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IMPROVING THE WORK EFFICIENCY OF AN AIR CONDITIONING SYSTEM BASED ON A CHILLER

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Abstract: *This article deals with evaporative cooling devices used in air conditioning systems. Various ways of lowering the air temperature to the dew point have been identified as a result of improvements to the devices considered. It is also indicated that the circulating water temperature in the system can be lowered to the air temperature on the wet bulb thermometer. As is known, recirculating water is often used as a cooling water in process units to reduce water consumption in industrial plants. Circulating water is heated by recirculation and the heated water is cooled in ventilated cooling towers. This method of cooling water by direct evaporation is based on the thermodynamic disequilibrium of atmospheric air and the difference in psychometric temperatures between dry and wet thermometers. This method of water cooling, offered in air conditioning systems for dry and hot climates, is very effective. Modern, efficient solutions are needed for a wide range of energy-saving techniques in air conditioning systems. One such solution is to pre-cool the air entering the unit (in heat exchangers) or to use natural cooling sources. The use of an energy-saving chiller with an indirect evaporator as a source of cold water in hot and dry climates is therefore recommended in air conditioning systems.*

Keywords: *dry and hot climate, direct evaporative cooling, moisture content, heat and mass transfer, water cooler-chiller, circulating water supply*

INTRODUCTION. To reduce the consumption of water used as a cooling medium in process units (intermediate and end heat exchangers of compressors, condensers of refrigeration machines, etc.), water recycling is usually used. For reuse, the heated water is cooled in a fan cooling tower, a contact device where the water is cooled by partial evaporation in the flow of outside air. The final chilled water temperature depends on the cooling tower design factors and the external air parameters [1-15].

MATERIAL AND METHODS*.* This method of direct evaporative cooling of water is based on thermodynamic non-equilibrium of atmospheric air and psychometric temperature difference between dry and wet thermometers, which is a renewable energy resource for cold production. A number of works have been devoted to improving the heat and mass transfer processes in cooling towers in order to reduce the chilled water temperature, but all improvements in cooling tower design only bring the final chilled water temperature closer to its theoretical cooling limit, which is the outdoor air wet-bulb temperature. In practice, the water in cooling towers is cooled to a temperature 3÷5 ℃ higher than the outside air wet-bulb temperature.

One solution for further reduction of the cooled water temperature in the cooling tower is pre-cooling (at constant moisture content $d_{o.a.}$) of the outside air before it enters the cooling tower, i.e. transition to indirect-evaporative cooling. Suggestions for reducing the chilled water temperature in the cooling tower. In order to increase the cooling capacity of the cooling tower and reduce the theoretical cooling water limit below the outdoor air wet-bulb temperature, a device [1÷5] has been developed in which the outdoor air is pre-cooled in a plate heat exchanger by the cooled and humidified air leaving the cooling tower (Fig. 1-*a*). The calculations show that for every 4 ℃ of outdoor air cooling before it enters the cooling tower, on average, we will get an additional temperature reduction of 1 ℃ of cooled water, therefore, when implementing this proposal, the effect of additional water temperature reduction will be only 1÷1.5 ℃. More noticeable additional cooling of water can be obtained only by deeper pre-cooling of outdoor air, for this purpose in [6, 7] it is proposed to pre-cool the outdoor air in a regenerative indirect evaporative cooling heat exchanger (RIEC).

In this countercurrent heat exchanger two types of alternating channels are used: dry and wet, where the air changes its parameters differently, at that the air enters the wet channels after its precooling in the dry ones (Fig. 1-*b*). The alternation of channels is made by using a special material, e.g. Miplast, one side of which has a capillary-porous surface capable of absorbing and storing water in its structure, while the other side is waterproof. In damp ducts the temperature of the air is reduced by its contact with the capillary-porous surface which is moistened by water. In dry channels, the air is isolated from contact with water and its temperature and enthalpy are reduced due to cooling from the channel wall, which has a temperature determined by processes in neighbouring wet channels. In dry ducts, air is cooled at $d_{o.a.} = const$, so its cooling limit temperature will be the dew point $t_{pre} = t_{d.p.}$.

The air cooled in the dry ducts of the regenerative indirect evaporative cooling heat exchanger enters the counterflow cooling tower, where the water is cooled due to partial evaporation to a temperature close to the outdoor air dew-point temperature. The disadvantage of this method of water cooling can be considered only the use of two heat and mass exchange apparatuses at once (cooling tower and RCIO heat exchanger). Earlier in [3] a method of cooling air and water (in the limit to the dew point of outside air) using a cooling tower as a heat and mass exchange apparatus and a countercurrent heat exchanger (air-water type) for pre-cooling of outside air was proposed (Fig. 2-*a*). Part of the air cooled in the heat exchanger (G_a) is sent to the cooling tower, the other part $(G_{w.a.})$ is proposed to be used as supply air for air conditioning systems.

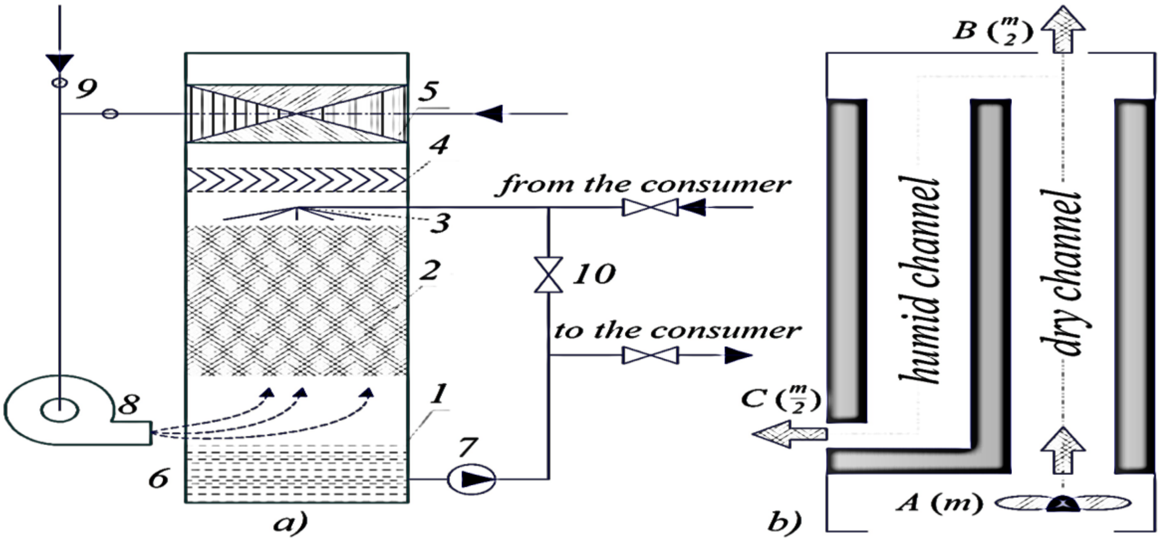

Fig 1. Schematic diagram of indirect-evaporative cooling tower (*a*): 1 – casing; 2 – nozzle; 3 – nozzle; 4 – drift eliminator; 5 – plate heat exchanger; 6 – water tank; 7 – pump; 8 – fan; 9 – dampers; 10 – valves and (*b*) method of regenerative indirect evaporative air cooling

Part of the water cooled in the cooling tower enters the countercurrent heat exchanger for air cooling, the other part is discharged to the consumer, where it can be used for cooling air and technological equipment. The processes considered in the scheme are shown in the $i-d$ diagram in Figure 2-*b* for clarity.

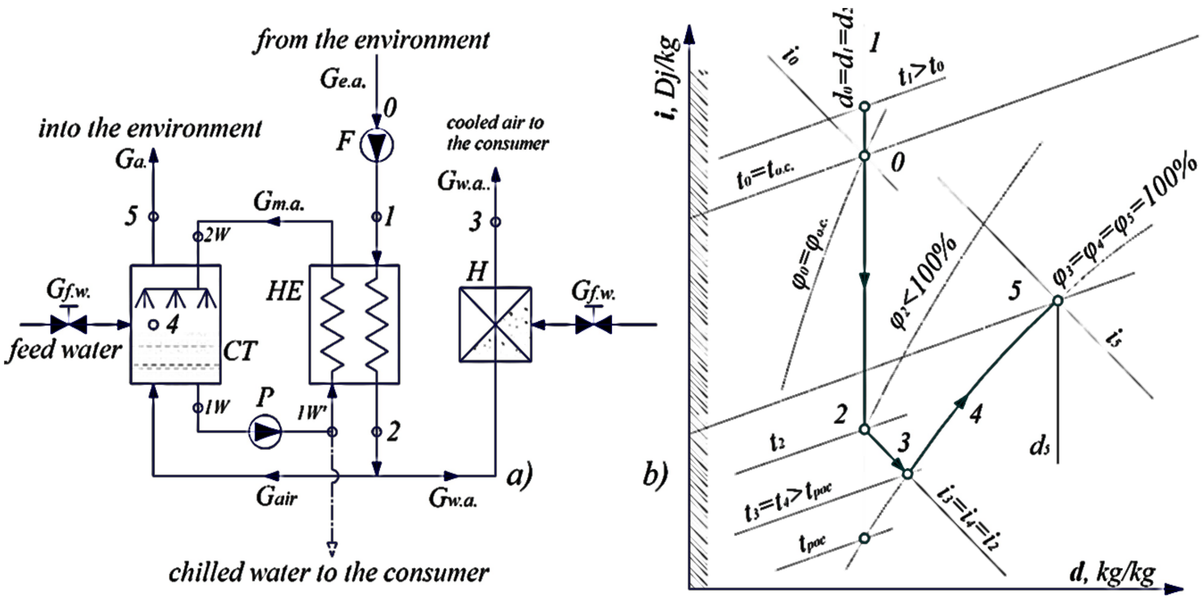

Fig. 2. Schematic diagram of regenerative indirect evaporative air and water cooling system with cooling tower (*b*): *F* – fan; *CT* – cooling tower; *HE* – heat exchanger; *E* – environment; $G_{m.a.}$, $G_{c.w.}$ – basic mass flow rates of cooled air and cooling water; $G_{w.a.}$ – operating mass flow rate of air (directed to consumer); $G_{c.w.}$ – mass flow rate of auxiliary flow; *H* – pump; *U* – air humidifier and $i-d$ processes diagram (*b*).

Practically according to the same scheme and with useful use of only chilled water for a consumer the authors of [4] implemented an indirect evaporative water chiller which is used as a source of cold water (chiller) in air-conditioning systems of some public buildings in cities of China (Fig. 3).

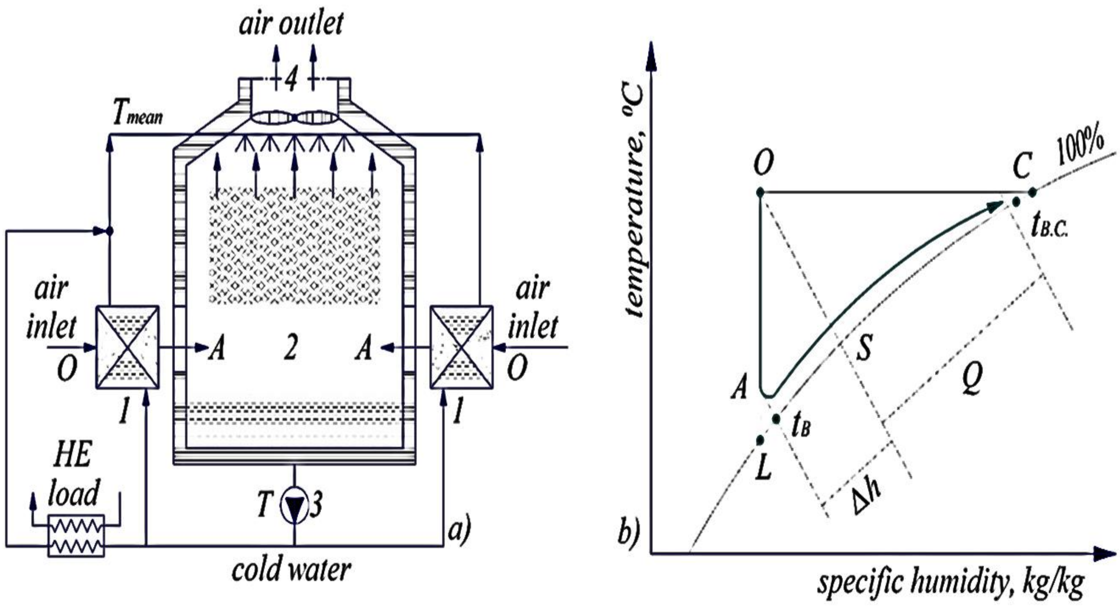

Fig. 3. Operating principle of the water chiller (*a*), structure of the indirect evaporative cooler (*b*), cold water production process in $i - d$ diagram

The indirect evaporative chiller consists of two water/air counterflow heat exchangers (1), a counterflow cooling tower (2), a water pump (3), an exhaust fan (4). Outside air enters at point (*O*), and first enters the air-water heat exchangers to pre-cool to point (*A*), with the amount of cooling water in the heat exchanger determined from the condition of equality of water equivalents of air and water flows. Then the cooled air enters the cooling tower and is used for evaporative cooling of water, a smaller part of which is then sent for air cooling in countercurrent heat exchangers 1, and the larger part of the cooled water is supplied to the building air conditioning system (Fig. 4).

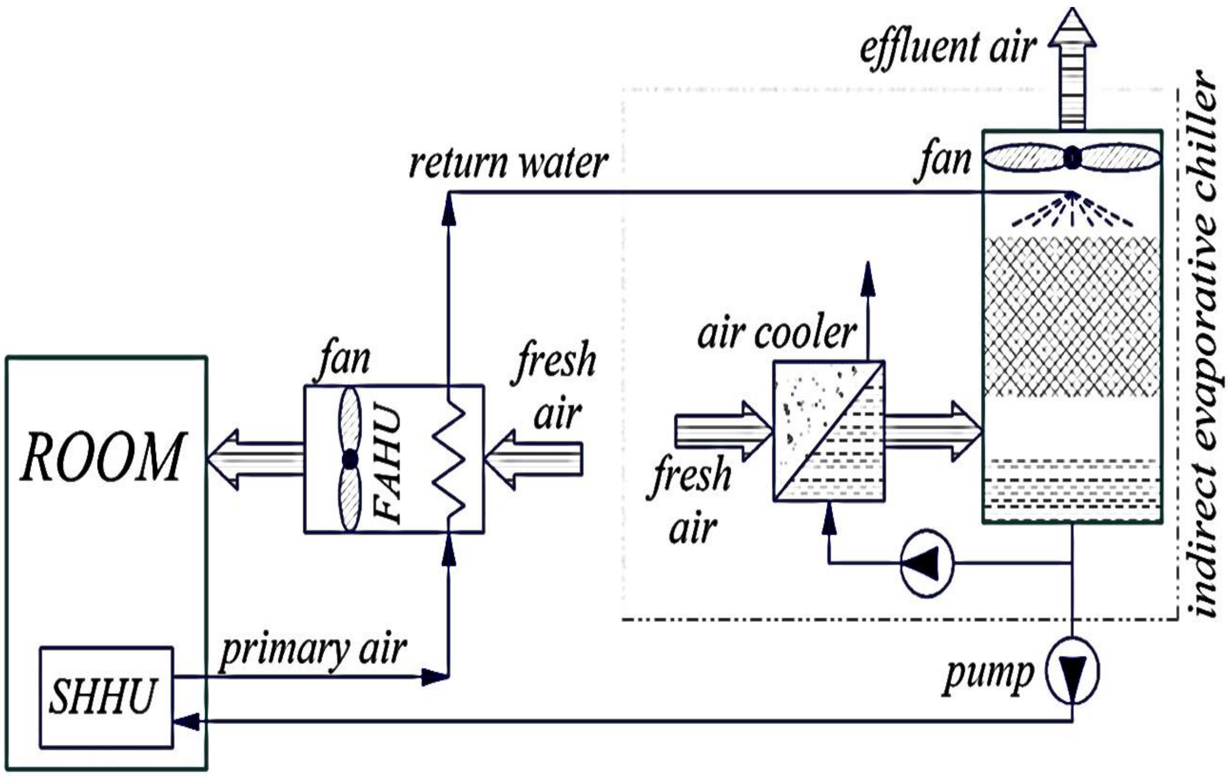

Fig. 4. AVC scheme using an indirect-evaporative chiller

RESULTS AND DISCUSSION. According to the results of tests of pilot plant operating on the principle of indirect-evaporative chiller [4], part of which is presented in Fig. 5-*a* and 5-*b*, the following conclusions are drawn:

–the temperature of water chilled in the indirectly-evaporative chiller is between the dew-point temperature $t_{d.p.}$ and the wet-bulb temperature $t_{h.a.}$ of outside air, and its value can be estimated as the average of these characteristic temperatures (Fig. 5-*a*)

–the temperature of the water cooled in the indirect evaporative chiller is 2÷4 ℃ higher than the dew point temperature of the outside air (Fig. 5-*b*).

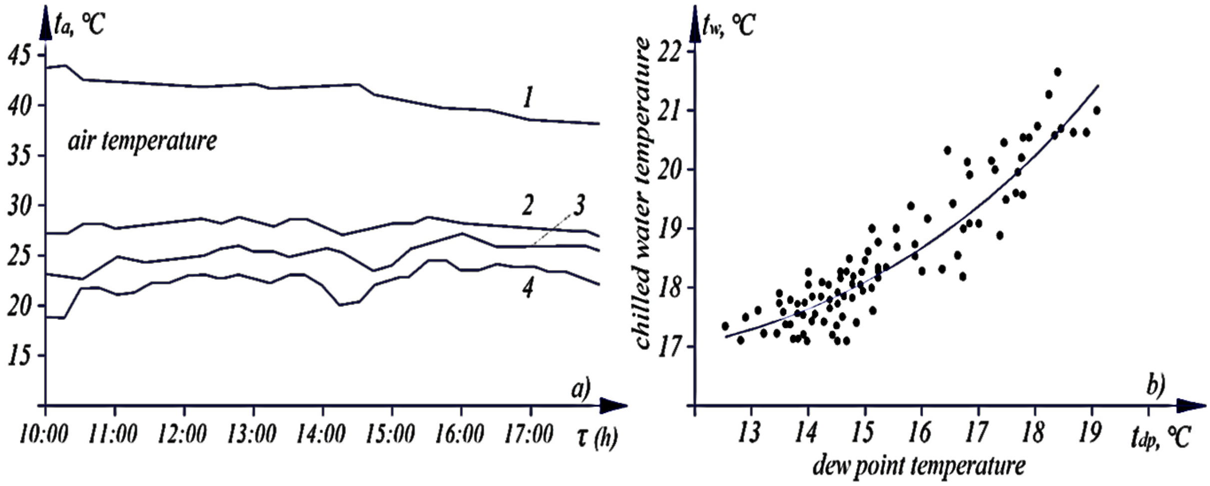

Fig. 5. (a) Test results of indirect-evaporative chiller: 1, 2 – dry $(t_{d.a.})$ and $(t_{h.a.})$ thermometer temperatures; 3 – chilled water temperature (t_w); 4 – air dew point temperature $(t_{d.p.})$. (b) dependence of indirect evaporative chiller outlet water temperature on outdoor dew point temperature.

When the outdoor dew point temperature is about 15℃, the water is cooled down to 18℃, and since only the exhaust fan and circulation pump consume power, the cooling factor of the indirect evaporative chiller in this mode is 8-10. When the outdoor dew point temperature drops to 10 ℃, the chilled water temperature decreases accordingly and the chiller's cooling factor increases to 18. The authors of [4] note that as this is the first practical use of an indirect-evaporative chiller, the design has not been optimized. Among the design and equipment drawbacks are: insufficient heat-exchange surface of air-water heat exchangers, insufficient capacity of the exhaust fan. These shortcomings have been taken into account in the design of the new indirect-evaporative chiller. By 2010, indirect evaporative chillers and air conditioning systems (AHUs) using them have been adopted in more than 15 projects, to serve public buildings with a total floor area of about 120,000 m^2 in China. The cooling capacities of installed chillers range from 120 to 700 *kW*. In these buildings, indirect-evaporative chillers have been used as a cooling source for the air-conditioning system, producing chilled water with a temperature of 16÷19℃. Test results show that air temperatures in air conditioned rooms are 24÷27 ℃ and relative humidity 50÷60%, which corresponds to comfortable conditions [4, 14].

CONCLUSION. In regions with hot and dry climates the energy-saving indirect-evaporative chiller can be successfully used as a source of cold water for air conditioning system, replacing traditional steam-compression chillers. The proposed method of cooling water for the air conditioning system can have an even greater effect in regions with dry, hot climates. For a wide application of the proposed energy-saving air conditioning method, modern, efficient solutions are needed to enable the use of 18÷20 ℃ cold water for comfortable indoor air conditioning.

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