REPORT ON SIMULATION STUDIES CONDUCTED IN THE FRAMEWORK OF THE IEA HPP ANNEX 43 (TASK D)

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1 INTRODUCTION

This report deals with several simulation studies of gas driven absorption heat pumps, which have been conducted in the framework of the IEA HPP Annex 43. Firstly, annual simulations with a model of a real prototype and with an alternative system design have been carried out, while different influencing factors have been taken into account.

Secondly, annual simulations have been compared simulatively to two standard/guideline based methods for the estimation of the seasonal efficiency of gas absorption heat pumps (VDI 4650-2, 2010 and EN12309-6, 2016).

2 ANNUAL SIMULATIONS: INFLUENCE OF SYSTEM DESIGN, BUILDING, HEATING SYSTEM, AND LOCATION

A simulation study was conducted in order to analyze the influence of the system configuration, the building type (heat demand), the heating system (flow temperature), and the climatic zone (ambient temperature) on the seasonal efficiency of gas driven absorption heat pumps. Initially, a prototype of a gas driven NH3/H2O absorption heat pump of the Austrian company E-Sorp GmbH was modeled by means of the software Engineering Equation Solver (EES, 2015). The cycle of this heat pump is based on the so called GAX (Generator-Absorber-Heat-EXchange) design, see Figure 1. The resulting simulation model was validated against measurement data obtained from experiments at the Institute of Thermal Engineering as well as against field test data over 18 days being provided by E-Sorp GmbH. Eventually, the validated simulation model was modified in order to represent another system design (solution heat exchanger SHX instead of GAX), see Figure 2. As a reference system for the evaluation of the saving potentials of those two heat pumps, a modern condensing boiler was considered. Its efficiency was modeled in a straightforward way as a linear function of the heating water’s return temperature.

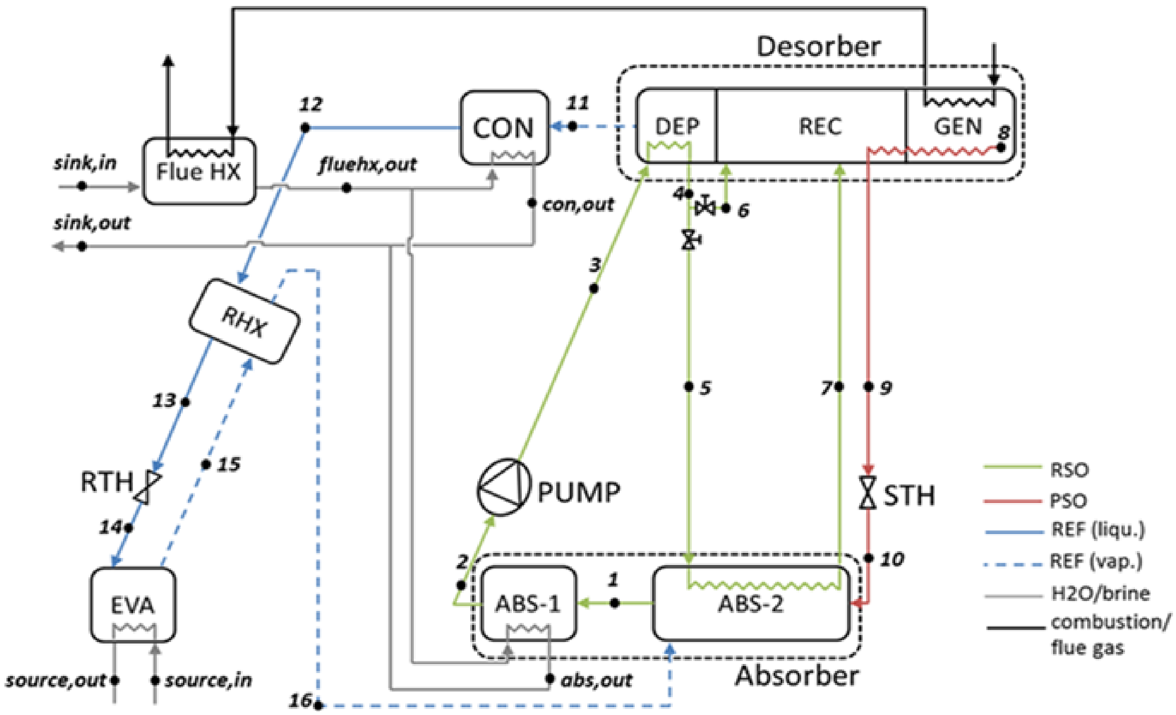

Figure 1: Schematic of the modelled GAX cycle

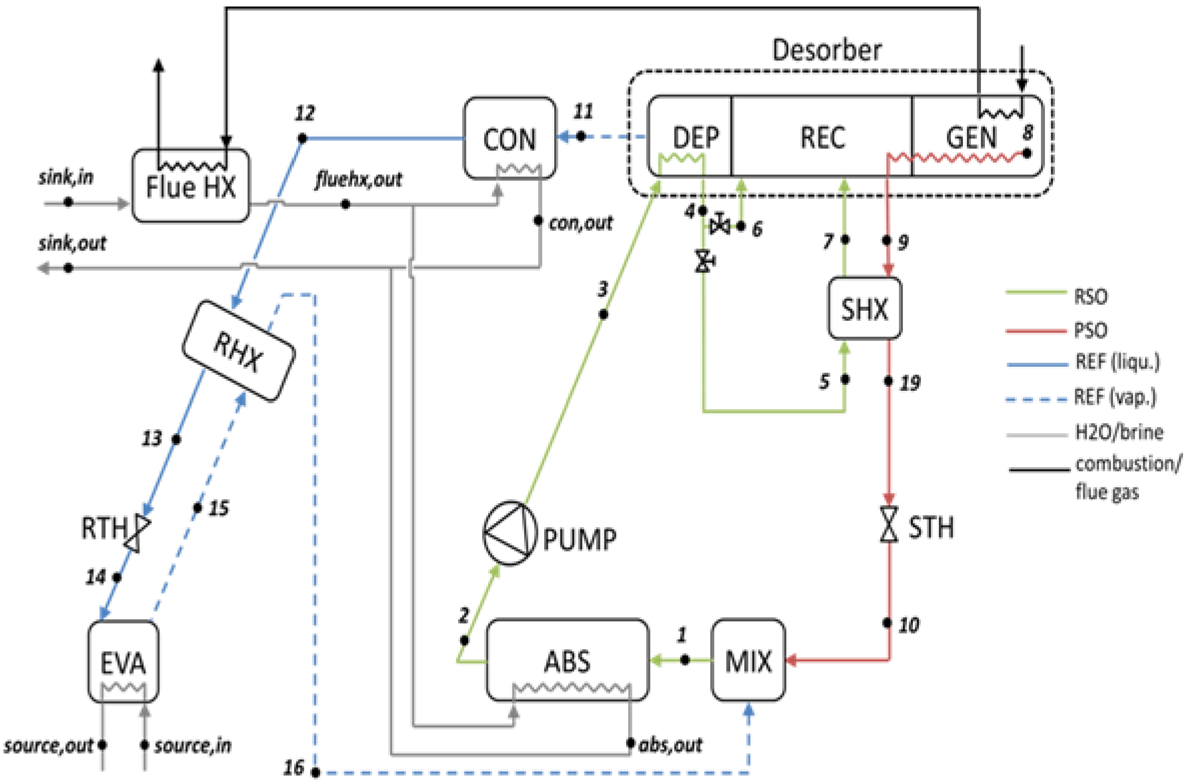

Figure 2: Schematic of the modelled SHX cycle

Climatic data sets from three different locations in Austria (Eisenstadt, Graz, and Innsbruck) have been used (Meteonorm, 2016). Since air source heat pumps were examined, the heat source temperature was computed as a function of the ambient temperature given by the climatic data. Two different heating systems (max. flow temperatures 35 °C and 55 °C) have been considered and the required flow temperatures have been computed from the ambient temperatures by means of linear heating curves. In order to obtain the heating load as a function of the ambient temperature, three different building models of buildings (127.3 m^2) with an annual heating demand of 45, 60, and 100 kWh/(m^2a) for the reference climatic conditions of Zurich have been used (SFH45, SFH60, and SFH100) (Heimrath und Haller, 2007). For every hour of the year, the required burner capacity depending on the ambient temperature, flow temperature, and heating load was computed by the EES-models. By summing up the heating load as well as the burner capacity over the whole year, the seasonal efficiency can be computed (by neglecting transient effects).

Depending on the system configuration (GAX/SHX) and the other influencing factors, the seasonal efficiencies of the absorption heat pumps (with regard to the lower calorific value) were between 1.436 and 1.672 and between 1.018 and 1.046 for the condensing boiler. There was no significant difference between the two cycle designs for heating systems with a max. flow temperature of 55 °C. However, for heating systems with a max. flow temperature of 35 °C, the GAX-design was clearly superior. On the one hand side, this is due to the fact that decreasing flow temperatures lead to increasing temperature overlaps between the ab- and desorption and hence to a more efficacious GAX effect. On the other hand side, decreasing flow temperatures lead to an increasing difference between the mass flow rates between rich and poor solution and therefor to an increasing temperature mismatch in the SHX, which in turn causes increasing exergy losses in that component. The influence of the location and the building type on the annual efficiency was relatively small. There were slight differences in the average ambient temperature for the three different locations and in the average flow temperature for different building types. Since those two temperatures influence the efficiency, those differences led to slight differences in the annual efficiencies.

The saving potential compared to the condensing boiler in terms of energy consumption, costs, and CO_2 emissions is 27 % in the worst case (GAX design, location Innsbruck, max. flow temperature 55 °C, building SFH45). This is equivalent to annual savings of 1380 kWh of natural gas, 95 EUR (assuming a gas price of 0.069 EUR/kWh), or 276 kg CO2 (0.2 kg CO_2/kWh). In the best case (GAX design, location Eisenstadt, max. flow temperature 35 °C, building SFH100) the saving potential is 37 % or annually 4242 kWh of natural gas, 293 EUR, and 848 kg CO_2, respectively, in absolute numbers. The seasonal efficiencies (SGUE_Hi) of both the gas heat pump and the condensing boiler for those worst and best cases are depicted in Figure 3. Note that the annual heating demand of the considered buildings is relatively low (especially in comparison to retrofit applications). Obviously the saving potentials in absolute numbers increases proportionally with increasing annual heating demands.

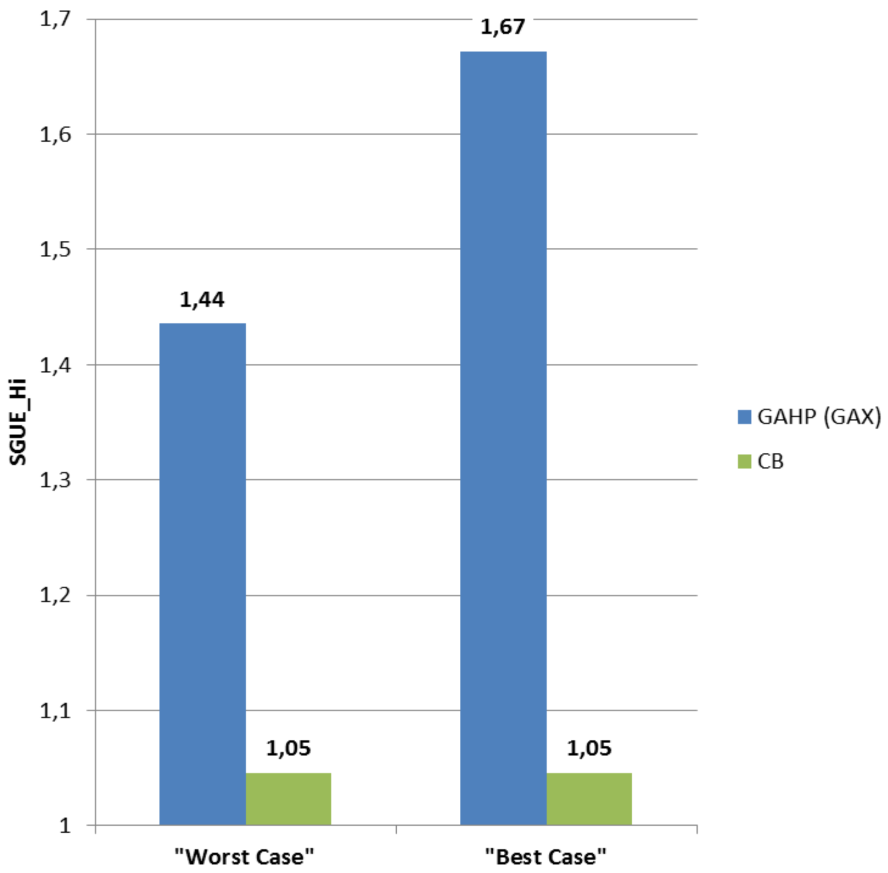

Figure 3: Annual efficiencies (SGUE_Hi) of the gas absorption heat pump (GAHP) and the condensing boiler (CB) for the worst and the best regarded case

3 COMPARISON OF DIFFERENT METHODS FOR THE CALCULATION OF SEASONAL PERFORMANCE MEASURES

In practice, the annual efficiency is usually determined by methods that are based on the efficiency at some representative operating points instead of detailed annual simulations. The seasonal efficiency can then be estimated from those representative operating points. For instance, according to VDI 4650-2 (2010) the annual utilization efficiency for space heating $\eta_{N,h}$ is determined by unweighted averaging over 5 operating points with different part load ratio and corresponding flow temperatures. According to EN 12309-6 (2016) the efficiencies of all operating points, that occur during a year, are computed by linear interpolation from 5 representative operating points. The SGUEh (Seasonal Gas Utilization Efficiency for heating) is then determined by averaging over the whole year, while the single operating points are weighted according to their heat load hours (BIN method). Both annual utilization efficiency for space heating $\eta_{N,h}$ (VDI 4650-2, 2010) and SGUEh (EN12309-6, 2016) are defined as the ratio of annual heating energy output and annual fuel energy input and are therefore comparable with each other. The degree of accordance between those two performance indicators and between them and the annual efficiency determined by annual simulations has been examined by means of simulations (Emhofer et al., 2017).

The study has been conducted using the above described simulation model of the E-Sorp prototype (GAX design). This prototype is equipped with two needle valves, which can be used in order to modify the cycle. In the framework of an earlier project, the influence of the valve positions on the efficiency has been analyzed, which led to an optimization proposal (labelled valve position 2 in the following) compared to the standard position (valve position 1). Both valve positions have been considered in the here discussed simulation study. Climatic data of Strasbourg has been used for the annual simulations, since the BIN method described in

EN 12309-6 (2016) is based on this location. A ground heat source was assumed for all calculations and instead of using building models and computing the flow temperature by means of heating curves as described in Section 2, the distributions of both heating load and flow temperature over the year were taken from EN 12309-6 (2016). Furthermore the efficiencies for the representative operating points according to VDI 4650-2 (2010) and EN 12309-6 (2016) have been computed with the simulation model and be used to determine the annual utilization efficiency for space heating $\eta_{N,h}$ and the SGUEh, respectively.

Table 1 shows an overview of the seasonal efficiencies calculated with different methods. As can be seen, there is very good agreement between the annual simulations and the BIN method according to EN 12309-6 (2016). However the method described in VDI 4650 2 (2010) significantly overestimates the seasonal efficiencies determined by annual simulations. This is due to the fact, that all 5 representative operating points are weighted equally and therefore operating points with relatively small part load ratio and low flow temperatures (which generally yield a relatively high efficiency) are overrepresented compared to their actual heat load hours per year. Furthermore, the inlet temperature from the ground source increases with decreasing part load in the VDI guideline, whereas the temperature stays constant in the EN standard.

Table 1: Seasonal efficiencies determined by means of different methods (simulations)

Method	Valve position 1	Valve position 2
Annual Simulation with constraints from the EN12309-6 (2016)	1,669	1,708
EN12309-6 (2016) for average climate and low heating temperatures	1,665	1,709
VDI 4650 2 (2010)	1,737	1,821

Furthermore the SGUEh according to EN12309-6 (2016) has been determined experimentally in the laboratory of the Austrian Institute of Technology. As can be seen in Table 2, the simulation model overestimates the SGUEh based on measurements for both valve positions. One reason is that assumptions for several parameters with a significant influence on the heat pump's efficiency (such as NH_3 mass fraction of the poor solution and temperature glide in the evaporator) had to be made for the simulations, while those parameters are adjusted by the heat pump's control in the actual appliance. However, the actual control strategy does not necessarily coincide with the assumptions made. Hence, the discrepancies between experiment and simulation indicate a certain optimization potential concerning the control strategy.

Table 2: Comparison of experimentally and numerically determined SGUEh according to EN12309-6 (2016)

	Valve position 1	Valve position 2
Experiment	1,574	1,672
Simulation	1,665	1,709

4 CONCLUSION

Annual simulations have been conducted in order to evaluate the saving potential of two different gas heat pump cycles compared to a condensing boiler. Different heating systems, building types, and Austrian locations have been considered as influencing factors. The maximum saving potential (for the best case of combinations of considered influencing factors) is 37.4 % or annually 4242 kWh of natural gas, 293 EUR, and 848 kg CO_2, respectively, and the minimum one (for the worst case) is 27,2 % or annual savings of 1380 kWh of natural gas, 95 EUR, and 276 kg CO2. However, only buildings with a relatively small annual heat load have been examined and the saving potentials (in absolute numbers) for other applications (in particular retrofit) are expected to be significantly higher.

Furthermore, annual simulations with the constraints of the EN12309-6 (2016) have been compared to simulative predictions of the seasonal efficiency according to guidelines and standards, namely VDI 4650-2 (2010) and EN12309-6 (2016) for ground heat sources. The seasonal performance calculated with the VDI 4650-2 (2010) is significantly higher than the performance calculated with the EN12309-6 (2016) for average climate and low heating temperatures. The reason is that operating points with a relatively high efficiency are overrepresented in the guideline compared to their actual occurrence over the year in Strasbourg and due to the fact that the inlet temperature from the ground heat source is significantly larger at small part loads in the VDI guideline.

Finally, the seasonal efficiency determined according to EN12309-6 (2016) by means of simulations has also been compared to an experimentally determined seasonal efficiency. The simulations overestimated the actual measured value, which can be partly attributed to a mismatch between assumptions related to the control strategy and the actual control system in the real appliance. Therefore there is some potential for an optimization of the control strategy of the prototype.

5 LITERATURE

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