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EFKOS – Effizienz kombinierter Systeme mit Wärmepumpe

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Introduction / Goals

The European Union as well as Switzerland, both aim for higher energy efficiency and increased use of renewable energies to reach their respective goals in energy efficiency and reduction of CO_2 emissions. The EU's Energy related Products (ErP) directive is the most important initiative by the EU to improve energy efficiency by 20% by the year 2020 [1]. In the building sector, this regards amongst others heat pump systems for space heating, space cooling and domestic hot water (DHW) production. To prove the efficiency of such units, internationally harmonized calculation methods for assessment are required. Yet there are such tools for conventional heat pumps, but as new technologies such as inverter driven (also known as variable-speed) compressors for electrical heat pumps -for both, single and combined systems (systems for space heating/cooling and alternate or simultaneous DHW production)- emerge, a knowledge gap opens. These units continuously adjust their heating power output to the actual demand, while conventional heat pumps usually rely on an ON-OFF mode when demand decreases. Most available standards do not cover variable capacity heat pumps by now.

While power control may lead to a lower overall performance of the unit alone, the efficiency of an entire heating system is strongly depending on the demand side, basically the sink-temperature levels. This means that the whole system, including building quality, emission system and weather must be taken into account for a meaningful assessment. It's a common practice to calculate seasonal performance factors by a model, assigning different operating conditions of the heat pump to different outdoor-temperature classes (bin model). But the limits of application of such a method are unclear, especially if applied to ultra-low energy buildings.

It's one of the main goals of this project to elaborate and verify a calculation process for the assessment of continuous control heat pump systems. The methodology should be widely accepted by manufacturers, and preferably based on already available data such as EN 14511 testing points [2]. It's also intended to prove the reliability of the bin methodology and –if found to be necessary– suggest other calculation models.

Work accomplished and Results

In a first step at the beginning of this project, existing standards have been reviewed. Most of them do not take special care of continuous capacity control HP units as long as no rated performance data is available. EN 15316-4-2 [3] considers part-load conditions for ON-OFF types of heat pump units by regarding stand-by power consumption in OFF-mode, which decreases overall efficiency. Since the beginning of the project, the European standards EN 14511:2012 and EN 14825:2012 reached their final state. EN 14825 [4] deals about the calculation of seasonal efficiencies of fixed and variable speed heat pumps. The standard introduces a formula on how to handle part-load conditions for fixed speed heat pumps by a calculation process based on rated performance data from EN 14511:2012 by introducing a so called «degradation coefficient». This coefficient describes efficiency losses due to ON-OFF cycling by considering power consumption in the compressor-off state. If it is not known from measurements, the standard defines default values to be used. This formula is referred to in ISO/DIS 13612-2 [5], the only standard where continuous power regulation heat pumps are taken into account by a certain extent, but the standard is still under development. From all reviewed standards, only EN 14825 and ISO/DIS 13612-2 cover cooling modes.

The Swiss standard SIA 384/3 [6] has finally been published in spring 2013. The standard fills the gap between calculation for building energy demand and resulting final energy consumption for various heat generators. Regarding heat pumps, it is based on EN 15316-4-2 and thus does not contain information on how to handle capacity controlled units, but describes a method on how to deal with combined systems (e.g. HP/solar-thermal).

In a next step, two different methodologies for a COP matrix setup of ON/OFF controlled have been worked out and their accuracy has been verified by measurements of an air-to-water heat pump, although both methodologies are applicable for air-to-water, brine-to-water and water-to-water heat pumps. While a model “A” is based on linear interpolation/extrapolation (using an iterative process to calculate heating-power as a function of outlet temperature), a refined model “B” also regards effects of varying temperature spreads across the condenser due to changing mass flow rates by the approach of linearly interpolating exergetic efficiency, which can be estimated at rated points. While the deviation between calculated and measured COPs are kept below 6 % for model “A”, the mismatch decreases below 4 % for the more sophisticated model “B”. Model “B” leads to somewhat better results especially at higher outlet temperatures and low loads. As both models allow an accurate calculation of power and COP data for any point of operation (within limits), both models can be used to provide required input data for an EN 14825 seasonal efficiency calculation process from a minimum input data set of 6 test points according to EN 14511.

The development of EN 14825, especially its application for regulations within the framework of ErP directive and the planned energy label for heat pumps on the European market [7] has been followed tightly. Although not a member state of the EU, Switzerland’s market and Swiss manufacturers will also be strongly influenced by this development. Although not yet published in the EU's official journal, actual information indicates that labelling of heat pumps could become possible in the very near future, although it’s not expected to be required before 2015. In an international collaboration a web-based calculation tool, which generates the EU energy labels and technical reports (required for marketing approval purposes), has been developed and is now tested by manufacturers. This tool implements the aforementioned model “A” for the setup of the COP matrix and allows its calculation relying on EN 14511 measurement points (EN14511:2007 and 2011 editions). The tool is applicable for A/W, B/W and W/W heat pumps but is yet still under development. While variable capacity heat pumps are not readily implemented, this extension is planned as a next step.

The model “B” has been implemented and tested into the CARNOT Toolbox [8] of the Matlab/Simulink [9] simulation environment. Additionally to the description above, dynamic effects of the thermal inertia of both, evaporator and condenser have also been implemented. The model has been validated and has been used to test the lately published SIA 384/3 standard, concentrating on solar/heat pump combination (Fig. 1). For this purpose, heating systems which are also designed to prepare DHW were set up, using a single family house according to the actual regulatory insulation level (A simplified model of the building described in [10]).

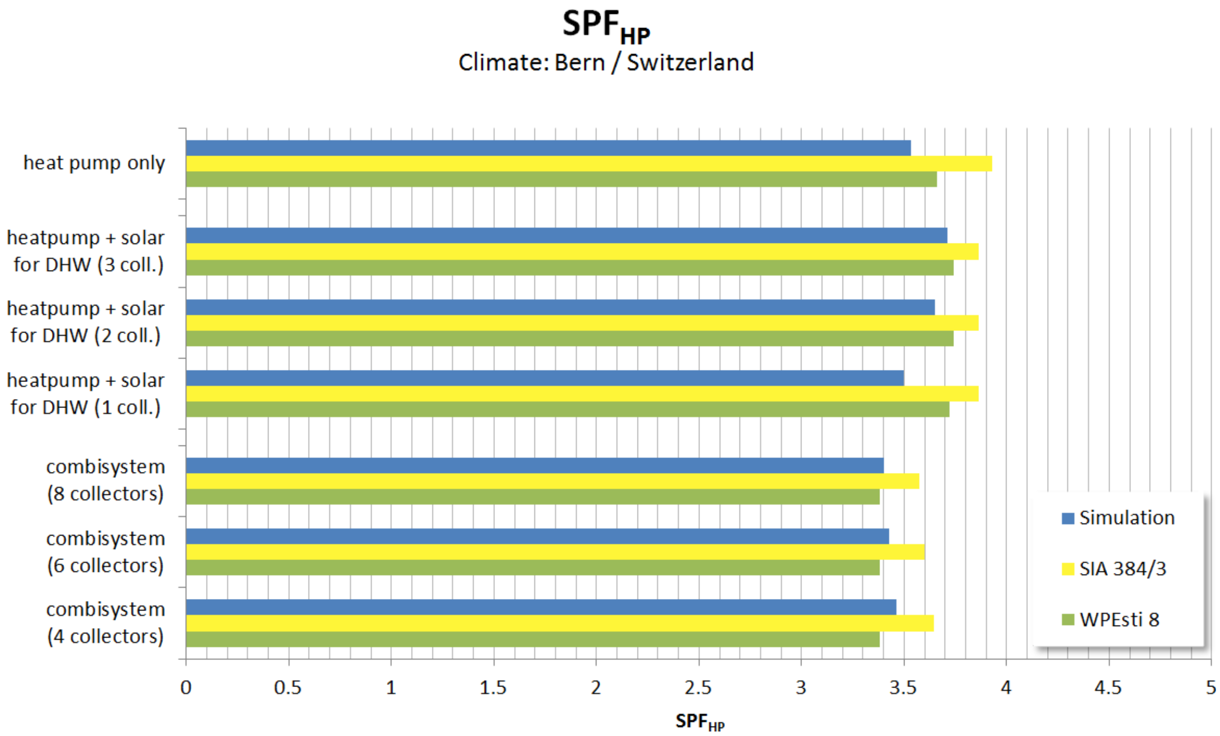

Fig. 1: ***Comparison of detailed SIA 384/3 calculation vs. simulation results of the heat pump SPF (COP boundaries, without circulation-pumps or stand-by operation) . A draft version of latest WPesti calculation tool has also been included in the comparison.***

Three variants for the heating system were set up, all based on an air-to-water heat pump: A simple heat pump only configuration, a heat pump that is supported by solar-thermal collectors for DHW preparation as well as a "true" combisystem using a heat pump and solar-thermal array for both, heating and DHP preparation purposes. In any case, the heat source for the heat pump is outdoor air. For both variants using solar-thermal energy, three collector field sizes (1, 2 or 3 collectors for DHW support resp. 4, 6 or 8 collectors for DHW and space-heating support) were simulated, while typical heat storage sizes of 500 l ... 1000 l were used. The building is located in Bern as representative city for the climatic conditions of the Swiss plateau with moderately low winter temperatures.

A good coincidence of all calculations outputs is obvious from the comparative results in Fig. 1. What cannot be seen from this graph is the quality of the control strategy, which strongly influences efficiency and energy consumption of the heat pump. In fact, keeping indoor air temperatures as close as possible to standard conditions -those assumed in SIA 384/3 calculation- makes out a good portion of the close match between simulation results and standard calculations in Fig. 1, especially for the heat pump only variant: The operation of the floor emission system was controlled by a simple indoor temperature sensor with a setpoint of 20 ºC. With the exception of the combisystem, operating times of the floor emission system circulation pump fall together with the on-off controlled heat pump operation (space heating mode). In any case, the indoor temperature is held very tight at 20 ºC throughout the heating season in all simulations, while in real situations indoor temperatures are rather in a range of 21 ºC … 24 ºC, thus leading to lower efficiency values and thus a higher deviation from standard calculations.

Additional evaluations of the simulation results show that stand-by power makes a major contribution to the overall electricity consumption. A constant 46 W power input during compressor-off times sums up to about 360 kWh per year, which is in a range of 14...28 % of the total heat pump electricity use. As with the implementation of directive 2009/125/EC the publication of such non-active power draw data will become mandatory in the EU, there is no hindrance to include these values in standard calculations.

In further investigations, the influence of uncertainties of the input parameters on the simulation results has been examined in a Monte Carlo analysis: Usually, all simulation input parameters such as setpoint temperatures to control the heat pump are assumed to be precise, while in reality these values are always afflicted by a certain amount of uncertainty - in the given example the measurement uncertainty of the temperature sensors. This may lead to somewhat higher or lower than the setpoint temperature levels, which finally end up in lower or higher efficiency values. When going from simulations to real buildings, such uncertainties can never be overcome. Therefore, even in a perfectly built house there will most probably always be some deviation between simulated and measured efficiency values. The analysis given here shows how precise a simulation can be when accounting these uncertainties of input parameters, ignoring all other real world influences such as built quality, actual weather conditions or user behaviour. The given numbers therefore show an upper limit of the precision that can be achieved. Fig. 2 shows the SPF_{HP} distribution of a heat pump system with solar thermal support for DHW preparation (Results cannot be compared to those given in Fig. 1 due to a slightly different system setup). For the analysis, system parameters such as heat-transmission coefficient of walls (U-values), energy gain through windows (g-value), mass flow rate for pumps, temperature setpoints and so on have been randomly varied by an amount of at most ±5% each in such a way that the probability distribution of the input parameter values follows a normal distribution. Having a special look at the heat pump, compressor tolerance has not been included in this analysis, although tolerances of COP values may be as high as 10% [11]. The outcome of the analysis show that the mean of the seasonal performance is at 3.29, but it may lie anywhere between 3.17 and 3.41, which is a ±4 % accuracy.

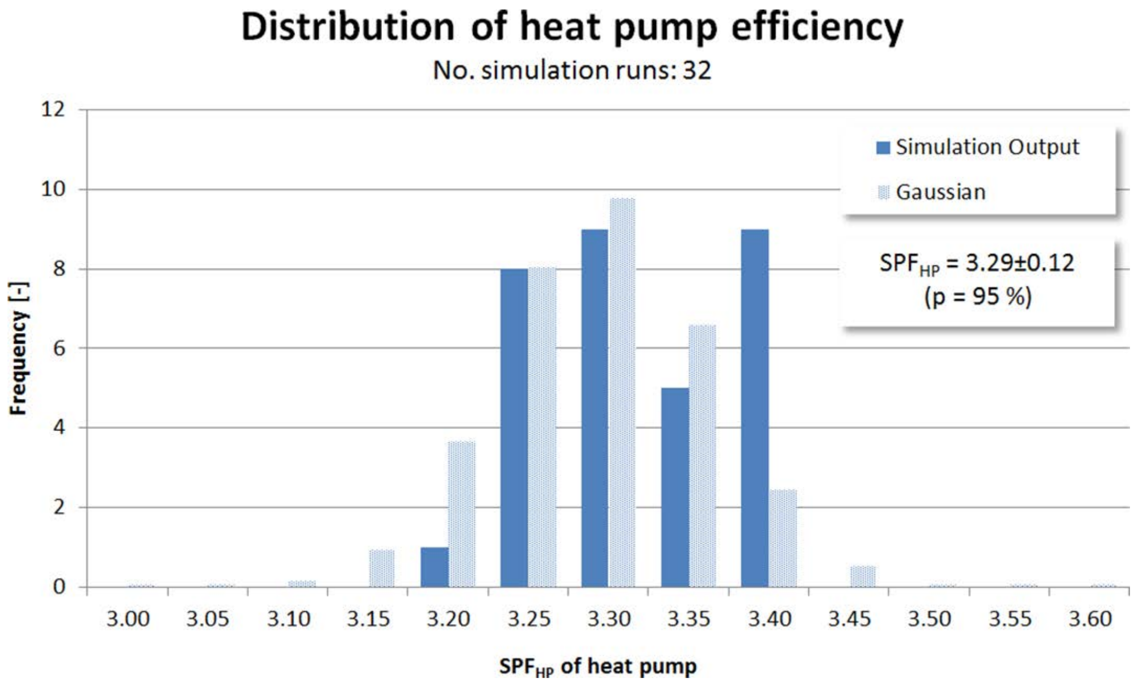

Fig. 2: ***Distribution of SPF_{HP} in a Monte-Carlo analysis. The figure shows simulation output as well as how an ideal Gaussian distribution would look.***

National and international collaboration

This project is part of the Swiss contribution to IEA-HPP Annex 39, «Method for testing and rating of residential HP and AC seasonal performance» which will be prolonged til autumn 2014. Additionally, international collaboration has been established with the German heat pump association (Bundesverband Wärmepumpen, bwp) representing major heat pump manufacturers.

National collaboration exists with the development team of SIA 384/3 «Heizungsanlagen in Gebäuden - Energiebedarf».

Outlook

The model developed so far now shows good results and with input data as available from heat pump manufacturers. It shall now be extended to variable capacity heat pumps. The validation process of this extension shall be based on measurements and/or simulations of a to-be implemented heat pump model at refrigerant level. The ongoing developments of related standards such as ISO 13612-2 and the implementation of European efficiency requirements will still be followed tightly.

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