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PERFORMANCE ASSESSMENT METHODS FOR BOILERS AND HEAT PUMP SYSTEMS IN RESIDENTIAL BUILDINGS

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ABSTRACT

According to the European Commission, 40% of the total energy use belongs to the buildings sector. That corresponds to 36% of CO2 emissions in the European Union alone. Currently, HVAC systems are the major energy users in the building sector. Therefore, there is a necessity to assess the performance of different energy/comfort systems in buildings. However, finding a way to mitigate the performance gap between the calculated and real energy use in dwellings is of great importance. In Flanders, the Energy Performance and indoor climate regulation (EPB) dates back to 2006. Since the building context related to energy demand has changed significantly over the past years, investigation on how to evolve building energy assessment method framework in the EPB regulation in Flanders by dealing with the current issues will be indispensable. In 2017, new EN52000 series of standards have been published, containing extensive methods of assessing the overall energy performance of buildings.

The main focus of this article is to analyze the assessment methods for the energy performance of *boilers* and *heat pumps* for *residential* appliance by comparing methodology stated in respected Energy performance and indoor climate regulation in Flanders (EPB), EcoDesign regulations and EN52000 standard series. The aim for future research is to determine the parameters that mostly influence on the performance and in a next step compare the predicted performance to real energy use.

KEY WORDS: Building system performance, HVAC, boilers, heat pump, regulations, standards

1. INTRODUCTION

With extensive urbanization, the number of the buildings in urban areas will increase, resulting in a higher energy demand. The building sector is the biggest energy user exceeding industry and transportation sectors. The reason may be lying in inaccurate building design, oversized equipment particularly in operational stages or in inappropriate performance measurements techniques. Building energy performance assessment methods are crucial in order to obtain the efficiency of energy use in buildings. They represent ground bases in a way of making any decisions for improving energy efficiency and buildings use in general. Assuring new building performance assessment methodologies stands as a possibility to cope with aggravated energy issues as well.

Residential buildings account for 75% of the total building stock in European Union [1]. Used energy in dwellings is mostly taken by space heating (68.4%) and hot water production (13.6%) [2]. Energy used for powering electrical appliances in the dwelling is far less significant with the share of (3.8%) for cooking and (14.1%) for lighting. Data were retrieved on the ratio of energy use by the end uses divided by the number of permanently occupied dwelling. This is illustrated in Figure 1 and is represented for the countries of EU.

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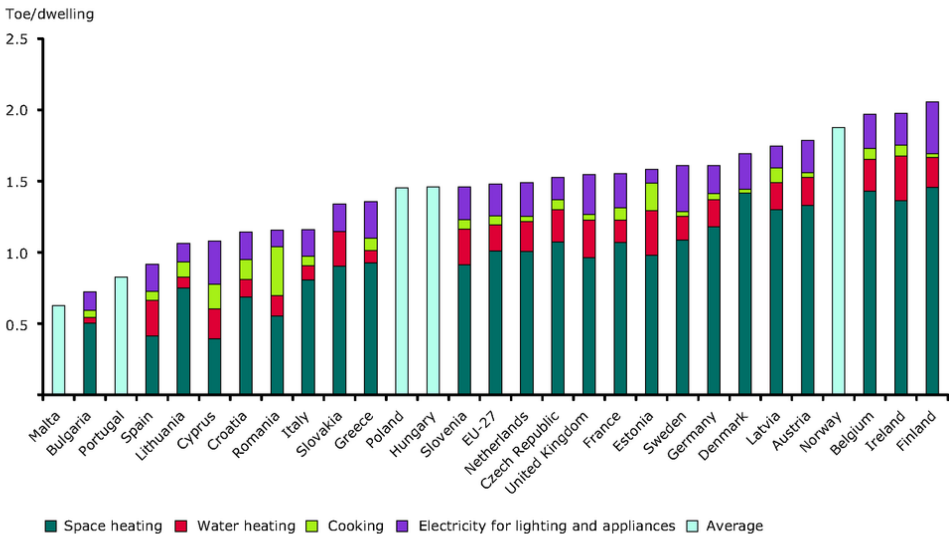

Fig. 1 Energy use per dwelling in EU countries [3]

Developing enhanced assessment methods shall serve in providing building owners or occupants an insight in energy use of their property and how the performance being appraised comparing with benchmarks, which then should guide in awareness of cost-effective energy savings [4]. In literature there are many definitions for "energy efficiency". According to Oxford dictionary [5], energy efficiency is defined as "The ratio of the useful work performed by the machine or in a process to the total energy expended or heat taken in", can be lowered by excluding unnecessary energy use in buildings while attaining desired comfort level of the occupant. According to a directive of EU council [6], in the building sector there is a great potential for achieving cost-effective energy savings that corresponds to 11% less final energy used by 2020. In line with household cost savings, facilitation of CO2 emission in building sector should also be attained respectively. Hypothetically, without any further international policies, energy use related CO2 emissions are expected to rise by 70% till 2050 [2].

According to International Energy Agency (IEA), Annex 53 project, six factors are significant in order to determine building energy performance: (1) climate, (2) building envelop, (3) building services and energy systems, (4) building operation and maintenance, (5) occupant behaviour and (6) achieved indoor environmental quality [7]. As already mentioned, the biggest portion of energy use in building belongs to domestic hot water (DHW) and heating. Hence, the aim of this work is to analyze the performance of the boilers and the heat pumps for residential heating system appliance.

2. REGULATIONS DESCRIPTION

2.1 Energy performance and indoor climate

Energy performance and indoor climate regulation (EPB) for new buildings and energy performance certification regulation (EPC) for existing buildings represents the present regulations in Flanders, Belgium. The regulations have adopted the European Energy Performance of Buildings Directive (EPBD) that was published in the year 2002 [8]. More than a decade ago, in the year 2006, the first edition of EPB came into force followed by the adoption of EPC in 2008. The methodology established in the EPB regulation is partly based on a standard that was made in Netherlands in 1998. Buildings are assessed through a calculation procedure provided by Flemish Energy Agency (VEA) [9] that results in an "E-level" of the building which indicates the primary energy level of the building [10]. The calculations are done following several parts. At first, by assuming an indoor set-point temperature to be at 18°C, monthly based semi-steady state calculations are being made for calculating energy needs for heating and cooling the building. Second, energy needs for hot water are additionally calculated. Third, auxiliary energy for pumps and ventilation fans is estimated. Finally, the "E-level" of the building is obtained by dividing summed up values from mentioned indicators with a reference value. On the other hand, the reference value represents a function of different geometrical parameters.

The difference between the real and calculated energy use can be evident. Burman [11] has compared the actual energy performance of an educational building with its theoretical performance using UK policy based on EPBD methodology. Inspected low carbon building was constructed in 2008 in accordance to the UK Building Regulations 2006. The building was designed as sealed envelope with heat recovery mechanical ventilation including variable speed fans. Heating system of the building includes four ground source heat pumps which are supported by gas-fired condensing boiler as the back-up system. The results show a significant difference in energy performance between the real and theoretical performance for all building energy use systems. Delghust [12] has compared real energy use and calculated energy use in accordance to Flemish EPB regulation for 537 dwellings. The results have shown that EPB regulation is overestimating the heating energy use by average 25% for all different kinds of heating system. The lack of fit is not shown only by the average overestimation of the energy use, but also with the prediction error, from highest overestimation of 68% to handful of underestimations of maximum 47% (Figure 2).

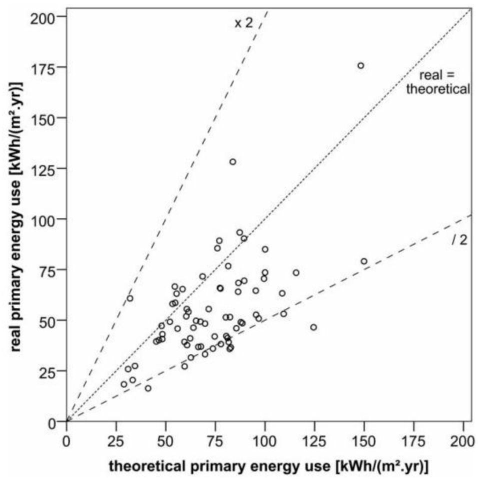

Fig. 2 Real and theoretical values of yearly primary-energy use for space heating and domestic hot water [12]

In the last years, the building construction sector has advanced significantly towards construction and renovation of more energy efficient buildings. In order to decrease energy use and carbon emissions, the existing assessment methods need to be verified by confronting:

- Performance gap- theoretical dwelling energy use calculated in accordance with energy performance assessment methods does not match to real energy use;
- Inappropriate assessment period- performance assessment is based on yearly primary energy balance;
- Interconnected market responses, building-grid interaction, neglected dwellings embodied energy that influences operational energy use.

However, reports testify that EPB regulation had a very positive impact on Flemish society. Despite the systematic growth of the housing stock, EPB regulation has contributed to the reduction of greenhouse gas emissions in Belgium with the drop of CO_2 emissions by 16.6% in the period between 1990-2015 [13]. With

"E-level" leap from E84 in 2006 to E43 in 2014 for residential buildings [8] and an approximate number of 250,000 individuals that came in contact with the regulation, there is a clear motive of the constant evolvement of EPB regulation. The most recent Flemish EPB regulation published in December 2017, aims in harmonizing the exiting methodology for assessing the building energy performance with Ecodesign requirements.

2.2 Ecodesign

The Ecodesign Directive provides a framework which allows setting mandatory Ecodesign requirements for particular products and allows the European commission to regulate the minimum performance of products. Last helps to prevent the creation of barriers to trade, improve product quality and environmental protection. However, Ecodesign requirements must not lower the functionality of a product, its safety, or have a negative impact on its affordability or consumers' health. The harmonized rules at EU level ensure that no divergent national or regional measures on Ecodesign hinder the free movement of goods and oblige manufacturers to comply with many disparate regulations [14].

The inspections have shown that Ecodesign requirements have contributed to the elimination of the least performing products from the market, significantly contributing to the EU's 2020 energy efficiency objective. The requirements have also supported industrial competitiveness and innovation by promoting the better environmental performance of products throughout the internal market.

2.3 Standard for assessing the overall energy performance of buildings EN 52000

In summer 2017, around 30 European (CEN) standards, in relation to the Energy Performance of Buildings (EPB), were published by the European Committee for Standardization (CEN)[15]. The standards come as part of still to become EN-ISO 52000 international package of standards that is considered as one of the most important present instruments to support the adequate implementation of EPBD policy. However, in this paper, newest CEN standards that reflect generation efficiency of boilers and heat pumps have been inspected.

3. GENERATION EFFICIENCY OF BOILERS

Even though the future of implementing traditional boilers as the central heating energy source in residential buildings is open to question, a survey shows that these heating systems are still dominating annual sales across Europe [16]. Therefore, there is a clear necessity of providing constant improvement of boiler manufacturing technology and efficiency. For this purpose, a methodology for obtaining generation efficiency of boilers is inspected by processing different approaches offered in EPW[17]- Flanders energy performance assessment regulation for residential buildings 2017, Ecodesign regulation 813/2013 [18] with support of 2014/C 207/02 communication [19] and 2015/1189 [20] regulation and EN 15316-4-1 [21] European standard.

3.1 EPW regulation

The newest published Annex 5 document of EPW regulation of Flanders brings two approaches on defining generation efficiency of boilers. The first is based on data required in Ecodesign regulation 813/2013 and principles of the older methodology of the original EPW regulation. It applies to specific types of boilers[1] that are all brought to the market starting from 26/09/2015. The second represents previous methodology for

[1] Space heating using gas or liquid fuel type B1 boilers with the nominal capacity not exceeding 10kW; Combination gas or liquid fuel type B1 boilers with the nominal capacity not exceeding 30kW; Boilers that are not gas or liquid type B1 boilers with the nominal capacity not exceeding 400kW.

defining the generation efficiency of all boilers that is now applicable only for the boilers that are out of above mentioned scope. In fact, both methods are based on the same principles with the difference in using fuel's calorific value. The first method is based on higher calorific value while second refers to the lower calorific value of the fuel used.

Generation efficiency for boiler space heating system is defined by correcting part load efficiency at 30% of rated heat output with return boiler water temperature of 30°C in test conditions. For both condensing and non-condensing boilers, part load generation efficiency is corrected by 3 factors: (1) installation size, (2) location of the boiler and (3) whether or not the boiler is kept permanently warm during the time. In the methodology, the first mentioned factor is not completely defined. It has a value that equals 1. Further on, values for the second and third factor are assumed as default values. If the boiler is placed outside the closed space and is kept permanently warm, efficiency decreases by 2% and 5% respectively. Part load efficiency for condensing boilers is corrected by additional estimation which corresponds to the temperature difference between the test conditions, considering the seasonal average and the return boiler water temperature in the application. The regulation also specifies a default value of generation efficiency for boiler space heating of 73% which is additionally corrected by boiler location factor and operational time.

3.2 Ecodesign regulations

While the methodology of EPW implies to estimate the generation efficiency for the complete installation, Ecodesign regulations set the effort in estimating the efficiency of the unit itself. Ecodesign regulation 813/2013 offers a list of technical requirements for placing in the market or putting into service, space heaters and combination heaters with rated heat output up to 400 kW under specified laboratory testing conditions. Regulation implies determination of seasonal space heating energy efficiency in active mode by assuming that 15% of the operational time, fuel boilers are working in full load, while in the other 85% of the time, they are working in part load of 30% of the rated heat output. Used boiler time operation division is sharply made not necessarily in the line with actual performance. On the other hand, the return boiler water temperature for 30% working capacity is assessed for different boiler types. Further on, seasonal space heating energy efficiency is obtained by correcting the seasonal space heating energy efficiency in active mode with several factors. Corrections due to temperature controls, auxiliary electricity consumption, standby heat loss and ignition burner power consumption are decreasing seasonal space heating energy efficiency. In the case of cogeneration boiler, seasonal space heating energy efficiency is increased by the electrical efficiency of the boiler multiplied by conversion coefficient with a value of 2.5. Stated estimation is open to question since it is defined without considering the general system dimensioning.

3.3 European standard

As mentioned before, European standards that are investigated for the purpose of this paper are part of a series of standards aiming at international harmonization of the methodology for assessing the energy performance of buildings. EN 15316-4-1 specifies a large spectrum of required inputs, resulting in outputs and a method to take into account the energy performance of heating generation devices based on fuel combustion. The standard implies three possible inputs for the generation efficiency calculation: (1) default values, (2) product values and (3) measured values. Equations are based on correcting the nominal power heat output which is limited to the value of 400 kW by involving correction factors that depend on the boilers type. Default values are given in the standard's Annex. On the other hand, product values by manufacturers may be used for establishing generation efficiency, under the condition, that the tests are done in accordance to the appropriated European standard (EN 303 heating boilers set of standards). However, boiler efficiency using measured data can be obtained, for both full load and intermediate load, by dividing subtracted average power input to the generator by thermal losses through the chimney and thermal losses of the boilers envelope with the same average power input to the generator. Regarding the calculation of boiler efficiency in intermediate load, the previous formulation is extended by using intermediate load factor and, if existed, recovered latent heat of condensation defined in the standard. Relations on how to calculate these parameters by measuring necessary factors during operating state of the boiler are, as well, offered by the framework.

4. GENERATION EFFICIENCY OF ELECTRICALLY POWERED HEAT PUMPS

Heat pumps are foreseen as a key technology for achieving low-carbon heating tendency [22]. With the ability to balance intermittent renewable energy supply through pro-active demand-side management and energy storage technologies, heat pumps intend to become the main energy source for heating systems. Following these inclinations, the methodology for obtaining generation efficiency of electrically powered heat pumps is analyzed in Flemish regulation EPW[17], Ecodesign regulations 813/2013 [18], 206/2012 [23] and communication 2014/C 207/02 [19] together with European standard EN15316-4-2 [24] and technical report CEN/TR 15316-6-5 [25].

4.1 EPW regulation

Depending on heat pump type and release date, EPW regulation sets two possibilities for obtaining generation efficiency of heat pumps. The first is developed in order to be harmonized with Ecodesign requirements 813/2013 and 206/2012 for space heating heat pump appliance. Therefore, it is applicable to specific heat pump design[2]. Generation efficiency for space heating system using electrically powered heat pumps is calculated by dividing rated heat output during time while heat pump was switched on, with the sum of the influence of seasonal coefficient of performance for the whole installation while the heat pump is in active mode (SCOPinst), together with different heat outputs that correspond to specific operational state of the heat pump. Different heat pump operational states are: (1) heat pump is off due to thermostat-off mode of the emission system, (2) heat pump is using power to prevent mixture of refrigerator and oil in the compressor, (3) heating system and heat pump are both in off mode, (4) heat pump is in stand-by mode. In the regulation, default values for the duration of each specific state are expressed in hours and they depend on heat pump type. Like in the case of boilers, EPW intends to specify the generation efficiency of the whole heating system. For the heat pumps, this is done through relation for establishing previously mentioned parameter SCOPinst. There, the seasonal coefficient of performance while the heat pump is in active mode (SCOPon) is corrected by multiple correction factors that are related to the performance state of the whole installation. A list of all correction factors is included and partially described in [17]. SCOPon is determined by exactly the same methodology offered in relevant Ecodesign regulations with the exception for two ducts air to air heat pump. There, the coefficient of performance of the unit itself (COPnom) is reduced by 30%. An additional explanation is described further on in 4.2. Ecodesign regulations. In the lack of data for applying above described methodology, the regulation also sets default values for heat pump and energy use generation efficiency of 1.25 for air to air units and 2 for other heat pump types.

On the other hand, the second approach described in EPW regulation applies to other heat pumps that are out of the scope of the first approach. There, the generation efficiency of the entire heating system using electrically powered heat pumps is calculated by correcting heat pump coefficient of performance obtained under European standard EN14511 [26] test requirements with defined installation correction factors. The standard EN14511 defines test procedures for the rating of heat pumps and chillers under steady-state conditions and at full capacity.

[2] Electrically powered soil, ground/surface water and outside air to water heat pumps that are put on the market from 26/09/2015 with nominal capacity not exceeding 400kW and outside air to air heat pumps that are put on the market from 01/01/2013 with nominal capacity not exceeding 12kW.

4.2 Ecodesign regulations

The scope of Ecodesign requirement 813/2013 coincides with the previously described scope regarding boilers. However, mentioned regulation 206/2012 applies on electric mains-operated air conditioners with rated heat capacity not exceeding 12 kW and comfort fans with electric fan power input less than 125 W. Both regulations are indicating calculation of the seasonal space heating energy efficiency of heat pumps by dividing seasonal coefficient of performance (SCOP) with the primary energy conversional coefficient and by correcting it with corrections due to temperature controls and due to the electricity consumption of ground water pumps (if existed). In fact, both of these correction factors are reducing the seasonal coefficient of performance by 8% default. On the other hand, the seasonal coefficient of performance is calculated by using exactly the same relation described in the first approach of EPW for obtaining generation efficiency for space heating. However, there are differences, since Ecodesign requirements are considering the performance of the unit and not the entire installation as EPW intends to accomplish. European communication document 2014/C 207/02 brings duration of specific heat pump operational regimes depending on applicable climate. EPW's SCOPinst is replaced straight away with SCOPon which represents the average coefficient of performance of the unit in active mode. Beyond, SCOPon is calculated using part load performance, electric back-up heating capacity and units coefficient of performance for designed heating season conditions (outside temperature and corresponding hours). For the heat pumps that use outdoor air as heat source during the heating season, the Ecodesign regulations acquire 4 mandatory outside temperatures (-7ºC, +2ºC, +7ºC, +12ºC) for establishing designed rated heat output and coefficient of performance of the heat pump.

4.3 European standard

Standard EN 15316-4-2 contains methodology for calculating the thermal energy provided by heat pump systems for space heating or domestic hot water DHW use. Required inputs, outputs and calculation methods are described within the standard. Despite the fact that the standard is processing different heat pump types, for the purpose of this paper the focus is set on electrically-driven vapour compression cycle heat pumps. Standard is applicable on heat pumps that use different heat sources in order to deliver heat to the water. By expressing energy balance for the electrically driven heat pump generation in heating mode, standard brings indication of certain parameters and aspects. Compressor electrical energy input and average coefficient of performance are expressed as deduction of the sum of thermal energy output and total heat losses of the generation subsystem by ambient heat energy used as heat source and subsystem auxiliary energy input.

Depending of the input data provided, standard offers 2 paths for the calculation of the energy performance of the heat pump generation system. For both paths, thermal capacity and coefficient of performance (COP) are declared values by the manufacturer [25]. The first path represents hourly method based on a reference value for COP and thermal capacity at full load according to EN 14511 test conditions. Here, default values are proposed to calculate COP and thermal capacity for any condition at full load. COP value at standard rating conditions and at full capacity is corrected by weighting factor that depends on heat pump type and takes into account the respective change either of evaporator inlet temperature or compressor outlet temperature. Thermal capacity values are obtained through interpolated temperature values used for COP calculation at full power and then corrected with weighting factors based on previous principles. Further on, standard implies calculation method for establishing COP, energy use by compressor, on/off state of the unit and the use by auxiliaries in part load operation. The calculation of the part load factor is based on the time of operation to satisfy the energy demand for the heating system and compared to the remaining time after operation for domestic hot water. The second path relies on heat pump performance parameters, thermal capacity and COP, at operating conditions that are established according to test conditions and methodology described in EN 14825 [27]. The newest version of EN 14825 standard was published as aspiration for harmonizing the European standard to Ecodesign requirements and terms. Therefore, it is consisted for both full load and part load values for thermal capacity and COP of the heat pump. By interpolating test results, the values are adapted to operating conditions using exergetic approach presented in the Annex D of the standard. The idea of the method is to keep thermodynamic quality of the process constant over the whole operating range. However, since the exergetic efficiency changes within operating range in the real process, the accuracy of this methodology is acceptable for temperatures that are near standard test points.

5. CONCLUSION

Long-term targets set out in European Union Roadmap-2050 request emissions from the building stock, with the largest share of housing stock, to be cut by around 90% till the year 2050. Both energy efficiency measures and the transit from fossil fuels to decarbonized electricity, e.g. by using heat pumps merged with renewable energy are indispensable for reaching ambitious targets. Balancing intermittent renewable energy supply through pro-active demand-side management and energy storages will serve as leading instruments in order to reduce the energy use of residential buildings. Proper implementation of these strategies and the building stock guidance towards reduced emissions has to be done with adequate policy framework.

There are many standards, regulations and legislations dealing with energy assessment methods. However, the different approaches vary considerably. Therefore, in this article, an overview of EPW regulation of Flanders, relevant Ecodesign requirements and newest CEN standards for assessing generation efficiency of boilers and electrically powered heat pumps has been made. Even though, appearing problems during analysis such as unclearness and lack of consistency in some documents made the analysis wearing, an effort for pointing out key indicators in subject systems has been realized. All the regulations and standards use myriad of assumptions for assessing generation efficiency of both systems. Despite the reliance of improved EPW regulations on Ecodesign requirements, possibly undefined relation between unit and installation system may be the future area of investigation. Newest CEN standards, with desire for international harmonization, may serve as an instrument for the further implementation of EPBD policy. Additionally, the challenge to assess minimal energy input, while achieving comfort conditions, in order to evolve Flemish regulation, may be done by inspecting building integrated systems behavior with dynamic simulations. As a part of a future work, advanced models need to be developed capable of simulating the interaction between electricity or heat grid, renewable energy sources, buildings integrated energy systems. They will serve as a medium for understanding the impact on carbon emissions and to develop more adequate calculation methods and performance indicators for building energy assessment.

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