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APPROXIMATE METHOD FOR THE ESTIMATION OF ENERGY PERFORMANCE OF HEAT PUMPS CONNECTED TO THE SYSTEM OF ENERGY MANAGEMENT OF FACILITIES

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Abstract. *Due to their efficiency heat pumps have found great application in the building industry, the process industry, in various technological processes in the production of food, to the space technology system, etc. When heat pumps are coupled to the energy management system which monitors and optimizes work parameters not only of the heat pump but also work parameters of other systems, such as solar and photovoltaic panels, thermal energy storages, electric batteries and the whole system, it is necessary to have a mathematical model that with sufficient accuracy and without great complexity estimates energy performance of the heat pump itself and the whole energy system. In this article a relatively simple mathematical model of a heat pump, with which it is possible to get values for the COP at any given time and under given conditions, was given. The obtained results of the model, applied to the air-water heat pump, used the input meteorological data of the mean air temperature for Belgrade, were presented. The verification of the obtained results of the model was made by using the catalogue data for the COP of the the Ecodan Monobloc Air Source Heat Pumps manufactured by Mitsubishi Electric.*

Key words: *Heat pumps, Carnot cycle, modeling, energy management system.*

1. INTRODUCTION

Current efforts to reduce energy consumption in all areas that cover human needs lead to the ever-increasing use of technical solutions that are energy efficient but also reliable at the same time. In order to get the most efficient energy systems, these solutions need to be integrated into a smart, functional energy system, energy management system. In the case of housing or industrial buildings, those are building energy management systems. These energy management systems constantly monitor and collect data related to the energy consumption in buildings (buildings, individual parts of buildings or building equipment), as well as data that include, for example, the daily schedule of use of building premises, all in order to reduce energy consumption for heating, cooling,

lighting, etc. In energy efficient facilities whose energy systems include photovoltaic panels, solar panels, heat pumps, heat accumulators, batteries, systems for the delivery of electricity to the distribution network, etc., it is necessary to predict the energy consumption for the operation of certain technical systems, i.e. it is necessary to know in advance the energy inputs and outputs of each of the existing systems. In the case of heat pumps, it is necessary to predict the energy performance of the heat pump (electricity consumption, heating power, heating coefficient). A mathematical model that enables the assessment of the energy performance of a heat pump is a sub-model of the mathematical model of the energy management system of an object used to optimize the energy costs of an object [1]. Bearing in mind the fact that a large number of heat pumps are present on the market, which, apart from their construction, differ in the used working media (R22, R404A, R407C, R410A, ...), it is necessary that the mathematical model of the heat pump as part of the complex mathematical model of the energy management system object, be as general as possible, but at the same time sufficiently accurate. In this regard, a model that relies on Carnot reversed cycle is given below, which avoids the dependence on the working medium but retains the dependence on the temperature ranges in which the heat pump operates.

2. MATHEMATICAL MODEL

The reversed Carnot cycle is a comparative cycle for comparison with the actual cycles that take place in cooling devices and heat pumps. For the needs of the model, the concept of the ideal heat pump is assumed. The scheme is shown in Figure 1. Thermal source is an environment that can be, for example, air from the environment, gases from industrial plants, water, soil, etc. The average water temperature used for heating purposes is determined based on the following equation:

$$T_m = \frac{T_{w,in} + T_{w,out}}{2} \quad (1)$$

where $T_{w,in}$ and $T_{w,out}$ are temperatures of the heating fluid i.e. the water from the heating system. The ambient temperature that represents the heat source is denoted by T_{env}. For Carnot heat pump, the cycle for the given temperature ranges are presented in Figure 2.

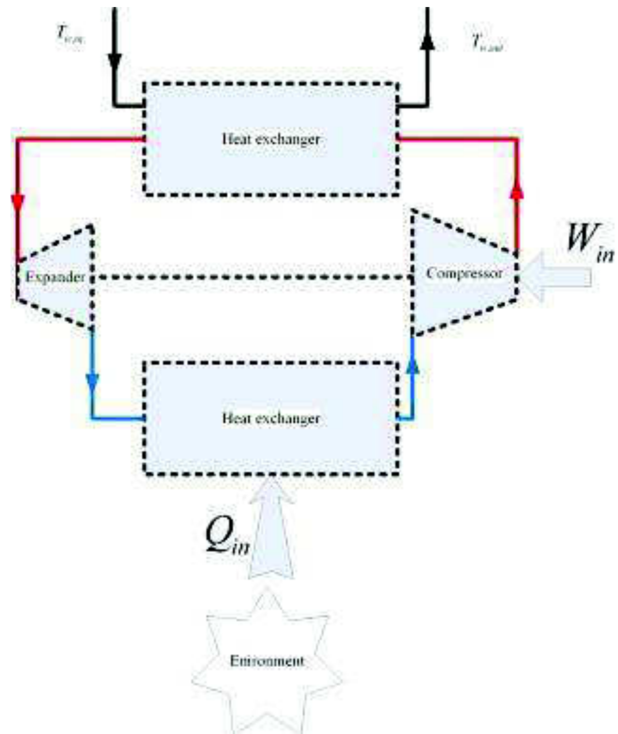

Fig. 1 Theoretical Carnot Heat Pump

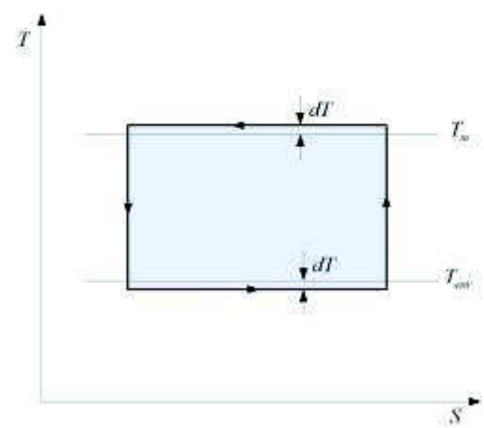

Fig. 2 Carnot reversed cycle in u T-S diagram

Figure 2 shows the temperature difference (the mean temperature difference) that must exist between the working media in order to carry out a spontaneous heat exchange process. In practice, this temperature difference ranges from 4 to 7 K. Thus, to achieve an approximate dependence of the energy consumption of an actual cycle, the Carnot ideal cycle occurs between the actual temperatures of the heating fluid T_m and the ambient temperature T_{env}. The heating coefficient of the Carnot circular process is determined on the basis of the expression:

$$COP_{CHP} = \frac{Q_{out}}{W_{in}} = \frac{Q_{out}}{Q_{out} - Q_{in}} = \frac{(T_m + dT)\Delta S}{(T_m + dT)\Delta S - (T_{env} - dT)\Delta S} \tag{2}$$

$$COP_{CHP} = \frac{T_m + dT}{T_m - T_{env} + 2dT} \tag{3}$$

The heating coefficient of an actual heat pump can be presented as a percentage of the heating coefficient of Carnot reversed cycle that would occur between the same heat source (T_{env}) and heat sink (T_m) temperatures. If the proportionality coefficient f, then the coefficient of heating of a real heat pump is:

$$COP_{RHP} = f \cdot COP_{CHP} = f\,\frac{T_m + dT}{T_m - T_{env} + 2dT} \tag{4}$$

The proportionality coefficient depends primarily on the isentropic efficiency of the compressor and ranges from 0.5 to 0.7[2][3].

3. Results and discussion

For the purpose of analyzing the accuracy of the simplified heat pump model, the air-to-water heat pump will be monitored, whilst the average air temperature for the City of Belgrade for the month of December 2016 is used for the air temperature (Figure 3).

If the heating water input temperature in the heat exchanger $t_{w,in} = 30°C$ and the outlet temperature of the water $t_{w,out} = 35°C$, are known, then for the given temperature of the source, heating coefficient/time dependence can be determined by the simplified model (Figure 4).

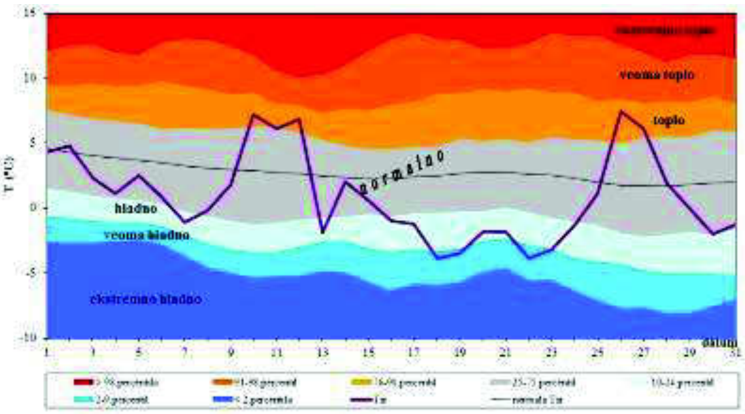

Fig. 3 The average daily air temperature for Belgrade in December of 2016 [4]

The values obtained for the heating coefficient of the actual heat pump shown in Figure 4 can be checked using the catalog values for the heating coefficient of the heat pumps given by the manufacturer. For the purposes of this paper, data from Mitsubishi Electric, i.e. data for heat pumps Ecodan Monobloc Air Source Heat Pumps type air-water are used. Based on the manufacturer's data (Table 1), it can be seen that the heating coefficient of the heat pumps for the outdoor air temperature of -3 ° C and the water inlet / outlet temperature of 30/35 ° C ranges from 2.8 to 3.01.

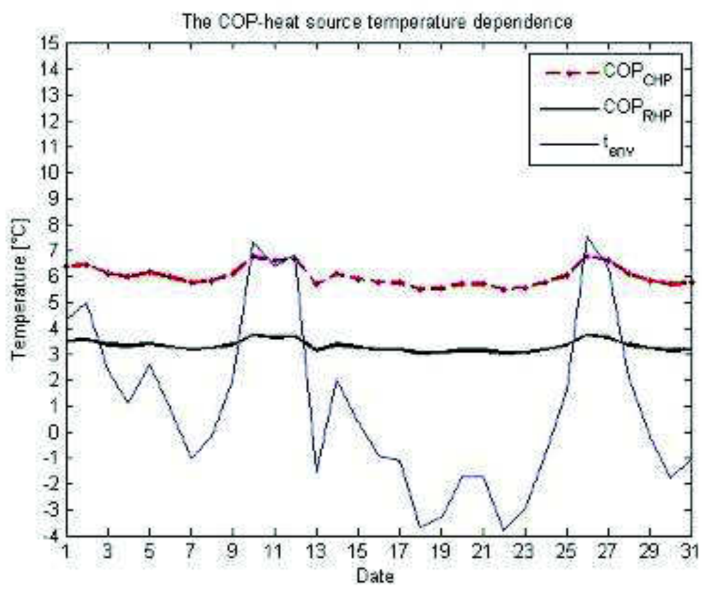

Fig. 4 COP – heat source temperature dependence

Table 1 Ecodan Monobloc Air Source Heat Pumps [5]

OUTDOOR UNIT		PUHZ-W50VHA2(-BS)	PUHZ-W85VHA2(-BS)	PUHZ-W112VHA(-BS)	PUHZ-HW140VHA2(-BS)	PUHZ-HW140YHA2(-BS)
HEAT PUMP SPACE HEATER - 55°C	ErP Rating	A++	A++	A++	A++	A++
	ηs	127%	128%	125%	126%	126%
	SCOP	3.25	3.27	3.2	3.22	3.22
HEAT PUMP SPACE HEATER - 35°C	ErP Rating	A++	A++	A++	A++	A++
	ηs	162%	162%	164%	157%	157%
	SCOP	4.12	4.12	4.18	3.99	3.99
HEAT PUMP COMBINATION HEATER - Large Profile*1	ErP Rating	A	A	A	A	A
	ηwh	99%	97%	100%	96%	96%
HEATING*2 (A-3/W35)	Capacity (kW)	4.8	8.3	11	14	14
	Power Input (kW)	1.63	2.96	3.65	4.81	4.81
	COP	2.95	2.8	3.01	2.91	2.91
OPERATING AMBIENT TEMPERATURE (°C DB)		-15 ~ +35°C	-20 ~ +35°C	-20 ~ +35°C	-25 ~ +35°C	-25 ~ +35°C
SOUND PRESSURE LEVEL AT 1M (dBA)*3*4		45	48	53	53	53
LOW NOISE MODE (dBA)*3		40	42	46	46	46
WATER DATA	Pipework Size (mm)	22	22	28	28	28
	Flow Rate (l/min)	14.3	25.8	32.1	40.1	40.1
	Water Pressure Drop (kPa)	12	13.5	6.3	9	9
DIMENSIONS (mm)*7	Width	950	950	1020	1020	1020
	Depth	330+30*5	330+30*5	330+30*5	330+30*5	330+30*5
	Height	740	943	1350	1350	1350
WEIGHT (kg)		64	77	133	134	148
ELECTRICAL DATA	Electrical Supply	220-240v, 50Hz	220-240v, 50Hz	220-240v, 50Hz	220-240v, 50Hz	380-415v, 50Hz
	Phase	Single	Single	Single	Single	3
	Nominal Running Current [MAX] (A)	5.4 [13]	10.3 [23]	11.2 [29.5]	14.9 [35]	5.1 [13]
	Fuse Rating - MCB Sizes (A)*6	16	25	32	40	16

*1 Combination with EHPT20X-MHCW Cylinder

*2 Under normal heating conditions at outdoor temp: -3°CDB / -4°CWB, outlet water temp 35°C, inlet water temp 30°C.

*3 Under normal heating conditions at outdoor temp: 7°CDB / 6°CWB, outlet water temp 35°C, inlet water temp 30°C as tested to BS EN14511.

*4 Sound power level of the PUHZ-W50VHA2 is 61dBA, PUHZ-W85VHA2 is 62.5dBA, PUHZ-W112VHA is 65dBA, PUHZ-HW140VHA2 is 65.5dBA, PUHZ-HW140YHA2 is 67.5dBA. Tested to BS EN12102.

*5 Grille.

*6 MCB Sizes BS EN60898-2 & BS EN60947-2.

*7 Flow Temperature Controller (FTC) for standalone systems PAC-IF062B-E Dimensions WxDxH (mm) - 520x150x450

ηs is the seasonal space heating energy efficiency (SSHEE) ηwh is the water heating energy efficiency

Comparison of these data with the data for the heating coefficient obtained by the model (Figure 4), it can be clearly concluded that there is a satisfactory agreement, whereby the coefficient of correlation in the model is considered to be $f = 0.55$. In real conditions, it

is necessary to measure the performance of the heat pump, i.e. experimentally determine the value of the correlation coefficient f.

4. CONCLUSIONS

Bearing in mind that it is practically impossible to create a heat pump model that would be applicable in all energy management systems, which would include all the specificities of the heat pumps that are in the market, the Carnot reversed cycle with the introduction of the correlation coefficient can be used for the optimization of energy consumption in facilities with sufficient accuracy. The heating coefficient f represents the Carnot cycle percentage approximation of the actual cycle. In this way, a connection is established between the external ambient temperature (air, water, ...) variable and the variable of the temperature of the water in the heating system. Therefore, the given model for optimization requires the monitoring of the temperature of the heat source, the input and the exit temperature of the water temperature, and the mass flow of heating water over time. The given model provides sufficient accuracy and the possibility of correcting the input parameters of the model, providing at the same time a possibility for application for the largest number of heat pumps used for heating objects for different purposes.

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REFERENCES

1. V. Lešić, A. Martinčević, M. Vašak, Modular energy cost optimization for buildings with integrated microgrid, Appl. Energy. 197 (2017) 14–28. doi:10.1016/j.apenergy.2017.03.087.

2. G.F. Hundy, A.R. Trott, T.C. Welch, Chapter 2 - The Refrigeration Cycle BT - Refrigeration and Air-Conditioning (Fourth Edition), in: Butterworth-Heinemann, Oxford, 2008: pp. 15–29. doi:https://doi.org/10.1016/B978-0-7506-8519-1.00002-5.

3. Cooling Equipment, in: Energy Audit Build. Syst., CRC Press, 2010: pp. 9–22. doi:doi:10.1201/b10342-10.

4. Republički hidrometeorološki zavod Srbije, Mesečni bilten za Srbiju, Decembar 2016.godine.

5. Mitsubishi Electric, Ecodan Monobloc Air Source Heat Pumps, 2 (2015) 2–3. http://www.midlandrenewables.ie/docs/MITSUBISHI-MONOBLOC-EXTERNAL-UNIT.pdf.

6. Whitney, S.E.C., Brigham, J.E., Darke, A.H., Reid, J.S.G., Gidley, M.J. (1995) *In vitro assembly of cellulose/xyloglucan networks: ultrastructural and molecular aspects,* Plant J., 8(4), pp. 491-504.