Common Benchmark Ecolabel & GPP Criteria for Hydronic Central Heating Systems

Elena Rodriguez Vieitez & Oliver Wolf

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1 OVERVIEW

This paper presents a proposal for the development of Ecolabel & GPP criteria for hydronic central heating systems (those using hot water to distribute heat), including the feasibility of developing a common benchmark to horizontally address different heating systems as one single product group. The heating systems under study may be intended for the provision of ambient heating, domestic hot water, or both.

The product group "hydronic central heating systems" represents a very large group. As presented in Table 7 of the Draft Task 1 Report on the "Development of EU Ecolabel and GPP Criteria for Heating and Cooling Systems" (IPTS, 2010), the group of hydronic central heating systems accounts for roughly 86% of the total use-phase primary energy consumption by heating systems (central and space heating systems together) in the EU, therefore representing most of the environmental impact of all types of heating systems taken together.

The research suggests that it is possible in principle to develop common benchmark criteria. The study would allow for a comparison between different technologies such as boilers, heat pumps, combined heat and power, district heating, etc. The restriction to central heating systems would make the study more focused, while at the same time representing most (around 86%) of the environmental impact of heating systems in the EU. The study will also elucidate whether attempting to develop a common benchmark performance measure would or not lead to the exclusion of any of the central heating technologies from Ecolabel & GPP criteria. Evidence from the literature suggests that it might be possible to develop Ecolabel & GPP criteria for a wide variety of technologies, and restrictions might need to be made for example regarding the type of fuel used by different technologies.

The common benchmark will be based on a combination of measures, the most important of which will most likely be a measure of energy efficiency (based on primary energy use), but will also include a number of other magnitudes related to greenhouse gas emissions, toxic air emissions, materials resource efficiency, recyclability, refrigerant emissions, and a number of other environmental impact measures.

Section 2 presents a brief account of hydronic central heating technologies. Section 3 presents proposals and possible common performance benchmarks gathered from the literature. After reviewing these proposals, Section 4 presents an overview of how different state ecolabels have addressed heating systems, pointing that there is no ecolabel program so far that has developed criteria for all central heating systems taken together as a group, and instead have developed criteria for individual central heating products. Section 5 presents potential outcomes of this study, and possible benefits of developing a common performance benchmark for hydronic central-heating systems. Section 6 is a summary.

2 HYDRONIC CENTRAL HEATING SYSTEMS

This study will address hydronic central heating systems, which are those that use hot water to distribute heat inside the different spaces and rooms of a building[1]. The heating is generated in a centralized way, meaning that the point of generation of the heat is different than the points of emission, with a distribution system operating between the source and the final emission points in the rooms.

The most common devices for achieving the heat distribution are circulators, which pump the hot water to the final emission points. Alternative ways to distribute heating in a central system (but outside the scope of the proposed study) are the distribution of heat by means of air forced through ductwork, or steam fed through pipes.

There are different types of processes involved in the heat emission at the final points, including:

- Heat convection in radiators. Hot water is distributed to "radiators" installed in rooms and spaces to be heated. The heat transfer to the rooms occurs mainly by convection (despite the device being called radiator), as hot water circulates through the pipes in the radiator unit.
- Under floor heating. A type of central heating end application where the heat is distributed using conduction and radiant heat. The circulation of hot water through pipes located under floor coverings results in the heating of the floor and subsequently the room. The temperature is lower than that of radiators because it is a more efficient way to transmit the heat. Because the room is heated from the floor up, under floor heating is a very effective way of maintaining constant conditions within an area.
- Ceiling heating: Operating in a similar way as under floor heating but located inside ceilings.

Systems to generate the heat: The typical system consists of a single boiler feeding a network of pipes, which in turn deliver the heat through radiators. This is the most common type of central heating found in homes today. Alternatively, heating is generated by combined heat and power and heat pumps, as listed below:

- Central heating boilers (CH boilers) are devices designed to provide hot water mainly for ambient heating, with a variety of fuels (natural gas, oil, wood, biomass, electricity, etc.), and different technologies such as condensing or non-condensing technologies. Condensing boilers use the latent heat of evaporation contained in the water vapor of flue gases, and are significantly more energy efficient.

[1] The scope of buildings will encompass household, commercial and industrial buildings.

- Water heaters are similar to CH boilers, but their main purpose is the provision of domestic hot water.
- Central heating combi-boilers (CH combis), a combination of boiler and water heater.
- Heat pumps. Heat pumps can be used to extract heat from a variety of sources: ground rock, ground water, surface water, air, etc. They also have a large variety of applications. Heat pumps can be used to heat water in hydronic central heating systems, typically providing heat delivery by under floor heating systems.
- Combined heat and power (CHP), or cogeneration units are based on the "simultaneous generation of thermal energy and electricity and/or mechanical energy". The heat distribution takes place by the direct use of exhaust gases, steam or hot water. Micro-CHP units are defined as those with < 50 kWe capacity, and small-scale CHP as those with < 1 MWe capacity. CHP units may be powered by a variety of energy sources including biomass and biogas.
- District heating is defined as a central heating system where the heat is generated by a cogeneration plant, or alternatively a boiler, solar heating, or other sources. The common medium for heat distribution is water, but steam is also used. The terms district heating and CHP are often indistinctively used; district heating however usually means a larger system where heat is distributed to several houses or large urban areas. In contrast, CHP units can be sized to fit a single building.

Typical sources of energy depend on the specific heating technology, but may include electricity, solar thermal, heat transfer from ground, water, or air by heat pump technology, natural gas, wood, biomass, etc., and combinations of energy sources. Solar thermal heating appears to be on the increase for ambient heating and hot water provision in buildings. There is a tendency towards less reliance on electricity and more on renewable sources or natural gas for the function of heating water in buildings.

3 COMMON BENCHMARK PROPOSALS

When heating systems are compared it is important to take into account the primary energy used. As will be introduced later, one of the proposed benchmarks for energy efficiency of heating systems is based on comparing how much primary energy is consumed per amount of heating energy provided. It is important to note that heating energy is a low-grade type of energy. Also it is important as a guideline that we should not introduce energy to a building at a higher grade than its use requires. It is probably a more environmentally sound option to use renewables (heat pumps, biomass, solar heating) or combined heat and power that uses part of the heat, rather than turning electricity into heat (a very wasteful process). The concept of exergy has been used recently in the literature as a means to account for the difference in quality between heat and electricity.

According to the background document for the development of EU Ecolabel criteria for heat pumps (Forsén, 2005a) on pages 26-27 of Part I, a possibility for a common benchmark is the primary energy ratio (PER)[2]. In addition (Pettersson, 2010), there should be at least a common benchmark for greenhouse gas emissions limit, given in maximum amount of grams of CO_2 per kWh of heating output[3], or per kWh of primary energy input[4].

The primary energy ratio (PER) is simply the ratio between useful energy output divided by the necessary energy input. This ratio is a measure of the overall efficiency of a heating system, taking into account the energy losses related to the generation of electricity. A higher PER corresponds to a more energy-efficient system. The report (Forsén, 2005a, 2005b) provides a comparison of PER for boilers and heat pumps. From this comparison it is clear that heat pumps are overall advantageous if compared horizontally with boilers.

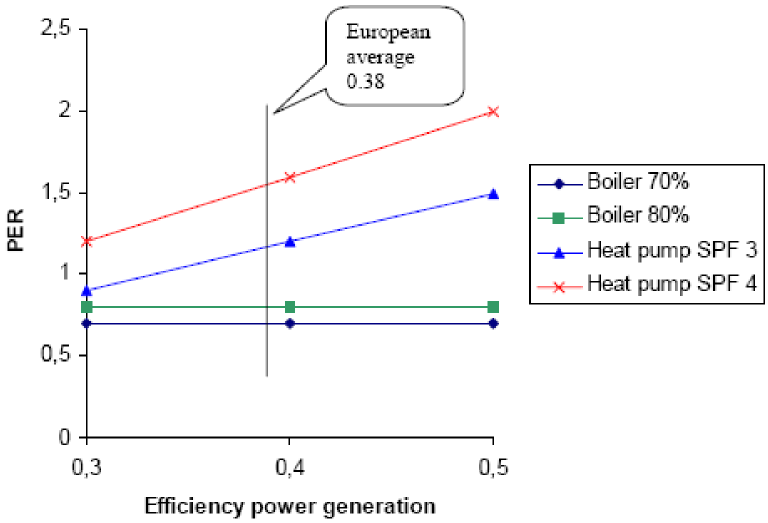

Figure 1. Comparison of primary energy ratio (PER) for boilers and heat pumps, from Figure 13, page 27 (Forsén, 2005a). A higher PER corresponds to a more energy-efficient system. SPF is the seasonal performance factor of a heat pump; a higher SPF corresponds to a more energy-efficient heat pump.

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[2] **Primary energy (CEN standards).** Energy that has not been subject to any conversion or transformation process. Primary energy may be either resource energy or renewable energy or a combination of both. For a building, it is the energy used to produce the energy delivered to the building. It is the delivered energy divided by the conversion or transformation factor of each form of energy.

A building generally uses more than one type of energy (e.g. gas and electricity). The primary energy approach facilitates the principle of simple addition of different types of energy (e.g. thermal and electrical) because the approach integrates the losses of the entire energy chain. Therefore the primary energy consumption may be used for comparison of different types of energy systems.

The energy production losses located outside the building system boundary (e.g. district heating system) are taken into account by the primary energy approach. These losses and gains are calculated using primary energy conversion factors.

[3] The EU Ecolabel for heat pumps establishes that the global warming impact of heat pumps must not be greater than 210 g CO_2/kWh useful heat as an average during a year.

[4] Electricity production is considered to have a conversion efficiency of 40% (in the conversion of primary energy to electricity).

Table 1. Comparison of primary energy ratio (PER) for boilers and heat pumps based on the average efficiency of electricity generation in Europe (=0.38), from Table 6, page 27 (Forsén, 2005a). A higher PER corresponds to a more energy-efficient system. SPF is the seasonal performance factor of a heat pump; a higher SPF corresponds to a more energy-efficient heat pump.

Heating system	Primary energy ratio (PER)
Boiler 70%	0.7
Boiler 80%	0.8
Heat pump, SPF 3	1.14
Heat pump, SPF 4	1.52

It is important to note that the efficiency of heat pumps depends among other factors on the ambient temperature. Therefore if common benchmark criteria are developed, it is recommended to make a distinction among three climate zones in Europe, and thus develop criteria for each of the three climate zones (Pettersson, 2010).

Other energy analyses in the literature have also used the concept of primary energy ratio (Strathclyde, 2010) in the same way as the heat pump background document. According to these researchers for example, the engine-driven heat pump provides almost twice as much heat per unit of fuel burned as the electrical heat pump. A comparison of primary energy ratio for different heating systems is shown in Figure 2. From this figure we can appreciate that not all heat pumps are necessarily more efficient than boilers, and here a gas boiler is found to be more efficient than an electric heat pump.

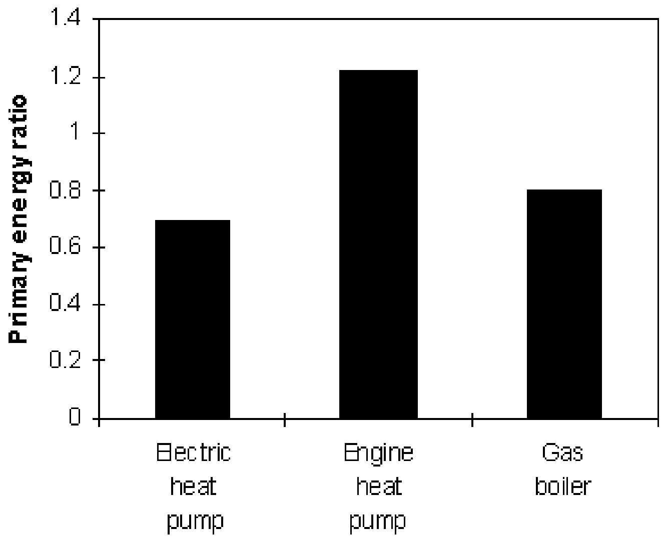

Figure 2. Primary energy ratios for three heating systems from Strathclyde (2010)

Another research study (Gustavsson, 2002) made an interesting comparison of a large number of heating systems in terms of their primary energy ratio (total primary energy use in MWh, per unit MWh of heating output) as can be seen in Figure 3, evaluated for the Swedish context. This research confirms that primary energy ratio is a widespread benchmark for comparison of heating systems; the study reports that the most energy-efficient systems are heat pumps, followed by a number of heating systems such as boilers (fuelled by different types of energy sources). The least efficient technologies were found to be electric heating systems such as resistance heaters and electric boilers.

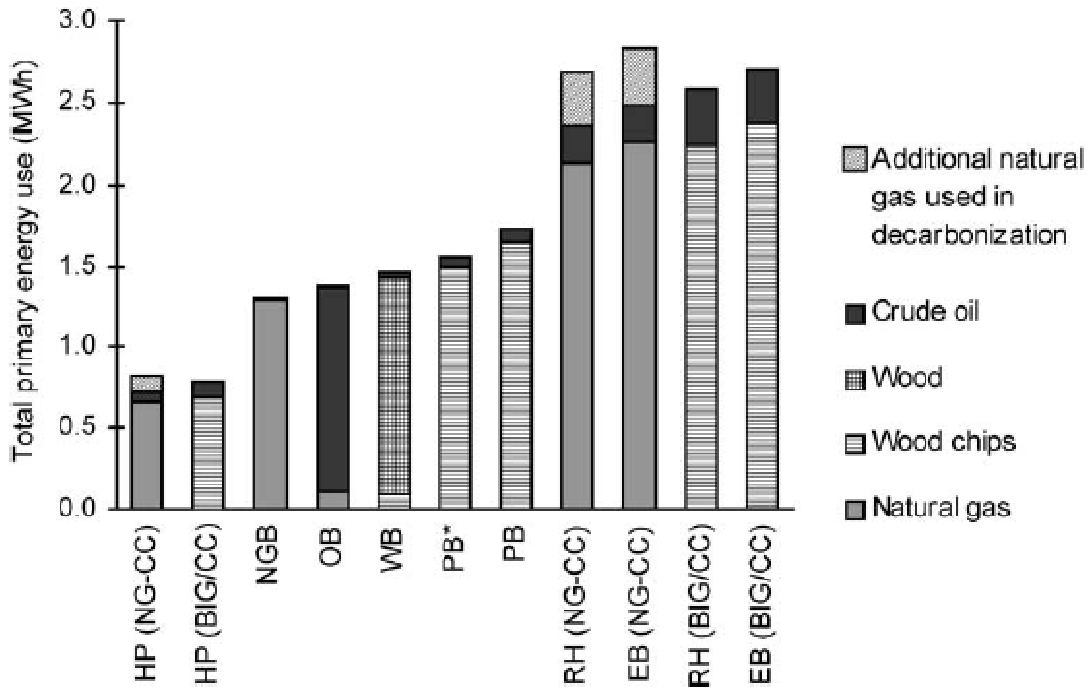

Figure 3. Comparison of primary energy use for different heating systems, when producing a reference amount of heating of 1 MWh (Gustavsson, 2002). The heating systems considered were heat pumps (HP), natural gas boilers (NGB), oil boilers (OB), wood boilers (WB), pellet boilers (PB), resistance heaters (RH), and electric boilers (EB).

The heat pumps background document (Forsén, 2005a, 2005b) also presents a magnitude for the calculation of the greenhouse gas emissions, the Total Equivalent Warming Impact (TEWI), which was developed at Oak Ridge National Lab in the 90s. The TEWI calculation incorporates direct and indirect greenhouse gas emissions over the whole lifetime into a single number expressed in CO_2 mass equivalents (also used in the heat pumps criteria in the Blue Angel label).

In the heat pumps report (Forsén, 2005a, pages 25-26), data are provided comparing the CO_2 equivalent emissions for different gas boilers and heat pumps, for different scenarios where electricity has different emissions factors ranging from 0.1 to 0.9 kg $CO_2/kW_{electricity}$. The conclusion is that in most (but not all) cases, heat pumps result in significant reductions in CO_2 emissions when compared to gas boilers.

The use of primary energy calculation has been introduced in other EU instruments, such as the Energy Performance of Buildings Directive. According to the recast of EPBD (2010), "effective rated output" means the maximum calorific output, expressed in kW, specified and guaranteed by the manufacturer as being deliverable during continuous operation while complying with the useful efficiency indicated by the manufacturer.

In Annex I of the recast of EPBD (2010) there is a general framework for calculating the energy performance of buildings that refers to primary energy use:

1. The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid over-heating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.

2. The energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of **primary energy use**, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages or a specific value for on-site production. The methodology for calculating the energy performance of buildings should take into account European standards and shall be consistent with relevant Union legislation, including Directive 2009/28/EC.

The EPBD directive does not give an explicit formula for calculating the efficiency, but points out that the method shall give information on the primary energy and final energy consumed by the building.

In addition to primary energy ratio, other authors have proposed alternative measures of efficiency, such as that of exergy (Dincer, 2002; Heijungs, 2007). Research by Heijungs (2007) provides a measure of "eco-efficiency" on the basis of thermodynamic efficiency, more specifically a ratio of input to output exergy. This measure of "eco-efficiency" based on exergy is proposed in part to combat the proliferation of different measures of efficiency that one can find in the literature, and to account for the difference in quality of different types of energy (electricity, work, heat) that are however measured in the same energy units. Exergy instead represents only the amount of energy that is available to produce useful work. In this way, a given quantity of electricity (in energy units) has more exergy than the same energy quantity of heat.

Usually, the energy efficiency ratios that are reported in the literature do not discriminate between heat and electricity, as they both have units of energy. As a result, the coefficient of performance of a heat pump is greater than 1, as the amount of heat delivered is greater than the amount of electricity input to the heat pump.

The advantage of using a ratio of exergies would be that this ratio would always be below 1, facilitating the comparison between different heating technologies. This eco-efficiency would be defined as $\eta = B_{out}/ B_{in}$, where the B's are exergies of inputs and outputs. Thermodynamic analysis demonstrates that this ratio is always below 1. In summary, Heijungs and others propose an eco-efficiency indicator, based on thermodynamics, and accounting for differences in quality. With this indicator, efficiency losses measure losses in the quality of the energy.

4 HEATING SYSTEMS IN OTHER ECOLABEL SCHEMES

Although it appears technically feasible in principle to develop common criteria for a product group "hydronic central heating systems", there is no Ecolabel program that has developed criteria for all heating systems as a group, or for all hydronic central heating systems as a group. Reasons for that differ and are related also to non technical but more political issues. It has been considered opportune to support certain types of fuel such as biofuel, solar energy etc. instead of fossil fuel for heat generation. Technical resons not to take up a systems approacch so far refer to the technical heterogeneity of the different heating systems, and also to the complexity when transferring this information to end consumers in an understandable way. As a result, Member States labelling schemes currently follow a product oriented approach with a focus on renewable energies.

5 POTENTIAL OUTCOMES OF THIS STUDY

A study on the possibility of developing common benchmark criteria is an interesting research topic. Since the literature presents many possible ways to developing magnitudes to compare the efficiency of heating systems, the study would allow for a thorough literature review and possibly the choice of the most appropriate measure, whether it would be based on primary energy consumption, exergy, etc.

A consequence is that, if a common benchmark is developed that is mainly based on energy efficiency, possibly only heat pumps would be awarded an ecolabel (example, Figure 3). However, since the common benchmark will include other environmental considerations[5] such as CO_2 emissions, then some less energy efficient technologies (such as boilers when compared to heat pumps) may qualify for an Ecolabel depending on the type of fuel used (for example biomass if the outcome of the LCA study is that the system fuelled by biomass emits less greenhouse gases).

[5] Impacts addressed by Ecolabel: energy efficiency, global warming potential, refrigerant use, components, packaging, practicality/availability, test methods, installation/maintenance, recyclability of materials, human health effects of materials, toxic air emissions, etc.; all of them evaluated from an LCA perspective.

It is important to note that each heating technology (ex. heat pumps, or boilers) represents a heterogeneous group by itself. For example, given that there are many different types of heat pumps, the EU Ecolabel criteria for heat pumps (2007/742/EC) establishes different minimum requirements for "primary energy ratio" (PER) depending on the type of heat pump technology (air/air, air/water, brine/air, etc.)[6]. In this way for example, the minimum established PER values for heat pumps oscillate between 1.04 and 2.04. This is an evidence that a common benchmark will need to not only include the consideration of energy efficiency, but a number of other environmental considerations including CO_2 emissions or other air emissions, that may allow the award to a particular heating systems (for example, a boiler) that might be less energy efficient.

The current market is also a factor that will play a role in the development of the common benchmark. For example, given that boilers are a significant part of the heating systems market today, the 15-20% best-performing boilers might represent a significantly larger group than the 15-20% best-performing heat pumps.

It is important to note that Ecolabels are revised every few years (4 or 5 years). Therefore the development of Ecolabel criteria should be a dynamic and flexible process that evaluates heating systems technology on a timely basis and addresses the market as it is today. This approach will achieve the maximum timely environmental positive impact, and it does not prevent from changing the conditions in the future. There are many examples from other state label systems that show that these labels are flexible instruments that adapt as technology changes. For example in the Nordic countries, there used to be criteria for oil and gas-fuelled boilers. The market showed that these types of fossil-fuelled systems were becoming less popular, and therefore in the recent years, the Nordic ecolabel for these boilers was discontinued. In the meantime, a strong market for biofuelled boilers was being developed, and afterwards an Ecolabel for these types of systems was developed.

6 SUMMARY

The proposed study will constitute a preparatory study on central heating systems that use hot water to distribute heat in buildings. The main objective is to study the feasibility of developing a common benchmark that would allow a customer to make a choice among different central heating technologies for the function of ambient heating and/or providing hot water to a building. Systems that provide hot water are essential not only for the delivery

[6] In the EU Ecolabel criteria, the Coefficient of performance (COP) is the ratio of heat output to electricity or gas input for a specified source and output temperature. The Energy efficiency ratio (EER) is the ratio of cold output to electricity or gas input for a specified source and output temperature.

The primary energy ratio (PER) is given by COP*0.40 (or COP/2.5) for electrically driven heat pumps and by COP*0.91 (or COP/1.1) for gas driven or gas absorption heat pumps, where 0.40 is the current European average electricity power generation efficiency including grid losses and 0.91 is the current European average gas efficiency including distribution losses according to directive 2006/32/EC.

of ambient heating, but because the provision of hot water is a function that is a necessity in buildings (in contrast, ambient heating alone may be delivered directly by other media such as air).

This preparatory study may lead to the conclusion that it is possible to develop a common Ecolabel & GPP benchmark for all hydronic central heating systems. The study may also result in separate Ecolabel & GPP criteria for some and/or all of the individual heating systems under consideration.

A study on a common benchmark for hydronic central heating systems would include a literature review on the concept of efficiency for heating systems, as derived from the academic literature, CEN standards, European Directives, and other Ecodesign and Ecolabel background research. It would also include a market study, an environmental impact assessment, etc. The study may (or may not) lead to the exclusion of certain heating system technologies.

Defining the scope of the study as "hydronic central-heating systems" has two main advantages: (1) it will allow for the study of central-heating boilers (the product that was found to represent the largest environmental impact of all heating systems (IPTS, 2010), and (2) it will investigate the possibility of making a horizontal comparison of the environmental performance of all hydronic central heating systems. This study will provide data that will facilitate customers or builders to compare different technologies in a horizontal way to choose the ones with the lesser environmental impact. The Ecolabel & GPP criteria will give a market advantage to the best technologies, and will stimulate the development of the best environmentally performing units.

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