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Improving the performance of the direct and indirect evaporative cooling system: A review

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ABSTRACT

The energy-efficient and ecologically friendly cooling method known as evaporative cooling is very common. When water evaporates, cooling the air, a significant quantity of heat is transported from the air to the water, lowering the air's temperature. This process is known as evaporative cooling. In order to reduce energy consumption and provide adequate cooling comfort, this paper analyzes the most significant evaporative cooling advancements and technologies.

1. Introduction

The requirement for A/C in buildings has grown as summer temperatures have risen in recent years. Additionally, since the compression systems used to cool the air demand a significant amount of electrical energy, which largely depends on fossil fuels. This method of air conditioning is therefore neither environmentally beneficial nor sustainable. Evaporative-cooling are considered alternatives as they consume less electrical energy compared to traditional compressor systems. Therefore, this technique has received a lot of attention from researchers in theoretical and experimental studies over the past years. The life cycle of an air conditioner has traditionally included hot regions like the Gulf region [1-2]. The need for air conditioning is rising quickly in other places with moderate climates as a result of climate change [3],[4]. A significant amount of energy is consumed as a result of the rising demand for AC. The International-Energy-Agency (IEA) predicts that by 2050, the amount of electricity used for air conditioning will have increased 3-6 times and will be close to 6000 TWh [5],[6]. The most widely used AC technique is built on the mechanical vapor compression cycle (MVC). Great technological maturity, high robustness, and low costs are advantages of MVC. However, for a few decades, MVC's specific energy consumption has remained constant around 0.85 0.02 kW/Rton, making further advancements in energy efficiency more and more challenging [2]-[7]. However, they are energy-intensive and only competitive in locations with waste heat [8]-[11]. Other revolutionary technologies, such as absorption and adsorption chillers, have also evolved. The industry is highly motivated to provide more environmentally friendly AC technologies with the goals of lowering energy consumption and carbon emissions. In cooling applications, the indirect evaporative cooler (IEC) is thought to provide promise as an alternative to MVC [12]. It consumes less energy since it cools mostly through the evaporation of water. The coefficient of performance (COP), which measures energy efficiency, shows that IEC is significantly more energy efficient than MVC [13]. The ease of design and operation is another benefit of IEC. IEC has attracted a lot of scientific attention in recent years. The literature is replete with thorough summaries of the most recent developments in IEC [14]-[17]. IEC has certain inherent limitations, despite the enormous potential for energy savings. First off, it is unsuited for humid places because of how badly its performance suffers with rising ambient humidity. Additionally, IEC has very little control over the supply air conditions because it's a passive cooler. This research intends to provide a broad overview of evaporative cooling systems and the most recent advancements in this area that offer adequate cooling comfort and lower building energy use. Reviewing both theoretical and empirical studies and research on the topic of evaporative cooling and its various forms, as well as its most significant benefits and drawbacks, is done.

2. Classification of Evaporative Cooling Systems

Depending on the kind of mass and heat transfer that takes place between water and air. An overview of the several basic evaporative cooling system types for building cooling is shown in Fig. 1

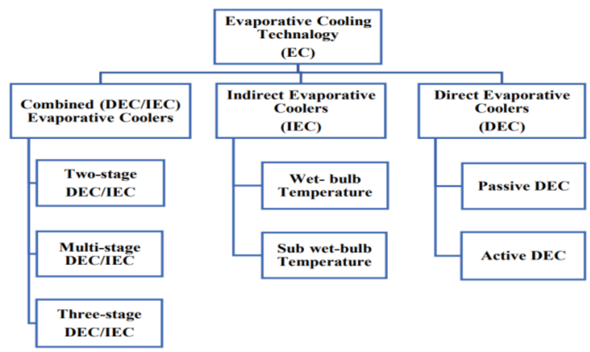

Fig. 1: Different evaporative cooling

2.1. Evaporative cooling technology

Evaporative cooling is based on the principle that water absorbs heat so that the liquid state turns into steam, and thus the sensible is transformed into latent-heat. One of the most important benefits of evaporative cooling is its low cost, good energy savings, improve indoor air quality and also reduces carbon dioxide emissions from power plants [18]. Many researchers have been conducted to study evaporative cooling systems. The water to be cooled is transferred into a cooling tower built of ceramic tubes in the ceramic evaporative cooling system that Velasco et al. [19] devised. As a temperature reduction of between 5 and 12 °C was attained, this kind of device enables the inside air to be recalculated. Jain [20] created a two-stage evaporative cooling system to increase the system's effectiveness at high humidity levels and lower air temperature. The findings revealed a (100 to 110%) increase in cooling efficiency. The performance of a two-stage evaporative cooling system was improved by El-Dessouky et al. [21]. In this case, the operating system was viewed as a function of the package's thickness and the rate of water flow as a function of the direct and indirect evaporative cooling unit.

Shaheen and Hmmadi [22] conducted a theoretical and experimental study for a hybrid system consisting of a conventional refrigeration unit and an evaporative air cooler.

2.1.1. Direct Evaporative Cooling (DEC)

Several attempts have been made in the past years to study the performance of air coolers that operate in the direct evaporative cooling method in order to improve their performance to meet human comfort requirements within the air-conditioned space. The following is a review of research related to this aspect:

The researcher, Selim, and others [23] conducted an experimental study of the performance of a direct evaporative air cooler, as their study focused on the thickness and mass of the filling. And increase the mass from (1-1.75 kg). The researcher did not address the increase in the decrease in air pressure resulting from the increase in the thickness and mass of the filling, and thus the increase in the consumption of electrical energy and the reduction of air flow.

Using cooling pads made of various materials, including jute, luffa, and fiber, the researcher (Al-Sulaiman, [24] evaluated the cooling-performance of an evaporative cooler. To assess these materials, he did a comparison with a humidified pad made of commercial pads. broadly utilized The investigation revealed the following cooling pad efficiencies: 62.1% for Indian hemp, 55.1% for loofah, (49.5%) for commercial pad, and 38.9% for fiber palm. The findings showed that commercial materials and palm fibers had significantly lower cooling effectiveness, whereas jute had the maximum efficiency. Jute offers the best substitute among the readily accessible commercial materials, nevertheless, if the surface of the fiber can be improved to increase its mold resistance. The effectiveness of a direct evaporative cooler and the pressure drop through wet pads (HDPE and rice husks) in an evaporative cooling system were both evaluated by Soponpongpipat and Kositchaimongkol, [25]. To compare the outcomes with rice husks and HDPE, they experimented with a commercial humidifying pad. They discovered that husks For the test conditions, wet rice demonstrated an average saturation efficiency(ASE) of (55.9%), whereas recycled HDPE cushions (ASE) of (29.1%). The pressure reduction across the polycarbonate and rice husk cushions, however, was substantially greater than that across the commercial cushions.

The researcher Dagtekin and others [26] conducted a study on a cooling pad made of cellulose to study the effect of air velocity on the cooling efficiency and the temperature of the equipment to the space to be cooled. Their results showed that the air velocity had a direct effect on the decrease in air temperature and cooling efficiency. They recommended a range of air velocities (0.5-1.5 m/s).

The researcher Malli and others [27] tested the thermal performance of two types of cellulose material, and the thickness values differed in a range ranging from (150-75 mm) in three different cases for each type. The amount of evaporated water increases and the pressure drops. However, the relative humidity and the effectiveness decrease, as a result of the increase in the entry air velocity. The speed ranged from (4-1.8 m/s). The results showed that the effectiveness reaches (80%), while other cases such as reducing the entry air velocity and increasing the wetting of the pillow can reach (100%).

A study was conducted by Niyomvasa et al. [28] to compare two varieties of cooling cushions made of drapery fabric and unfinished seersucker fabric. According to the findings, the average temperature difference between interior and outdoor air for curtains was (2.9^{o}C) and for raw cotton fabric it was (1.7^{o}C). Since the fabric tissues are thin by nature, they have a higher heat transfer and enable a significant amount of heat exchange between the dry side and the wet side. It was also discovered that the average saturation efficiency of curtain fabric was (54.8%) and for raw cotton fabric (33%). Therefore, applications involving indirect evaporative cooling are well suited to it. (Kulkarni & Rajput, [29] did a theoretical analysis of the performance of an evaporative cooler consisting of cooling panels of different shapes and materials. They used the geometries of the cooling panels-rectangular, cylindrical, and hexagonal-made of hard cellulose, aspen, corrugated paper, and high-grade polyethylene-to theoretically examine the performance. Density A hexagonal pillow made of aspen material had the highest level of efficiency (91%) because it has a larger surface area, which increases the amount of water in the air that evaporates and lowers the air temperature. In contrast, a rectangular panel made of cellulose material had the lowest efficiency (72.4%) under the same working conditions. Maurya et al. [30] studied three types of cooling pads made of aspen, cellulose, and coconut fibers, based on the summer weather conditions of Bhopal, India. The results obtained by the researchers showed that at air speed (0.5m/s), the effectiveness of the wet bulb was highest for aspen materials with a percentage of (80.99%) compared with (69.48%) for cellulose and (68.15%) for coconut. As the saturation efficiency of the board depends on the surface area wetted because the increase in the surface area leads to greater evaporation of water in the air, thus reducing the air temperature.

Al-Hilal and Al-Tuwaijiri, [31] studied the evaporative cooling efficiency of palm fiber pillows and paper pillows with intersecting grooves of the type (Keldak) under the climatic conditions of the city of Riyadh in the Kingdom of Saudi Arabia, in an air-flow corridor where cooling pillows were installed at one end and fans to extract air at the other end. The results obtained from the study showed that the highest average efficiency of cooling pads with cross grooves and palm fiber pads (77% and 69%, respectively) were obtained when the thickness of the cooling pad was (10 cm) and the rate of water addition was (11/1m), while The lowest cooling efficiency of paper cushions with cross grooves (53%) obtained at thickness (5 cm) and water addition rate (3 l/m) and the lowest average cooling efficiency of palm fiber pillows (47%) obtained at thickness (10 cm and water addition rate) 3 and 3 L/m, respectively). This study was conducted at noon only when the temperatures and relative humidity were within 45°C (and 10%, respectively), and there was no study of the system's performance at other times during the day. The researchers concluded that In the event that the thickness of the cooling pad is small and the rate of water addition will negatively affect the efficiency, and in the case of a rate of water addition in a small amount while the thickness of the pad remains in a greater amount, it will also reduce the cooling efficiency, due to the lack of complete wetness of the surfaces of the pad.

In an experimental study, researchers Liao and Chiu [32] used an air duct to study the performance of a direct evaporative cooling system in Taiwan. The effect of air velocity, water addition rate, pressure difference through the cushion, and cushion thickness on the efficiency of the evaporative cooler was studied.The obtained results showed that the cooling efficiency of the coarse-type cushion ranged between (63.88 to 64.77%) and between (63.88 to 64.77%). (80.50 to 81.68%) and between (81.75 to 86.32%), respectively, at a thickness of (5, 10, and 15) cm and an air velocity between (1 to 1.5 m/s), while the cooling efficiency of the soft-type pillow ranged between (47.22 to 57.23). %) and between (62.93 to 72.25%) and between (76.68 to 85.51%), respectively, at thicknesses of (5, 10 and 15 cm) and air velocities between (1 to 1.5) m/s. The researchers concluded from the study that by increasing the thickness For cooling pad and air velocities less than 1.5 m/s, the efficiency is increased.

The researchers Karabash, and (Dowdy)[33] conducted a test of cellulose as a medium for direct evaporative cooling to calculate the heat and mass transfer coefficients, as they used cellulose with a wet surface area of (350 m^2/m^3) with a thickness of (305 mm). They reached a saturation efficiency. ranging from (90 to 94%),

Camargo and others, [34] developed a mathematical model for a direct evaporative cooling system and presented their experimental results obtained from tests of cellulose as a cooling medium with a wetted surface area (370 m^2/m^3). Heat transfer, mass transfer coefficient of air, wetted surface area and relative humidity.They concluded that the efficiency increases at high dry bulb temperature and low air velocity.

In a study conducted by Dagtekin et al. [35]on cellulose as a cooling pad to study the effect of air velocity on air temperature and cooling efficiency, their results showed that there is no mathematical relationship between air velocity and the decrease in air temperature and cooling efficiency. They recommended air velocities through the cooling pad ranging from 0.5 to 1.5 m/s.

The researcher Malli et al. [36] also conducted a test on two types of cellulose material, each type with different thicknesses, for three cases, to determine its thermal performance. Their obtained results showed that the total pressure drop and the amount of evaporated water increased when the inlet air velocity and thickness increased for both types, while the efficiency and relative humidity decreased when the inlet air velocity increased. The thickness of the cellulosic material ranged from (75 mm to 150 mm) and the facial velocity ranged from (1.8 m/s) to (4 m/s). The results showed that the effectiveness for some cases reaches more than 80%, while for other cases it can to reach 100%.

2.1.2. Indirect Evaporative Cooling (IEC)

The objective of the indirect evaporative cooling method is to reduce the sensible heat of the air without causing any change in the moisture content, this is done by using a heat exchanger. Several types and configurations of the heat and mass exchanger are used for IECs, such as plate-fin HMX, plate-type HMX, tube-fin HMX, tubular-type HMX, and HPHX. The indirect evaporative cooling system consists of a heat exchanger, fan, pump, water tank and water distribution system. The working fluids are separated by a highly conductive plate. Evaporative cooling systems are classified according to the extent to which they cool the supply air into Wet-bulb temperature IEC systems and sub wet-bulb temperature ICE systems, as shown in Figure 2 [37]. There are many factors that affect the performance of indirect evaporation cooling systems, the most important of which are: cooling power (CP), wet bulb efficiency (WBE), dew point efficiency (DPE), coefficient of performance (COP), and power consumption (PC).

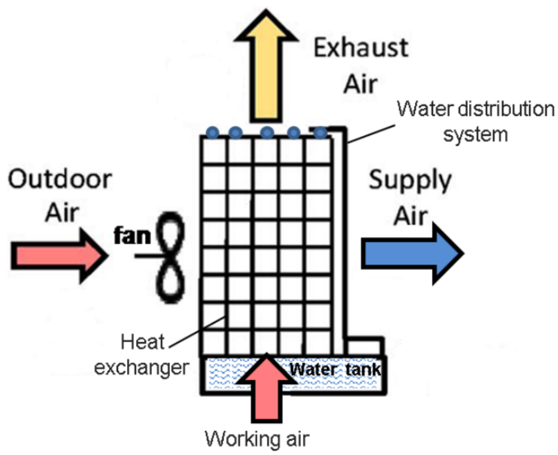

Fig. 2 represent the basic structure of IEC

Indirect evaporator is based on the heat and mass transfer between air on one side and air with cooling water on the other [1-3], [6-8], [11,12], [14-18], [22-26], [30-34], [36,37], and [40,41]. In many HVAC applications, such as those for data centers, movie theaters, supermarkets, and office buildings, IEC is recognized as a cooling approach that is appropriate. Chen and others[65] developed a computational model for heat and mass transfer to know the cooling performance of a system operated by indirect evaporation, as a set of calculations were made for a shell and tube type heat exchanger for this system that uses room air (return air) or outside air (fresh air) as secondary air which is used to cool the main air supplied to the space. The study was carried out first by using the return air as a secondary air, then using fresh air as a secondary air to cool the main air that will be supplied to the space to be cooled. The cooling capacity and system efficiency were found to be higher when room air is used as secondary air.

Boxem et al., [66] presented a study of an indirect evaporative cooling system incorporating a counter flow heat exchanger with zigzag fins on both sides. This model was used to predict the performance of a cooler with an air flow rate (400〖m〗^3⁄h). The researchers concluded from this study that the cooling performance of this system is 20% for an indoor air temperature of less than 24°C and 10% for an indoor air temperature that is higher. from 24°C.

Zhao et al. [67] conducted a numerical study on a counter-flow heat exchanger as an indirect evaporative cooling unit, as they suggested a range of design conditions to achieve the greatest performance of this system. These conditions represented the inlet air velocity, which ranges from -0.5 m/s. 0.3) and the height of the air passage is 6 mm or less, and the ratio of length to height of the air passage is 200, and the ratio of the incoming air to the operating air is around 0.4, and they concluded that this system under these conditions can give an effectiveness of a wet bulb up to 1.3 for the British atmosphere.

The researcher Pescod, [68] proposed a simplified design of the evaporative air cooler that uses parallel plastic sheets with small protrusions, although the thermal conductivity of the plastic sheets is very small and the thermal resistance through the thin plastic sheet will be less than the thermal resistance between the air and the sheet at the dry side of the exchanger. Predict The efficiency will be higher than the experimental results.

The researchers (Kettleborough, and (Hsieh)[69] also described the counterflow in the indirect evaporative air cooler, as the primary air flow is upward and the secondary air flow is downward. Numerical analysis was used to study the performance of this unit, by applying the wetness ratio, it was found that there is a good agreement between Data that has been calculated and measured from the system.

The researchers (Erens, and (Dreyer) [70] also reviewed three different models that describe the air cooler that depend on indirect evaporation, namely: (1) the Poppe model, which considers the variables as the Lewis factor, the rate of water evaporation, and the percentage of saturation in the secondary air; (2) The Merkel model can be derived from the Pope model by considering the Lewis factor as one quantity and neglecting the amount of water that evaporated and assuming that the secondary air does not approach the saturation state (3); the simplified model assumes that the water temperature is constant in The cooling system The researchers applied these models to an indirect evaporative air cooler that uses a cross flow heat exchanger and recommended that it is preferable to use the simplified model for small units and for primary design purposes.

(Chengqin, and Hongxing)[71] developed an (analytical model) for an indirect evaporative cooling system with parallel/reverse flow similar to any other type of analysis model. Surface temperature.As well as assuming that the effect of water evaporation and water temperature varies along the length of the heat exchanger and the Lewis factor and the surface wetting ratio is not the same.The results obtained from the analytical solution were found to be in good agreement with those numerical results in previous research.

Khalid A. Joudi,) and (khawla)[72] conducted a study that includes numerical modeling, as this numerical modeling includes a study of the change in the performance of the exchanger with the change of its dimensions from 300 〚mm〛^2 to 〚mm〛^21000, as well as a study of the change in the distance between the plates from mm^3 to 15 mm, and the air velocity changed into this exchanger from 0.3 m/s to (5 m)/s, and the weather conditions of Iraq were used as external design conditions to represent the change in external temperatures.

The researcher Yousif [73] studied the effect of the heat exchanger on the performance of the evaporative cooling system, as the study was on two types of coolers that depend on the principle of evaporation, a direct evaporative cooler without a heat exchanger, and an indirect evaporative cooler (with a heat exchanger). The heat exchanger was made of copper, then the exchanger tubes were placed in rows, the distance between each row was 4 cm, the length of each tube was 55 cm, the height was 60 cm, the diameter of the tube was 1 cm, and the number of tubes was 15 tubes. This study was conducted in the last week of January 2014 in a village in Sudan.

The researcher Pescod, [74] conducted the development of an indirect evaporative cooler and replaced the plate exchanger made of metal with another made of plastics and investigated the effect of plastics on the thermal performance of the system. and the temperature of the dry bulb (36^oC), and the effectiveness of the system was (85%). The researcher defined the effectiveness as a criterion for the thermal performance of the evaporative cooling system, and it represents the amount of reduction from the ambient air temperature entering the system to the main air supplied to the space to be cooled.The researcher concluded by using different velocities that ranged between (0.3-4m/s) that the efficiency decreases with increasing air velocity, meaning that the relationship is inverse between them. It was found that when the fins are used on the inner surface of the designed plates, the efficiency increases due to the increase in heat transfer due to a shift in the flow type and the penetration of the adjacent thermal layer, which increases the heat exchange.

The researcher (Chan, [75] studied four different exchangers, but with the same dimensions designed by the researcher Pescod, but with different interfacial surfaces and distances. In terms of changing the shape of the surface, he concluded that within specific speed limits, the extended surfaces (fins) with a straight shape give more efficiency than the flat surfaces. With a pointed shape, and in terms of changing the interlayer distances, the researcher found that changing the interlayer distance of the plates from (3-3.6 mm) has no significant effect on performance. Colloidal silica.

The researcher Pescod, [76] conducted an analytical study of the heat exchangers that he designed in his previous study mentioned above and made of plastics. He presented seven models of equal size (20 * 20 * 30cm), he studied the effect of the interfacial distance between the plates and the change in the geometry of the plates on the efficiency, he concluded The researcher showed that when making protrusions on the surfaces of the plates, it leads to an improvement in heat transfer, which leads to a significant increase in the effectiveness of the system.

The researcher Pescod, (1975) once again cared about plate heat exchangers with the aim of using them in indirect evaporative cooling systems within the climatic conditions of the regions of the continent of Australia. 36^oC) and the temperature of the wet bulb is about (25^oC), and since most of the continent's atmosphere in the summer season does not exceed the temperature of the wet bulb of air (25^oC), this method of cooling is suitable for most regions of the continent.

The researcher Ali [77] presented an experimental study of the performance of indirect evaporative coolers with plate exchangers. The researcher used galvanized iron sheets with (33) plates and dimensions (300 * 600 mm), and the thickness of one plate was (1 mm) and the distance between the plates was (300 mm). The air flow is of the orthogonal type. The study was done using two models of exchangers of the same specifications mentioned, one of which is finned and the other is unfinished. The researcher concluded that the finned plates give a higher cooling efficiency than the non-finned plates.

The researcher (Kettleborough & Hsieh, [78] developed a mathematical model using the computer for a heat exchanger with orthogonal flow made of sheets made of plastics. It has a clear effect on effectiveness, and in terms of comparing its practical results with regard to effectiveness, it was found that its results matched to a large extent with the results reached by the two researchers (Pescod, Chan).

The researcher Rasheed, [79] analyzed the regular and irregular flow of air inside the channels of the exchanger and found out the effect of the type of flow on the efficiency, using the mathematical model of the researcher (Kettleborough). He also studied the effect of wettability with water for the secondary surfaces on the efficiency. Significantly effective He also studied the increase in the water recycling rate from (5) to (15) times as much as the rate of water evaporation, and it was found that the efficiency was clearly affected by the increase in the water recycling rate.

The researchers, Said & Khassaf, [80], evaluated the performance of the indirect evaporative cooling system in Iraqi homes. The study was conducted on residential homes designed by the Housing Corporation in three governorates (Nineveh, Baghdad, and Basra). And the weather conditions recorded by the Meteorological Department were adopted over a period of thirty years. The researchers found that the results of the study indicate the possibility of using indirect evaporative cooling systems throughout the country, as it provides a state of comfort, especially in the governorates (center and south), as it is characterized by its hot and dry climate in the summer.

The two researchers, Enwia, & AL-Shawe, [81] focused on a study on the indirect evaporative cooling system with a plate exchanger. Since the heat exchanger is considered the basis of the system's work, they made a heat exchanger consisting of aluminum sheets, and the air flow is in two perpendicular paths. The secondary (wet) air is cooled by spraying water mist from above which in turn cools the primary (dry) air supplied to the space. The researchers also studied the change in the shape of the surface of the plates and the distance between the plates and their effect on the effectiveness of the wet bulb. The lower the percentage of wetness, the less effective the wet onion will be.

The researcher Hussein [82] conducted a practical study on the lamellar exchanger with orthogonal flow used in an indirect evaporative cooling system. The researcher used aluminum sheets with a thickness of (1 mm) and the number of (33) with a length of (66 cm) and a width of (52 cm). Water is sprayed from the top of the exchanger on the wooden filling placed inside the secondary air passages to be moistened. The researcher studied the effect of water and air flow on the efficiency. He used ranges of humidified water from (100-100 L/hr) and ranges of primary air from (0.75-0.06 kg/s).) and for secondary air from (0.34-0.05 kg/s). The researcher found, through his results, that changing the air flow greatly affects the efficiency of the system, as the increase in the flow rate of the main air leads to a decrease in efficiency (an inverse relationship). Gradual in system efficiency (positive relationship), especially for medium ranges of water flow after (600 L/hr) the increase in efficiency is slight. The researcher also studied the effect of placing a metal clip in the main airway, and noticed that it causes an increase in efficiency (approximately 30%), but this increase is accompanied by a rise in pressure drop by (32%).

The researcher Joudi & Mehdi, [83] applied the principle of indirect evaporative cooling to a typical Iraqi house with a variable cooling load.

The researchers Brooks & Field, [84] fabricated a model of an indirect evaporative cooler that contains a heat exchanger with a cross-flow of air. It contains a heat exchanger made of corrugated plastic sheets stacked vertically to form the primary and secondary channels of the heat exchanger. They found that the cooling efficiency is rather low. And they analyzed the reasons for the weakness in the cooling efficiency, represented by poor water distribution, poor distribution of air entering the exchanger, and insufficient heat transfer area.To solve the problem of poor water distribution, they suggested using a water distribution network so that the water is allowed to descend directly to the lower area of the passages Heat exchange They put a metal clip inside the air passages that acts as a primary coolant for the incoming air to increase the cooling efficiency in the system.In terms of increasing the heat transfer area, it can be solved by increasing the surface roughness of the plates.

Wang, et al. [85] conducted a theoretical and experimental study of an indirect evaporative cooler containing composite fibers, and compared the composite fibers in terms of heat transfer efficiency with cotton and polyurethane fibers. They found that the blended composite fibers had the highest heat transfer efficiency over the others.

Chengqin & Hongxing [86] developed an analytical model of four types of heat exchangers in an indirect evaporative cooling system at two types of flows (cross / orthogonal) for air stream under realistic operating conditions. They developed the analytical model assuming that many parameters are constant (Lewis factor, wettability, flow rate and temperature of water mist, and water vapor content). After conducting a comparison between the results of the analytical solutions with the numerical results and obtaining agreement between them. Conduct performance analysis for the four types of flows. It was found that the orthogonal flow performed better than the cross flow.

Qiu, [87] studied the practical performance of an indirect evaporative cooler, and its real performance is much lower than the values provided by the main specification. The researcher found through his study that the reason for the poor performance is the poor distribution of water, as the researcher noticed when the cooler was running that part of the surfaces were wet and the other was dry. To solve this problem, the researcher added a water sprinkler device on top and integrated a solar panel powered by solar energy to provide power for the fans and water pump in the cooler. It was found that the cooling capacity and performance factor of the upgraded cooler were three times greater than the original main one. The amount of temperature reduction was in the range (3 - 8^{o}C) for all test conditions.

The researcher (Heidarinejad, et al. [88] conducted an experimental study on the performance of the two-stage evaporative cooling system (direct - indirect) and the effect of different climatic conditions on the cooling efficiency of the system. The direct evaporative cooling stage consists of a cellulose pad with a thickness of (15 cm). While the indirect evaporative cooling stage consists of a heat exchanger of size (500 x 500 x 400 mm) with surfaces made of plastic and a distance between channels (7 mm). The results reached by the researcher showed that under different climatic conditions (dry temperature ranges from (49-27^{o}C) and wet bulb temperature ranges from (15-33^{o}C), the effectiveness of the wet bulb of the device was higher by (108-111%) than the non-evaporative cooling system

The researchers also conducted (Hmood & Joudi, [89] numerical modeling, to study the change in the performance of the exchanger with the change of its dimensions from (1000-300 mm2) and the change of the inlet air velocity from (0.3-5 m/s), and the Iraqi climatic conditions were used to represent the change in temperature. external. The results obtained from this study showed that the thermal performance of the exchanger increases with the low velocity of the inlet air, the increase in the dimensions of the exchanger, and the small distance between the plates, as well as when the wet bulb temperature is low or medium value.

The researcher (Kanzari, et al. [90] presented a mathematical model for an indirect evaporative cooler that reaches the temperature of the supplied air below the temperature of the moist bulb of the ambient air. It contains an exchanger made of porous ceramic material that gives the dew point temperature without increasing the moisture content of the air supplied to the room. It showed The results of the computer simulation show that the proposed design is able to cool the air to temperatures lower than the temperature of the wet bulb in the ambient air and achieve the effectiveness of the wet bulb of about (1.7).

Conclusion

In this paper, a review was made of direct and indirect evaporative cooling techniques, which can be applicable in high efficiency in heating and cooling systems used in many fields where water is used as a means to reduce air temperature by a large amount. Evaporative cooling systems are considered one of the most efficient and environmentally friendly systems. Evaporative cooling differs from common cooling systems in that it provides efficient cooling without the need for an external power source. It is recommended that more research and development be done regarding potential applications of evaporative cooling systems that enhance air conditioning systems.

Raferance

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