EFFECTS OF ELECTRONIC EXPANSION VALVES ON HEAT PUMP PERFORMANCE

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Abstract: The use of electronic expansion valves in heat pumps allows a preciser run of the superheat of the refrigerant. Enhanced new products for this purpose are now available. With them, the designer can define the cycle continuously (stepless) compared with today's compromise using fix adjusted thermostatic expansion valves. Over the whole range of application the delivered capacity is piloted. Of special interest are situations as for example air/water heat pump with air inlet temperatures above + 15 °C. The control of the electronic component is to integrate in the heat pump control procedure in order to guarantee an optimized run of the whole heat pump system with all its changing data. The paper shall present the latest developments and first test results, how and how far COP's and especially SPF (seasonal performance factor) can be improved by the use of electronic expansion valve. The research shall also reduce the application cost of the electronic expansion valves in order to allow the wide application also in small heat pumps.

Key Words: ***heat pumps, electronic expansion valve, efficiency***

1 INTRODUCTION

In the late nineties the small heat pumps till 100 kW thermal output made a significant increase of overall performance by applying scroll compressors and new refrigerants as for example R407C, after 2000 followed by EVI (enhanced vapor injection) refrigerant-cycles to provide output temperatures of + 65 °C. The today's potential to increase the performance of small heat pumps is to find more and more in the fine and dynamic tuning of the refrigerant cycle. There are different elements to consider for this dynamic run of the heat pump, for example variable compressor output, variable speed of ventilator, variable speed of circulation pumps. The electronic expansion valve is one of them. It's main influence is focused on the efficiency of the refrigerant cycle. For the individual components as well as for the interaction between them electronic control and adapted software is necessary. In other words: the new generation of small heat pumps is characterized by dynamic operation and a dynamic refrigerant cycle. These heat pumps will be able to modulate the capacity similar as the capacity modulating wall hung boilers. And they shall be even more efficient over the whole year, having a higher seasonal performance factor.

2 GENERAL EFFECTS OF ELECTRONIC EXPANSION VALVES (EEV)

With the expansion valve, the refrigerant flow through the evaporator and its complete evaporation shall be controlled. The heat pump refrigerant cycle achieves its maximum efficiency, when a minimum and stable superheat before the compressor is granted [1]. Ideal would be dry evaporation with superheat 0 K, but in order to have a stable run a superheat of around 5-8 K is often applied. In the following explanations, the electronic expansion valve (EEV) is compared with the thermostatic expansion valve (TEV).

2.1 Adaptation to changes: response time

The adaptation after changes, for example of the heat load or heat demand, is visible by the oscillation around the targeted superheat. The EEV reacts with a shorter time period and smaller amplitude of the oscillation than the TEV. This is shown for the restart phase of a refrigerant cycle with R407C after a long stop in the experiments and diagram of Aprea/Mastrullo [2], see Figure 1. The same difference appears after other changes of the evaporator heat load.

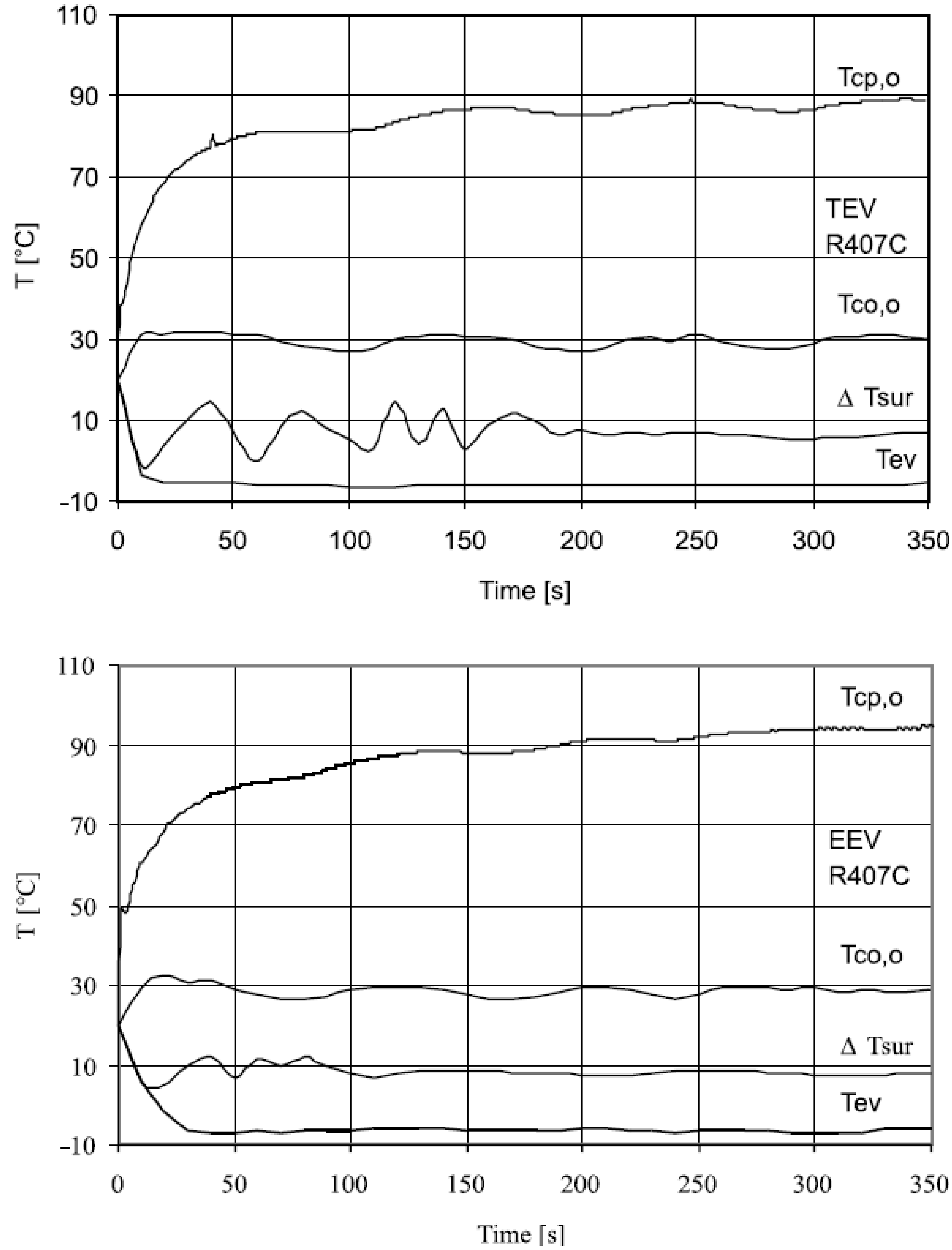

Fig. 1: Dynamic response of superheat (ΔTsur) after start [2]

2.2 Stable superheat in all operation conditions of heat pump

2.2.1 Stable superheat in the whole range of evaporator heat load

The TEV is adjusted to the superheat (sh) at a certain operation point, for example to an outside temperature (Te) of minus 5 or 7 °C for an air/water heat pump. Due to it's control characteristic, the TEV only in small range able to keep the superheat stable, see result of measurements in a heat pump circuit changed from TEV to EEV in Fig. 2.

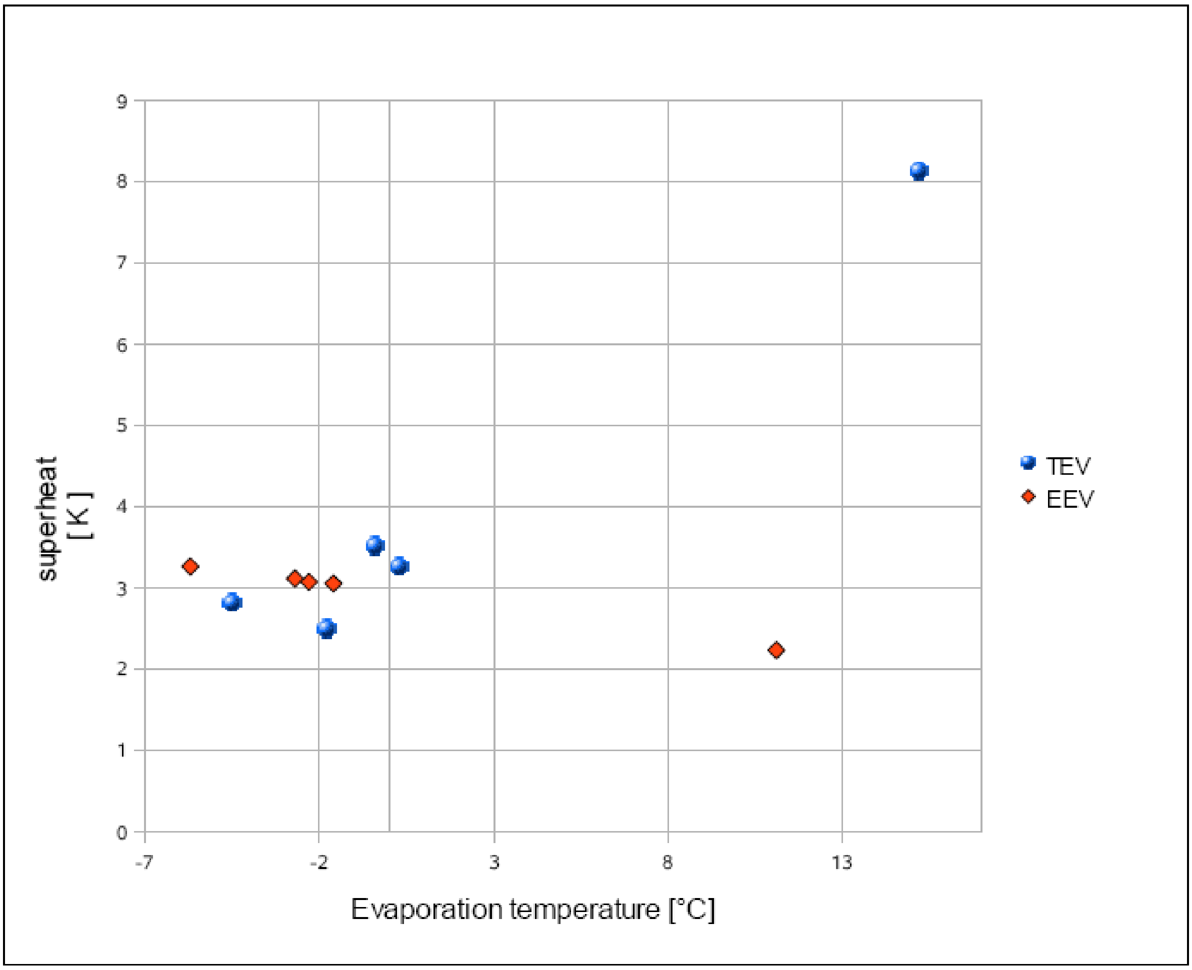

Fig. 2: Test results show the difference between TEV and EEV

The EEV however optimizes continuously the refrigerant flow rate and reaches a stable superheat under different heat load conditions of the evaporator. Fig. 3 shows the typical characteristic of an air/water heat pump in middle Europe with TEV and EEV. The further away from the standard operation point, the bigger the difference between the two valve versions. Thus, heat pumps with wide range of heat load conditions of the evaporator can take much profit using an EEV.

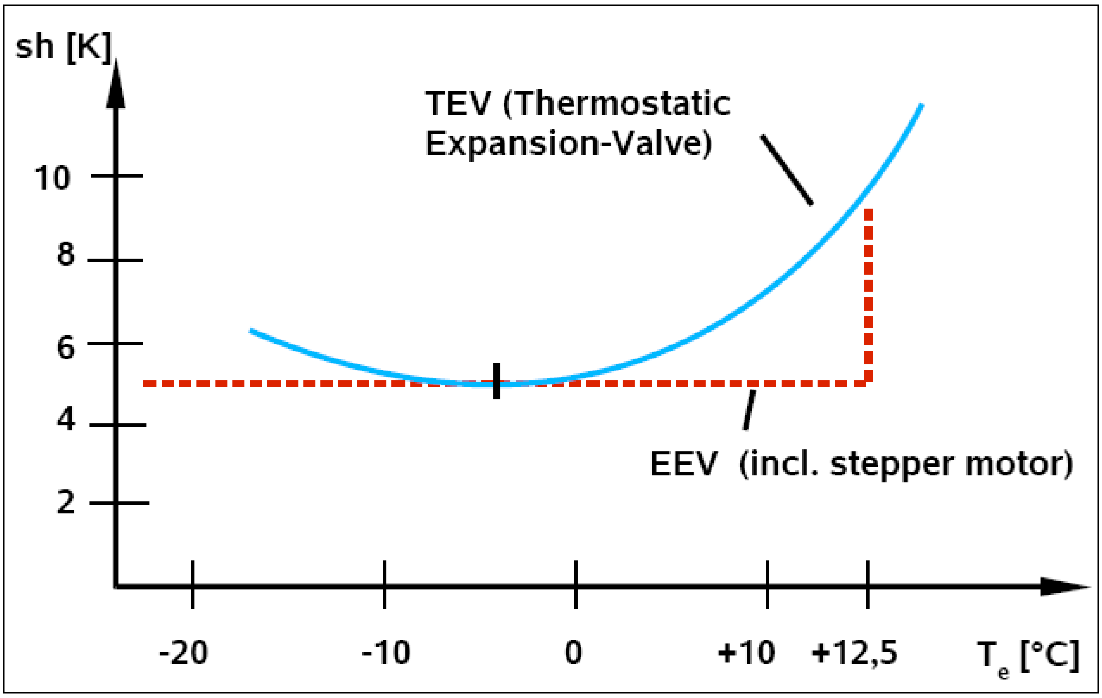

Fig. 3: Superheat as a function of outside temperature for an air/water heat pump

2.2.2 Stable superheat for variable output capacity modulation

In another operation mode the stabilisation of the superheat is of special interest: when we operate with part load, especially when we modulate continuously the output capacity from around 20 to 100 % in a ratio of 1:5. Using a TEV, the reaction on the superheat is proportional to the output capacity $Q_{o.}$ At the smallest part load the superheat must be adjusted and increase proportionally when full load, for example from 5.5 K to 11 K. That means, the superheat at full load mode is not optimal and we are far away from the maximum efficiency at this operation point. For operation with part load for variable output capacity, the EEV is able to adapt the refrigerant flow in order to keep the superheat stable on the calculated value, for example 5 K. In Fig. 4 the difference of the superheat between TEV and EEV is evident. The influence on the COP (coefficient of performance) in periods with high demand (full load or near to full load) is especially significant. The stabilisation of the superheat in every operation below 100 % load, in order to reach the particular maximum efficiency, is of high importance because of the specific higher electricity consumption of the compressors in part load operation.

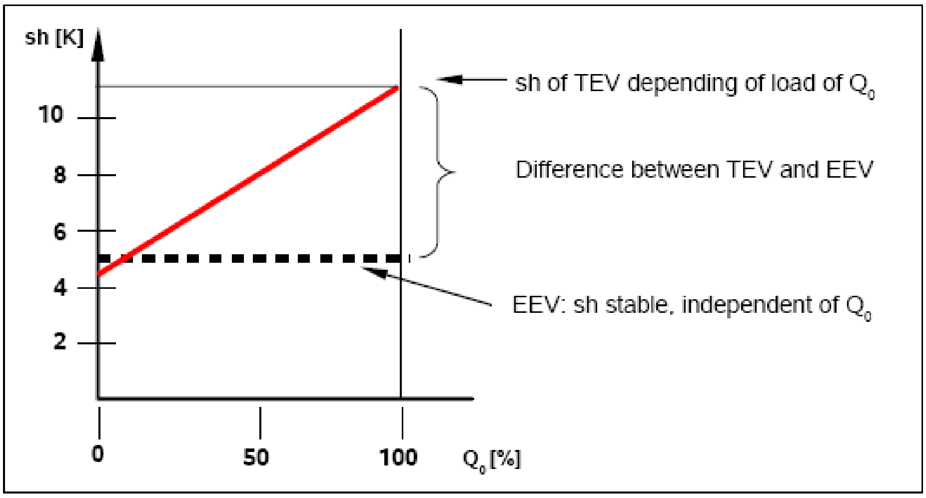

Fig. 4: Superheat (sh) as a function of variable heat production realized by part load operation (modulation of output capacity Q_o)

3 APPLICATION FOR AIR/WATER HEAT PUMPS

3.1 Different demands result in different requirements

Heat pumps can provide different services: heat in the winter season, heat in the transient seasons, heat for domestic hot water production, heat for swimming pools, space cooling. Here the case study is an air/water heat pump with the purposes space heating and production of domestic hot water.

3.1.1 **Special requirements of space heating**

The air/water heat pump works more powerful and efficient the warmer the used outside air is. However: the warmer the outside air the lower the heat demand for the space heating is, see Figure 5.

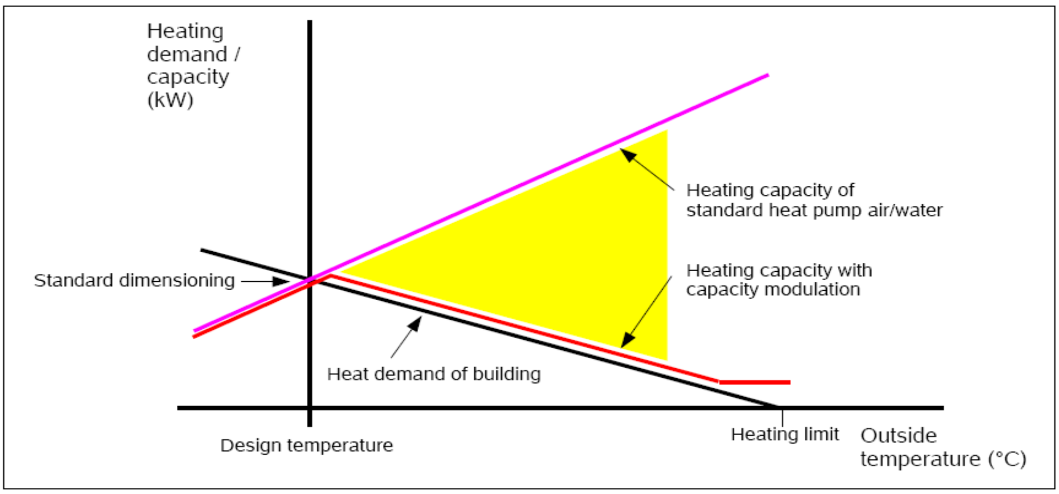

Fig. 5: Requirements of space heating for an air/water heat pump

This contradiction and the high volatility of the outside air are reasons, why the design of air/ water heat pumps requires far more effort and know how than water/water heat pumps. Both, the standard and the capacity modulating version of the air/water heat pump take advantage of the EEV. The standard type because of the wide range of the outside temperature (see 2.2.1), the capacity modulating type because of proportionality of superheat and Q_o of TEV (see 2.2.2).

3.1.2 **Requirement for domestic hot water (DHW) production**

Domestic hot water (DHW) should be produced as quick as possible and the temperature in the DWH tank should be achieved as near as possible to the maximum temperature of the heat pump. Limiting is the heat exchanger capacity between heat pump and hot water. For a standard air/water heat pump the calculation of the heat exchanger must consider the capacity in warm seasons to have high pressure stops under control. During warm season, the difference of the superheat for DHW production is shown in Fig. 6. EEV is of advantage as the distance to the standard operation point creates for TEV an important ΔT to ideal superheat of 2 to 5 K.

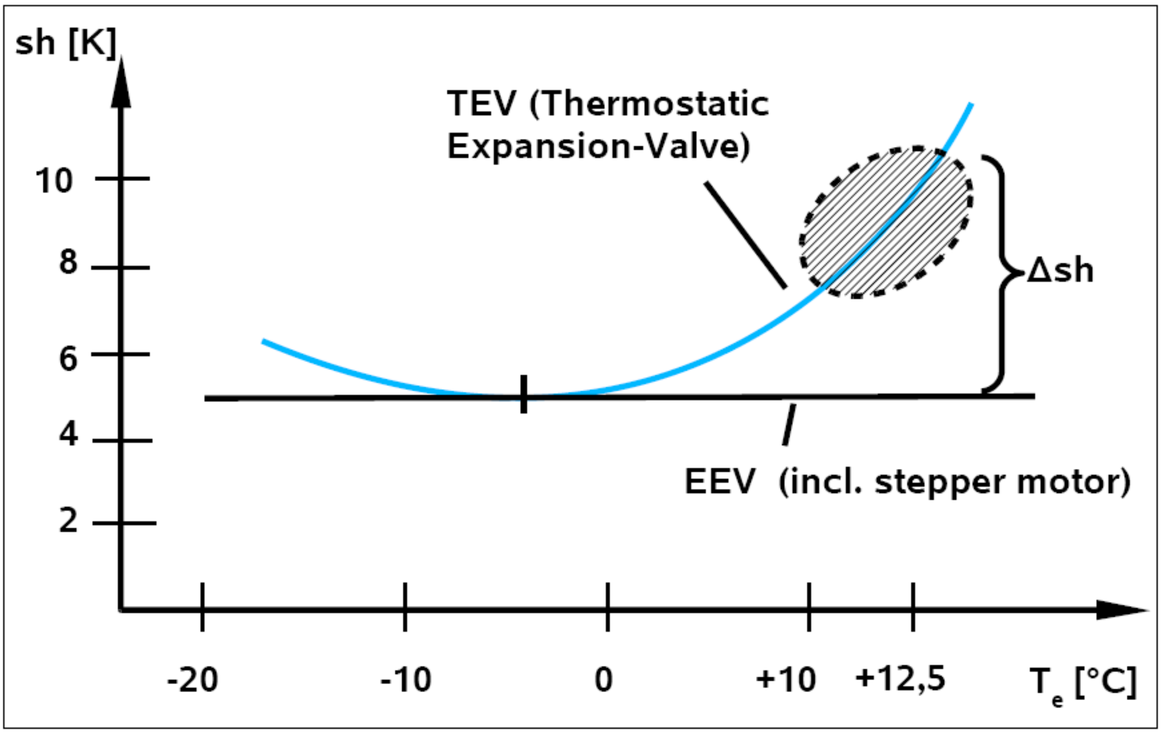

Fig. 6: unfavorable deviation of TEV for DHW in warm seasons (T_e > 10°C)

For the requirement to produce DHW as quick as possible, standard and capacity modulation version heat pump apply the full capacity or the calculated part load according to the heat exchanger. The second requirement to produce the maximum possible temperature in the DHW tank is given for the standard version by the Delta T of the mentioned heat exchanger. In the case of the capacity modulation type, at the maximum temperature can be approached with reduced ΔT by reducing step by step the capacity to the minimum part load. Therefore two advantages of the EEV help in this stage to optimize the efficiency of the heat pump: the better response time to changes, see 2.1, and the stable superheat during the modulation, see 2.2.2.

3.2 Effect on COP and SPF for air/water heat pumps

The effects of EEV on COP and SPF for air/water heat pumps are various. They are based on the three items of chapter 2: response time on changes, wide range of operation points and rate of capacity modulation.

3.2.1 Static comparison of COP

For the COP the comparison of single operation points at 100 % load is shown in Table 1. This static comparison shows differences from 2.2 to 17.5 %. The smallest difference occurs in the standard operation point (-7 / 45) , where the TEV is adjusted to the minimum superheat. The standard type values have been measured according to the previous standard EN 255. As the new standard EN 14511 allows strictly only a ΔT of 5 K for the heat delivery, the calculated difference in COP is as reported or higher.

COP for respective operation point (°C), according to respective EN	Standard type with TEV, ca. 9 kW, EN 255, [3]	Capacity modulating type with EEV, ca. 2-9 kW, EN 14511, full load	Difference in COP (%)
2 / 35	3.3	3.8	14,8
-7 / 35	2.7	2.8	3.7
7 / 35	4.0	4.7	17.5
-7 / 45	2.25	2.3	2.2
2/ 45	2.7	3.0	11.1

Table 1: Comparison of COP between TEV and EEV equipped air/water heat pumps

3.2.2 Comparison of SPF

In the comparison of SPF the dynamics of the use during a year are considered. The SPF can be calculated or simulated with standardised use under standardised conditions. In the following the German calculation method for application according to VDI Guideline 4650 [4] is done between the same air/water heat pumps as in 3.2.1. The use of EEV helps to reach a significant better SPF for the calculated place Frankfort (Germany), see Table 2.

SPF according [4] for respective type with TEV or EEV, max. flow temp. +35 °C	Standard type with TEV, ca. 9 kW, EN 255, [3]	Capacity modulating type with EEV, ca. 2-9 kW, EN 14511, full load	Deviation of SPF (%)
SPF	3.77	4.33	+ 14.8

Table 2: Comparison of SPF between TEV and EEV equipped air/water heat pumps

The calculated SPF comparison according to [4] above includes not the DHW production, but only space heating. It does also not consider part load operation of the heat pump. Therefore the influence of the part load operation on the SPF is not visible. For that, other algorithm for the simulation of SPF for capacity modulating heat pumps with EEV must be used. Respective field measurements are set up.

4 CONCLUSIONS

The main advantages concerning the efficiency of the EEV compared with the TEV are in three items: quicker response time for changes, stable superheat in the whole range of operation conditions, stable superheat for full as well as part load operation. The effect on the COP and SPF for air/water heat pumps with high dynamic operation conditions is significant. The more the operation conditions vary, the more the advantages of EEV get measurable. Under stable or quasi stable conditions, for example of a ground water heat pump with constant ground water temperature, the effect of TEV on efficiency is similar or only slightly lower. The evaluation of the effect of capacity modulation in heat pumps needs further attention.

5 REFERENCES

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