



CALCULATION OF THE EFFICIENCY OF AN EVAPORATIVE COOLING SYSTEM FOR COOLING RESIDENTIAL HOUSES

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Abstract. *To ensure comfortable climatic conditions in residential buildings, the temperature and humidity of the indoor air play an important role. To maintain the required parameters of the indoor air at a certain level, various air ventilation and air conditioning systems are used. The use of such systems significantly increases the energy consumption for cooling rooms. Currently, the issues of reducing energy consumption in room cooling systems and using solar energy to increase the efficiency of cooling systems are relevant. The use of solar energy in air cooling systems increases the energy efficiency of the system and significantly reduces the harmful impact of the system on the environment.*

Keywords: *residential building, cooling system, evaporative cooling, cooling air, heat load, solar radiation intensity, room.*

Introduction. Currently, a large number of studies have been conducted on the study of indoor air temperature changes in rooms with air-cooled systems. Ampofo and Karayiannis [1] conducted an experimental study of natural convection in a square room with differential heating, using air as the working fluid. The hot and cold walls have the same temperatures of 50°C and 10°C. The authors measured the air velocity and temperature at different locations inside the room. They also determined the local and average Nusselt number, wall heat radiation, turbulent kinetic energy, and temperature transfer rate. Maitorena et al. [2] conducted an experimental and numerical study of natural air convection in an open cubic room. Four different values of the same heat flux were transferred to the vertical wall,

ranging from 55 to 333 W/m². The authors measured the air temperature at several points in the room. They compared the experimental results with the results obtained using the Fluent software. According to the results, the maximum difference between the experimental and theoretical results for the heat transfer coefficient and the Nusselt number was 10.8% and 14%, respectively. Rodriguez et al. [3] conducted an experimental and theoretical study of a ventilated room. The authors used a room with inlet and outlet holes on the upper wall. A constant heat flux is transferred to the left wall, the right wall has a constant temperature, and the remaining walls are assumed to be adiabatic. When they compared the experimental and theoretical results, they found that the difference between the experimental and theoretical values increased by about 1% as a result of changing the Rayleigh number. The maximum difference in heat transfer coefficient was 2.0% for $Ra = 2,73 \cdot 10^8$ and 3.0% for $Ra = 4,53 \cdot 10^8$.

Results and discussion. Experimental studies to determine the heat load of the experimental house were conducted in an experimental house built at the heliopolygon of Karshi State Technical University. The heat load was calculated as the sum of the heat transferred to the interior of the house through the external structure of the house, windows and doors, depending on the outdoor air temperature and solar radiation intensity. The heat load of the house was calculated for cases with and without windows and doors covered with curtains. The results of changes in solar radiation intensity, outdoor air temperature and indoor air temperature when the doors and windows of the experimental house were not covered with curtains are shown in Figure 1, and the results of changes in heat load are shown in Figure 2. Experimental studies were conducted on August 12, 2024, from 8⁰⁰ to 18⁰⁰.

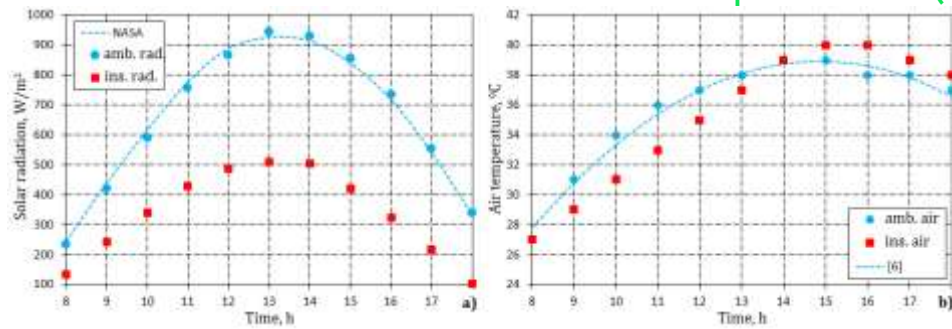


Figure 1. Results of solar radiation intensity (a) and air temperature changes (b) (12.08.2024)

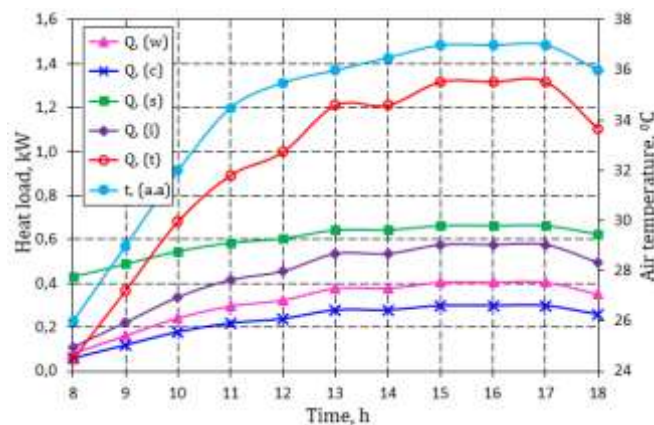


Figure 2. Results of changes in the thermal load of the experimental house (12.08.2024)

According to the results presented in Figure 1, a, on August 12, the solar radiation intensity varied within the range of 243.8...926.2 W/m², with a total of 7.23 kWh/m². The solar radiation intensity entering the room through windows and doors varied within the range of 102.8...509.4 W/m², with a total of 3.70 kWh/m². According to the results in Figure 3.4, b, the outdoor air temperature varied within the range of 27...39°C, with an average temperature of 35.82°C. The indoor air temperature varied within the range of 27...40°C, with an average of 35.27°C. The indoor air temperature was higher than the outdoor air temperature at 14⁰⁰ and was 38°C at the end of the day. According to the results shown in Figure 2 above, the total heat load transmitted through the external wall of the experimental house was 3.42 kW, the total heat load transmitted through the ceiling was 2.54 kW, the total heat load transmitted through solar radiation and windows was 6.56 kW, and the

total heat load transmitted through infiltration was 4.84 kW. Considering the heat lost through the floor of the experimental house, the total heat load was 10.47 kW. The share of the heat load components was 19.73% through the wall, 14.63% through the ceiling, 37.77% through solar radiation, and 27.87% through infiltration, with the largest heat load being transmitted through solar radiation. The results of the changes in solar radiation intensity, outdoor air temperature, and indoor air temperature when the doors and windows of the experimental house were covered with curtains are shown in Figure 3. The experimental studies were conducted on August 13, 2024, between 8⁰⁰ and 18⁰⁰.

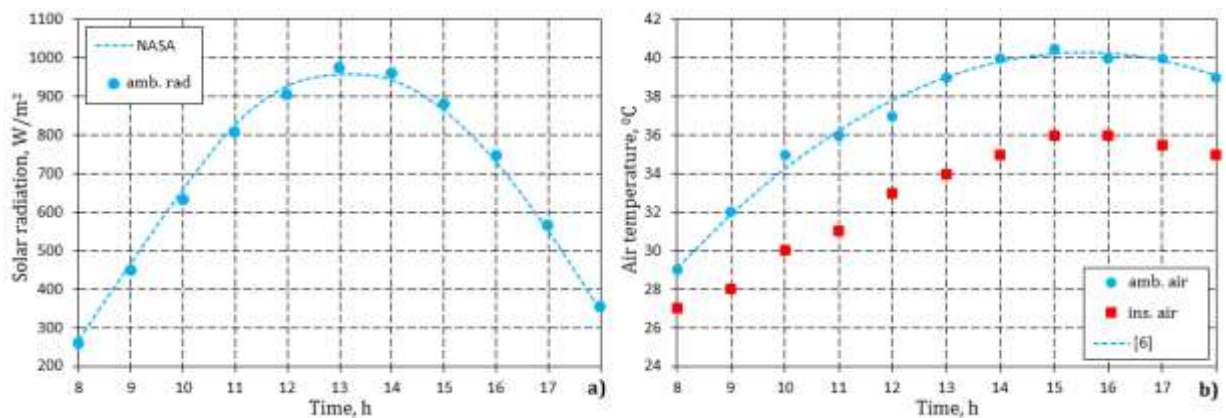


Figure 3. Results of solar radiation intensity (a) and air temperature changes (b) (13.08.2024)

According to the results presented in Figure 3, a, on August 13, the solar radiation intensity varied in the range of 268.9...956.9 W/m², totaling 7.54 kWh/m². According to the results in Figure 3, b, the outdoor air temperature varied in the range of 29...40.5°C, with an average temperature of 37.05°C. The indoor air temperature varied in the range of 27...36°C, with an average of 32.77°C. The average temperature was 7% lower due to the fact that the windows and doors of the room were covered with curtains. The results of the change in the heat load of the experimental house when the windows and doors were covered with curtains are shown in Figure 4.

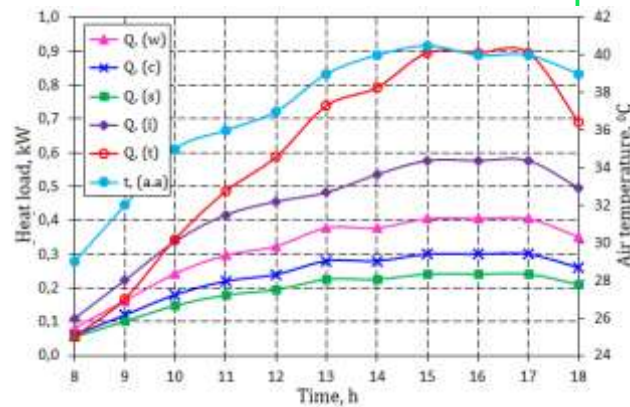


Figure 4. Results of changes in the thermal load of the experimental house (13.08.2024)

According to the results presented in Figure 4 above, the total heat load transmitted through the external wall of the experimental house was 3.87 kW, the total heat load transmitted through the ceiling was 2.87 kW, the total heat load transmitted through solar radiation and windows was 2.32 kW, and the total heat load transmitted due to infiltration was 5.44 kW. Considering the heat lost through the floor of the experimental house, the total heat load was 8.23 kW. The share of the heat load components was 26.71% through the wall, 19.81% through the ceiling, 15.97% through solar radiation, and 37.51% through infiltration, with the largest heat load being transmitted through infiltration. Also, the total heat load was reduced by 21.4% due to the return of solar radiation intensity through the curtain.

To eliminate the heat load in the experimental house, it is necessary to determine the efficiency of the ECS. In this case, it is necessary to determine the parameters of the cooling air and the exhaust air, as well as the required volume of cooling air. The temperature of the cooling air is determined by the following formula:

$$t_{c.a} = t_{i.a} - \Delta t_p \quad (1)$$

bu yerda Δt_p is the permissible temperature difference, °C, which depends on the choice of the principle of air distribution. When the room height is 2.5 m and above, Δt_p is taken in the range of 4-6°C.

It is known that during the cooling period there are optimal parameters of the microclimate in living rooms, which are as follows [4]: air temperature 22...25°C, relative air humidity 30...60% and air velocity ≤ 0.2 m/s. According to these standards, we assume the calculated temperature of the indoor air of the room to be 24°C. In this case

$$t_{c.a} = 24 - 5 = 19^{\circ}\text{C}$$

The temperature of the air being exhausted using an exhaust fan is determined as follows:

$$t_{o.a} = t_{i.a} + (H - h) \text{grad}t \quad (2)$$

where $H=2.7$ m is the height of the room; h is the height of the working zone of the room, m; if the work is performed in a standing position, $h=2$ m is taken, if the work is performed in a sitting position, $h=1.5$ m is taken; $\text{grad}t$ is the temperature gradient at the height above the working zone of the room, which is determined by the height of the room depending on the specific excess heat in the room [5].

The relative excess heat is defined as:

Solishtirma ortiqcha issiqlik quyidagicha aniqlanadi:

$$q_r = \frac{Q_{ex}}{V_{room}} \quad (3)$$

where Q_{ex} is the amount of excess heat generated in the room, W; $V_{room}=32.4$ m³ of the internal volume of the room.

The temperature gradient is determined by the determined value of the relative excess heat as follows [5]: when $q_r > 23.2$ W/m², $\text{grad}t=0.8-1.5$; when $q_r=11.6-23.2$ W/m², $\text{grad}t=0.3-1.2$; when $q_r < 11.6$ W/m², $\text{grad}t=0-0.5$. Based on the above, the efficiency of the BST in terms of cooling air is determined by the following formula:

$$V_{c.a} = \frac{3,6 \cdot Q_{ex}}{c_{p,a} \rho_{c.a} (t_{o.a} - t_{c.a})} \quad (4)$$

where $c_{p,a}$ is the specific heat capacity of the cooling air, J/(kg·°C); $\rho_{c.a}$ is the density of the cooling air, kg/m³.

The efficiency of the air intake system is as follows:

$$V_{in} = V_{c.a} - kV_{room} \quad (5)$$

where k is the redundancy factor, which takes into account the fact that the amount of cooling air supplied to provide excess pressure in cooled rooms exceeds the amount of air being removed, and is taken equal to 1 since the house has one window and door [5].

Taking into account the above and in the presence of excess heat load in the room, the cooling air efficiency of the ECT was determined for two cases (without curtains and with curtains) (Figure 5).

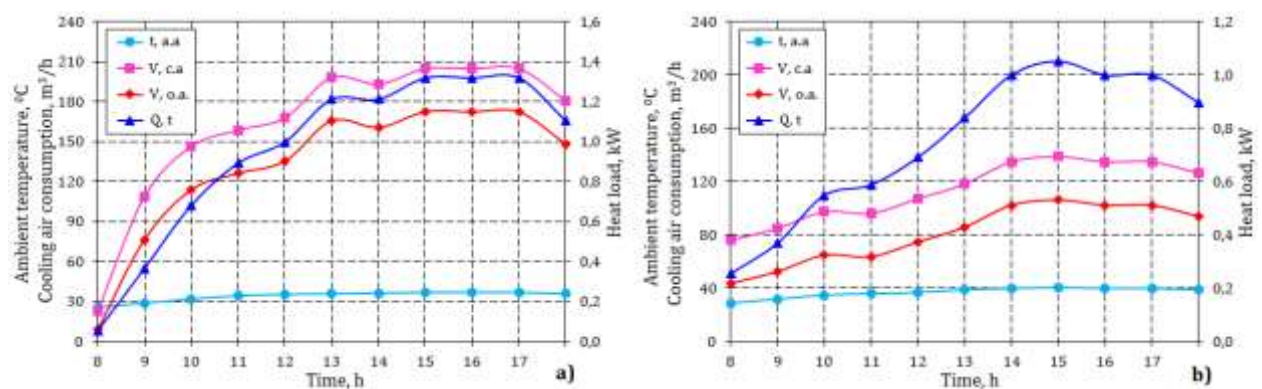


Figure 5. Cooling air consumption: without curtain (a) and with curtain (b) conditions

According to the results presented in Figure 5, a, the cooling air consumption increased with the increase in heat load. On August 12, 2024, from 8⁰⁰ to 18⁰⁰, the air temperature varied between 26...37°C and the cooling air consumption varied between 23.2...204.7 m³/h, averaging 162.8 m³/h. The exhaust air volume varied between 9.18...172.3 m³/h, averaging 132.0 m³/h. According to the results in Figure 3.8, b, on August 13, 2024, from 8⁰⁰ to 18⁰⁰, the air temperature varied between 29...40.5°C and the cooling air consumption varied between 76.15...138.7 m³/h, averaging 113.6 m³/h. The amount of exhaust air varied between 43.75...106.3 m³/h, averaging 81.2 m³/h. According to the analysis of the results, the use of curtains reduces the cooling air consumption by an average of 38.48%. Therefore, the use of curtains during the cooling season significantly reduces the cooling air consumption and the electricity consumption of the ECT.

Conclusion. When the doors and windows of the experimental house were not covered with curtains and the solar radiation intensity entering the room was 3.70 kWh/m^2 , the average temperature of the indoor air was 35.27°C and the total heat load was 10.47 kW . It was found that 19.73% of this heat load was transmitted through the walls, 14.63% through the ceiling, 37.77% through solar radiation, and 27.87% through infiltration. When the doors and windows of the experimental house were covered with curtains and the solar radiation intensity was 7.54 kWh/m^2 , the average indoor air temperature was 37.05°C and the total heat load was 8.23 kW . Of this heat load, 26.71% was transmitted through the wall, 19.51% through the ceiling, 15.97% through solar radiation, and 37.51% through infiltration. It was also found that the total heat load was reduced by 21.4% when curtains were used.

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