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From Product to System Approaches in European Sustainable Product Policies: Analysis of the Package Concept of Heating Systems in Buildings

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Abstract: Different policies with the goal of reducing energy consumption and other environmental impacts in the building sector coexist in Europe. Sustainable product polices, such as the Ecodesign and Energy Labelling Directives, have recently broadened the scope of their target product groups from a strict product approach to extended product and system approaches. Indeed, there is a potential for greater savings when the focus is at a system level rather than on regulating individual products. Product policies for space and water heating systems have recently introduced and implemented the package label, which is a modular approach, standing between the extended product and the system approaches. This paper presents a systematic analysis of the different system approaches of various policies from an engineering perspective. It analyses in detail the package concept and its features through a practical application using a real case study. It focuses on how the package concept can support decisions made in the building design phase and, in particular, how can support the choice of appropriate components based on estimating system performances. This brings building engineers and regulators closer regarding the use of more consistent data on energy performance. Finally, this paper highlights the need to improve the alignment of the building-related product policies with the Energy Performance of Buildings Directive.

Keywords: product policies; heating systems; buildings

1. Introduction

Different European policy instruments with the goal of reducing energy consumption in the building sector coexist. While macro-policies, such as the Energy Efficiency Directive or the Energy Performance of Buildings Directive (EPBD) set global (by country, by sector, etc.) energy targets, micro-policies, such as the Ecodesign Directive or the Energy Labelling Directive, set specific energy targets (by product groups).

At the macro level, the Roadmap to a Resource Efficient Europe mentions that improved construction and use of buildings in the European Union (EU) would influence 42% of our final energy consumption [1]. Improvements in the energy efficiency of buildings could contribute to the 80–95% target of reducing greenhouse gas (GHG) emissions by 2050 compared with 1990 [2]. Heating and cooling are the EU's biggest energy-consuming sectors, representing 50% (546 Mtoe) of final energy consumption in 2012, and much of it is wasted through insufficient insulation or inefficient equipment in buildings, among other causes [3]. The implementation of the EPBD promotes energy efficiency by reducing the energy used to maintain indoor environmental quality through heating and cooling, ventilation, lighting and operating appliances, and by the use of renewable energy in buildings [4]. The EPBD requires Member States to set minimum requirements with respect to overall energy performance on the proper installation, equipment size, adjustment and control of new, replacement and upgraded technical building systems.

At the micro level, European sustainable product policies, such as the Ecodesign and Energy Labelling Directives, EU Green Public Procurement and the EU Ecolabel have the common goal of making the European market more sustainable [5]. Indeed, they have been very successful in improving the energy efficiency of energy-using products such as electric motors, washing machines, refrigerators or dishwashers. The Ecodesign and Energy Labelling Directives' requirements for space and water heaters are expected to bring annual energy savings of 600 TWh and reduce CO_2 emissions by 135 million tonnes by 2030 [3]. These product policies initially addressed individual products, adopting a strict product approach. However, the importance of considering additional products or components that significantly influence total energy efficiency was soon realised. In fact, there is great energy-saving potential when the focus is at a higher level, rather than only on regulating individual products.

Ecodesign Regulation 640/2009 regarding electric motors [6] was the first EU product policy to apply an extended product approach, which consists of extending the system boundaries to include other products (e.g., drives for a motor) that influence the performance of the product under study (e.g., the overall energy efficiency of the electric motors). Recently, a system approach has also been applied to electric motors used in ventilation units (e.g., Ecodesign Regulation 1253/2014 in ventilation units [7]), which considers all or some of the components (motor, drive, casing, ducts, controls, etc.) needed to deliver a service. Similarly, product polices on lighting [8] have also implemented a system approach.

Therefore, EU product policies have been broadening the scope of their target product groups from a product approach to a more system approach. The product approach calculates the energy performance of one product (included in a product group), while the extended product approach calculates the performance of one product (included in a main product group) based on its function and could include the influence of other products. In contrast, the system approach calculates the performance of a system that delivers a service, and this system is considered to be the product group itself. Recently, energy labelling of water and space heating systems (e.g., Regulations 812/2013 [9] and 811/2013 [10]) have introduced and implemented the package label, which includes the energy efficiency of a group of certain heating components (water/space heaters and solar device and/or temperature control). This paper focuses on this package concept, in particular on heating systems, and the way it calculates the package energy efficiency which is different from the extended product and system approaches. This package concept is useful for designers, since it allows them to choose the product performance that will make up the legal package label.

The design of efficient heating systems is a huge challenge, since buildings are complex systems, composed of many and very heterogeneous components, materials and devices that interact with each other, the outside environment and their users [11]. Indeed, the decisions made in the building design phase [12], and in particular on the components chosen for the system, are crucial to avoid major environmental impacts. System designers need to satisfy heating demands, calculate heat loads and achieve system optimisation that will allow performances to be predicted [13]. Many engineering methods have been developed for the system level [14]. In this regard, EU product policies could be useful to design efficient heating systems [15]. Nevertheless, the way in which product policies calculates the energy efficiency and the real energy performance of the whole heating system can vary greatly. There is still a technological gap between building designers and regulators that needs to be filled to ensure the achievement of overall energy efficiency objectives [16].

This paper presents a systematic analysis of different system approaches of various policies, taking an engineering perspective. The aim of the paper is to investigate how the package concept of EU product policies helps in estimating the system performance and supports the design work. It considers the example of the package concept in heating systems in buildings as the main basis of the investigation. The paper also discusses the challenges for European environmental policies to align macro- and micro-level policies more closely.

The method followed in carrying out this research work had two steps. Firstly, the package concept was analysed theoretically through examination of relevant EU Regulations and then analysed with regard to the product, extended product and system approaches. Secondly, the package concept was applied to a real case study, which includes water and space heating systems. The analysis of the case study represents how data from product policies can be useful in a design context. This second step therefore contributes to the analysis of the package concept from a practical point of view and it brings some points of discussion (advantages, limitations and improvement potential) regarding the methodology used by the package concept.

The paper is presented in five sections. Section 1 describes the background and introduces the product, extended product and system approaches, and the package concept of the EU product policies. Section 2 includes the theoretical analysis of the package concept and its calculation methods, in particular those for heating systems in Regulations 812/2013 [9], 811/2013 [10] and 1187/2015 [17]. Section 3 analyses the practical application of the package concept in a real case study, which includes water heating and space heating systems. Lessons learnt from the case study and the advantages and limitations of the package concept are discussed in Section 4. Finally, the paper concludes in Section 5.

2. Analysis of the Package Concept in EU Energy Labelling Regulations for Heating Systems

2.1. The Origin of the Package Concept

The package label appeared first in Regulations 812/2103 [9] and 811/2013 [10] on space and water heaters, respectively, and later in Regulation 1187/2015 [17] on solid fuel boilers. In Regulations 811/2013 and 812/2013, the package concept was introduced very late in the policy process development, during the consultations prior to the adoption of the delegated act [18]. Suppliers of solar devices and temperature controls (often small and medium-sized enterprises and consumer organisations) were not able to communicate the benefits of their products by providing information on their products in an isolated manner (as part of the product fiche of heaters) because: (1) their products are usually placed on the market by their clients (dealers or installers) and therefore consumers do not have easy access to this information and (2) the information on the potential energy savings of these devices can be understood only when they are used in combination with heaters.

The provision of information on solar devices and temperature controls to consumers was initially too limited and the package concept was introduced to overcome this market barrier [18]. The package label and fiche allow the independent provision of information by suppliers and dealers. The calculation is simple, meaning that performances provided by the manufacturer of the solar device and/or temperature controls can be combined easily with the efficiency provided by the heater manufacturer. The dealer can then make up the package label according to separate product fiches provided by suppliers of heaters, solar devices and temperature controls. In this way, it is possible to avoid discrimination against configurations offered by dealers/installers consisting of parts that were placed on the market individually, compared with the identical configuration offered by a single supplier/dealer [19]. In addition, consumers are able to compare equivalent systems delivering the same service (e.g., water heating).

2.2. From Product, to Extended Product and System Approaches

The strict product approach of product policies has evolved towards the inclusion of a greater number of products in two directions (see Figure 1); on the one hand, to the extended product approach (e.g., motors) and the system approach (e.g., lighting), and on the other hand, to the package concept (e.g., heating). The package concept is a type of modular approach. Depending on the number of products included, this modular approach lies between the extended product approach and the (sub-)system approach (Figure 1), since it could include a few or several products.

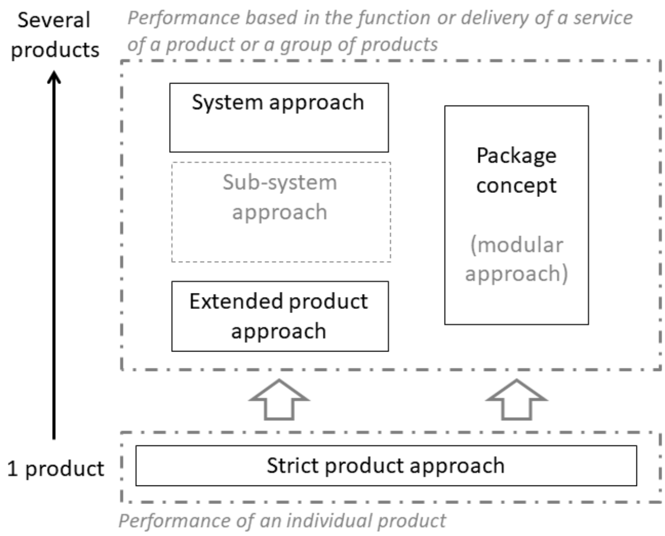

Figure 1. Schematic positioning of the different approaches of EU product policies in terms of the complexity of the system of products considered.

The difference between the extended product and system approaches on one hand and the package concept on the other hand is that the package efficiency is made up of a group of products whose presence and influence can be easily identified (Figure 2). For instance, the package label shows graphically all the components included in a package, whereas labels in the extended product or system approaches show the energy performance without indicating whether or not the influence of other components was included in the calculation.

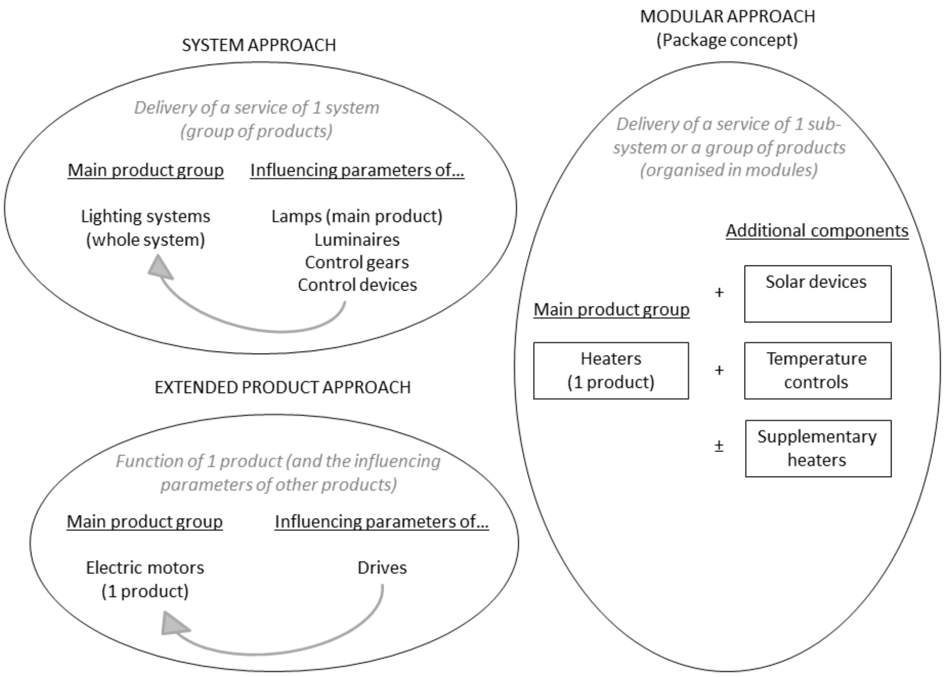

Figure 2. Differences between the calculation methods of the extended product, system and modular approaches (with examples).

The energy efficiency of the extended product and system approaches is calculated using a formula that includes the function or service delivered by the main product as well as the influencing parameters of other components. The main product is that for which the regulation in question was initially created. The components are the additional products that have been included in the calculation of the efficiency of the main product. The energy efficiency of a package is the sum (positive and negative) of the efficiency of the main product group and that of certain additional products or components as set in the EU Regulations (Figure 2).

Therefore, the calculation method used to determine the package efficiency is flexible enough to allow the addition of new (individual) components regardless of the manufacturer. In contrast, the calculation methods used in product policies, which apply the extended product or system approaches (e.g., motors and lighting systems), could not incorporate additional components easily, since the whole formula would have to be revised.

The implementation of the package concept involves different actors: manufacturers, suppliers, dealers, installers, end users and system designers. Firstly, manufacturers and/or importers have to provide information regarding the performance of the products (and sometimes of packages) they put on the EU market, since the Ecodesign and Labelling Directives are mandatory instruments. If a water or space heater is placed on the market together with solar devices and/or temperature controls by the same dealer, this one has to provide the package label of this group of components. In addition, although these heating components have been purchased separately, the installer must also provide the package label. Therefore, end users and consumers are able to make informed choices and carry out fair comparisons on the heating products and packages they purchase. Finally, building engineers are able to take informed design decisions at the system level and, although they are not bound by the package label regulations, they are important players in the global chain and are responsible for the proper and efficient design of heating systems. They should provide the technical specifications for the procurement process, such as the performance of products and packages (i.e., energy class) to be installed in the heating system.

2.3. Products' Scope and Calculation Schemes of the Package Concept

Figure 3 summarises the scope of the different product groups defined in EU regulations that address packages.

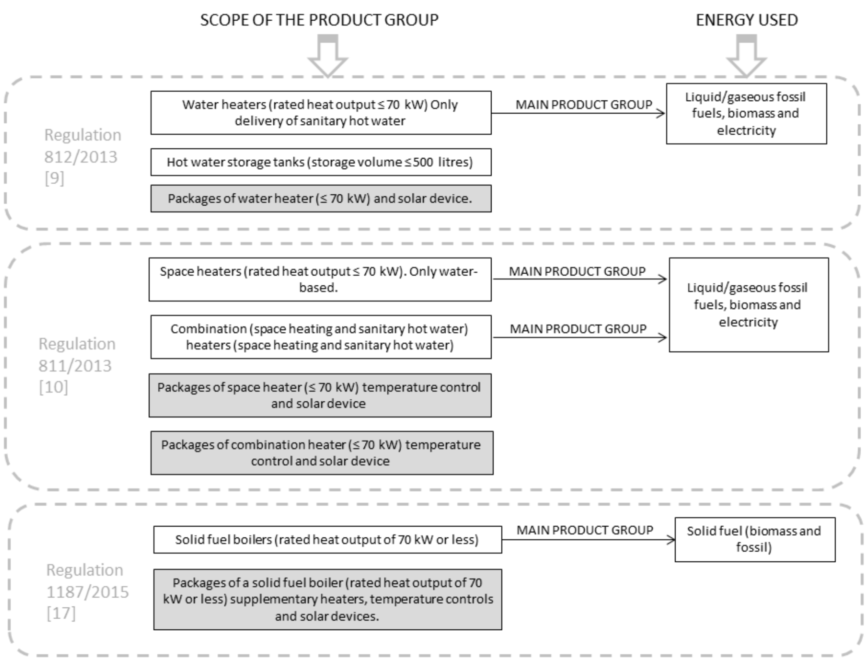

Figure 3. Scope of the EU Regulation which include the package concept.

Some of the products/packages affected by these regulations provide only water heating or space heating, while others provide both water and space heating (combination heaters). All of them include heaters providing heat to water-based central heating systems for space heating purposes and/or for delivering hot drinking and sanitary water (i.e., air or other means of heating distribution are out of scope) and use very heterogeneous technology (e.g., electric/gas boilers, heat pumps, cogeneration heaters) using renewable (e.g., biomass, solar) and non-renewable energy sources (e.g., liquid, gaseous or solid fossil fuels, electricity) (Figure 3).

Table 1 shows which products are included in the packages of the EU regulations cited in Figure 3 (third and fourth column of Table 1). According to these regulations, a boiler is a water, space or combination heater that uses fossil fuels, biomass fuels or electricity (using the Joule effect in electrical resistance heating elements). A heat-pump-based water, space or combination heater uses ambient heat from an air source, water source or ground source, and/or waste heat for heat generation and may be equipped with one or more supplementary heaters. The definition of a solar device includes not only the solar collectors, but also solar hot storage tanks and pumps in the collector loop of the solar sub-systems.

Table 1. Overview of the efficiency package calculation schemes in EU regulations.

EU Regulation	Where the Calculation Method Is Specified in the Regulation	Main Product/Preferential Heater	Additional Components	Result Offered by the Package
Regulation 812/2013 [9]	*Annex 4* of regulation, *Figure 1*	Water heater	Solar device	Water heating energy efficiency
Regulation 811/2013 [10]	*Annex 4* of regulation, *Figure 1*	Space and combination heater	Solar device Temperature control Supplementary boiler Supplementary heat pump	Seasonal space heating energy efficiency
Regulation 811/2013 [10]	*Annex 4* of regulation, *Figure 2*	Cogeneration space heater	Solar device Temperature control Supplementary boiler	Seasonal space heating energy efficiency
Regulation 811/2013 [10]	*Annex 4* of regulation, *Figure 3*	Heat pump space and combination heaters	Solar device Temperature control Supplementary boiler	Seasonal space heating energy efficiency
Regulation 811/2013 [10]	*Annex 4* of regulation, *Figure 4*	Low-temperature heat pumps	Solar device Temperature control Supplementary boiler	Seasonal space heating energy efficiency
Regulation 811/2013 [10]	*Annex 4* of regulation, *Figure 5*	Boiler combination heaters and heat pump combination heaters	Solar device	Water heating energy efficiency
Regulation 1187/2015 [17]	*Annex 4* of regulation, *Figure 1*	Primary solid fuel boiler	Solar device Temperature control Supplementary boiler	Energy efficiency index

The calculation schemes included in these regulations (second column of Table 1) specify the calculation method of the package energy efficiency and the package efficiency class according to parameters of the main product and additional components (see example in Figure 4). When the "main product" is combined with at least one of the "additional components" in Table 1, the package efficiency/label shall be calculated. The results of the calculations for each of these schemes provide the water heating energy efficiency, the space heating energy efficiency or the energy efficiency index (last column of Table 1), depending on the result type the package offers.

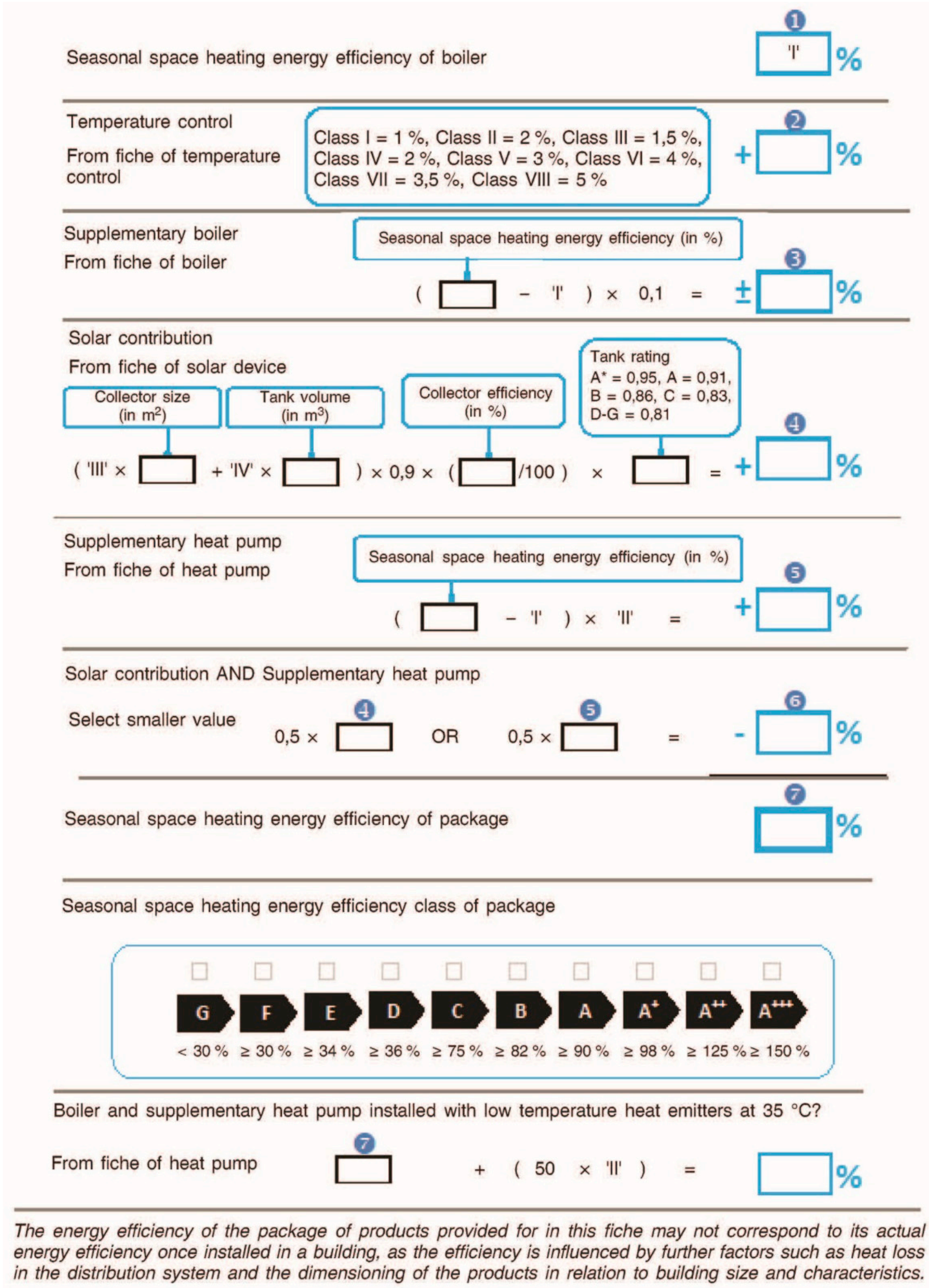

Figure 4. Illustration of *Figure 1* (space and combination heaters) of Regulation 811/2013 (*Annex 4*) [10] © European Union, http://eur-lex.europa.eu/, 1998–2017.

Figure 4 shows as an example the section of Regulation 811/2013 that explains how to calculate the package energy efficiency and how to set the energy class for a package of a combination heater with temperature control, supplementary heaters and solar devices.

Table 2 analyses in detail each of the calculation schemes (*Figures* of *Annex 4* of Regulations 812/2013, 811/2013 and 1187/2015). It shows the parameters that might be involved in the calculation of the energy efficiency of each type of package.

Table 2. Technical parameters involved in the calculation of the package energy efficiency.

Category of Product	Products	Product Parameters	Intermediate Parameters	Package Parameters
Main product	Water heaters, space and combination heaters and solid fuel boilers	Water/seasonal space heating energy efficiency (%) Reference energy, Q_{ref} (KWh)	–	Water/seasonal space heating) energy efficiency (%)
Solar devices	Solar collectors	Collector area (m^2) Collector efficiency (%)	Annual auxiliary electricity consumption, Q_{aux} (kWh/year), and annual non-solar heat contribution, Q_{nonsol} (kWh/year)	Solar contribution (%)
	Solar pump	Power consumption (W) Standby power consumption (W)		
	Solar storage tank	Storage volume (m^3) Energy class (A, B, C, etc.) or standing losses (W)		
Controls	Temperature controls	Class (I, II, III, IV, V, VI, VII)	–	Contribution to seasonal space heating (%)
Supplementary heaters	Supplementary boiler or heat pump	Seasonal space heating energy efficiency (%)	–	Parameters of the supplementary boiler (%)

All the calculation schemes (Figures from the Regulations) follow a similar structure in which the package parameters (last column in Table 2) are added or subtracted to obtain the overall energy efficiency (or index) of the package (see example in Figure 4). The package parameters show the contribution of the products to the package efficiency. In some cases, the calculation of the package efficiency (or index) is provided not only for average but also for colder and warmer climates in percentages ("average climate conditions", "colder climate conditions" and "warmer climate conditions" mean the temperature and global solar irradiance conditions characteristic of the cities of Strasbourg, Helsinki and Athens, respectively). The energy class (A^{++}, A^{+}, A, B, etc.) of the package is set for each type of package (specific Figure of each Regulation) according to the package energy efficiency ranges.

The energy efficiency (or index) might be higher than 100% because the efficiencies of solar devices and/or temperature controls are added to the efficiency of the main product group. Efficiencies higher than 100% are accepted in the definition of low-emission energy efficiency [20], which does not consider the renewable energy consumption, to minimise the non-renewable consumption. This type of energy efficiency has been used commonly in building-related policies oriented towards low-emission designs. This has been an effective way in which the package concept of EU product policies has rewarded renewable energy sources and energy-saving components. One of the aims of these packages is to assess the benefits of using solar devices and temperature controls together with heaters.

3. Application of the Package Concept to a Real Case Study

This section presents how the package energy efficiency and class is calculated for a real domestic hot water (DHW) system, including solar devices and a space heating (SH) system for a 60 m^2 dwelling. Both systems have the same gas boiler (Figure 5). In the DHW system, the boiler is a backup of the solar sub-system, whereas in the space heating system, it provides all the hot water needed for the space heating.

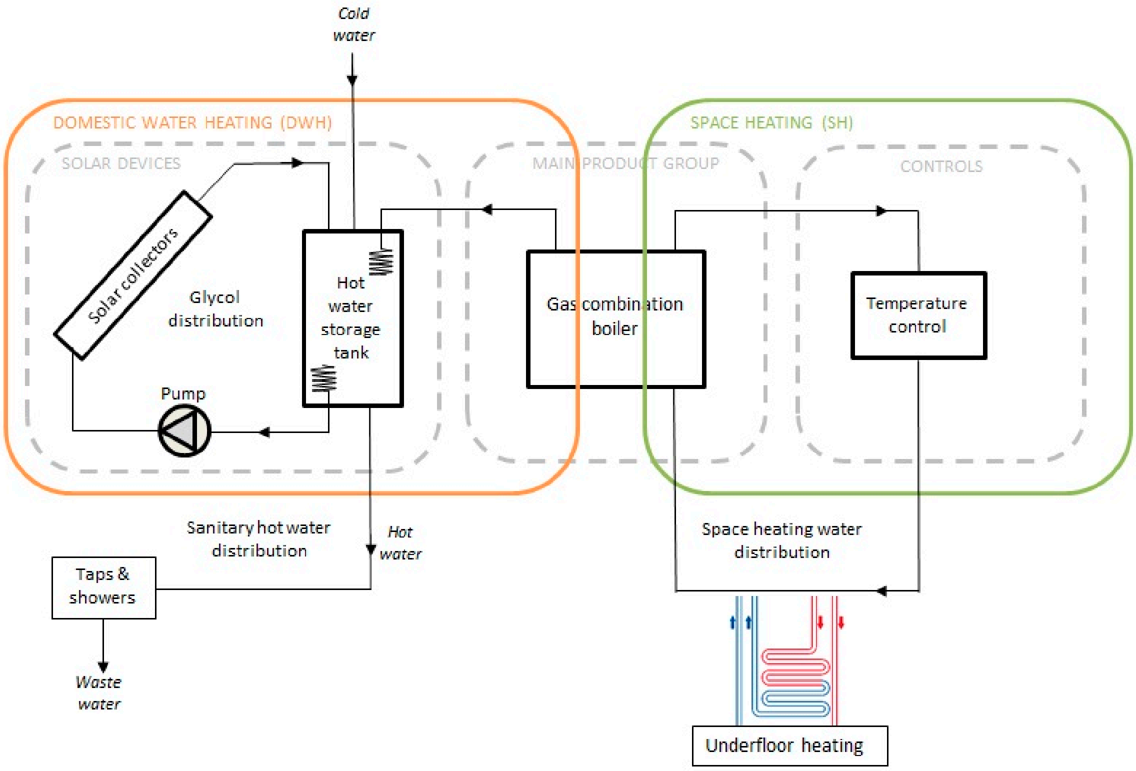

Figure 5. Heating systems considered in the case study.

The DHW system consists of the water heater, a solar collector with a glycol pump, a sanitary water pipe network, a storage tank with two coils, three taps and one shower. The SH system includes mainly the boiler, the distribution components, the underfloor heating and the temperature controls.

Table 3 shows the EU regulations that affect the products and packages described in the case study. The package and label are composed of a combination heater with solar devices and a temperature control, according to Regulation 811/2013. Two different calculation schemes are used to calculate the water heating energy efficiency and the space heating energy efficiency of each of the functions of the heating systems (Table 3). However, because the house had been completely refurbished in 2012, that is, before the regulation entered into force (September 2015), the labelling of the package was not available when the installation took place. In this section, the package energy efficiency is calculated and the energy class set for both DHW and SH systems (in Table 3) using data available from the installed products.

Table 3. Energy label regulations affecting the case study.

Label	Product/Package	Efficiency Type	EU Regulation (Calculation Schemes)
Product label	Gas combination boiler	Water heating energy efficiency Space heating energy efficiency	Regulation 811/2013 [10]
	Storage tank	Standing losses	Regulation 812/2013 [9]
Package label	DHW system: gas combination boiler plus solar devices (solar collector, solar storage tank and solar pump)	Water heating energy efficiency	Regulation 811/2013 *Annex 4, Figure 5* [10]
	Space heating system: gas combination boiler plus temperature control	Space heating energy efficiency	Regulation 811/2013 *Annex 4, Figure 1* [17]

Table 4 shows the technical parameters, provided by manufacturers of the devices, needed to calculate the package water heating energy efficiency of the DHW system and the package space heating energy efficiency of the SH system in the case study.

Table 4. Technical parameters of the heating systems in the case study.

System	Product Category	Components	Parameter	Value	Units
DHW system	Solar devices	Solar collector (flat plate)	Collector aperture area	2.06	m^2
			Zero loss collector efficiency	75.2	%
			First-order heat loss collector efficiency	3.55	$W/m^2 \cdot K$
			Second-order heat loss collector efficiency	0.018	$W/m^2 \cdot K$
			Incidence angle modifier	0.94	–
		Solar storage tank	Storage volume	160	l
			Backup storage volume	80	l
			Thermal dispersion	1.52	W/K
			Standing losses	69	W
		Solar pump	Power consumption	28	W
	Main product	Gas boiler	Water heating energy efficiency	74.4	%
SH system			Space heating energy efficiency	92	%
	Controls	Temperature controls	Type V: % contribution of the space heating energy efficiency of the package [21]	3	%

According to Regulation 811/2013 [10], combination heaters have two different energy efficiencies, one for each of their functions. The manufacturer declared that the combination boiler in this case had an energy label A for the DHW and space heating systems. The water heating function of the boiler had a load profile M, according to tapping patterns described in Regulation 811/2013 [10] for combination water heaters (relevant for Q_{ref}). The storage tank had an energy label C, according to Regulation 811/2013 [10].

According to Regulation 811/2013, for the calculation of the water heating energy efficiency, additional intermediate parameters are needed (Table 5). The Q_{nonsol} and Q_{aux} have been calculated with SOLCAL [22]. SOLCAL is free software available online, which is recommended by European Commission [23] for calculating the non-solar energy needed in the package and includes several technical parameters for the solar devices.

Table 5. Parameters needed for the calculation of the water heating energy efficiency in the case study.

Parameters for DHW System	Value	Units	Source/Calculation
Q_{ref} (M profile)	5.845	kWh/year	Regulation 811/2013 (*Annex VII, Table 15*)
Q_{nonsol}	1050	kWh/year	SOLCAL calculation [20]
Q_{aux}	56	kWh/year	SOLCAL calculation [20]
I′ = water heating energy efficiency of the boiler	74.4	%	Boiler manufacturer (Regulation 811/2013)
$II' = 220 \times Q_{ref}/Q_{nonsol}$	1.225	–	Formula from Regulation 811/2013 (*Annex IV, Section 6b*)
$III' = (Q_{aux} \times 2.5)/(220 \times Q_{ref})$	0.109	–	Formula from Regulation 811/2013 (*Annex IV, 6b*)
Solar contribution = $(1.1 \times I' - 10\%) \times II' - III' - I'$	2.69	%	Formula from Regulation 811/2013 (*Figure 5*)

Table 6 shows the results for the water heating energy efficiency and class of the DHW system and the seasonal space heating energy efficiency and class of the SH system in the case study, when implementing the calculation scheme from *Figure 5* of Regulation 811/2013.

Table 6. Package energy efficiencies and class for the case study.

Type of Package Energy Efficiency			Package Energy Class [10]
Water heating energy efficiency	For an average climate, this is I′ plus solar contribution	77.1%	A
	For a colder climate, this is the value for an average climate minus 0.2 × solar contribution	76.6%	–
	For a warmer climate, this is the value for average climate plus 0.4 × solar contribution	78.2%	–
Space heating energy efficiency	Seasonal space heating energy efficiency of boiler plus the package parameter of the temperature control	95%	A

Figure 6 shows the resulting package label for the case study. The main product group (the combination boiler) and the additional components (solar collector, storage tank, temperature control and supplementary heater) are shown on the left and the efficiency classes for each of the functions are shown on the right of the label.

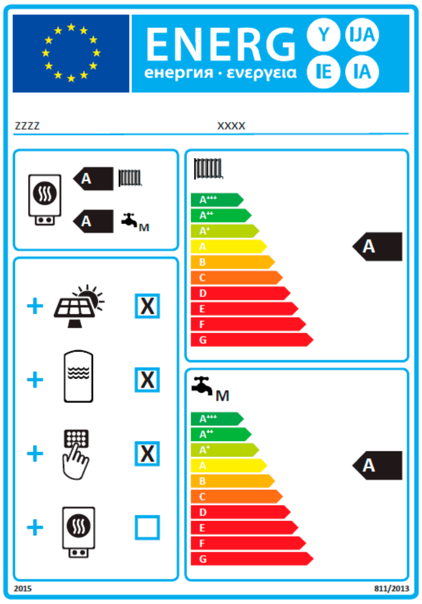

Figure 6. Label for the package of combination heater, temperature control and solar device in the case study.

3.1. Analysis of the Improvement Potential of the Package When Upgrading the Products

This section shows how data from product policies could be used by building designers to produce better design alternatives (DAs). Building engineers, who are responsible for heating system design, could make different product choices based on the different performance levels of the products. Further analysis of the case study reveals how upgrading each product (which can be proposed by building designers) can affect the package energy efficiency.

Therefore, the performance levels of each product have been assessed. Firstly, the influence of each individual product (without modifying the other products) on the potential improvement of the packages is analysed. Secondly, different DAs are presented according to the combination of the improved performance levels of one, two and three products.

In the DHW system, the heater already has the highest energy class, class A, but its water heating energy efficiency could be increased to 100% by choosing a better boiler [10]. In theory, the heater could achieve energy classes that are higher than class A, but only in packages of boilers with solar devices and temperature controls [10]. However, in this analysis, we consider the improvement of only one component (considering the boiler and solar devices separately) to calculate the package efficiency;

therefore, we disregard energy classes higher than class A. Therefore, two heaters are considered (with efficiencies of 74.4% and 100%). One solar collector (2.06 m^2), two collectors (4.12 m^2) and three collectors (6.24 m^2) with the same characteristics are considered. The highest possible energy class of the solar storage tank is class A$^+$ with no standing losses (SL = 0 W); however, in this analysis, we consider only tanks with minimum standing losses (SL) of 15 W, which is closer to reality. Therefore, five storage tanks are considered, one for each performance level based on their standing losses; C of the case study (SL = 69 W), C maximum (SL = 58 W), B (SL = 41 W), A (SL = 30 W) and A$^+$ (SL = 15 W). In this analysis, the solar collectors and the solar storage tank have been considered as two separate products to distinguish their individual influences, although Regulation 811/2013 considers them together in calculating the solar contribution. Figure 7 shows the influence of each product on the improvement of the overall water heating energy efficiency of the package. Figure 8 presents the package water heating energy efficiency values of the combinations of the performance levels of one, two and three products, showing the easiest and most realistic DAs.

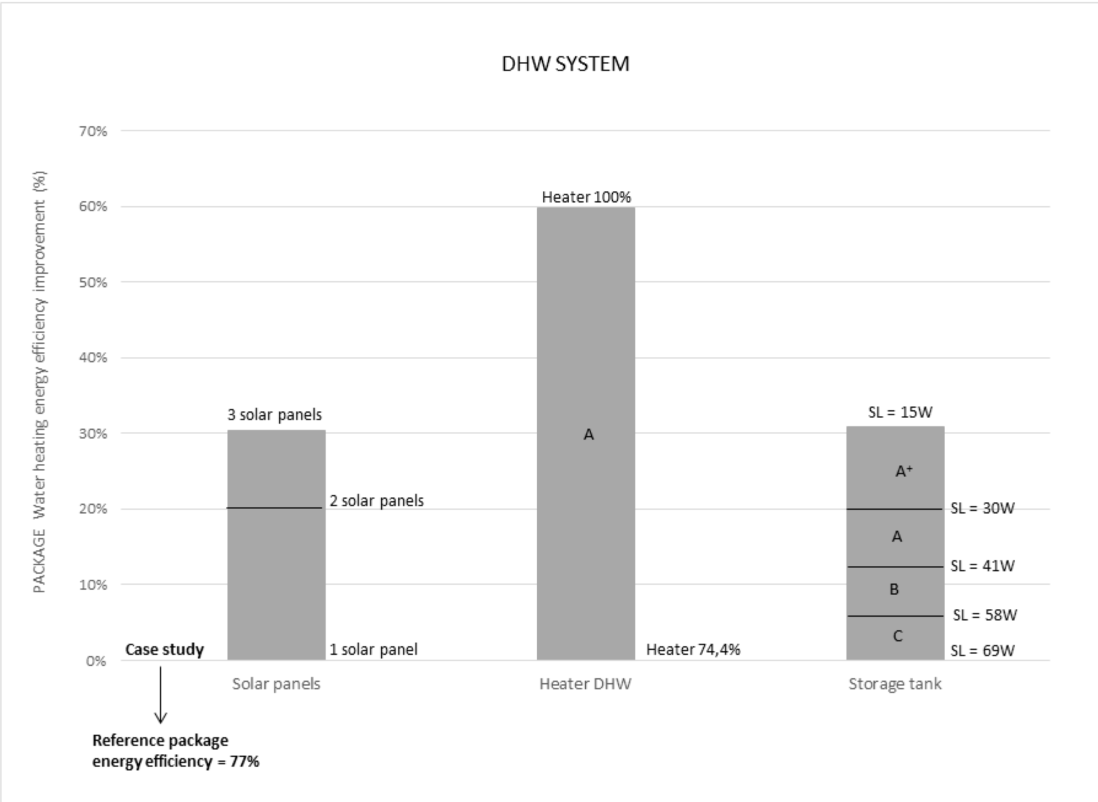

Figure 7. Contribution of individual products to the water heating energy efficiency improvement of the package.

The case study gave a package water heating energy efficiency of 77% (Table 6), which is the reference line. The heater or boiler alone had the highest improvement potential (60%) for the package, which could reach 137% (DA1 in Figure 8) of package energy efficiency. A storage tank with an energy class A$^+$ (SL = 15 W) could increase the package energy efficiency to 108%. Storage tanks with energy class C maximum (SL = 58 W) would improve the package energy efficiency to 82% (DA2 in Figure 8). Installing three solar collectors (6.24 m^2) would improve the package energy efficiency by 30% (107% package energy efficiency). Using two solar collectors instead of one would increase the energy efficiency of the package to 97% (D2 in Figure 8).

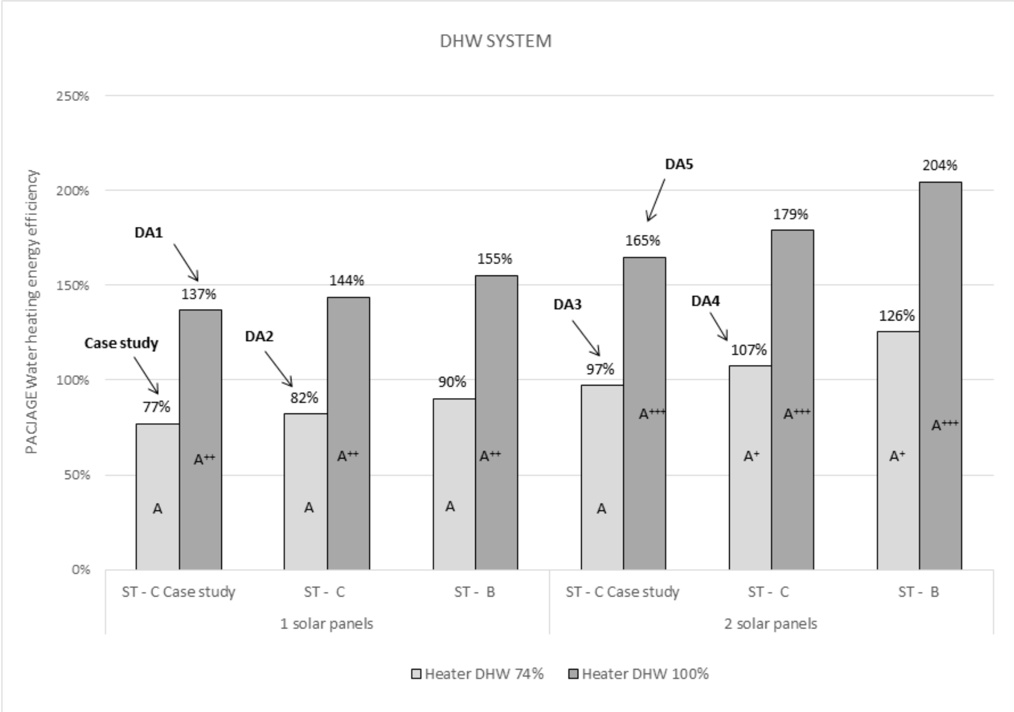

Figure 8. Combined options to improve the water heating energy efficiency of the package.

However, storage tanks of class A or above would require innovative solution technologies, such as evacuated systems or aerogels, and the installation of three solar collectors might not be justified in such a small house (60 m^2). Therefore, to simplify the figures, the unrealistic storage classes A and A^+ and the option of three solar collectors are not assessed in the analysis of better DAs (Figure 8).

Figure 8 shows results of combining the improvements resulting from different package products (the heater, the storage tank and the solar collectors) under the same assumptions as in Figure 7 to select a new design that could upgrade the package water heating energy class to better than class A. Five DAs are proposed when upgrading one product or the combination of two products in the system. Firstly, to achieve a package energy class A^+, a storage tank in energy class C with SL = 58 W and two solar collectors would have to be used (DA4). Secondly, a package energy class A^{++} could be achieved using a heater with 100% water heating energy efficiency (DA1). The highest package energy class A^{+++} could be achieved using two solar collectors or panels and a heater with 100% water heating energy efficiency (DA5).

Regarding the seasonal space heating energy efficiency of the package, Figure 9 shows the results of the analysis for the system when upgrading the performance of either the heater or the temperature controls. Two heaters have been considered, with 92% and 98% space heating energy efficiencies. The former is the one used in the current design of the case study and the latter corresponds to an EU Ecolabel [24]. Three temperature control classes have been considered: control class V (the one used in the case study, which is a modulating room thermostat for use with modulating heaters), class VI (a weather compensator and room sensor for use with modulating heaters) and class VIII (a multi-sensor room temperature control for use with modulating heaters), which contribute 3%, 4% and 5%, respectively, to the seasonal space heating energy efficiency of packages (temperature control class VII is not included in this analysis, since the heater in the case study is a modulating boiler and this class is for use with on/off output heaters [21]).

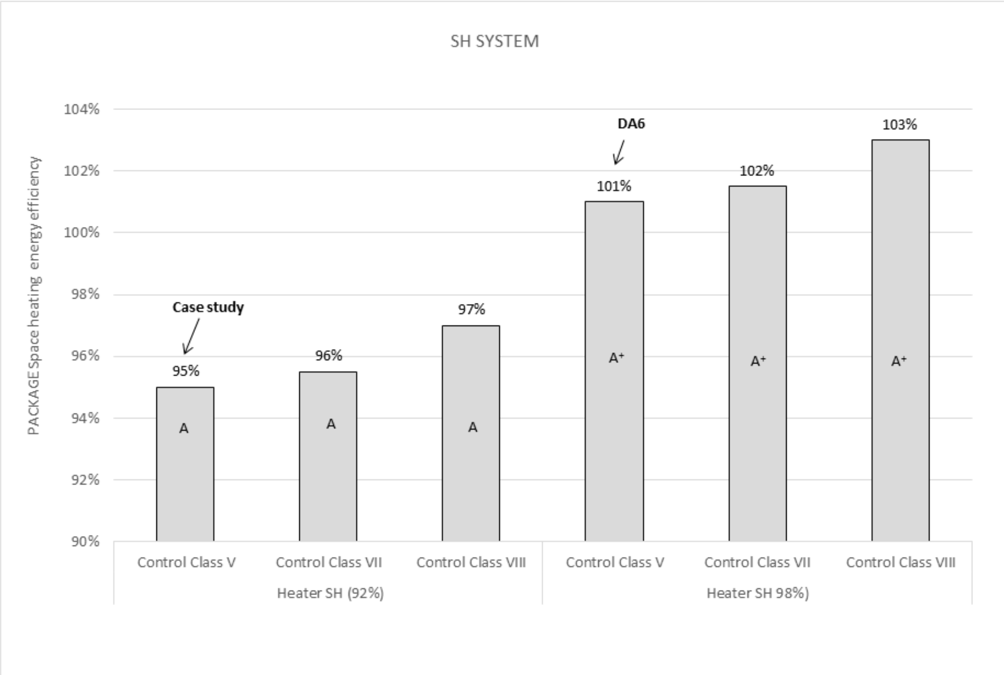

Figure 9. The Influence of the heater and the controls on the space heating system.

The heater or boiler has a greater influence on the package efficiency than the temperature controls (Figure 9). By improving the space heating energy efficiency of the heater from 92% to 98%, the package would increase its efficiency from 95% (package energy class A) to 101% (DA6; package energy class A^+). Improving the temperature controls to those in the highest class increases the package efficiency only to 97%. However, controls in class VIII, which use multiple sensors, might not be appropriate for a 60 m^2 dwelling.

Table 7 presents the summary of results for the different DAs proposed in this analysis. In principle, the easiest way to improve the energy efficiency of the package would be to modify only one product (DA1, DA2, DA3 and DA6). However, DA2 and DA3 do not improve the package energy class, which remains class A. DA4 and DA5 require the modification of two products, although they achieve a higher package energy class (classes A^+ and A^{++}). The space heating energy efficiency has very limited potential for improvement. We propose only DA6, which requires the space heating energy efficiency of the boiler to be upgraded and results in the package achieving slightly higher energy efficiency (101%) and becoming class A^+.

Table 7. Summary of the results for the package-improving potential of upgrading the products.

System	DAs—DESIGN ALTERNATIVES	Package Energy Efficiency (%)	Package Energy Class
DHW	Case study	77	A
	DA1	137	A^{++}
	DA2	82	A
	DA3	97	A
	DA4	107	A^+
	DA5	165	A^{+++}
Space heating	Case study	95	A
	DA6	101	A^+

4. Discussion

4.1. Lessons Learnt from the Case Study from a Design Perspective

The package concept was implemented using a real case study, which includes a water heating system and a space heating system (Section 3). In accordance with Regulation EC 811/2013 [10], two different energy efficiencies were delivered: the water heating energy efficiency (based on the heater and the solar devices, which include the solar collectors, the storage tank and the solar pump) and the space heating energy efficiency (based on the heater, as before, and the temperature control). The package water heating energy efficiency was 77.1% (class A, see Table 6) and the package space heating energy efficiency was 95% (class A, see Table 6). Further analyses were carried out in this case study and DAs (including improved designs) were analysed (see Section 3.1). This design perspective showed that, thanks to the package concept, it is possible to identify the improvement potential of the system easily when considering several potential upgrades of products to higher classes. Several alternatives (improving the boiler, adding a new solar panel, changing the storage tank or a combination of these solutions) for reaching a given objective are possible, and data for the assessment of these alternatives are available from the package energy label declaration. For instance, changing the storage tank to one with a C energy label and adding another solar panel would increase the package energy efficiency from 77% to 107% and the package energy class from A to A^{+} (see Table 7). Then, this analysis shows the usefulness of using data from product policies to support design decisions.

However, it was also shown that the package concept is not a complete approach because it does not consider all the products contributing to the performance of the system, such as the heat distribution system and/or the delivery components (e.g., the taps and showers or the underfloor heating), which could have a significant influence on the losses/savings of the overall system (see e.g., Section 3 and Figure 5).

The case study (Section 3) demonstrates that product policies could have added value in design choices. The use of EU product policy data has the advantage that it is based on homogeneous and agreed calculation methods, which makes fair comparisons of products possible [25]. These figures are available from either the regulations themselves or the manufacturers' technical documentation. In addition, the rapid development of the technology of energy-consuming products means that these regulations must be updated regularly; therefore, designers have information on the products that are available in the current market. Therefore, although the calculation methods applied in product policies might have some limitations in the accuracy of the performance figures they provide, they could be sufficient for building professionals who need data that are available and do not have to be very precise in the early stages of design.

4.2. Limitations and Perspectives of the Package Concept

The method of calculating package energy efficiency by adding different product performances (heater, solar devices and temperature controls) might be not accurate, since it does not represent the real interactions of these products. However, it is the best available in the policy context, since it has been agreed among stakeholders (e.g., industry, government, consumers organisations) and allows the comparison of different equivalent packages.

In the future, more accurate energy efficiency calculations could be made available, by two means. One is the development of benchmarks for packages. The energy benchmarking of systems engineering involves comparing the energy performance of a system with a common metric that represents the optimal performance of a reference system [26]; this, is not available yet for heating packages. Benchmarking is a key policy model to improve building energy efficiency and retrofitting [27]. Once the energy labels of packages are well established and documented (the regulation came into force in September 2015), the benchmarking of packages of heating systems will probably be easier and policy makers will be able to set efficiency targets for these packages. Alternatively, considering that the real efficiency of a system is not the sum of the efficiencies of its components, harmonised calculation methods should be developed by standardisation organisations so that the calculated efficiency of the system can be closer to reality. Design teams could also benefit from such standardised methods in the future when looking for design alternatives.

Another limitation is that the package is just a sub-system and not the whole system; heat distribution or delivery components, which are also parts of heating systems, are not included. However, the modular approach of the package concept could allow the inclusion of new additional components, which have not yet been considered. In addition, the package concept does not include other relevant criteria. The schemes set in Figures of Annex 4 of Regulations 811/2013 [10], 812/2013 [9] and 1187/2015 [17], which detail each package energy efficiency calculation methods, include a footnote describing some limitations on the results for the package energy efficiency. For example, it is stated (see footnote in Figure 4) that the efficiency of the package might be influenced by additional factors, such as distribution losses and the dimensioning of products according to the size and characteristics of the building. In addition, neither climate conditions nor losses due to the building characteristics, which can have a significant influence on the energy services demand of the dwelling, are considered. However, the inclusion of distribution and delivery components and other relevant criteria in the systems may fall under the competence of the EPBD.

4.3. Links between Building-Related Product Policies and Energy Performance of Buildings Directive

The modular approach of Ecodesign and Energy Labelling Directives packages is different from but complementary to the system approach under the EPBD, in which the entire installation and the building heat losses are considered, although the heat demand and the required heating capacity are also relevant [19]. Both policies complement each other to realise a large energy-saving potential. The Ecodesign and Energy Label Directives guarantee good-quality individual heating products, including products used for retrofitting, while the EPBD addresses the performance of the whole building and is applicable mainly to new buildings. The introduction of the package label could be seen as an attempt to bridge the gap between the two policies. However, the picture is still fragmented. The links between products, systems and buildings are weak and the Ecodesign/Energy Labelling product groups do not necessarily cover all the essential products in the system [28].

The EPBD considers the building itself as the system boundary for the purpose of analysis (Figure 10) and includes its particular global context (e.g., external climatic conditions, building characteristics, envelope, energy services demand). Therefore, "all the system" in Figure 10 means not only all the products of the system but also this global context. It also defines the "technical building system" as the technical equipment for the space heating, cooling, ventilation, hot water, lighting or a combination thereof, for a building or building unit (Figure 10). Member States, through the EPBD, should set minimum energy performance requirements for technical building systems (including hot water and space heating systems). Ecodesign measures for heaters and related products provide harmonised minimum efficiency requirements (Article 8 of the EPBD [4] links the EPBD with Ecodesign and Energy Labelling Directives').

The technical building system (from the EPBD) and the system approach (from product policies) have a common level of analysis at the technical building system level, for instance in the "space heating system", understood as the group of products and components needed to deliver space heating in a dwelling. However, despite their obvious relationship, the EPBD and building-related product policies work in parallel since they have different definitions for the term "system". Nowadays, they are independent policies and address different situations in which a product may be purchased or installed (although the EPBD sets requirements for buildings' energy performance in the case of new buildings or major renovations and will thereby also affect the choice of the heating system, it does not cover cases where only a boiler is retrofitted in an old building. In these cases, the Ecodesign and Energy Labelling Directives support the choice of an efficient product). The EPBD has a top-down approach, while the building-related product policies have a bottom-up approach. These policies should be better aligned, in particular by ensuring the coherence of their scope. For instance, the technical building system should be equivalent to the system approach of product policies. In this way, it would be possible to bring macro-scale (e.g., the EPBD) and micro-scale (e.g., EU product policies) policies closer together in the building sector, so that consistent top-down and bottom-up energy-saving targets can be implemented.

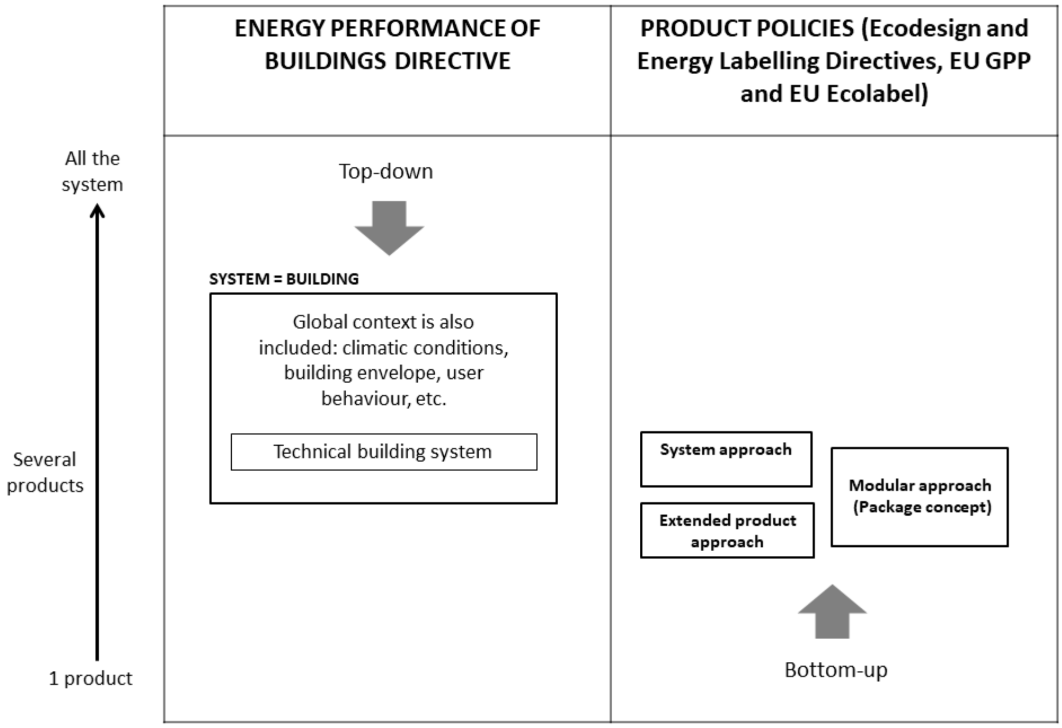

Figure 10. Link between the EPBD and building-related product policies.

5. Conclusions

This paper presents an analysis of some EU product policies, in particular examining how they address the energy efficiency of complex systems that contain several products. A particular focus is on the package concept, which is a modular approach between the extended product and the system approaches (Figure 1). The package concept has so far been applied only to heating systems, in particular through Regulations 811/2013, 812/2013 and 1187/2015 (Section 2). The calculation method of the package energy efficiency is straightforward to apply; therefore, it can be implemented easily by manufacturers and dealers and understood easily by consumers. It is more flexible than the formulae used in the extended product or system approaches because it allows new components' efficiencies to be added easily to the efficiency of the main product group. Then, although design of efficient heating systems is complex and require advanced modelling skills, designers of systems could benefit greatly for having access to such simple assessment methods at early stage of the design. However, it has some limitations regarding missing components that are part of heating systems (e.g., distribution and delivery components) and regarding insufficient consideration of the interactions between components. The real efficiency of a system is not the simple sum of the efficiencies of its components. In addition, dimensioning of products according to the size and characteristics of the building and the geographical and climatic conditions are not considered in the analysis of the package energy efficiency.

The package concept was implemented in a real case study that includes a water heating solar system and a space heating system (Section 3). The package energy efficiency and class (see results from Table 6), and label (Figure 6) was calculated using a step-by-step process for these systems. In addition, based on the case study, further package analyses relevant for designers were carried out on the potential to improve the packages if the products are upgraded. In particular, six design alternatives are presented in Section 3.1 (see Figures 7 and 8) in which the package energy efficiency and/or class are improved when the boiler, the storage tank are upgraded or when more solar panels are added. These analyses showed the potential of using product policies to support technical decisions in the system design phase. This brings building engineers and regulators closer together regarding the use of more consistent data on energy performance.

The package concept of heating systems and the EPBD are complementary, but the latter considers the building itself as the system for the purpose of analysis (Figure 10). It is still an open question where systems based on modular approaches of building-related product policies end and where the technical building systems defined in the EPBD begin. In this regard, a common policy development would be needed to address equivalent terminology and the boundaries of systems.

To improve the calculation method of the energy efficiency of packages, we propose the use of benchmarks and the further development of standardisation methods. In addition better alignment of building-related product policies with EPBD would lead to overcome limitations such as better considering additional components, the building characteristics and envelope, or the climate conditions. In addition, further research is needed to develop calculation methods that are better aligned to each of these policies applied to the energy efficiency of systems.

Author Contributions: Maria Calero-Pastor carried out all of the research work (design of research, data collection, analysis and interpretation of the results) and was the main author of the paper. Fabrice Mathieux contributed to the design of the research, the structure of the paper, the creation of figures and the discussion of results. His contribution concerned mainly the sustainable product policies perspective. He contributed mainly to Section 1 (introduction), Section 2 (analysis of the package concept) and Section 4 (discussion). Daniel Brissaud contributed to the design of the research, the structure of the paper and the discussion of results. He contributed mainly to Section 1 (introduction) and Section 2 (analysis of the package concept). As an expert in engineering systems, his main contribution concerned efficient heating systems design. Luca Castellazzi contributed to the review of the whole paper as an expert in energy efficiency and energy policies. His writing contribution was particularly relevant in Section 2, Section 3 (the application of the package concept to a real case study) and Section 4 (discussion), in particular to the links between the building-related product policies and the EPBD.

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

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