

SOLAR COLLECTOR WITH HEAT PUMP

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Abstract. In order to increase water temperature, which has been heated by the solar collector, a heat pump is suggested to use. There theoretical calculation has been carried out and the results show that by the use of a heat pump it is possible to make the domestic water heating unit, consisting of a solar collector and heat pump. The objective of the investigation is to base the operation of such a unit. In order to be sure about the work of the unit there experimental investigation has to be performed. For that it is envisaged to develop the unit by the use of flat plate solar collector and the heat pump, which is made from the refrigerator cooling aggregate working in opposite direction.

Key words: solar radiation, solar collector, heat pump, water heating.

Introduction

Solar collectors are widely used for hot domestic water heating in many countries of the world. According to over investigation during summer months it is possible to use solar collectors for water heating in Latvia too, regardless of large number of cloudy and rainy days even in summer time [1]. On the average we have about 1800 sunny hours per year in comparison with southern countries which have 2200 and more sunny hours per year, therefore the solar radiation often is not enough to reach the necessary hot water temperature by the use of solar collectors only.

On a clear sunny day the power of global radiation reaches 1000 W m^{-2} , a part of which is direct, and a part, diffuse radiation (Table 1). May June and July together gives about 52 % of total yearly radiation, but December and January make only less than 2 % of yearly radiation in Latvia.

Table 1

Diffuse radiation out of global in Latvia [2]

	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Diffuse radiation, %	78	73	53	49	44	42	48	51	55	68	73	83	50

On the average in summer months (April-September) the specific solar radiation is only about 500 W m^{-2} on a horizontal surface. During the rest of months the specific power of radiation is lower and that is not enough for domestic water heating needs. Therefore we are looking for ways to increase the water temperature by the use of other technical means. One of them is a heat pump. The construction and principles of operation of the heat pump are well known and they are available in the market. We have made a theoretical examination about the possibility of simultaneous work of a solar collector and heat pump as one unit, and now we have to make an experimental investigation of its operation in real field conditions. For all that the price of the heat pump is too high for as. In order to organize the experiment we have to make the unit by ourselves, and by the use of cheaper and available materials.

The objective of the investigation is to clear up the efficiency of the common work of a solar collector and heat pump.

Materials and Methods

The principal scheme of the construction and operation of such a unit in Fig. 1 is presented, consisting of a solar collector, hot water accumulator and heat pump.

For the experimental investigation it is envisaged to make up the unit, in which as a heat pump the aggregate of a refrigerator will be used (Fig. 2). To the evaporator of the refrigerator aggregate there the heat exchanger 10 with the hot water tank 8 is connected. The radiator of the refrigerator aggregate will be used as the condenser 14 of the heat pump, and placed into the hot water basin 13.

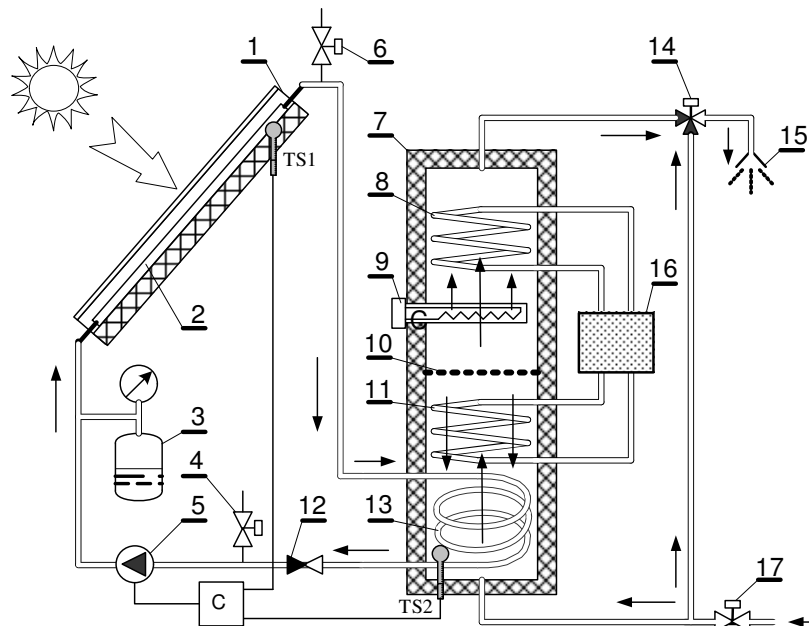


Fig. 1. Principal scheme of the unit of solar collector and heat pump: 1 – solar collector; 2 – absorber of the collector; 3 – expansion vessel; 4 – heat carrier inflow valve; 5 – circulation pump; 6 – air outlet valve; 7 – hot water tank; 8 – heat pump condenser; 9 – electric heater; 10 – perforated diaphragm; 11 – heat pump evaporator; 12 – contr-flow valve; 13 – heat exchanger; 14 – water mixing valve; 15 – hot water consumer; 16 – heat pump; 17 – cold water inlet; TS – temperature sensor; C – control device

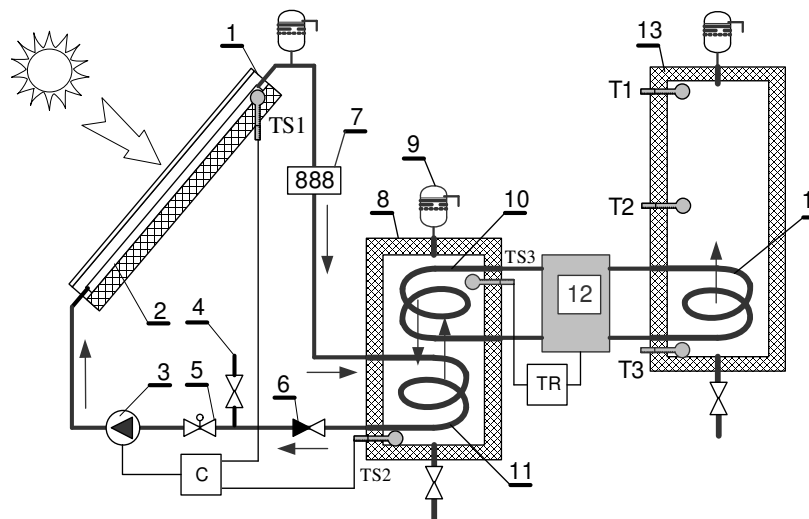


Fig. 2. Operational scheme of the experimental unit: 1 – solar collector; 2 – absorber; 3 – circulation pump; 4 – inlet valve; 5 – flow control valve; 6 – cont-flow valve; 7 – heat counter; 8 – heat exchanger-thermos; 9 – expansion vessel; 10 – heat pump evaporator; 11 – heat exchanger of collector circle; 12 – heat pump; 13 – hot water storage tank; 14 – condenser of heat pump; TS – temperature sensor; C – control unit; TR – temperature regulator; T1...3 – thermometers

The principle of operation of the system is as following. When the absorber of the collector is heated by the sun and the temperature of the heat carrier, measured by the sensor TS1, becomes higher then in the hot water tank 8 (Fig. 2), measured by the sensor TS2, the control device VB switches on the pump 3, which transforms the heat from the absorber into the hot water basin 8. When the temperature in the hot water tank 8, measured by the sensor TS3, reaches the value stated in the temperature regulator TR, it switches on the heat pump 12. The heat pump 12 transforms the heat from the hot water tank 8 to the hot water tank 13, consuming for this some amount of electric energy.

Results and Discussion

In order to have a stationery-working regime at different radiation power on the collector, instead of solar radiation there electric lamps with controlled power will be used. For the power measuring and obtained energy registration in the collector circle there the heat counter 7 will be used. For the registration of the amount of heat accumulated in the hot water tank 13, it is envisaged to use the measurements of the thermometers $T_1 \dots T_n$ and formula (1)

$$Q_k = 0.278 \cdot 10^{-3} \cdot G \cdot C_p \cdot \Delta T_{ab}, \quad (1)$$

where: Q_k – heat energy, produced by collector, $W \cdot h^{-1}$;

G – amount of heat carrier, kg;

C_p – specific heat of heat carrier, $J \cdot k^{-1} \cdot g^{-1} \cdot ^\circ C^{-1}$ (for water $C_p = 4.18 \cdot 10^3 J \cdot k^{-1} \cdot g^{-1} \cdot ^\circ C^{-1}$);

ΔT_{ab} – difference between the heat carrier inlet into absorber T_i and outlet

T_o temperatures.

$$\Delta T_{ab} = T_i - T_o, \quad ^\circ C. \quad (2)$$

In order to analyze the operation of the developed system the following is assumed:

- the system will operate at the range of ambient air temperature $T_a = 0 - 30 \text{ } ^\circ C$;
- temperature in the heat exchanger tank 8 $T_{ex} = 25 \text{ } ^\circ C$;
- temperature in the hot water tank 13 $T_w = 70 \text{ } ^\circ C$;
- maximum heat carrier temperature at the outlet of absorber $T_{o,max} = 30 \text{ } ^\circ C$;
- difference between heat carrier inlet and ambient air temperatures $T_i - T_a = 0 - 30 \text{ } ^\circ C$ or on the average $T_i - T_a = 15 \text{ } ^\circ C$.

As the difference between the temperatures $T_w - T_{ex} = 70 - 25 = 45 \text{ } ^\circ C$, then from Table 2 the heat transfer coefficient of the heat pump $\varepsilon = 4.0$ [3].

Table 2

Heat pump transfer coefficient depending on condenser and evaporator temperature difference $T_w - T_{ex} = \Delta T$

$\Delta T, \text{ } ^\circ C$	20	30	40	50	60
ε	8.5	6.4	4.4	3.6	2.9

For the experiment it is envisaged to use the refrigerator frost aggregate XKB8-JIMY with power $P_a = 160 \text{ W}$. Then the power produced by the unit is

$$P_u = P_a \cdot \varepsilon = 160 \cdot 4 = 640 \text{ [W]}. \quad (3)$$

For the operation of the unit the necessary power of the solar collector [3]

$$P_k = P_u - \frac{P_u}{\varepsilon}. \quad (4)$$

In our case

$$P_k = 640 - \frac{640}{4} = 480 \text{ [W]}. \quad (5)$$

On the other hand the power of the solar collector can be determined as

$$P_k = A[P_s \cdot \eta_0 - K_k(T_i - T_a)], \quad (6)$$

where: P_k – power of solar collector, W;

A – absorber area, m^2 ;

- P_s – power of radiation on the collector surface, W m^{-2} ;
 η_o – optical efficiency of the collector;
 K_k – total heat losses coefficient of collector, $\text{W m}^{-2} \text{ } ^\circ\text{C}^{-1}$;
 T_{ev} – heat carrier average temperature in the absorber, $^\circ\text{C}$;
 T_i – heat carrier inlet temperature into absorber, $^\circ\text{C}$;
 T_a – ambient temperature, $^\circ\text{C}$.

The optical coefficient η_o of the solar collector does not depend on the intensity of solar radiation P_s on the collector surface, and temperatures difference $T_i - T_a$. It is calculated by expression

$$\eta_o = \alpha \cdot \tau, \quad (7)$$

where τ – coefficient of penetrability of solar rays through the glass pane (0.6 – 0.95);
 α – absorption coefficient of solar radiation by the absorber (0.85 – 0.98).

The efficiency of a solar collector [4]:

$$\eta_k = \eta_o - K_k \frac{T_i - T_a}{P_s} = \eta_o - K_k \cdot y, \quad (8)$$

where

$$y = \frac{T_i - T_a}{P_s}. \quad (10)$$

If the heat loss of the collector is characterized by two coefficients [5], then

$$\eta_k = \eta_o - \frac{k_1(T_i - T_a)}{P_s} + \frac{k_2(T_i - T_a)^2}{P_s}, \quad (11)$$

where k_1, k_2 – heat loss coefficients of the collector.

The instantaneous efficiency of the collector is given as

$$\eta_i = F'(\alpha \cdot \tau - K_k y), \quad (12)$$

where F' – efficiency of the absorber [6].

$$F' = \frac{K_o}{K_k}, \quad (13)$$

where K_o – heat transfer resistance from heat carrier to the ambient air, $\text{W m}^{-2} \text{ } ^\circ\text{C}^{-1}$.

The values of the heat loss coefficient for a flat plane solar collector depend on the type of the collector as well as its design, and are collected in Table 3.

Table 3

**Numerical values of optical and heat loss coefficients
for different types of collectors [4]**

Type of collector	Optical efficiency η_o	Heat loss coefficient K_k , $\text{W m}^{-2} \text{ } ^\circ\text{C}^{-1}$
Without selective coating and glass	0.95	15.0
The same with one glass	0.85	7.0
The same with two glasses	0.75	5.0
Selective coating with one glass	0.80	3.5
With vacuum tubes	0.75	2.0

Choosing the type of the solar collector it is purposeful to use the monogram given in Fig. 3. For example, in our case due to small difference between the temperatures $T_i - T_a = 15\text{ }^\circ\text{C}$ from Fig. 3 it is seen that using the collector without glass cover its efficiency at the radiation intensity $P_s = 400\text{ W m}^{-2}$ will be about 0.37. If the temperature difference $T_i - T_a$ will change from 0 to $30\text{ }^\circ\text{C}$, the value of efficiency will change from 0.95 to 0. Better results will be obtained using the ordinary collector with one glass cover. It will operate at smaller radiation intensity, for example, at $P_s = 300\text{ W m}^{-2}$ and the temperature difference $T_i - T_a$ from 0 to $30\text{ }^\circ\text{C}$ and its efficiency will be with in the limits of 0.85 – 0.13.

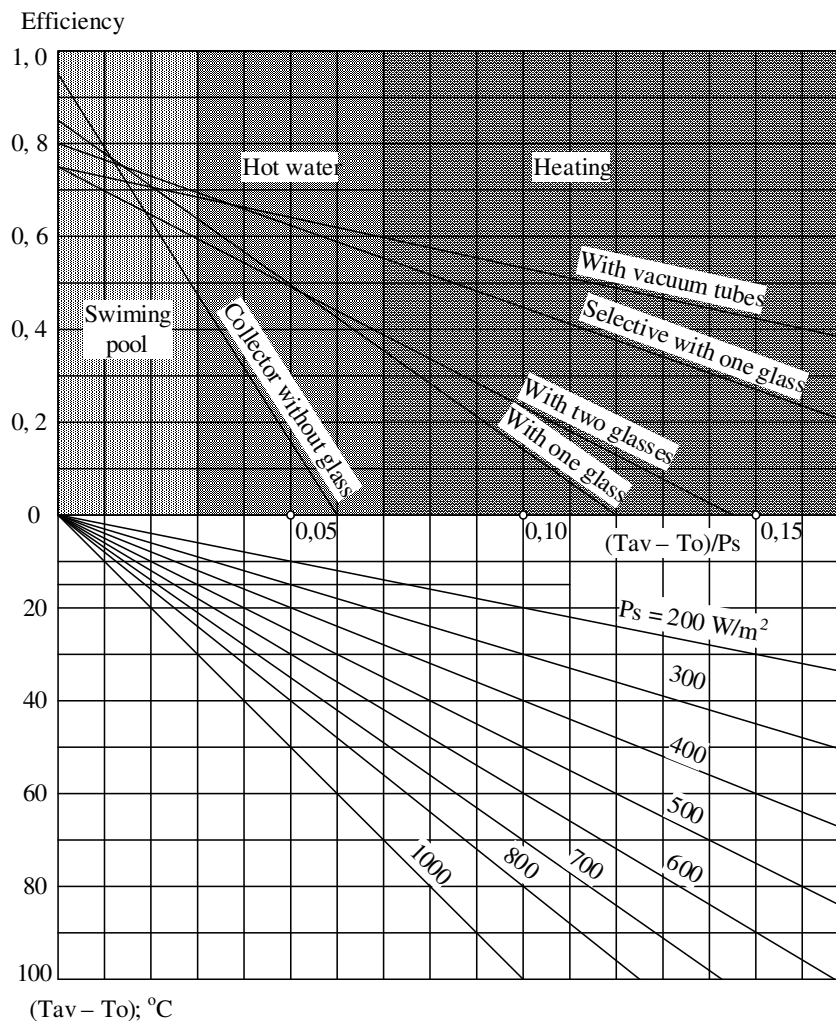


Fig. 3. The collector efficiency depending on the power of the solar radiation P_s and design of the collector, as well as the average difference between the heat carrier temperature in the absorber and surrounding air temperature ($T_i - T_a$)

Using the ordinary collector with two glass covers its efficiency will be lower at small temperature differences, but higher at higher temperature differences, that is 0.75-0.23. From the monogram it is seen that higher efficiency and in wide temperature range will be of collectors with selective coatings. Using this type of collectors it is possible to heighten the temperature value given for the heat exchanger tank, for example, from 25 to $40\text{ }^\circ\text{C}$. In that case the heat pump will operate at the temperature difference $T_i - T_a = 20\text{ }^\circ\text{C}$ and the value of its heat transfer coefficient will be about 8. The collector will be more expensive, but the consumption of electricity, lower. To clear out the relationship between these factors is one of more important objectives of this experiment.

Conclusions

1. For more precisely investigation of the use of heat pump in common unit with solar collectors, experimental investigation have to be carried out.
2. At higher efficiency solar collectors are operating when their absorber plates have selective coatings.

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