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Measurements of Laboratory Heat Pump Characteristics

Renewable energy sources are becoming more prominent in securing the energy needs of mankind. The survey and analysis of current status in the use of these appliances indicated the need of application of this technology. Low-potential energy sources of heat are sufficient from the quantitative and qualitative point of view. Heat pumps contribute to saving energy and reducing consumption. Working model of a heat pump for laboratory purposes was designed and constructed. It is intended for demonstration and implementation of laboratory measurements. The utilization of this device is suitable also for the use of solar energy. The heat pump is designed to allow user-friendly utilization for demonstration and experimental laboratory measurements. The achieved parameters of laboratory heat pump model are comparable with mass-produced heat pumps.

Keywords: low-potential heat, heat pumps, COP, construction

I. INTRODUCTION

The use of low-potential, or waste heat through heat pumps is very actual. The importance of heat pumps is increased by the fact that they were classified as renewables under the conditions set out in the strategy of increased use of renewable energy sources approved by the European Parliament [1]. In Slovakia, the government intended the goal to gain 800 TJ of heat by using the heat pumps by 2015 [2].

The principle of the heat pumps has been known for nearly a century. They use low-potential heat from the environment. This heat is constantly renewed and it is the final form of all energy conversions. All produced energy, and solar energy, is ultimately converted to low-potential heat. This heat is deemed unusable and is freely released into the environment as waste heat. Heat emissions have become a serious global environmental problem. They ultimately contribute to a global warming and climate changes. Heat pumps consume the low-potential heat and convert it to a higher potential, which is reusable.

Technical potential of the low-potential heat is huge. The heat pumps are able to exploit it effectively. If this resource is not used, energy must be produced from another energy source, but again there is a low-potential waste heat production [3].

So far, humans manage energy resources as if they were disposable. To ensure our energy needs we continuously burn huge quantities of fuel, but their energy is used only partially.

Large amount of hot water and heating air is lost as waste, and their energy content is almost unchanged after use. It results from the basic laws of thermodynamics. The heat pump is one of the devices that allow a more rational use of heat [4].

II. OPERATING PRINCIPLE

The task of the heat pump is to remove an amount of heat from low-temperature substance, to transform energy to a higher – exploitable potential, and to add heat to high-temperature substance. The amount of energy input and output remains roughly unchanged. It is necessary to deliver energy from an external source to operate the heat pump, but this energy is returned at the device output. To implement this process, principles of refrigeration technology are applied. Thermodynamic refrigeration cycle involves evaporation, compression, condensation and expansion [5]. This circuit is composed of four basic components: evaporator, compressor, condenser and expansion valve (Fig. 1).

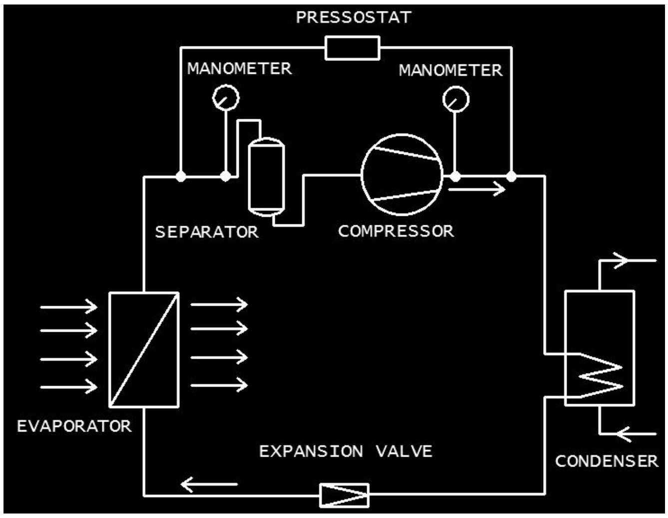

Fig. 1 Scheme of the experimental heat pump

A refrigerant in the evaporator is evaporated at a low value of temperature and pressure, and changes its state from liquid to gas. During evaporation process the refrigerant obtains energy from the primary circuit, which is a source of low-potential heat. The heated refrigerant in its gaseous state is circulated by the compressor. It is warmed strongly during the process of compressing with contribution of thermal losses of an electric motor of the hermetic or semi-hermetic compressor, and with contribution of frictional heat. The heated refrigerant has a higher temperature than the temperature of the heated medium in the secondary circuit. The part of its heat is transferred to a medium in the secondary circuit. The secondary medium can be water in the tank, or air to be heated. In the process of condensation, the refrigerant changes its state from gas to liquid and enters the expansion valve. The refrigerant is sprayed by the valve into the evaporator again.

III. CONSTRUCTION OF LABORATORY HEAT PUMP

The design and construction of heat pump model was based on a literature study and an analysis of the current design of heat pumps. For the conceptual design of the construction of the laboratory model, various design solutions and their parts were compared in order to achieve optimal properties of the resulting design in real production possibilities. Specification limits were determined before design and construction of the model in the form of demands on the model properties.

The heat pump "air – water" system was proved as the most suitable for the design and implementation of a laboratory model and for the laboratory measurements. The laboratory heat pump was designed in accordance with the diagram in Fig. 1. Practical implementation of the laboratory model is shown in Fig. 2.

In term of mechanical construction, the heat pump model consists of two connected parts: the supporting structure and the central unit.

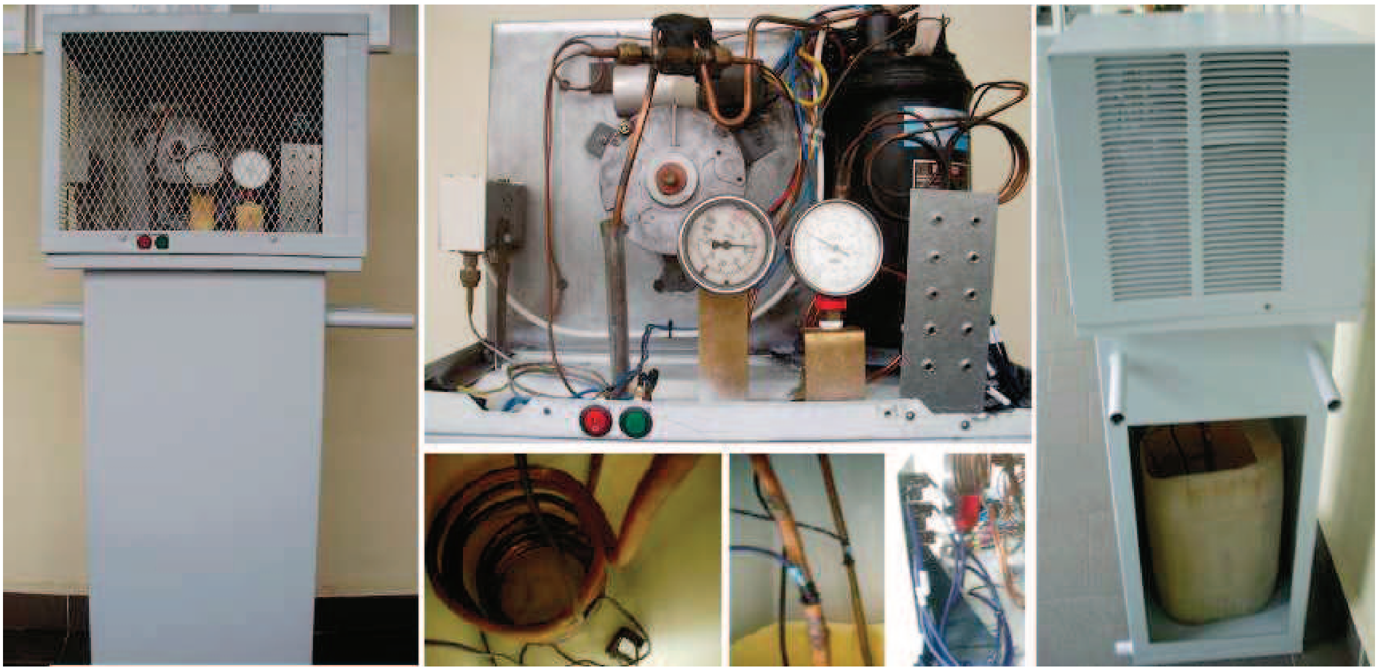

Fig. 2 Practical construction of the laboratory heat pump "air – water"

The central unit in the upper part contains the evaporator, the compressor with a maximum power of 1000 W, radial ventilator, refrigerant distribution, separator, manometers, high-pressure and low-pressure compressor protection (pressostat), the control panel and power supply. Some components from discarded refrigeration and air conditioning equipments were also used for the construction.

At the bottom of the central unit a spiral condenser is located. It is immersed in the heated medium located in the supporting base. The supporting structure has plan dimensions of 380 x 380 mm and a height of 900 mm.

IV. LABORATORY MEASUREMENT OF HEAT PUMP MODEL OPERATION

After the heat pump design, laboratory measurements were proceeded in order to determine its operating characteristics and output parameters. The main goal was to monitor the temperature of the inputs and outputs of design elements. The model is constructed so that it is possible to measure the temperature values in the following measurement points:

1. t_1 – condenser input,
2. t_2 – condenser output,
3. t_3 – evaporator input,
4. t_4 – evaporator output,
5. t_5 – compressor input,
6. t_6 – heated medium,
7. t_7 – separator input,
8. t_8 – compressor output,
9. t_9 – air leaving the evaporator,
10. t_{10} – air entering the evaporator.

Digital thermoelectric sensors are placed at selected measurement points according to Fig. 3.

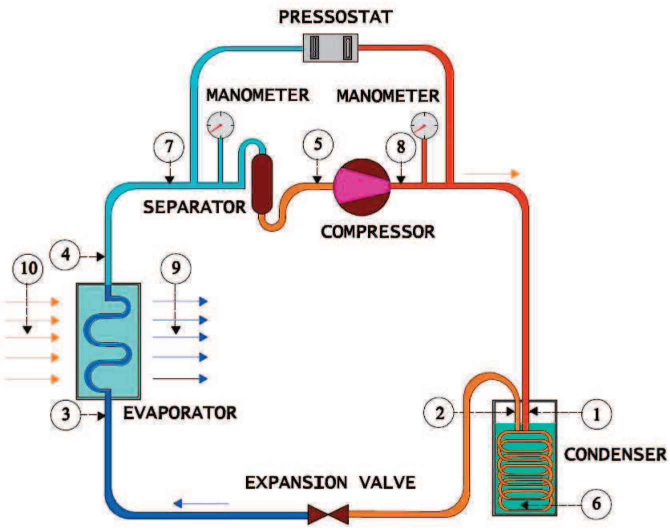

Fig. 3 Measurement points of the laboratory heat pump

The compressor is driven by an electric motor, which is monitored by an associated measuring instrument. The values of voltage, current, power factor, instantaneous power, as well as the total consumed electrical energy were measured.

The measurements were performed on the heat pump in a room with air temperature of 22 °C. At the beginning, the medium in a tank with a volume of 21 l has temperature of 15.81 °C. After 18 minutes there was an increase of temperature to 41.38 °C. During the measurement, the temperature values of the heat pump were changed. Fig. 4 shows changes of the temperature values from t_1 to t_{10}, as well as the instantaneous input power during the measurement.

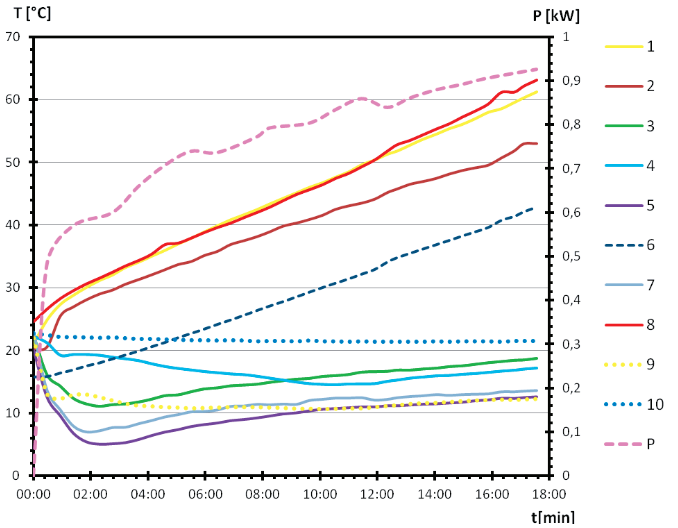

Fig. 4 Values of temperatures and input electric power during the heat pump operation

Energy efficiency of heat pumps is determined by the ratio of useful heat movement to work input. The term coefficient of performance (*COP*) is used. It is possible to define it as the ratio of the output heat given by the heat pump Q_t (kWh) to the electricity consumption of the heat pump Q_e (kWh):

$$COP = Q_t / Q_e \quad (1)$$

These variables from one of the experimental measurements are shown in Fig. 5.

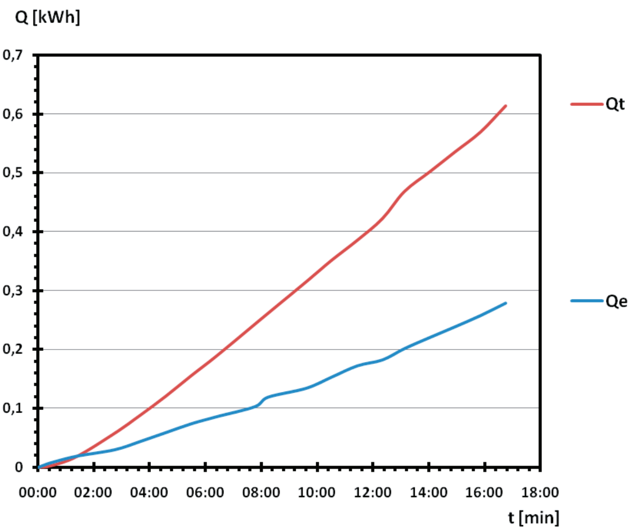

Fig. 5 Comparison of thermal energy produced and electrical energy consumed by the heat pump

The courses of *COP* during this measurement and the temperature of the heated medium $T_m \approx t_6$ are shown in Fig. 6. The measured dependences of Fig. 5 and Fig. 6 show that the course of *COP* at the beginning of the heating rises sharply to value of 2.5 and maintained in the range 2.3 to 2.5 independently of temperature.

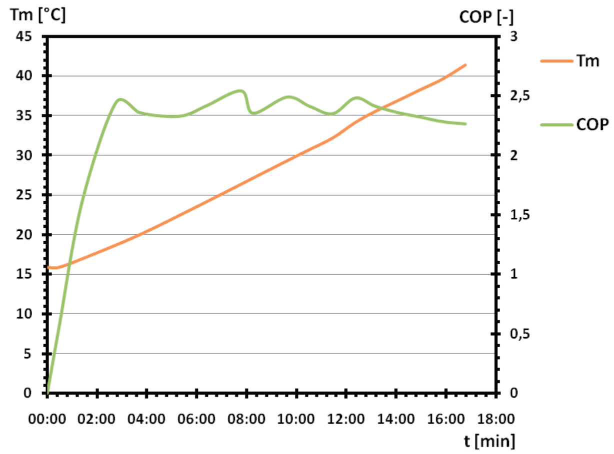

Fig. 6 Thermal carrier medium temperature and *COP* value during the experiment

Measurements with the medium of a higher volume of 35 l at different ambient temperatures were made too. Ambient temperature was 23 °C in the first case (HP1) and 14.8 °C in the second case (HP2). Starting value of medium temperature was 13.5 °C in both cases. The results were compared with the same amount of heated medium at the same temperature range using resistance heating (RH).

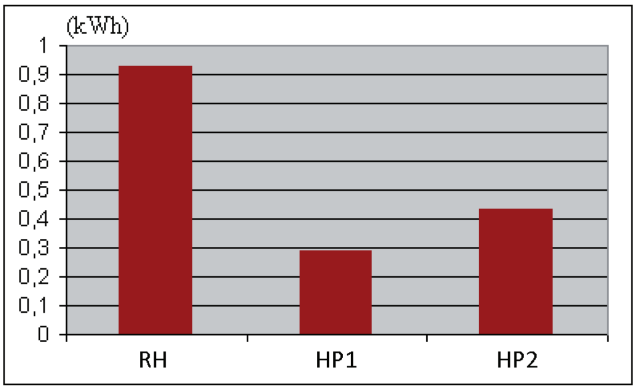

Fig. 7 Comparison of electricity consumption for medium heating

Fig. 7 shows that the laboratory heat pump is several times more efficient for heating compared to the method of resistive heating. It was confirmed that the temperature of the heat source has a significant impact on energy consumption for heating. *COP* achieved the value of 2.3 to 3.2 depending on the temperatures difference.

V. CONCLUSIONS

The European Parliament adopted a strategy of increased use of these resources in 2008. In this strategy, heat pumps were fully included among the renewable energy sources despite their dependence on electricity. The main argument for the inclusion was high energy efficiency of the heat pumps and their contribution to CO_2

emissions reduction. Therefore, the use of low-potential, or waste heat through heat pumps is very actual.

The heat pump allows increased heat production rationally by its transformation to a higher potential. Very convenient is the co-operation of heat pumps with solar and geothermal systems to achieve higher efficiency [6], [7]. Very promising is also combined generation of heat and electricity from photovoltaic cells [8], [9].

Literature study also pointed at the need for training of specialists with design skills and the possibilities of using these devices. For this purpose it was designed the laboratory heat pump. Experimental measurements confirmed the functionality and the possibility of its use in teaching.

In future it would be appropriate to supplement the laboratory heat pump by a frequency converter to supply the compressor. It would allow adaptation of compressor power to the required heat consumption, because it varies according to season and day period. Considering the compressor power of 1 kW it can be reached more rational operation of the heat pump. At present the heat pump can work only at full power, which requires the switching off in case of insufficient consumption [10], [11].

To optimize the operation of the laboratory heat pump, microcontroller-based technical equipment and programming tools could be also used [12].

The achieved technical parameters and *COP* of laboratory heat pump are comparable to the number of mass-produced heat pumps. The measured results show that the use of heat pumps can deliver significant savings of primary energy sources, and therefore it would be appropriate to implement support programs that would make their use more attractive.

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