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A Review on Investigation of Evaporative cooling

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Abstract

Air-conditioning plays an essential role in ensuring occupants thermal comfort. In order to achieve these comfort Evaporative cooling provide the better solution to conventional vapour compression system. These paper aims to review experimental and theoretical work carried on indirect evaporating cooling along with direct evaporating cooling and combined one. The theoretical direct evaporative cooling work, defines the optimum shape of the cooler as well as the influence of various parameters i.e. primary flow velocity, pad thickness, and flow rate of water on cooling performance. Whereas different constructive parameter of indirect evaporative cooling are also covers in the review. The results of the theoretical data are well agreed with experimental one. Two stage evaporative cooling can be successfully employed to hot and dry climatic area.

Keywords: Direct evaporative cooling, indirect evaporative cooling.

1. Introduction:

Energy demand worldwide for buildings cooling has increased very rapidly in the last few decades. it is observed that building sector is responsible for around 30-40% of world total energy consumption. Heating, Ventilation and Air Conditioning (HVAC) is the major energy user in a building. Due to great consumption of energy there is needed to develop energy efficient cooling system. The depletion of fossil fuel resources, and demands for reducing pollution are the motivations for replacing conventional energy resources with natural resources like evaporating cooling and radiant cooling. Evaporative cooling is an efficient and economically feasible method. It is a sustainable solution because the working fluids are air and water. It is the technology of cooling the air by evaporation of water which has been used in the past centuries. When water evaporates its absorbs the heat from surroundings air, resulting in the cooling of air. After water evaporates it enters the air as water vapour with latent heat therefore the air is humidified. Depending upon the contact of air with the water, evaporating cooling may be direct or indirect. In direct evaporative cooler (DEC) the air is in direct contact with water, it achieves the temperature drop along with increasing humidity. However in many applications increasing humidity is not desirable, in these case indirect evaporating cooling (IEC) can be employed [1].

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A typical indirect evaporative cooling unit as shown in Figure.1.It consists of a series of parallel plates with every second slot open for the air to be cooled (referring as primary air flow) flowing in the horizontal direction. In every other slot of the parallel plates, a secondary air stream flows upward while the liquid water is sprayed downward in the vertical plates. The primary air stream is not direct contact with liquid water and is cooled by the plate in which the distributed water film evaporates in the secondary air stream For this reason; the indirect evaporative cooling does not affect the absolute humidity of the primary air stream while reducing its temperature [2]. But indirect evaporative cooing fails to deliver grater temperature drop, hence it is better accommodate both system in order to satisfy thermal comfort condition. The major challenge in the design of an evaporating cooling system is to achieve high heat and mass transfer rates and low pressure drops, so that an evaporative cooling unit can be more efficient and more compact.

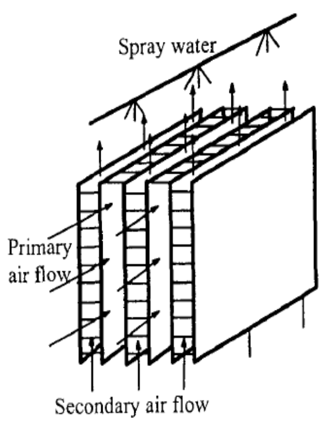

Figure 1. View of IEC [3]

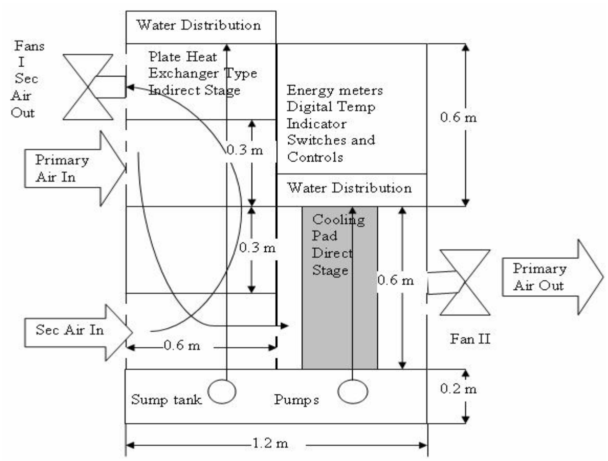

Figure 2. Experimental Set Up IEC/DEC [11]

2. Theoretical Analysis:

The evaporative cooler involves both heat as well as mass transfer these phenomenon is little bit complex one. to have proper prediction of the cooling system there are different models of indirect evaporative cooler has been suggested by different researchers in order to judge the thermal performance of the evaporative cooler.

2.1 Indirect evaporative cooler

X. C. Guo et.al [4] analyse the performance of indirect evaporative cooler numerically and develop a modal based on the fundamental energy equation. cross flow indirect evaporative modal has been taken in to consideration. He studied the effect of various parameters such as velocities of the primary and the Secondary air stream, the channel width, the inlet relative humidity and the wetability of the plate on its thermal performance are investigated. The result of the work shows that, by increasing the value of primary air temperature and velocity, effectiveness of the cooler come down and the outlet temperature of the air increases. Whereas by increasing the value of wetability factor and ratio of inlet velocity of secondary air stream to primary air stream, effectiveness of the cooler increases and temperature at the outlet of primary air come down.

M. Shariaty, et.al [5] discussed the effect of air stream direction on indirect evaporative cooler with respect to thermal comfort criteria. In addition they also suggested the different types of IEC (parallel, counter, cross flow) model and codes were defined in MATLAB. The result of the mathematical model shows the performance is strongly depends upon ambient air humidity and temperature. The models were also investigated with CFD technique. The CFD program was validated against theoretical data from the literature and good agreement between the prediction and measurement was achieved. Results reveals that if air relative humidity is maintained lower than 70% comfort condition are satisfied even at 50^0c.among all the flow configuration higher performance is achieved with the counter flow system.

Erens, Dreyer et.al[6] reported three different models describing evaporative indirect cooler. Poppe model- considering a variable Lewis factor, spray water evaporation rate and modelling. Merkel model- can be derived from Poppe model by assuming a Lewis factor of unity and negligible effect of spray water evaporation. Simplified model assuming that, the water temperature is constant throughout the cooler. They applied these models to a cross flow indirect cooler and simplified model was recommended for small units and for initial design purpose because results obtained from the model are accurate compare to other models.

C.Zhan, et.al [7] investigates the performance comparison between counterblow and cross flow heat exchangers for indirect evaporative air cooler numerically. They also reported the effect of Chanel shape (rectangular, triangular, and square) on the cooling performance of IEC. it is found that when the ratio of length to width of channels is 16:1, supply air can achieve a lowest temperature for both configuration. With increasing the air temperature wet bulb effectiveness of counter flow configurations about 7% greater than that of cross flow configurations.

2.2 Direct evaporative cooler

A.Fouda et.al [8] developed the Simplified mathematical model for describing the heat and mass transfer between air and water in direct Evaporative cooler. The model consists of governing equation with boundary conditions. Latent heat of evaporation is taken as heat sources in the energy equation. the model studied the effect of pad thickness on outlet temperature and cooling efficiency of the cooler. Graphical analysis shows that with increasing pad thickness Drop in temperature as well as cooling efficiency increases.

J.M.Wu et.al [9] investigates effect of various parameters such as velocity of the air, inlet air dry bulb temperature and wet bulb temperature on the cooling efficiency of the Evaporative cooler. The cooling effects of four different region of northwest china were predicted by the proposed model numerically. Result analysis reveals that there is negligible effect of air dry bulb and wet bulb temperature on the cooling efficiency.

Y.J. Dai et.al [10] studied cross flow direct evaporative cooler theoretically. A mathematical model, including the governing equations of liquid film and gas phases as well as the interface conditions, has been developed. Analysis results indicate that The evaporative cooler using honeycomb paper as packing materials is compact in size and weights less; it can as well act as a humidifier in arid region. Under typical conditions, it can reduce the air temperature by 9^0c and increase the humidity ratio by about 50%.

3. Experimental Approaches:

As explained above lot of theoretical work has been done so far but unless and until it is not proved with the experimental results it is of no use. Different research put their efforts to analyse the performance of indirect evaporative cooler under different conditions experimentally.

3.1 Reviewing studies

Kulkarni.R.K, et.al [11] experimentally investigated the cooling performance of the two stage direct\indirect evaporative cooling system. Experimental set up is illustrated in Figure.2.they attempts to evaluate the performance of two stage indirect-direct evaporative cooler with three different cooling media (Wood wool, Aspen fiber, Cellulose) of different geometrical shapes(Rectangular, Semi-hexagonal, semi-cylindrical) for direct stage. it is observed that primary outlet temperature It varies between 31.7^0c and 37.2^0c for IEC, between 24.2^0c and 31.1^0c for DEC and between 27.3^0c and 31.7^0c for combined mode. It is thus possible to reduce the temperature of incoming air below its WBT by the use of two stages cooler. Such operation will be beneficial in extreme climates. Overall efficiency is higher with the aspen material followed by cellulose.

G.Heidarinejad et.al[12]conducted the test on two stage evaporative cooling system various simulated climatic conditions.IEC unit is made from plastic wet heat exchanger where as direct unit from cellulose 15 mm thick material. Results shows that under various climatic conditions effectiveness of IEC stage and combined stage varies between 55-61% and 108-111% respectively.. Same work has been carried by Azhar Mohammed [13]. he came with the final conclusion that outlet temperature of air in two stage modes ranges between 23 ^{0}C and 25 ^{0}C.where More than 60% power saving could be obtained by this system in comparison with mechanical vapor compression system.

Direct evaporative cooler alone could not achieve the temperature below the dew point temperature. F.Bruno et.al [14] developed experimental set up for dew point evaporative cooler..He judges the performance characteristics of counter flow indirect evaporative cooler in regards to its outlet temperature and electrical energy efficiency. The results show that on the warm day, lowest daily outlet temperature obtained was 14.7^0c. Whereas energy efficiency ratio in the range of 7.5-11.

Jain et.al [15] developed and tested a two stage evaporative cooler to improve the efficiency by using wooden shave as the packing material. Room return air was evaporatively cooled and used in a heat exchanger to cool the incoming dry air. The effectiveness ranged from 1.1 to 1.2 and this cooler could achieve favourable temperature and relative humidity conditions for storage of tomatoes for 14 days.

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Aftab Ahmad et.al [16] carried out experimental study of indirect evaporative cooler under controlled environmental condition. The study investigated the performance of a 5-ton capacity indirect evaporative cooler with 43.9^{0}c dry-bulb temperature and 19.9% relative humidity but for different air flow rate. Experimental results shows that intake energy efficiency ratio varies between 7.1 -55.1 it is also reported that energy efficiency ratio was directly proportional to the wet-bulb depression. The study also showed that the indirect evaporative cooler is suitable for hot and dry climatic conditions.

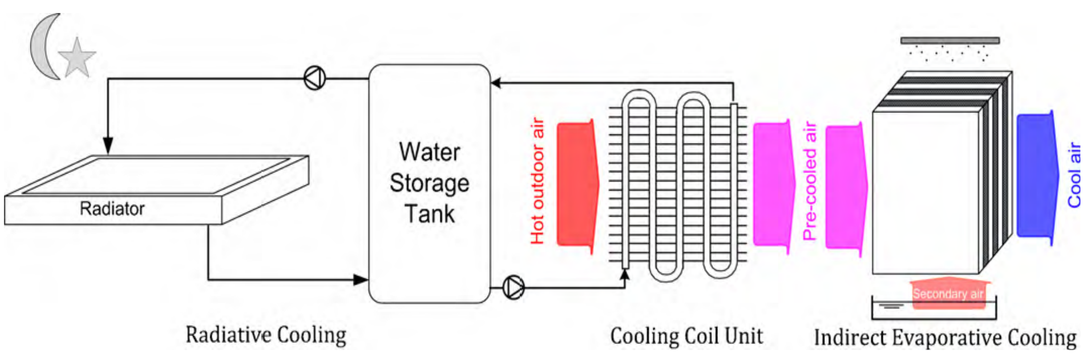

Figure 3. System of radiative cooling and cooling coil assisted IEC [17]

M.Farahani, [17] was contributed to develop two-stage system of nocturnal radiative and indirect evaporative cooling for conditions in Tehran. It is shown in Figure.3. The air is pre-cooled before entering in to IEC as primary air. He tested three different conFigureuration of IEC based on different sources of secondary air. Experiment is conducted in three different cities. Considerable drop in temperature is achieved and effectiveness of the system varies from80%-120%.

4. Literature Review

Investigator	Year	Remark
X. C. Guo et.al[4]	1998	Theoretically analyse thermal performance of IEC. The results are useful for the design of an indirect evaporative air cooler.
P.J.Erens et.al [6]	1993	Define the optimum shape of cooler unit based on the ratio of primary to secondary air velocity ratio.
Melikyan et.al[8]	2011	Developed the mathematical model of DEC. Graphical Analysis Shows the cooling efficiency is related to pad thickness and primary

		air velocity.
Kulkarni R.k et.al[11]	2011	Investigate two stage evaporative system experimentally and drawn the results that system overall efficiency varies between 119.5 % to 74.3 %.
Heidarinelad et.al[12]	2009	Experimentally investigate effect of constructive parameter on IEC under different environment condition.IEC effectiveness varies from 55-61% .

5. Summary

Using water for evaporation as a mean of decreasing air temperature is considerably the most environmentally friendly and effective cooling system. The literature review Indicate that Evaporating cooling is successfully employed to building air-conditioning. Following conclusion can be presented from literature review.

1. Moisture addition is taking place in the direct evaporative cooler so it put the limitation to employ the system in humid climates.

2. Constructive Parameter such as dimensions of the system, flow rate of the primary as well as secondary air, flow configuration of the system plays the vital role in the result of outlet temperature.

3. Two-stage evaporating cooling can be successfully adopted in hot and dry climatic conditions. Where it assures that outlet temperature of the process air can be decreased below its wet bulb temperature which is not possible with one stage IEC.

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