MONITORING THE SYSTEM PERFORMANCE FACTOR OF DOMESTIC HEAT PUMP SYSTEMS IN FLANDERS (BELGIUM)

J. Hoogmartens[1*], G.Franck[2], W. Van Passel[2], L.Helsen[1]

[1]Department of Mechanical Engineering, University of Leuven (K.U.Leuven), Celestijnenlaan 300A/B-3001, Leuven, Belgium
[2]University College Lessius Mechelen, Campus De Nayer, J. De Nayerlaan 5-2860, Sint-Katelijne-Waver, Belgium

ABSTRACT

The heat pump market in Belgium is growing fast. Predictions for the next decade are also promising. Until recently, private consumers had only the availability of well defined, laboratory COP data of different heat pump systems. This work wants to compare these catalogue data to real heat pump system performances. This comparison is executed by setting up an extensive field trial on heat pump systems in recently built dwellings in the Flemish region. The global results agree with a recent German field trial.

INTRODUCTION

The green market is growing fast, more and more consumers, assisted by governmental incentives, choose for renewable energy sources. One of the technologies using a renewable energy source is the heat pump (RES Directive 2009/28/EC). Heat pump systems provide high levels of thermal comfort at reduced electrical energy use. In addition, they have a very low level of maintenance requirements (Lund et al. 2004; Inalli et al. 2004; GSHPA 2011). Despite all benefits the Flemish heat pump market is still in its initial phase of growth. Compared to Sweden, Austria, Germany and Switzerland, the Flemish region of Belgium, and by expansion Belgium as a whole, still has a large market potential for heat pumps (EHPA 2010). The slower growth is probably caused by high investment costs, low governmental incentives and a lack of real performance data. Still, a growth of the heat pump market is foreseen for the next decade (ODE 2011).

Private consumers ask for real-life performance and cost data in a typical Flemish context (climate, subsidies, underground, …) Usually, consumers only get performance indicators from manufacturers which are determined in well defined laboratory conditions. These conditions differ substantially from real conditions due to integration and control of the heat pump within the global system. More and more manufacturers tend to go in the direction of publishing real heat pump performance indicators (Thercon 2011; Heliotherm 2011), but there is still a long way to go.

Therefore, an extensive field measurement campaign has been set up in the region of Flanders, focusing on domestic heat pump systems in typical new built dwellings which all have an occupied space area between 115 and 450 m^2 (most of them at the upper end of this range) and which are all detached single-family dwellings. All measured heat pump systems are connected to a water-based heat emission system which is current practice in new buildings with a heat pump system. The main part of the systems monitored is located in Flanders, however this border has not been taken very strictly, resulting in a few measurements in the Walloon region and The Netherlands too. The first installation was ready for monitoring in October 2009.

METHODOLOGY

During a period of 18 months (October 2009-March 2011), 15 different domestic heat pump systems have been monitored and evaluated: 11 using air as a heat source, 1 using ground

Corresponding author email: jan.hoogmartens@mech.kuleuven.be

water as a heat source and 3 using the heat stored in the ground.

System boundaries and performance calculation

The heating performance of heat pump installations in buildings is defined by the seasonal performance factor (SPF). The European standard (EN 15316-4-2 2009) defines the system boundary for SPF determination of heating systems in buildings. The formula used in the European standard EN 15316-4-2 (Eq. 1) defines the SPF as the ratio between the sum of the heat requirements for space heating and domestic hot water distribution (including heat losses of storage tanks) on the one hand and the sum of the electrical energy input of the heat pump, back-up heater and the auxiliary energy input to the generation subsystem on the other hand.

$$SPF1 = \frac{(Q_{SH} + Q_{DHW})}{E} \quad (1)$$

With Q_{SH} representing the heat for space heating (kWh), Q_{DHW} the heat for DHW consumption (kWh) and E the electrical energy used (kWh).

To measure a correct SPF at least two heat sensors are needed, one for measuring the heat production for space heating and one for measuring the heat production for domestic hot water consumption. Additionally, one electrical energy sensor is needed. If the installation has both three phase and mono phase installation components, an extra electrical energy sensor is necessary. All heat pumps, delivering heat for domestic hot water (DHW), have a DHW tank. Therefore, the heat losses of the DHW tank are often neglected (by installing one heat sensor after the condenser), resulting in an alternative SPF definition. All electrical components are measured following the European standard. In that way the cost of one heat sensor is saved and still an accurate measurement can be done. Neglecting heat losses of storage tanks was also common practice in other foreign measurement campaigns (Fraunhofer 2010).

Table 1 summarizes the main characteristics of the monitored cases together with the results. The last column of Table 1 indicates which SPF determination method is used in the different cases. For 2 of the 15 cases all sensors are installed as it should be to determine the SPF according to the earlier mentioned European standard EN 15316-4-2 (Eq. 1).

As mentioned before, usually an adaptation is applied to the thermal part of the definition. In most of the tested heat pump systems (13 of 15 cases) the sensors were installed such that the performance can be determined following Eq. 2.

$$SPF2 = \frac{(Q_{SH} + Q_{DHW'})}{E} \quad (2)$$

With $Q_{DHW'}$ representing the heat for domestic hot water produced by the heat pump unit.

Monitored cases

The majority of test cases are located in Flanders, nevertheless, three cases are located in the Walloon region of Belgium and two in the Netherlands. The majority of tested cases are heat pump installations in recently built dwellings. These newly built dwellings are often large, detached, single-family houses, which is a building type used more in Belgium compared to e.g. the Netherlands. All monitored heat pump systems use floor heating as heat emission system. The main characteristics for each measured case are listed in Table 1. In the first column the heat pump type is indicated. Because all measured heat pump systems have floor heating as heat emission system, water is always the heat delivery medium. Therefore, only differentiation by heat source is made. Three types of heat sources are considered. One heat pump has ground water as heat source. A group of three geothermal heat pumps is divided into one horizontal brine to water heat pump and two vertical brine to water heat pumps. The other eleven tested heat pumps use the outside air as heat source.

To get a rough idea about the building and installation the second and third column give a list of the installed heat pump power, in specified test conditions (between brackets), and the amount of occupied surface area, respectively. The letter (F/W/N) written after the occupied surface area indicates the region/country where the heat pump system is installed.
In the next column the measurement period is presented. The fifth column describes whether the heat pump unit also produces heat for domestic hot water (Y), or only space heating (N). If the specific amount of energy used for domestic hot water consumption could be determined, it is expressed as a relative number of the total energy use based on energy measurements during the last heating season, October 2010-March 2011. The sixth column shows whether the electrical stand-by losses of the heat pump unit are taken into account or not. The importance of these stand-by losses is discussed in the next part of the paper.

DISCUSSION AND RESULT ANALYSIS

In the second last column of Table 1 the COP is shown. The test conditions (between brackets) are the same as those shown in the second column. These COP values are published by manufacturers and will be compared to the performance of the heat pump system in real circumstances. The last column specifies the SPF, as defined before.
Overall, the SPF of geothermal heat pump systems varies in the range 2.8-4.0. The worst performing geothermal heat pump system is appropriately sized for source, heat pump and heat emission system, but uses a heat pump prototype which was not yet proven. This is most likely the reason of the lower SPF.
Fig. 1 shows a parity plot of the published COP data and the measured SPF data, indicating a large deviation between both. The water/water heat pump (empty diamond symbol on Fig. 1) shows a large difference because of its beneficial COP test conditions (high source temperature) and the neglection of the energy consumption of the source pump in the COP test. In the field test source pump powers between 600 and 850 W were measured, which is a substantial fraction of the compressor power and therefore an important reason for the difference between COP and SPF. This comparison proves that, at least for geothermal heat pump systems, it is hard for consumers to choose between different manufacturers based on performance data in test conditions. By advertising this single COP value a too high expectation is created on the consumers' side.
For air source heat pumps a variation in SPF values is observed within the range 2.5-3.7. One of the lower SPF values of 2.5 can be explained by the large amount of DHW-consumption. For the other low SPF value no explanation is found. Two of the three best performing air source heat pumps only deliver heat for space heating, while the third also produces domestic hot water. This heat pump is sized according to the Code of Good Practice (ANRE 2005), while the heat emission system is heavily oversized. As a consequence, the heat pump works much of the time in better performing part load conditions. Because this heat pump is only tested for half a year, dominated by space heating (and thus not taking into account the high fraction of DHW production in summer), the yearly performance of the heat pump will probably be lower (about 0.1). Also air source heat pumps exhibit a large difference between COP catalogue data and real SPF data. The same conclusions as for geothermal heat pump systems can be formulated here, although the test conditions for air source heat pump are more standardized and therefore air source heat pumps are more grouped in the parity plot on Fig 1. To interpret the monthly performance of the air source heat pumps in more detail, the monthly average outdoor temperature of Uccle (Belgium) is plotted in Fig 2. The two coldest winter months were January and December 2010. From May/June to August/September 2010 less heat for space heating is necessary because of higher average outdoor temperatures. The

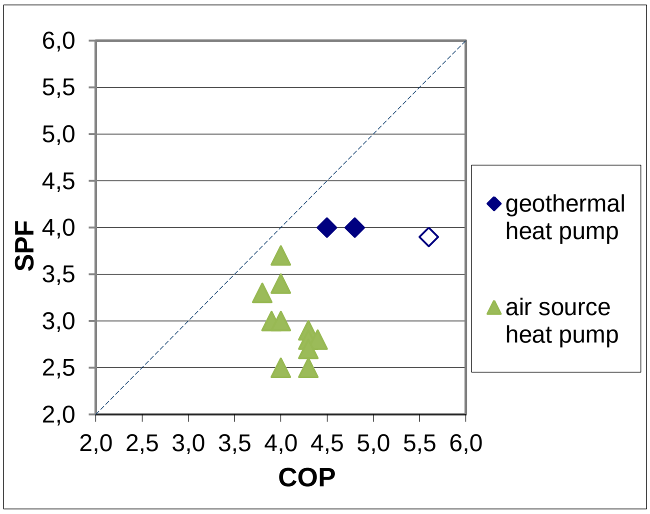

Figure 1: Parity plot of COP catalogue data and measured SPF data

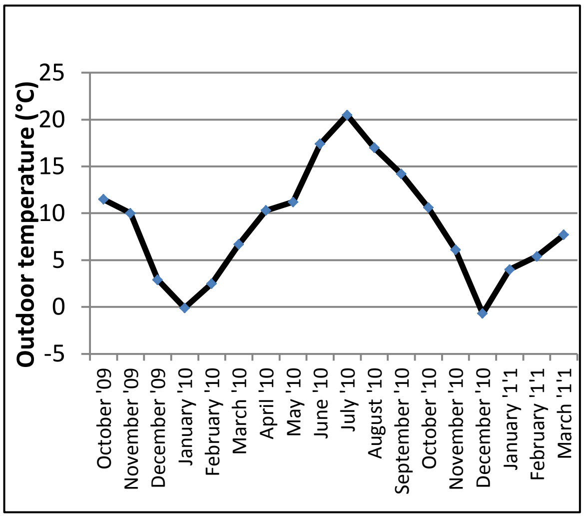

Figure 2: Average monthly outdoor temperature Uccle (Belgium)

heat delivered by the heat pump in these months is mainly for domestic hot water consumption. More detailed analyses can be made by combining Fig. 2 and Fig. 3.
The bars in Fig. 3 represent the number of monitored air source heat pump systems. The black line indicates the average monthly performance factor (PF) of all heat pump systems tested during the respective months. The dotted lines represent the 90% confidence interval for the monthly PF based on the student t-distribution of the monitored data. The most striking conclusion from the average performance curves is the low performance in summer for air source heat pumps.

Heat pump type	Installed heat pump power (kW)*	Occupied surface (m^2)	Sample period	DHW (Y/N)	Electric stand-by losses measured (Y/N)	COP *	SPF
W/W	17.1 (10-35)	256 F	Oct 09-Ma 11	Y 6.1%	N	5.6 (10-35)	SPF2 = 3.9
H.B/W	8.8 (0-35)	220 F	Oct 09-Ma 11	Y 3.9%	N	4.8 (0-35)	SPF1 = 4.0
V.B/W	15.4 (0-35)	250 F	Nov 09-Dec 10	Y	Y	4.5 (0-35)	SPF2 = 4.0
V.B/W	16 (0-35)	290 W	Nov 09-Ma 11	N	Y	prototype	SPF2 = 2.8
A/W	16.1 (7-35)	200 F	Nov 09-Ma 11	Y 5.3%	Y	4.3 (7-35)	SPF2 = 2.9
A/W	16.1 (7-35)	280 F	Nov 09-Dec 10	Y 2.2%	Y	4.3 (7-35)	SPF2 = 2.5
A/W	16.2 (7-35)	350 F	Oct 09-Dec 10	Y	Y	3.9 (7-35)	SPF2 = 2.8
A/W	9 (2-35)	266 F	Ma 10-Ma 11	N	Y	3.8 (2-35)	SPF1 = 3.3
A/W	8 (7-35)	200 F	Oct 09-Ma 11	Y 8.1%	Y	4.4 (7-35)	SPF2 = 2.8
A/W	12 (7-35)	160 W	Ma 10-Ma 11	Y 6.0%	Y	4.3 (7-35)	SPF2 = 2.7
A/W	10.3 (7-35)	115 N	Oct 10-Ma 11	N	Y	4.0 (7-35)	SPF2 = 3.4
A/W	16.2 (7-35)	180 N	Oct 10-Ma 11	Y 8.4%	Y	3.9 (7-35)	SPF2 = 3.0
A/W	13.7 (7-35)	316 F	Oct 10-Ma 11	Y 5.0%	Y	4.0 (7-35)	SPF2 = 3.7
A/W	8.0 (7-35)	148 W	Oct 10-Ma 11	Y 5.3%	Y	4.0 (7-35)	SPF2 = 3.0
A/W	6.5 (7-35)	127 W	Oct10–Ma 11	Y 34.8%	Y	4.0 (7-35)	SPF2 = 2.5

*Table 1: SPF of different domestic heat pump systems. F= Flanders region, W= Walloon region, N= The Netherlands; SPFi refers to SPF calculated according to equation i. * test conditions given between brackets in °C*

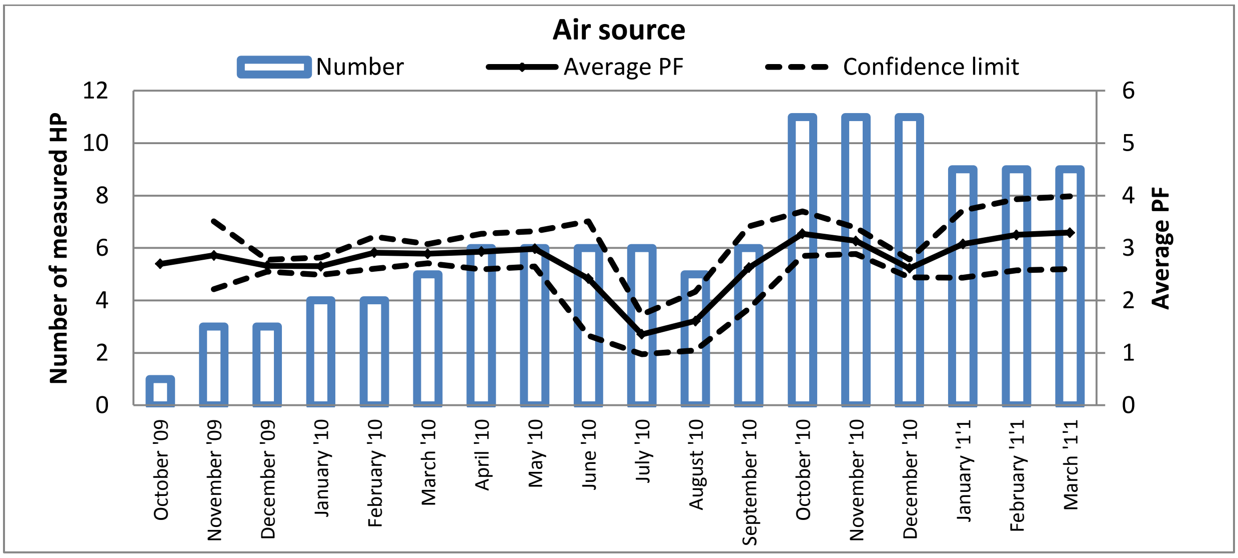

Figure 3*: Average monthly PF for air source heat pump systems; bars: number of tested heat pump systems; black line: monthly PF; dotted lines represent 90% confidence interval for PF*

This trend can be explained by the relatively large energy demand for domestic hot water, which requires higher condenser temperatures compared to space heating. The same conclusion yields for geothermal heat pump systems. A second important reason is the electrical stand-by loss of the heat pump system. It can lower the monthly performance factor by up to 0.7. All air source heat pumps take the electrical stand-by loss into account. The influence on the SPF is, however, negligible, because the energy need for domestic hot water in summer is much lower than the energy need for space heating and domestic hot water production in winter. Air source heat pumps are, evidently, much more sensitive to outdoor climate. This is clearly visible in the black performance curve for the second winter presented in Fig. 3 (by the dip in the PF curve for December 2010 corresponding to a low average outdoor temperature (see Fig. 2)). The start and end of the heating season varies between the different cases, which is visible from the larger confidence intervals for June 2010 in the air source heat pump cases. In these months some heat pump systems are working in combined space heating and domestic hot water production regime, while others operate in domestic hot water production summer regime.

The average SPF of all monitored geothermal heat pump systems is 3.7. The average SPF for air source heat pumps is calculated for the whole group of heat pump systems on the one hand and for the 6 heat pumps which were monitored for at least one year on the other hand. The SPF values are respectively 3.0 and 2.8.

Comparison with foreign studies

Comparing the results of this field test to similar, recent foreign field tests (Fraunhofer 2011) the same trends can be derived. The average SPF (AZ3) of geothermal heat pumps in the Fraunhofer study is 3.75. This agrees with the average performance of geothermal heat pumps in this field test, 3.7. The same conclusions are obtained for air source heat pumps. Compared to the German field trial, similar SPF's were measured. The total system performance (AZ3) of the measured cases is 2.74. The average SPF of the Flemish field test is 2.8.

CONCLUSION

This research work forms a very important source of information, since it provides the global system performance of Flemish domestic heat pump systems in real life. The results prove that well installed heat pump systems can deliver large energy savings, however badly installed heat pump systems perform worse than expected and as a consequence a significant

part of the potential energy savings may be lost. Good system design and installation, accounting for the interaction between, heat pump, heat source, storage system and building with heat distribution and emission system, are thus of utmost importance. Comparing COP catalogue data and monitored SPF values, highlights large differences. These differences can be minimized by designing, sizing and controlling the global system (heat source, heat pump, storage tanks and heat emission system) appropriately.
Furthermore, domestic hot water production occurs at lower performance factors caused by the requirement for higher condenser temperatures and higher electrical stand-by losses of the system. This effect is more pronounced during summer since this period is characterized by a higher fraction of DHW production relative to space heating. The lower performance in summer does not have a substantial impact on yearly performance of the heat pump system because the energy demand for space heating in winter is much higher compared to the energy demand for DHW production in summer, for the building cases considered in this study. For extremely low energy buildings or passive buildings the global contribution of DHW production may become more important.
Finally, these results have to find their way back to the design phase. First steps have already been taken by using the results into a Code of Good Practice for Heat Pump Systems in the Residential Sector.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support of the Flemish Agency for Innovation by Science and Technology (IWT) through funding the Collective Research Project WP-DIRECT (IWT-CO-070662-WP-DIRECT). Moreover, the constructive discussions with the companies are highly appreciated.

REFERENCES

EC Directive 2009/28/EC on the promotion and use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Available from http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF, consulted on April 15, 2011

EHPA newsletter issue n°3, November 2010. Available from http://www.ehpa.org/uploads/media/2010_3_ehpa_newsletter_01.pdf, consulted on May 3 2011

Fraunhofer, 2010: Wärmepumpen Effizienz, Messtechnische Untersuchung von Wärmepumpenanlagen zur Analyse und Bewertung der Effizienz im realen Betrieb, Available from http://wp-effizienz.ise.fraunhofer.de/download/wp_effizienz_endbericht_kurzfassung.pdf, consulted on March 15, 2011

GSHPA, http://www.gshp.org.uk/faqs.htm#FAQ20 consulted on April 30, 2011

Heliotherm, 2011:http://213.33.76.126/heliotherm.com/livedaten/live.asp, consulted on April 10, 2011

Inalli M, Esen H. Experimental thermal performance evaluation of a horizontal ground-source heat pump system. Applied Thermal Engineering 24 (2004) 2219–2232

Lund Jet al. Geothermal (ground-source) heat pumps, a worldwide overview. GHC bulletin, September 2004

Ministerie van de Vlaamse Gemeenschap, afdeling ANRE, code van goede praktijkvoor de toepassing van warmtepompsystemen in de woningbouw, 2005

ODE, 2011: http://www.ode.be/warmtepompen/de-cijfers/potentieel, consulted on 09-04-2011

EN 15316-4-2, Heating Systems in Buildings–Methods for the Calculation of System Energy Requirements and System Efficiencies-Part 4.2 Heat Pump Systems, CEN, Brussel 2009

prEN 15450, Heating systems in buildings - Design of heat pump heating systems, CEN, Brussel, 2007

Thercon, 2011: www.Liveheatpump.be, consulted on April 10, 2011