Article

Labeling of Installed Heating Appliances in Residential Buildings: An Energy Labeling Methodology for Improving Consumers' Awareness

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Abstract: In the EU 28, the installed heating appliance stock is quite old, with an actual replacement rate of 4%. This is directly reflected in the average efficiency of the installed heating systems, where around 60% of the stock is rated with an energy class of C or D (the lowest classes of the energy label scale). The European project HARP aims at raising consumers' awareness of the planned replacement of their old and inefficient heating appliances with more efficient and renewable solutions. In this direction, an energy labeling methodology for old appliances has been developed to rate the installed stock before the introduction of the EU energy label. The methodology has been developed for space heating appliances and water heaters, targeting two types of users: end consumers and professional users. The validation considered about 4600 space heating appliances and 800 water heaters built between 1972 and 2019. Three heating appliances and two water heaters were tested in the laboratory, confirming the reliability of the proposed methodology. The expected impact of defining an energy labeling methodology for installed heating appliances increases the current replacement rate of these appliances in the EU from 4% to 5%.

Keywords: energy label; ERP; heating appliances; water heater appliances; consumers' awareness

1. Introduction

The penetration of efficient and renewable heating solutions faces several barriers hindering a wider acceptance by end users despite the fact that several of these solutions are already available in the market [1–6]. Different options for space heating systems and water heaters can be found in the literature, including heat pumps and hybrid systems, a combination of solar thermal or PV systems with other generation systems and improvement of control strategies [7–12]. Awareness can be raised by providing information about the expected performance with an energy label [1,13–22], or by providing information about the actual energetic performance [23–25]. In the second case, information on consumption can reduce consumption, on average, from 4% to 20% depending on the application [23–25].

The adoption of energy labels covers different fields: all the "energy-related products" (ErP) (a detailed framework is described by Russo et al. [17]) in Europe; refrigeration systems in Brazil [13]; refrigeration and washing machines [14], and buildings [15,16], in China.

A total of 76% of the installed heating appliances in the EU 28 heating appliance stock are driven by fossil fuels, and around 60% of the installed appliances are rated within the two lowest classes of the energy label scale for new products, classes C or D. In contrast, a large majority of heating appliances now available in the market are rated as class A, or superior [26]. Translating this to the seasonal efficiency, calculated according to Commission Regulation (EU) No 811/2013 [27] and Commission Communication 2014/C

207/02 [28], the efficiency is lower than 82%. The actual replacement rate for heating appliances in the EU 28 is 4% per year, meaning that users replace their unit after 25 years. In the literature, the average lifetime for these appliances is 20 years for boilers and 15 years for heat pumps [29–33].

The energy-related product directive, Directive 2009/125/EC [34], also known as the ErP directive, has been introduced by the EU Commission to support the consumer decision process regarding the acquisition of new appliances. However, the actual old and inefficient heating appliance stock clearly indicates consumers' lack of awareness about the efficiency of their own appliances. This relates to appliances placed on the market before EU Regulations 811/2013 [27] and 812/2013 [35] came into force for space heating appliances and water heaters, respectively, which are the focus of the labeling methodology proposed in this paper.

In Europe, there are currently one compulsory and three voluntary schemes for labeling installed heating appliances. The voluntary schemes were developed by national industry associations, the Spanish association FEGECA [36], the French association UNICLIMA [37] and the Italian association ASSOTERMICA [38]. The purpose is the same, but the implementation is different: the FEGECA label presents only the energy class, and it is defined as a function of the boiler's age and type, while UNICLIMA also includes the heating fuel in the classification. ASSOTERMICA developed a web app that labels gas boilers (since these appliances represent 74% of the Italian stock [26]) requiring the boiler type, the age and the nominal power as input. In addition, ASSOTERMICA's web app offers the possibility of a detailed calculation. Germany has a compulsory energy label for boilers older than 15 years with a nominal capacity of up to 400 kW. The label is generated by selecting the brand and the model within an application connected to a database of the Federal Ministry for Economic Affairs and Energy (BMWi) [39]. The data contain a list of all the installed boilers in Germany provided by the German industry.

The mentioned label schemes for installed heating appliances present some limits: the classification of boilers is different; the French and Spanish labels do not provide the efficiency (needed to calculate the economic benefits of replacement) as output; and the German methodology is not applicable to other countries since its database contains only products sold in Germany. Starting from this analysis, an energy labeling methodology for installed space heating appliances and water heaters was developed in the framework of the EU-funded H2020 HARP project, Heating Appliances Retrofit Planning, the aim of which is to increase consumers' awareness of the opportunities of a planned replacement of old and inefficient heating appliances. The idea of labeling old appliances allows consumers to compare the performance of an old appliance with that of new products available in the market, supporting the replacement decision process of consumers.

The methodology considers a simplified version and a detailed version. The simplified version supports a "common user" that would like to know more about their appliance and does not have any technical background, and the detailed version supports a "professional user" that usually performs prescribed checks of heating systems. The outputs of the labeling methodology are the "seasonal efficiency" of space heating appliances, the "water heater efficiency" and the corresponding energy class. The common user can directly compare the energy class of the installed solution with that of new products available in the market, while a professional user can use the efficiency to raise their clients' awareness and furthermore calculate the energy and economic benefits of an appliance retrofit. This methodology is implemented via the HARPa online application developed within the project, aiming to facilitate access to the methodology outputs and support the evaluation of installed heating appliances.

One important aspect to consider in the performance evaluation of installed heating appliances is the degradation effect due to the aging of the appliance components. Different economic and energetic studies available in the literature [29–33] investigated the aging effect which is briefly explored in Section 2.1 to consider this effect in the labeling of installed appliances.

2. Methods

The development of the labeling methodologies for space heating appliances and water heaters followed the same approach as indicated in the block diagram of Figure 1.
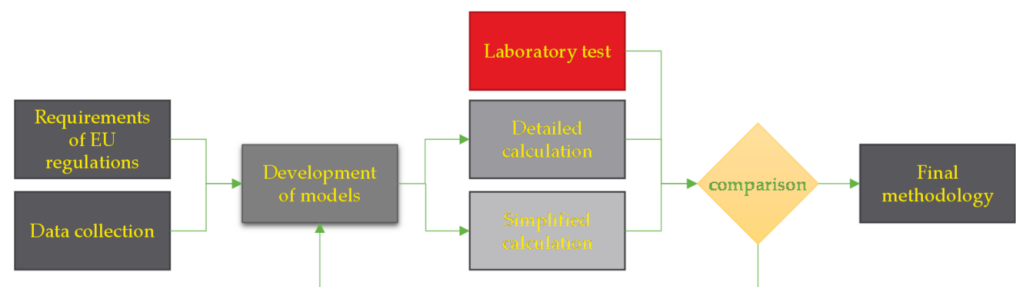

Figure 1. Development of the methodology for labeling existing appliances.

The first step was the requirement analysis of EU Regulations 811/2013 and 812/2013 to develop a calculation methodology compliant with the EU regulations, and to allow the user to compare, on the same basis, the performance of old appliances with that of new products. In addition, the technical testing standards that have a relationship with those regulations were consulted to define a base of the calculation method: Regulations EU 811/2013 with Communication 2014/C 207/02 [27,28], EN 15502-1 c.9.5 [40] and EN14825 [41], for the space heating appliances, and Regulations EU 812/2013 [35], EN 13203 [42], EN 50440 [43], EN 60379 [44] and EN16147 [45].

In parallel with this activity, a dataset was compiled for the validation of the proposed methodology. The data collection considered different sources.

- Database of boilers used to label boilers in Germany [39]: collection of data of 6237 gas and oil boilers, 4449 with a capacity below 70 kW;
- Data provided by the project partners such as the national industry associations "Assotermica" and "Uniclima" and national energy agency "Adene": collection of 200 gas and oil boilers, 120 gas water heaters;
- Market analysis: collection of 450 water heaters (200 electric WH, 200 gas WH, 50 heat pump WH);
- Standards EN 15316-4-1 [46], EN 15316-4-2 [47], EN 15316-5 [48], EN12831-3 [49], UNI EN 15378-3 [50], UNI 10389:2019 [51] and UNI 9182 [52].

1. Understand which data were available for old products to calculate the energy label since the old datasheets are not compliant with the standards in force;
2. Provide a definition of a simplified selection of default values for a common user (e.g., EN 15316-4-1 can be applied by a professional user).

The models and the calculation methodology were developed considering the requirements of the actual regulations and corrected in the validation phase. One aspect considered in the model is the degradation of performance due to the aging of the system, and this is presented in Section 2.1. Degradation was evaluated with data collected from manufacturers and a literature review.

Validation was necessary to minimize the deviation of the simplified version since several values should be assumed as default because a common user does not have the technical skills for understanding the parameters required in the detailed calculation. The first interaction between the model development and the calculation was needed to correct the models, and the following interaction was needed to calibrate the default values. The comparison between the simplified calculation and the detailed calculation considered the output of the calculation, named "seasonal efficiency" for space heating appliances (Section 2.2) and "water heater efficiency" for water heaters (Section 2.3).

A laboratory test was performed on installed units with the aim of confirming the validity of the data collected, in order to verify the aging coefficient and the calculation.

From the measurements performed in the laboratory, the seasonal efficiency of heating appliances and water heater efficiency were calculated.

2.1. Effect of Degradation Due to Aging

An energy label can be issued for installed appliances with an age of more than 20 years. To consider the effect of component degradation, an aging coefficient is included in the calculation. The degradation depends on the appliance technology and on the maintenance level. For example, in some countries, users are required to hire a professional for maintenance and efficiency checks. When this is not followed, the user may not even be aware of the necessity of appliance maintenance. Therefore, the methodology foresees two cases: "normal" maintenance according to the prescribed program, and "bad" maintenance in case it is not performed or is poorly performed.

The manufacturers provided a vast amount of data for gas boilers, while for the other technologies, a literature review was required. Different energy and economic studies exploring heating systems have found an exponential correlation between age and the aging coefficient [29–33].

$$C_{age} = (1 - M)^{age} \tag{1}$$

where M depends on the appliance and the maintenance level of the appliance. The equation has been included in the methodology considering age ranges and M values as a function of the appliance and maintenance as indicated in Table 1.

Table 1. Degradation coefficient as a function of appliance, maintenance and age.

Age	Gas/Oil Boilers		Heat Pumps		Electric Boilers	
Maintenance	Normal	Bad	Normal	Bad	Normal	Bad
M	0.005	0.015	0.01	0.03	0.001	0.002
<10	1.00	0.86	0.90	0.74	1.00	1.00
10–15	0.98	0.80	0.86	0.63	0.99	0.97
16–20	0.95	0.74	0.82	0.54	0.98	0.96
21–25	0.90	0.69	0.78	0.47	0.97	0.95
26–30	0.88	0.64	0.74	0.40	0.96	0.94
>30	0.87	0.59	0.70	0.34	0.95	0.93

2.2. Labeling of Space Heating Appliances

The steps required for the definition of energy labeling of space heating appliances are shown in Figure 2. The first step is the selection of the user type. The common user will introduce only a few inputs and the remaining will be established according to the default values needed for the calculation, while the professional user can introduce all the technical parameters of the appliance.

The calculation is performed considering the seasonal efficiency as prescribed by Regulation EU 811/2013, which is composed of the "on efficiency" with the inclusion of correction factors $F_{(i)}$. As indicated in Section 2.1, the methodology considers the degradation of the efficiency.

$$\eta_s = \eta_{son} \cdot C_{age} - \sum F_{(i)} \tag{2}$$

For boilers, the seasonal on efficiency is considered as the weighted average of the 30% part load efficiency η_1 and the full load efficiency η_4 calculated with the upper heat capacity:

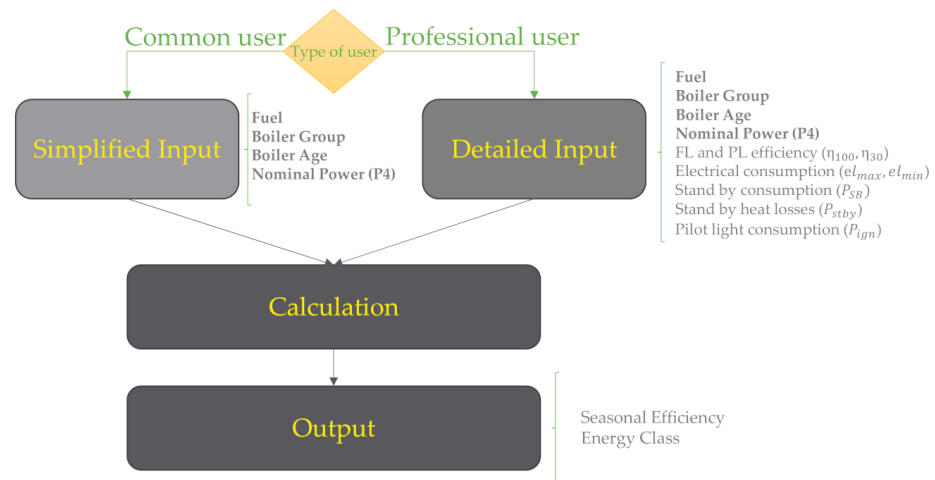$$\eta_{son} = 0.85 \cdot \eta_1 + 0.15 \cdot \eta_4 \tag{3}$$

Figure 2. Schematic diagram for the energy labeling of space heating appliances.

The correction factors consider: $F(1)$ when there is no temperature control, $F(1)$ being 3%; $F(2)$, the correction for the auxiliary electricity consumption; $F(3)$, the effect of standby heat losses; and $F(4)$, the effect of pilot light consumption:

$$F(2) = \frac{2.5 \cdot (0.15 \cdot el_{max} + 0.85 \cdot el_{min} + 1.3 \cdot P_{SB})}{0.15 \cdot P_4 + 0.85 \cdot P_1} \cdot 100 \tag{4}$$

$$F(3) = \frac{0.5 \cdot P_{stby}}{P_4} \cdot 100 \tag{5}$$

$$F(4) = \frac{1.3 \cdot P_{ign}}{P_4} \cdot 100 \tag{6}$$

Sources: Regulation EU 811/2013—Annex VIII. Communication 2014/C 207/02 [27,28]; EN 15502-1 c.9.5 [40].

The default values were defined with the equations presented in EN 15316-4-1 [46]. The part load efficiency η_{30} and the full load efficiency η_{100} are calculated with a logarithmic function of the nominal capacity.

$$\eta_{30} = c_3 + c_4 \cdot \log(P_n) \tag{7}$$

$$\eta_1 = \eta_{30} \cdot \frac{H_i}{H_s} \tag{8}$$

$$\eta_{100} = c_1 + c_2 \cdot \log(P_n) \tag{9}$$

$$\eta_4 = \eta_{100} \cdot \frac{H_i}{H_s} \tag{10}$$

The correction factors consider the effect of thermal losses on standby P_{stby}, standby electricity consumption P_{SB}, part load electricity consumption el_{min}, full load electricity consumption el_{max} and pilot light consumption P_{ign}:

$$P_{stby} = c_5 \cdot (P_n)^{C_6} \tag{11}$$

$$P_{SB} = c_{7,SB} + c_{8,SB} \cdot (P_n)^{n_{SB}} \tag{12}$$

$$el_{min} = c_{7,P1} + c_{8,P1} \cdot (P_n)^{n_{P1}} \tag{13}$$

$$el_{max} = c_{7,Pn} + c_{8,Pn} \cdot (P_n)^{n_{Pn}} \tag{14}$$

where $c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8$ and n are defined in the standard as a function of boiler group. The reference value for pilot light consumption was assumed to be 150 W considering the

values presented by the preparatory study of the eco-design directive of VHK (Task 4) [53] and by the TH-C method (Table 73 [54]). The coefficients are presented in Table A3.

The labeling methodology of heat pumps follows a different calculation. In this case, the default values are taken from EN 15316-4-2 [47] that defines the reference performance in terms of COP and heat capacity for the different types with the correction factors to consider different boundary conditions. The calculation of seasonal performance follows EN 14825 [41] for the three reference climates considered in Regulation 811/2013 [27] for the labeling of new heat pumps. The climates are "Average" (corresponding to Strasbourg), "Colder" (Helsinki) and "Warmer" (Athens).

The reference capacity is 12 kW defined at the conditions: air 7 °C to water 45 °C, with a reference COP = 3.0, or water (or brine) 10 °C to water 45 °C, with a reference COP of 3.7.

The seasonal efficiency of heat pumps is calculated from the SCOP with the conversion coefficient CC 2.5 to convert electricity into primary energy and with two possible correction factors. $F(1)$ corresponds to the absence of temperature control (3%), and $F(2)$ should be applied to consider the circulators of the water or brine source (5%)

$$\eta_{SH} = \frac{SCOP}{CC} - \sum F_{(i)} \tag{15}$$

2.3. Labeling of Water Heaters

As presented in Figure 3, consistently with the labeling of space heating appliances, the first step is the selection of the "type" of user. In this case, the input to select is different from the common user and the professional user. The common user needs to select the WH type, the age and the number of inhabitants. The calculation is different for each type of water heater. The first distinction is the presence or the absence of storage, and the second one is the energy vector. Gas-driven appliances can assume both fuel and electricity consumption, while electric appliances solely consider electricity consumption.
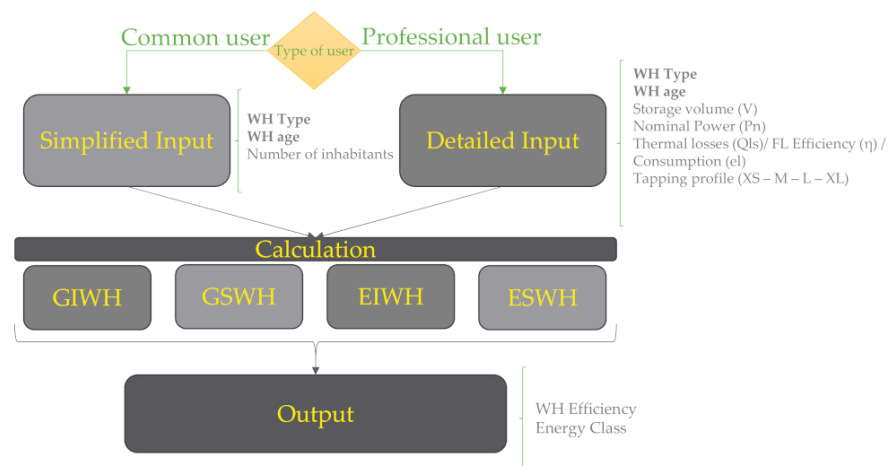
Figure 3. Block diagram of labeling of water heaters.

The number of inhabitants is linked to the tapping profile foreseen in Regulation 812/2013. The profiles define a daily energy draw-off considering a standard consumption. The problem of linking the energy required for DHW with the number of inhabitants is that the consumption considered for the design of DHW systems is different than the consumption assumed in the different national standards (e.g., EN12831-3 [49] and UNI9182 [52]). Table 2 presents the correlation performed with the calculation, with EN12831-3 and the indication for the consumers in the Label Pack A+ (LPA+) project [7].

Table 2. Correlation between tapping profile and number of inhabitants.

	Energy	EN12831-3	LPA+
S	2.1 kWh/day	1	0
M	5.85 kWh/day	2–3	1–2
L	11.7 kWh/day	4–5	3–5
XL	19.1 kWh/day	6–9	6–8
XXL	24.5 kWh/day	10–12	9+

The water heater efficiency η_{WH}, calculated according to Regulation EU 812/2013, considers the possibility of a smart control of the appliance and a correction factor. The correction factor depends on the type of water heater.

$$\eta_{WH} = \frac{Q_{ref}}{\left(Q_{fuel} + CC \cdot Q_{el}\right) \cdot (1 - SCF \cdot smart) + Q_{corr}} \tag{16}$$

$$\text{Electrical}: \ Q_{corr} = -k \cdot CC \cdot \left(Q_{el} \cdot (1 - SCF \cdot smart) - Q_{ref}\right) \tag{17}$$

$$\text{Conversational}: \ Q_{corr} = -k \cdot \left(Q_{fuel} \cdot (1 - SCF \cdot smart) - Q_{ref}\right) \tag{18}$$

$$\text{Heat Pumps}: \ Q_{corr} = -k \cdot 24 \cdot P_{stby} \tag{19}$$

where Q_{ref} is the energy extracted for DHW, Q_{fuel} and Q_{el} are the consumptions of fuel and electricity, "smart" can be 0 in the case of the absence of a smart function or 1, SCF is the effect of the smart function and is measured, k is a factor for the correction (from 3XS to XL, $k = 0.23$; for XXL, $k = 0$) and $CC = 2.5$. Source: Regulation EU 812/2013 [35].

The efficiency for the installed water heaters assumes the absence of a smart control ("smart" = 0) and considers the aging degradation.

$$\eta_{WH} = \frac{Q_{ref}}{\left(Q_{fuel} + CC \cdot Q_{el}\right) + Q_{corr}} \cdot C_{age} \tag{20}$$

To calculate the fuel and electricity consumption of water heaters with storage, the thermal losses should be calculated defining the energetic model of the water heaters. The efficiency of the water heater is strongly dependent on the load [55–61]. One important indication is given in IEA-Task 45 [61] that reports the influence of technological evolution: storages built before 2005 have thermal losses 1.3 to 2 times higher than the new products.

The generator consumption Qin is calculated with an energetic balance in the stationary condition since the water heater's controller keeps the storage temperature constant. The same assumption was made in [55,56].

$$Q_{in} - Q_{ls} - Q_{ref} = 0 \tag{21}$$

The electricity consumption of an ESWH is calculated as the sum of the heat extracted in the draw-off and the storage losses.

$$Q_{el} = \frac{Q_{ref} + Q_{ls}}{\eta} \tag{22}$$

The fuel and electricity consumption of a GSWH is calculated with Equations (23) and (24), while that of a GIWH is calculated with Equations (25) and (26).

$$Q_{fuel} = \frac{Q_{ref} + Q_{ls}}{\eta_{100} \cdot H_i / H_s} = \frac{\left(Q_{ref} + Q_{ls}\right)}{\eta_{100}} \cdot \frac{H_s}{H_i} \tag{23}$$

$$Q_{el} = \int P \, d\vartheta = el_{max} \cdot \vartheta_{on} + P_{sb} \cdot \vartheta_{off} \tag{24}$$

$$Q_{fuel} = \frac{Q_{ref}}{\eta_{100} \cdot H_i / H_s} = \frac{Q_{ref}}{\eta_{100}} \cdot \frac{H_s}{H_i} \tag{25}$$

$$Q_{el} = \int P \, d\vartheta = el_{max} \cdot \vartheta_{on} + P_{sb} \cdot \vartheta_{off} \tag{26}$$

The default values of storage thermal losses are calculated with the equations presented in EN 15316-5 [48].

$$Q_{ls} = f_{sto,dis,ls} \cdot \frac{H}{1000} \cdot (\vartheta_{set} - \vartheta_{amb}) \cdot t \tag{27}$$

$$H = \frac{1000}{c_4 \cdot c_5} \cdot (c_1 + c_2 \cdot V^{c_3}) \tag{28}$$

where $f_{sto,dis,ls}$ is 3 for the presence of a thermal bridge, and otherwise it is 1; H is the heat loss coefficient and is calculated as a function of the storage volume.

The default values needed for the electric water heaters are presented in Table A4, while the values for gas water heaters are presented in Tables A5 and A6. The storage heat loss coefficients are presented in Table A7.

3. Results and Discussions

3.1. Data

For the simplified calculation, default values should be used. However, the values presented in EN 15316-4-1 are very technical and difficult to assess for a common user. Indeed, the values presented in Tables A3, A5 and A7 of EN15316-4-1 are defined according to the construction year, boiler groups and boiler typologies. The groups are "standard", "low-temperature" and "condensing", while the typology corresponds to "multi-fuel", "atmospheric solid fuel", "atmospheric gas boiler", "fan-assisted boiler", "burner replacement (only for fan-assisted)", "circulation water heater" and "combination boilers".

The classification in the database of the Federal Ministry for Economic Affairs and Energy (BMWi) [39] presents the same "boiler group", while it presents similar but different "boiler typologies" such as "atmospheric", "combined", "forced ventilation", "central heating" and "domestic hot water".

Figure 4 presents the shares of boiler typologies and groups of the different models present in the database. It can be noticed that while the gas boilers present different typologies, the oil boilers present only "combined" and "forced ventilation" typologies. More than half of the share is represented by low-temperature boilers. The analysis of Figure 4 and the difference between the default values of the different typologies within the same boiler group encouraged the adoption of default values only as a function of the boiler group.

Figure 5 presents the efficiency of the gas and oil boilers as a function of the construction year and size considering the different series of boiler groups. The figure represents the technological evolution and emphasizes the importance of raising consumers' awareness concerning the performance of their heating appliances, given that a still quite a significant share of the EU heating appliance stock is more than 20 years old. The efficiency detailed in Figure 5 does not consider the aging degradation, reflecting only the efficiency of the old product when introduced in the market (or in other terms, the rating plate performance).
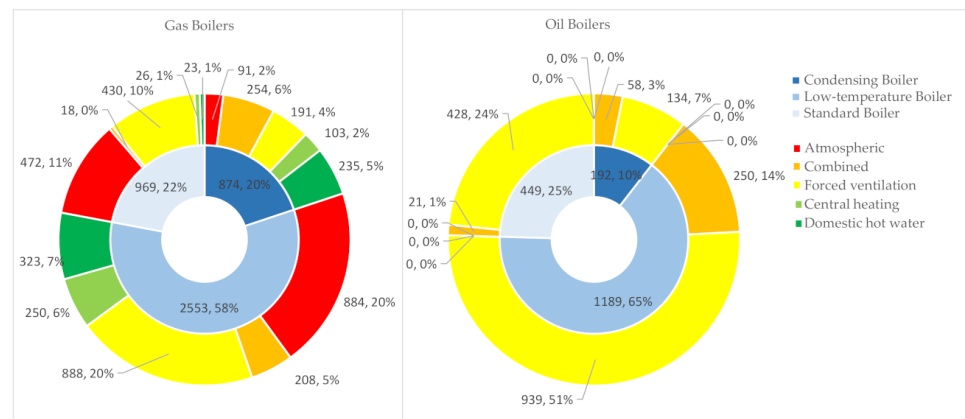
Figure 4. Share of boiler typologies and groups in the dataset expressed in "number of units" and "percentage" (e.g., 2553, 58% means 2553 units and 58%). Elaboration of [39].
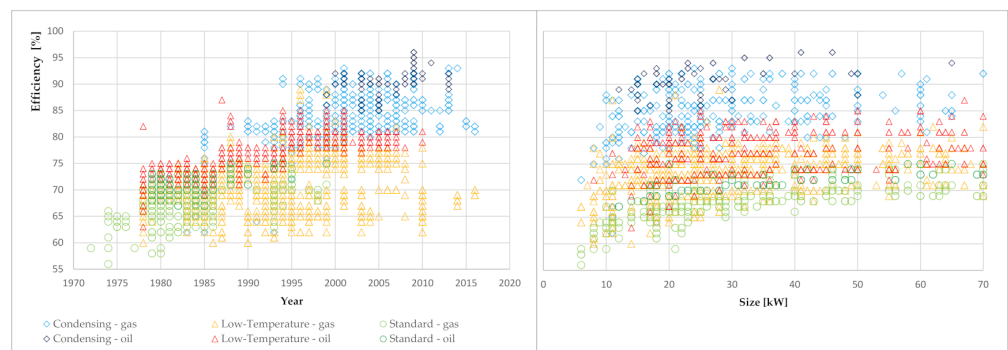
Figure 5. Efficiency of gas and oil boilers as a function of the construction year and size. Elaboration of [39].

3.2. Labeling of Space Heating Appliances

The validation of the labeling methodology for space heating appliances considered 4600 models built between 1972 and 2019.

Figure 6 presents the comparison between the simplified and the detailed calculation after the validation phase. The statistics regarding the deviation between the two calculations are presented in Table A1, which considers the average deviation, the span (maximum negative deviation and maximum positive deviation) and the standard deviation.
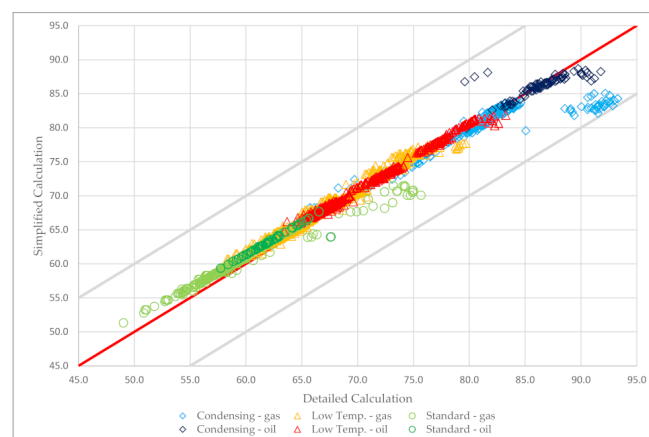
Figure 6. Comparison of seasonal heating efficiency of simplified and detailed calculations.

Figure 6 clearly indicates a difference in performance between the boiler groups: the standard boilers present a seasonal efficiency that ranges between 50% and 75%, while the condensing boilers reach a seasonal efficiency of 95%. The lowest values for each data series are obtained for older products since the effect of the degradation coefficient is higher. This consideration can also be taken into account by comparing the default values presented in Appendix B with the coefficients of Table 1.

The comparison of the simplified calculation and the detailed calculation confirms the validity of the default values used in the simplified calculation. This means that a professional user can use the default values in the case of there being an absence of some data of the heating appliance.

Table 3 presents the comparison between the simplified calculation, the detailed calculation and the measured values obtained in the laboratory. For this purpose, three boilers were tested after continuously working in a real building where the owner performed normal maintenance. The comparison of the part load efficiency and full load efficiency shows that the data used for the detailed calculation agree well with the laboratory measurement. The simplified calculation, instead, has an acceptable deviation from the other two values since it was obtained from the default values.

Table 3. Laboratory test compared with the model.

Unit	Type	Pn (kW)	Fuel	Age (y)	Simplified		Detailed		Measured	
					η_{30}	η_{100}	η_{30}	η_{100}	η_{30}	η_{100}
1	Standard	24	Oil	31	84.3	86.9	89.0	90.4	88	89.3
2	Condensing	24.7	Gas	11	99.5	94.5	107.0	97.6	N.A.	98.1
3	Condensing	34.2	Gas	11	99.5	94.5	109.1	97.4	110.1	97.8

3.3. Labeling of Water Heaters

The validation of the energy labeling for water heaters considered 200 electric storage water heaters and 200 gas instantaneous water heaters. However, the data collected for the ESWH represent products built in the last decade as data of older products were not available. To simulate old appliances, interviews with manufacturers and installers were conducted to understand the difference between old and new appliances. The outcome was that the old appliances were characterized by high thermal losses and thermal bridges. To consider this effect, the factor $f_{sto,dis,ls}$ presented in Equation (27) was considered to be 3 for old products and 1 for new products.

Figure 7 presents the comparison between the simplified calculation and the detailed calculation after the validation phase. The statistics regarding the deviation between the two calculations are presented in Table A2, which considers the average deviation, the span (maximum negative deviation and maximum positive deviation) and the standard deviation.

Table 4 presents the comparison between the simplified calculation, the detailed calculation and the measured values obtained in the laboratory. For this purpose, two gas water heaters were tested by performing the tapping cycle detailed in Regulation 812/2013. The two units were found to produce 14 L/min of hot water that corresponds to an L profile which extracts 11.7 kWh/day. As in the case of space heating appliances, the two water heaters were taken from a real building, and their age is indicated in the table. Even in these cases, the owners had performed normal maintenance of the appliances.

Table 4. Laboratory test compared with the model.

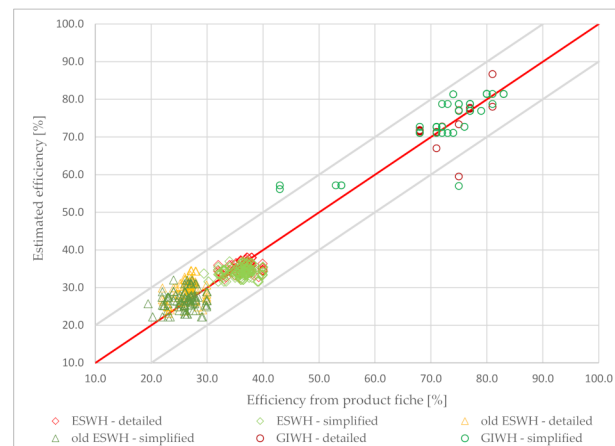| Unit	Age	TP	Simplified				Detailed				Measured		
	(y)		P_n	η_{100}	η_{wh}'	η_{wh}	P_n	η_{100}	η_{wh}'	η_{wh}	P_n	η_{100}	η_{wh}
1	22	L	25	87.8	78.8	74.9	24.5	85.4	77.3	73.4	23.5 ± 0.5	85.0 ± 0.5	71.1 ± 0.5
2	11	L	25	87.8	78.8	77.2	24.5	86	77.8	76.2	24.4 ± 0.5	85.9 ± 0.5	74.5 ± 0.5

Figure 7. Comparison of water heater efficiency of simplified and detailed calculations and product fiche.

The table presents the parameter $\eta_{wh}\prime$ that does not consider the aging coefficient and corresponds to the efficiency the products would have when they were placed on the market. Instead, the water heater efficiency η_{wh} includes the aging coefficient. With the laboratory measurement, the $\eta_{wh}\prime$ cannot be indicated since the units were taken directly from the place of use and the performance as new was not possible to assess.

In terms of the simplified calculation, the only difference between "unit 1" and "unit 2" is the aging coefficient (the first unit has 22 years, while the second one has 11 years) that is reflected in the final efficiency. These units have the same characteristics (standard boiler, with the same nominal capacity and tapping profile) that correspond to the same default values. In the detailed calculation, the parameters present in the data plate or in the datasheet of the unit were used, and they present a small difference in the full load efficiency.

The laboratory results show that "unit 1" presents a nominal capacity that is 1 kW lower than the declared one, while "unit 2" presents only 0.1 kW of difference that is lower than the measurement uncertainty.

The degradation coefficient decreases the efficiency of "unit 1" by 3.9% (22 years old), while the efficiency of "unit 2" is decreased by about 1.6% (11 years old). From the test, the difference between "unit 1" and "unit 2" is 3.4%, which reflects a higher degradation of the performance of the oldest unit.

3.4. General Discussion

The necessity of improving the attitude of consumers toward the adoption of efficient and renewable energy sources has been highlighted by several authors [1–6]. Neves and Oliveira [1] reported the importance of energy labels to motivate consumers to adopt an efficient heating appliance; the activity presented in this paper covers the gap of the installed appliances introduced in the market before EU Regulations 811/2013 and 812/2013 came into force. The proposed energy labeling methodology is compliant with the mentioned regulations, allowing consumers to compare the energy class of their old appliance with the energy classes of new appliances in the market.

The EU Commission has foreseen a rescaling of the energy labels of ErP since there is continuous technological evolution of the appliances present in the market. The effect of rescaling refrigerator labels has been evaluated by Faure et al. [18]. The rescaling of heating appliances and water heaters has not been published yet, but the labels calculated with the proposed methodology can easily be adapted when the new regulation is published since the energy labels are defined based on the calculated efficiency.

The equations used for the calculation of seasonal heating efficiency and water heater efficiency are based on European regulations and European standards since the initial aim

was to be compliant with the regulations in force in Europe. However, the definition of the performance of space heating appliances and water heaters can be considered universal.

The seasonal efficiency of heating appliances and the water heater efficiency can be used in the case of utilization in a system, the importance of which has been highlighted by Calero-Pastor et al. [19], and for the calculation of building certificates [20,21]. As additional adoption of the labeling methodology, Adene is currently evaluating the implementation of the energy labeling methodology for existing appliances in the phase of certification of Portuguese buildings.

The methodology has been implemented in the HARPa online application to support consumers in the decision process to change their heating systems. Andor et al. [22] showed the effect of adding the operating cost to the label that fosters the choice of efficient appliance. In this direction, the HARPa tool presents the operating cost calculated for the old appliance and for the new appliances.

The impact of labeling old appliances will be monitored during the HARP project in order to understand how many consumers will be motivated to replace their old and inefficient appliances.

4. Conclusions

An energy labeling methodology has been developed to rate the performance of installed heating appliances and water heaters, aiming to raise consumers' awareness of the inefficiency of their old appliances. The labeling methodology considers a simplified version for final users and a detailed version for professional users.

The validation process considered 4600 boilers and 400 water heaters, built between 1972 and 2019, covering both fossil fuel and electric appliances, but the method can also be applied to biomass boilers. The hypothesis of simplifying the inputs required for the common user with only one classification according to "boiler group", neglecting the "boiler typology" (as defined in EN15316-4-1), was confirmed with the validation. Indeed, the simplified calculation presented an average deviation of 0.7% for space heating appliances and 1% for water heaters if compared with the detailed calculation. The standard deviation was found to be 1.3% for space heating appliances and 2.5% for water heaters, meaning that most of the units were rated with a possible deviation of $\pm5\%$.

In addition, laboratory tests were performed to verify the calculation on three space heating boilers and two water heaters.

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Data Availability Statement: The data of "German boilers" presented in this study are openly available at [39]. The remaining data are not publicly available due to confidentiality agreement.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Result Statistics

Table A1. Deviation between simplified and detailed calculations for heating appliances.

	All	Standard	Low-Temperature	Condensing
Average Deviation				
Gas	−0.67	−1.08	−1.01	0.21
Oil	−0.75	−1.13	−0.86	0.30
ALL	−0.70	−1.10	−0.96	0.24
Maximum Negative Deviation				
Gas	−2.88	−2.28	−2.81	−2.88
Oil	−7.18	−1.62	−2.52	−7.18
Maximum Positive Deviation				
Gas	9.63	5.61	2.00	9.63
Oil	4.06	3.64	1.99	4.06
Standard Deviation				
Gas	1.44	1.18	0.60	2.32
Oil	0.75	0.43	0.47	1.38
ALL	1.29	1.06	0.57	2.21

Table A2. Deviation between simplified and detailed calculations and water heater efficiency for water heaters.

	ESWH	GIWH	ALL
Average	−1.4	−0.8	−1.0
Maximum negative deviation	−7.6	−14	−14
Maximum positive deviation	4.3	18	18
Standard deviation	2.3	2.6	2.5

Appendix B. Default Values

Table A3. Coefficients for the calculation of default values for SH boilers.

		c_1	c_2	c_3	c_4	c_5	c_6	$c_{7,Pn}$	$c_{8,Pn}$	n_{Pn}	$c_{7,Pi}$	$c_{8,Pi}$	n_{Pi}	$c_{7,P0}$	$c_{8,P0}$	n_{P0}
Standard	y ≤ 1978	80.0	2.0	75.0	3.0	9.0	−0.3	0.0	45.0	0.5	0.0	15.0	0.5	15.0	0.0	0.0
Standard	1978 < y ≤ 1987	82.0	2.0	77.5	3.0	7.5	−0.3	0.0	45.0	0.5	0.0	15.0	0.5	15.0	0.0	0.0
Standard	1987 < y ≤ 1994	84.0	2.0	80.0	3.0	7.5	−0.3	0.0	45.0	0.5	0.0	15.0	0.5	15.0	0.0	0.0
Standard	y > 1994	85.0	2.0	81.5	3.0	8.5	−0.4	0.0	45.0	0.5	0.0	15.0	0.5	15.0	0.0	0.0
Low-Temp.	y ≤ 1978	85.5	1.5	86.0	1.5	6.0	−0.3	40.0	0.1	1.0	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	1978 < y ≤ 1987	85.5	1.5	86.0	1.5	6.0	−0.3	40.0	0.1	1.0	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	1987 < y ≤ 1994	85.5	1.5	86.0	1.5	6.0	−0.3	40.0	0.1	1.0	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	y > 1994	88.5	1.5	89.0	1.5	6.1	−0.4	40.0	0.4	1.0	20.0	0.1	1.0	15.0	0.0	0.0
Condensing	y ≤ 1978	89.0	1.0	95.0	1.0	7.0	−0.4	0.0	45.0	0.5	0.0	15.0	0.1	15.0	0.0	0.0
Condensing	1978 < y ≤ 1987	89.0	1.0	95.0	1.0	7.0	−0.4	0.0	45.0	0.5	0.0	15.0	0.1	15.0	0.0	0.0
Condensing	1987 < y ≤ 1994	92.0	1.0	97.5	1.0	7.0	−0.4	0.0	45.0	0.5	0.0	15.0	0.1	15.0	0.0	0.0
Condensing	y > 1994	93.0	1.0	98.0	1.0	4.0	−0.4	0.0	45.0	0.5	0.0	15.0	0.1	15.0	0.0	0.0
Pellet				Note1				40	2	1	40	1.8	1	15	0	0
Wood chip				Note1				60	2.6	1	70	2.2	1	15	0	0

Note 1: See standard/low-temperature/condensing. Only the auxiliar consumption is changed.

Table A4. Default values of volume and nominal capacity for electric water heaters.

	ESWH								EIWH			
	Vmin	Vmax	Vavg	DV	Pmin	Pmax	Pavg	DV	Pmin	Pmax	Pavg	DV
XXS	10	15	12.08	**12**	1.2	1.2	1.2	**1.2**	1.2	1.2	1.2	**1.2**
XS	N.A.	N.A.	N.A.	**12**	N.A.	N.A.	N.A.	**1.2**	1.2	2.4	1.44	**1.5**
S	30	30	30	**30**	1.2	1.5	1.39	**1.4**	N.A.	N.A.	N.A.	**12**
M	48.5	200	83.7	**100**	1.2	2.5	1.41	**1.5**	N.A.	N.A.	N.A.	**18**
L	78	300	167.6	**150**	1.2	3	1.875	**2**	N.A.	N.A.	N.A.	**24**
XL	500	500	500	**500**	6	6	6	**6**	N.A.	N.A.	N.A.	**31**
XXL	N.A.	N.A.	N.A.	**650**	N.A.	N.A.	N.A.	**8**	N.A.	N.A.	N.A.	**40**

The default values have been defined considering the commercial value closest to average of the dataset. The default values are indicated in bold.

Table A5. Default values of volume and nominal capacity for gas water heaters.

	GSWH								GIWH			
	Vmin	Vmax	Vavg	DV	Pmin	Pmax	Pavg	DV	Pmin	Pmax	Pavg	DV
XXS	N.A.	N.A.	N.A.	**80**	N.A.	N.A.	N.A.	**5**	N.A.	N.A.	N.A.	**9**
XS	N.A.	N.A.	N.A.	**80**	N.A.	N.A.	N.A.	**5**	8.7	9.4	9.3	**9**
S	N.A.	N.A.	N.A.	**80**	N.A.	N.A.	N.A.	**5**	19.2	19.3	19.3	**19**
M	48	115	81.4	**80**	5	5	5	**5**	17.4	22.7	19.5	**19.5**
L	115	160	138.6	**140**	4.3	16	7.4	**7.5**	22	30	24.5	**25**
XL	195	200	196.3	**200**	5.2	16	9.2	**10**	23.8	35	29.5	**29**
XXL	190	950	458	**450**	16	67	33.9	**34**	45	65	55	**55**

Table A6. Coefficients for the calculation of default values for gas water heaters.

		c_1	c_2	$c_{7,Pn}$	$c_{8,Pn}$	n_{Pn}	$c_{7,P0}$	$c_{8,P0}$	n_{P0}
Standard	y ≤ 1978	80.0	2.0	0.0	45.0	0.5	15.0	0.0	0.0
Standard	1978 < y ≤ 1987	82.0	2.0	0.0	45.0	0.5	15.0	0.0	0.0
Standard	1987 < y ≤ 1994	84.0	2.0	0.0	45.0	0.5	15.0	0.0	0.0
Standard	y > 1994	85.0	2.0	0.0	45.0	0.5	15.0	0.0	0.0
Low-Temp.	y ≤ 1978	85.5	1.5	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	1978 < y ≤ 1987	85.5	1.5	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	1987 < y ≤ 1994	85.5	1.5	40.0	0.1	1.0	15.0	0.0	0.0
Low-Temp.	y > 1994	88.5	1.5	40.0	0.4	1.0	15.0	0.0	0.0
Condensing	y ≤ 1978	89.0	1.0	0.0	45.0	0.5	15.0	0.0	0.0
Condensing	1978 < y ≤ 1987	89.0	1.0	0.0	45.0	0.5	15.0	0.0	0.0
Condensing	1987 < y ≤ 1994	92.0	1.0	0.0	45.0	0.5	15.0	0.0	0.0
Condensing	y > 1994	93.0	1.0	0.0	45.0	0.5	15.0	0.0	0.0
Pellet		Note1		40	2	1	15	0	0
Wood chip		Note1		60	2.6	1	15	0	0

Note 1: See standard/low-temperature/condensing. Only the auxiliar consumption is changed.

Table A7. Default values for storge heat losses.

Storage Type	C1	C2	C3	C4	C5
Electric heater−horizontal storage	0.939	0.0104	1	45	24
Electric heater−vertical storage V ≥ 75 L	0.224	0.0663	0.67	45	24
Electric heater−vertical storage V < 75 L	0.1474	0.0719	0.67	45	24
Solar storage	0	0.16	0.5	1000	1

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