MODELLING OF HEAT PUMP AND DHW SYSTEM FOR PARAMETRIC STUDY OF HEATING SYSTEMS IN LOW ENERGY BUILDINGS

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ABSTRACT

This paper deals with: i) modeling of a ground water heat pump and a thermally stratified fluid storage tank in a building energy simulation software ii) validation of the models using measurements taken in a real building and by comparison with experimental results from existing literature and iii) application of the models in a simulation based parametric study of the thermal and energy performance of combined low temperature space heating and domestic hot water system in a typical residential building confirming to current European standards.

INTRODUCTION

Performance of HVAC systems in practice may differ considerably from that in laboratory conditions when subjected to the dynamic conditions in a real building.

Predictions based on simple mathematical calculations may also lead to over-estimation or under-estimation of the system performance. The complexity and uncertainty involved in HVAC systems' performance in buildings makes a whole-building simulation based study indispensable. The thermal and energy performance of a heat pump based combined hydronic space heating system and domestic hot water system depend significantly on the building type, form, site micro-climate, degree of thermal insulation of the building envelope, usage pattern, heat source type, domestic hot water demand, control strategies, the required flow temperature of the space heating system, ventilation system, infiltration and use of thermal storage systems. Parametric study of such integrated systems has always been of interest to researchers (Olesen, 2006, Sakellari et al., 2005), especially with the increasing degree of stringency in the building energy regulations. A computational simulation based parametric study relies on the accuracy of the numerical models of the HVAC components used in such simulations. However there is always a compromise between the accuracy of model and the required simulation time. Keeping these in mind a ground water heat pump and a stratified thermal storage tank have been modeled in building energy simulation software, IDA ICE (IDA Solver User's Guide, 1999, Sahlin, 1996) for parametric study of the heating systems in modern low energy buildings. Several models of heat pump have been proposed by researchers from time to time. These models can be classified as *steady state models, transient state models* and *quasi-steady state models* from the operational point of view of the refrigeration cycle. Most of the models developed and applied in energy performance analysis of heat pumps in buildings are *equation-fit* models (Sundell, 1980) or *lumped parameter* based models. *Deterministic* models require input from experimental data, not available to the researchers who are involved in building energy calculation but not directly in heat pump development or improvisation. However they are known to yield more accurate results than the *equation-fit* models in most cases. After a thorough study of the applications and limitations of the heat pump models available in literature, the *parameter estimation* based model of water-to-water heat pump developed by Jin and Spitler (Jin et al., 2002, Jin et al., 2003) is implemented in IDA ICE. This model uses deterministic model for each heat pump component while the parameters for the governing equations can be estimated solely from manufacturer's catalogue data. This model also allows for extrapolation. The thermally stratified fluid storage tank model is a one-dimensional transient heat conduction based model (Oliveski et al., 2003) with mixing parameters to account for the mixing effect of charging and discharging operations. In order to verify the performance of this combined model with respect to real situation a real single family residential building in Rosenheim with an installed ground water heat pump, a domestic hot water tank, a radiator based space heating system and a fresh water supply system was simulated in IDA ICE. Results of annual simulation were compared with the field measurements of compressor hours, heat output, compressor power input and COP. Further results of selecting different maximum simulation time-steps have been studied.

DESCRIPTION OF MODELS

Models of a water-to-water heat pump and a stratified thermal storage tank with mixing effects at the inlet and outlet are implemented as components of the HVAC plant in IDA ICE. The one dimensional transient heat conduction based model of thermally stratified fluid storage tank accounts for the following physical processes: i) conduction heat transfer between the water and the surrounding environment, ii) conduction across the thermocline, iii) mixing near the inlet diffuser, iv) natural convection inside the tank, v) temperature inversion. Mixing at the inlet diffuser is taken care of by the mixing coefficients for the energy lost due to mixing between the inlet stream and the tank fluid. Results of simulation of charging cycle and with no external flow in the tank have been verified with experimental results from literature (Al-Najem et al., 1993).

The main logic of the steady-state water-to-water heat pump model is same as described in (Jin et al., 2002). Modifications and additions to the basic model have been made to incorporate the links with building heat distribution system, the domestic hot water supply, the control systems and other user defined schedules. To account for the use of a particular refrigerant, refrigerant property subroutines have been developed to calculate the refrigerant properties like enthalpy at various stages of the refrigeration, saturation pressure and specific volume of the super-heated vapour.

SIMULATION

The models have been used in the annual thermal and HVAC system simulation of a real single family house in Rosenheim, equipped with a ground water heat pump of nominal capacity 8.4 kW (W10/W55) with scroll compressor, a high temperature radiator based space heating system, a buffer tank of 300 litres capacity and a fresh water system. This house was built following German Standard 1995. It has a total heated floor area of 180 m^2 and an annual heat demand of 21810 kWh for domestic hot water and space heating together. The heat pump alternately supplies the buffer tank and the space heat distribution system. The control system ensures a constant temperature spread of approximately 6 K at the condenser. As mentioned earlier, integration of the heat pump and the tank model as plant components and connecting them with the heat distribution circuit of the zones with accurate modeling of the control system required a lot of modifications in the basic models, which will be dealt with in the main paper. Occupant schedule, domestic hot water demand and usage schedule, annual ground water temperature data and the control strategy have been modeled accurately. Parameter estimation of the heat pump was performed using Nelder-Mead simplex method of multi-variable optimization. Result of optimization is shown in Table 1. The selected case study building was then retrofitted to the current EnEV standard. Low temperature hydronic floor heating system was introduced in the zones with a stable heat demand profile. A smaller heat pump was selected to meet the new heat demand and the resultant change in the thermal and energy performance of the heat pump was determined by simulation. Further the effects of changing the thermal mass of the floor construction and the resultant peak shaving, of the flow rates and temperatures of the floor heating systems on the thermal and energy performance of the heating systems with heat pump have been simulated, results of which will be discussed in detail in the main paper.

DISCUSSION AND RESULT ANALYSIS

Some preliminary results of comparison between measured values and simulations shown in Figures 1 and 2 show a close correlation between actual and predicted results. Figure 3 shows the performance of new heat pump on a typical winter day with the running time. Results of the tank model operation with mixing parameters are in better conformance with the experimental results of charging cycle. Thus it can be concluded that with other necessary components of the building modeled accurately, the parameter estimation based ground water heat pump model combined with a stratified thermal storage tank model can predict the system performance very close to reality and can be a reliable tool for parametric study of heating systems in low energy buildings. Due to absence of the exact hourly weather data of Rosenheim for the monitoring year, however there may be minor difference in the results from what could be obtained with the exact data. To ensure that the error has no significant effect on the results of simulation a comparative study of the ASHRAE weather data and the on site measured values of parameters was made.

Table 1
Parameter estimation results of the case study heat pump in heating mode

PARAMETERS	VALUES
Source heat transfer coefficient	2401.9 W
Load heat transfer coefficient	3618.52 W
Superheat	7.32 °C
Swept volume	.00128 m^3/s
Built-in volume ratio	1.66
Leakage coefficient	0.000817
Loss factor for electromechanical work loss	0.866
Constant work loss	729.93 W

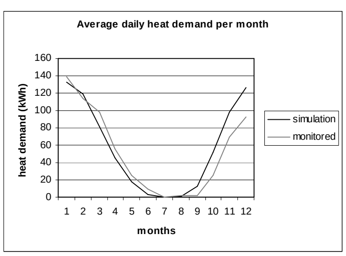

Figure 1 A comparison of average monthly heat demand for space heating obtained from simulation with the results of annual monitoring

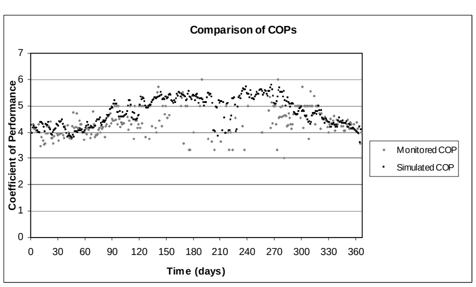

Figure 2 Coefficient of performance of the heat pump obtained from monitored data compared with result of annual simulation

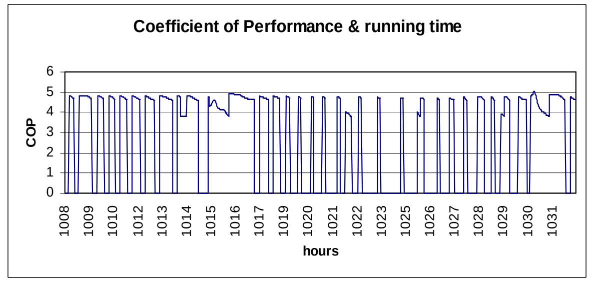

Figure 3 Coefficient of performance of new heat pump in EnEV house in a typical winter day in February

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