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Simulation of Solar Energy Use in Livelihood of Buildings

I Ya Lvocich[1], A P Preobrazhenskiy[1], O N Choporov[2]

[1]Faculty of Informatics, Voronezh Institute Of High Technologies, 73a, Lenina street, Voronezh 394043, Russia
[2]Faculty of Information Technologies and Computer Security, Voronezh State Technical University, 14, Moscow prospect, Voronezh 394026, Russia

E-mail: komkovvivt@yandex.ru

Abstract. Solar energy can be considered as the most technological and economical type of renewable energy. The purpose of the paper is to increase the efficiency of solar energy utilization on the basis of the mathematical simulation of the solar collector. A mathematical model of the radiant heat transfer vacuum solar collector is clarified. The model was based on the process of radiative heat transfer between glass and copper walls with the defined blackness degrees. A mathematical model of the ether phase transition point is developed. The dependence of the reservoir walls temperature change on the ambient temperature over time is obtained. The results of the paper can be useful for the development of prospective sources using solar energy.

1. Introduction

In the past few decades, renewable energy sources are promising from the point of view of contribution to the global energy balance due to the fact that ensures replacement of depleting fossil fuel and is the ecological improvement of the environment [1-4].

The solar energy can be considered currently as the most technologically available and economically viable form of renewable energy. The use of it in order to provide heat supply objects should not be considered only for areas with a warm climate and sufficient number of cloudless days of sunshine and the amount of solar radiation [5-9].

The aim of this paper is to investigate the possibilities of increase of efficiency of utilization of solar energy on the basis of mathematical modeling.

To achieve this aim it was necessary to carry out the following problems:

1. To give the analysis of solar heating systems.
2. To give the recommendations for the refinement of a mathematical model of a solar collector.
3. To carry out computational experiment.

2. The analysis of solar heating systems

The systems of solar heating for intensification of the processes of radiation are divided into active and passive[10-15]. In passive systems as devices for collecting solar radiation, converting it into thermal energy and storage the building envelope is used [16-20]. This method of utilization of radiation, typically include large windows on the southern facades of buildings and the accumulation of excess heat in these cases occurs in the arrays of internal walls and floors. Taking into account the large glazing of buildings to reduce heat loss at night, cold season and heat gain during the summer season, translucent fences are equipped with movable shielding insulating devices [21].

To improve the efficiency of the passive solar heating system we can arrange additional translucent fencing of the southern wall of the building and location of openings for air circulation at floor level and ceiling. When covering dark paint compositions of the concrete wall of the storage efficiency of the disposal process radiation can exceed 40 %.

The passive solar heating economically viable in resourced areas characterized by moderate temperatures and ample sunshine during the cold period of the year. Along with the high heat storage capacity of the southern walls in the case of passive heating of the outer fence needs to have a thermal insulation, including movable shielding, collectively providing energy efficient buildings.

Distinctive features of active solar heating systems is the availability of technical devices for the capture and transformation of radiation, such as collectors, heat exchangers, accumulators and automation[10].

Active solar heating is classified under the following headings:

- - achieve thermal regimes: high and low temperature;
- - intended for heating, hot water and cooling systems;
- - time of operation: seasonal and year-round;
- - coolant: air and liquid;
- - according to the method of coolant circulation: natural (gravity) and forced over by the action of the fan or pump;
- - according to the method of heat transfer utilized in the heating system and hot water: single-loop (without intermediate heat exchanger) and ghosting.
- - for the duration of energy storage: short-term and seasonal;
- - in physical-chemical processes occurring in batteries, they are divided into: capacitive (using the heat capacity of a substance without changing the state of aggregation), the phase transition based on the absorption or release of heat during the flow of reversible chemical and photochemical reactions;

The efficiency of active systems significantly exceeds the passive, but her performance in the aggregate affect the efficiency of the individual components and devices, however, are the defining characteristics of the collectors. Solar collector device for collecting solar thermal energy (solar power plant), portable visible light and near infrared radiation.

Solar collectors are by far the most efficient devices using energy from the sun. For example, efficiency of photovoltaic panels is only about 14-18%, whereas solar collectors effectively used in approximately 80-95% of absorbed solar energy.

One kind of solar collector is a solar collector [11,12,16]. Design of the vacuum collector are similar to a thermos: one tube inserted into another with a larger diameter. Between them, the vacuum is perfect insulation. For year-round systems the collectors are vacuum tube with built-in timetrouble (heat pipes). Thermochrome is a closed copper tube with a small content of low-boiling liquid. Under the influence of heat, the liquid evaporates and collects heat from the vacuum tube. Vapors rise into the upper part of the tip, where congenerous and transfer heat to the coolant of the primary circuit water or antifreeze heating circuit. The condensate drains down and everything repeats again.

This type of collector is primarily aimed at reducing heat loss through the vacuum between the body heat and the outer shell of the collector. Looks like this manifold as a set of glass tubes from which the oxygen had been sucked, and inside the iron tube black color which actually heats up. This design allows you to save up to 95% of the thermal energy received from the sun. The water can be heating up to 270—300 C.

3. Simulation of radiative heat transfer between two parallel surfaces

Let's consider the process of radiative heat transfer between glass and copper walls with a degree of blackness σ_1 and σ_2 and temperature values of the walls T_1 and T_2 (Figure1).

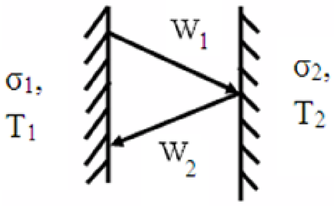

Figure 1. T_1, T_2 is the temperature of the first and second walls, respectively; σ_1 and σ_2 - degree of blackness of the first and second walls, respectively; W is the density of radiation from one wall to another.

According to the Stefan-Boltzmann law the radiation density from a glass plate is determined by the formula:

$$W_1 = \sigma_1 \cdot C_1 \cdot (\frac{T_1}{100})^4 \quad (1)$$

Likewise, from the copper plate:

$$W_2 = \sigma_2 \cdot C_2 \cdot (\frac{T_2}{100})^4 \quad (2)$$

The specific heat flow from one plate to another is determined by the formula:

$$Q = Q_1 - Q_2 \quad (3)$$

If we substitute the formulas (1) and (2) to (3), specific heat flow from one plate to another is calculated as:

$$Q = \sigma_x \cdot C_0 \cdot ((\frac{T_1}{100})^4 - (\frac{T_2}{100})^4) \quad (4)$$

where

$$\sigma_x = \frac{C_x}{C_0} = \frac{1}{\frac{1}{\sigma_1} + \frac{1}{\sigma_2} - 1} \ and \ C_x = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} - \frac{1}{C_0}} \quad (5)$$

As a result of heat flow can be determined on the basis of the formula:

$$\frac{\partial Q}{\partial t} = \sigma_n \cdot C_0 \cdot ((\frac{T_1}{100})^4 - (\frac{T_2}{100})^4) \cdot F \cdot t \quad (6)$$

where F is the area of the plates, and t is time. You can write other way

$$\frac{\partial Q}{\partial t} = \frac{dT_1}{dt}(C_{glass} + C_{cu} + C_{liq}) \cdot m \quad (7)$$

where C_{glass} - specific heat capacity of glass; C_{cu} - specific heat capacity of copper; C_{liq} - specific heat of the liquid. On the basis of formulas (6) and (7) we come to equality:

$$\sigma_n \cdot C_0 \cdot ((\frac{T_1}{100})^4 - (\frac{T_2}{100})^4) \cdot F \cdot t = \frac{dT_1}{dt}(C_{glass} + C_{cu} + C_{liq}) \cdot m \quad (8)$$

4. A mathematical model of radiant heat exchange in a solar collector

Let's consider a solar collector (Figure 2): length 1850 mm; width 950 mm; height 125 mm; area F=1,76 m^2, weight 37 kg, C_{glass}=0,670 kJ/(kg•K) is specific heat capacity of glass, C_{cu}=0,385

kJ/(kg•K) is specific heat capacity of copper, C_{liq}=3.34 kJ/(kg•K) is specific heat of air, σ_1=0,937(degree of black glass), σ_2=0,057(degree of blackness of the copper), C_0=5,67 W/m^2 K^4.
After substitution of the initial data in (5), we get: $\sigma_n = 0,058$.
Substituting into the equality (8) the original data we get: $\frac{dT_1}{dt} = 13,7 \cdot 10^{-10} t(T_1^4 - T_2^4)$

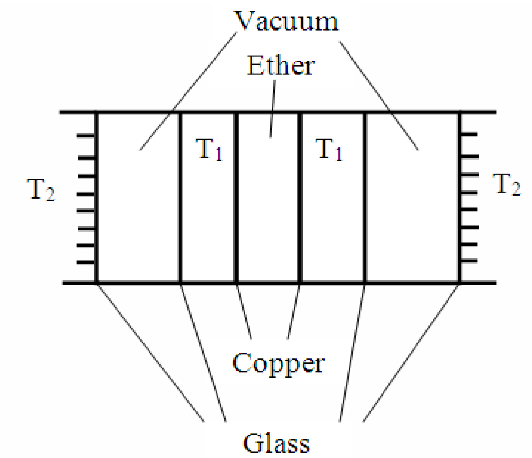

Figure 2. The element of vacuum tube in the solar collector, T_2 is the temperature of the external air; T_1 is the temperature in the inner region of the glass tube.

Spend integration of the obtained expressions

$$\int_{T_2}^{T} \frac{dT_1}{T_1^4 - T_2^4} = 13,7 \cdot 10^{-10} \int_0^t t dt \qquad (9)$$

We consider the left part of this equality. After decomposing a fraction into factors based on the method of undetermined coefficients, we obtain:

$$\frac{1}{T_1^4 - T_2^4} = \frac{3}{2 \cdot (T_1^4 + T_2^4)} + \frac{1}{2 \cdot (T_1^4 - T_2^4)} \qquad (10)$$

We substitute (10) into (9) and get

$$\int_{T_2}^{T} \left(\frac{3dT_1}{2 \cdot (T_1^4 + T_2^4)} + \frac{dT_1}{2 \cdot (T_1^4 - T_2^4)}\right) = 13,7 \cdot 10^{-10} \cdot \int_0^t t dt \qquad (11)$$

$$\int_{T_2}^{T} \frac{3dT_1}{2 \cdot (T_1^4 + T_2^4)} = \frac{3}{2T_2} arctg\left(\frac{T - T_2}{T_2}\right) + C \qquad (12)$$

$$\int_{T_2}^{T} \frac{dT_1}{2 \cdot (T_1^4 - T_2^4)} = \frac{1}{4T_2} \ln \left| \frac{T}{2T_2 - T} \right| + C \qquad (13)$$

After substituting (12) and (13) into (11) we get the equality:

$$6 \cdot arctg\left(\frac{T - T_2}{T_2}\right) - \ln \left| \frac{T}{2T_2 - T} \right| = 54,8 \cdot t^2 T_2 + C$$

In the end: $f(T) = 54,8 \cdot t^2 T_2 + C$.
There are three solutions: $T = T_2$, $T < T_2$, $T > T_2$.

Case 1: , i.e. $\frac{dT_1}{dt} = 0$. Case 2: $T > T_2$ – cooling. Case 3: $T < T_2$ – heating

We can imagine this graphically (Figute 3):

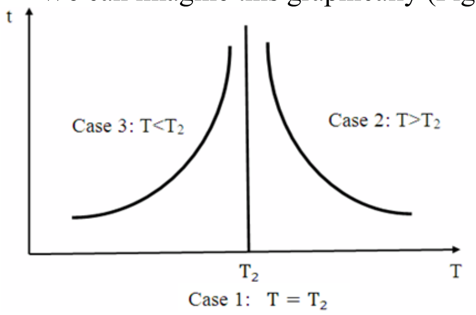

Figure 3. A graph of the temperature in the interior of the glass tube T_2 of the solar collector from the ambient air temperature T_1 over time

5. A mathematical model of the phase transition point of the ether

The heat flow required for the phase transition of the ether is determined by the formula

$$\lambda \frac{dm}{dt} = \sigma_n \cdot C_0 \cdot ((\frac{T_1}{100})^4 - (\frac{T_2}{100})^4) \cdot t \qquad (14)$$

where [22] λ= 11 W/m^2·K; T_c = 467 K; $\sigma_n = 0{,}937$.

λ– transfer coefficient of the substance; T_c – critical temperature.

Integrating and substituting the original data will get the addiction :

$$m = (114{,}8594 - 0{,}24149045 \cdot (\frac{T_2}{100})^4)t^2 \qquad (15)$$

We have 3 solutions: $T < T_c$ – liquid; $T = T_c$ – phase transition; $T > T_c$ – gas.

The intensity of solar collectors depends on the ambient temperature. The efficiency of solar systems largely depends on their correct installation. The size of the angle relative to the horizon depends on the work of the collector. The common tilt angle of the collector mounting location is the corresponding value of latitude. It is not recommended to set the collector tilt angle smaller than 20°, since the heat pipes operate most efficiently in the range of from 20° to 70°. It is acceptable to angle of ±10° of latitude, which is not observed a significant reduction in system performance. Corner is below the latitude of 15° increases the heat in the summer, while the increase in the angle of 15° leads to an increase in the efficiency of the system in the winter.

6. Conclusions.

A mathematical model of the phase transition point of the ether is developed. A mathematical model of radiant heat transfer vacuum solar collector is clarified. The dependence of change of temperature of walls of the reservoir from the ambient temperature over time is obtained. The results of the paper can be useful in the development of prospective sources using solar energy.

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