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ENERGETIC EXAMINATION OF AIR-WATER HEAT PUMP FOR MODELING PURPOSES

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Abstract: Nowadays the growth of energy prices requires continuous increase in energy efficiency. More than 60% of the annual energy use of buildings is spent for heating and if the climate system is supplemented with a cooling system in the summer, this ratio can increase further. Due to the sizes and different needs that might have occurred, control of the heating-cooling system of large buildings could cause difficulties. Growing utilization of renewable energy sources (e.g. by using heat pumps) in these buildings caused by increase in prices and environmental awareness makes design the control system more difficult however, using adequate model-based design principles, higher efficiency climate systems can be operated. As a first step of a PhD research on the climate control system of buildings using heat pumps for heating and cooling we set up a model experiment with an air-water heat pump where we cooled and heated some water and during this process we measured all the important energetic parameters – temperatures, volume flows and electric energy consumption of the system. This allows us to set up an identified model of the heat pump that can be applied also in a more complex system model to understand and optimize energetic control systems. This article deals with description and evaluation of these measurements.
Keywords: heat pump, model experiment, metrology, modeling

1. INTRODUCTION

Growth of energy prices and environmental awareness in architecture and building services engineering causes spreading of using of Heating Ventilation Air Conditioning (HVAC) systems with combined energy sources using partially renewable resources. Within this, application of heat pumps with different primary and secondary fluids (e.g. air-source or ground source heat pumps) in buildings and associated facilities has a particular importance for heating and cooling purposes (Géczi, et. al., 2013), often combined with a complex supplementary heating system e.g. by using a solar collector or photovoltaic system. (Tóth, et. al., 2011)

For control of internal temperature and other climate parameters of buildings there are well algorithms e.g. in terms of the value of set-point program-controlled, and weather dependent control can be mentioned. However in buildings using combined energy sources where there are several options to meet the energy needs the control can be much difficult. (Hámori, 2008) Nowadays during the control design of such systems empirical formulas and results of economical calculations are taken into account. Due to continuous change in prices and neglect of other important aspects e.g. the greatest possible use of renewable sources or minimizing of CO_2 emission it is not a right approach. However using of adequate design solutions allows realization of optimal control functions even by several aspects. For construction of an optimal control the first step is getting to know the operation and dynamical behaviors of these systems with development of a control model. (Carman, et. al., 2010) (Cho, et. al., 2010)

2. MATERIALS and METHODS

2.1. Materials

The model experiment is based on a Microwell HP 700 type air-source air-water heat pump. There were also a pump with a nominal flow rate of 16 m^3/h, a tank with 1 m^3 volume, pipelines, valves and measuring instruments. With the installation there was possible to set the volume flow through the heat pump manually using a bypass pipe and valves after the pump with constant flow-rate. The base of the measuring system was an Almemo 2590-9 type data acquisition system connected to PC. The measuring system was set to 20 s sampling interval.

We measured temperature of ambient air, on the input and output water of the heat pump and the in the tank of water by four pieces of K-type (NiCr-Ni) thermocouples. We also measured humidity of ambient air. Measurement of electrical energy consumption was done by an Actaris SL7000 type multifunction electrical measuring unit that has an LED indicated impulse output that provides 10000 pulses/kWh. For detection these pulses and measure them with Almemo system we developed a phototransistor based optical sensor adaptor with a TTL level converter circuit. We also measured voltage and input current separately to make it possible to compute power factor of the heat pump. For measurement of volume flow we used an Arad WST type flow meter equipped with a Reed-switch providing one contact as 10 liters of water flows through the pipeline. For accurate sensing we developed a simple microcontroller based frequency measuring device that calculated and displayed the flow rate by measuring the time between two signals of flow meter. Figure 1 shows the construction and measured parameters of the experimental measuring system.

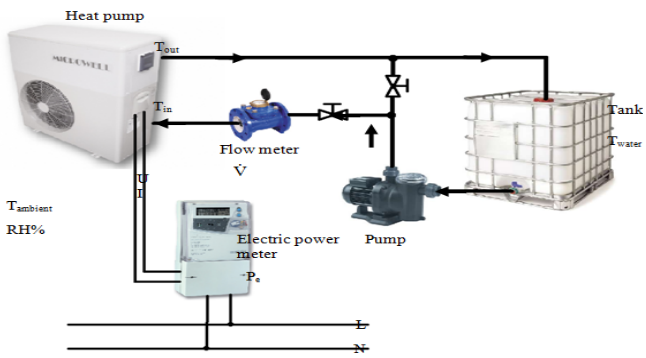

Figure 1. Construction of the measurement assembly

2.2. Methods

Heat pumps usually can be used also for heating and cooling. During the experiments we heated and cooled the tank of water from about 10°C to 50°C then back to 10°C with the heat pump at constant flow-rate. More than 40 heating and cooling cycles were measured at different ambient temperatures from March to June in 2013.

Air-source heat pumps like the one that we used during our examinations are utilizing the heat energy of the ambient air and usually heat or cool water with that. In the heat pump air is blown through the evaporator heat exchanger where the low pressure working fluid is evaporating. Then the gas is compressed by an electrically driven compressor unit and pressed into another heat exchanger called condenser where the heat energy in a higher temperature is transferred to water. After condensation the fluid flows through a pressure lowering expansion valve and the cycle is closed in the evaporator. One of the most important parameters of heat pumps is coefficient of performance or COP value that shows the relation of output heating or cooling power (Qout) and input electric power (Pe):

$$COP = \frac{|Qout|}{Pe} \tag{1}$$

Ideal heat pumps that implement a Carnot-cycle have the highest COP value (COPC) that depends only on the temperature of the condenser (TC) and the temperature difference between the condenser and the evaporator (TC-TE): (Forsén, 2005)

$$COP = \frac{Tc}{T_C - T_e} \tag{2}$$

The efficiency of heat pump ηC - that can be important in case of modeling - shows relation between theoretical maximum COPC and the COP calculated based on the measurement data:

$$\eta = \frac{COP}{COP_c} \tag{3}$$

Typical value of η_C for air-water heat pumps is between 0.45 and 065. (Komlós, at. al., 2007)

There are two common ways of modeling heat pump operation. One of them writes the thermodynamic equations of all the four states represented by four main parts of the heat pump. (Badiali, Colombo, 2010) The simplest one deals only with the energy flows in and out of the system. Figure 2 shows the block diagram of simplified energy flow model of an air-water heat pump where T_a is the ambient air temperature (inlet and outlet) T_w is the water temperature (inlet and outlet), m_a and m_w are the mass flows of the air and water, c_a and c_w are the specific heat of the air and water, Q_{in} is the input heat flow Q_{out} is the output heat flow and P_e is the electric power.

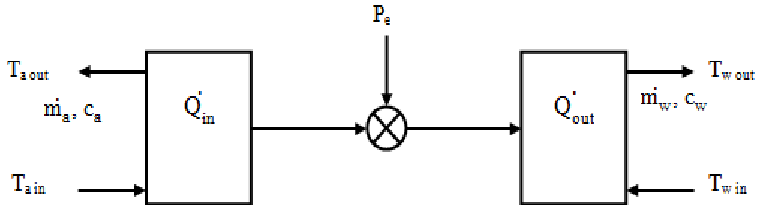

Figure 2. Diagram of simplified heat pump model

The output heat flow:

$$Qout = COP \cdot P_e \tag{4}$$

The input heat flow:

m_a, c_a $\quad$ m_w, c_w

$$Qin = Qout - Pe = (COP - 1) \cdot P_e \tag{5}$$

The output temperature of air:

$$T_a\,out = \frac{m_a c_a (T_a in - T_a out) - Qin}{c_a} \tag{6}$$

where: C_a is the heat capacity of ambient air in the heat pump

The output temperature of the water:

$$T_w\,out = \frac{m_w c_w (T_w in - T_w out) + Qin}{c_w} \tag{7}$$

where: C_w is the heat capacity of heated or cooled water in the heat pump (van Schijndel, de Wit, 2003)

3. RESULTS and DISCUSSION

After the measurements a block-oriented solution of the mathematical model described above was prepared in Matlab/Simulink software to validate it with laboratory experiments and identify parameters. Figure 3 shows the Simulink block diagram for solution of (4)-(7) system of equations.

For using the model preparation of measurement data needed. A Matlab script for data processing read the data stored in text file, then computes input (electric) and output power and COP values, finally generates the variables containing time series of data needed by the simulink model.

About the physical parameters of the heat pump operation only the heat capacities (C_a and C_w) were unknown because flow of water was measured and airflow of the fan was given in operation manual. Therefore the parameter to identify was the heat capacity of water. Since output air temperature was also unknown, heat capacity of air could not be identified.

For identification method of least squares and built-in method for minimum search in Matlab were used. The result shows heat capacity of water is C_w=137744.8 J/K, which means mass of water in the heat pump computed with c_w=4181.3 J/kgK:

$$mw = \frac{C_w}{c_w} = \frac{137744.8}{4183.3} = 32.9kg \tag{8}$$

After parameter identification validation of model was done with a full heating cycle where water was heated from 14°C to 46 °C at 14.5 m^3/h water flow and 2520 m^3/h airflow. Result of the validation is presented on figure 4 where fit of measured and simulated (computed) value of output water temperature can be seen.

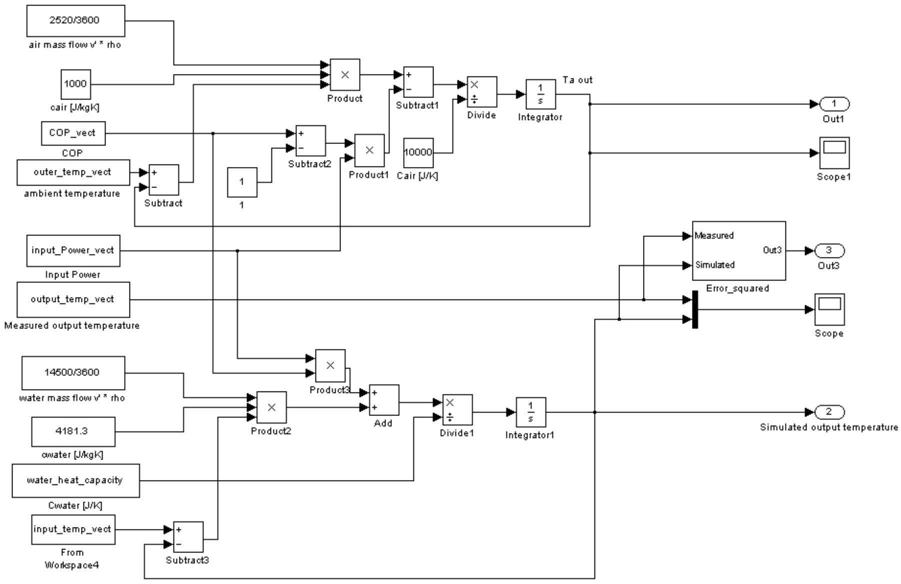

Figure 3. Simulink block diagram of heat pump model

As a result of the research we built up a model experiment for testing of different types of low power heat pumps for residential use and found out that the energy flow method of modeling heat pumps in heating operation is applicable on air-water heat pumps and main operational parameters can be identified with this. Building up the full identified model of the heat pump including the heat capacity of the air and integration in a complex energetic system needs further investigations.

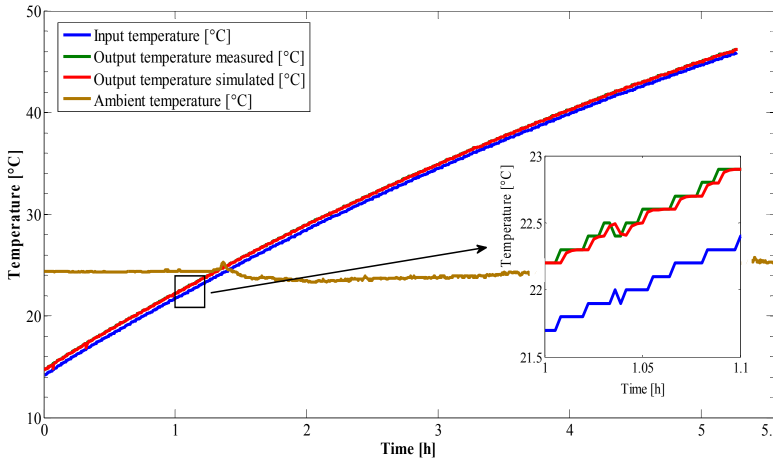

Figure 4. Result of the model validation at a heating cycle of the heat pump

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