridges (1 or 2 doors) based on Panel Elecdom data

Scale	Main fridge Mean consumption Y1 (kWh)	Main fridge Standard Dev Y1 (kWh)	Number fridges case 1	Number fridges case 2	Number fridges case 3	Expected Precision case 1	Expected Precision case 2	Expected Precision case 3
COUNTRY	302	154	110	165	220	**10%**	**8%**	**7%**
EU-27	302	154	**880**	**1 320**	**1 760**	**3%**	**3%**	**2%**

Source: Elecdom project And authors' analysis

Table 19. Expected accuracy as a function of the sample size for freezers based on Panel Elecdom data

Country	Zone	Ownership freezers* (%)	Mean consumption Y1 (kWh)	Standard Dev Y1 (kWh)	Number freezers case 1	Number freezers case 2	Number freezers case 3	Number freezers case 1	Number freezers case 2	Number freezers case 3
Germany	CENTRE	50%	288	181	55	83	110	17%	14%	12%
France	CENTRE	54%	288	181	60	90	119	16%	13%	11%
Italy***	SOUTH	41%	288	181	46	68	91	18%	15%	13%
Spain	SOUTH	35%	288	181	39	58	77	20%	16%	14%
Poland	EAST	29%	288	181	32	48	64	**22%**	**18%**	**15%**
Netherlands	CENTRE	61%	288	181	68	101	135	15%	12%	11%
Romania	EAST	43%	288	181	48	71	95	18%	15%	13%
Sweden	NORTH	69%	288	181	76	114	152	**14%**	**12%**	**10%**
		TOTAL	288	181	**424**	**633**	**843**	**6%**	**5%**	**4%**

Source: Statista 2021[42]

The accuracy for fridges is around 2-3% at European level (function of the sample size). Logically, the precision is lower (4 to 6%) for freezers as the sample is smaller.

9.1.11 Selection criteria

The following influencing factors, at household level, have been identified for fridges and freezers at this preliminary stage:

- Household income or socio-professional category
- Dwelling types and location: 3 types of housing (rural -dispersed-, urban -collective- and suburban)
- Housing type: house or flat
- Household composition: single, couple (young and old), family with child(ren).

As the participants will install the dataloggers by themselves, it will be possible to get a sample well scattered within the selected countries in order to take into account a good geographical representativeness (climatic, cultural, daylight…). The pre-sample characteristics will be compared to the national statistics and outliers will be discarded.

The selection criteria will have to be confirmed by the future contractor at the beginning of the mission.

9.1.12 Selection mode

For this project it is necessary to find participants in eight European countries that satisfy the previous described selection criteria. We propose to subcontract this mission to an Online Panel Provider (OPP) which has the capabilities to target appropriate audiences thanks to its panel of thousands of profiled consumers. Online panels are groups of pre-recruited individuals who have agreed to take part in surveys, focus groups, or in-depth interviews. To get recruited into a panel, individuals share a large amount of household data, demographic data, and behavioural characteristics during the registration phase. Sharing this information makes segregation and recruitment easy for future research studies. People are recruited from various channels (Internet, social media and email). Many OPPs reward their panelists in the form of gift coupons.

[42] Ownership rate of freezers in Europe 2021, by country Published by Arne von See May 5, 2021 https://www.statista.com/statistics/1174500/refrigerator-freezer-ownership-rate-european-countries

Project organisation

In order to complete this challenging project, a very qualified Project Manager (PM) should first be appointed. This company will be in charge of supervising the whole project, choosing and managing the subcontractors.

9.1.13 Preparation of the in-situ measurement campaign

Selection and purchase of the monitoring equipment

The metering equipment to be used is described in section 0. A call for tender should be launched at the beginning of the project in order to find the appropriate product at the best price.

NB: due to the current electronic component shortage the delivery time could be very long (at least 6 months).

Recruitment of the Online Panel provider

In parallel, the OPP should be recruited by the PM. This company should be selected with great care as it will play a key role in the project. It will be the direct contact of the participants. Ideally, it should be an international firm with offices in the 8 countries; otherwise, it could be a company with contracts with researchers in the 8 countries able to provide direct contact with the participants. It will not only provide the sample but also performs different tasks as document translation, hotline (see following sections for a more detailed description).

Preparation of the different documents

The different necessary documents are described in the following paragraphs. They will all be:

- Developed by the PM
- Translated and coded (when necessary) by the OPP.

Recruitment tools (advertising and pre-recruitment questionnaire)

In order to enrol participants, a short, clear and user-friendly description of the project should be written. The text should also explain what is expected from the applicant (install a datalogger on his/her main fridge and freezer (S1) or all the fridge(s) and freezer(s) (S2) for one year and fill in a questionnaire related to each appliance) and what will be the reward.

It will be accompanied by a short pre-recruitment questionnaire. The following questions could be asked (non-exhaustive list):

- Do you plan to move out during the year to come?
- How many fridges have you got? (If the answer is none the applicant is rejected)
- Do you plan to change at least one of your fridge(s) during the year to come? (If the answer is yes, the applicant is rejected)
- How many freezers have you got?
- Do you plan to change at least one of your freezer(s) during the year to come? (If the answer is yes, the applicant is rejected)
- Socio professional category
- Housing type (house or flat)
- Household composition (single, couple (young and old), family with child(ren))
- Address
- Email address
- Phone number

These documents will need to be translated in the different languages and to be coded for later Internet broadcast.

Household questionnaire that goes with in-situ measurement

A technical and behavioural questionnaire will be developed in order to collect the information described in section 6.3. The participant will also be asked to upload some pictures (dataplate of each appliance, fridge/freezer settings, fridge/freezer in its environment…).

Monitoring equipment installation guidelines and procedure

The datalogger will be shipped with paper-based installation guidelines.

GDPR form

As personal data will be collected during the project, a GDPR form needs to be filled in by the participants at the beginning of the project. Its creation will be sub-contracted to a GDPR consultant. If legally possible, the form will be filled in and sign online (for example after answering the household questionnaire). The GDPR consultant will be in charge of the whole GDPR strategy of the project i.e., the content of the different GDPR documents.

Recruitment of candidates

The validation of the representativeness of the sample will be sub-contracted to a Statistical Consultant (SC). This company will validate the relevance of the selection criteria that are proposed (see section 9.1.11) and will assist the OPP at each step of the recruitment process.

Pre-recruitment of the potential candidates (online)

The OPP will send the online advertising and the pre-recruitment questionnaire to its panelists that meet the selection criteria.

Validation of the consistency of the sample

Based on the positive answers, the OPP assisted by the SC will build a first sample.

Initial contact with participants (phone)

By experience we know that some candidates that first declare online their willingness to participate will then withdraw from the study when they receive the monitoring devices. In order to avoid this situation, the OPP will call each respondent to re-explain the project and confirm his/her consent. During this call, he/she will confirm his/her coordinates. The SC will closely follow this process as the sample characteristics will probably be continuously modified.

9.1.14 In situ End-use measurements

Questionnaire and GDPR form

Once the oral agreement has been reached, the online household questionnaire (see section 8.1.11) will be sent to the participant. Its last part will contain the GDPR consent form.

Parcel preparation and shipping

The PM will centralise the final list of candidates of the eight countries that have fulfilled the household questionnaire and the GDPR form. It will then send the monitoring device(s) with the installation guidelines to each household.

Installation support for the monitoring equipment

Participants will have to install the plug-in energy datalogger(s) on their fridge(s) and freezer(s). A dedicated hotline (mail and phone number) will be available in each country in order to help with troubleshooting. It will be managed by the OPP assisted by the PM if necessary.

Validation of the correct installation

The confirmation of the correct installation will be validated by picture(s) sent by the participant to the OPP. The picture(s) will show the datalogger plugged between the electrical socket and the fridge(s)/freezer(s). At the end of this stage, the participant will receive a first gift card.

Hotline during monitoring campaign

A hotline, managed by the OPP and the PM, will remain available throughout the measurement period.

Return of the monitoring equipment

After one year, participants will receive a pre-paid return label in order to send the datalogger back to the PM. They will be sent a second gift card, once the data are downloaded.

9.1.15 Data processing

The PM will first clean the data files. Then, statistical adjustment will be made by the SC in order to correct improprieties or limitations in observed data and to remove the influence of nuisance variables. Afterward, the PM will process the data and will be able to answer the questions listed in section 9.1.3.

9.1.16 Summary of the tasks and the key actors

Table 20 summarises the actors of the project and their tasks. The Project Manager has the central role and must be multi-skilled. The second key-actor is the Online Panel Provider. Several companies have been contacted to build this methodology. The best solution would be to find an Online Panel Provider that can do all the described tasks. If it is not possible, it will be necessary to find local contacts in every eight countries for the hotline assistance (installation phase, monitoring period, return of the dataloggers).

Table 20. Summary of the actors of the project and description of their tasks

Actors	Tasks
Project Manager (PM)	- Selection and purchase of the monitoring equipment - Recruitment of the Online Panel Provider, the Statistical Consultant and the GDPR Consultant - Design of the different documents (advertising, pre-recruitment questionnaire, household questionnaire, installation guidelines, GDPR form, document describing the return procedure for the datalogger) - Parcel preparation and shipping - Assistance for the hotline during the installation phase et throughout the measurement period - Data processing
Online Panel Provider (OPP)	- Translation of the different documents (advertising, pre-recruitment questionnaire, household questionnaire, installation guidelines, GDPR form, document describing the return procedure of the datalogger) - Coding of the questionnaires and GDPR form - Recruitment process (online pre-recruitment, initial contact by phone, household questionnaire, GDPR form) - Hotline during the installation phase et throughout the measurement period - Management of the return of the monitoring equipment
Statistical Consultant (SC)	- Validation of the representativeness of the sample at each step of the recruitment process (validation of the selection criteria, continuous validation of the consistency of the sample during its building) - Assistance in data processing (statistical adjustment)
GDPR Consultant	- Development of the GDPR strategy

Source: Authors' analysis

Suggestions to promote and exploit self-reporting appliances in the future

The on-going review of the Ecodesign Directive might introduce the topic of 'self-reporting appliances', i.e., smart products able to measure their own performance and communicate it to the user, manufacturer, and beyond. The European Commission sees it as a way of automatically gathering (anonymised) performance data on large samples of products.

Two obstacles need to be noted though:

- The data gathering is conditioned to the user consent, and there might be a large number of households uncomfortable with sharing their product usage patterns
- There is a risk of manufacturers tampering with the data, in order to show more favourable results or hide potential non-compliance or low performing product data.

Thus, there are some uncertainties on the gathered data representativity, and particularly during the transition period when only specific high-end models will be self-reporting. In the meantime, only in-situ measurement may deliver.

If and once self-reporting becomes standard, it might be conceivable to organise hybrid campaigns, in which representative samples would still need to be constructed and complementary questionnaires used, but the phase of product measurement would be substantially facilitated.

Estimated budget of the different domestic refrigerators and freezers monitoring strategies

This section intends to propose an estimated budget for the different fridges and freezers monitoring strategies.

Table 21 shows the hypothesises of the six different strategies proposed.

Table 21. Summary of the different strategies

Strategy	Monitoring strategy	Number of households		Number of monitored appliances (EU)	
		Per country	EU (Sample: 8 countries)	Fridges	Freezers
S1	Only the main fridge and freezer (if there is one) are monitored in each household.	110	880	880	424
S2		165	1 320	1 320	633
S3		220	1 760	1 760	843
S4	All Fridges and freezers are monitored in each household. Electricity consumption, ambient	96	768	880	424
S5		144	1 152	1 320	633
S6		192	1 536	1 760	843

Source: authors' analysis

Table 22 gives the cost breakdown between the different contractors and sub-contractors for the 6 different strategies.

Table 22. Cost breakdown between the different contractors and sub-contractors for the 6 different strategies

Strategy	Main/All fridges& freezers	Number of households / country	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers purchase& shipping- (€)	Total costs (€)
S1	Main	110	92 800	254 510	8 175	10 000	253 022	618 507
S2	Main	165	118 400	368 090	8 175	10 000	378 993	883 658
S3	Main	220	143 200	481 310	8 175	10 000	505 144	1 147
S4	All	96	91 200	226 202	8 175	10 000	250 693	586 270
S5	All	144	116 000	325 628	8 175	10 000	375 499	835 302
S6	All	192	140 000	424 694	8 175	10 000	500 486	1 083

Source: authors' analysis

The cheapest strategy is S4 which consists in monitoring all the fridges and freezers of a limited number of households (96 households per country) in 8 representative countries (880 main and secondary fridges and 424 main and secondary freezers at EU levels). It lies to an expected precision at European level of:

- 3% for fridges
- 6% for freezers.

Detailed costs for each monitoring strategy

In Annex 2.2, the budget for each strategy to monitor fridges and freezers is broken down between the different tasks and actors. Costs are only indicative as they can be changes depending on the selected dataloggers, the ownership rate of freezers and secondary fridges or freezers in the different countries, the length of the document to translate, the incentives proposed by the Online Panel Provider.

10 Methodologies to collect and analyse relevant real-life energy use data: Gas boilers (ENER lot 1)

This section addresses specifically individual residential gas boilers, wall and floor standing boilers producing heating energy and possibly domestic hot water (DHW). Collective gas boilers and tertiary buildings are out of the scope of this study.

This section provides a methodology for collecting and analysing relevant data on heating and hot water consumption and boiler efficiency. It explicitly details the technical and organisational aspects and the role of the different stakeholders when launching a European in-situ measurement programme.

Gas boiler - General information

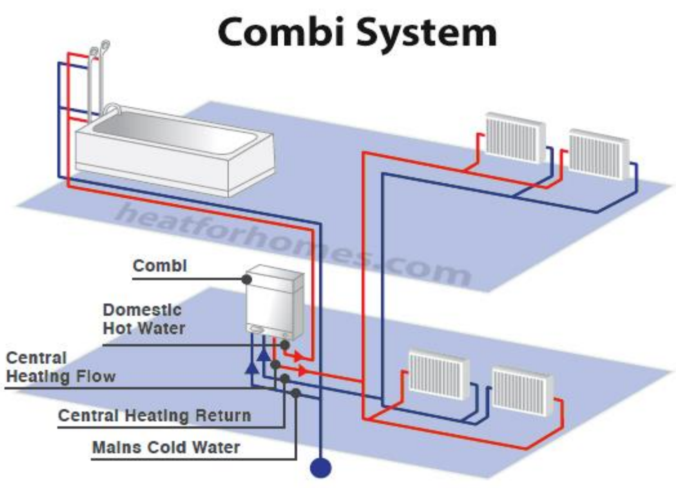
A gas boiler is an appliance that burns gas to produce heat that is transferred to water for space heating and/or domestic hot water production.

Several types of boilers can be differentiated:

- Single or "double service" (with or without DHW production),
- Instantaneous, semi-instantaneous, mini-accumulated DHW production, accumulated with integrated/separate tank,
- Standard or condensing boiler,
- Smoke evacuation by suction cup or chimney

The dual service (or mixed) boiler produces the thermal energy required for central heating and domestic hot water. For heating, different types of emitters, such as high or low temperature radiators, convectors, underfloor heating or radiant ceilings, distribute heat by convection and/or radiation. Each emitter requires a water temperature that can vary from 30°C to 90°C during the heating season for high temperature cast iron radiators or from 21°C to 25°C for ceiling heating. In general, the flow temperature can be related to the age of the flat, as a well-insulated building does not need high temperature radiators. However, there are also exceptions, such as in Spain, where small high-temperature radiators are preferred to low-temperature radiators because of their price and the reduced space they occupy in the flat, and despite the loss of comfort.

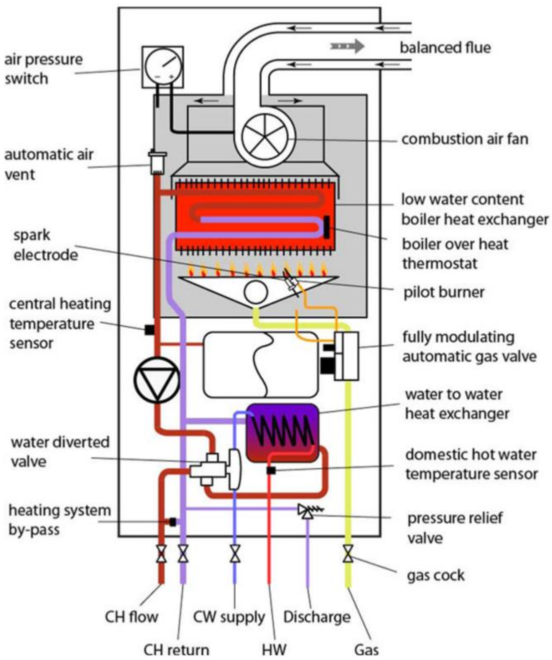
Figure 37. Diagram of a gas combination boiler, source: heatforhomes.com



Source: https://heatforhomes.com/services/new-boilers/

In order to produce heat with gas-fired combination boilers, various components are needed to collect and distribute the heat. Other components ensure the safety of continuous gas combustion, such as the gas valve, the burner, the ignition electrodes, or the air pressure switch that controls the fan acting as a superheat thermostat in the heat exchanger.

Figure 38. Main parts of a gas condensing boiler



source: http://condensingboilergoitsuba.blogspot.com/.

Ecodesign and energy labelling rules for gas boilers in Europe

The EU Ecodesign Directive 2009/125/EC and the energy labelling Directive 2010/30/EU apply to heating and hot water equipment from 2013, through two specific Commission Regulations: No 813/2013[43] and No 811/2013[44], respectively. The aim of these regulations is to reduce the environmental impacts of new products placed on the market and to provide consumers with a means of comparing these products on their performance and energy consumption. Single and double service gas boilers (also known as "combi-boilers") must meet the requirements of this directive.

Requirements apply to:

- The seasonal performance of the equipment,
- Noise emissions,
- Emissions of nitrogen dioxide[45],
- The information provided to the consumer on the energy label.

[43] Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters

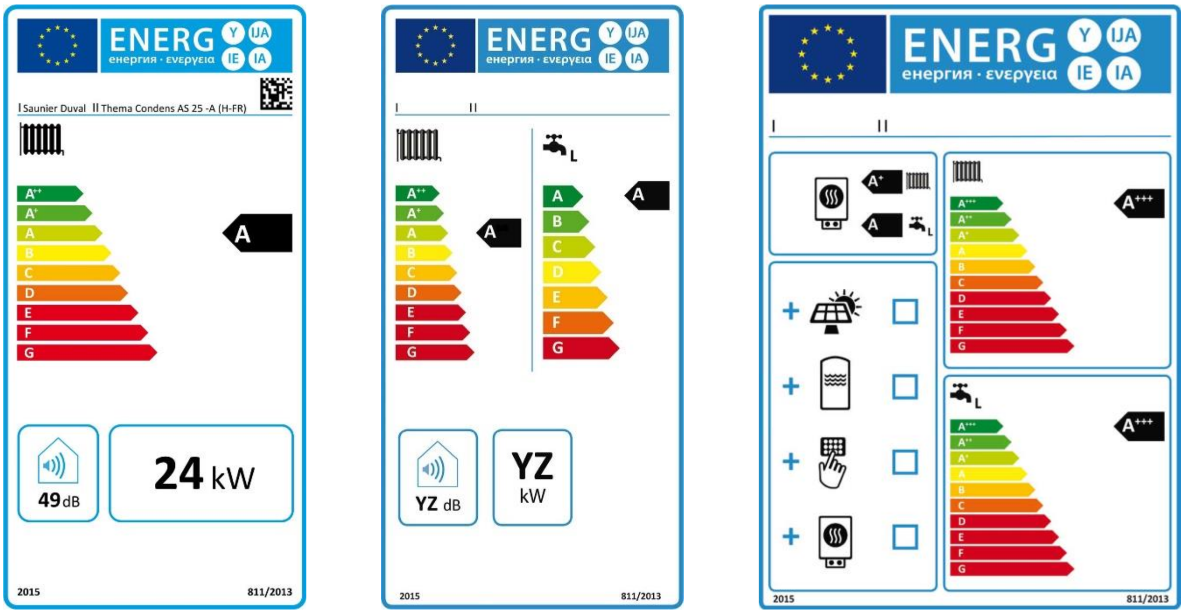
[44] Commission Delegated Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device

[45] It is measured as the sum of nitrogen monoxide and nitrogen dioxide, and expressed in nitrogen dioxide

These performance requirements have driven most standard boilers out of the market in favour of condensing boilers, which offer better operating efficiency.

Figure 39. Examples of boilers' energy label

Single service gas boiler | Double service gas boiler | Combined gas + other boiler



Source: elyotherm.co.uk/erp-energy-related-products

10.1.1 Calculation methods for heating

Energy contained in the gas tested

Boilers are only certified with a reference gas (gas family class chosen by the manufacturer).

EN 15502 describes the calculation to be used to refer the energy of the gas used in the test to that of the reference gas used for certification.

The calculation linking the low calorific value, LCV of the gas used to the LCV of the reference gas is shown below. The common European agreement is to use the LCV, also for condensing boilers, and not the gross calorific value, GVC. However, the energy bill is calculated with the GCV which is the amount of energy contained in the gas, as specified in EN 437. Here we use the GCV as Hs.

$$E_{s,gas} = \sum_{0}^{24h} \left(H_{s,ref} * \frac{10^3}{3600} * v_{gas} * \sqrt{\frac{1013.25 + p_{gas}}{1013.25} * \frac{p_{atm} + p_{gas}}{1013.25} * \frac{288.15}{T_{gas}} * \frac{d_{real}}{d_{ref}}} \right)$$

With :

$\boldsymbol{H_{s,ref}}$	Gross calorific value (GCV) of the reference gas, in MJ/m^3 at 15°C and 1013.25 mbar.
$\boldsymbol{v_{gas}}$	Gas flowrate measured during the test in m^3 /h.

p_{gas}, p_{atm} Pressure of the gas and atmosphere during the test. These terms are used to correct the GCV of the gas to reference conditions.

T_{gas} Temperature of the gas during the test. This term is used to reduce the GCV of the gas to reference conditions.

d_{real} The relative density of the gas during the test (dry density of the gas compared to the dry density of the air). This term is used to relate the GCV of the gas used during testing to the reference gas conditions d_{ref} and the actual gas mixture measured.

The standard distinguishes mainly three families of gases:

1. Low energy" family, 1a: 13.56 to 15.87 MJ/m^3 at 15°C and 1013.25 mbar.
2. Natural gas" family encompassing several groups and subgroups such as
   - 2H and 2E: 31.86 to 45.28 MJ/m^3 at 15°C and 1013.25 mbar
   - 2L: 30.98 to 36.91 MJ/m^3 at 15°C and 1013.25 mbar.
3. Liquid gas family
   - 3B/P: 88.52 to 125.81 MJ/m^3 at 15°C and 1013.25 mbar
   - 3P: 88.52 to 95.65 MJ/m^3 at 15°C and 1013.25 mbar

Nominal thermal energy for heating

The nominal heating energy supplied by the boiler is calculated by measuring the water flow and the temperature rise of the water in the boiler.

$$E_{s,thermal} = \sum_{0}^{24h} \left(v_w * c_w * \left(T_{flow} - T_{return}\right)\right)$$

With:

c_w Specific heat of water: 1.160 to 1.166 Wh/(kg. K)

v_w Central heating water flow rate in litres/hour to achieve a temperature rise of 20K. The flow temperature is set to 80°C and/or 60°C according to the manufacturer's specifications.

$T_{flow,return}$ Water temperatures at the boiler flow and return respectively.

Net thermal efficiency

In addition to the gas energy, the gas boiler needs electricity from the controls, the gas valve, the central heating pump and the combustion fan, which are also measured (E_{elec}).

The net thermal efficiency at nominal conditions is defined as:

$$\eta_{s,day} = \frac{E_{s,thermal}}{E_{gas} + E_{elec}}$$

Nominal efficiency

The nominal efficiency η_1 for space heating is specified in the European standard EN 15502-1 for gas boilers, with a permitted tolerance of +/- 2%.

It is calculated by dividing the nominal thermal energy (Cf 0) by the tested gas consumption (Cf. 0) under nominal steady state conditions:

- Flow temperature 80°C and / or 60°C (manufacturer's declaration) with a flow rate that allows a lower return temperature of 20K;
- Ambient temperature of the boiler room at 20°C;
- Temperature stabilised after 10-30 minutes of continuous operation;
- Only with the reference gas at the reference gas pressure (the manufacturer declares which gas family he would comply with).

Part-load efficiency

The part-load efficiency η_4 is calculated as follows:

- Rated output power at a flow temperature of 80°C and/or 60°C (return temperature 20K lower).
- Part-load power of 30% of rated power for part-load efficiency measurement with a return temperature of:
    - 30°C for condensing boilers;
    - 37°C for high efficiency boilers;
    - 50°C for standard boilers.

Seasonal performance

The seasonal efficiency, or seasonal energy efficiency, is finally used to define the energy class of the boiler, specified in the European directive 813/2013.

Figure 40. Boiler energy classes for heating based on seasonal efficiency $\boldsymbol{\eta_s}$

A+++[8]	≥ 150%
A++	≥ 125%
A+	≥ 98%
A	≥ 90%
B	≥ 82%

[8] A+++ class only applies after 26 September 2019.

Source: European directive 813/2013

This efficiency is the sum of the weighting of 85% of the part-load efficiency η_4 plus 15% of the efficiency at rated power η_1 minus efficiency losses due to controls, auxiliaries, standby losses and ignition losses.

$$\eta_s = \eta_{son} - \sum F_i \quad = 0{,}85 * \eta_1 + 0.15 * \ \eta_4 - \sum F_i$$

With:

$\eta_{1,4}$ Net thermal efficiency of the boiler at nominal load and part load respectively.

$\boldsymbol{F_{(1)}}$ Correction factor for the negative contribution of temperature controllers. For boiler, combi or CHP heating systems, F(1) = 3%.

$\boldsymbol{F_{(2)}}$ Correction factor for the negative contribution of auxiliary electricity consumption. For single and dual fuel boilers:

$F_{(2)}$ = 2.5*(0.15*elmax + 0.85*elmin + 1.3*P_{SB} / (0.15 * P_4 + 0.85*P_1))

$\boldsymbol{F_{(3)}}$ Correction factor for the negative contribution of maintenance consumption (standby losses). For single and dual fuel boilers:

$$F_{(3)} = 0.5 * P_{stby}/P_4$$

$\boldsymbol{F_{(4)}}$ Correction factor for the negative contribution of the ignition burner.

$F_{(4)} = 1.3 * P_{ign}/P_4$

Impact of control equipment

Heating equipment can be awarded additional n_s thermal efficiency points as a 'package'[46], depending amongst other parameters (e.g. presence of solar thermal) on the class of controller it is fitted with.

Table 23. ErP classification of controllers

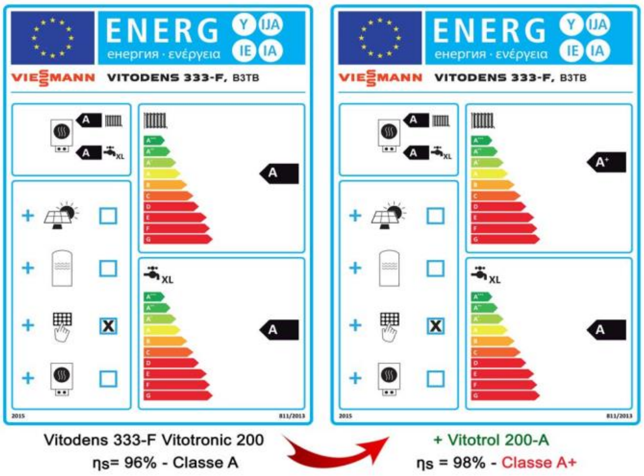
Class I	Room thermostat on/off	**n_s** + 1 pt
Class II	Climate controller with compensation, for use with modulating heaters	**n_s** + 2 pts
Class III	Climate controller with compensation, for use with on/off heaters	**n_s** + 1.5 pts
Class IV	PID room thermostat, for use with on/off heaters	**n_s** + 2 pts
Class V	Modulating room thermostat, for use with modulating heaters	**n_s** + 3 pts
Class VI	Climate control and room sensor, for use with modulating heaters	**n_s** + 4 pts
Class VII	Climate control and room sensor, for use with on/off heating systems	**n_s** + 3.5 pts
Class VIII	Multi-sensor room temperature controller for use with modulating heaters	**n_s** + 5 pts

Source: European directive 813/2013

For example, the energy label of the "Viessmann Vitodens 333-F" boiler is increased from A to A+ if the "Vitotrol 200-A" remote control option, which incorporates a room temperature sensor (class IV), is taken into account.

[46] Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device Text with EEA relevance

Figure 41. Viessmann Vitodens 333-F with and without controller



Source: elyotherm.co.uk/erp-energy-related-products

10.1.2 Calculation method for Domestic Hot Water production

Filling profiles

The efficiency for domestic hot water is specified in the relevant European Directive ErP 813/2013. The efficiency is calculated as follows:

- The manufacturer selects a hot water draw-off profile between 0.345kWh (3XS) and 93.52kWh (4XL) of useful energy consumed daily for domestic hot water. Tap flow rates, 2 litres/min (3XS) to 96 litres/min (4XL), and temperatures, 25 to 55°C, are specified over a 24-hour test according to the chosen profile. The manufacturers are required to choose the maximum achievable profile for their appliances or the next lower profile. As 24 or 32kW instantaneous boilers are able to produce 11.4 or 15.2litres/min with a temperature rise of 30°C, manufacturers are then required to declare the XL or XXL draw-off profile.
- The efficiency is the division of the useful energy set by the withdrawal profile with the measured energy consumed to achieve the withdrawal profile chosen by the manufacturer.

$$\eta_{wh} = \frac{Q_{ref}}{(Q_{fuel} + CC \cdot Q_{elec})(1 - SCF \cdot smart) + Q_{cor}}$$

$$Q_{cor} = -k \cdot (CC \cdot (Q_{elec} \cdot (1 - SCF \cdot smart) - Q_{ref}))$$

$$SCF = 1 - \frac{Q_{fuel.week.smart} + CC \cdot Q_{elec.week.smart}}{Q_{fuel.week} + CC \cdot Q_{elec.week}}$$

With :

ηwh	Energy efficiency (%).
Q ref	Daily useful hot water draw-off" (kWh/d) from the regulatory draw-off profile (M, L, XL,...)
Q fuel	Measured daily fuel consumption.
Q elec	Measured daily electricity consumption based on the low calorific value LCV.
CC	European primary energy conversion factor for electricity (CC=2.5).
Qcor	Room correction term expressed in kWh, which takes into account the fact that the
k	Room correction term (k=0.23 for profiles 3XS to XL and k=0 for profiles > to XL)
SCF	Smart control factor". If SCF ≥ 0.07 then smart=1.

Figure 42. EU Regulation 812/2013- Energy efficiency classes for water heating ηwh in % , according to declared draw-off profiles.

	3XS	XXS	XS	S	M	L	XL	XXL
A^{+++}	$\eta_{wh} \geq 62$	$\eta_{wh} \geq 62$	$\eta_{wh} \geq 69$	$\eta_{wh} \geq 90$	$\eta_{wh} \geq 163$	$\eta_{wh} \geq 188$	$\eta_{wh} \geq 200$	$\eta_{wh} \geq 213$
A^{++}	$53 \leq \eta_{wh} < 62$	$53 \leq \eta_{wh} < 62$	$61 \leq \eta_{wh} < 69$	$72 \leq \eta_{wh} < 90$	$130 \leq \eta_{wh} < 163$	$150 \leq \eta_{wh} < 188$	$160 \leq \eta_{wh} < 200$	$170 \leq \eta_{wh} < 213$
A^{+}	$44 \leq \eta_{wh} < 53$	$44 \leq \eta_{wh} < 53$	$53 \leq \eta_{wh} < 61$	$55 \leq \eta_{wh} < 72$	$100 \leq \eta_{wh} < 130$	$115 \leq \eta_{wh} < 150$	$123 \leq \eta_{wh} < 160$	$131 \leq \eta_{wh} < 170$
A	$35 \leq \eta_{wh} < 44$	$35 \leq \eta_{wh} < 44$	$38 \leq \eta_{wh} < 53$	$38 \leq \eta_{wh} < 55$	$65 \leq \eta_{wh} < 100$	$75 \leq \eta_{wh} < 115$	$80 \leq \eta_{wh} < 123$	$85 \leq \eta_{wh} < 131$
B	$32 \leq \eta_{wh} < 35$	$32 \leq \eta_{wh} < 35$	$35 \leq \eta_{wh} < 38$	$35 \leq \eta_{wh} < 38$	$39 \leq \eta_{wh} < 65$	$50 \leq \eta_{wh} < 75$	$55 \leq \eta_{wh} < 80$	$60 \leq \eta_{wh} < 85$
C	$29 \leq \eta_{wh} < 32$	$29 \leq \eta_{wh} < 32$	$32 \leq \eta_{wh} < 35$	$32 \leq \eta_{wh} < 35$	$36 \leq \eta_{wh} < 39$	$37 \leq \eta_{wh} < 50$	$38 \leq \eta_{wh} < 55$	$40 \leq \eta_{wh} < 60$
D	$26 \leq \eta_{wh} < 29$	$26 \leq \eta_{wh} < 29$	$29 \leq \eta_{wh} < 32$	$29 \leq \eta_{wh} < 32$	$33 \leq \eta_{wh} < 36$	$34 \leq \eta_{wh} < 37$	$35 \leq \eta_{wh} < 38$	$36 \leq \eta_{wh} < 40$
E	$22 \leq \eta_{wh} < 26$	$23 \leq \eta_{wh} < 26$	$26 \leq \eta_{wh} < 29$	$26 \leq \eta_{wh} < 29$	$30 \leq \eta_{wh} < 33$	$30 \leq \eta_{wh} < 34$	$30 \leq \eta_{wh} < 35$	$32 \leq \eta_{wh} < 36$
F	$19 \leq \eta_{wh} < 22$	$20 \leq \eta_{wh} < 23$	$23 \leq \eta_{wh} < 26$	$23 \leq \eta_{wh} < 26$	$27 \leq \eta_{wh} < 30$	$27 \leq \eta_{wh} < 30$	$27 \leq \eta_{wh} < 30$	$28 \leq \eta_{wh} < 32$
G	$\eta_{wh} < 19$	$\eta_{wh} < 20$	$\eta_{wh} < 23$	$\eta_{wh} < 23$	$\eta_{wh} < 27$	$\eta_{wh} < 27$	$\eta_{wh} < 27$	$\eta_{wh} < 28$

Source: EU Regulation 812/2013

10.1.3 Critical look on the regulation

Critical look regarding space heating

Two points of the regulatory approach on heating efficiency could be improved:

- The EN15502 standard allows an uncertainty level of +/- 2% during testing[47]. However, the "verification procedures for market surveillance purposes" allows that "the seasonal space heating energy efficiency η_s is not more than 8 % lower than the declared value at the rated heat output of the unit"[48]. Thus, currently, is given to manufacturers the possibility of 5 to 6.5% (i.e. 8% - 2% - 0,5% uncertainty) higher declaration of the $\boldsymbol{\eta_s}$ value, than possible by calculation;
- There is no standard that takes into account the impact of cycling losses. However, it considerably reduces the seasonal efficiency measured in the field, due to the boiler short operating cycles, especially when the heating needs are low (outdoor temperatures between 5 and 16°C).

The boiler short operating cycles observed in the field, which degrade its efficiency, are related to:

- The power demand profiles of the dwellings, which vary over time (due to the effect of controls, internal and solar gains in the dwellings, etc.).
- The recurring oversizing of heating installations.

The European standard EN 12831 is set as follows to meet the building's needs (power need of the installation, emitters and the boiler):

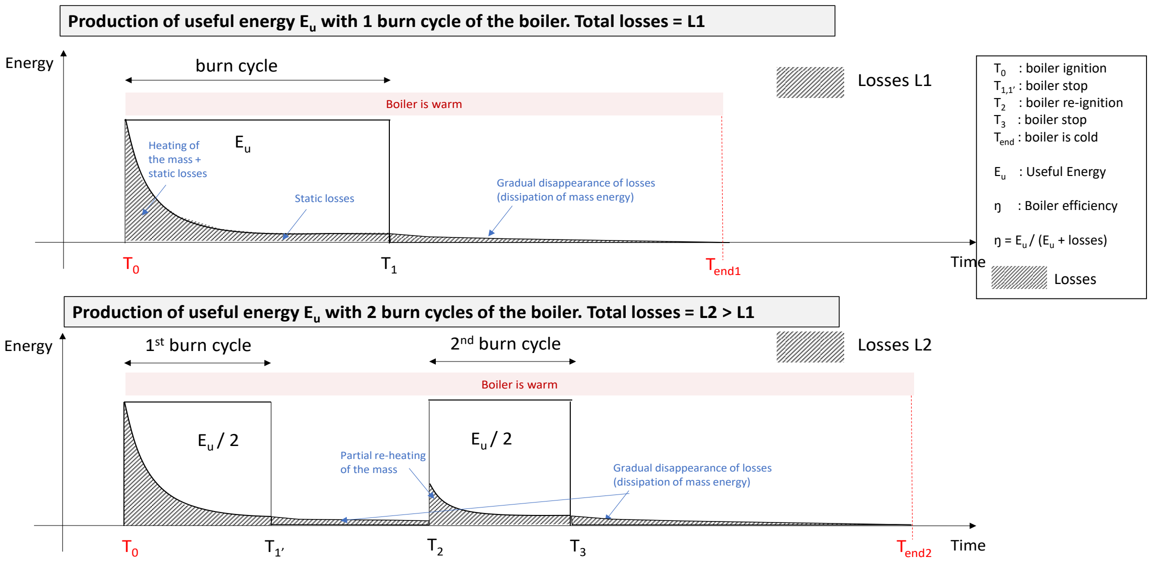
[47] The ns value is calculated with the nominal and part load efficiency tested during product certification to be in the scope of +/- 2% according the product standard EN 15502–1. The variability in the correction factors F1 to F4 will not change this measurement uncertainty.

[48] Annex IV of the COMMISSION REGULATION (EU) No 813/201.

- Lowest outdoor temperature measured in the region[49].
- Highest possible ventilation airflow at this location.
- 20% overload for miscellaneous and morning start-up after reduced ambient temp. during the night.
- Gross estimate of the U-value in W/(m²K) and the total heat loss area of the building
- The installer takes the closest (above) boiler output from to the one calculated with these parameters.

This leads to install boilers with 30-40% higher output than the building needs at the coldest time of the season. So, the boiler frequently cycles ON/OFF because it is not able to modulate enough (if a modulating boiler is installed). In this situation, energy losses of up to 30% can be observed. These operating cycles, observed in the field, are, in our opinion, the primary factor in the discrepancy between the efficiencies measured in laboratories and the actual efficiencies in the field. As it can be noted in Figure 43, When there are more cycles to provide a given amount of energy, the boiler is hot for longer time so the losses increase; this results in longer ignition cycles to heat up the mass that has cooled down between two cycles: here (T3 - T2) + (T1' -T0) > T1 -T0.

Figure 43. Illustration of the increase in energy loss with increasing number of cycles.



Source: authors' analysis

Critical look regarding domestic hot water production

The end-user often chooses a combi boiler mainly because it takes smaller floor space than a boiler with separate storage. The drawback is that the DHW power need is 3 to 16 times higher than the power needed for central heating at the ErP part-load efficiency with a weighting of 85%. Recent developments in burners have made it possible to achieve today a modulation rate of 80 to 90% (compared to only 60 to 70% in the past). However, it does not avoid short operating cycles, given the ever-reducing heat demand and oversizing of the appliances.

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[49] since 1970, no adaptation has been made so far despite climate changes

Due to the thermal mass stored in a hot water tank, 24 kW boilers with a 50 or 100 litre tank could theoretically gain one class over 32kW instantaneous boilers.

This point is not enough taken into account inthe current tests, which use draw-off profiles that are often too high compared to reality (XL, XXL in particular). These profiles tend to minimise losses in relative terms and therefore erase the interest of storage.

A reduction of draw-off profiles used to qualify the production of DHW could therefore be considered, in order to encourage the use of storage tanks, and reduce the total energy consumption.

In France, successive thermal regulations have reduced the power needed to heat buildings but in the meantime the power necessary to produce DHW has increased for "comfort" reasons. It implies a very high modulation requirement in order to meet heating needs which combi-boilers are not able to cover (see the Figure 44 below). The number of short operating cycles, and the related energy losses, therefore increase.

Figure 44. Evolution of the installed DHW power in France over the years

FR : H1b			*< 1988*		*> 1988*		*> 2000*		*> 2005*		*> 2012*		
	outside temp.	*need in %*	need	installed	need	installed	need	installed	need	installed	need	installed	
P_{nom}	-9,0°C	*100%*	*19,8*	***24***	*13,2*	***24***	*8,6*	***32***	*6,4*	***32***	*5,3*	***32***	*kW*
$P_{15\% ERP}$	-1,2°C	**53%**	**10,4**	***43%***	**7,0**	***29%***	**4,6**	***14%***	**3,4**	***11%***	**2,8**	***9%***	**kW**
$P_{85\% ERP}$	3,9°C	**37%**	**7,4**	***31%***	**4,9**	***20%***	**3,2**	***10%***	**2,4**	***8%***	**2,0**	***6%***	**kW**
	16,0°C		3,3 x		4,9 x		9,9 x		13,3 x		16,1 x		

Source: authors' analysis

- French climatic region: H1b, the coldest region in France
- Outdoor temperature taken for design of a building according to EN 12831: -9°C
- Average temperature of 15% of ErP consumption achieved with -1.2°C, i.e., 53% of the power required (far from the ErP standard).
- Average temperature of 85% of ErP consumption achieved at 3.9°C or 37% of the required power (close to the ErP standard).
- For installations prior to 1988, the correspondence between the installed capacity (choice of boiler for heating + DHW) and the required capacity is quite good.
- For central heating installations after 1988, the installed capacity of 24 kW and then 32 kW (heating + DHW) follows an opposite trend to the new heating needs of the buildings.

In summary, it seems important to consider the following points, when revising the combined boilers test procedures:

- The impact of oversizing installed capacity on equipment efficiency;
- Updating the extraction profiles (heating, DHW) used in the tests, so as to reproduce in the laboratory the numerous operating cycles observed in the field (a phenomenon that has a major impact on the measured efficiency);
- Favouring installations using a large well insulated volume of DHW storage, as opposed to instantaneous production (linked to the previous point).

Parameters to be monitored

10.1.4 Factors influencing the energy consumption and efficiency of gas boilers

What is the performance of a gas boiler?

The efficiency of a boiler is the ratio between the useful energy it produces and the energy it absorbs:

- The absorbed energy corresponds to the energy contained in the gas consumed by the boiler;
- The produced energy is the thermal energy derived from the combustion of the gas by the boiler. This energy ends up as useful energy and heat loss;
- The useful energy is the sum of the useful energy both supplied to the heating system and for the DHW. The useful energy is considered "at the boiler terminals".
- Boiler losses are equal to the absorbed energy minus the useful energy.

Boiler losses are related to:

- For a very small part, the imperfect combustion of the burner (unburned gases);
- For the major part, the heat loss from the boiler through its walls, especially through the smoke exhaust when the furnace is hot (thermal stack effect).

Energy contained in the gas

The energy contained in the gas depends mainly on its composition and its flowrate. Its temperature, pressure, density and atmospheric pressure also influence the result. The composition of the gas is regulated in Europe by EN 437, which specifies harmonised information at European level on the gas category, gas families, gross calorific values of its reference gases and limit gases and the range of pressure that may exist in a local gas network. In addition, Member States are required to notify the Commission and other Member States of the types of gas, gross calorific value, gas composition and gas fuel supply pressures used in their territory (European Parliament Regulation (EU) 2016/426, Article 4, Gas supply situation, since 21 October 2017). The data sheets for gas boilers usually indicate the category and family of gases they can tolerate, in addition to their rated output power.

Figure 45. Example of a gas boiler data sheet.

ThemaPlus Condens MA 20/26-CS/1 (N-BE)	Unité	Valeur
Numéro d'article		0010025079
Type de chaudière		Mixte
Catégorie gaz		I2N & I3P
Numéro CE		CE-0063DL3988
Données ErP		
Efficacité énergétique saisonnière pour le chauffage (ηs)	%	94 / A
Efficacité énergétique saisonnière pour l'eau chaude (ηWh)	%	83 / A
Profil de soutirage	-	XL
Puissance thermique nominale	kW	20
Rendement à charge partielle (30% et retour 30°C) (Hi/Hs)	%	110 / 99,1
Rendement à charge nominale (100% et 80/60°C) (Hi/Hs)	%	97,3 / 87,7
Pertes à l'arrêt	kW	0.045
Consommation d'électricité auxiliaire à pleine charge	kW	0.033
Puissance électrique en mode veille	kW	0.002
Puissance maximale de la pompe	W	43
Type de pompe	-	Moteur à rotor noyé
Indice EEI de la pompe	-	0.2
Niveau de puissance acoustique, à l'intérieur	dB (A)	47
Emission Nox	mg/kWh	38
Classe de Nox	-	6

Source: Sunier Duval

In Europe, appliances that are using gas are divided into three categories according to the families of gases they accept:

- I: appliances that use only one group of gas families.
- II: Appliances that can be installed for two different gas families, through local adaptation (change of injector) or adjustment of the gas valve by a certified professional, the gas power is adapted.
- III: Appliances that can be installed for three different gas families, through local adaptation (change of injector) or adjustment of the gas valve by a certified professional, the gas power is adapted.

This gas categories allow manufacturers to produce a single boiler that can accommodate the different gases in the field. In Europe, three different groups of gas families will be found for appliances:

- Family Group 1, low energy gases 1a, 1b, 1c, 1d and 1e: mixtures of gases with low methane or propane content and less nitrogen, hydrogen and/or air.
- Family group 2, natural gas families 2H, 2L and 2E: gas mixtures with high methane content and low nitrogen, hydrogen and/or propane content.
- Family group 3, liquid gas families 3B/P and 3P: propane, butane or propylene gas.

Each gas family contains different gases such as:

- One reference gas: efficiency, gas power and nominal heat output for an appliance are only tested with this gas.
- One to three limit gases: these gases are used to check the good functioning of the boiler in terms of light back gases that contains hydrogen, lift flame gases that contains nitrogen and incomplete combustion and scooting gases that contains propane and/or ethane. As appliances are only tested with the reference gas, it means that no information is available about the efficiency or heat output variation with limit gases although they can be found in the field.

The gas boiler designed to fit one gas family group must cope without any manual post-installation adaption by a professional:

- with the possible gas changes in this group (as defined in the standard)
- with the possible changes in the field, like changes of:
    - gross calorific value and density of the gas
    - gas and atmospheric pressure
    - gas temperature.

In any case, the boiler must adapt the gas flowrate to the building power demand with the same power output. It represents a gas flowrate variation from -9% to +6% compared to the reference conditions in certification. This means that if the outside conditions (gas temperature, gas pressure, and the atmospheric pressure) are not measured but set to the reference values, we will get the same power variation (-9% to +6%). This variation is more or less identical for all gas families.

The split of this power variation is as follows:

- All outside conditions measured, but with atmospheric pressure set to the reference value of 1013.25 mbar (instead of 1048.9 mbar to 951.8 mbar): +1.7% to -3.1%
- All outside conditions measured, but with the gas pressure set to the reference value of:
    - 1a: 8 mbar instead of 15mbar or 6mbar: +0.2% to -0.7%
    - 2H & 2E: 20mbar instead of 25mbar or 17mbar: +0.3% to -0.5%
    - 2L: 25mbar instead of 30mbar or 20mbar: +0.5% to -0.5%
    - 3B/P: 29mbar instead of 35mbar or 25mbar: +0.4% to -0.6%
    - 3P: 37mbar instead of 45mbar or 25mbar: +1.2% to -0.7%
- All outside conditions measured, but with the gas temperature set to the reference value of: 20°C instead of -22°C (lowest outside temperature in the climate class C, if gas pipework is outside) to +35°C (maximum summer outside temperature): +2.5% to -7.1%

If this analysis is extended to the other gas families, with the measurement of the gas pressure, the gas temperature, and the atmospheric pressure, but with the gross calorific value and the relative density set to the reference value of the reference gas, the flow rate will vary in comparison to the real value by:

- Low energy gas family, 1a: 0 to 6%
- Natural gas families:
  - 2H: -10% to +12%
  - 2L: -5% to 0%
  - 2E: -10% to +12%
- Liquid gas families:
  - 3B/P: 0 to 19%
  - 3P: 0 to 2%

In summary, it is essential for the calculation of the gas energy ($\boldsymbol{E_{s,gas}}$) to know the daily relative density of the gas consumed by the boilers and that, despite this information, external conditions lead to uncertainties ranging from -10 to +12% for the 2H and 2L gas families.

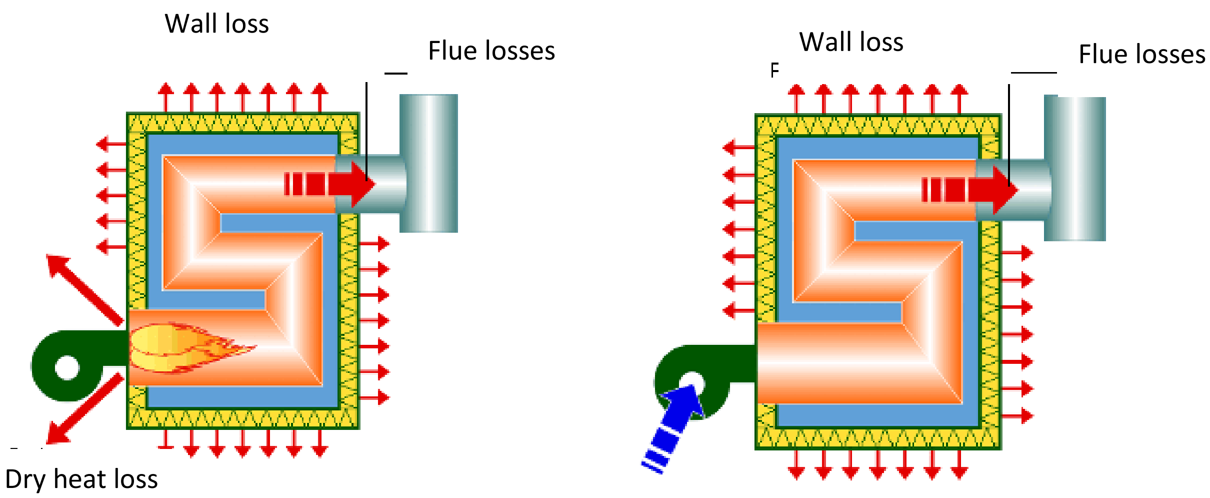
Losses of the installation

The losses of a boiler are related to:

1. Its Design:
   - Flue gas losses
   - Heat loss from the boiler casing to the room
   - Loss of DHW storage in the boiler [38]
   - Heat losses in the flue gas (thermal draught)

2. Its Installation and operation:
   - Boiler setting (constant flow temperature constant or related to outdoor temperature)
   - Operating cycle (linked to the boiler sizing and the heat demand profile)
   - Return temperature for a condensing boiler
   - DHW storage temperature (with an integrated tank).

Figure 46. Illustration of energy loss of a gas boiler



Source: https://energieplus-lesite.be/evaluer/chauffage4/

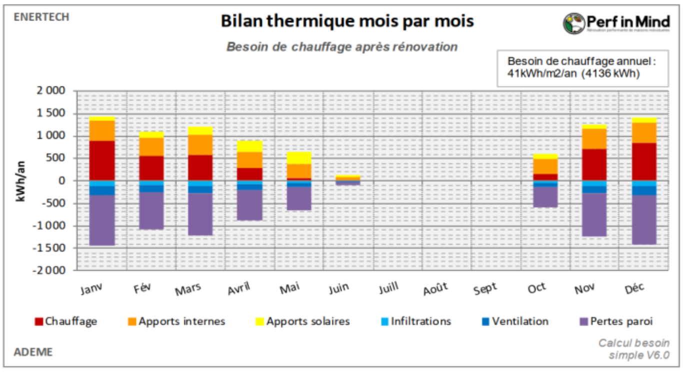
Supplied useful energy

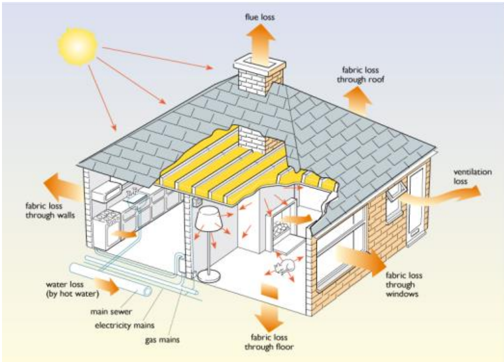
Useful heating

Heating is necessary to compensate for building losses when internal and external heat inputs are not sufficient to maintain a comfortable temperature.

- ➢ The external heat and solar gains depend on the weather and the configuration of the building (orientation and surface of the glazed elements, solar factors of the glazing, insulation of the walls etc.);
- ➢ The internal heat gain depends on the occupants (number and duration of occupancy) as well as on the electrical consumption of household appliances;
- ➢ The heat loss of the building depends on the weather (temperature, wind, etc.), the building envelope (wall insulation, air tightness) and the mechanical ventilation system.

Figure 47. Illustration of the thermal balance of a building





Source : https://www.open.edu/openlearn/nature-environment/energy-buildings

NB: All losses, and therefore heating consumption, also depend on the behaviour of users. Indeed, not all occupants have the same expectations for ambient temperature during occupancy and not all of them want the ambient temperature in their dwelling to be lowered at night.

Useful DHW

Domestic hot water consumption depends on:

- The drawn volumes (that depend on behaviour and flow rates at the drawing points)
- Losses from external storage to the boiler and the distribution.

DHW production can be instantaneous, semi-instantaneous, mini-accumulated or with an integrated storage tank, allowing the storage of DHW at a fixed set temperature. The storage losses depend on the storage volume, the set DHW temperature and the ambient temperature of the room.

Auxiliaries' electrical consumption

The auxiliaries' electricity consumption corresponds to:

- Boiler controls and gas valve (5 to 10W)

- Circulators for heating, and possibly for hot water (10W to 150W)

- Combustion fan (10 to 30W)

- The electronic control of the boiler.

The operating times and power variations of the auxiliaries require continuous monitoring of their electricity consumption in order to include them in the balance sheet.

10.1.5 How to qualify heating and DHW consumptions?

Table 24 summarises the main parameters influencing the consumption and/or efficiency of the boilers, according to the points developed in the previous paragraphs. Section 10.5.2 details how these different parameters can be monitored.

Table 24. List of parameters influencing boiler consumption and efficiency

Influencing factors	1 - GCV Gas	2 - Useful thermal energy	3 - Absorbed electrical energy
Gas composition	✓		
Gas flow rate	✓		
Gas temperature	✓		
Gas pressure	✓		
Outdoor temperature	✓	✓	
Indoor temperature		✓	
Building envelope		✓	
Mechanical ventilation		✓	
Technical characteristics of the boiler		✓	
Technical characteristics of the installation (storage,		✓	
Heating management by the occupants		✓	
Household electricity consumption (internal gains)		✓	
Hydraulic flow rate (heating + DHW)		✓	
Flow/return temperature (heating)		✓	
Cold water and DHW outlet temperatures		✓	
Power consumption of the boiler			✓

Source: Authors' analysis

Benefits of the project to improve and inform EU policies

The results of a European monitoring campaign of gas boilers will be very useful for both the evaluation of the EU regulatory process (e.g., Ecodesign Impact Accounting study) and to inform future improvements of the Ecodesign and Energy Label Regulations. It would bring considerable added-value to the Ecodesign preparatory studies. The results and lessons learned may also be used in several other ways.

The benefits have already been described in the previous sections. In this paragraph we apply our general conclusions to the specific case of gas boilers.

10.1.6 Information expected from the field data collection

The following information could be derived from the in-situ measurement programme (non-exhaustive list):

- What is the average gas GCV per country? How does it change over the year?
- What is the average annual gas consumption for heating and DHW (for given types of housings)?
- What is the average annual production of heating and/or DHW of individual gas boilers?

- What is the average efficiency of individual gas boilers? For heating production? For DHW production?
- What is the average length of the heating season by country and/or climate zone?
- What is the number and average duration of a heating operating cycle?
- Is the field operation similar to the laboratory test?
- What is the average load rate of a boiler? How does it vary throughout the year?
- What is the average daily heating load curve during the heating season?
- What is the correlation between heating consumption and outdoor temperature?
- What are the temperature regimes and what do they depend on?
- What are the operating regimes of the auxiliaries and what are they controlled by?
- What are the levels of heating controls, from boiler to emitters?
- Is there a gas consumption when a boiler is switched off?
- What is the electrical consumption of the boilers?
- Are there any explained or unexplained trends that undermine the impact of ecodesign and energy labelling regulations?
- Are there any key factors that are not sufficiently or inadequately covered by the regulations?

10.1.7 Ecodesign impact accounting

The in-situ measurement campaign will provide a highly-welcome calibration point for the Ecodesign Impact Accounting calculations that estimate theoretically the benefits of Ecodesign and Energy Labelling. It will also allow to better understand the determinants of energy use of gas boilers and improve the modelling of impact assessments.

Provide a first calibration point

In-situ monitoring campaign will give a precise picture, in a given year, of:

- The average constitution of the stock of gas boilers in households (in terms of model, energy class, nominal power, single or mixed boiler, standard or condensing, etc) that can be confronted to the theoretical stock models based on sales data and assumptions used in Ecodesign Impact Accounting and resulting in potential data corrections and improvements;
- The power level and average operating durations in the field, leading to substantial improvements of the typical imprecise assumptions that are used at EU level;
- Comparing the theoretical energy consumption calculations against a field measurement, allowing for questioning the sources of potential deviations and identifying the main sources.

Such a calibration point is important to improve the modelling data and factors taken into account, and ensure the accounting modelling delivers credible impact assessments.

Provide insights on the impact of Ecodesign and Energy Labelling

A measurement campaign provides information for a given year, so in theory it is a relatively static picture making it difficult to depict trends over the years.

However, in a sample of hundreds of households, there will be product models of different ages and different technologies. By classifying them by purchase date and streamlining and harmonising as much as possible the measured energy performance, some historical comparison may be drawn.

10.1.8 Informing the revision of Ecodesign and Energy Labelling Regulations

The in-situ measurement could provide valuable insights on several aspects of the regulations to prepare future reviews, including:

- The appropriateness of the energy label and efficiency index formulas to drive market change in the right direction;
- The credibility of test methods to reflect real-life use;
- Other aspects currently overlooked in regulations.

10.1.9 Additional benefits and opportunities

On top of informing Ecodesign and Energy Labelling regulations, the results of the measurement campaign would have many other benefits, such as:

- Providing information by country and by climate zone on the levels of final energy consumption for heating and DHW;
- Improving energy demand models at European and national levels, with better data on gas boilers;
- Providing useful quantitative information for awareness raising and educational campaigns on sustainable behaviours and energy saving tips
- Feeding other initiatives, reports, and projects on product efficiency covering heating and DHW
- Supporting national authorities in charge of monitoring and surveying markets
- Raising public, media and opinion leader awareness on sustainability challenges with heating products
- Improving NILM or deep neural network systems.

Monitoring strategy

10.1.10 Scope of instrumentation

Type of climate

Climate is one of the most important explanatory factors of the heating consumption of dwellings. We propose to consider the 8 countries with the largest number of gas boilers as sampling frame. They cover all climatic zones except the arid zones:

- Oceanic (France, Denmark, Netherlands)
- Warm temperate (Spain, France, Italy)
- Continental (Germany, Poland, Romania, Belgium)
- Mediterranean (Spain, Italy, France)
- Mountainous (Spain, Italy, France, Romania)

More details regarding the choice of the countries are given in section 10.8.1.

Type of installation

The installations covered by this study are individual gas boilers in the residential sector, such as wall or floor standing boilers producing heating and which may or may not include DHW production. Collective gas boilers and tertiary buildings are out of scope. Some types of combination boilers (with an additional heating system) will also be out of the scope of this study for the reasons detailed in the section 10.5.2.

Furthermore, copper or steel distribution networks will be preferred due to the proposed type of metrology and the uncertainties linked to contact temperature sensors as detailed in paragraph 10.6.3.

Type of gas family

In order to ensure reliable measurement of gas consumption, gas boilers that are not connected to a gas network with a billing meter should be excluded from the scope of the study.

As already mentioned in the paragraph 0, the energy contained in a gas varies according to its family and the associated borderline gases. Given these variabilities and the fact that the most widespread families of natural gas in Europe are 2H and 2L (G20 and G25 gases), the study will therefore be limited to these gases.

10.1.11 In-situ measurements

Parameters to measure

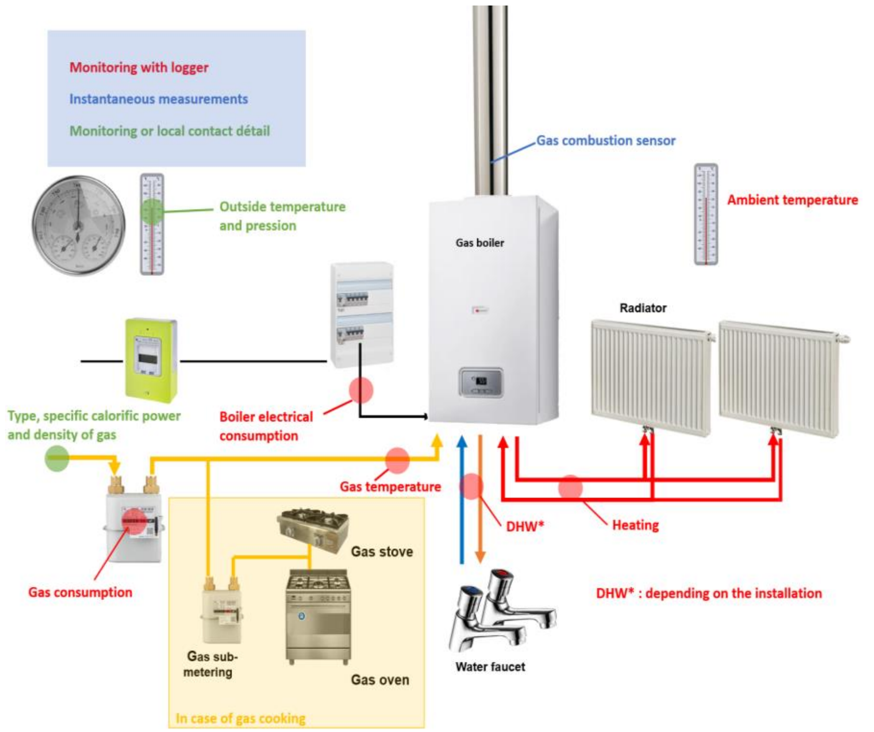
The different measurement points or readings to be taken are presented in Table 25 and Figure 48. They correspond to the different parameters that influence the consumption and the efficiency of the boilers.

Table 25.. List of parameters to be monitored

Parameters to be measured and collected	Continuous measurements (Time step of 1 minute)	In situ measurements and data collection	Information to be collected
Gas composition			✓ (daily)
Gas flow rate	✓		
T°C gas	✓		
Gas pressure			✓
Outdoor temperature			✓ (hourly)
Combustion gas analysis		✓	
Indoor temperature	✓		
Heating flow rate	✓		
Flow and return temperature heating	✓		
DHW flow rate (if gas DHW production)	✓		
T°C cold water and DHW tap water	✓		
Building envelope	-	-	-
Technical characteristics of the installation and boiler		✓	
Occupant behaviour	(T°C int)		
Electricity consumption of the dwelling	-	-	-
Boiler power consumption	✓		

Source: Authors' analysis

Figure 48. Visualisation of the parameters to be monitored



Source: Authors' analysis

The total gas consumption of the dwelling, the gas and electricity consumption of the boiler, the useful productions of heating and DHW with the associated temperature levels, as well as the ambient temperature of the dwelling could be derived from these data.

Important notice:

1. In case of use of an auxiliary energy for heating (e.g. by a wood stove, electric convector, etc.);, the heating consumption of the dwelling will not be known in its entirety
2. In case of using an auxiliary energy for DHW (e.g., solar), the DHW consumption of the dwelling will not be known in its entirety and depending on the configuration of the installation, the measured DHW consumption will include or not the storage losses.

These important aspects need to be covered by questions asked of the participants to provide additional information.

Figure 49, 50 and 51 show different types of heating and domestic hot water installations. Cases 1 to 4 illustrate installations that do not pose any problems for monitoring the total energy output of the boiler.

Figure 49. Heating and DHW installations suitable for in-situ measurements

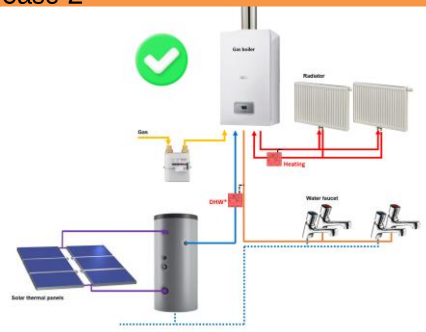
Case 1

Heating useful energy

Domestic hot water useful energy + volume of drawing

Efficiency + gas consumption of boiler

Case 2



Heating useful energy

Domestic hot water boost + volume of drawing

efficiency + gas consumption of boiler

Case 3

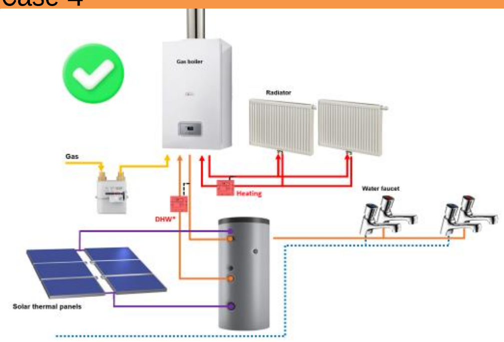
Heating useful energy

Domestic hot water useful and losses of hot water tank

Efficiency + gas consumption of boiler

Gas consumption of boiler

Case 4



Heating useful energy

Domestic hot water boost

Efficiency + gas consumption of boiler

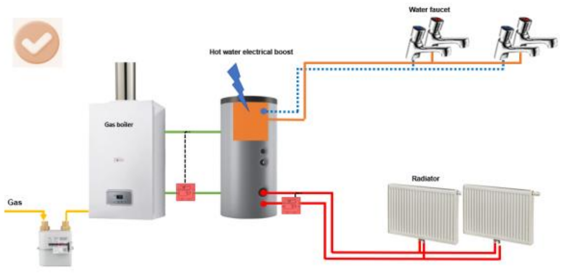
Gas consumption of boiler

Source: Authors'analysis

Cases 5 to 6 illustrate installations present difficulties for in-situ measurements as they do not allow the use of the heat produced by the boiler to be determined (heating or DHW). It is possible to determine a total production efficiency but not a production efficiency for heating (as described by the label).

Figure 50. Heating and DHW installations presenting difficulties for in-situ measurements

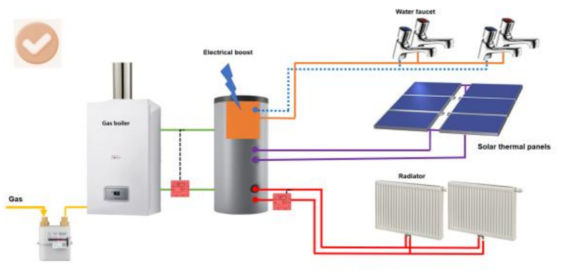
Case 5



Efficiency + gas consumption of boiler

Heating useful energy

Case 6



Efficiency + gas consumption of boiler

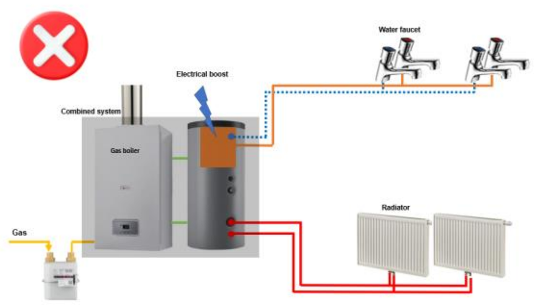
Heating useful energy

Source: Authors' analysis

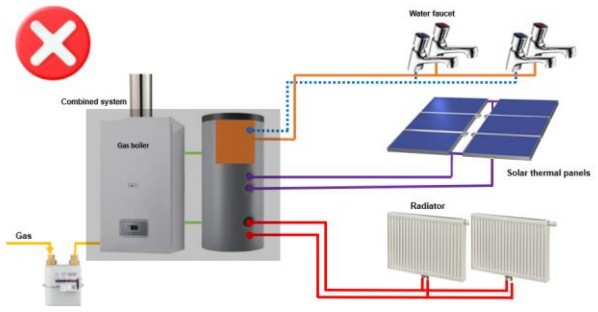
Cases 7 and 8 illustrate installations to be avoided absolutely because they are integrated "multi-energy" productions where the useful energy produced by the gas generation cannot be measured, nor the gas energy consumed for the heating production.

Figure 51. Heating and DHW installations to avoid for in-situ measurements

Case 7



Case 8



Source: Authors' analysis

As mentioned in the paragraph 10.6.2, dwellings with a gas cooking system should preferably be excluded.

Installation of the monitoring equipment

The installation of the monitoring equipment requires one to two qualified professionals for 2 to 4 hours.

Thermal monitoring requires the intervention of a plumber/heating engineer for the installation of the flow meter (especially in the case of the installation of an intrusive heat meter which means changes in the existing installation), the temperature probes and instantaneous readings and measurements on the heating installation.

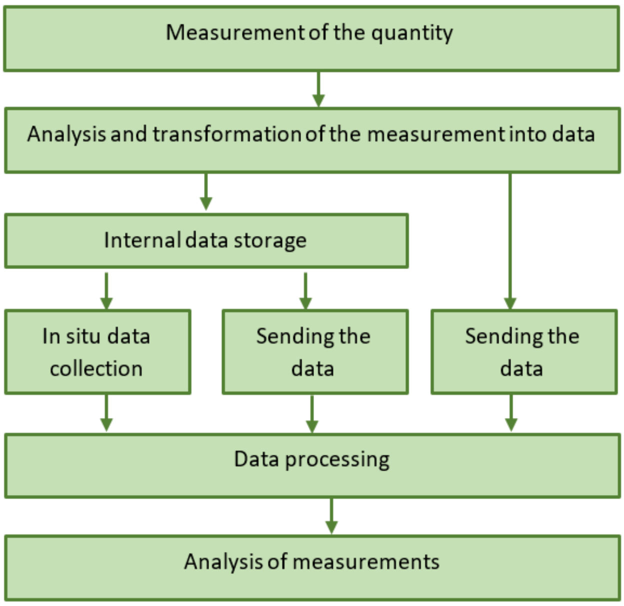
Monitoring the electrical consumption of the auxiliaries requires the intervention of a qualified electrician (the standards are country-specific, for example for France qualification is B2V BR of the NFC 15100).

This multi-actor implementation of the metrology can be perceived as annoying by the participants. It is important to explain the reasons, the nature and duration of the interventions in advance to avoid any rejections. It could also be useful to accompany the monitoring with feedback at the end on what can be done in the dwelling to improve the efficiency of the building and the operation of the heating.

NB: the list of household selection criteria is presented in paragraph 10.1.22.

10.1.12 Data collection and processing

A sensor consists of a sensitive element and an intelligence system that manages a time stamp and a measurement interval, transforms this measurement into data that is then stored or transferred. The measurement chain is carried out in the following way:



Instant, averaged or incremented data

Gas metering

Gas consumption is measured from the pulse output of the billing meters. Each pulse corresponds to a volume of gas consumed (in general 1 pulse = 0.01m3). There is no solution for recovering the real gas index at a fine acquisition frequency (less than 1 hour).

If the meter on the pulse output is disconnected, the consumption during the disconnection period will not be known.

This is why it is important to read the gas meters at the beginning and end of the measurement campaign in addition to the installation of a meter.

The measurement of gas volume is detailed in the paragraph 10.1.15.

Metering of thermal energy

There are several ways to collect heat meter information:

- Pulse collection (for volume and/or heat) depending on the type of meter installed (intrusive, non-intrusive). In this case, it is important to read the heat meter index at the beginning and end of the measurement campaign;

- Collection of indexes (for volume) and instantaneous values (flow) for volume meters with a communication module with a bus output;
- Collection of indexes (for volume and/or heat) and instantaneous values (flow, temperature) for heat meters with integrator having a communication module with bus output.

Note that communication modules with bus output are often optional and must be carefully chosen according to the desired information (energy/volume/temperature/other), the resolution of this information (1kWh/0.1kWh/0.01kWh/...) and the chosen communication protocol.

The measurement of thermal energy is detailed in paragraph 10.1.16.

Temperature, atmospheric pressure

The measure can be:

- A one-off measure at each time interval;
- An averaged value over the duration of the interval.

Averaging over the measurement interval is the best solution but is not mandatory, especially if a fine time step (1 minute) is chosen.

Power consumption

It can also be a one-off measure (in this case it is rather the power that is measured) for each time interval or an averaged value over the duration of the interval. Averaging is mandatory for the consumption measurement.

Data format

The data can be provided in the following formats:

1. One value for a given time step. The advantage of this type of measurement is the simplicity of use (database creation or any other computer processing). The drawback is the generation of large data files. For example, for a measurement interval of 1 minute, 525,600 values will be recorded over a year.
2. Values only when there are some changes. The advantage is that the size of the files is reduced to a minimum. However, data processing is more complex.

Storage of measurements in sensor memory

The choice of sensors with an internal memory allowing to store several months of data is preferable in terms of reliability: In case of problem of communication, the data are stored and can be downloaded during maintenance operations or at the end of the measurement campaign (depending on the choice of the local relay).

Sensor communication

Unlike data storage, which should be given priority, the possibility of making sensors communicative seems important but is not mandatory.

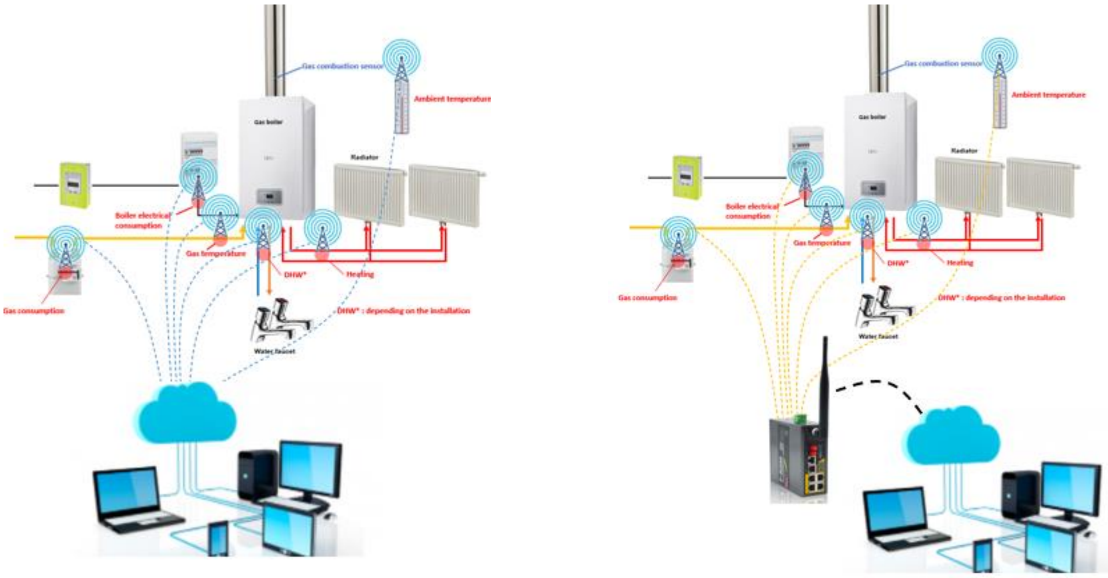
There are two possibilities for communication:

Each sensor can be autonomous and transmit its own data (Lora, Sigfox). In this case each sensor has its own subscription and transmits its data autonomously.

The sensors within the same house communicate with a data concentrator (hub). The role of the concentrator is to gather all the data collected in the dwelling and transmit it to a remote server. One of the advantages of this technique is to have a unique timestamp for all the sensors.

As the quantity of data to be transmitted will be important (with a recommended measurement time step of 1 minute), option 2 (installation of a data concentrator) seems to be a better option.

Figure 52. sensor communication system options



Solution 1 (independent sensors) Solution 2 (using a hub)

Source: Authors' analysis

It should be noted that the use of sensors storing all the data adds a very appreciable and robust security of the data.

Information to be collected on site

It is necessary to make sure that the local gas distributor is able to provide a daily data for the gross calorific value and the relative density of the gas delivered to the dwelling, ideally with information on the mean value and uncertainty of the measurement.

It will also be useful to take advantage of the in-situ intervention (installation of the monitoring equipment) to collect information on the building envelope and the HVAC equipment.

In order to determine the heating/DHW consumptions, the boiler consumption and efficiency, the following information must be collected:

- Gas:
  - Billing meter index (at the beginning and the end of the monitoring campaign)
  - Delivery pressure

- Building:
  - Postcode
  - Year of construction
  - Heated surface (m²)
  - Construction process
  - Surface and orientation of glazings
  - Ventilation system installed
- Occupant:
  - Number and age of occupants during the week and/or the weekend
  - Occupation during the week and the week-ends
- Boiler and the heating/DHW system:
  - Boiler type, brand, model
  - Date of manufacture
  - Gas class
  - Natural draft or suction cup appliance
  - Type and number of heating elements (radiators, underfloor heating), twin-tube or single-tube.
  - Internal boiler control system (settings)
  - Presence of an external DHW storage
  - Presence or not of a control of the heating circuit as a function of the outside temperature
  - Room control system or not
  - DHW settings
  - Circulators internal or external to the boiler

10.1.13 Local relays

The management of the in-situ measurements must be done at country level by a local relay. Indeed, one or more local relays seems necessary to ensure that the metrology is correctly installed and the information is well collected.

These local relays will have the following role:

- Assist the project manager in the selection of the sample, in particular the national geographical areas to select (see paragraph 10.1.23)
- Contact and train the plumbers, heating engineers and electricians to install the meters and to collect information in-situ
- Contact the energy supplier(s) to obtain the daily GCVs (and density if possible) of the gas at the delivery points for the boilers of the sample. The need to know the GCV and relative density is a prerequisite for the calculation of the efficiency.

These local relays will themselves need to have a very good knowledge of thermal engineering, both in terms of equipment (HVAC) and building envelope.

Measurement system and measurement uncertainties

10.1.14 Measuring combustion quality

It could be interesting to carry out instantaneous measurements of O_2, CO and NOx concentration in the combustion products with a flue gas analyser. It is indeed one of the four performance requirements imposed by the EU Ecodesign Directive 2009/125/EC mentioned in the paragraph 10.2. In addition, this analysis can provide information about:

- O_2: The stoichiometric operation of the boiler (access to air in the combustion process) and if the O_2 level is near to the stoichiometric value, the combustion efficiency is good.
- CO: the possible incomplete combustion at the starting-up or with borderline gases or without maintenance of the gas valve.
- NOx: the quality of combustion and burner operation or a lack of maintenance.

The main constraint with this measurement is that it must be carried out with the boiler running and forcing a boiler to start up can be complicated depending on its control modes. In addition, it is usually necessary to drill the duct to carry out the measurement.

10.1.15 Measuring gas consumption (volume)

Characteristics of gas meters

Gas meter in the main European countries is a dry volumetric version, having soft walled measuring chambers that expand and contract like bellows and measure gas by filling and emptying. The measurement uncertainty depends on the volume of gas to be measured.

Example of ACTARIS SAS meter, type RF1 G6:

- Qmax = $10m^3$ /h

- 3%: Qmin to 2Qmin

- 2%: 2Qmin to Qmax

Information on the volume of gas consumed can be retrieved and recorded via a pulse recorder. Typically, residential gas meters provide one pulse per dm^3 (1 pulse = $0.01m^3$).

Figure 53. gas meters transmitter systems

Terminal block transmitter	Binder connector transmitter	Wireless transmitter
		

Source: Authors' analysis

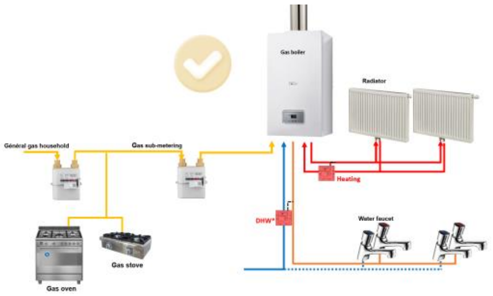
Case of gas cooking

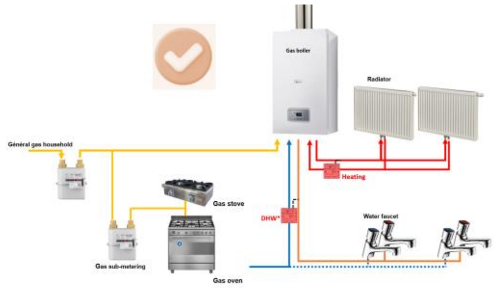
Dwellings with a gas cooking system should preferably be excluded. However, depending on the share of dwellings in each country with a gas cooking system, this exclusion may complicate the selection of the sample. For example, in France, about 1 in 2 dwellings using gas for heating also has a gas cooking system.

There are two possible approaches to include them in the sample:

- A calculation approach can be considered to separate the gas consumption of each use (heating/DHW/cooking) as described in Annex 1. However, this method has potentially high levels of uncertainty (e.g., in the order of 10%) and is not compatible with the assessment of the efficiency of boilers;
- A metering approach by installing a gas sub-meter (identical to a billing meter) because the addition of an extra gas meter is necessary to know the gas consumption of the boiler. It should be noted that the cost, space and safety constraints associated with the installation of the additional meter are significant. The following two diagrams illustrate the two possible cases.

Figure 54. gas cooking measuring options





Gas consumption of the boiler = gas consumption of the house - gas consumption of the stove

Source: Author analysis

Due the constraints of the two solutions mentioned above, we first consider that dwellings with gas cooking will be excluded from the scope of the study.

NB: The complete list of household selection criteria is presented in paragraph 10.1.22.

10.1.16 Measurement of thermal energy at the boiler outlet

The useful energy produced by the boiler is measured by one or more heat meters depending on the type of installation.

A heat meter consists of the following 3 elements (see figure 15, paragraph 5.3.5):

1. A flow meter;
2. A "hot" temperature sensor;
3. A "cold" temperature sensor.

In addition, an integrator converts these three elements into thermal energy and displays the various measured, calculated and stored values.

It should be noted that if one of these three elements is wrongly positioned or wrongly calibrated, inaccurate or defective, the conversion into thermal energy will be inaccurate and unusable, hence the interest in taking care with the installation of these meters if one wishes to evaluate the boiler's efficiency accurately.

Heat meters may or may not have an integrator for calculating thermal power:

- Without integrator: In this case, separate elements are used to perform the flow, temperature and integration functions. This is generally the case for so-called "non-intrusive" meters, which do not require any special skills or heavy intervention in the heating installation. However, the measurement errors and uncertainties are greater than those of meters with integrators.

- With integrator: In this case the system is "standardised", tested and qualified in terms of errors. This is generally the case for so-called "intrusive" meters which require changes in the installation (cutting the network, draining the heating distribution circuit, welding) and thus the intervention of a plumber/heating engineer, which can be a major operational obstacle for the monitoring campaign.

The following paragraphs aim at determining the uncertainties in the useful energy measurement for each of the 3 elements, with and without integrator, as well as the advantages and constraints of each solution.

Temperature measurements (water and gas)

“Intrusive" heat meters (Sappel, Kamstrup, etc.) are delivered with temperature sensors, whereas in the case of "non-intrusive" heat meters (Keyence, for example), temperature sensors must be purchased separately from the flow meter in order to calculate the energy.

In both cases, the temperature sensors used can be divided into two main families: RTDs (PT100 type) and NTCs (thermistor type).

Measurement uncertainty related to the probe

The uncertainties of the two main families of temperature sensors are given below:

RTD (Resistance *Temperature* Detector) has a tolerance that varies according to the type of material (copper, platinum, nickel) and the temperature range.

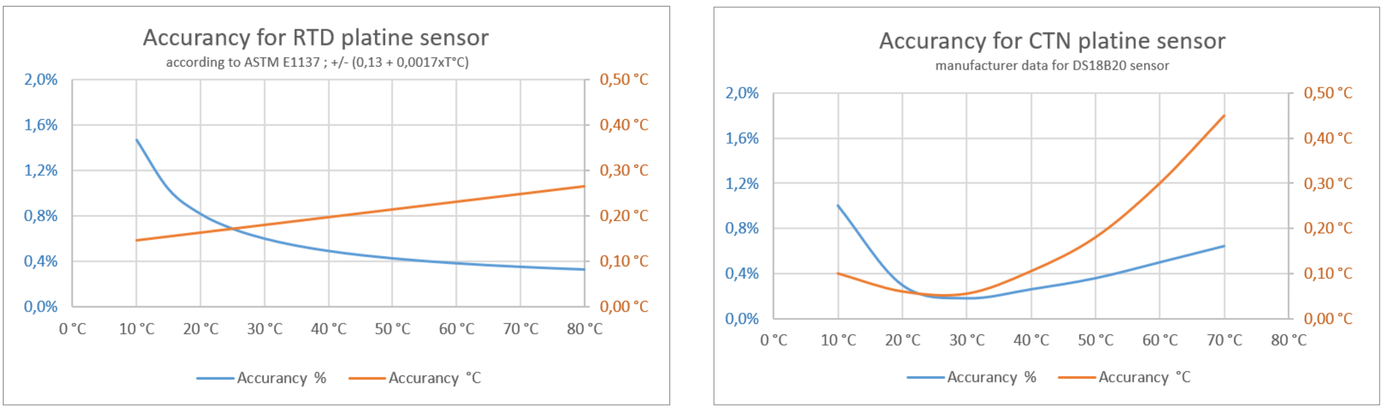
Most sensor manufacturers produce platinum RTDs with accuracy levels that comply with IEC 60751 or ASTM E1137 RTD standards.

The percentage of error with this type of probe varies from ± 0.3% to ± 1.4% over the temperature ranges included in the study.

NTC thermistors (Negative Temperature Coefficient) with a tolerance that varies according to the temperature range.

The percentage error of this type of probe varies from ± 0.4% to ± 2% over the temperature ranges included in the study.

Figure 55: RTD and NTC families sensor accuracy



Source: Authors' analysis

Uncertainty related to the temperature difference

EN 1434-1 norm[50] allows a maximum error on the temperature difference measurement of paired probes[51] of Et = ± (0.5 + 3 (ΔΘ min./ΔΘ) %).

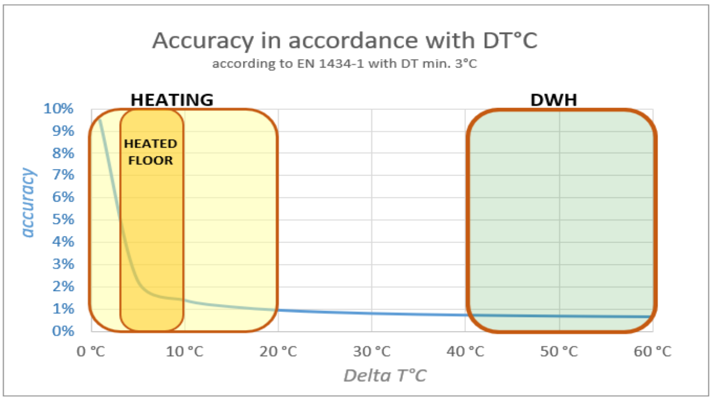
This error is a function of the temperature difference and therefore depends on the type of production (heating or DHW), of emitter (steel radiator or underfloor heating) and the pump setting, among other things.

For heating, the temperature difference is usually of 5 to 10°C for underfloor heating or fan coil systems and up to 20°C for conventional radiators. The maximum error allowed by EN 1434-1 varies by a factor of 5, ranging from ± 1% to ± 5%.

For DHW production, the temperature difference between cold and unmixed hot water ranges usually from 30 to 50°C. The error is relatively stable in this range and is around ± 0.5%.

Uncertanty levels can be very high when the average temperature difference of the installation is low. We therefore suggest that to exclude gas boilers supplying underfloor heating from the scope of the study.

Figure 56: Accuracy in accordance with temperature difference according to EN1434-1



Source: standard EN1434-1

Uncertainty related to the installation of temperature sensors

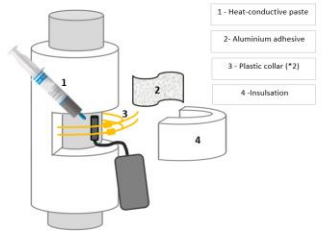
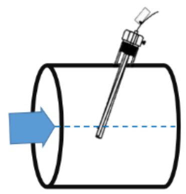
Surface and immersion temperature sensors can be found on the market. In the case of "intrusive" heat meters, the temperature sensors will be installed in a pocket, whereas in the case of non-intrusive meters, the installation method will be surface mounted.

While surface probes have the advantage of being non-intrusive, they have the drawback of being sensitive to stratification and, above all, to the type of duct material. Insulation of the probe is required in all cases. However, in-contact probes do not react well to fast variations in temperature of the fluid in the pipe.

[50] EN 1434-1:2015+A1:2018 - Thermal energy meters - Part 1: General requirements

[51] Paires probes are probes that are calibrated to give exactly the same value under the same conditions of use.

Figure 57. Type of installation of temperature sensors

	
Surface mounting	Mounting in an immersion sleeve

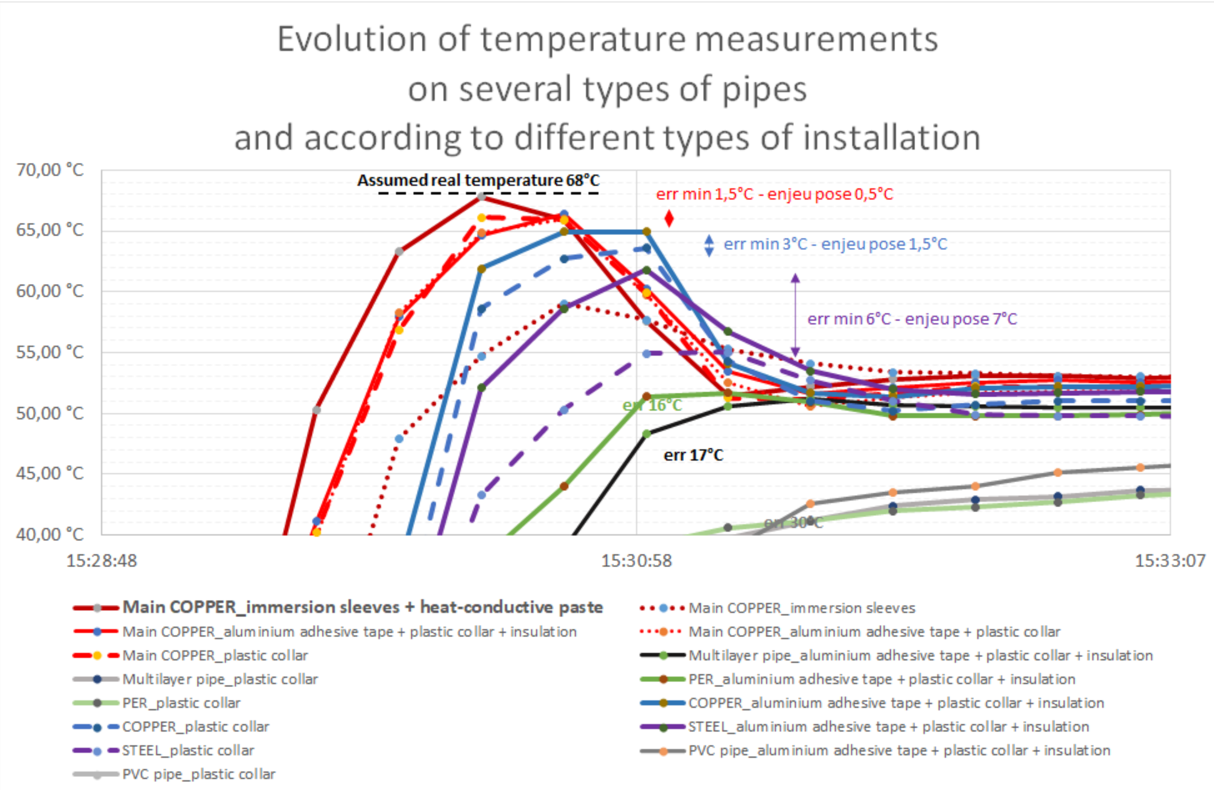
Source: Authors' analysis

Tests have been carried out by the French Engineering company Enertech in order to quantify the levels of accuracy of the temperature measurement according to the parameters mentioned above.

The conclusion is that in order to obtain the most reliable measurement possible, it is necessary to:

- Ensure a perfect contact between the probe and the duct
- Cover the probe with insulation
- Avoid plastic ducts (PER, multilayer and PVC).

Figure 58. Accuracy of the fluid temperature measurement as a function of pipe types and mountings



Source: Author analysis

So, surface-mounted probes should only be used for heating/DHW installation made of copper or steel.

Water volume measurements

As mentioned earlier, the installation of a flow meter can be "intrusive" or "non-intrusive":

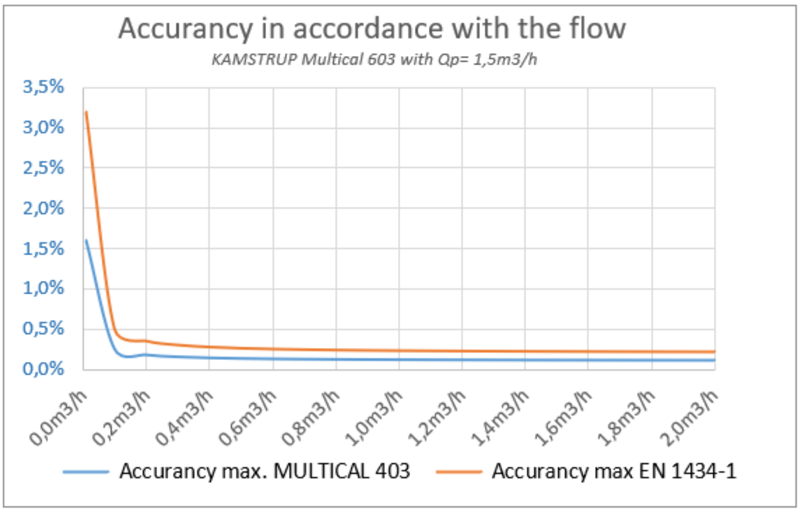
Intrusive meter: the installer has to cut the pipes, install the meter, install the immersion sleeves and re-weld these different components without any leakage. This solution is not suitable for all heating installation. Indeed, in order to install the meter without deterioration, it is necessary to have an accessible straight length of pipe. Furthermore, the participants must accept an intervention consisting in modifying their installation. In general, the meter is not removed at the end of the monitoring campaign (too expensive and risk of leakage).

Non-intrusive meter: the installation is much easier and the footprint is smaller. However, it is necessary to have a sufficient straight length of pipe. At the end of the in-situ measurements, these meters can be easily be removed and the installation is left exactly as it was initially.Uncertainty related to intrusive flow measurement

EN 1434-1 norm allows a maximum error on the flow measurement of $E_f = \pm (0.2 + 0.02\ Qp/Q)\%$ with a maximum of ± 5%.

As an example, the ultrasonic flowmeters of the much-used “KAMSTRUP MULTICAL 603” or “ITRON SHARKY 775” energy meters have an error of less than ± 0.5% when the measured flow is greater than or equal to 1/10th of their nominal flow rate (Qp).

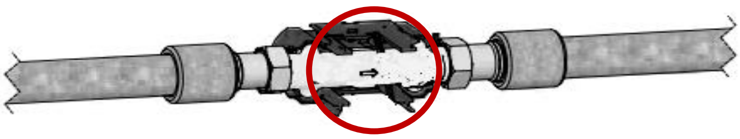
Figure 59. Accuracy as a function of the flow according to EN1434-1



Source: Author analysis

The installation of an intrusive ultrasonic flowmeter offers a high measurement accuracy. The trouble lies in its installation, which should be done by a plumber or a heating engineer. Note that it has to be installed in the direction of the flow which is generally indicated on the device.

Figure 60. intrusive ultrasonic flowmeter



Source: Author analysis

Uncertainty related to the non-intrusive solution

Whereas energy meters such as KAMSTRUP's MULTICAL 603 or ITRON's SHARKY 775 comply with standards (such as EN 1434-1), this is not the case for the non-intrusive solutions presented below.

One of the mains reasons in favour of this solution is its ease of implementation. It has therefore more chance to be accepted by the participants.

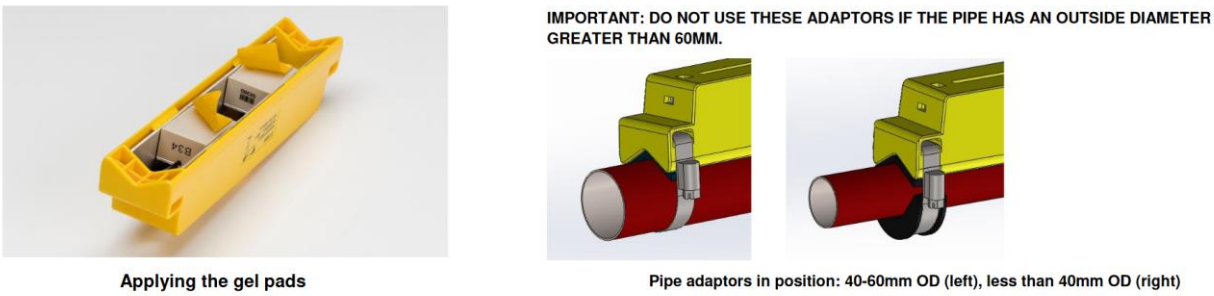
The MICRONICS U1000 flow meter can be used for this application. The supplier indicates an accuracy of ± 0.725°C on its temperature sensors and ± 3% of the flow reading for velocities above 0.3 m/s (i.e., 0.34m^3 /h for duct diameter of 20mm, which is low). Enertech has measured on its test bench an accuracy more like ± 15% for small diameter ducts.

The main drawback of the non-intrusive solution is that it is given to operate on pipes ranging from 20mm to 110mm internal diameter, which is in accordance with heating circuits but not very realistic for the DHW production.

The uncertainties related to the installation of the MICRONICS U1000 come from:

- Incorrect setting of the meter and the (adjustable) spacing of its ultrasonic sensors, related to the type of pipe, the internal diameter of the pipe and the type of fluid (water or glycol);
- The correct application of a layer of gel that prevents air bubbles between the sensor and the pipe;
- The choice to add or not an adaptor depending on the diameter of the pipe.

Figure 61. Mounting specifications for the non-intrusive MICRONICS U1000 meter



Source: Micronics

KEYENCE FD-Q flowmeters, according to different tests conducted by ENERTECH, have an accuracy of ± 15% without manually adding of a correction factor. The repeatability of the measurement is excellent. Furthermore, when adding a bench-calibrated correction coefficient, the accuracy level is about ±5%.

This correction coefficient ("span") can be calibrated directly on site in the case of an open domestic hot water circuit, by comparing a flow rate measurement at a tap point with the measurement indicated on the flow meter. But it is very complicated to calibrate it on site for a closed heating distribution circuit. In this case, the correction factor will have to be defined in advance based on results on the test bench.

ENERTECH, thanks to the tests mentioned above, has developed a database that gather the correction coefficients for nearly 250 configurations, taking into account the type of pipe (PER, multilayer, steel and copper), the pipe diameter (from 10 to 42mm), the position of the flowmeter (horizontal or vertical, with or without linear upstream and/or downstream of the collector) for different flow rates.

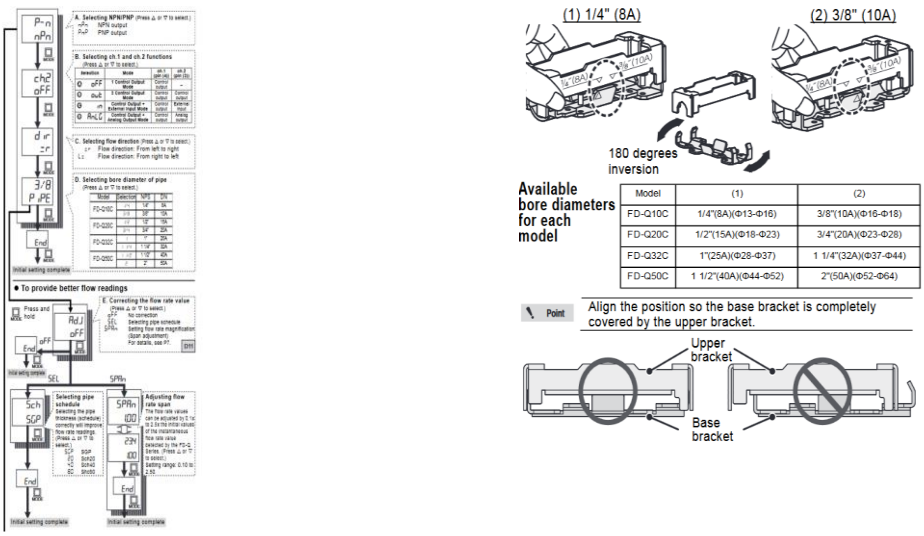
Unlike the MICRONICS U1000, KEYENCE's FD-Q flowmeters operate over a relatively small diameter range, which enhances their accuracy. In-situ measurements of gas boilers may require 3 different types of FD-Qs (FD-Q10C (13 to 18mm outer diameter); FD-Q20C (18 to 28mm outer diameter); FD-Q32C (28 to 44mm outer diameter)).

Note that it will be necessary to know the pipe characteristics (diameter, material, foreseen position) before the meters are installed.

The risks associated with the installation of this type of sensor are:

- Incorrect settings (flow direction, duct diameter, span, cut-off rate),
- A wrong mounting of the meter (wrong installation of its top and bottom brackets).

Figure 62. Mounting specifications for the non-intrusive KEYENCE's FD-Q meter



Source: Keyence

Also note that the KEYENCE FD-Q is not equipped with temperature sensors and any integrator for energy calculation. This flow meter must therefore be installed with temperature sensors in order to calculate a thermal energy (Cf 0). Surface-mounted probes will be installed in order to provide a fully non-intrusive solution.

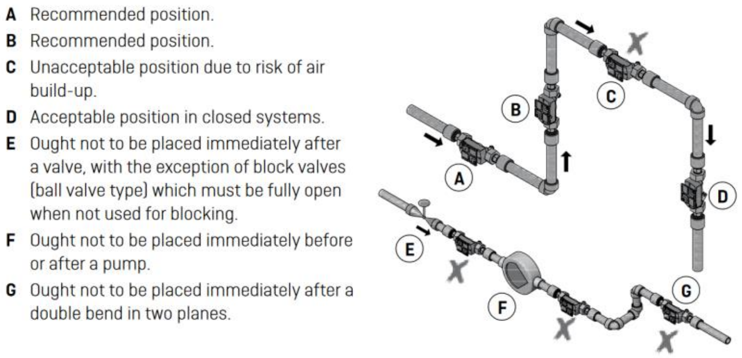
The volume index is given with 4 digits on the same unit as the one entered in the parameters (*integrated units flow*). The more precise the unit chosen, the more quickly the volume index is saturated (value displayed = "FFFF"), making it impossible to read the index at the end of the measurement campaign, which removes the security of the *a posteriori* verification of the measurement made.

Uncertainty of intrusive and non-intrusive solutions

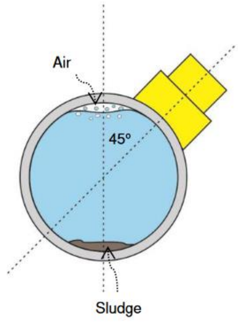
The choice of the location of the flow meter (intrusive or not) on the distribution network can lead to a level of uncertainty ranging from a few % to unusable data. This is clearly the most difficult measurement. Most manufacturers give precise information on the necessary conditions to be able to use their products.

It should be noted that in certain configurations of heating/DHW installations it will be impossible to install a flow meter.

Figure 63. Mounting specifications for flow sensors



Source: KAMSTRUP



Source: MICRONICS

Calculation of the thermal power

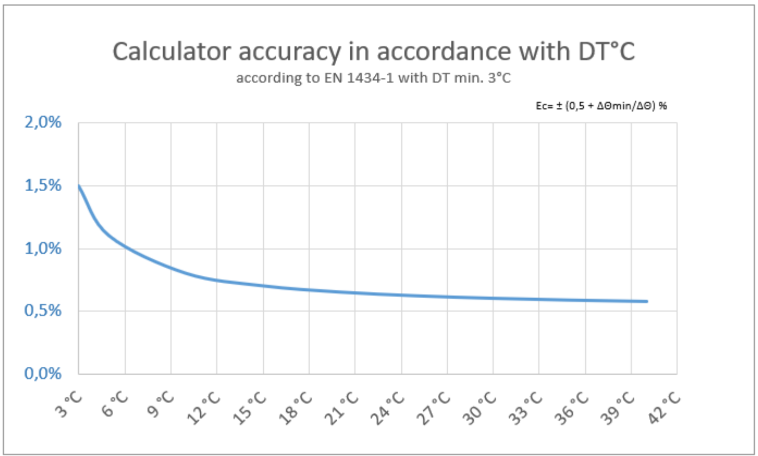
Uncertainty with an integrator

EN 1434-1 norm allows a maximum error on the flow measurement of Ec = (0.5 + (DTmin./DT))%.

Conventional "heat meters" are pre-equipped with temperature sensors and an integrator that calculates directly the power (e.g., MULTICAL 603 from KAMSTRUP or SHARKY 775 from ITRON).

Some non-intrusive flowmeters can also be equipped with an integrator which, combined with two temperature sensors, allows the calculation of the power (e.g., U10000 from MICRONICS or FD-H from Keyence).

Figure 64. Calculator accuracy as a function of the temperature difference according to EN1434-1



Source: standard EN1434-1

Uncertainty without an integrator

Another option consists in installing separately a flow meter (such as KEYENCE's FD-Q) and temperature sensors and to use the following formula to determine the power:

P = qv × 1.16 × ΔT with

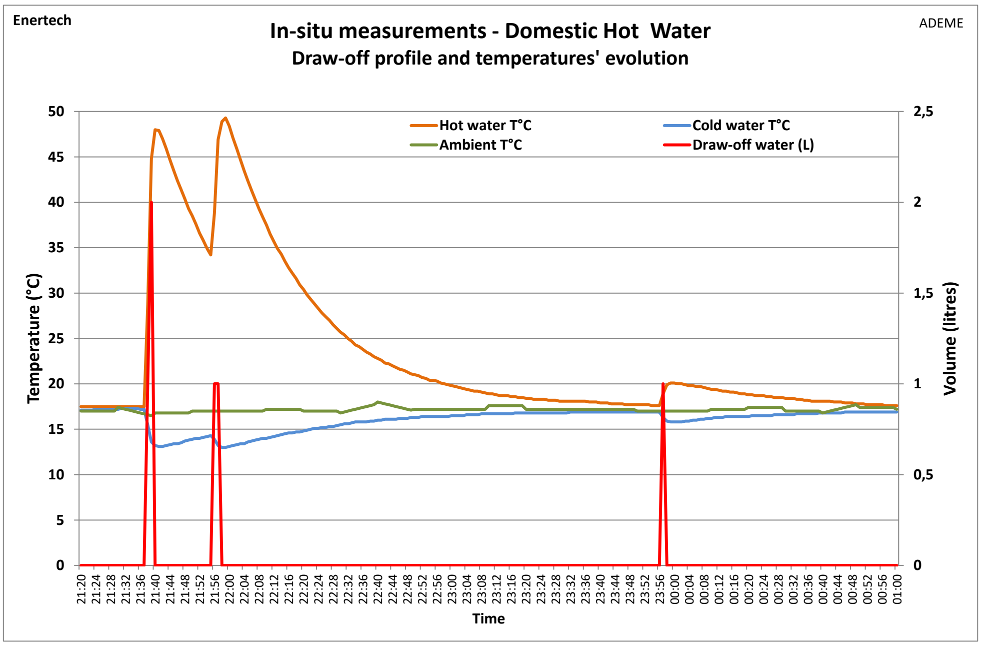
- *P in [kW]*
- *qv in [m³/h]*
- *1.16: Heat density of the water in [kWh/m³.K] ΔT: Temperature difference*
- *ΔT: Temperature difference received or lost by the water in [K]*

In this case, the “cold” and “hot” temperature measurements must be processed and synchronised before being associated with the volume measurements. This issue is particularly important with short draw-offs of DHW and can cause time-stamping problems between the different meters.

Water temperature measurements are only valid when there is water circulation in the duct, otherwise the measured temperature corresponds to the ambient temperature where the probe is located. Data processing is therefore necessary to consider only “correct” values.

As an example, Figure 65 illustrates a typical behaviour of "cold water" and "hot water" temperature sensors during DHW draw-offs. When no water is drawn off, the “hot” and “cold” water temperatures merge, tending towards the ambient temperature of the room. This example illustrates the possible error in the calculation in case of bad synchronisation between the three measurements.

Figure 65. Evolution of the temperatures (cold water, hot water, ambient) during DHW draw-offs



Source: Enertech

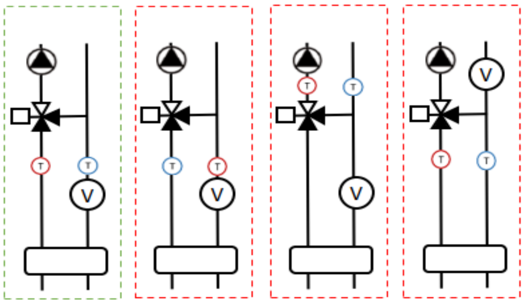
The nature of the pipe in which the temperature sensors are placed can also lead to a time lag between the volume drawn and the temperature of the fluid and thus distort the power calculation.

Uncertainty of the calculation related to the installation of the meter

In addition to the uncertainties associated with the installation of each individual element, there is also an error in the measurement if the location of only one of the three sensors is poorly chosen.

The most common errors are found when heating circuit temperature is controlled by a 3-way valve as it is sometimes hard to understand how the installation works.

Figure 66 . Illustration of right and wrong positioning of the flow meter and the temperature probes - in cases 2, 3 and 4 the measurement is not usable.



Source: Authors' analysis

In the case of DHW circuits, a simple inversion between flow and return temperatures providing a negative temperature difference can make the calculation by the integrator impossible.

Figure 67. Comparison between intrusive and non-intrusive heat meters

	Non instrusive	Intrusive
		
Material prices	x	✓
Cost of installation	✓	x
Acceptability of the participants	✓	x
Easy to install	✓	x
Risk of error in implementation	x	✓
Accuracy	x	✓
Restoring the installation to its original state	✓	x

Source: Authors' analysis

10.1.17 Measurement of the electrical consumption of the auxiliaries

Sensor accuracy

Two standards specify the accuracy class of electricity meters:

- The international standard IEC 62053-21/-22,
- The EN 50470-1/-3 standard on which the MID is based.

Class 1 of IEC 62053-21/-22 corresponds to a relative uncertainty of 1% on a measurement corresponding to the rating ($I_{nominal}$) of the measuring instrument

The EN 50470-1/-3 standard has 3 classes (A, B and C) with class A being equivalent to an accuracy of ± 2%, 1% for class B and 0.5% for class C.

The lower the level of measured intensity compared to the nominal intensity of the meter, the greater the error.

Uncertainty associated to the installation

While meters with direct connection (in series) do not pose any particular difficulties during installation, meters with current transformers (CTs) require particular attention during installation with regard to the direction of the CTs, the transformation coefficient and the matching of the phases between the voltage taps and the current measurements. If they are wrongly positioned, the data will be unusable. Heating and DHW installations are usually supplied by a specific line from the electrical panel. However, care should be taken to ensure that the circuit identified as the boiler circuit does not feed any other electrical appliances via any connection or junction box. As already mentioned in this document, the monitoring of electrical consumption of the auxiliaries requires the intervention of a qualified electrician (standard specific to each country).

10.1.18 Summary of measurement uncertainties

A model that takes into account all the measurement uncertainties mentioned above is proposed in this paragraph in order to frame the overall measurement uncertainty. (See appendix 0 for more details).

This model scans the following parameters to calculate the temperature differences and the flowrates that will likely be found in the field:

- Type of climate;
- More or less insulated buildings;
- Heating flow temperature;
- Heating circulator with constant or variable flow rate;
- Dwelling with 1 or 2 gas meters (boiler only or boiler + cooking).

Figure 68 shows the results.

Figure 68. Global measurement uncertainty ranges – Gas boiler consumption and efficiency

			Measurement Uncertainty* scale
GAS	Gas Gross Calorific Value	**Daily** GCV error -from supplier- (**2H, 2L**)	± 6%
	Gas flowrate measurement error (boiler)		± 2%
	Gas flowrate measurement error (cooking)		± 2%
	Error on gas energy consumption	Dwelling with gas boiler only	**± 8%**
		Dwelling with gas boiler + gas cooking	**± 10%**
Usefull energy HEATING	Intrusive heat meter (Uncertainties : flow 2%, temp. 0,3K)	Mean flow/return temp. diff. during heating season of 5°K	± 8%
		Mean flow/return temp. diff. during heating season of 20°K	± 3%
	Non intrusive heat meter (Uncertainties : flow 4%, temp. 0,6K)	Mean flow/return temp. diff. during heating season of 5°K	± 16% (1)
		Mean flow/return temp. diff. during heating season of 20°K	± 6%
Usefull energy DHW	Intrusive heat meter (Uncertainties : flow 3%, temp. 0,3K)	Mean flow/return temp. diff. during heating season of 35°K	± 3%
		Mean flow/return temp. diff. during heating season of 55°K	± 3%
	Non intrusive heat meter (Uncertainties : flow 3%, temp. 0,6K)	Mean flow/return temp. diff. during heating season of 35°K	± 4%
		Mean flow/return temp. diff. during heating season of 55°K	± 4%
Usefull Energy **	Intrusive heat meter	Low flow/return temp. diff. for heating and DHW	**± 7%**
		High flow/return temp. diff. for heating and DHW	**± 3%**
	Non intrusive heat meter	Low flow/return temp. diff. for heating and DHW	**± 14% (2)**
		High flow/return temp. diff. for heating and DHW	**± 6%**
Electrical energy	Measurement uncertainty on electric auxiliary consumption		**2%**
Global Efficiency ***	Intrusive heat meter	Low flow/return temp. diff. for heating and DHW	**± 17%**
		High flow/return temp. diff. for heating and DHW	**± 13%**
	Non intrusive heat meter	Low flow/return temp. diff. for heating and DHW	**± 24% (3)**
		High flow/return temp. diff. for heating and DHW	**± 16%**

(*) Considering installation of sensors according to the state of the art + synchronisation of the clocks of the 3 measurement channels
(**) Considering a mixed boiler with 15% of useful energy provided to DHW and 85% provided to space heating
(***) ERP efficiency which includes the provided useful energy and electric auxiliary energy
(1) ±10% instead ±16% of with 3 temperature sensors on heating ducts
(2) ±8% instead ±14% of with 3 temperature sensors on heating ducts
(3) ±18% instead ±24% of with 3 temperature sensors on heating ducts

Source: Authors' analysis

Based on these results, it seems reasonable to consider:

- A measurement accuracy of 8 to 10% on the final gas energy consumed by the boiler, provided that the daily GCV of the gas is available at each delivery point;
- 13 to 17% accuracy on boiler efficiency with an intrusive heat meter;
- 16 to 24% accuracy on boiler efficiency with a non-intrusive heat meter (15-19% with 3 contact probes instead of one on the heating pipes).

Important note on performance measurement:

These uncertainty figures are maximum error ranges. This means that we do not believe that each individual case can claim a higher accuracy. On the other hand, measurements on the same type of boiler in a large number of dwellings will reduce the level of uncertainty in the average efficiency estimated for the same type of boiler. In summary, the table above shows standard deviations of errors but the average of these will be close to 0 in a large number of cases.

Taking into account these results and the efficiency ranges that define the different energy label classes for heating (8% to 25% per class), it seems possible to objectively compare the label obtained in the laboratory with that measured "in the field", if several dozen cases are measured per boiler model.

10.1.19 Validation of the metrology before a large deployment

Given the very specific and specialized nature of gas boiler instrumentation, the study could be confronted with "arbitrary" criticisms of the performance of the metrology deployed in the field, and therefore of the relevance of the results obtained.

Therefore, it seems necessary to first validate the chosen metrology in an accredited laboratory, in order to objectively assess the difference between this metrology and that used in the ErP tests.

This validation by an accredited laboratory (for example COFRAC in France) can also help to decide on choices such as the use of intrusive or non-intrusive flowmeters, the type and installation of temperature probes or the need to use one or several temperature probes.

For this purpose, a precise specification must be provided to the accredited laboratory containing the list of meters with requirements for their location, installation method, parameterisation, acquisition frequency, etc.

The tests should be carried out according to at least two protocols:

- EN297 standard, in order to compare manufacturers, laboratory and on-site measurements.
- With the use of "real" heating and domestic hot water requirements taken from the field, for example with load profiles derived from previous field measurement campaigns (to reproduce the short-cycle operation of boilers observed in the field).

The laboratory measurement protocol should include:

- The measurement protocol required for the establishment of the EN297 standard, i.e., the following measurement points:
    - Atmospheric pressure;
    - Pressure in the furnace;
    - Gas pressure;
    - Water flow rate;
    - Gas flow rate;
    - Room temperature, water flow, water return;
    - CO, CO_2 and O_2;

    - Calorific value of the gas;
    - Gas density;
    - Power consumption of the boiler/auxiliary.

- The set of measurement points proposed in this report for an in-situ measurement program:
    - Surface-mounted temperatures probes: hot water flow, hot water return, gas supply;
    - Hot water flow rate (with the same timestamp as the temperature probes);
    - Gas flow rate;
    - Power consumption of the boiler/auxiliary.

- Information to determine the energy content of the gas
    - Daily GCV value;
    - Gas density;
    - Atmospheric pressure.

It would also be important to test the reproducibility of measurements by setting up several sensors of each type. The laboratory will indicate how many similar sensors must be tested to determine the accuracy.

The validation of the metrology should take place at least on one boiler, but it may be interesting to test a second boiler with very different technical characteristics in order to evaluate the sensitivity of the performance to the type of thermal load.

Boiler 1	Boiler 2
Condensation	Standard
Instantaneous DHW production	*Integrated DHW tank*
Fan assisted evacuation	Chimney evacuation
ErP Class VIII controller	Constant flow temperature

Validation should be done over a period of 2 to 3 months of measurement to take into account variations in gas composition and density.

Monitoring duration

Due to the high seasonality of heating and hot water loads in Europe, the measurement campaign should last at least one full year. A longer monitoring duration will be valuable but it will cause problems of budget and acceptance of the participants.

The optimal duration for such a campaign is one year per dwelling.

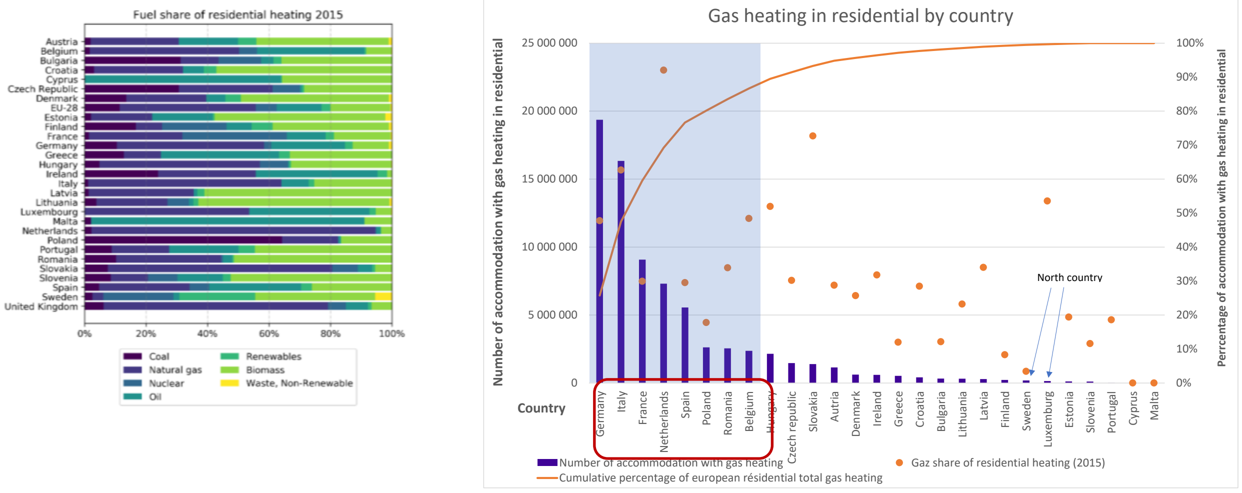
NB: It is not necessary a priori to evaluate the whole sample of boilers in the same year, so it is possible, in the case of non-intrusive metrology and depending on the total duration of the campaign, to move the same fleet of sensors several times.

Selection of the sample of households

10.1.20 Geographical location of the sample

Using data from the *EU-28 Residential Heat Supply and Consumption: Historical Development and Status report* [39], we estimate that 87% of gas boilers in the EU are concentrated in 8 countries (Germany, Italy, France, Netherlands, Spain, Poland, Romania and Belgium).

Figure 69. Dwellings with gas heating in EU



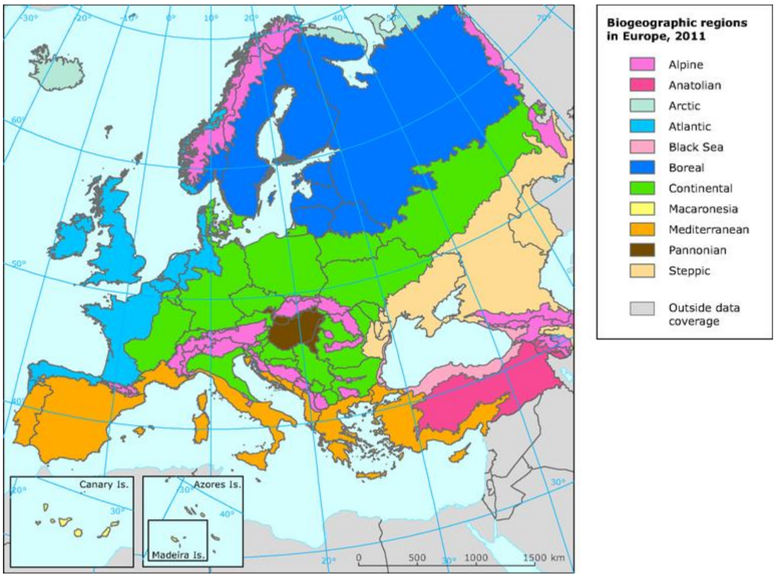
Source: EU-28 Residential Heat Supply and Consumption: Historical Development and Status and authors' analysis

In order to get a better representation of the Northern European countries, we propose to select households in Denmark (0.62 million boilers) rather than in Belgium (2.3 million gas boilers).

The 8 countries of the sample would be Germany, Italy, France, Netherlands, Spain, Poland, Romania and Denmark. According to our estimates, they represent 84% of the EU boiler stock.

Figure 70. Map of countries selected for the study

Figure 71. biogeographic regions in Europe – source: www.eea.europa.eu/data-and-maps



source: www.eea.europa.eu/data-and-maps

NB: Within these climatic zones, altitude should be taken into account as it has a potentially strong influence on heat consumption as well as on the GCV value of the gas.

10.1.21 Sample size

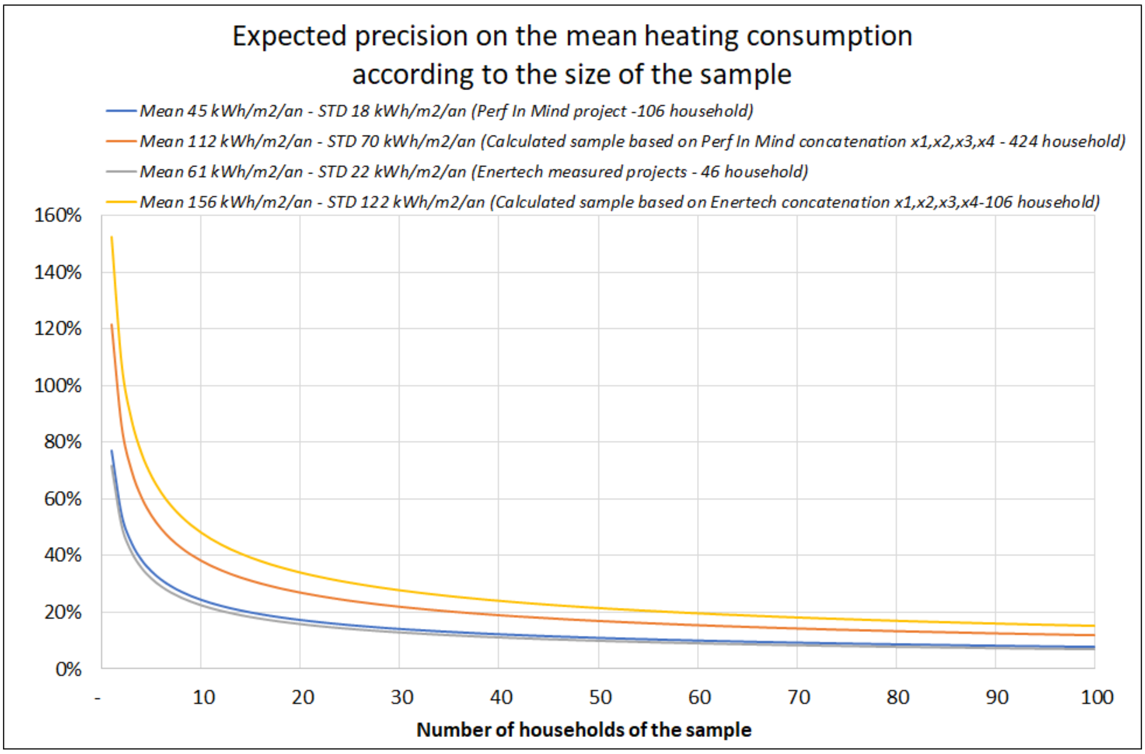
The sample size is a compromise between representativeness and cost.

Given the differences in climate, construction processes, types of heating installations, building regulations etc. between the different countries, it is necessary to use a large sample. A recent study [40] on the heating consumption of 106 individual dwellings in France shows differences ranging from 1 to 7 on the surface heating consumption despite the fact that these dwellings are all located in the same country and are all *theoretically* renovated to an energy efficient level.

The application of a statistical sampling model based on the accuracy of estimating the average of a set of values from a random sample of these values[52] , allows the curves presented in Fig. 72 to be drawn.

[52] Model based solely on knowledge of the mean and standard deviation of the series

Figure 72. Expected precision of the mean heating consumption as a function of the sample size



	Case 1		Case 2		Case 3		Case 4		Mean case	
Sample	Expected precision	Precision improvement per household	Expected precision	Precision improvement per household	Expected precision	Precision improvement per household	Expected precision	Precision improvement per household	**Expected precision**	**Precision gain per household**
10	24%		38%		23%		48%		**33%**	
20	17%	0,7%	27%	1,1%	16%	0,7%	34%	1,4%	**24%**	1,0%
30	14%	0,3%	22%	0,5%	13%	0,3%	28%	0,6%	**19%**	0,4%
40	12%	0,2%	19%	0,3%	11%	0,2%	24%	0,4%	**17%**	0,3%
50	11%	0,1%	17%	0,2%	10%	0,1%	22%	0,3%	**15%**	0,2%
60	10%	0,1%	16%	0,1%	9%	0,1%	20%	0,2%	**14%**	0,1%
70	9%	0,1%	15%	0,1%	9%	0,1%	18%	0,1%	**13%**	0,1%
80	9%	0,1%	14%	0,1%	8%	0,1%	17%	0,1%	**12%**	0,1%
90	8%	0,0%	13%	0,1%	8%	0,0%	16%	0,1%	**11%**	0,1%
100	8%	0,0%	12%	0,1%	7%	0,0%	15%	0,1%	**11%**	0,1%

Source: Authors' analysis based on various Enertech's monitoring campaigns:

These results indicate that a sample of 50 boilers per country should provide results with an average accuracy of 15 %. Doubling the sample size (100 dwellings per country) would only bring a 3 % improvement for a significant doubling of the cost of the campaign.

50 dwellings per country, i.e., 400 dwellings in total seems a good compromise between accuracy and cost constraints.

10.1.22 Selection criteria

In the previous paragraphs, several important selection criteria are listed. The following restrictions have been identified:

- Exclusion of collective gas boilers and tertiary buildings.
- Exclusion of dwellings not connected to a gas network with a billing meter.

- Exclusion of dwellings equipped with gas meters that are not compatible with the installation of pulse emitters.
- Exclusion of installations using other gas families than 2H and 2L.
- Exclusion of dwellings for which gas distributors are unable to provide daily information on the GCV and density of the gas delivered.
- Exclusions of boilers integrating a source of energy complementary to gas (for example solar energy) that does not allow the monitoring of the useful energy production of the boiler alone .
- Exclusion of dwellings whose heating installation does not have a straight length of pipe sufficient for the installation of heat meters.
- Exclusion of installations operating structurally on low temperature difference, such as underfloor heating or radiant ceiling.
- If non-intrusive heat meters are preferred, installations with pipework in materials other than copper or steel are excluded.
- Possible exclusion of dwellings using gas for cooking.

These limitations should not affect the representativeness of the sample.

10.1.23 Selection mode

For this project it is necessary to find participants in 8 European countries that satisfy the previous described selection criteria. In order to create a representative panel, the following stages are required:

1. Partnering with local relays: Partnering with local relays in each country is essential in this project (Cf. 10.5.4). These relays will be able to help define the geographical areas of their country to cover according to the families of distributed gases, the types of housing (urban/peri-urban/rural) and the territories (valley/plain/mountain), while ensuring groupings by area in order to limit the travel time between each household.
2. Determining a first large sample: This task could be outsourced to an online panel provider (OPP) who has the ability to target appropriate audiences through their panel of thousands of profiled consumers. Online panels are groups of pre-recruited individuals who have agreed to participate in surveys, focus groups or in-depth interviews. To be recruited into a panel, individuals share a large amount of household data, demographic information and behavioural characteristics during the registration phase. Sharing this information facilitates segregation and recruitment for future research studies. People are recruited through different channels (Internet, social media and email). Many OPPs reward their panellists with vouchers.
3. Determining the final sample: The aim will be to ensure in each dwelling the confirmation of the participant and the technical feasibility of the instrumentation. A local technical contact may be useful to validate the technical feasibility.

Project organisation

In order to complete this challenging project, a very qualified Project Manager (PM) should first be appointed. This company will be in charge of supervising the whole project, choosing and managing the subcontractors.

This ambitious project can also only be carried out successfully with qualified local relays (Cf. 10.5.4). They will be responsible for supervising the entire project in their country, from the validation of the sample to the choice of the necessary subcontractors, including the contact with local gas providers to get daily GCV values at the various delivery points. The project manager (PM) will be responsible for supervising these local relays.

10.1.24 Preparation of the in-situ measurement campaign

Pre-study of GCV determination method

As already explained several times in this report, it is crucial in this project to ensure the availability of the daily GCV value at the delivery points and its related uncertainty. A monthly information about the energy that contains in the consumed gas is not enough to be able to discuss daily variations in boiler efficiency. If the GCV value has to be set to a reference value, because not available, the difference in power output to the limit gases (one or three) will go from -15% to 24%[53].

Therefore, it is necessary, before the launching of the measurement campaign, to start with a pre-study to define the best method to obtain this value. The main topics will be:

- Establishment of European regions where daily measurements of the GCV value and density are available:
  - Uncertainty of the certified appliance that executes the daily measurement
  - Gross calorific value daily standard deviation measured or estimated as generally observed
- Regions where a constant gross calorific value is observed by the gas distributors and no:
  - nearby biogas is injected: gas variation the most important
  - industrial plants are connected to grid with injection points: injections of hydrogen and propane are frequent and not predictable in time

This study should be done with the local distribution system operators (DSOs). It is as important as the selection of the participants.

Selection and purchase of monitoring equipment

As described in paragraph 10.1.19, it is highly recommended to first validate the metering equipment to be used prior a large deployment in the 8 countries. Once the choice of metrology has been validated, a call for tender should be launched to find the most appropriate and cheapest measurement kit.

Recruitment of the Online Panel Provider

The OPP should be recruited by the PM. This company must be selected very carefully as it will play a key role in the project. Ideally, it should be an international firm with offices in the 8 countries; otherwise, it could be a company with contracts with researchers in the 8 countries able to provide direct contact with the participants . It will not only provide the sample but also perform various tasks such as translation of documents, hotline, etc.

Preparation of the different documents

The various documents required are described in the following paragraphs. They will all be:

- Developed by the PM
- Translated and coded (if necessary) by the OPP.

Recruitment tools (advertising and pre-recruitment questionnaire)

[53] Low energy gas family, 1a: -9%; natural gas families: 2H: -7% to +11%, 2L: -7% to +6%, 2E: -7% to +24%; Liquid gas families: 3B/P: -15%, 3P: +16%

In order to enrol participants, a short, clear and user-friendly description of the project should be written. The text should also explain what is expected from the applicant and what will be the reward.

It will be accompanied by a short pre-recruitment questionnaire. The following questions could be asked (non-exhaustive list):

- What is your main heating system?
- Are there other sources of heating (e.g. by a wood stove, electric convector, etc.)?
- Is there an auxiliary energy for DHW (e.g., solar)? In this case, which is the the configuration of the installation[54]?
- Is your gas heating produced by an individual boiler or by a collective boiler? (If the answer is "collective boiler", the applicant is rejected)[55]
- Is your individual gas boiler connected to the network or is it fed by a propane tank? (If the answer is "tank", the applicant is rejected)[56]

Do you also have any other equipment connected to the gas network, such as a gas cooker, gas hobs, a free-standing bath heater, or anything else? (If the answer is yes, the applicant is rejected)

- Are you planning to change your gas boiler in the coming year? (If the answer is yes, the applicant is rejected)
- Do you intend to move within the next year? (If the answer is yes, the applicant is rejected)
- Socio-professional category
- Type of accommodation (house or flat)
- Year of construction of the house/flat
- Thermal renovation carried out
- Household composition (single, couple (young and old), family with children)
- Postal address
- E-mail address
- Telephone number

These documents will have to be translated into the different languages and be coded for later Internet broadcast.

Household questionnaire that goes with in-situ measurement

A technical and behavioural questionnaire will be developed in order to collect some useful information for the interpretation of heating and DHW consumption (level of comfort felt, use of automatic night reduction, etc.). The participant will also be asked to provide some photos (boiler dataplate, control, heating emitter, etc.).

Guidelines and procedure for installing monitoring equipment

The local relay will have to recruit and train technicians (plumbers/heating engineers in the case of installation of intrusive heat meters, electricians in all cases) who are qualified to install the meters and to collect the necessary technical information in situ.

The installation guidelines and procedures shall be written after validation of the metrology by an accredited laboratory.

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[54] See section 10.5.2 and figures 49, 50 and 51 "Heating and DHW installations presenting difficulties/to avoid for in-situ measurements
[55] these information should also be recorded as useful information even if not relevant for the aim of the measurement campaign

GDPR form

As personal data will be collected during the project, a GDPR form needs to be filled in by the participants at the beginning of the project. Its creation will be sub-contracted to a GDPR consultant. If legally possible, the form will be filled in and sign online (for example after answering the household questionnaire). The GDPR consultant will be in charge of the whole GDPR strategy of the project i.e., the content of the different GDPR documents.

10.1.25 Recruitment of participants

The validation of the representativeness of the sample will be sub-contracted to a Statistical Consultant (SC). This company will validate the relevance of the selection criteria that are proposed (see section 10.8) and will assist the OPP at each step of the recruitment process.

Pre-recruitment of potential participants (online)

The OPP will send the online advertising and the pre-recruitment questionnaire to its panelists that meet the selection criteria.

Validation of the consistency of the sample

Based on the positive answers, the OPP assisted by the SC will build a first sample.

Initial contact with the participants (phone)

By experience we know that some candidates that first declare online their willingness to participate will then withdraw from the study when they receive the monitoring devices. In order to avoid this situation, the OPP will call each respondent to re-explain the project and confirm his/her consent. During this call, he/she will confirm his/her coordinates. The SC will closely follow this process as the sample characteristics will probably be continuously modified.

10.1.26 In situ end-use measurements

Questionnaire and GDPR form

Once the oral agreement has been reached, the online household questionnaire (see section 10.9.2) will be sent to the participant. Its last part will contain the GDPR consent form.

Validation of correct installation

Confirmation of the correct installation of the metrology by the plumbers/heating engineers and electricians will be validated by photos and self-check sheets. Index readings and reports of interventions will be sent to each local relay who will centralise this information and forward it to the project manager.

At the end of this stage, and if the metrology is communicating, a data quality verification protocol should be carried out to complete the validation.

The participant will then receive a first gift card.

Hotline during the monitoring campaign

A hotline, managed by the local relay and the PM, will remain available throughout the measurement period.

Return of monitoring equipment

After one year, a new intervention will be necessary to remove the measuring and communication devices and to carry out the final reading of the meters. If the monitoring system is non-intrusive, only the intervention of an electrician will be necessary. Participants will then receive a second gift card.

10.1.27 Data processing

If a communicating system has been installed, the PM will be able to start cleaning the data files from the beginning of the measurement campaign. If dataloggers have been preferred, the cleaning can only be done after the removal of the monitoring equipment (data extraction).

After cleaning, statistical adjustment will be made by the SC in order to correct improprieties or limitations in observed data and to remove the influence of nuisance variables. Afterward, the PM will process the data.

10.1.28 Summary of tasks and the key actors

Table 26 summarises the actors of the project and their tasks. The Project Manager has the central role and must be multi-skilled. The second key-actors are the local relays.

Table 26. Summary of project actors and description of their tasks

Actors	Tasks
Project Manager (PM)	- Selection and purchase of monitoring equipment - Recruitment of online panel provider, statistical consultant and GDPR consultant - Design of the various documents (advertisement, pre-recruitment questionnaire, household questionnaire, installation guidelines, GDPR form, document describing the procedure for returning the datalogger). - Preparation and dispatch of measuring equipment - Hotline support during the installation phase and throughout the measurement period to local relays - Data processing
Local Relay (LR)	- Obtention from the energy supplier of the daily GCV of the gas at the delivery points of the monitored boilers - Definition of geographical areas by country (gas family, housing type, territories, etc.) - Translation of various documents (installation/ end of monitoring guidelines), - Hiring and training of plumbers/heating engineers and electricians for the installation of the meters and the information to be collected in situ - Validation of the proper instrumentation of the dwellings - Centralisation of data from monitoring equipment - Hotline during the installation phase and throughout the measurement period
Online panel provider (OPP)	- Translation of various documents (advertising, pre-recruitment questionnaire, household questionnaire, GDPR form) - Coding of questionnaires and GDPR form - Recruitment process (online pre-recruitment, first contact by phone, household questionnaire, GDPR form)

Statistical Consultant (SC)	- Validation of the representativeness of the sample at each stage of the recruitment process (validation of the selection criteria, continuous validation of the coherence of the sample during its constitution). - Assistance with data processing (statistical adjustment)
GDPR Consultant	- Development of the GDPR strategy

Source: Authors' analysis

10.10 Estimated budget of the different gas boilers monitoring strategies

This section intends to propose an estimated budget for the different gas boilers monitoring strategies.

The different measurement points or readings to be taken are presented in Figure 49 (see section 10.5.2). They correspond to the parameters that influence the consumption and the efficiency of the boilers.

The total gas consumption of the dwelling, the gas and electricity consumption of the boiler, the useful productions of heating and Domestic Hot Water (DHW) with the associated temperature levels, as well as the ambient temperature of the dwelling could be derived from these data.

10.1.29 Training sessions for the installation of the meters

The success of the in-situ measurements of the gas boilers depends directly on the quality of:

- The complex installation and dismantlement of the measuring equipment,
- The relevant onsite audit of the characteristics of the heating systems and of the house/flat.

To ensure this quality, it is necessary to train the plumbers/heating engineers and electricians of each country who will be in charge of the installation of the measuring devices.

The following 3-days training programme has been budgeted:

Day 1: Theoretical course and first test house installations

- Presentation of the different dataloggers (how to use/install them / for what type of appliance /how to configure them / Installation hints)
- Installation in a first test house/flat (Identification of the systems to monitor and of the electrical panel / Installation of the meters / House-flat audit / Data recording)
- Dismantling procedure (What to check at the end of the monitoring campaign)

Day 2: Test house installations

Day 3: Dismantling and end of monitoring campaign in the test houses

- Download and storage of the data contained in the memory of every metering device
- Training on the regular check of the data and maintenance operation (measurement systems with communication function)
- Check of the data quality and explanation of the sending procedure

10.1.30 Number of participants

Two strategies are budgeted below: monitoring of <u>25</u> or <u>50</u> dwellings per country in 8 different countries. For both strategies, we assume that:

- Most of the boilers to be monitored will be combined systems (heating and DHW),

- Intrusive flow meters will be used[56]
- Sensors within the same house will communicate with a data concentrator (hub) [57]

It should be noted that the measurement infrastructure should be confirmed or invalidated by an accredited laboratory prior to the roll-out of the European in situ-measurement campaign[58].

Table 27 recalls the number of households for the 2 different strategies that have been proposed.

Table 27 Summary of different strategies

Strategy	Number of households	
	By country	EU (Sample: 8 countries)
S1	25	200
S2	50	400

Source: Authors' analysis

10.1.31 Tasks of key actors

Table 28 summarises the tasks of the key actors in the project.

Table 28. Summary of project actors and description of their tasks

Actors	Tasks
Project Manager (PM)	- Selection and purchase of monitoring equipment - Recruitment of the local relays, the statistical consultant and the GDPR consultant - Design of the various documents (advertisement, pre-recruitment questionnaire, household questionnaire, installation and dismantlement guidelines, GDPR form). - Management of the shipping of monitoring equipment - Training of the plumbers/heating engineers and electricians - Hotline support during the installation phase and throughout the measurement period to local relays - Data processing
Local Relay (LR)	- Obtention from the energy supplier of the daily GCV of the gas at the delivery points of the monitored boilers - Definition of geographical areas by country (gas family, housing type, territories, etc.) - Translation of various documents (installation/ dismantlement guidelines), - Recruitment of the online panel suppliers - Recruitment of the plumbers/heating engineers and electricians for the installation of the meters and the information to be collected in situ - Supervision of the training session - Validation of the proper installation of the monitoring equipment in the houses/flats
plumbers/heating engineers and electricians	- Attending a training session for the installation of the meters and the information to be collected in situ - Installation and dismantlement of the meters

[56] Cf 2204_in situ measurement methodology_gas boiler: 5.3.2 Water volume measurements

[57] Cf 2204_in situ measurement methodology_gas boiler: 4.3.2.2 - sensor communication

[58] Cf 2204_in situ measurement methodology_gas boiler : 5.6 – Validation of the metrology before a large deployment

Online panel provider (OPP)	- Coding of questionnaires and GDPR form - Recruitment process (online pre-recruitment, first contact by phone, household questionnaire, GDPR form)
Statistical Consultant (SC)	- Validation of the representativeness of the sample at each stage of the recruitment process (validation of the selection criteria, continuous validation of the coherence of the sample during its constitution). - Assistance with data processing (statistical adjustment)
GDPR Consultant	- Development of the GDPR strategy

Source: Authors' analysis

10.1.32 Estimated budget of the different strategies

Table 29 gives the distribution of the costs between the different contractors and subcontractors for the 2 different strategies.

Table 29 Distribution of costs between the different contractors and subcontractors for the 2 different strategies

Strategy n°	Number of household/country	Project Manager (€)	Local Relay (€)	plumbers/heating engineers and electricians (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers purchase& shipping- (€)	Total costs (€)
S1	25	549 920	321 600	457 600	130 570	8 175	10 000	485 600	**1 963 465**
S2	50	869 920	601 600	857 600	130 570	8 175	10 000	925 600	**3 403 465**

Source: Authors' analysis

The most cost-effective strategy is S1, which consists of monitoring a limited number of households (25 households per country, in 8 representative countries) and has an expected statistical accuracy of about 25%. The S2 strategy (monitoring 50 households per country) has an expected statistical accuracy of about 15% [59].

10.1.33 Detailed costs of each strategy

In Annex 2.3, the budget for each strategy is broken down between the different tasks and actors. The costs are only indicative as they may change depending on the data loggers selected, the length of the document to be translated, the incentives offered by the online panel provider, etc.

IMPORTANT NOTE: it could be difficult to find participants as the monitoring equipment is quite intrusive (installation of flow meters that require work on the heating network).

[59] Cf 2204_in situ measurement methodology_gas boiler: 7.2 - Sample size

11 Conclusion

Ecodesign and Energy Labelling measures contribute to improve energy efficiency of products on the European market by setting minimum efficiency requirements and by providing a clear indication of the performance to consumers.. The 2020 European Court of Auditors (ECA) Ecodesign audit[60] formulated the following recommendation with respect to the ecodesign impact accounting model that is used by the European Commission to evaluate the impact of its Ecodesign and energy labelling policies[61]:

2(b) assess the scope for evaluating the results of the policy using sample-based methodology to measure actual energy consumption by end users with a view to improving the accuracy of the impact accounting model.

In order to fulfil this recommendation, it is necessary to identify suitable methods to capture real energy savings due to the implementation of Minimum Energy Performance Standards (MEPSs) under the EU Ecodesign. In other words, it could be beneficial to evaluate the results of the Ecodesign and Energy labelling policies using sample-based approach to estimate the actual energy consumption of appliances in Europe.

In this context, the first goal of this study was to, make the link between in-situ measurements campaigns and assessment scenarios and especially ecodesign impact accounting model.

The developed in-situ measurement campaigns will provide a calibration point for the Ecodesign Impact Accounting calculations that estimate theoretically the benefits of Ecodesign and Energy Labelling. It will also allow to better understand the determinants of energy use of the selected product groups and improve the modelling of impact assessments.

Results from in-situ measurement campaigns can also be useful to analyse a number of key implementation and design aspects of Ecodesign and Energy Labelling regulations, such as:

- Identifying trends and aspects that may have been overlooked or underestimated in the policy preparation and in policy assessment models (in terms of technologies, rebound effects, unsuspected regulatory consequences, aging of products, etc.);
- Assessing whether the standardised and theoretical values given to consumers on the Energy Labels are capturing to the extent feasible the average real-life use
- Giving potential evidence on circumvention and non-compliance issues;
- Improving Non-intrusive Load Monitoring (NILM) algorithms or deep neural network systems: e.g. it could be very useful to test NILM algorithm in the field (not only on set of existing data) in order to improve their performance and accuracy.

In this study, based on the outcomes of previous projects, the different aspects to be taken into account when designing an in-situ measurement campaign have been reviewed:

- Sample design with a special focus on statistical representativeness;
- Data acquisition (different metrological possible solutions) and management;
- General miscellaneous questions as metering length, information to collect on site to better describe the appliance of interest, personal data management.
-

These points have been tailored into practical field methodologies for the following product groups:

[60] https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=52828
[61] https://ec.europa.eu/energy/studies_main/final_studiesecodesign-impact-accounting_fr

- Televisions (ENER lot 5);
- Domestic refrigerators and freezers (ENER lot 13);
- Gas boilers (ENER lot 1).

Then the organisational aspects and the role of the different stakeholders to launch in a near future a proof of concept have been studied in detail, including a clear households' recruitment procedure, and the technical specifications of monitoring equipment to be used

Lastly, preliminary draft budgets have been elaborated built on real cost options, based on different monitoring strategies (e.g. sample size and accuracy). Therefore, the costs given in this report are only indicative.

The three measurement methodologies are described in details in specific report sections (e.g. parameter to be monitored, type of meters, sample size, expected precision, costs etc), but the following general recommendations can be drawn.

Monitoring strategy

The objective of the study is to elaborate a methodology for single products, but multi-products strategies could be drawn up to reduce the overall cost and to ease the organisation of in-situ measurements[62]. To this end, it should be possible to monitor several types of appliances in the same household, either at the same time or one after another, in order to limit the number of necessary dataloggers. The idea could be to use the same sample of dwellings to cover several electric household appliances. This can be done in the case of plug-in monitoring (e.g. TVs, refrigerators, washing machines). However, an expert electrician would be needed for products that are plugged directly in the switchboard (e.g. lighting, ovens etc) and a plumber would be necessary in case of gas boiler monitoring. In the latter cases, both organisation and costs are different and the cost savings of a multi-product campaign result to be limited.

Selection of the sample

As the sample size is a compromise between representativeness and cost, it is proposed to implement the in-situ measurements only in 8 European countries representing most geographical, cultural and living standards in order to optimize the costs. They cover all 4 empirical geographical zones (centre, east, north, south) and are rather homogeneous in terms of standard of living. The 8 foreseen countries are Germany, France, Italy, Spain, Poland, Netherlands, Romania, Sweden for TVs and Refrigerators (representing 77.5% of EU households), and Germany, France, Italy, Spain, Poland, Netherlands, Romania, Denmark for gas boilers (representing 84% of the EU boiler stock).

Monitoring duration

For all the three product groups, even if it more expensive, it is recommended to monitor the energy consumption during a whole year in each household. For gas boilers and refrigerators this is because seasonality has been proven to be an important factor, for TVs because their electricity consumption has never been monitored during one whole year at European level and it would be interesting to assess a possible seasonal correlation.

Challenges of carrying out in-situ monitoring campaign in a crisis period

[62] it is difficult to give a precise % cost savings as the size of the sample should be adjusted to be representative for the different appliances (different criteria are used for the sample selection)

The current high electricity and gas prices have an impact on household energy consumption and thus the result of an in-situ metering campaign in this energy crisis period could lead to biased results. However, this highly depends on the type of products: for everyday electric appliances such as e.g. refrigerators, TVs, washing machines etc. users are not going to change their behaviour that much, and thus, a measuring campaign would not be effected a lot by this critical energy price situation. Moreover, consumption data collected directly from the field are going to be very important in a crisis period in order also to guide political decisions. On the other hand, very high gas prices will have a big impact to the use of gas boilers. For this product group it would be better to postpone the measuring campaign or to forsee a duration of several years. It should also noted that, due to the current unprecedented crisis on electronic components, there is an important uncertainty on prices and delivery time of the dataloggers.

NILM and prerequisite on EU smart meters data resolution

Non-intrusive load monitoring (NILM) consists of measuring electricity consumption using a smart meter or a dedicated device (usually placed in the panel board) and patented algorithms. It relies on a single point of measurement, and has the potential to offer a low-cost, scalable method for acquiring end-use data. However, the accuracy of NILM systems at appliances' level is today still not proven and varies from one appliance to another. Due to this lack of relevant proof of accuracy, it is necessary to run more field tests of NILM systems in real houses before any massive roll-out. User port of the smart meter (P1, S1) could be a promising appliance monitoring solution in the future as it requires no installer. However, the resolution of the provided data have to be sufficiently high, and it is not always the case in the commercial smart meters used in EU. It is recommended to impose the necessary prerequisites in term of data resolution on the next generation of smart meter at EU level.

Importance to monitor also HP performance on the field

EU has recently introduced requirements across various policy programmes in order to gradually phase out gas boilers. At the same time, some countries are setting up quick actions towards the aim of zero CO_2 emissions in 2050 (e.g. France and the Netherlands). Heat Pumps (HP) may replace gas boilers in the future. This market is foreseen to grow rapidly in volume in the next years. According to EHPA (European Heat Pump Association) 2 million HP have been sold in 2021 and sales are projected to reach 4 million in 2024 with the massive replacement of gas boilers. In order to ensure an efficient roll-out of HP, it seems important to monitor also their performance on the field. In this way, it would be possible to give direct feed back to the building industry and the HP manufacturers about the actual average efficiencies. Based on these results, they could adapt the products if necessary. Therefore, it should be also evaluated an European in-situ measurements campaign for HPs, as the one already performed in Germany in 2007-2010 [13]

Self-monitoring and reporting appliances

The on-going review of the Ecodesign Directive aims at introducing the topic of 'self-monitoring and reporting appliances', i.e., smart products able to measure their own performance and communicate it to the user, allowed third parties like manufacturers or installers, and in an anonymised manner to authorities. It is seen as a robust way of automatically gathering anonymised performance data on a very large numbers of products, to assess and improve the effectiveness of ecodesign and energy labelling policies, and inform the public, in a similar manner as this is already in place for passenger cars. If self-reporting becomes standard, it might be conceivable to organise hybrid campaigns, in which representative samples would still need to be constructed and complementary used. Two challenges need to be noted though related to uncertainties on the gathered data and its representativeness:

- The gathering of anonymised data shouldn't be conditioned to the user consent, as there might be a large number of households unaware of the anonymisation and being unnecessarily uncomfortable with sharing product usage patterns; In addition manufacturers could, by specific warning menus, ensure that the majority of users would decline the sharing of such anonymous data. Both effects would introduce a significant bias to the gathered data, significantly affecting the meaning and value of its analysis and aggregation;

- There is a risk of manufacturers tampering with the data, in order to show more favourable results or hide potential non-compliance or low performing product data.

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List of abbreviations and definitions

AC	Air Conditioning
ADEME	French Environment and Energy Management Agency
CSV/TSV	Comma Separated Values/Tab Separated Values
CT	Current transformer
DHW	Domestic Hot Water
DSO	Distribution system operators
EC	European Commission
ECA	European Court of Auditors
EED	minimum energy performance standards
EDF	Electricite de france
EEI	Energy Efficiency Index
EIA	Ecodesign Impact Accounting
EPBD	minimum energy performance standards
EPREL	European Product Registry for Energy Labelling
EU	European Union
GCV	Gross Calorific Value
GDPR	General Data Protection Regulation
GPRS	General packet radio service
HEEP2	Household Energy End-use Project
IT	Information technology
LCD	Liquid Cristal Display
LCV	gas Low Calorific Value
G20 and G25	gas categories
CRT	cathode-ray tube
LAN	Local Area Network
MEPSs	minimum energy performance standards
NILM	Non-intrusive Load Monitoring
NoSQL	not only SQL
OPP	Online Panel Provider

PM	Project Manager
RTE	French electricity grid authority
SC	Statistical Consultant ().
SDR/HDR	Standard or High Dynamic Range
SQL	Structured Query Language
SRS	simple random sampling
SVOD	Subscription Video On Demand
TV	Television
VA	volt-ampere

List of boxes

Use the built-in function to generate a table of figures (References > Captions > Insert Table of Figures); or simply use the example in the template and update it (click on table field, press F9) when the report is complete.

List of figures

List of tables

Annexes

Annex 1: Breakdown of gas consumption by equipment (heating/DHW/cooking)

To be able to differentiate between central heating, DHW and / or cooking consumption, data from the gas meter should be processed.

1 Central heating gas flow

Counting ON if

- The gas counter is measuring flow rates above the minimum flow rate of the boiler and
- The central heating flow rate measures flow rates above 200l/h and
- The flow temperature is above 20°C and near to the calculated value of:
  - $T_{flow} = T_{return} + E_{gas}/eta_{s, estimated} / (v_w * c_w)$

  - E_{gas} : measured/estimated gas energy
  - $eta_{s, estimated}$: estimated boiler efficiency
  - v_w : measured heating flowrate
  - c_w : calculated heat capacity
- No temperature rises and flow rate is measured on the domestic hot water side and
- The subtraction of a gas flow rate from the cooking could be separated by:
  - During boiler running:
    - The gas counter is measuring a new additional gas flow rate next to the installed cooking power and
    - The suddenly additional gas flow rate measured is not bringing an increase in central heating flow temperature and
    - If the boiler flow temperature and central heating flow rate stays constant, the additional gas flow rate is identified as cooking gas flow rate
  - Boiler is not running:
    - The gas counter is measuring a flow rate that is under the minimum gas flow rate of the boiler but near to the installed cooking power
    - The gas flow rate measured is not bringing an increase in the central heating flow temperature
    - If the boiler flow temperature stays constant and the central heating flow rate is at 0 or stays constant, the additional gas flow rate is identified as cooking gas flow rate

2 DHW gas flow

counting ON if

- The gas counter is measuring flow rates above the minimum flow rate of the boiler and
- The domestic flow rate measures flow rates above 2l/h and
- The domestic hot water temperature is above 5°C and near to the calculated value of:
  - $T_{dhw} = T_{dcw} + E_{gas}/eta_{s, estimated} / (v_{dhw} * c_w)$

  - E_{gas}: measured/estimated gas energy
  - $eta_{s, estimated:}$ estimated boiler efficiency
  - v_w: measured DHW flowrate

  - c_w: calculated heat capacity
- No temperature rises and flow rate is measured on the central heating side
- The subtraction of a gas flow rate from the cooking could be separated by:
  - During boiler running:
    - The gas counter is measuring a new additional gas flow rate next to the installed cooking power and
    - The suddenly additional gas flow rate measured is not bringing an increase in central heating flow temperature and
    - If the boiler flow temperature and central heating flow rate stays constant, the additional gas flow rate is identified as cooking gas flow rate
  - Boiler is not running:
    - The gas counter is measuring a flow rate that is under the minimum gas flow rate of the boiler but near to the installed cooking power
    - The gas flow rate measured is not bringing an increase in the central heating flow temperature
    - If the boiler flow temperature stays constant and the central heating flow rate is at 0 or stays constant, the additional gas flow rate is identified as cooking gas flow rate

3 Gas cooking

counting ON if

- Gas counter is measuring flow rates above the minimum flow rate of the installed cooking and under the minimum gas flow rate of the boiler and
- The central heating or domestic hot water flow rates like the central heating or domestic hot water temperature are not moving

Annex 2: Detailed cost of each in-situ monitoring strategy

In this Annex the budgets for each monitoring strategy (6 for Televisions, 6 for fridges and freezers, 3 for gas boilers) are broken down between the different tasks and actors. Costs are only indicative as they can be changes depending on the selected dataloggers, the ownership rate of secondary televisions or fridges in the different countries, the length of the document to translate, the incentives proposed by the Online Panel Provider.

For the detailed cost evaluation the following assumptions and reference have been considered:

Project management : 800€/day	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden etc)
Selection and purchase of the monitoring equipment	
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	From quotations of several Online Panel Providers
Development of the household questionnaire that goes with in-situ measurement	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden...)
Code of advertising and pre-recruitment questionnaire, household questionnaire	From quotations of several Online Panel Providers
Development of monitoring equipement installation guidelines and procedure	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden...)
Development of the GDPR documents	From quotations of several GDPR consultants
Translation of the different documents	From quotations of several Online Panel
Declination at national level of selection criteria	From quotation of a statistical consultant
Pre-recruitment of the potential candidates	From quotations of several Online Panel
Validation of the candidates (consistency of the sample)	From quotation of a statistical consultant
Initial contact with participants (validation of the willingness to participate and of their coordinates)	From quotations of several Online Panel Providers
Incentives and incentives' management	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden etc) and quotations of several Online Panel
Parcel preparation and shipping	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden etc)
Installation support for the monitoring equipment	
Validation of the correct installation	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden...)
Hotline during monitoring campaign	
Return of the monitoring equipment	
Data processing	From experience of previous and current projects (Panel Elecdom, Intertek, Sweden...) and quotation of a statistical consultant

2.1 TELEVISIONS

S1: Monitor only the main television in 110 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				88 000	90 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	94 720	1 200			97 520
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		148 060				148 060
Parcel preparation and shipping	8 800				18 302	27 102
Installation support for the monitoring equipment	1 600					1 600
Validation of the correct installation	2 400					2 400
Hotline during monitoring campaign	3 200					3 200
Return of the monitoring equipment	7 200					7 200
Data processing	36 000		4 575			40 575
	86 400	**254 510**	**8 175**	**10 000**	**106 302**	**465 387**

S2: Monitor only the main television in 165 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				132 000	134 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	134 280	1 200			137 080
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management	0	222 080				222 080
Parcel preparation and shipping	11 200				27 453	38 653
Installation support for the monitoring equipment	2 400					2 400
Validation of the correct installation	4 000					4 000
Hotline during monitoring campaign	4 800					4 800
Return of the monitoring equipment	11 200					11 200
Data processing	46 400		4 575			50 975
	107 200	**368 090**	**8 175**	**10 000**	**159 453**	**652 918**

S3: Monitor only the main television in 220 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				176 000	178 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	173 340	1 200			176 140
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management	0	296 240				296 240
Parcel preparation and shipping	14 400				36 604	51 004
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	14 400					14 400
Data processing	58 400		4 575			62 975
	128 800	**481 310**	**8 175**	**10 000**	**212 604**	**840 889**

S4: Monitor all televisions in 65 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				88 000	90 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000	|				4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800	|				800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400	|		10 000		12 400
Translation of the different documents	1 600	|				1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	63 580	1 200			66 380
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management	0	88 210				88 210
Parcel preparation and shipping	6 400				10 815	17 215
Installation support for the monitoring equipment	1 600					1 600
Validation of the correct installation	2 400					2 400
Hotline during monitoring campaign	3 200					3 200
Return of the monitoring equipment	4 000					4 000
Data processing	36 000		4 575			40 575
	80 800	**163 520**	**8 175**	**10 000**	**98 815**	**361 310**

S5: Monitor all televisions in 98 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				132 000	134 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	87 916	1 200			90 716
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management	0	132 970				132 970
Parcel preparation and shipping	8 000				16 306	24 306
Installation support for the monitoring equipment	2 400					2 400
Validation of the correct installation	4 000					4 000
Hotline during monitoring campaign	4 800					4 800
Return of the monitoring equipment	6 400					6 400
Data processing	46 400		4 575			50 975
	99 200	**232 616**	**8 175**	**10 000**	**148 306**	**498 297**

S6: Monitor all televisions in 130 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				176 000	178 400
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000	|				4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800	|				800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400	|		10 000		12 400
Translation of the different documents	1 600	|				1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	111 060	1 200			113 860
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		176 540				176 540
Parcel preparation and shipping	9 600				21 630	31 230
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	8 800					8 800
Data processing	58 400		4 575			62 975
	118 400	**299 330**	**8 175**	**10 000**	**197 630**	**633 535**

2.2 FRIDGES AND FREEZERS

S1: Monitor only the main fridge and freezer (if there is one) in 110 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				468 540	470 940
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	153 964	1 200			156 764
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		259 000				259 000
Parcel preparation and shipping	12 800				31 946	44 746
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	12 800					12 800
Data processing	72 800		4 575			77 375
	140 000	**424 694**	**8 175**	**10 000**	**500 486**	**1 083 355**

S2: Monitor only the main fridge and freezer (if there is one) in 165 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				468 540	470 940
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000						4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800						800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400				10 000		12 400
Translation of the different documents	1 600						1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	153 964	1 200			156 764
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		259 000				259 000
Parcel preparation and shipping	12 800				31 946	44 746
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	12 800					12 800
Data processing	72 800		4 575			77 375
	140 000	**424 694**	**8 175**	**10 000**	**500 486**	**1 083 355**

S3: Monitor only the main fridge and freezer (if there is one) in 220 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				468 540	470 940
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	173 340	1 200			176 140
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		296 240				296 240
Parcel preparation and shipping	14 400				36 604	51 004
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	14 400					14 400
Data processing	72 800		4 575			77 375
	143 200	**481 310**	**8 175**	**10 000**	**505 144**	**1 147 829**

S4: Monitor all fridges and freezers in 96 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				234 720	237 120
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000	|				4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800	|				800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400	|		10 000		12 400
Translation of the different documents	1 600	|				1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	85 032	1 200			87 832
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		129 440				129 440
Parcel preparation and shipping	8 000				15 973	23 973
Installation support for the monitoring equipment	1 600					1 600
Validation of the correct installation	2 400					2 400
Hotline during monitoring campaign	3 200					3 200
Return of the monitoring equipment	6 400					6 400
Data processing	42 400		4 575			46 975
	91 200	**226 202**	**8 175**	**10 000**	**250 693**	**586 270**

S5: Monitor all fridges and freezers in 144 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				351 540	353 940
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000					4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800					800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400			10 000		12 400
Translation of the different documents	1 600					1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	119 748	1 200			122 548
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		194 150				194 150
Parcel preparation and shipping	10 400				23 959	34 359
Installation support for the monitoring equipment	2 400					2 400
Validation of the correct installation	4 000					4 000
Hotline during monitoring campaign	4 800					4 800
Return of the monitoring equipment	9 600					9 600
Data processing	57 600		4 575			62 175
	116 000	**325 628**	**8 175**	**10 000**	**375 499**	**835 302**

S6: Monitor all fridges and freezers in 192 households/country

	Project Manager (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Project management	4 000					4 000
Selection and purchase of the monitoring equipment	2 400				468 540	470 940
Recruitment of an Online Panel Provider, a statistical consultant, a GDPR consultant	2 400					2 400
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	4 000	↑				4 000
Development of the household questionnaire that goes with in-situ measurement	4 000	|				4 000
Code of advertising and pre-recruitment questionnaire, household questionnaire	800	|				800
Development of monitoring equipement installation guidelines and procedure	2 400	11 730				14 130
Development of the GDPR documents	2 400	|		10 000		12 400
Translation of the different documents	1 600	|				1 600
Declination at national level of selection criteria	800	↓	2 400			3 200
Pre-recruitment of the potential candidates	800	↑				800
Validation of the candidates (consistency of the sample)	1 600	153 964	1 200			156 764
Initial contact with participants (validation of the willingness to participate and of their coordinates)		↓				0
Incentives and incentives' management		259 000				259 000
Parcel preparation and shipping	12 800				31 946	44 746
Installation support for the monitoring equipment	3 200					3 200
Validation of the correct installation	4 800					4 800
Hotline during monitoring campaign	6 400					6 400
Return of the monitoring equipment	12 800					12 800
Data processing	72 800		4 575			77 375
	140 000	**424 694**	**8 175**	**10 000**	**500 486**	**1 083 355**

2.3 GAS BOILERS

S1 : 25 Gas boilers/country

	Project Manager (€)	Local Relay (€)	plumbers/heating engineers and electricians (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Preparatory study 1 (validation of availability of daily Gross Calorific Value) / Find local relay in each country	9 600							9 600
Project management	9 600							9 600
Hiring of plumbers/heating engineers and electricians	1 600	12 800						14 400
Preparatory study 2 (laboratory validation of the metrology before a large roll-out)							40 000	40 000
Selection and purchase of the monitoring equipment	3 200						445 600	448 800
Recruitment of plumbers/electricians, Online Panel Suppliers, a statistics specialist, a RGPD consultant	1 600	3 200						4 800
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	2 400			4 730				7 130
Development of the household questionnaire that goes with in-situ measurement	5 600							5 600
Code of advertising and pre-recruitment questionnaire, household questionnaire	1 600							1 600
Development of monitoring equipement installation guidelines and procedure	4 000							4 000
Development of the RGPD documents	2 400					10 000		12 400
Translation of the different documents	6 400	19 200						25 600
Declination at national level of selection criteria (gas family, housing type, territories, etc.)	800	6 400			2 400			9 600
Pre-recruitment potential candidates / Initial contact with participants (validation of the willingness to participate)				55 700				55 700
Validation of the candidates (consistency of the sample)	1 600				1 200			2 800
Incentives and incentives' management				70 140				70 140
Management of the shipping of monitoring equipment	6 400							6 400
Training of plumbers/heating engineers and electricians for the installation of the meters and the in-situ collection of information	173 120		57 600					230 720
Installation of the monitoring equipment			320 000					320 000
Validation of the proper installation of the monitoring equipment + in-situ measurement data centralisation (mainteance 1 year)	40 000	160 000						200 000
Hotline during monitoring campaign (for dwellings and plumbers/heating engineers and electricians)		120 000						120 000
Hotline during monitoring campaign (for local relays)	40 000							40 000
Dismantling of the monitoring equipment			80 000					80 000
Data processing	240 000				4 575			244 575
	549 920	**321 600**	**457 600**	**130 570**	**8 175**	**10 000**	**485 600**	**1 963 465**

S2 : 50 Gas boilers/country

	Project Manager (€)	Local Relay (€)	plumbers/heating engineers and electricians (€)	Online Panel Provider (€)	Statistical Consultant (€)	GDPR Consultant (€)	Dataloggers *purchase& shipping-* (€)	Total costs (€)
Preparatory study 1 (validation of availability of daily Gross Calorific Value) / Find local relay in each country	9 600							9 600
Project management	9 600							9 600
Hiring of plumbers/heating engineers and electricians	1 600	12 800						14 400
Preparatory study 2 (laboratory validation of the metrology before a large roll-out)							40 000	40 000
Selection and purchase of the monitoring equipment	3 200						885 600	888 800
Recruitment of plumbers/electricians, Online Panel Suppliers, a statistics specialist, a RGPD consultant	1 600	3 200						4 800
Development of the recruitment strategy and tools (advertising and pre-recruitment questionnaire)	2 400			4 730				7 130
Development of the household questionnaire that goes with in-situ measurement	5 600							5 600
Code of advertising and pre-recruitment questionnaire, household questionnaire	1 600							1 600
Development of monitoring equipement installation guidelines and procedure	4 000							4 000
Development of the RGPD documents	2 400					10 000		12 400
Translation of the different documents	6 400	19 200						25 600
Declination at national level of selection criteria (gas family, housing type, territories, etc.)	800	6 400			2 400			9 600
Pre-recruitment potential candidates / Initial contact with participants (validation of the willingness to participate)				55 700				55 700
Validation of the candidates (consistency of the sample)	1 600				1 200			2 800
Incentives and incentives' management				70 140				70 140
Management of the shipping of monitoring equipment	6 400							6 400
Training of plumbers/heating engineers and electricians for the installation of the meters and the in-situ collection of information	173 120		57 600					230 720
Installation of the monitoring equipment			640 000					640 000
Validation of the proper installation of the monitoring equipment + in-situ measurement data centralisation (mainteance 1 year)	80 000	320 000						400 000
Hotline during monitoring campaign (for dwellings and plumbers/heating engineers and electricians)		240 000						240 000
Hotline during monitoring campaign (for local relays)	80 000							80 000
Dismantling of the monitoring equipment			160 000					160 000
Data processing	480 000				4 575			484 575
	869 920	**601 600**	**857 600**	**130 570**	**8 175**	**10 000**	**925 600**	**3 403 465**

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