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Evaporative Air Cooler - A Review

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ABSTRACT

Evaporative Air Cooler technology originated from the concept of air cooling with water media very long decade ago. The cool fresh air for domestic and commercial use can be provided mechanically using the air conditioning (AC). The use of AC equipment will increase energy consumption in conjunction with the increasing amount of carbon emissions released into the air atmosphere. In an evaporative air cooler air is cooled by evaporating water in the equipment. Evaporation of water requires heat, so energy or latent heat taken from the air molecules - so the actual temperature of the air drops. The amount of water evaporates increase with the increasing water temperature. Relative humidity increases with the increasing of water temperature and remains constant at the same water temperature reported by few researchers whereas cooling effectiveness increase with the increasing of air stream velocity. Evaporative cooler can minimize consumption of fuel and lower the pollutants in the atmosphere as caused by VCRS. The evaporative cooler performs very well in hot and dry climate. It was reported that the best evaporative cooling period commences in the month of May and finishes in September and minimizes energy consumption for the fresh air cooling with almost 80%. This review is aimed to evaluate the effect of temperature changes on the cooling medium using different cooling pads. In this review we have discussed the utilization of a desert cooler, its performance and drawbacks associated with them along with the results presented by various authors in this field. It is concluded from this extensive survey of literature that evaporative cooling is economical then the existing VCRS systems.
Keywords : Alternate Cooling pads, Energy efficiency, Evaporative cooling, Water spray.

I. INTRODUCTION

EVAPORATIVE cooling is a heat and mass transfer process of decreasing the air temperature that uses water as an evaporative medium for cooling of air in which heat transfer from air to water takes place in large amount. The DEC cools the air when the it creates a contact with water present in the wet cooling pads. The evaporative cooling is very popular in arid areas due to its relativity in low initial and functional cost compared to air conditioning. The outside air is pulled using the fan through media (pads) that are kept wet by water that is sprayed on them in direct evaporative cooling system. If the outside air is sufficiently dry and hot, the water evaporates on the surface of pads and the heat required for evaporation is taken from air and air is cooled. The dust particles are trapped on the surface of the pad and washed down along with the water. Thus, air is cooled and filtered. In contrast, evaporative cooling systems provides with low energy consumption. The most commonly used DEC are basically metal cubes or plastic box structures with flat air filters arranged vertically, called “pads”, in their walls. the pads are kept moist by the water streaming continuously onto their uppermost edges and further distributing it downwards with the help of gravity. The processed air is drawn by fans operated with motor within the coolers. After the air is cooled and humidified while being flowing between the pads, it leaves the cooler as “conditioned air” for cooling purpose. Coolers consists regulators to vary the leaving air states as needed like 2-speed or 3-speed. The falling water is recirculated from the water basin by the water pump. The cooling efficiency of the evaporative cooling system is found to be increased by imparting the following three methodologies in the system, viz., (i) Arrangement of suitable internal components for increased evaporation; (ii) Combining the DEC and IDEC systems; and (iii) Using different pad materials with different Thicknesses.

Evaporative cooling provides considerable amount of comfort in many locations. However, locations where the humidity is very high, only ECS cannot be used alone for providing thermal comfort especially in houses, offices buildings, etc. The researchers till now carried out researches on evaporative air-cooling process mainly focus on reducing the DBT of the incoming air. Theoretically when the dry bulb temperature of the room and wet bulb temperature of the outside ambient air are equal, the efficiency of 100% can be achieved; Evaporative cooling effectiveness is defined as the ratio of dry bulb temperature across the equipment (cooler) and the difference between inlet DBT and inlet WBT. The purpose of this literature review is to collect and highlight some researches on evaporative cooling technologies as much as possible. The review covers direct evaporative cooling criteria, applications, advantages and disadvantages.

EVAPORATIVE COOLING TECHNOLOGY

The classification of Evaporative air coolers are: 1) Direct evaporative air coolers, in this type the two working fluids (water and air) are in direct contact; 2)The other type is Indirect evaporative coolers, in this system the working fluid is separated by a surface; (3) The Combination of direct and indirect evaporative coolers.

1) DIRECT EVAPORATIVE COOLING (DEC)

The oldest, simplest and cheapest type of cooling system is the evaporative cooling, in this type the direct contact of outdoor air with water takes place, i.e. the sensible heat is converted to latent heat to cool the air. The classification of Direct evaporative cooling systems are: First is the Active DECs which are electrically powered to operate and the naturally operated Passive DECs with zero power consumption.

2) INDIRECT EVAPORATIVE COOLING (IEC)

The aim of the indirect evaporative cooling is cooling of air by decreasing sensible heat without change in humidity,which is a major advantage over DEC systems. The components of IEC unit are: a heat exchanger (HX), small fan, pump, water tank, and water distribution lines. The classification of IEC system are: Wet-bulb temperature IEC systems and Sub wet-bulb temperature IEC systems.

3) INDIRECT-DIRECT EVAPORATIVE COOLING (IDEC)

The combination of both systems DEC and IEC can give better results, since Direct evaporative cooler shows higher effectiveness but increase in humidity while IEC gives lower effectiveness but the humidity is constant, The classification of main components of IDEC system are as follows: heat exchanger of IEC unit, evaporative pad of DEC unit, water recirculation system, water storing tank, and blowers.

ADVANTAGES AND DISADVANTAGES

Based on collected information of direct evaporative cooling system different advantages and disadvantages can be summarized as follows:

Advantages:

- The low cost and high effectiveness are themain advantages of evaporative coolers.
- Gives a wide range of applications and versatility in the apartments, dwellings, commercials and industrial units.
- Direct evaporative devices act like filters, removing dust particles present in air.
- No special skills are required to operate and therefore it is most suitable for rural application.
- Locally available materials can be used.
- The energy consumption is reduced by 70% therefore it is highly efficient.
- Less expensive to install and operate.
- It can be easily made and maintained.
- Due to higher flow rates the distribution of air is found to be better.
- The fans create positive pressures in the conditioned space, so that outside air is prevented from getting infiltrated.
- No chemicals are used.

Disadvantages:

- It is associated with the water consumption for the operation of these systems, which is rarely found resource in hot and dry climates, where this system best work.
- Need to be watered daily because ECS requires a constant water supply to wet the pads.
- It may lead to disease due to micro-organisms if the water used is not cleaned in regular basis and the pads are not maintained properly.
- Requirement of space from outside the home.
- Water with high mineral content leaves mineral deposits on the wetting medium and on the internal parts of the cooler gets damaged.
- DEC is suitable to dry and hot climate. The relatve humidity can go upto 80% in moist conditions, so much of higher humidity is not suitable for direct supply into residence, because it may cause rusting, and mildew of materials.

II. LITERATURE REVIEW

The air conditioning systems based on VCR system are used in many buildings and offices. These systems are harmful to environment as they consume extensive power. Hence, it is important to have low energy consuming devices which includes evaporative cooling systems in order to provide thermal comfort in buildings.

The maximum efficiency at velocity 1.790 m/s and thickness of 150 mm was founded by **Abdullah *et al.*** [1] in pad 5090, on other hand the maximum pressure drop is achieved at thickness of 75 mm for pad 7090 and velocity 1.8 m/s. The saturation efficiency decreases with increase in mass flow rate of air was observed by **R. K. Kulkarni *et al*** [2].They have also seen that higher saturation efficiency can be achieved with material having higher wetted surface area and they obtain result, the aspen and cellulose material gives highest and lowest efficiency of 87.5% and 77.5% respectively. The performance of palash fibers gives better result than that of other materials were concluded by **J.K. Jain, D.A.Hindoliy** [3] Palash fiber effectiveness was founded to be 13.2% and 26.31% more than that of aspen and khusfibers respectively. Special setup to evaluate the performance of natural fibers was designed by **Faleh Al-Sulaiman** [4].He founded the results that the average cooling efficiency is highest for jute at 62.1%, compared to 55.11% for luffa fibers, 49.90% for the reference commercial pad and 38.90% for date palm fiber. The analysis and performance of coconut coir pad as a media in direct evaporative coolers was done by **Akintunji*et al.*** [5] The mass flow rate of primary air varies between 0.160 kg/s to 0.540 kg/s and the performance analysis of the coconut coir pad is based on the saturation efficiency, leaving air temperature, relative humidity, cooling capacity and water consumption.The decrease in saturation efficiency from 64.7% to 55.9% was founded on the basis of air flow rate in coconut coir and from the results they concluded that at lower air mass flow rates the coconut coir performed better, wherelower leaving air temperature and relatively higher relative humidity are obtained. The efficiency of two different type of cooling pads made of a curtain fabric and a raw cotton fabric was studied by **Banyat*et al.*** [6] The effect at various speed of blower at 725, 1015, 1450 rpm was analysed by him and also investigated the water flow rate 26 lit/min.A procedure for testing evaporative cooling pads was developed by **Koca et al.** [7]They showed that face air velocity, pad angle, static pressure drop across the pads and pad thickness are important parameters affecting pad performance. The performance of DEC in hot and humid regions of Malaysia was experimentally investigated by **Abdul Rehman *et al.***[8] output air temperature, 27.5 to 29.4 was founded by him while cooling capacity ranges between 1.380 kW to 5.530 kW. **R.Bonkhanouf*et al.*** [9] presented a computer model and experimental result for porous ceramic materials with outride DBT 45 He proved that, with maximum cooling capacity of 280W air can be cooled below its WBT, the overall effectiveness of wet bulb is found more than unity. The functionality of The three different cellulose pads in an experiment set in accordance with the standards of AMCA and ASHRAE was assessed by **Koca*et al.*** [10] The first pad which was examined at the study was found to have thickness of 10 cm with 45 to 45° chamfer angle and the second had a 15 cm thickness with 45 to 45° chamfer angle. The cooling efficiency of the pad with 10cm thickness and 45 to 45° chamfer angle, was founded by him which varied from 73to 90% at 1.5 to 2.5 ms-1 air velocity. A study in Cukurova Region (Adana, S.Turkey), to determine the most suitable pad material for evaporative cooling system was carried by **Dağtekin*et al.*** [11], by comparing different pads made of poplar sawdust, nutshell and cellulose, it was determined by authors that cellulose based pad was the most suitable material for the mentioned region. **Hacisevki H *et al.*** [12] theoretically studied the availability of evaporative cooling systems in closed environments in the region based on the Nicosia- Cyprus region 1996 and 1997 climate data, evaporative cooling systems could be used especially between May and June months in Nicosia-Cuprus region was further determined. The three different pad materials efficiencies at different temperatures and air velocity in a study conducted in Evora -Portuguese was evaluated by **Cruz *et al.*** [13]. In the study conducted at four different temperature ranges with an air velocity of 1.6,3.2, 4.8 and 5.6 ms-1 respectively, the highest cooling efficiency (80% and more), was achieved at 3.20 ms-1 air velocity at temperatures of 32 to 34°C. Some performance characteristics of the cellulose-based evaporative cooling pad at different air velocities in Mediterranean climate conditions was examined by **Yild*et al.*** [14] In his study, the values chosen for the velocity of the air passing through the pad were 0.5, 1.0 and 2.0 ms-1, while the pad wetting water flow rate (4 Lmin-1m-2) was kept stable. As a result of the study covering the period from June to September, the cooling efficiency at the selected air velocity was found to be 77 to 84%. Some performance characteristics of an evaporative pad cooling system in a broiler poultry house at Mediterranean climate conditions was examined by **Dağtekin*et al.*** [15] The study results that it was completed in July to August, the cooling efficiency of the system varied between

70 and 80% was determined and nearly 10°C temperature decreases were attained at the outer environment air extracted into the poultry house by passing through the pads.

A study of performance of evaporative cooler with different cooling pad shapes and materials was theoretical performed by **R.K.Rajput*et al.*** [16] . Different shapes such as Rectangular, cylindrical and hexagonal shaped pads of rigid cellulose, corrugated paper, high density polythene packing and aspen fiber material were considered. Geometrical parameters of pad shape like area, volume were calculated for air velocities between 0.75 to 2.25 m/s. For the performance of weather analysis data of Bhopal, India inlet condition of 39.9 0C dry bulb temperature and relative humidity of 32.8 % were selected. With increase in mass flow rate of air saturation efficiency decreases having highest value of 91 % for hexagonal shaped pad with aspen material. The cooling capacity increases with air mass flow rate having minimum value of 35826 kJ/h for rectangular pad with cellulose material for air mass flow rate of 0.3 kg/s.The effects of thickness and inlet air velocity on pressure drop and efficiency of evaporative cooling pads was studied by **Liao et al**. [17] Two different kinds of pad materials were used a coir fiber and a nonwoven fabric perforated pads, the cooling efficiencies varied from 81.19% to 81.89% and 89.69% to 92.86% for nonwoven fabric perforated and coir fiber material pads, respectively. The performance of three natural fibers (palm fiber, jute and luffa) as wetted pads in evaporating cooling was experimentally evaluated by **Al-Sulaiman** [18] For an air velocity of 2.4 m/s, the cooling efficiency was found for jute about 62.1%, as compared to 55.1% for luffa fibers, and 38.9% for date palm fiber. A compact wind tunnel to simulate evaporative cooling pad-fan systems was developed by **Liao and Chiu** [19].They did the investigation on the effects of water flow rate by testing the two different materials for pads and, pad thickness and inlet air velocity on evaporative cooling efficiency. The pads were made from coarse fabric PVC of parameters having sponge mesh 2.5 mm diameter in pinhole and fine fabric PVC sponge mesh 7.5 mm diameter pinhole. Their results showed that the efficiency of coarse fabric PVC sponge is higher than the fine fabric PVC sponge. The two correlations for heat transfer coefficients were founded by **Rawangkulet al.** [20] he did experimental analysis of the performance of coconut coir material as a direct evaporative cooling pad. Evaporative cooling efficiency and pressure drop across two small coconut coir pads of different configuration in a range of velocity1.88–2.79 m/s was determined by them. They confirmed that coconut coir has valid potential and can be used as a wetted media in evaporative cooling systems. **Buffington et al**. (1978) [21] did the comparison of four different materials of evaporative cooling pads to determine the variation in cooling efficiency. The velocity of the air passing through the pad was kept stable at 0.75 ms^{-1}in the study. At the end of the study, they stated that the cement compounded sugar beet pulp pad showed the maximum cooling efficiency and was followed by a cellulose based pad, while the rubberized pig bristle showed the lowest efficiency. **Malli et al.** [22] An experimental investigation was conducted on two types of cellulosic cooling pads i.e. 5090 and 7090. They found that by increasing frontal velocity and the thickness of the pads the pressure drop and the rate of the evaporated water increases and if the frontal velocity is increased then the effectiveness and the variation of the humidity decreases. **Bishoyi et al.** [23] did an experimental investigation on two types of evaporative cooling pads under the Indian climate conditions and found that evaporative cooling pad made of Aspen has an energy efficiency ratio and cooling capacity lower than cooling pad made of Honeycomb paper.

AbdollahMalli et al [24] performed the experimental study on the performance of thermal cellulosic pads made of corrugated papers. He tested the polyethylene samples in a sub sonic wind tunnel. For several inlet air velocities the research work on Pressure drop, humidity variation, evaporated water and effectiveness have been done. The most efficient technique used in cooling towers, humidifiers and evaporative coolers is direct evaporative cooling. During this process the water is sprayed continuously on the pads and the warm air is drawn by the fan through the wetted pads, these pads extracts the heat from the air and the air leaves the system at a lower temperature. Manufacturers have designed pads made of cellulose paper with an aim to improve the cooling effect in different applications like residential sectors, storage warehouses, etc. These pads are energy efficient, cheap; compact is size and light in weight and also pollution free. **B.L.Thakor** [25] in their present work discus about the global warming and its prime concern to the human being. Global warming has got different types of harmful effects. The change in weather of the Globe is taking place in an unpredictable way and Due to global warming and greenhouse effect the countries on equatorial line and on tropics are facing high temperatures. Industrialization leads in increase in concentration of the greenhouse gases. A special machine evaporative air conditioner has been developed to overcome the effect of high temperature and to achieve the human comfort conditions. Principles of evaporative air cooler with air conditioning system together are used in this evaporative air conditioner to give the better results. **J.M. Wu et al** [26] studied and theoretically analysed the heat and mass transfer between the air medium and water in DEC. The discussion covers how the frontal air velocity and thickness of pads effects the cooling of direct evaporative cooler. Approximately 2.5m/s frontal velocity was recommended for the determination of pads frontal area module for the recommended air flow. On finishing the test it was concluded that the relation between cooling efficiency and energy balance analysis of air was valid. **E.Velasco Gómez el al** [27] said that evaporative cooling process is a very common phenomenon in nature by comparing the two systems i.e. evaporative cooling and air conditioning. Evaporative cooling is a cheaper and low energy consumption method and a best replacement to air-conditioning. To overcome the risk, EC was produced from humid environment and is achieved due to the difference of vapor pressure between the surface and the air, in such a way that water evaporates and thus reducing the generation of aerosols to the minimum, responsible for the spread of legionnaire disease. Aerosols are produced in conventional systems because the water is sprayed or comes directly in contact with the stream of air. In this paper a winter AC system suitable for the regions with cold and dry winters was given by **Mohamed M. El-Awad** [28]. The heating process is added just after the humidification process in this system which is a simple modification of the evaporative air-cooler. The theoretical framework is taken to estimate the system was discussed in the paper.The process of heating is done by utilizing the clean and renewable energy source i.e. solar energy, the system also maintains the major advantage of EAC over refrigeration systems with respect to the environmental impact. A neutral network framework to guess the air handling performance of Direct evaporative air cooler under several working conditions was bought by **Qiang et al.** [29]. For environmental controll in agricultural buildings the DC application using water evaporation is widely used. **Zhang** [30] did the assumption that the water evaporates completely to study the heat and mass transfer characteristics of a wetted media. By related investigation of the processes of heat and mass transfer in Direct evaporative air cooler and the cooling tower. A theoretical research of a cross-flow DEC was presented by **Dai and Sumathy** [31]. this investigation covered constitution of the wet long-lasting honeycomb paper as the wetted pad and the alternating layers of two types of papers with various wave angles which results in formation of air channels were regarded as parallel surface channels with constant spacing. The study of cellulose pads for measurement of adiabatic humidification and dehumidification cooling performance was done by **Zhang and Chen** [32]. The study of performance of the stainless-steel pad and the perforated aluminium pad was done by **You and Zhang** [33]by assuming the adiabatic humidifying process.

III. GAPS IN LITERATURE FUTURE SCOPE

The following are the few research gaps and future scope in the literature: The methodological analysis used by various authors are partially difficult to understand.

- Extensive number of papers are available in various fields of EC but very few papers are available related to integral direct evaporative cooling arrangement.
- Very less research work is done related to reduce noise in operation.
- In future the research is must in the areas such as redusing water consumption, inceasing quality of air, reduction in noise in operation and integral direct evaporative cooling arrangement which are not explored yet with full potential.

IV. CONCLUSION

Following conclusion can be drawn from the literature review performed above:

Direct Evaporative cooling can provide advanced level of thermal comfort in humid as well as dry regions. Researchers trying to search or develop newly efficient and good quality pad materials from all over the world which is important to achieve improved performance of evaporative cooling devices. Evaporative cooling has large potential to provide indoor comfort condition at reduced operation cost in region where WBT is less than 24^{O}C. The process of decreasing air temperaure using water for evaporation is substantially the most environmentally friendly and effective cooling system.Evaporative air coolers have many advantages in this ongoing energy crisis and pollutant emission constrains. Thus, from the literature studied it can be concluded that the air coolers have scope for improvement for better comfort conditions by using new methods and by adding new features like the water spray arrangement inside the cooler in the open space available below the blower fan with the regular cooling medium (wetted pads).We are interested in continuing the work with an integral direct evaporative cooling system integrated with the pad structure. Such an integrated system could be widely used with a better performance than the today operated systems and under different conditions. This paper includes a review-based study in the evaporative cooling techniques in terms of its cost, power & energy consumption, effectiveness etc. but the methodologies presented by authors are partly difficult to understand. So, more attention and lot of research is required in this area for developing new technologies related to evaporative cooling such as making an arrangement of pipe structure in the internal space available below the blower for increasing the contact between air and water which will ultimately increase the effectiveness of the DEC.

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