Scheme of conditioning in room based on evaporative air cooling system using solar energy

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Abstract. The article is devoted to the development of promising low-power evaporative cooling systems using solar energy. At the same time, the placement of elements of the system in determining the temperature, the humidity of the air in such indoor areas is determined by the parameters at which the most favorable conditions for the optimal climate in the room are created. The article presents the structural and thermodynamic parameters of the developed two-stage evaporative cooler air. The creating two-stage evaporative cooling installation is shown the efficiency and effectiveness of the cooling air. Given preliminary studies where study the possibility of indoor climate and presented their results. Requirements to ensure the indoor climate. The test evaporative air cooler with rotated regenerative heat exchanger has a design air capacity of 160 m³/h and 200 W in the cold, it provides for an independent change in the rotation speed of heat exchangers, a change in the amount of sprayed water. The total consumed electric power is not more than 45 watts. Achieved cooling 7°C at an ambient temperature of 35÷40°C (July- August 2019).

1. Introduction
In the conditions of hot (temperature \( t > 35 \div 40 \, ^\circ C \)) and dry (relative humidity \( \varphi < 15\% \)) summers in Uzbekistan, these air parameters are far from comfortable, and, therefore, the use of microclimate normalization is necessary. Of particular importance is the cooling and humidification of air in working and residential premises, in passenger transport (buses and train cars). At the same time, air cooling by 6 ÷ 10 °C is optimal relative to the environment, bringing \( \varphi \) to 40 ÷ 60% [1].

Also, some industries impose rather stringent requirements on indoor air temperature for performing technological operations, cooling raw materials and intermediate materials or the final product. For example, in the areas for monitoring the parameters of semiconductor devices and microcircuits, the temperature should be (20 ± 1) °C, in the areas of silk-screen printing of thick-film materials, a temperature of (25 ± 1) °C is required, fresh milk should be cooled to 10 ÷ 12 °C for transportation and further processing [2]. Many technological processes of food production require rapid cooling of the final product (the production of ice cream, fruit juices, mayonnaise, meat products), and in the textile industry both cooling and humidification of air up to 40 ÷ 50 % are required to eliminate static electricity discharges and related fires and explosions [3].

One of the perspective ways to reduce the energy intensity of traditional air conditioning systems using compressor refrigeration machines is to use the thermodynamic nonequilibrium of atmospheric air as a renewable energy resource [4]. Systems using this energy to produce cold include direct and indirect evaporative air cooling [5], which can be successfully used in solar air conditioning.
installations. The principle of operation of solar air conditioning units [6, 7] based on pre-treatment of air in an adsorption dryer and subsequent cooling of the air flow in a rotating heat exchanger and evaporative chamber (figure 1).

Figure 1 shows the principle of operation of a traditional solar installation of air conditioning [8]. Outside air pre-cleaned in the filter (F) with parameters (1) is drained and heated in the sorbing nozzle of the rotor (AD) to state (2). After “dry” cooling with constant moisture content (2-3) in a rotary regenerative heat exchanger (RRHE), the air is adiabatically humidified in the evaporative chamber (EC) to state (4) and, with these parameters, the air is fed into an air-conditioned room in which it assimilates heat and moisture excess (4-5). The exhaust air is adiabatically humidified in the evaporative chamber (5-6), and then heated (6-7) in a rotating heat exchanger. The final heating of the air (7-8) going to the regeneration of the dryer nozzle is carried out in the solar collector (SC) and (with insufficient heating in the solar collector) in the heater (H). Changing the parameters of the regeneration air in the dryer nozzle corresponds to the line (8-9) on the i-d diagram [9]. Part of the exhaust air not intended for nozzle regeneration is vented to the atmosphere via bypass (BP). Vo and Vi are outlet and inlet ventilators.

In winter, an air dryer (AD) is not used, and the external supply air is directed through the bypass directly to the entrance to the rotary regenerative heat exchanger (RRHE), which in this case is a heat exchanger for exhaust using air. At addition, it becomes possible to organize exhaust air recirculation at the exit of the solar collector, or, when the situation allows, to partially use outdoor air for regeneration needs, which leads to a reduction in energy consumption for air treatment [10].

Figure 1. Solar air conditioning installation a) is installation scheme; b) is air treatment processes on the i-d diagram: (1-2) is air drying in the sorbing nozzle; (2-3) is cooling in a rotary heat exchanger; (3-4) is cooling and humidification in the evaporative chamber; (4-5) is assimilation of heat and moisture in an air-conditioned room; (5-6) is cooling and humidification of the flow of exhaust air in the evaporative chamber; (6-7) is heating of exhaust air in a rotary heat exchanger; (7-8) is heating of regeneration air in the solar collector and heater; (8-9) is humidification and cooling of air in the regeneration sector of the dryer nozzle.

It should be noted that solar air conditioning units, characterized by a high efficiency [3], have certain disadvantages. The main disadvantage is associated with an increase in relative humidity at the outlet of the evaporative chamber (up to 80-90%), which significantly reduces the assimilative ability of the supply air in rooms with a predominance of moisture. As a result, the conditions of comfort in an air-conditioned room during the summer season may be violated.

At [10], several solutions are proposed aimed at eliminating the negative phenomena associated with humidification of the supply air in the summer season and increasing the efficiency of air cooling by replacing the evaporative chamber with rotary regenerative heat exchangers.
Rotating regenerative heat exchangers provide a process [11], in which the air does not have direct contact with water, and its cooling occurs through the heat exchange surface. Its plates, which receive cold from the exhaust air, are transferred to another incoming air stream, while its temperature is further reduced. The air stream cooled by water in the absence of direct contact with it is called the main one, and the air stream in which the water evaporates, which absorbed this heat from the main stream, is auxiliary.

The tasks of the development of these devices in solar air conditioning units are due to the possibility of:
- lowering the temperature level of the resulting cold [12, 13];
- increasing the efficiency of the assimilation of latent heat in air-conditioned rooms [14, 15];
- reducing energy consumption due to the targeted combination of various traffic patterns of exchanged flows [16,17];
- rational use of the heat of phase transformations and the renewable energy resource of the thermodynamic nonequilibrium of ambient air [18, 19, 20].

2. Methods
The laboratory two-stage evaporative air cooler with rotating regenerative heat exchangers was designed and manufactured (Figure 2), and a program was developed to study the main indicators of its operation in different modes and climatic conditions (late spring, summer, and early autumn).

The studied unit works as follows (Figure 3). Outside air from the atmosphere 1 is supplied by a blower 2 to the wet 3 and dry 5 sections of the first RRHE 6. Water 4 is sprayed into the wet section of the same RRHE, which evaporates, cools, and removes heat from the air stream 3. Passing through the wet section of the first RRHE, saturated humid air cools the intermediate coolant located in this section, located in the sectors of the rotor of the RRHE. Then this stream of air saturated with water vapor is released into the atmosphere (8). The rotor of the RRHE is driven into rotation at a speed of 6-8 rpm by an electric motor with a gearbox.

After half the revolution of the rotor, the cooled intermediate coolant is in the dry section, through which the second air stream 5 from the atmosphere passes, is cooled and flows (9) into the wet section of the second RRHE 11, where water 10 is sprayed. After the second RRHE, the moisture-saturated cooled air can be supplied to room 12 or emitted into the atmosphere depending on the required conditioning conditions. The third section 7 of atmospheric air enters the dry section of the second RRHE; it is cooled as a result of heat exchange with a cold intermediate coolant and then (13) enters the room. By changing the ratio of air flows 12 and 13, you can adjust both the degree of cooling of the room and the humidity in it.
Figure 2. The laboratory two-stage evaporative cooler with rotating regenerative heat exchangers
An important condition for the continuous operation of all evaporative coolers, including the test one, is the emission of used air from the refrigerated room into the atmosphere. Otherwise, sometime after the start of the operation of the evaporative cooler, the air in the room is saturated with water vapor (as a result of continuous evaporation of water), and the cooler ceases to fulfill its main function. The air stream discharged from the room and having a low temperature compared to atmospheric but high humidity can be used to cool the air stream 1 coming from the atmosphere to the cooler. This will increase the energy efficiency of the cooler in question. Ambient air is supplied to the cooler by two VN-2 fans; an electric motor with a RD-09 gearbox (8 - 10 rpm) is used to rotate the RRHE.

Laboratory tests were carried out with cooling of room with a volume of 20 m³. To ensure accurate psychrometric measurements of the initial and final air parameters, sections of rotated regenerative heat exchangers were provided with the air speeds of more than 4 m / s. In the immediate vicinity of the cassette, thermometers were installed, by which a control measurement of the initial and final air temperature was carried out using a dry thermometer. Using a thermometer in the pan, the temperature of the recirculated water was measured.

The front section of the cassette is 0.4 × 0.39 = 0.156 m². By moving the front grid of the cartridge, it was possible to change the layer depth through 25mm (25, 50, 75 and 100mm). The evaporative device 10 provided for each layer depth a uniform distribution of water over the upper section of the cartridge. Air flow rates varied from 150 to 850 m³ / h, which corresponded to the weight velocity in the front section of the cartridge from 0.3 to 1.8 kg / m²•sec. Water consumption for layer spray varied from 8 to 160 kg / h. The study of evaporative layers was carried out under the conditions of complete recirculation of sprayed water in the absence of heat exchange through the enclosing structures of the stand and negligible heat influx from the pump. Therefore, the air cooling process was close to adiabatic. Indeed, the air temperature by wet thermometers before and after the irrigated layer, the water temperature in the pan was practically equal (the difference between these temperatures in the experiments did not exceed 0.1 ° C).

The aerodynamic resistance of the layer was measured by the difference in static pressures in sections 6 and 7, where there were equal air velocities. Thermometers had a fission price of 0.1° C. Batiste cases on wet thermometers were washed after every hour of testing and were replaced when contamination was detected. The collector 4 and washers on a measuring vessel of water were carefully analyzed. Under the steady-state mode of setting the experiment, characterized by the constancy of the quantities and parameters of air and water, five-fold measurements of the readings of all instruments were made with an interval of 1 minute. At intervals of 10 minutes, five-time measurements were repeated 3 or 4 times. The experiments were considered successful if two or three, five-time measurements closely matched.

At the same time, in each experiment, the water consumption for evaporation was determined by the loss of water in the pan. The correctness of the experiments was checked by the convergence of the amounts of water measured by the gravimetric method and calculated by the difference in the moisture content of the air.

The amount of power consumed allows the use of solar photovoltaic generators of low power and reasonable cost to drive all the cooler mechanisms. Further optimization of the design and parameters of the developed cooler is possible. In particular, coordination of the parameters of the water supply pump with its flow rate is required.

3. Results and Discussions
The use of two RRHE allowed to increase the degree of air cooling, to eliminate the rigid connection between the degree of its cooling air and humidity, and also to optimize the relative humidity of the air being cooled (within 40÷60%).

| Parameters | 1 minute | 20 minutes | 40 minutes | 1 hour 30 minutes | 3 hour |
|------------|----------|------------|------------|------------------|--------|
| 20.08.2019. Ambient air $t = 31^\circ$C, $\varphi = 34\%$ |
4. Conclusions

The test evaporative air cooler with RRHE has a design air capacity of 160 m³/h and 200 W in the produced cold, it provides for an independent change in the rotation speed of heat exchangers, a change in the amount of sprayed water.

The total consumed electric power is not more than 45 watts. Achieved cooling 7 °C at an ambient temperature of 35 ÷ 40 °C (July - August 2019).

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