About possibility of using natural sources of cold in air conditioning system

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Abstract. Issues of microclimate mitigation in Uzbekistan during the summer period require urgent resolution. It should be noted that currently, there is very little research and practical recommendations related to the formation of a favorable microclimatic environment in cities with a hot climate. The simplest and most economical way of cooling in dry and hot climates is the evaporative cooling of a dry air stream. One of the possible ways to increase the system's efficiency is the use of night evaporative cooling of water, followed by its accumulation for daytime cooling in heat-insulated batteries. The conducted experiments testify that rather simple and cheap natural sources of cold can be used along with cold machine sources for air conditioning residential buildings in Uzbekistan.

1 Introduction

The issues of mitigating the microclimate of Uzbekistan in the summer period require urgent resolution. Medical and prophylactic institutions are especially in dire need of resolving this problem. Due to the complexity and insufficient mastery of the equipment, air conditioning systems are not widely used. The cost of artificial cooling in the air conditioning system is expensive. Therefore, when developing machine methods for creating an artificial microclimate, one should also consider the positive qualities of the climate of the southern regions. At the same time, it is necessary to correctly reveal the potential possibilities of nature and supplement and develop these possibilities in the desired direction with the most rational engineering means.

The simplest and most economical cooling method in dry and hot climates is evaporative cooling of the dry air stream. The absence of expensive refrigeration equipment in such installations significantly reduces cost and operating costs and simplifies design and maintenance.

Air conditioners, where the air is cooled by the evaporation of water in the air stream, can be based on the principle of direct and indirect cooling. In air conditioners with direct evaporation of water, the temperature of the air supplied to the room decreases because of its adiabatic humidification; that is, the heat content of the air is unchanged. The disadvantage of these air conditioners is the very high humidity of the air that enters the room.

Air conditioners with indirect air evaporation are free from such a disadvantage. The air supplied by the fan to the room of such air conditioners was cooled in the surface air cooler, in contact with the walls of the tubes, inside which water circulates. Some water was cooled by evaporation when sprayed in the cooling tower. With a sufficiently large surface of contact with air, the water is cooled almost to the saturation temperature of the surrounding air (t_{wb}). The cooled water is collected in the cooling tower sump, and then pumped back into the surface air cooler.

2 Methods

The experiments were carried out on the air conditioning of residential buildings by indirect evaporation in 2018 - 2019. The surface air cooler was a suspended metal ceiling (radiation cooling system). The results of the experiments have shown the possibility of obtaining the required internal comfort even at relatively high temperatures of the coolant (17÷19 °C).

One of the possible ways to increase the system's efficiency is the use of night evaporative cooling of water, followed by its accumulation for daytime cooling in heat-insulated batteries. Experiments have shown [1, 2] that the air conditioning unit should operate 12–13 hours daily (mainly from 9 am to 10 pm). At night, the cooling requirement is low and can be satisfied with natural ventilation. Coolant circulation can be provided by one pump by changing the pumping direction using valves. The system can operate automatically.

Summer tests of 2018-2019 showed that the temperature of the water cooled at night is 3-4 °C lower than the temperature of the water cooled during the day, and the final water temperature approaches the saturation temperature (t_{wb}) of the outside air. Several research [3] has confirmed this conclusion. Such a cooling system can be used only with free air movement. It is known that between the Earth's surface and the atmosphere, which have different temperatures, there is a radiant heat exchange, and the radiation intensity depends on the temperature difference and the physical properties of the radiating surfaces [4, 5].

The conditional temperature of the sky, determined by the formula (1) [4], for most regions of Uzbekistan in summer conditions is negative:

$$t_s = \frac{T_{aa}}{2.93}\sqrt[4]{54.5 - 23.5 \cdot 10^{-0.069 \cdot P_0}} - 273 \qquad (1)$$

where T_{aa} is the absolute temperature of the ambient air (°C),P_0 is the partial water vapor pressure in the ambient air (mm Hg).

The temperature of the Earth's surface is always positive compared to $t_f$in summer conditions. As a result of radiant heat exchange between the Earth and the sky, there is a constant heat escape from the Earth's surface into the world space. Along with evaporative cooling, this phenomenon can be used to obtain natural cold, but this requires large surfaces that are not shaded by surrounding objects isolated from the Earth's side. Naturally, the roofs of residential buildings can serve as such surfaces. At the same time, the water, which should be cooled, is passed at night in a thin layer along the roof slope, and because of evaporation and radiation, the water temperature decreases. Water cooled overnight is collected in the accumulator. During the day, it can be used as a source of cold.

When calculating the air conditioning system, it is interesting to determine the final temperature of the refrigerant flowing down the inclined plane, depending on various factors. At the same time, the calculated data are: the cold demand of the house (Q_0), the length (l)and width (a) of the roof, other factors (temperatures, wind speed, relative humidity, and so on) can be characterized by meteorological indicators [6÷10].

When composing the differential equation of the thermal balance of water flowing down an inclined plane (roof), the friction force between air and flowing water is not taken into account:

$$dQ_{acc} = dQ_{conv} - dQ_{eva} - dQ_{emis} + dq \tag{2}$$

where dQ_{acc} is the amount of accumulated cold water flowing down an inclined plane in the process of heat and mass exchange with the environment (W); dQ_{conv} is the convective heat gain from the environment to the surface of the flowing water (W); dQ_{ev} and dQ_{emis} is the amount of heat lost from the surface of flowing water in the evaporation process into the environment and radiation to the sky (W); dq is the additional heat gain from surrounding objects (W).

Expression (2) in expanded form has the following form:

$$G_a \cdot c_p \cdot dt_w = \left[\alpha_k(t_e - t_w) - \beta_p \cdot r(P_w - P_0) - \alpha_{rad}(t_w - t_s) + q\right] \cdot dl \tag{3}$$

where G_a is the flow rate of flowing water per unit of flow width $\left(\frac{kg}{m*s}\right)$;$c_p$ is the heat capacity of water $\left(\frac{kJ}{kg\cdot K}\right)$; dt_w is the change in water temperature on an elementary section of the length of the inclined plane dl(°C); α_k is the coefficient of convective heat transfer between the surface of the flowing water and the environment $\left(\frac{kW}{m^2\cdot K}\right)$; $t_e$and t_w are the temperatures of the environment and the flowing water (°C); β_p is the coefficient of mass transfer related to the difference in partial pressures$\left(\frac{kg}{m^2\cdot s}\right)$; r is the latent heat of vaporization $\left(\frac{kJ}{kg}\right)$; P_w and P_0 are partial pressure of water vapor above the surface of the flowing water and in the ambient air (mm Hg); α_{rad} is Coefficient of radiant heat transfer between the surface of the flowing water and the sky $\left(\frac{kW}{m^2\cdot K}\right)$; t_s is conditional sky temperature (°C); l is the length of the inclined plane (m).

For the stationary regime of heat and mass transfer between the surface of flowing water and the environment, the following equation is typical:

$$\alpha_k(t_e - t_{wb}) = \beta_p * r\left(P_{t_{wb}} - P_0\right) \tag{4}$$

where $P_{t_{wb}}$ is the partial pressure of water vapor above the surface of the flowing water at saturation temperature (mm Hg).

Approximating the curves $P_w = f(t_w)$and $P_{t_{wb}} = f(t_{wb})$ by a straight line within 12÷15°C, we have

$$\begin{cases} P_w = t_w - 1.5 \\ P_{t_{wb}} = t_{wb} - 1.5 \end{cases} \tag{5}$$

We express $t_e$through t_{wb}according to the formula (4).Substituting the values of $P_{t_{wb}}$, P_w and t_e from expressions (4) and (5) into equation (3) and solving it concerning t_w, we have:

$$t_{con} = t_R + (t_{in} - t_R) \cdot e^{-\frac{l\cdot(\alpha_k+\beta\cdot r+\alpha_{rad})}{G_c*c_p}} \tag{6}$$

Where

$$t_R = \frac{t_m(\alpha_k-\beta\cdot r)+\alpha_{rad}\cdot t_s+q}{\alpha_k+\beta\cdot r+\alpha_{rad}} \tag{7}$$

t_{con} and t_{in} are the final and initial temperatures of the flowing water (°C).

The change lies within

$$t_{dp} \le t_R \le t_{wb} \qquad (8)$$

Where t_{dp} is the dew point (°C).

3 Results

To verify the formula (6), field research was conducted during the summer of 2018. A thin layer of water flowed down an inclined plane with a length of 5 m and a width of 1 m for 23 hours. The temperature of the cooled water was maintained at 23 °C using an electric heater. This condition was adopted according to the experiments carried out in the summer of 2018 [7]. Experiments have established that to ensure normal comfort indoors, the maximum temperature of the coolant should not exceed 23÷24°C. The temperature distribution of the flowing water along the length was measured with thermometers. The water flow was kept constant using a special vessel. The inclined plane was paired with metal sheets insulated with an air layer.

On fig.1 shows the results of observations in the summer of 2018. The temperature of the chilled water depends significantly ont_R, $t_s$andt_e at a certain value of land G_a. The experimental curve agrees well with the theoretical one calculated by the formula (6).

Theoretical calculations and experiments show that the value of the temperature t_R in formula (6) is the theoretical limit of water-cooling under the combined action of night radiation and evaporation. Chilled water temperature (t_R) approaches t_R asymptotically. As can be seen from the graphs of the temperature distribution along the length of the inclined plane depending on the water flow rate, calculated by the formula (6) (Fig. 2), the temperature of the cooled water is directly proportional to the flow rate of the liquid and inversely proportional to the length of the inclined plane.

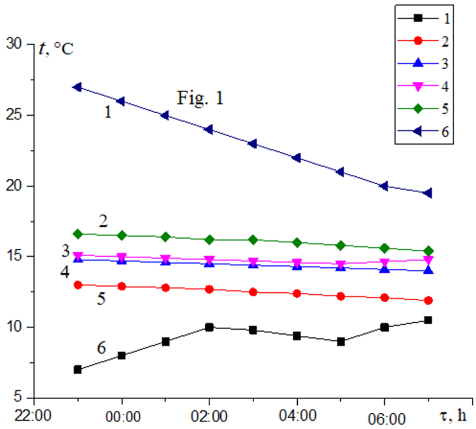


Fig.1. Results of research: 1, 2 are thermograms of the outside air according to dry and wet thermometers; 3, 4 are theoretical and experimental temperatures of chilled water; 5 is t_R; 6 is dew point.

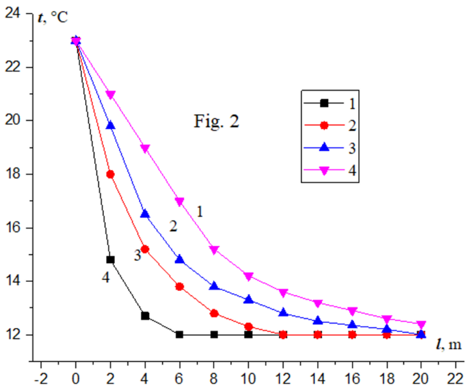


Fig. 2. Temperature distribution of flowing water along the length of the inclined plane depending on its flow rate: 1 is 200 $\frac{\text{litr}}{\text{hour}}$; 2 is 150$\frac{\text{litr}}{\text{hour}}$; 3 is 100$\frac{\text{litr}}{\text{hour}}$; 4 is 50 $\frac{\text{litr}}{\text{hour}}$.

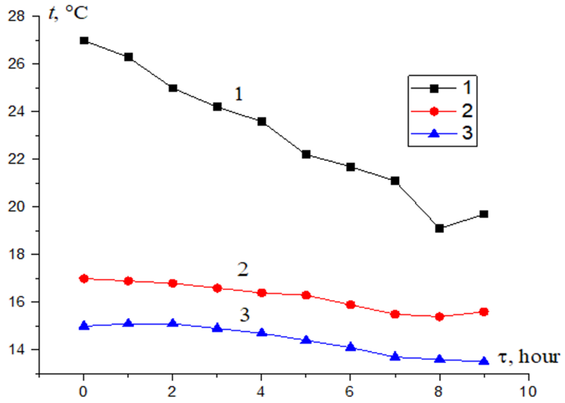


Fig. 3. Dependence of chilled water temperature on the weather: 1, 2 are outside air thermograms according to dry and wet thermometers; 3 is chilled water temperature.

Experimental research on night water cooling, conducted in the summer of 2018, showed that the temperature of the chilled water, all other things being equal, depends on the state of the night sky (the shape and percentage of clouds). This can be explained by the reflection of infrared radiation from the water surface from clouds. Fig.3 shows the dependence of chilled water temperatures on the type of weather (clear on August 22, semi-clear on July 19, cloudy on July 9) at $l = 5$ m, $G = 10\ \frac{l}{h}$. The use of night radiation in clear weather, together with night evaporation, reduces the temperature of the stored water by an average of 2 °C compared to the temperature of water cooled only by night evaporative cooling.

Under the conditions of Uzbekistan in summer, the probability of cloudy weather is 0.15 - 0.20 with the prevailing form of cloudiness A [1]. Experiments carried out in semi-clear weather show that the influence of sky cloudiness up to two points with cloud form A_e on the temperature of chilled water is insignificant.

Note that the liquid flow rate $G_a$in equation (6) can be expressed in terms of the thickness of the water film δ and the speed w.

$$\delta = \sqrt[3]{\frac{\mu_в * G_a}{\rho^2 * 1200 * \sin\theta}} \tag{9}$$

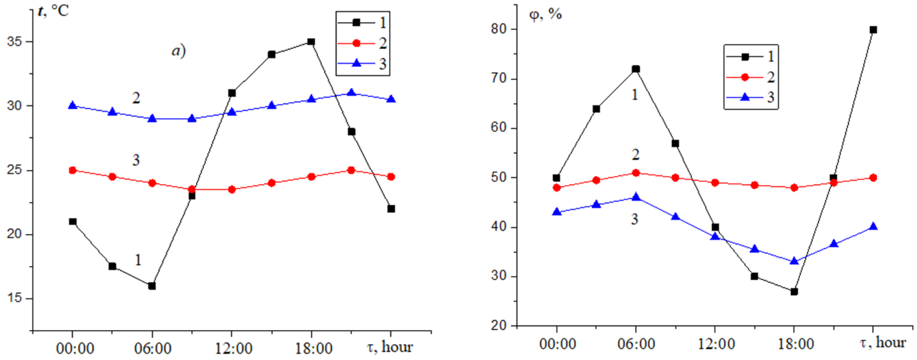
$$W = \frac{G_a}{3600 \cdot \rho \cdot \delta} = \sqrt[3]{\frac{\sin\theta}{3\mu_в\rho}\left(\frac{G_a}{3600}\right)^2} \tag{10}$$

where μ_w is the dynamic viscosity of water (Pa · s), θ is the angle of inclination of the surface to the horizon (deg), ρ is the density of water $\frac{kg}{m^3}$.

The cubature of the storage tank to provide a given cooling requirement of the room can be calculated by the formula

$$V = \frac{Q_0 \cdot n}{\rho \cdot c_p \cdot \Delta t} \tag{11}$$

where Δt is the temperature difference in the accumulator during the day (°C), n is the number of hours of operation of the conditioning unit during the day (hour).



a *b*

Fig. 4. Thermal (a) and moisture (b) diagrams of the outside air, indoor cooled, and uncooled control rooms: 1 is outside air, 2 is control uncooled room, 3 is cooled room.

On fig.4 shows the weekly results of experiments in 2018 on radiative cooling of rooms using natural cold sources with a temperature of 15÷16 °C. With a daily change in outdoor air temperature of 15 °C, the air temperature of the cooled room changes by 1 °C, and the relative humidity is within the requirements. The air temperature of the control-uncooled room obviously does not correspond to the comfortable one and exceeds the temperature of the cooled room by 6÷7 °C.

4 Conclusion

The conducted experiments during 2018-2019 testify that rather simple and cheap natural sources of cold can be used along with machine cold sources for air conditioning residential buildings in Uzbekistan.

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