INTERNATIONAL SCIENTIFIC CONFERENCE
CIBv 2010
12 – 13 November 2010, Braşov

HEAT PUMP OPERATION: PRICE & COMFORT

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Abstract: As the operating conditions of a heat pump system are the result of multiple interactions between the building and the heat pump system but also between heat pump and its thermal source being influenced by the climatic conditions a complex function between the location, season, consumption pattern, climate change and the thermal comfort exists. On the other hand the source and the sink temperature variation affect the annual performance of the heat pump as a heat generation system. The energy balance of the human body is necessary to be achieved for its thermal comfort which depends on several factors usually reflected by the ambient air temperature correlated with the surrounding-walls temperature. A better insulation of the outer walls can lead to a lower indoor temperature necessary for a better environmental comfort. Experimental data have been collected from a below the grade room assisted by a heat pump system. The purpose of the study was a more efficient operation of the system characterized by a reduced temperature swing of the walls, being less influenced by the air temperature amplitude and by the daily solar radiation. Energy savings resulting from a more efficient cycling operation in the limits of comfort can lead to possible conclusions regarding the architecture and the insulation of the walls.

Key words: Heat Pump System, Thermal Comfort, Electricity Price and Efficiency

1. INTRODUCTION

A heat pump system was conceived and implemented in the Building Services Department at Transylvania University of Brasov in order to study its operation parameters for a low energy demand room. The room being prevalent situated under the grade has a lower heating demand during the winter but is colder as usual in the summer period. As a result the heat pump operates throughout the year, this way improving the system efficiency. The system consisting of the building, heat pump and thermal source, denoted as BHPTS, is analyzed in the context of climatic condition, thermal comfort and price of electricity.

2. THE HEAT PUMP LABORATORY

The heat pump system presented in Figure 1 has as the low-temperature source the air exhausted from the building by the fan-coil, Figure 2, installed in the main hall at the ground floor.

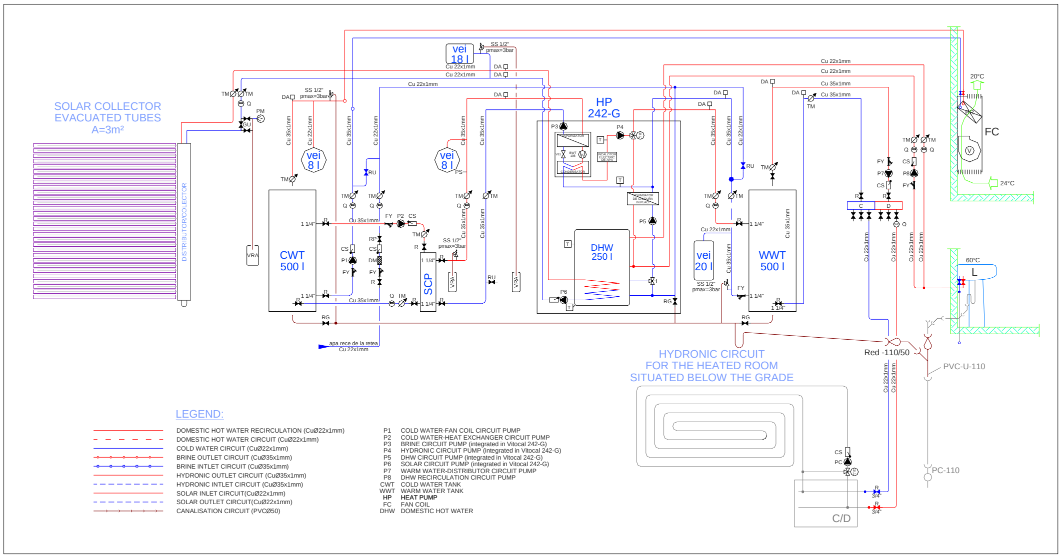

Fig. 1 Schematic of the heat pump system laboratory

The heat recovered from the exhausted air by the water circulated through the fan coil is transferred to an intermediary cold water tank of 500 l. A plate heat exchanger inserted between the cold water tank and the heat pump protects the heat pump evaporator from scaling and freezing dangers. The warm water prepared by the heat pump (30 to 40 °C) is then distributed through a hydronic circuit existing in the floor of the room, situated 2.5 m below the grade (the sink), as shown in Figure 3.

Fig. 2 Heat-recovery fan coil

Fig. 3 Thermo vision of the hydronic circuit

To prevent the frequent cycling of the heat pump a 500 l insulated warm water tank, as shown in Figure 4, is inserted between the heat pump and the hydronic circuit. The heat pump has its own domestic hot water tank provided with a heat exchanger connected to a 3 m^2 evacuated solar collector assisting the unit. This solar collector is vertically installed on the exterior South-South-West wall of the laboratory, as shown in Figure 5.

Fig. 4 The heat pump between the cold and the warm water tank

The entire system is automatically controlled by the control unit of the heat pump. A Smartcontrol 1.5 Software is used for data acquisition, in order to obtain views of Y/t-diagram with max 3 Y-axes and indication of operation mode, and extended zoom function/overview diagram such as: digital displays, measurement list of the parameter min, max, and main. This software uses two types of universal, modular, highly accurate, CAN-bus-connected data loggers: OPUS 208 equipped with 8 channels and OPUS 200 equipped with 2 channels, thermo resistances PT100 and thermocouples K as sensors, as shown in Figure 6, for measuring the temperatures in the essentials points of the system, doubled by contact thermometers.

Fig. 5 The evacuated solar collector

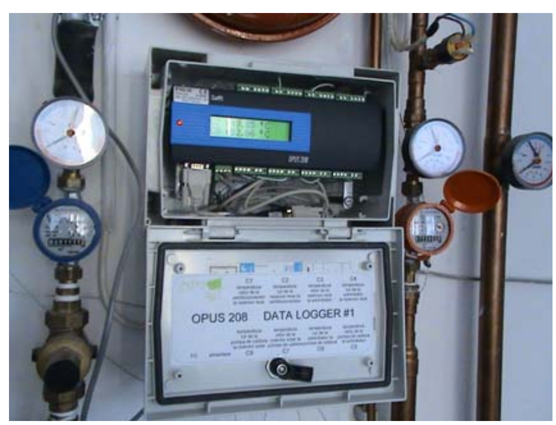

Fig. 6 The OPUS 208 data logger

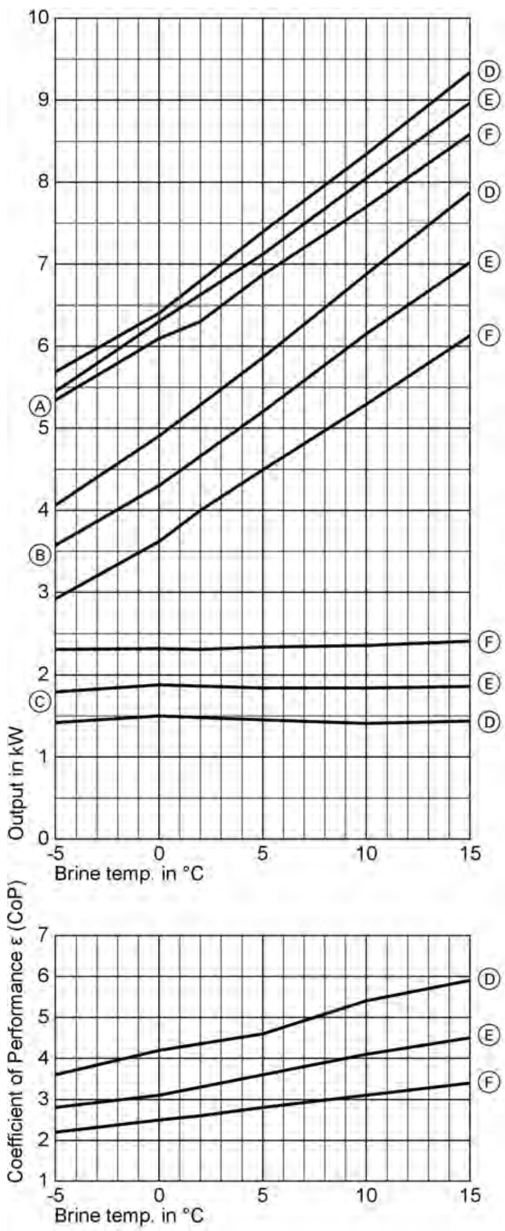

Fig. 7 – Heat pump performance

The heat pump performance [1]is presented in Figure 7 where the meaning of the letters is:

A - Heating output
B - Refrigerating capacity
C - Power consumption
D – Temperature of hot water = 35 °C
E – Temperature of hot water = 45 °C
F – Temperature of hot water = 55 °C

The COP and the performance data presented in Figure 7 and in Table 1 were calculated with reference to DIN EN 14511, according to the manufacturer product description leaflet.

Table 1 Heat Pump Performance Data

Operating point	**B0/ W35**	**B0/ W35**	**B0/ W35**
Heating output, kW	6.4	6.3	6.3
Refrigerating capacity, kW	4.9	4.3	4.0
Power cons., kW	1.5	1.9	2.3
COP	4.2	3.2	2.6

Depending on the source temperature the heating output/refrigerating capacity and the COP of the heat pump are determined for steady state conditions. In real operation condition these characteristics will be affected by losses essentially caused by the cycling process. The compressor cycling is the way through which the heat generated by the heat pump is adapted with the heating demand of the building. The electrical consumption of the heat pump compressor and of the supplementary electric heater is metered by two dedicated 380V electric meters. The monitoring of the rest of electrical components (heat pump control panel, circulation pumps, data loggers, etc.) is done by a 220V dedicated meter.

The system consisting of the building, heat pump and thermal source, denoted as BHPTS, is analyzed in the context of climatic condition and thermal comfort.

3. THERMAL COMFORT AND WALL INSULATION

The BHPTS system designed and operated to offer the thermal comfort inside the building is affected by the climatic condition too. The laboratory room being predominantly situated under the grade its walls are rather under the influence of the earth temperature in contrast with other parts of the building being affected by the air temperature[2]. As a result the inner wall-surface temperature is higher in those parts being under the zero ground level, as can be seen in Figure 8.

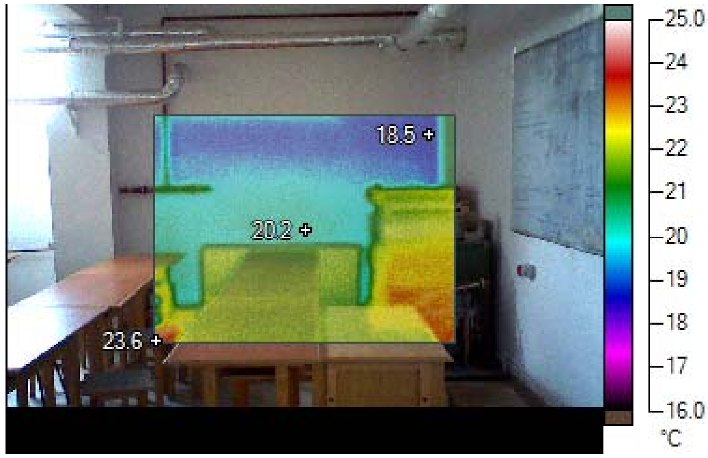

Fig. 8 Thermo vision of the exterior wall of the lab: only the upper part of the exterior wall (18.5 ^{o}C) is in contact with the ambient air, the rest of it being under the grade (20.2 to 23.6 ^{o}C)

The mean radiant temperature of that inner-surface of the wall is 20.2 ^{o}C compared with the 18.5 ^{o}C specific for the upper part of the same wall and being in contact with the exterior ambient air (about -22 ^{o}C at that time). This pattern is characteristic for an insulated wall having higher interior temperatures during the heating season and reduced swing temperature along the year. This results in a lower level of heat losses. Not only the exterior air temperature but also the solar radiation has a minor influence on the indoor comfort parameters. The ground temperature, which is almost constant, affects positively the heating demand during the heating season.

On the other hand studies carried out on this subject [3] have shown the correlation existing between the indoor air temperature and the surface temperature of the walls, having as parameters the activity level and the clothing insulation, as shown in Figure 9.

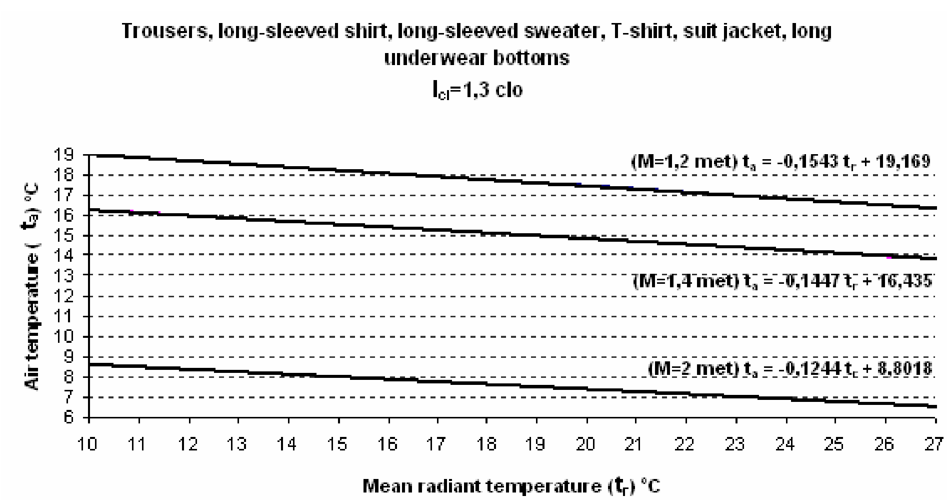

Fig.9 Indoor air temperature as a function of the mean radiant temperature for I_{cl}=1.3 clo

To cover the heat losses and for the set comfort condition the heat pump, i.e. its compressor has a cycling period of two-and-a-half hours, with a continuous operation of one hour as shown in Figure 10. The same period can be found in the temperature variation for different circuits and its limits, for a steady operation are presented in Table II.

The indoor temperature was kept constant at 22 ^{o}C while the temperature of floor at its surface remained in a narrow limit i.e. 29±1^{o}C with a period of 2 hours and 45 minutes.

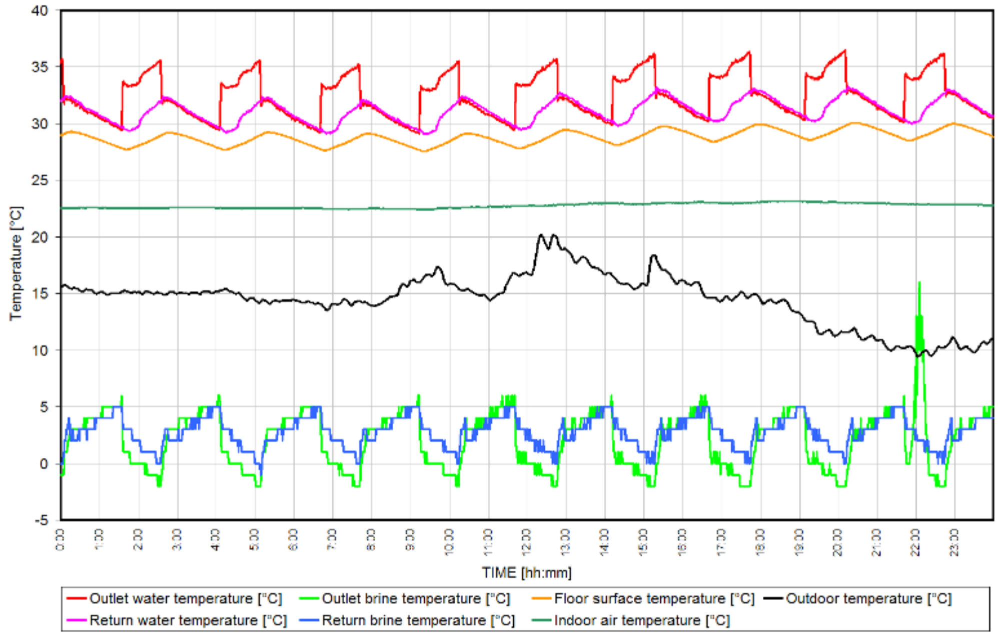

Fig. 10 Temperature history for the steady operation heat pump mode, indoor and outdoor air temperature

The Entering Water (brine) Temperature EWT stayed in the limits of 0 and 5°C, while the Leaving Water (brine) Temperature LWT was 5 to -2°C. During the compressor stop the LWT tend to become the same as the EWT. After the compressor start a difference of about 2°C exists between EWT and LWT.

Table2 Steady Operation Temperatures

Circuit			**Min [°C]**	**Max [°C]**
HP tank	Cold water	inlet HP	0	5
		outlet HP	-2	5
	Warm water	inlet HP	29	33
		outlet HP	30	36
Radiant floor surface			28	30

The heated water exiting the heat pump is 33±3°C and 31±3°C when it returns.

In case the fan coil stops a cycling operation of the heat pump is performed as the result of information received by the HP control unit. When the thermal energy transferred from the evacuated air to the cold water tank is insufficient compared with the energy extracted by the heat pump from this tank than the temperature inside the storage tank is reduced progressively. Figure 11 presents this lowering of the temperature: return brine temperature is 9±5 °C in steady operation mode and only 0±2 °C in the cycling operation mode. After this test a floor surface temperature rising occurs: from 17…19 °C to 21…24 °C. The indoor air temperature reflects this change too. The higher temperature of the outlet water temperature is the result of the frequent cycling of the heat pump, lasting from 12.30 h to 16.30 h and is based on the electricity used to drive the heat pump and not on the thermal energy extracted from the source and a lower energy efficiency results.

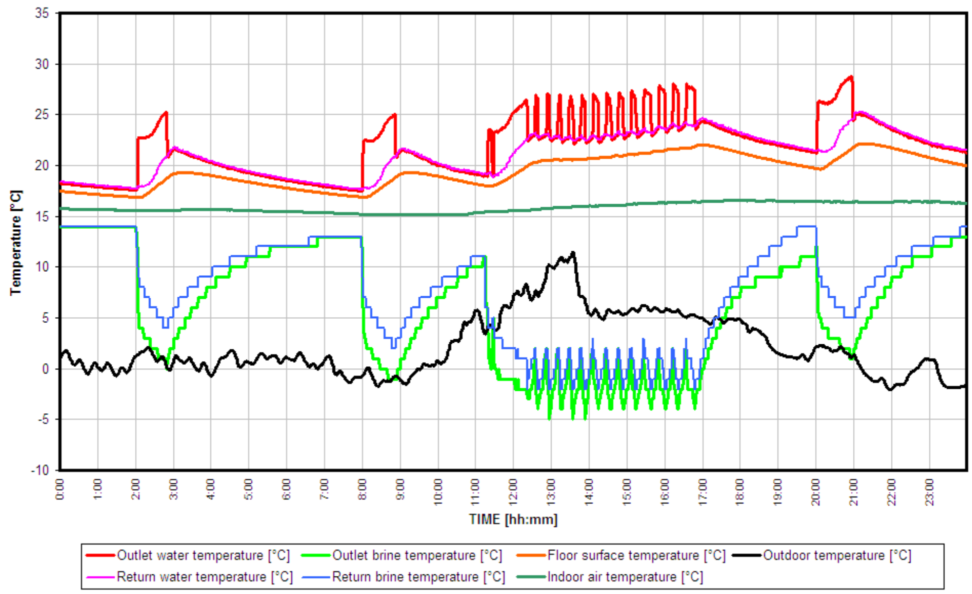

Fig. 11 Temperature history for the cycling operation mode, indoor and outdoor air temperature

Cycling operation (3 times per hour ON/OFF) results from the manufacturer preset in order to protect the heat pump against freezing. When the brine temperature at the heat pump exit is as low as -5 °C the control stops the compressor and restarts it when the temperature arises 2 °C. The heat pump cycling reduces its performance: the cycling capacity adjustment factor decreases as a result of the run time.

4. HEAT VS. PRICE OF THE ELECTRICITY

Considering the price of the electricity used to drive the heat pump a correlation of the thermal energy price with the temperature of the water entering the heat pump can be put in evidence as shown in Figure 12.

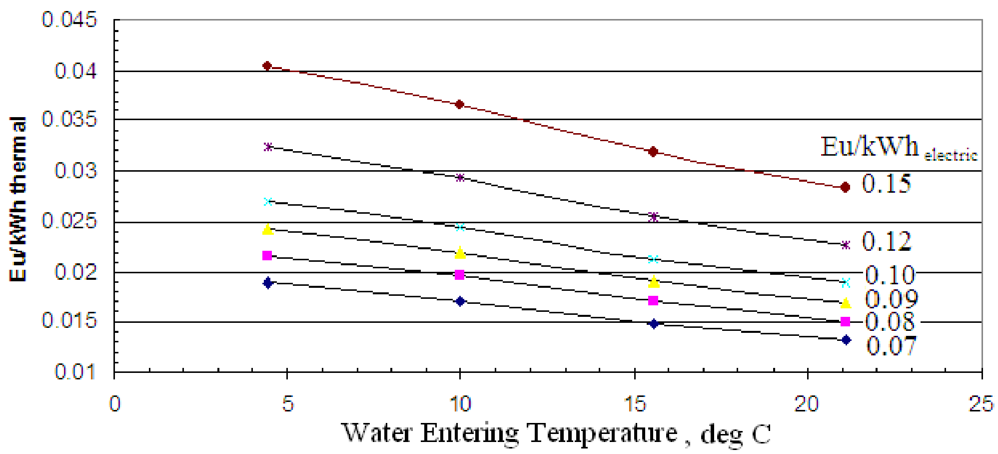

Fig. 12 The price of the heat delivered by the heat pump as a function of the entering water temperature EWT and having the price of electricity as a parameter

Because of the price of electricity which changed in Romania during the last years (0.0781 €/kWh in August 2007 compared to 0.0875 €/kWh in April 2009)) and possible future adjustments, a wider range has been considered, i.e. 0.07 to 0.15 €/kWh. The cost per kWh thermal does not include the energy required by pumps or fans used for the operation of the heat pump. As can be noticed the temperature of water entering the heat pump affects the price of the delivered thermal energy: if the water entering the heat pump has a temperature of 20 ^oC instead of 5 ^oC then a saving of about 26 % results. But if the price of electricity is reduced with five eurocents (from 12 to 7 eurocents) the saving will be of 43%. The price of electricity and its production efficiency [4]is essential for the price of the thermal energy delivered by the heat pump. However, the price of electricity depends on its production efficiency and this could be an interesting issue for future developments in the field.

5. CONCLUSIONS

The heat pump as an energy efficient equipment is strongly affected by the required temperature used for space heating. On the other hand the thermal comfort can be kept even if the indoor air temperature is lower but for an appropriate inside-surface temperature of the walls, floor and ceiling. The temperature lift is also essential for the system COP and it determines the heat source temperature for a required temperature of the water, i.e. DHW or hydronic heating.

Studies carried out in the heat pump laboratory developed in the Building Services Department at Transylvania University of Brasov have shown the importance of the thermal insulation of the surrounding walls: the thermal comfort can be kept in reasonable limits at lower inside air temperatures as a result of the reduced losses due to the under the grade disposition of this room. This means that the thermal insulation of the building is essential for an improved operation of heat pump systems.

The exaggerated cycling operation must be avoided by an appropriate sizing and by the temperature settings.

An important role in an expanded installation of heat pump system will be the price of electricity: 1 to 5 cents/kWh less for every energy unit will affect dramatically the efficiency of these systems. This is related to the electricity production efficiency.

The comfort depends on the price of electricity and on the accurate sizing of the heat pump related to the building losses not only on the price and development of heat pump systems alone.

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Received October 30, 2010