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WORKING METHOD OF A HEAT PUMP

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Abstract *The operating principle of the air-source heat pump is based on the physical property that the boiling point of a fluid increases with pressure. A heat pump has four main components: evaporator, compressor, condenser and expansion device. The examined heat pump is used for making domestic hot water and air condition. Decreasing energy resources of the Earth and enhanced energy consumption are typical of our life. However, one of the basic conditions to survive is that the amount of the energy used every day should be reduced. The energy used to air-condition a room and the possible use of secondary energies generated by the air-conditioning is studied in the research. The heat energy distracted by a heat pump out of the room is not let outside as heat loss, but it is used for making domestic hot water. The efficiency of the heat pump is examined with varied air parameters inside. About 0.3 kW electric power taken by heat pump from national electricity network. Heat pump can be separated from united electrical network by solar energy system; this article shows solution for this method too.*

Keywords *Air-conditioning, coefficient of performance (COP), domestic hot water supply, effectiveness, heat pump.*

INTRODUCTION

In general, the purpose of air-conditioning is to generate temperature lower than the ambient temperature and keeping it constant inside the room to air-condition [8]. In practice, heat pumps driven by an electric compressor are generally used. The ratio of the heat energy egressed by the heat pump and the energy taken from the electric supply for driving the compressor (and the fans) is called the coefficient of performance of the cycle. The higher the coefficient of performance of a heat pump is the more economic it is, it varies between 2 and 5 according to the structure of the heat pump, the ambient temperature outside and the way of application. See the schematic diagram of a heat pump in Figure 1.

The following relation can be described between the energies in Figure 1:

$$Q_h = Q_c + W \tag{1}$$

where:

Q_c	the heat distracted from the room	[J],
Q_h	the quantity of heat egressed to the hot water tank	[J],
W	electric energy taken by the heat pump	[J].

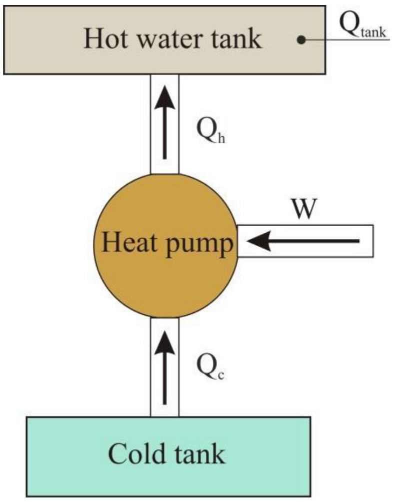

Figure (1) Schematic diagram of a heat pump

Theoretical coefficient of performance of the heat pump [1-6]:

$$COP = \frac{Q_h}{W} = \frac{Q_c + W}{W} \tag{2}$$

where:

COP coefficient of performance of the heat pump [-].

The heat energy stored in the hot water tank of the heat pump as hot water:

$$Q_{\text{tank}} = m_w c_w \Delta T_w \tag{3}$$

where:

Q_{tank} heat energy stored in a hot water tank [J],

m_w mass of the heated water [kg],

c_w specific heat of the water, $\left[\frac{\text{kJ}}{\text{kg}^\circ\text{C}}\right]$,

ΔT_w difference of the mean temperature at the bottom and on the top of the water tank $\left[{}^\circ\text{C}\right]$.

As a result of the losses of the system:

$$Q_h > Q_{\text{tank}}. \tag{4}$$

The heat loss on the condenser side:

$$Q_{loss} = Q_h - Q_{\text{tank}} \tag{5}$$

where:

Q_{loss} loss generated in the heat exchanger (condenser) [J].

Thus the relation of the actual and theoretical coefficients of performance can be written on the operation of the heat pump, using relation (3):

$$COP > COP_{\text{actual}} = \frac{Q_{\text{tank}}}{W} = \frac{m_w c_w \Delta T_w}{W}. \tag{6}$$

The heat pump system is a cycle that consists of two heat exchangers (evaporator, condenser), a compressor and a butterfly valve [7]. Each element is joined by a pipe filled with transfer medium. The operation of the heat pump is illustrated in Figure (2).

1 The compressor condenses the gaseous transfer medium (R134a) using electric energy (which heats) and circulates it in the system permanently.

2 The heat of the hot gas inside the fan-coil unit - through a water heat exchanger - is used for making hot water, while the medium cools down, precipitate and turned into fluid again.

3 The liquid medium flows to a space of bigger cross section, through an expansion valve, to the evaporator. The pressure declined hereby makes the medium, which expands and strongly cools accordingly, gaseous again.
4 By utilizing hundreds of cubic meters of air sucked through the evaporator, heat is distracted from the surroundings, which makes the air cool down in the room. Then this hotter vapour is condensed again starting from the first step.

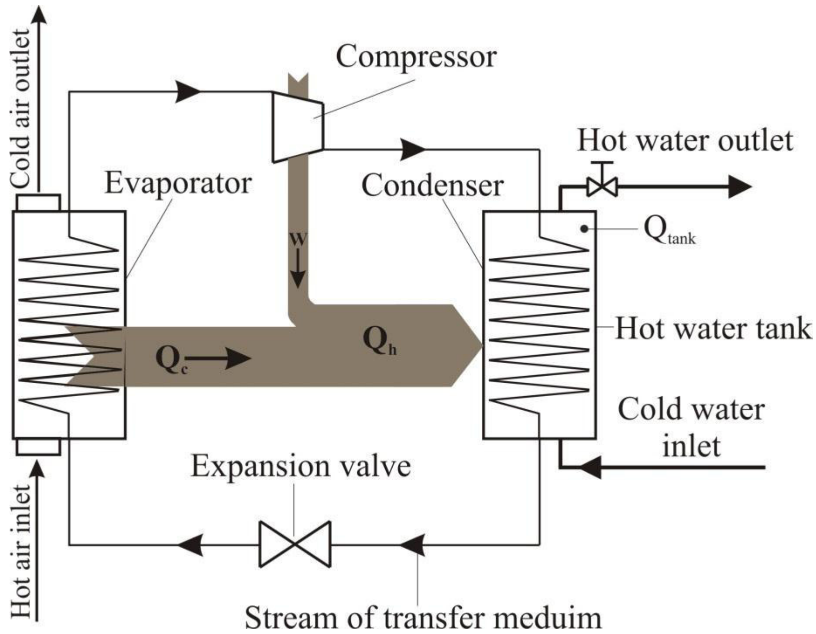

Figure (2) Working process of the heat pump cycle

Heat pumps are heat engines of reverse operation. The thermodynamic cycle can be followed on the temperature-entropy (T-s) diagram (Figure 3). The process starts from point 1, where the medium at p_i pressure and T_i temperature occurs as saturated vapour. Processes 1 and 2 are adiabatic compressions that happen in the compressor. Normally, this change of state is indicated in the diagram as a vertical line (isentropic compression), but in reality the change of state is irreversible, entropy permanently increases, thus the curve slightly bends to the right.
Processes 2 to 5 happen in the condenser: processes 2 and 3 are the distraction of overheating heat; in point 3 the vapour reaches saturated state at pressure p_f . In processes 3 and 4 the temperature does not change, more and more vapour precipitates and the liquid state emerges in point 4. Processes 4 and 5 in the condenser is the possible after-cooling of the fluid medium, then processes 5 and 6 is the thermodynamic process, which results in sudden fall of the pressure, at the end of which the medium expands to p_f pressure and T_f temperature, the liquid partly (approximately half of it) evaporates suddenly and the medium turns into wet, vapour state. This is an isenthalpic process, i.e. during the process the enthalpy does not change.
Finally, in processes 6-1, the medium takes heat in the evaporator from the space to cool at permanent temperature and pressure, while the moisture content of the vapour declines gradually. Then the medium returns to the starting point of the cycle, to state 1, and the process starts again. Naturally, all mentioned above apply to an ideal medium; the processes rather differ in deed [10].

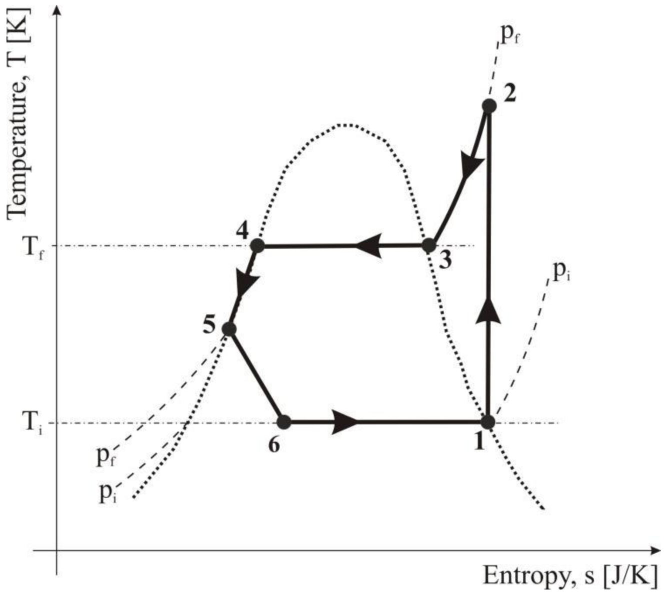

Figure (3) Cycle of the vapor-compression refrigerator on the temperature-entropy diagram

MATERIALS AND METHODS

A heat pump installed in one of the rooms of the site of Óbuda University in Doberdó Street is examined focusing on the economy of air-conditioning. The examination is performed depending on the measuring order illustrated on Figure 4.

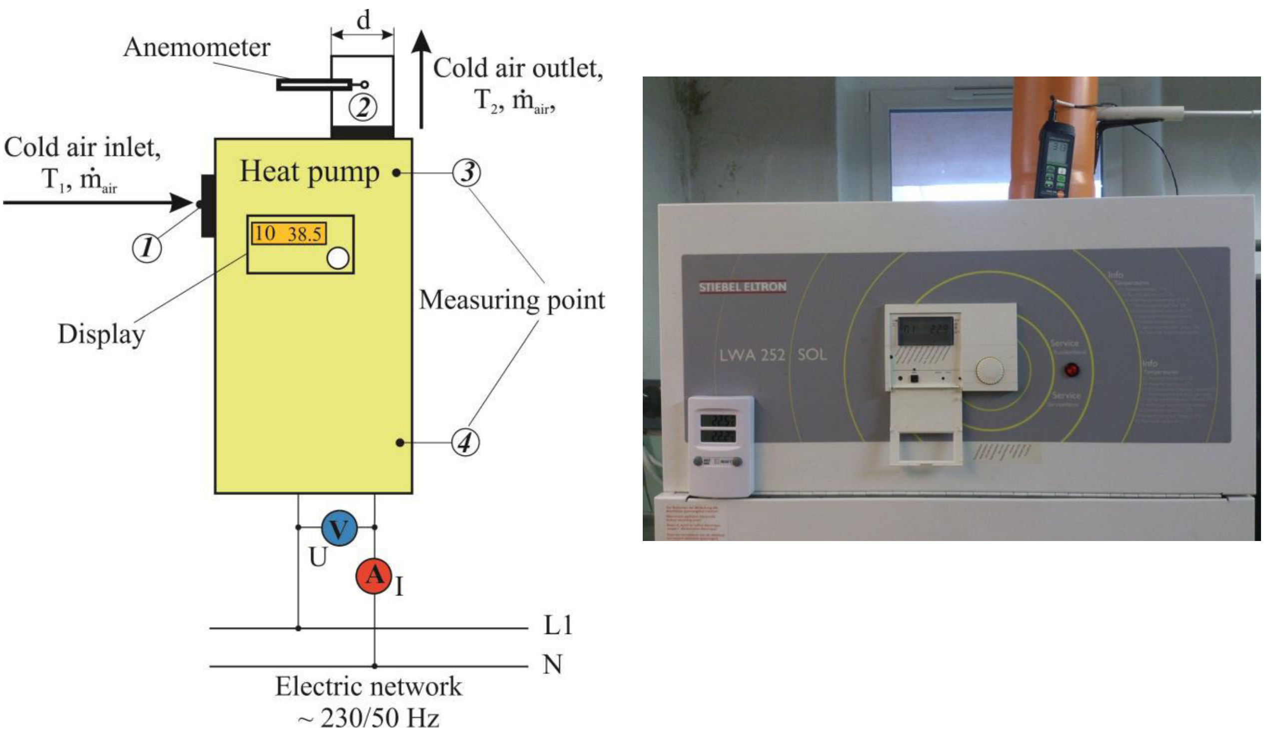

Figure (4) Measuring order of a heat pump

The measuring system consists of the following main elements:

- air-water heat pump to examine,
- anemometer type testo 435,
- ammeter and voltmeter,
- thermometers built in the heat pump.

RESULTS

The temperatures of the air let in and out of the pump are measured at the measuring points 1 and 2 as illustrated on Figure (4). At point 2 the air flows out of the pump through a pipe end of 160 mm diameter. The speed of the air let out of the pump is measured with an anemometer type testo 435, the average of which is: $v_{air} = 3.3\ ms^{-1}$. During the time of warming up ($t = 242\ \min \approx 4\ h$) the volume flow rate of the air blown out is $237.6\ m^3h^{-1}$. The outcoming values relating to the measuring time are illustrated in Microsoft Excel. Afterwards, the trend lines are defined by using regression, indicating the determinant coefficients R^2.

Table (I) Temperature measuring results

Measuring time, t [min]	Inlet air temperature, T_1 [°C]	Outlet air temperature, T_2 [°C]	Hot water temperature up, T_3 [°C]	Hot water temperature down, T_4 [°C]
0	24.2	22.5	26.9	26.4
5	24.2	17	27	26.4
10	23.5	13.2	27.6	26.4
15	23.1	12.5	28.2	26.4
30	22.6	12.1	30	26.4
45	22.5	11.4	31.6	26.5
60	22.4	11.1	33.2	26.5
75	22.3	10.9	34.7	26.6
105	22.2	10.9	37.5	26.7
135	22.2	11.1	40.3	27
165	22	11.1	43.1	27.4
195	21.8	11.2	45.8	27.9
225	21.7	11.3	48.5	28.5
242	21.7	11.2	50	29.8

Figures 5 and 6 illustrate the inlet and outlet temperatures of air listed in Table (I).

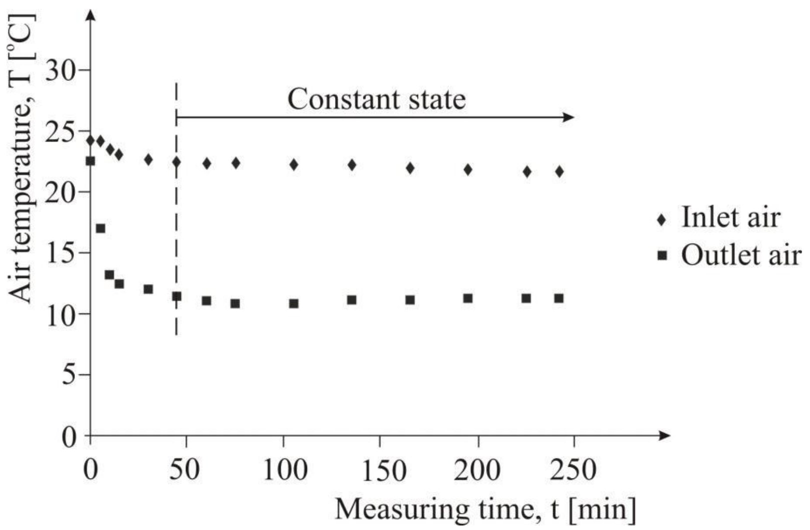

Figure (5) The temperatures of inlet and outlet air during the operation of the heat pump

Figure (6) indicates the regressive approach of the air let in and out, also marking the determinant coefficients.

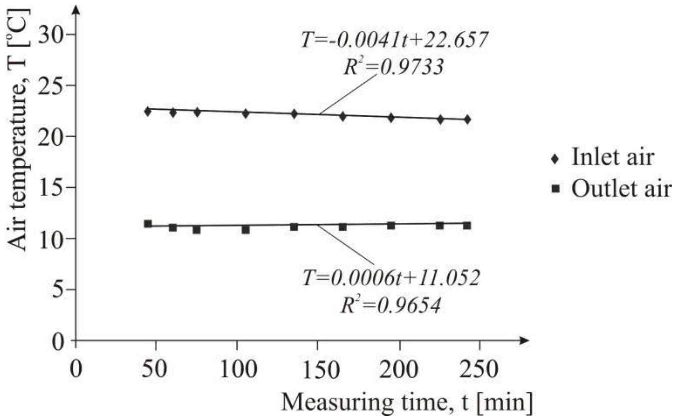

Figure (6) The temperatures and regression of inlet and outlet air in the constant state

At measuring point 3 in Figure (4), the temperature is measured at the top of the hot water tank, and at point 4, the temperature is measured at the bottom of the tank. Table (I) contains the measuring results. Figure (7) shows the temperatures of the hot water tank.

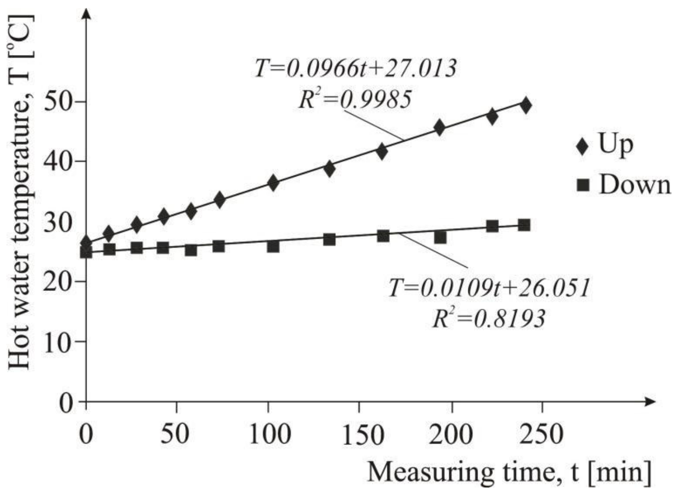

Figure (7) The temperatures of the hot water tank up and down

Figure (8) indicates the temperatures of the evaporator.

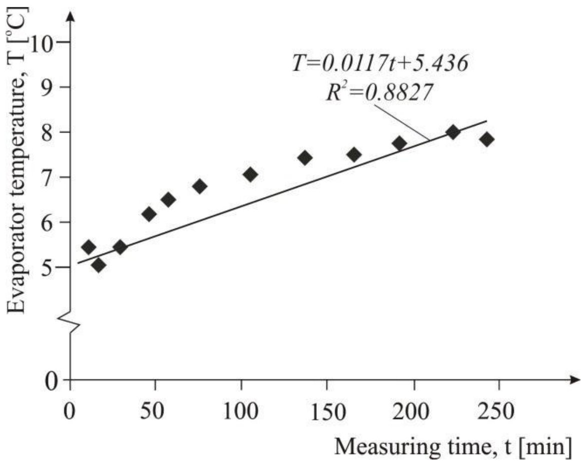

Figure (8) Temperature ranges of the evaporator

Figure (9) presents the current consumption of the heat pump with constantly $U = 224\ V$ alternating voltage; the graph indicates increasing current consumption. The value of the power factor during the operation of the heat pump is $\cos\varphi = 0.9$.

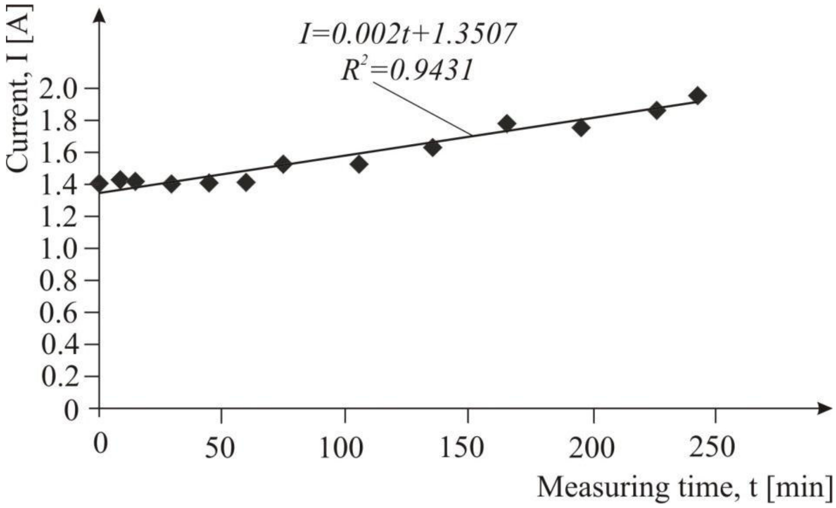

Figure (9) Current consumption of the heat pump

Rewriting relation (6) to performances:

$$COP_{actual} = \frac{Q_{\text{tank}}}{W} = \frac{P_{\text{tank}} \cdot t}{P_e \cdot t} = \frac{P_{\text{tank}}}{P_e} \quad (7)$$

where:

P_{tank}	heat power of the hot water tank	[kW],
P_e	electric power taken by the heat pump	[kW].

Taken electric power based on the measured data:

$$P_e = U\bar{I}\cos\varphi = 224 \cdot 1.53 \cdot 0.9 = 308.5\,W \approx 0.3\,kW. \quad (8)$$

where:

U	effective value of the alternating voltage	[V],
$\bar{I}$	average of the measured currents (based on the data of Figure 9).	

Volume flow rate of the inlet and outlet air:

$$\dot{V}_{air} = A\bar{v}_{air} = \frac{d^2\pi}{4}\bar{v}_{air} = \frac{0.16^2\pi}{2}3.3 = 0.02 \cdot 3.3 = 0.066\,m^3/s = 237.6\,m^3/h. \quad (9)$$

where:

A	cross section of the and air pipe end in and out	[m^2],
d	diameter of the air pipe end in and out (Figure 4)	[m],
$\bar{v}_{air}$	the average speed of the air outlet in the cross section out	[m/s].

The mass flow of the inlet air:

$$\dot{m}_{air} = \dot{V}_{air}\rho_{air} = 0.066 \cdot 1.2 = 0.0792 \approx 0.08\,kg/s = 288\,kg/h. \quad (10)$$

here:

ρ_{air}	density of the air	[kg/m^3].

Heat power extracted from the air:

$$\dot{Q}_c = \dot{m}_{air}c_{air}\Delta T_{air} = \dot{m}_{air} \cdot c_{air}\left(\bar{T}_1 - \bar{T}_2\right) = 0.08 \cdot 1 \cdot \left(22.6 - 11\right) = 0.928 \approx 0.93\text{ kW}. \quad (11)$$

where:

c_{air} specific heat of the air at constant pressure $\left[\frac{kJ}{kg^\circ C}\right]$,

ΔT_{air} difference of the mean temperatures of the inlet and outlet air $[^\circ C]$.

Quantity of the heat of the hot water based on (3) and Figure (10):

$$Q_{tank} = m_w c_w \left(\overline{T}_{34f} - \overline{T}_{34i}\right) = 290 \cdot 4.2 (40.0 - 26.65) = 16260.3 \text{ kJ} \approx 16.26 \text{ MJ}. \quad (12)$$

where:

$\overline{T}_{34i}$ the mean temperature of the water tank at the beginning of measuring $[^\circ C]$,

$\overline{T}_{34f}$ the mean temperature of the water tank at the end of measuring $[^\circ C]$.

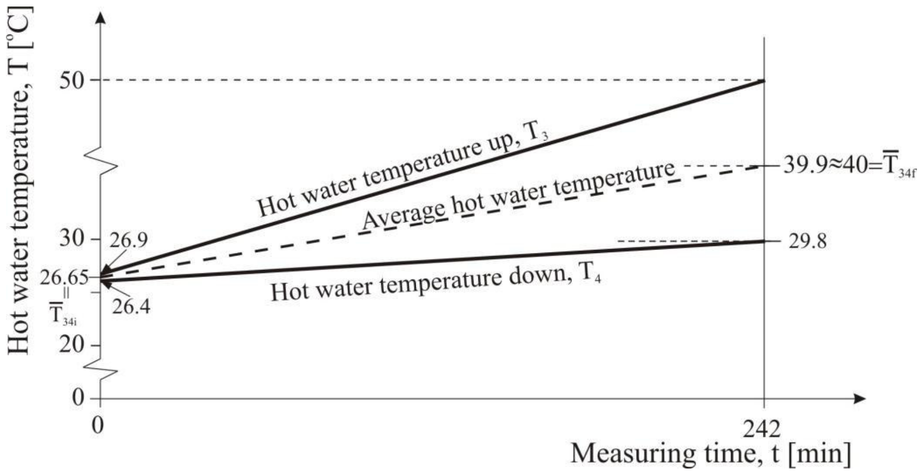

Figure (10) Temperature ranges of the hot water tank depending on measuring time

Heat power:

$$P_{tank} = \dot{Q}_{tank} = \frac{Q_{tank}}{t} = \frac{16.26 \cdot 10^6}{14.52 \cdot 10^3} = 1.119 \approx 1.12\, kW. \quad (13)$$

where:

t measuring time (warming up time) [s].

Applying this factor the result is relation (7), i.e. the actual coefficient of performance of the heat pump:

$$COP_{actual} = \frac{P_{tank}}{P_e} = \frac{1.12}{0.3} = 3.73 \approx 3.7. \quad (14)$$

CONCLUSION

The value of the coefficient of performance, while examining the heat pump energetically, is $COP = 3.7$, which corresponds to the value defined in the technical literature.

At present, concerning air intake air conditioners, the heat energy taken from the space to air-condition is generally let outside the room. In our research a system is established that enables the heat energy that has been managed as loss so far, to be utilized for making domestic hot water. This energy decreases the amount of electricity taken for making domestic hot water. Thus the efficiency of the system (air-conditioning and making domestic hot water), having been examined, is nearly 100%.

The time of the static return of investment of the system may be defined by the following relation [9].

$$\text{Time of return of investment} = \frac{\text{Invested sum of money}}{\text{Savings annually}}. \quad (15)$$

Return of investment of this system may be expected within 5 years.

On the effect of more intensive radiation of the sun the temperature of the air is increasing. On this effect the warmer feed-water produced by solar collector and connected to the inlet arm for cold water of the heat pump increases the efficiency of the heat pump.

The production of the electricity of the solar panel system is also increasing while the electricity supply of the heat pump is rendered. The air-water heat pump working in this way is an effective device for energy production. The theoretical scheme of its realization is shown in Figure (11).

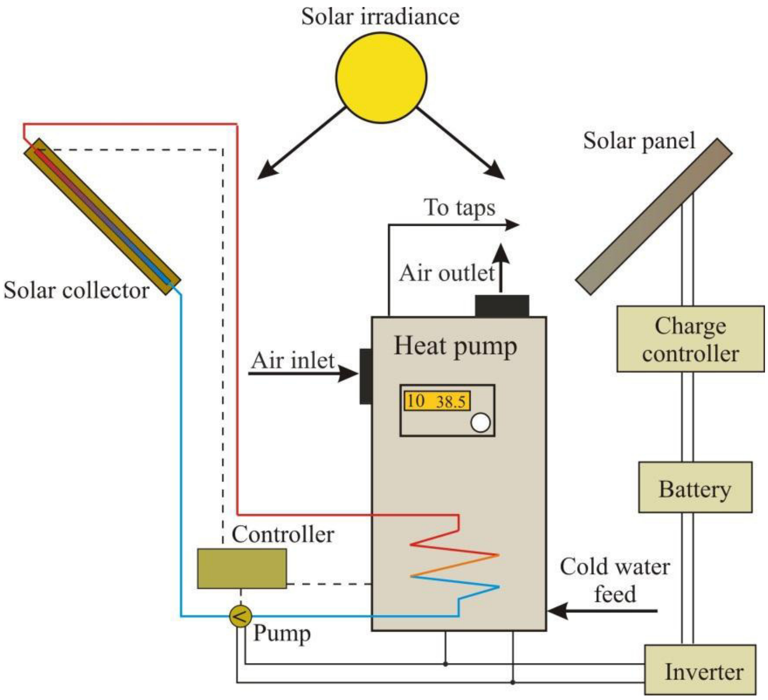

Figure (11) Used of solar energy system

This makes possible the disconnection from the national mains. Thus the supply of energy (domestic hot water, air conditioning) and the electricity of a family house can be realized from renewable energy-sources.

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