Reliability of the European energy label for heating appliances – optimization of test standards for heat pumps

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Abstract

The European standards EN 14511 and EN 14825 are representing standardized procedures for testing the energy efficiency of heat pumps and air conditioners with electrically driven compressors for both space heating and cooling. In this study, these standards are analyzed and validated. It was figured out that the currently used methods implicate high complexity and high financial effort. Test laboratories claim that for certain types of construction, e.g. air sourced heat pumps, the standard procedures show deficits in delivering repeatable and reproducible results in inter- and also intralaboratory tests. In order to clarify the circumstances and to identify the deficits more in detail, a round robin test with independent and accredited laboratories was initiated. The aim is to develop an optimized test procedure that improves the feasibility of the testing procedure and finally its application. This study should lead to a more repeatable and reproducible testing procedure, which is also compatible with the state of the art in heat pump technology and real operation conditions.

Introduction

In consideration of climate change issues engineers and scientists are working continuously on optimizations and innovations in the energy sector in order to increase the energy efficiency of energy using and energy related goods on the market (Harby K. et al.,2016; Soni S. K. et al., 2016). There is huge potential for energy savings when it comes to heating which represents about 70 percent of the energy consumption in households in Europe (European Commission, 2017). Especially heat pumps (HP) are promising high efficient technology products which have a significant contribution to reach the targets of the Marrakesh climate change conference 2016.

However, to guarantee the full realization of the energy saving potential of the EU Eco-design and Energy Labelling Directives an effective market surveillance is required. Due to the limited financial resources of the market surveillance authorities reliable, quick and cost-effective test methods are necessary for the elimination of non-compliant products.

In this paper, an overview of the German HP market is given focusing on the energy efficiency development of the three HP types of construction and their shares in the energy efficiency classes. The three types of HPs can be categorized according to the heat source used, which are i) air (air/water HP), ii) ground water (water/water HP) and iii) brine (brine/water HP). Brine flows through pipes in the ground and absorbs the heat, whereas air/water and water/water HPs have no such inter-circuit and use the heat of their source media directly (Pehnt M., 2010). The development of the energy efficiency is explained with a short excursion to the technical development and the state of the art in HP technology. The methods, EN 14511 and EN 14825, used to determine the energy efficiency of HPs are outlined in the section Methodology. The subsequent section Results presents the advantages and disadvantages of these methods and discusses the repeatability and reproducibility of the experimental results. The paper concludes with remarks on the proposed new test procedures.

German market for heating appliances

During the last years, a strong development in energy efficiency of HPs has proceeded on the German market. This is, among others, due to funding programs such as the Market Incentive Program of the German government (Federal Ministry of Economic Affairs and Energy, 2015) and the introduction of the energy label for HPs (Commission Delegated Regulation (EU) No 811/2013, Commission Delegated Regulation (EU) No 813/2013).

The energy efficiency development of HPs in Germany has been analyzed in detail based on a data set from BAFA (Federal Office for Economic Affairs and Export Control, 2016) and data from a study of the Swiss Federal Office of Energy (Swiss Federal Office of Energy SFOE, 2015). In Figure 1 the average values of the Coefficient of Performance (COP) at standard rating conditions for the three types of HP construction is shown. The COP, which is equivalent to the energy efficiency, has improved by about 1.0 between 1993 and 2016. Due to the different heat sources, the three types of HP construction achieve average energy efficiencies in the following order: water/water HPs, brine/water HPs and air/water HPs, with the water/water HP representing the most efficient type of HPs. Recently, water/water HPs achieve an average COP of 5.8, brine/water HPs achieve 4.5 and air water achieve an average COP of 3.5, respectively. The improvement of the energy efficiency is predominantly due to a general optimization in the design of the HP construction and the emerging inverter technology. The inverter technology enables a continuous power regulation (comparable with the variable speed drives used in electric motors, etc.). Instead of an on/off mode, HPs with an inverter run continuously, but at variable power, which leads to a significant reduction of the energy consumption.

In the case of air/water HPs an additional improvement of the defrosting procedure led to an increase of energy efficiency.

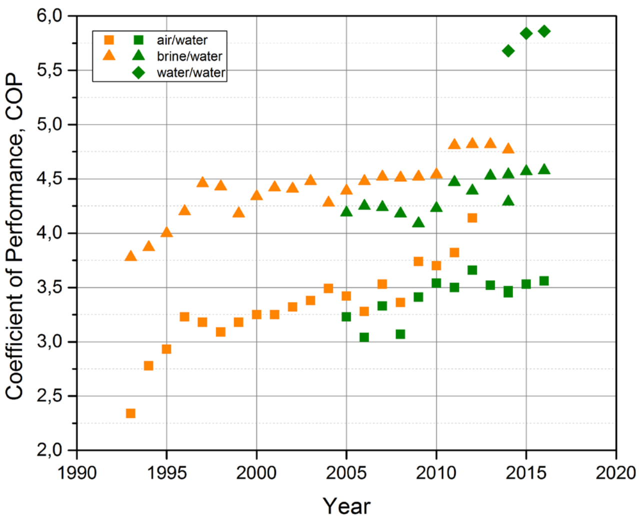

Figure 1. Increase of COP of the different types of HP constructions over the past years. The COP was determined according to EN 255 (orange) and EN 14511 (green), respectively (Federal Office for Economic Affairs and Export Control, 2016, Swiss Federal Office of Energy SFOE, 2015).

This is especially due to the automatic control but also due to the development of alternative defrosting procedures including: warm-air defrosting, electric heating defrosting, hot water spray defrosting, hot gas by-pass defrosting and reverse cycle defrosting.

It should be noticed that in 2005 the test method EN 14511 was introduced, which requires a temperature spread of 5 K during the measurement. Before 2005 the EN 255 assessed HPs more generously due to a temperature spread of 10 K during testing. Due to this circumstance, the COP values determined with EN 14511 are consistently lower than the COP values determined with EN 255.

The EN 14511 and EN 14825 use different operating points to determine the energy efficiency of an HP. These operating points refer to the measurement of energy consumption under certain rating conditions, e.g. different source temperatures, different sink temperatures, air humidity or water flow rate. Figure 2 shows the COP for over 2000 HPs of different types of construction in different operating points. The first part of the designation stands for the inlet source temperature whereas "A" stands for air as the heat source medium, "B" stands for brine and "W" for water, respectively. The second part represents the supply temperature for the heating circuit.

It reveals that the COP increases with rising temperature of the heat source as it is exemplarily shown for air/water HPs. However, for the same or similar heat source temperature air/water HPs deliver lower COP values than brine/water or water/water HPs. The relative lower efficiency of air/water HPs can be explained in terms of the heat capacity of the used heat source medium. The specific heat capacity of air (~1 $kJ\,K^{-1}\,kg^{-1}$) is substantially lower than the specific heat capacity of brine (3.5 $kJ\,K^{-1}\,kg^{-1}$) or water (4.1 $kJ\,K^{-1}\,kg^{-1}$)(H.-J. Kretzschmar, 2014). The consequences are a reduced heat transfer and a lower COP.

Additionally, the ambient temperature and thus the applied operating points of the standard methods EN 14511 and EN 14825 depend strongly on climate conditions. The test methods consider these climate influences by giving specifications for measuring at realistic temperatures and thus the energy efficiency of air/water HPs is generally lower than the energy efficiency of brine/- and water/water HPs. During a heating period in Germany the average source temperature of air is 6.5 °C (Institut Wohnen und Umwelt, 2017) compared to 0 °C of brine or 10 °C of water, respectively (Energieexperten.org, 2017). Disadvantageously the ambient air temperature fluctuates strongly, whereas brine and water temperature are approximately on a constant level. This is also taken into account by the test method EN 14825 which assumes the source temperature of brine and water HPs to be constant. Whereas, in turn, for the air sourced HPs the source temperature is varied. However, the inverter technology is able to compensate this disadvantage partially but may not be considered correctly by the current test method due to the measurement in fixed operating points.

Further, Figure 2 depicts the enormous diversification of obtainable energy efficiencies of up to 2 units difference in the COP value.

According to the findings mentioned above HPs of the German HP market are classified in the energy efficiency classes from A+++ to C which are equivalent to the seasonal coefficient of performance (SCOP). Figure 3 shows the results of a market analysis based on the BAFA data set including over 2,000 models of HPs available on the German heating market. The majority of HPs available on the German market achieve energy classes from A+++ to A+. In comparison to the other types of construction, the majority of lower efficient HPs are air/water HP.

Methodology

To identify deficits of the standard test methods more in detail a round robin test (RRT) was initiated. The evaluation of the practical application of the test method serves as a basis for the proposals of a new standard test procedure. Two HPs are tested in a RRT by commissioning five independent and accredited laboratories to determine on the one hand the quality of the laboratories and on the other hand the repeatability and reproducibility of the test method. Each laboratory repeated the whole measurement procedure four times. The models selected for the RRT are brine/water HPs because RRTs with this type of HP have already been conducted before. Consequently, a benchmark already exits and results can be compared. The power range of the two models was selected to represent the upper and lower third for the heating demand for private houses in Germany, which are 9.7 kW and 42.9 kW, respectively.

The European standard EN 14825 (Commission Delegated Regulation (EU) No 813/2013) for medium climate and a supply temperature of 55 °C is used to carry out the RRT. In contrast to EN 14511 which only measures the COP and thus only represents the efficiency of the HP at a certain operating point, the EN 14825 determines the seasonal coefficient of performance (SCOP) and allows concluding on the seasonal energy consumption. The SCOP is calculated by using different COPs, measured at defined operating points, related climate zones and special operating states (e.g. standby mode). To conclude for the primary energy consumption, the SCOP is charged to the seasonal space heating energy efficiency (η_s). Advantages and disadvantages of the EN 14825 will be discussed in the subsequent section.

Results

ROUND ROBIN TEST

On the one hand, the RRT implies the quality of the testing institutes and, on the other hand, the repeatability and the reproducibility of the test procedure of the standard EN 14825 can be identified. In the following part, first results are presented for the determined SCOP/η_s.

Seasonal space heating energy efficiency (η_s)

The seasonal performance for the HP's energy efficiency classification was determined for two HP models. The results of the first laboratory are presented below.

The declared results of the manufacturers were confirmed. The intra-laboratory results show only slight deviations which indicates that the testing procedure is repeatable and accurate (see Figure 4). The procedure itself revealed high complexity and turned out to be very time intensive since it took two months to finish the first tests in one laboratory. This is especially due to the low tolerances of ±0.1 K for the temperature and the inertia of the HP system which complicates the precise and quick approximation of a steady state without significant fluctuation. The testing of air/water HPs could be even more time intensive due the temperature sensitivity of air and the random occurrence of defrosting cycles.

In addition, the theoretical analysis of the test methods revealed further disadvantages of the EN 14825. Test laboratories have significant room for selecting certain parameter values for the calculation of the seasonal performance. Parameters such as the bivalent temperature $T_{bivalent}$ and the rated power P_{design} do have a strong influence on the results of the calculation. As $T_{bivalent}$ is the lowest temperature at which the HP can provide the heating capacity alone it defines the heating curve. Whereas P_{design} has a direct impact on the seasonal heating load by which

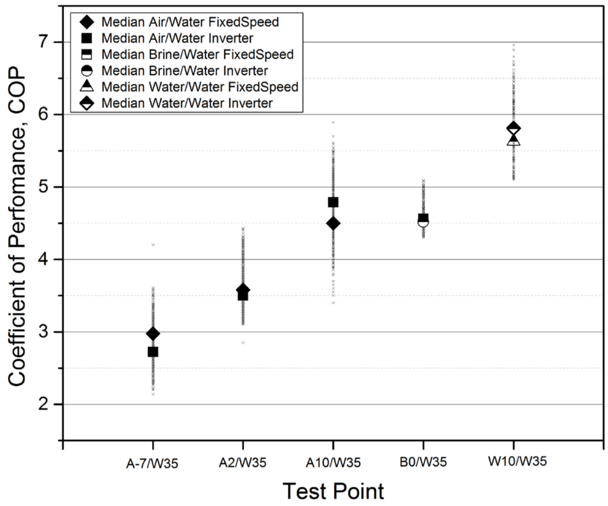

Figure 2. Coefficient of Performance of the different types of HPs in the operating points of EN 14511 and EN 14825. (Federal Office for Economic Affairs and Export Control, 2016).

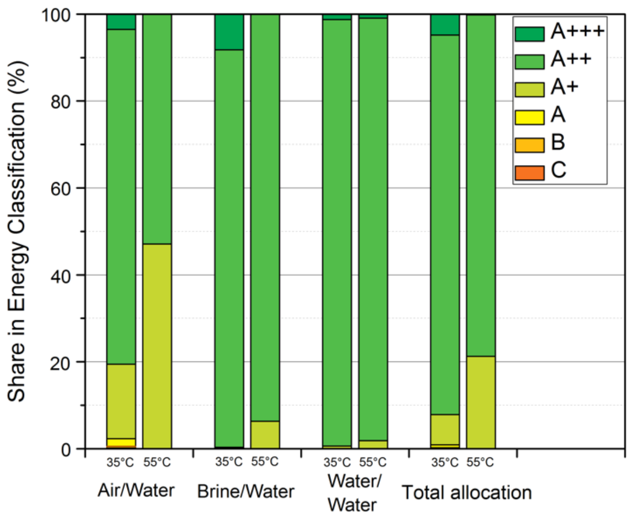

Figure 3. Share of energy efficiency classes (proportional to the SCOP) for the different types of HPs.

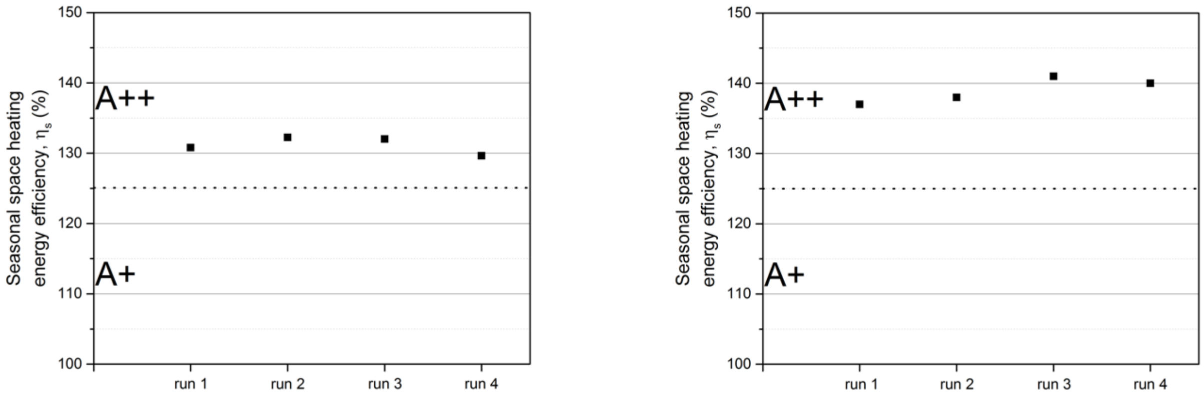

Figure 4. Measured η_s of the two Brine/Water HP models in the first laboratory of the RRT.

manufacturers may profit by declaring an advantageous value for P_{design}. Most laboratories indeed use values for $T_{bivalent}$ and P_{design} given by the manufacturer but some also use the measured values. This divergent handling might lead to a decrease in the reproducibility that is demanded by surveillance agencies for a reasonable assessment in product testing. To achieve reproducible results in the RRT the laboratories were instructed to use $T_{bivalent}$ and P_{design} that is given by the manufacturer.

PROPOSALS FOR NOVEL STANDARD TEST PROCEDURES

In consideration of market surveillance authorities demanding test methods that are applicable, cheap and not very time-intensive, on the one hand, and deliver repeatable and reproducible results, on the other hand, approaches are listed in the following:

- Investigation for adjusted tolerances regarding temperature values (e.g. required accuracy of ±0.1 K for temperature measurement to determine heating capacity) will be undertaken with the aim to reduce time effort.
- A calculation for the seasonal energy consumption that is alternative to the current test standard will be developed to increase reproducibility.

Further approaches for screening methods are contemplated as follows, since market surveillance authorities need test methods with low complexity and little time effort:

- Measuring under two significant test conditions to estimate the whole performance of the HP by interpolation. Data sets as depicted in Figure 2 could serve as a reference for such a screening method.
- A method for a component analysis for predicting the HP's energy efficiency will be developed. Main components of the HP (e.g. the compressor) will be classified and their dependency on the HP efficiency identified.

The following approaches will be undertaken in order to achieve more realistic test results regarding field operation conditions:

- Development of a method for inverter HPs to ensure tests are representative of field operation as this changes due to technical product development. Mavuri S. et al., 2014 already tested a first approach for "unlocked" testing successfully.
- Simulation for a transfer from laboratory results to field behaviour of the HP.

Conclusions and recommendations

In this paper the standard test methods EN 14511 and EN 14825 were both analyzed theoretically and experimental investigations of the measurement methods were carried out with the aim to develop an optimized test procedure with improved feasibility. The intra-laboratory results were found to be repeatable. However, the measurement was very time consuming, and thus cost intensive, due to the difficile adjustment of temperature accuracy of ± 0.1 K for the measurement under steady state conditions. It was pointed out that for effective conformity testing of the market surveillance authorities reliable, quick and cost-effective test methods are needed. In this context, new test procedures and in particular new approaches for screening methods were proposed.

Moreover, a comprehensive overview of the energy efficiency development of the three HP types of construction on the German market is given. The energy efficiency of HPs steadily increased during the last decades due to more advanced components, improved defrosting procedures and the use of inverters. However, the current test method does not render the benefits of an inverter HP due to the measurement in fixed operating points. Hence, the prospective future direction of research dealing with standardized measurement of the energy efficiency of HPs will be the method development for the "unlocked" testing of the inverter HPs.

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