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Assessing the validity of European labels for energy efficiency of heat pumps

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ABSTRACT

The European Union implemented Ecodesign and Labelling Directives to support the market diffusion of energy efficient products. Accurate signals for consumers on energy efficiency (EE) are essential, as disinformation might lead to sub-optimal market allocations. Considering complex devices such as heat pumps (HPs), a conflict between simplicity of calculation on the one hand and accuracy on the other hand arises. For this reason, main differences on EE between real working conditions and test procedures carried out according to regulations are examined within this study: Firstly, the most important deviations between the test procedure and the current state of the art are presented. Secondly, their influence on the validity of HP labels is investigated using spreadsheet calculations and a MODELICA simulation model. The results indicate that the omission of important influence factors – such as local conditions and the applied control strategy – in the regulations leads to significant differences between reality and labelling. The band of uncertainty found within this study covers high deviations of + 80% to − 24% from the label value. Therefore, we provide several recommendations to mitigate these deviations and to optimize the information content of the label. Among these are the implementation of a higher spatial resolution of climate conditions, the consideration of higher insulation standards, and the inclusion of effects caused by price-driven controls of the HP unit.

1. Introduction

By ratifying the Paris Agreements on October 5th, 2016, the European Union (EU) and its contract partners committed themselves to limit global warming to 2 °C in comparison to pre-industrial levels [27]. According to the International Energy Agency [46], 40% of the necessary emission reductions can be achieved by increased EE. For this reason, Directive 2009/125/EG [33] with regards to eco-design and Directive 2010/30/EU [34] concerning labelling of energy-related products were initiated by the European Parliament among other regulations. These two directives are often referred to as “ErP-Directives” (i.e. energy related products).

The importance of the household sector for achieving the necessary reduction in CO_2 emissions is e.g. underlined by Blesl et al. [10]. Within this sector, the primary energy demand for space heating and warm water supply holds a share of 82% [15]. The EU implemented Regulations 811/2013–814/2013 [28–31] in order to create incentives for consumers to buy efficient space and water heaters as well as for producers to design their products with a particular focus on EE. The first incentive is created by conveying information to the consumer via labels and the second one by implementing efficiency standards that must not be undercut (eco-standards).

When trying to calculate EE of heating devices in a simple and transparent way, a conflict between accuracy and simplicity arises. Especially for more complex heaters and heating systems, such as HP systems, an adequate compromise between these two requirements needs to be found. The problem of inaccurate labelling for complex energy systems is already known from Energy Performance Certificates for buildings, as shown by Cayre et al. [13], Scheer and Motherway [66], and Majcen et al. [55]. Furthermore, the importance of labels to demount information asymmetries and enable customers to make profound choices is an increasingly important topic in different fields of current research, as demonstrated by van Amstel et al. [3], Shi [68], Zhou and Bukenya [77], and McFadden and Huffman [56]. Within these publications, it is stated that product labels can generate transparency in complex decision situations for non-specialists and thereby enable profound customers' choices. Moreover, Henkel [44] showed that EE is a significant decision criterion for customers of heating devices.

Therefore, the goal of this manuscript is to examine whether the current EU calculation method for EE of HPs is sufficiently accurate to inform consumers, or if simplifications and disregarded influences may

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Nomenclature

Formula symbols

BIV	Bivalent point [°C]
CD	Coefficient of degradation [/]
COP	Coefficient of performance [/]
H	Hours [h]
HT	Heating threshold [°C]
P	Electric power [kW]
PL	Part load factor [/]
Q	Heat [kWh]
$\dot{Q}$	Heat flow [kW]
SCOP	Seasonal coefficient of performance [/]
t	Time [s]
T	Temperature [°C]
TOL	Temperature of operation limit [°C]
W	Electric energy [kWh]
η	Efficiency [/]

Indices

BIV	Bivalent point
CK	Crankcase heating
H	Heat Load
HE	Heating
HP	Heat pump
HT	High tariff
IH	Immersion heater
j	Temperature class
LT	Low tariff
S	Seasonal
SB	Standby
TO	Temperature control off

lead to disinformation and result in market disturbances. The review of the labelling directive published by the European Commission [32] concluded that the benefits of the regulation outweigh its costs without assessing the validity of the applied calculation schemes. To the best knowledge of the authors, such an evaluation has not been conducted yet. Hence, this manuscript is intended to fill this research gap.

In order to study the accuracy of the calculation scheme, the following section provides a comparison between efficiency influences on HPs known in literature and the current labelling and eco-standard calculation method for air-source, geothermal and groundwater HPs. The Section 3 describes the two approaches of spreadsheet calculation and MODELICA [24] simulation applied within this study. Section 4 illustrates the results achieved with both methods. The subsequent Section 5 serves to discuss and contextualize them. Furthermore, recommendations for improved label accuracy are provided within this section. The Section 6 summarizes the results and provides a conclusion.

2. Description of the labelling method and comparison to state of the art

Before a review of current literature in the field of HP efficiency is presented, the spreadsheet calculation method used within the EU labelling procedure is described briefly. This serves as a starting point for the following analyses.

Regulations 811/2013–814/2013 focus on the efficiency assessment of both space and water heaters as well as of complex heating systems. Within the scope of this manuscript, water heaters and complex heating systems are excluded for reasons of simplicity. Therefore, the focus is on the assessment of single HP units and the more complex calculation method for combined heating systems is not presented in the following.

In order to determine the HP's efficiency, the standard calculation scheme utilizes spreadsheet calculations. For a more detailed insight into the described scheme, refer to publications by European Commission [29], DIN [20,21]. For air-source HPs, six measurement points according to the investigated temperature zone (average, warmer or colder) are defined. In addition to test conditions (A-D), measurements need to be conducted for the bivalent Point (*BIV*) and the operation limit temperature (*TOL*). The HP's coefficient of performance (*COP*) and its heat output are determined for each measurement point. As this *COP* reflects the HP's performance under full load conditions, a method to integrate part load behavior is applied. This is based on linear behavior for air-sink HPs and non-linear behavior for water-sink HPs:

$$Air-sink: \quad COP_{part\ load}(T_j) = COP_{full\ load}(T_j)*[1-CD*(1-PL)] \tag{1}$$

$$Water-sink: \quad COP_{part\ load}(T_j) = COP_{full\ load}(T_j)*\frac{PL}{CD*PL+(1-CD)} \tag{2}$$

where the part load factor *PL* is calculated as the quotient of heat demand and heat output at full load and the degradation coefficient *CD* is set to 0.4 by default (air-sink) respectively 0.9 (water-sink).[1]

The heat load $\dot{Q}_h$ is calculated for each outdoor temperature class T_j based on a linear heat load curve and the nominal heat load $\dot{Q}_{nominal}(T_{design})$ at design temperature T_{design} which is set to $-10\,°C$ for average climate conditions.

$$\dot{Q}_{heat}(T_j) = \frac{T_j - 16\,°C}{T_{design} - 16\,°C} * \dot{Q}_{nominal}(T_{design}) \tag{3}$$

For temperatures below the bivalent point, the HP's output is not sufficient to cover the heat demand. Therefore, an immersion heater is needed to cover the difference. The *COP* of the supplement heating device is set to 100% by definition.[2]

The resulting *COPs* at part load and the HP's heat output are then inter- and extrapolated to cover all temperature classes [20,21]. A calculation example for a non-modulating air-water HP is given in DIN EN 14825 ([21]: p. 78) and shown in Table 1. The *TOL* is set to $-10\,°C$ and BIV to $-6\,°C$ for the sample calculation. The HP's output temperature varies between 22 °C and 35 °C as floor heating is assumed ([21]: p. 76).

For the case of geothermal and groundwater HPs, a spreadsheet as shown in Table 1 is used as well, but only a single measurement point is defined. Brine HPs are measured with a source temperature of 0 °C and groundwater at 10 °C for every temperature class.

For the overall efficiency determination, the ratio of total covered heat load $Q_{heat,total}$ (i.e. the HP's energy output, sum of column eight in the sample Table 1) and total electricity consumption $W_{electric,total}$ (i.e. the HP's energy input, sum of column nine in the sample Table 1) is calculated representing the average seasonal coefficient of performance during operation $SCOP_{on}$.

$$SCOP_{on} = \frac{Q_{heat,total}}{W_{electric,total}} = \frac{\sum_j Q_{heat,j}}{\sum_j W_{electric,j}} \tag{4}$$

The next step in the standard calculation method is to expand the temporal system boundaries by including standing losses during non-

[1] The degradation coefficient CD is implemented to approximate cycle losses caused by switching the HP on and off.

[2] If a fuel-based heating device is applied to cover peak load, its efficiency needs to be measured.