Heat pipes for passive solar heating systems

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Abstract. In the presented research work, heat pipes of gravitational and ring type were investigated. Two types of heat pipes were fabricated and tested under natural conditions for the study. According to the results of experiments, depending on the materials and dimensions of the heat pipes under study, the average value of the temperature difference in the gravitational heat pipe is 1.7 times higher, and the thermal resistance is 1.3 times lower. Keywords: heat pipe, heat exchanger, energy saving, solar energy.

1 Introduction

The rapid depletion of fossil energy sources (https://earthbuddies.net/when-will-we-run-out-of-fossil-fuel/), the use of 20-40% of the generated energy is consumed to power the energy consumption of residential buildings (https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=WORLD&fuel=Energy%20supply&indicator=TESbySource), almost 30% of greenhouse gas emissions come from the building [1], the consumption of large amounts of energy [2] and virtual water [3] in the production of construction materials for buildings remains a factor causing environmental problems associated with energy and global climate change.

Taking into account that solar radiation falling on the earth is $3.0 \cdot 10^{24}$ J per year [4], which can partially cover the energy consumption of residential buildings using solar active and passive heating systems [5]. Although passive solar heating systems have advantages such as ease of control, low cost and relatively high efficiency, there are a number of disadvantages related to building orientation, temperature and light discomfort, etc. [6]. To eliminate these shortcomings, a number of studies have been carried out, including optimization of the thermal parameters of passive solar heating systems [7], rational use of translucent fences [8], and assessment of energy, economic and environmental indicators [9, 10].

The use of solar heat pipes in buildings is also becoming more popular every year [11]. The first research on heat pipes was initiated by Gaugler in 1942 [12], and then developed by Grove in the 1960s [13]. As can be seen from Fig. 1, the number of research works devoted to the use of heat pipes to improve the energy efficiency of buildings is increasing every year.

A heat pipe consists of three main components: a working fluid, a wick or capillary structure, and a container [14]. The heat pipe consists of three parts: the evaporator, the adiabatic region and the condenser (condensate-forming part) [15,16]. According to the

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structure, the heat pipe is divided into two types: traditional heat pipes and ring-shaped (pulsating) heat pipes [17]. Based on the principle of operation, there are such types of heat pipes as gravity, capillary and rotational [18]

2 Description of installation

In this work, the thermal properties of gravity and ring heat pipes were studied (Fig. 2). The function of the proposed heat pipes is to convert solar energy into thermal energy and transfer it to the building. At the same time, it consists in accumulating thermal energy within the walls of the building.

In case 1, the heat pipe was made of copper pipes according to the diagram in Fig. 2 a. The heat pipe consists of 3 parts, the 1st part is called the evaporator. This part of the device is connected to 30 pipes with a length of 45 cm and an internal diameter of 6 mm. In this part, the working fluid evaporates. Part 2 is called the condenser and is located inside the building above the evaporator. This part consists of 26 tubes with a length of 42 cm and an internal diameter of 6 mm. In the condensation part, the steam releases its energy and turns into condensate (liquid). Part 3 is the adiabatic part, which combines parts 1 and 2 above. This part consists of a rubber tube (hose) 30 cm long.

In case 2, the heat pipe was made of steel and plastic pipes according to the diagram in Fig. 2 b. The evaporative part of the device consists of 2 steel pipes with a length of 58 cm and an internal diameter of 32 mm, connected to each other using plastic pipes. The condensing part was also made of 2 steel pipes with a diameter of 32 mm and a length of 45 cm. The adiabatic part was made of a plastic pipe with an internal diameter of 15 mm.

In case 3, all parts of the heat pipe were made of copper with an internal diameter of 8 mm (Fig. 2 b). In the evaporation part of the installation, 7 tubes 45 cm long are connected, and the condensation part consists of 6 pipes 30 cm long. The adiabatic part connects the evaporation and condensation parts at a distance of 15 cm.

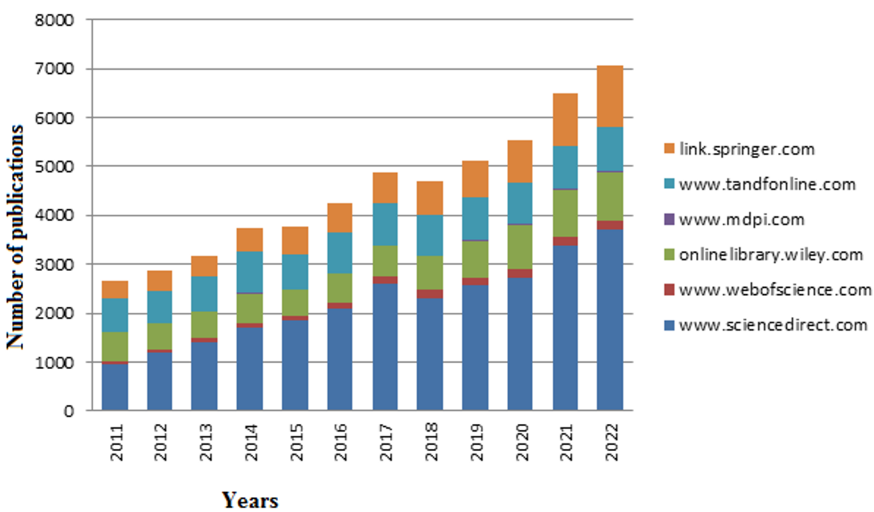
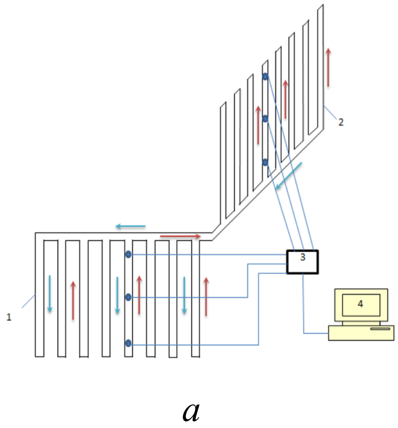


Fig.1. Number of articles published in international scientific databases on the use of heat pipes in buildings



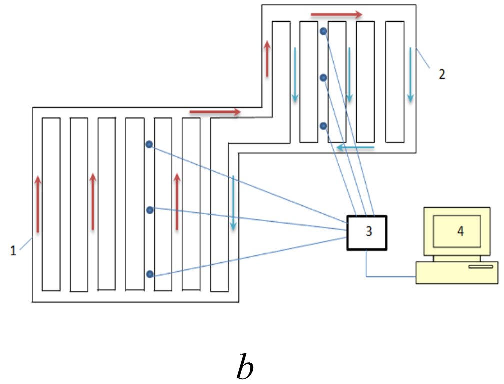


Fig. 2. Heat pipes under study: a-gravity heat pipe; b-ring heat pipe; red arrow – direction of movement of liquid vapor; blue arrow – direction of condensate movement; 1-evaporator; 2- condenser; 3-microcontroller; 4- computer.

3 The principle of operation of the installation

Solar radiation falls on the outer part of a building wall or on the outer surface of a heat pipe evaporator and is absorbed there. The absorbed solar radiation is converted into thermal energy in the pipes and transferred to the fluid inside the pipes. As the temperature of a liquid increases, the intensity of its evaporation also increases, and particles evaporating from its free surface move upward. The evaporated liquid moves through the pipe and passes to a condenser installed inside the wall, where it condenses. During the process of condensation, liquid vapors give up their energy to the pipe, and the pipe, in turn, due to convection and radiation, transfers heat inside the building to the room air.

3.1 Calculation method

Heat pipe thermal resistance [16,17]

$$R = \frac{T_e - T_c}{Q} \tag{1}$$

where R is the thermal resistance of the heat pipe, °C/W; T_e and T_c- evaporator and condensate temperatures, °C; Q is the thermal power supplied to the heat pipe, W.

The overall heat transfer coefficient h of a heat pipe can be determined by the formula

$$h = \frac{Q}{A(T_e - T_c)} \tag{2}$$

where h is the overall heat transfer coefficient, W/(m^2·°C); A is the heat exchange surface area on the evaporator, m^2.

3.2 Experiment

During the experiments, the following devices were used: universal pyranometer M-80M; temperature sensor DS18B20; Arduino Uno.

4 Results and discussion

Figures 3-5 show hourly changes in the temperature of the evaporating part (1) and the condensate-forming part (2) of the heat pipe. As can be seen from Fig. 3, during the experiment it was established that the maximum temperature of the evaporation part of the installation under study can reach 98°C at a maximum ambient temperature of 34°C. The temperature of the condenser part of the device reaches a maximum of 41°C.

In. Figure 4 shows the results of a two-day experiment conducted in a ring heat pipe. It is noted that at a maximum ambient temperature of 26°C, the maximum temperature of the device's evaporator is 90°C, and the maximum temperature of the condenser part reaches 30°C.

In Figure 5 also shows the results of an experiment carried out on an annular heat pipe. At a maximum ambient temperature of 34°C, the temperature of the evaporator part of the device rises to 73°C, and the temperature of the condenser part to 38°C.

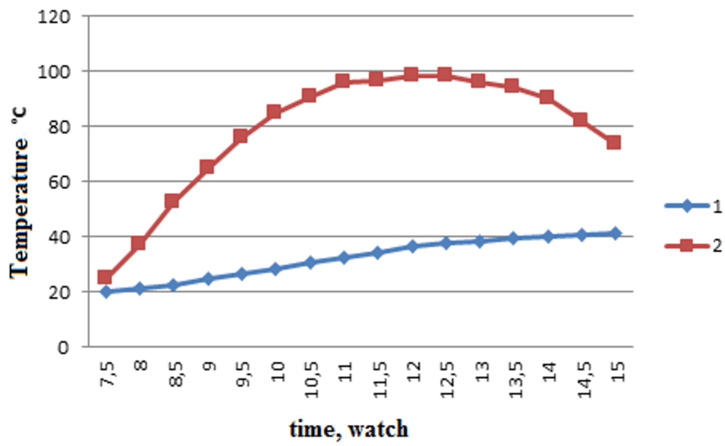


Fig.3. Hourly changes in temperature of the evaporator part (2) and the condensate-forming part (1) of the heat pipe (1.08.2022).

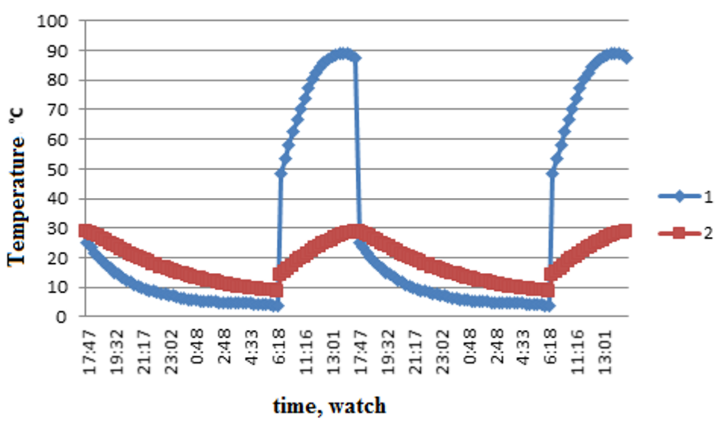


Fig.4. Hourly changes in the temperature of the evaporative part (1) and the condensate-forming part (2) of the heat pipe (October 8-9, 2022).

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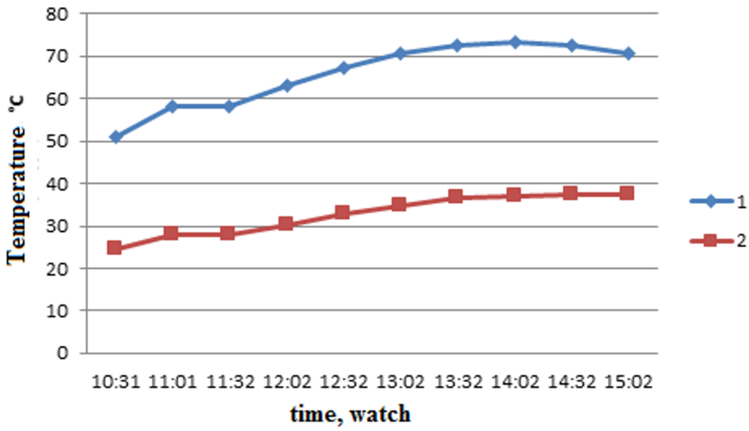

Fig.5. Hourly changes in the temperature of the evaporator part (1) and the condensate-forming part (2) of the heat pipe (05/31/2023).

In Figures 6-7 show the temperature change along the length of the structures under study at different ambient temperatures. As expected, at high heat fluxes the temperature difference is large. In a gravitational heat pipe, the temperature difference between the evaporator and the condenser is 60°C, and in a ring heat pipe up to 35°C**.**

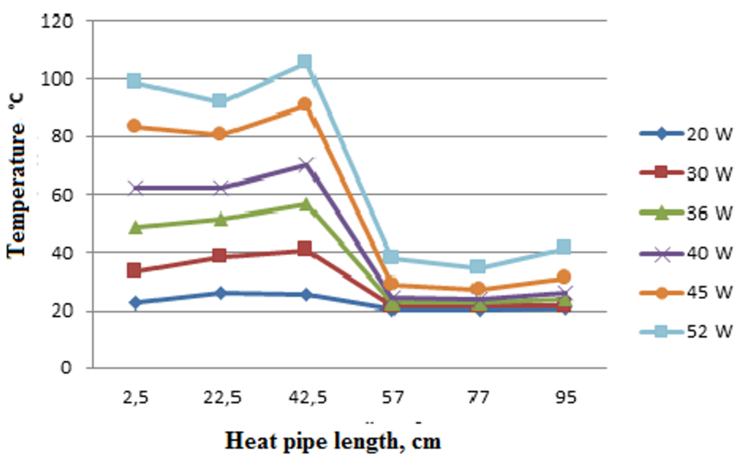

Fig.6. Temperature distribution along the length in a gravitational heat pipe

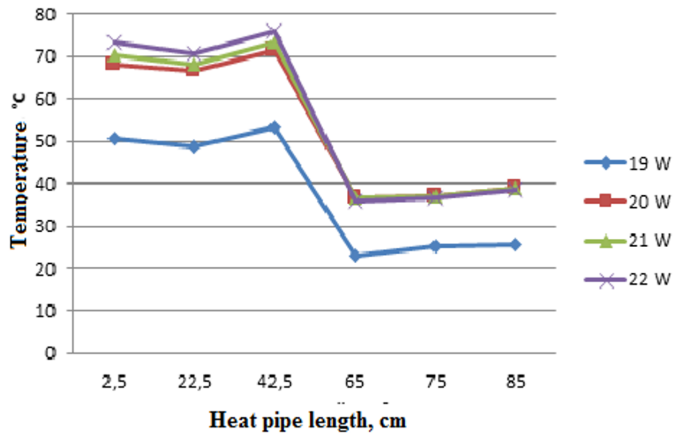

Fig.7. Temperature distribution along the length of an annular heat pipe

Calculations show that when the power supplied to the evaporative part of the device changes from 20 to 50 W, the thermal resistance of the gravitational heat pipe changes from 0.2 to 1.2 W/(m^2°C). In a ring heat pipe, the thermal resistance ranges from 1.4 to 16 W/(m^2°C) with a thermal power supplied to the evaporator from 18 to 22 W.

5 Conclusions

According to the experimental results, depending on the materials and sizes of the heat pipes under study, the average temperature difference in a gravitational heat pipe is 1.7 times higher, and the thermal resistance is 1.3 times lower.

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