A Review on Evaporative Cooling Technology

Bhushan D. Chaudhari [1], Tushar R. Sonawane [2], Shubham M. Patil [3], Prof. Anil Dube [4]
Department of Mechanical Engineering,
Sandip Institute of Technology and research Centre. [1, 2, 3, 4]
Email: bhushansharkopack@gmail.com[1], sonawane.tushar64@gmail.com[2],
shubhamptl115@gmail.com[3], anildube100@gmail.com[4].

Abstract- Now days due to energy crisis and harmful effect to environment, there is more and more urgent need of energy saving in air conditioning and water cooling demands in mainly consideration of all the free cooling techniques. Among them evaporative cooling is well known technique from long time which gives good results and wide number of applications in residential, commercial, agricultural, and institutional buildings to industrial applications like as spot cooling in power plants, foundries, etc. So in this paper the evaporative cooling, it's potential, and different trends in evaporative cooling are studied, which are environment friendly as it uses only natural energy as latent heat of water. The efficiency and effectiveness of evaporative cooling depends on surrounding climatic conditions which are studied in this paper, faster the evaporation rate we gate maximum cooling effect.

Index Terms- Evaporative cooling; ambient conditions; wick material; direct-indirect evaporative cooling.

1. INTRODUCTION

Commercially Vapor Compression System is used for cooling purposes. Which consumes large amount of electricity so as to running compressor, it also uses refrigerants like CFC which are very harmful to the environment. Its operation and design is also very complicated as compared to evaporative cooling. So the best alternative is evaporative cooling. This paper reviews various studies carried out related to the evaporative cooling recently and the past, also evaporative cooling technologies that could potentially provide sufficient cooling comfort, reduce environmental impact and lower energy consumption required for conventional systems. Types of evaporative cooling reviewed are direct evaporative cooling, indirect evaporative cooling and combined direct-indirect cooling systems. Currently, mechanical vapor compression coolers (MVC) are commercially dominant in use despite their more and more energy use and low performance in hot climate. In opposite, evaporative cooling systems uses very less energy and its performance increases as temperature increases and humidity decreases. However, the main drawback of the evaporative cooling is their high dependency on the atmospheric air conditions. Since the temperature difference between the dry and wet-bulb temperatures of the atmospheric air is the driving force of evaporative cooling. For mild or humid climate this difference in dry and wet bulb temperature is less, therefore, it results limited cooling capacity.[6]

1.1. Basic Evaporation principle

Evaporative cooling is a physical phenomenon in which the evaporation of liquid into surrounding air cools a body in contact with it. It cool down a body with using its heat contain so as to convert liquid into vapor state[1]. The wet bulb temperature, as compared to the air dry bulb temperature is the measure of the potential for evaporative cooling when considering water evaporating into air. The greater the difference, between the two temperatures, the greater the evaporative cooling effect[2]. Therefore, evaporative cooling works by utilizing the natural process of water evaporation, along with an air moving system, to create an effective cooling environment. The fresh and warm outside air moves through the wet porous pad that cooling the air through water evaporation.

1.2 Common Types of Evaporative Cooling Methods

There are mainly two basic types of evaporative cooling systems are present namely direct and indirect evaporative cooling systems[1]. In direct evaporative cooling system the air passes straight across the humidifier into the cooling chamber, while in an indirect evaporative cooling system the air is first pre-cooled with heat exchangers before passing it through the cooling pad or vice versa depending on the purpose of cooling[4]. The process is adiabatic in direct evaporative cooling and as total saturation of the air is not possible, 100% cooling cannot be achieved[3]. Therefore the performance and application of direct evaporative cooling systems are limited. Then again two basic types of direct evaporative cooling system are active and passive direct evaporative cooling systems. An active evaporative cooling system uses system of fans or blowers to drive the ambient air through the wet pad into the system[5]. This system can function against high static pressure and it can be combined with a heat exchanger (indirect evaporative cooling). A passive evaporative cooling system does not uses separate systems like fans or blower for driving air, it uses natural circulation of air to drive cold air into the system (direct evaporative cooling). Passive systems are mostly applicable in the windy environment with large amount of air moving around and low pressure head. This is the oldest method of evaporative cooling and sometimes referred to as zero energy cooling as it does not consumes any commercial energy.

1.3 Cooling Pad Materials for Evaporative Cooling System

As we seen water is the working fluid in an evaporative cooling system. Many materials are used for making available wet surface for passage of air so as to cool it. The main characteristic of these materials is the ability to hold water and allow air to pass through it i.e. its porosity is the main influencing factor. Several organic and inorganic materials have been tested for the evaporative cooling purpose under different climates. These include the perlite, palash fiber, coconut fiber[7], palm leaf, palm fruit fiber, expanded paper, metal pads, cellulose pad, hessian pads, Aspen, PVC pad, porous ceramic pad, wood shaven, jute, rice straw; excelsior of pine, fir, cotton wool, charcoal and latex foam. Others are luffa, cedar, red wood, spruce, plain and etched glass fibers, copper, bronze, galvanized screening , vermiculite, woven plastic, etc.

2. LITERATURE SURVEY:

Evaporative cooling is a physical phenomenon in which the evaporation of liquid into surrounding air cools a body in contact with it and it is experimently found by Aimiuwu (1992, 1993) that the long-term temperature of water in a porous ceramic pot to be 9.4–15 °C below the atmospheric temperature or room temperature and to have a smaller daily variation than the outside temperature. A temperature depression of 10–13 °C in a box shaped evaporatively cooled chamber (ECC) constructed of zinc or copper because the outer surface of that material was covered by continuously wetted charcoal layers observed by Taha et al. (1994) . Fruits and vegetables like pomegranates, bananas, mangoes, apples, tomatoes, and potatoes not only had significantly increased shelf lives (by a factor of 1.3–2.7) but also exhibited good appearance and physiological properties when stored in an ECC compared to storage under ambient conditions (Waskar et al., 1999; Dzivama et al., 1999; Kumar et al., 1999; Uppal, 1999; Thakur et al., 2002; Dhemre and Waskar, 2003; Mordi and Olorunda, 2003).

Anyanwu (2004) measured the transient response of an ECC (Evaporatively cooled chamber) to changes in the ambient relative humidity (RH) and temperature during both seasons like dry and wet seasons. The box shaped ECC had two clay walls with continuously wetted coconut fibre which is used as a cooling material which fills the gap between the walls. On average, the temperature inside the ECC was 1–8.5 °C and 3–12.5°C lower than the ambient value during the wet and dry seasons, respectively. The ECC also increased the shelf lives of tomatoes and pumpkins by factors of 2.9 and 5 above their open-air storage values and it was very good. Dash and Chandra (2001) developed a mathematical model to study the influence of structural and operational parameters on the interior environment of an ECC, which was mainly affected by the rate of evaporation on the outer surfaces of the ECC and the infiltration/exfiltration rates through the chamber.

Upchurch and Mahan (1988) studied therotically that the characteristic leaf temperature of well watered cotton plants to be 27 ± 2 °C as the ambient air temperature varied from 27–40 °C. According to Prange (1996), insects like bees, grasshoppers, beetles, and cockroaches use evaporative cooling as a thermoregulatory mechanism under certain conditions and maintain a body temperature below 48 °C to avoid heat stress in hot environments. Because of its potential for significant savings in energy consumption, evaporative cooling is drawing increasing attention in indoor air conditioning.

From a numerical simulation, Fu et al. (1990) concluded that the temperature of a structure subjected to a severe thermal radiative heat flux decreased due to the presence of an evaporating water film on the structure’s surface. Kassem (1994) studied theoretically and experimentally a farm structure in which air, humidified and cooled via passing through a vertically oriented wetted pad, entered at one end of the building and exited from the opposite end. His calculations revealed that increasing the water evaporation efficiency of the pad and regulating the air and water intake rates to follow the variation of the ambient temperature would lead to substantial savings in the energy and water consumptions.

Giabaklou and Ballinger (1996) and Ghiabaklou (2003) developed a system that used the evaporative cooling effect of water falling vertically along that filaments or guides to cool and humidify the air which entering a building. For hot and semi-arid regions like New South Wales, Australia, and Teheran, Iran, and in many more countries their model predicted indoor average maximum temperatures to be 9.1 °C and 12.7 °C lower than the temperature of the incoming ambient air, respectively but also shows that the evaporative cooling system would result in a more stable indoor temperature and thermal comfort level as estimated from the predicted mean vote. In an experimental investigation of porous ceramic evaporators for building cooling, Ibrahim et al. (2003) measured dry bulb temperature drops of 6–8 °C with a 30% increase in the RH of the inlet air. The cooling effect was enhanced by a high porosity of the evaporator, increased water supply pressure, and a single (compared with a twin) row of evaporators in the air duct. Hollow fibre membrane contactors, which have a large mass transfer area per unit volume, with water and air flowing inside and outside the microporus tubes, respectively, which results good also have a good potential for space air conditioning and have been investigated by Bergero and Chiari (2001) and Johnson et al. (2003).

Dai and Sumathy (2002) have presented a theoretical model in which wet honeycomb paper is used as the packing material orcooling material through which the air stream to be cooled and humidified flows in a cross-flow fashion. Tang and Etzion (2004) and Cheikh and Bouchair (2004) have developed dynamic models for predicting the thermal performance of roof ponds of special designs for cooling buildings in hot and arid climates.

From experimentation Zalewski and Gryglaszewski (1997) has found a heat and mass transfer model for evaporative fluid coolers in which water was sprayed over the surface of the tubes while air flowed outside the tubes in a countercurrent fashion. A correction to the mass transfer coefficient (initially calculated from the Lewis relation) was introduced which made model predictions for the thermal performance of the cooler agree quite closely with experimental measurements. From an extensive experimental investigation, Armbruster and Mitrovic (1998) introduced correlations for the Nusselt number and temperature decrease (due to evaporative cooling) for water falling freely from a horizontal tube to the next one below it. They observed that the major part of the cooling effect during the free fall of the water between adjacent tubes rather than when it flowed as a film around the tube. From a theoretical analysis of the evaporation of water flowing in a thin film around the fin of an air-cooled heat exchanger, Song et al. (2003) concluded that evaporation would significantly increase the cooling effect.

Chuntranuluck et al. (1998a) did experiment on an algebraic method for predicting the chilling time, an important consideration in the food industry, for a regular-shaped food (infinite slab, infinite cylinder and sphere), which cools by convection and evaporation at its surface. Their model agreed fairly well with experimental measurements of the chilling time of a food analogue (Chuntranuluck et al., 1998b) and (peeled and unpeeled) carrots (Chuntranuluck et al., 1997c). From experimentation with a variety of test structures, Nahar et al. (1999) recommended a roof with a shallow pond and movable insulation for buildings in rural arid areas or wherever it wants it used.

A many more suitable model, which describes the cooling of a high-moisture cylindrically shaped food via convection and evaporation at its surface, has recently been proposed by van der Sman (2003). This model was based on numerical calculations with the heat diffusion equation inside the food body, which showed that except for a short initial time period, the average temperature remained in a fixed location. However, van der Sman did not present any comparison of the predictions of his model with experimental data.[9]

2.1 Performance Studies on Evaporative Air Coolers

The performance of evaporative coolers depends on the outside air DBT and WBT that means only on bulb temperatures, and the system arrangement of the cooler which decides the rate of evaporation of water. The evaporation rate depends on air velocity across the wick material, frontal area of the wick material, thickness of wick material, water circulation rate and the flow arrangements for water circulation.

Khandelwal (2010) uses a regenerative evaporative cooling for energy saving opportunity in buildings. The results raveled that evaporative cooling has great potential to save energy up to 15.79%, where simple evaporative cooling has potential to save energy is up to12.05%. The room temperature range got in between 22-26^{o}C. El-Awad (2010) has studied the solar powered winter air conditioning system using evaporative coolers. In this system solar heat is used to preheat the water. Theoretical model is developed for room of size 3×3×3m^3 volumes, and it consumes energy around 0.1KW. It is found that to cool 500 cfm air flow minimum four hours are required with 150 LPD solar heater is needed.

The theoretical analysis on an evaporative cooling is essential for revealing the heat and mass transfer laws in evaporative cooling process as well as for predicting the process outputs under various working conditions. A number of experiments were conducted on numerical simulation of heat and mass transfer of DEC. Zhang and Chen analyzed the heat and mass transport processes in DEC and developed a simplified physical model for the DEC, in which the process air was forced to flow over a wet plate with simultaneous heat and mass transfer Qiang et al. proposed a neutral network model to predict the air handling performance of DEC under various working conditions. The direct cooling technology using water evaporation is widely used for environmental control in agricultural buildings. Zhang studied theoretically that the heat and mass transfer characteristics of a wet pad cooling device by assuming complete evaporation of the spraying water.

Du et al. obtained the cooling efficiency formula of DEC as a function of the pad thickness, heat transfer coefficient, face velocity and specific pad surface. A mathematical model of DEC and its associated boundary conditions were established and the distributions of the velocity and humidity were calculated by the easier method.

He et al. developed film media used for evaporative pre-cooling of air. The cooling efficiencies of the cellulose media 35% to 90% while PVC media are 8% to 60%. Lee and Lee has been fabricated a regenerative evaporative cooler and tested because they wants to improve the cooling performance, the water flow rate needs to be minimized as far as the even distribution of the evaporative water is secured.

At the inlet condition of 31 °C and 50% RH, the outlet temperature was measured at 21 °C which is well below the inlet wet-bulb temperature of 23.5 °C. Kulkarni and Rajput made a theoretical performance analysis of direct evaporative cooling which they get results of the analysis showed that the aspen fiber material had the highest efficiency while the rigid cellulose material had the lowest efficiency.[18]

Heidarinejad et al. has found, the results of performance analysis of a ground-assisted hybrid evaporative cooling system in Tehran. A Ground Coupled Circuit (GCC) provides the necessary pre-cooling effects, enabling a DEC that cools the air even below its WBT. Simulation results revealed that the combination of GCC and DEC system could provide comfort condition whereas DEC alone did not. This environmentally clean and energy efficient system can be considered as an alternative to the mechanical vapor compression systems and also it uses as it is different from VCC. Kachhwaha and Prabhakar presented simple and efficient methodology to design a house hold desert cooler, predict the performance of evaporative medium and determined pad thickness and height for achieving maximum cooling. Dai and Sumathy theoretically investigated a cross-flow direct evaporative cooler, in which the wet durable honeycomb paper constituted as the pad material, and the air channels formed by alternate layers of two kinds of papers with different wave angles were regarded as parallel plate channels with constant spacing.[18]

Basediya et al. presents basic concept and principle, methods of evaporative cooling and their application for the preservation of fruits and vegetables and economy also. Chen et al. presented a case study of a two-stage DEC air conditioning application in the northeast Chinese city of Lanz housing simulation. The results showed that the indoor temperature and humidity level can be maintained at design values using such a system. Moreover, the electrical installation power of a two-stage DEC system is only 51.7% of that of conventional central air conditioning systems. The energy saving potentials of using DEC for air precooling in air cooled water chiller units in 15 typical cities in China were calculated by Jiang and Zhang. The results showed that by using DEC, the COP of the chillers can be enhanced by 14–27% in most of those cities. According to the analysis results of You et al., using DEC in air-cooled chiller units, the energy efficiency ratio (EER) of air-cooled chiller units in Tianjing can be increased by 14% [26].FAO (1983) advocated a low cost storage system based on the principle of evaporative cooling for storage of fruits and vegetables, which is simple, and relatively efficient. The basic principle relies on cooling by evaporation.

The pad characteristics as well as the parameters of the air and the water in DEC significant influence the performance of DEC. Therefore, the measurement and test of the heat and mass transfer processes of various pads under different inlet air parameters attracted a lot of attentions. You and Zhang studied the performances of the stainless steel pad and the perforated aluminum pad by assuming the adiabatic humidifying process. The minimum mass flow rate of the air and the water were1.5–3.5 kg $m^{-2}s^{-1}$ and 0.8–1.4 kg $m^{-2}s^{-1}$, respectively. Moreover, Ge investigated the cooling and dehumidification performances of five types of perforated aluminum pads with different sizes at various circulation water temperature. Yang et al. tested that the cooling performance of the cooling pad which is of aluminum with specific surface area under the higher air velocity, which is very helpful to understand about eavaporative heat exchanger the cooling efficiency of the pad tested was about 60%.[18]

Elfaith et al (2003) have investigated the performance of porous ceramics evaporators for building cooling application. In this direct evaporative cooling low, medium and high porosity ceramics are tested very well. High porosity ceramics gives better results in temperature drop even when the flow rate of water is increased. They have recorded the temperature drop in DBT is around 6-8 K and increased in relative humidity recorded as 30%. Maximum cooling they have been achieved is 224 W/m^2. Zhang and Chen measured the adiabatic humidifying and dehumidifying cooling performances of cellulose pads. The experiment results shows that the optimum airflow rate. Feng and Liu investigated the heat and mass transfer process of the foam ceramic pad with a specific surface.[18]As we all know there is formation of scaling i.e. fouling occurs in system after some days. Qureshi and Zubair (2005) have studied this impact of fouling on the performance of evaporative coolers and condensers. So they have evaluated the decrease in effectiveness due to fouling is to be 55% for evaporative coolers and 78% drop in condenser.

Dagtekin (2009) has found the performance of pad evaporative cooling system in boiler house in a Mediterranean climate. Xuan et al. first introduced the working principles and thermodynamic characteristics of different types of evaporative cooling, including direct, indirect and semi-indirect evaporative cooling. Foud a and Melikyana discussed heat and mass transfer, process in direct evaporative cooler. The predicted results show validity of simple mathematical model to design the direct evaporative cooler, and that the direct evaporative cooler with high performance pad material may be well applied for air conditioning systems. There are 7 pads used for experiment of size 2.6 × 1.9 m. This cooling system has 5 exhaust fans with maximum discharge of $42000m^3/hr$. They found efficiency of 75% and temperature drop of 7.3^oC.

Workneh (2009) introduced forced ventilation evaporative cooling during storage of tomatoes and potatoes using different evaporative cooling methods. They have find the effectiveness of the system. The average dry bulb temperature of atmosphere air is 32^oC and the inside temperature is around 21.5^oC, so the average drop we get is around 11.5^oC.

2.2 Studies Related to Indirect Evaporative Coolers (IEC)

Joohyun Lee, et al.,[12] presented Experimental study of a counter flow regenerative evaporative cooler with finned channels. A regenerative evaporative cooler has been fabricated and tested for the performance evaluation The air flowing through the dry channels is cooled without any change in the humidity and at the outlet of the dry channel a part of air is directed to the wet channel where the evaporative cooling takes place. The regenerative evaporative cooler fabricated consists of the multiple pairs of finned channels in counter flow arrangement. The fins and heat transfer plates were made of aluminum and brazed for good thermal connection. Thin porous layer coating was applied to the internal surface of the wet channel to improve surface wettability. The cooling performance is found greatly influenced by the evaporative water flow rate. The evaporative water flow rate needs to be minimized as far as the even distribution of the evaporative water is secured just for to improve the cooling performance. At the inlet condition of 32°C and 50% RH, the outlet temperature was measured at 22°C which is well below the inlet wet-bulb temperature of 23.7°C.

Aftab Ahmad, et al.,[13] presented Performance evaluation of an indirect evaporative cooler under controlled environmental conditions. The study investigated the performance of a 5-ton capacity indirect evaporative cooler under controlled environmental conditions (43.9°C DBT and 19.9% RH) but for different air flow rates (631 to 2388 m3/h). The experimental results showed that the intake air energy efficiency ratio of the cooler varied from 7.1 to 55.1 depending on test conditions and air flow rate. The power consumption of indirect evaporative cooler was found to vary from 68.3 to 746 watts. Water consumption was found to vary between 0.0160 and 0.0598 m3/h. At full fan speed, an average of 58.7% of the total water consumed by indirect evaporative cooler was evaporated. The results indicated that intake air 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.

Frank Bruno,[14] has found On-site experimental testing of a novel dew point evaporative cooler installed in both commercial and residential application. The systems use a counter flow regenerative plat heat exchanger. The paper presents results obtained from testing a prototype cooler installed in both a commercial and residential application in a wide range of ambient or room or atmospheric conditions. Cooler can produce supply air at a temperature as low as it provided by conventional mechanical VCR if the cooler operates at high efficiency. When outside weather conditions were hot and dry, the cooling effectiveness of the cooler would increase. It was shows that, by comparing with mechanical VCR, the annual energy saving by using the evaporative cooler was between 50 to 56 %. The cooler in commercial application, average WB effectiveness was 106% and in residential application 125 %.

B. Naticchia, et al.,[15] demonstrated Energy performance evaluation of a novel evaporative cooling technique. A preliminary experimental evaluation of the energy performance of a new technology which is capable of canceling conduction gains through walls which is known as water-evaporative walls, which are not only able to prevent the entrance of energy fluxes from the external to the internal, but also to reduce wall temperatures to below the values found indoors. This solution basically suggests equipping standard ventilated facades with a proper water-evaporative system, which exploits the latent heat of water evaporation, in order to absorb summer cooling loads. The insulation will act as a standard insulating material and also as a porous surface to store water sprinkled or sprayed by the system and then gradually loose it when needed for cooling. The experimental analyses showed the effectiveness of this technology, which decreases the overall summer energy load in buildings by canceling conduction loads.

Maheshwari (2001) presented potential of indirect evaporative cooling .He find the indirect evaporative cooling has cooling capacity of 3.7 TR for indoor areas, and 2.4 TR capacity in coastal areas. For this cooling capacity 4.93KW energy required for indoor and 3.85 kW energy is required for coastal areas, whereas 1.11KW energy is required for indirect evaporative cooling which gives best resuts on evaporative system.

2.3 Evaporative pad material

On evaporative pad material Dutta et al. (1987) has found that the suitability of evaporative cooling system (both indirect and direct type) for most zones of India and maximum areas of Australia. Navon and Arkin (1994) had conducted feasibility study on utilization of direct–indirect evaporative cooling for residences in Israel and found that this system can provide a significantly higher level of thermal comfort. Bajwa, Aksugur, and Al-Otaibi (1993) and Heidarinejad et al. (2008) had proposed similar proposed on various kinds of evaporative cooling systems to find their suitability in multi-climate country which is very useful. Eldessouky Hisham and Al-haddad Amir (1996) conclude the thermal and hydraulic performance of a modified two stage evaporative cooler. They showed that the efficiency of evaporative cooling of coconut coir's pad was around 50% and close to that of the commercial paper pad (about 48%). Camargo, Ebinuma, and Silveira (2005) conducted experimental studies on direct evaporative cooler and determined convective heat transfer coefficients. Various considerations were the mode of operation, packing thickness, water mass flow rate. Liao and Chiar (2002) developed a compact wind tunnel to simulate evaporative cooling pad-fan systems for direct measurement of system performance. Two alternative materials of coarse and fine fabric PVC spongy mesh were tested as pads in wind tunnel or any other suitable plce to experiment. The effect of air velocity, water flow rate, static pressure drop across pad and pad thickness were experimentally examined. El-Dessouky, Ettouney, and Al Zeefari (2004) developed an experimental rig of two stage evaporative cooling and tested in the Kuwait environment. The system was formed of an indirect evaporative cooler unit followed by direct evaporative cooler. Gunhan, Demir, and Yagcioglu (2007) shows the suitability of some local materials as evaporative cooling material. Rawangkul, Khedari, Hirunlabh, and Zeghmati (2008) had tested evaporative cooling pad made of coconut coir in Thailand region. Maheshwari, Al-Ragom, and Suri (2001) had demonstrated energy saving potential of an indirect evaporative cooler in Kuwait and also in Arub countries. Sodha, Singh, and Sawhney (1995) introduced a rule of thumb in terms of the size of the floor area to be cooled for two different climates, namely hot dry and composite for direct evaporative coolers. Zhao, Liu, and Riffat (2008) had demonstrated several types of materials, namely metals, fibers, ceramics, zeolite and carbon as heat and mass transfer medium in the indirect evaporative cooling systems and from the investigation, the most adequate material and structure were identified.[7]

Zhao et al. [8] carried out a comparative study into several IEC available as well as suitable materials, including metals, fibers, ceramics, zeolite and carbon. It is suggested that the thermal properties of the materials, i.e., thermal conductivity and water retaining capacity (porosity), have little impact to the IEC's heat/mass transfer, and therefore, these two parameters play low keys in terms of material selection. Instead, shape formation/holding ability, durability, compatibility with water-proof coating, contamination risk and cost, are more important concerns in this regard. The wick (sintered, meshes, groves and whiskers) attained metals (cooper or aluminum) are the most appropriate structure/material over the others contamination risk and cost, are more important concerns in this regard. The wick (sintered, meshes, groves and whiskers) attained metals (cooper or aluminum) are the most appropriate structure/material over the others. The thumb rules used to predict evaporation losses in different evaporative heat exchangers are unified.

A single correlation is then developed that is easy and accurate with a wide range of applicability as the predicted values are in better agreement with experimental values as well as predictions made by accurate mathematical models that only requires the use of a calculator at the site. For accurate prediction, the range of application should be limited so that the smallest cooling range is higher than or equal to 3^{O}C, the maximum value of the inlet air relative humidity is 0.8, the dry-bulb temperature of the incoming air is between 50^{O}C and 15^{O}C and the water to air mass flow ratio is from 0.5 to 2. These limits cover a maximum portion of worldwide normal operating ranges of the investigated evaporative heat exchangers and, thus, the correlation has excellent practical application.

Table 1.Workdone on Evaporative cooling.

Sr. No.	Author Name	Description
1	Aimiuwu (1992,1993)	found the long term temp of water in a porous ceramic pot below the ambient temp
2	Taha et al (1994)	observed a temp depression in a box shaped evaporatively cooled chamber
3	Anyanwu (2004)	measured the transient response of an ECC to changes in ambient RH and temp during dry and wet seasons
4	Dash, Chandra (2001)	studied on the influence of structural and operational parameter on the interior environment of an ECC
5	Upchurch, Mahan (1998)	found the characteristic leaf temperature of well watered cotton plant
6	Prange (1996)	found insects uses evaporative cooling as a thermoregulatory mechanism
7	Fu et al (1990)	concluded that thermal radiative heat flux decreased due to the presence of an evaporative water filnm
8	Kassem (1994)	studied theoretically and experimentally on the increasing the water evaporation efficiency of the pad
9	Giabaklou, Ballinger (1996,2003)	proposed a system that used the evaporative cooling effect of water
10	Ibrahim et al (2003)	measured dry bulb temp drops of 6-8C with a 30% increase in the RH of the inlet air
11	Dai , Sumathy (2002)	uses the honeycomb paper is used as the packing material through which the air stream is cooled
12	Tang, Etzion, Cheikh, Bouchair (2004)	They developed model for predicting the thermal performance for cooling building in hot and cold climate
13	Zalewski, Gryglaszewski (1997)	They developed heat and mass transfer model for evaporative fluid cooler
14	Armbruster, Mitrovic (1998)	developed correlations for the Nusselt number
15	Song et al (2003)	concluded that evaporation would significantly increase the cooling effect
16	Qureshi, Zubair (2005)	studied the impact of fouling on the performance of evaporative coolers and condensers
17	Dagtekin (2009)	studied the performance of pad evaporative cooling system in boiler
18	Workneh (2009)	work on forced ventilation evaporative cooling during storage and found the effectiveness of system
19	Tilahun (2010)	find the feasibility and economic evaluation of low cost evaporation cooling system
20	Khandelwal (2010)	uses a regenerative evaporative cooling for energy saving opportunity in buildings
21	El Awad (2010)	studied the solar powered winter air conditioning system using evaporative cooler
22	Maheshwari (2001)	studied potential of indirect evaporative cooling
23	Chaktranouda, Doungsong (2010)	evaluate energy saving opportunity in split air conditioning by using indirect evaporative cooling

24	Qiang et al	established a neutral network model to predict the air handling performance of DEC under various working condition
25	Du et al	obtain the cooling efficiency formula of DEC as a function of the pad thickness, heat transfer coefficient, face velocity and specific pad surface
26	He et al	studied film media used for evaporative pre-cooling of air to improve the cooling performance
27	Xuan et al	introduced the working principles and thermodynamic characteristics of different types of evaporative cooling
28	Heidarinejad et al	discuss the result of performance analysis of a ground-assisted hybrid evaporative cooing system in Tehran
29	Kachhwaha, Prabhakar	present efficient methodology to design a house hold desert cooler, predict the performance of evaporative medium and determine pad thickness
30	Basediya et al	reported basic concept and principle, methods of evaporative cooling and their application for the preservation of fruit and vegetables and economy also
31	Chen et al	Presented a case study of a two stage DEC air condition application. The result showed that the indoor temperature and humidity level can be maintain
32	M. Jradi	presented Experimental and numerical investigation of a dew-point cooling system for thermal comfort in building
33	Joohyun Lee	presented experimental study of a counter flow regenerative evaporative cooler with finned channels
34	Aftab Ahmad	presented performance evaluation of an indirect evaporative cooler under controlled environmental conditioned
35	Frank Bruno	presented On-site experimental testing of a novel dew point evaporative cooler installed in both commercial and residential application
36	B. Naticchia	presented energy performance evaluation of a novel evaporative cooling technique
37	B. Riangvilaikul	presented an experimental study of a novel dew point evaporative cooling system
38	Dutta et al (1987)	described the suitability of evaporative cooling system (direct and indirect type) for most zones of India and large areas of Australia
39	Navon, Arkin (1994)	conducted feasibility study on utilization on direct-indirect evaporative cooling system. This system provide a significantly higher level of thermal comfort
40	Eldessouky Hisham, Al-haddad Amir (1996)	evaluated the thermal and hydraulic performance of a modified two stage evaporative cooler
41	Liao, Chair (2002)	developed a compact wind tunnel to simulate evaporative cooling pad-fan systems for direct measurement of system performance
42	Gunhan, Demir, Yagcioglu (2007)	evaluated the suitability of some local materials as evaporative cooling pad
43	Sodha, Singh, Sawhney (1995)	evolved a rule of thumb in terms of the size of the floor area to be cooled for two different climates

3.CONCLUSION

This paper undertook a review based study into the Evaporative Cooling (EC) technology in terms of its background, originality, current status, and researches. This all work has great significant for developing new technologies relates to Evaporative Cooling (EC), in order to get cooling at zero energy cost, no harmful effect to environment and also having low initial cost. So more attention is required in this area and lot of work has to be done.

REFERENCES

[1] Otterbein R. Installing and maintaining evaporative coolers. May/June 1996. Home Energy Magazine. http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/96/960511.html.

[2] Watt J R., Evaporative cooling handbook, 2nd edition. Chapman and Halt, New York 1986.

[3] Xuan Y M, Xiao F, Niu X F, Huang X, Wang S W. Research and application of evaporative cooling in China: A review (I). Renewable and Sustainable Energy Reviews, 2012; 16(5): 3535–3546. http://dx.doi.org/10.1016/j.rser.2012.01.052

[4] Jain D. Development and testing of two-stage evaporative cooler. Building and Environment, 2007; 42: 2549–2554:doi:10.1016/j.buildenv.2006.07.034

[5] Ndukwu M C, Manuwa S I, Olukunle O J, Oluwalana I B. Development of an active evaporative cooling system for short-term storage of fruits and vegetable in a tropical

climate. Agric Eng Int: CIGR Journal, 2013; 15(4): 307－313.

[6] Z. Duan *et al*., “Indirect evaporative cooling: Past, present and future potentials,” *Renewable and Sustainable Energy Reviews*, vol. 16, pp.6823-6850, 2012.

[7] J.K. Jain a, D.A. Hindoliyab, Experimental performance of new evaporative cooling pad materials.

[8] Zhao X, Liu S, Riffat SB. 2008;43(11):1902–11, Comparative study of heat and mass exchanging materials for indirect evaporative cooling systems. Building and Environ- ment.

[9] Ashutosh Mittala, Tarun Katariaa, Gautam K. Dasb, and Siddharth G. Chatterjeea, Evaporative Cooling of Water in a Small Vessel under Varying Ambient Humidity, .

[10] M. Jradi, S. Riffat (2014) Experimental and numerical investigation of a dew-point cooling system for thermal comfort in buildings, Applied Energy, vol. 132, pp. 524–535

[11] Emmanuel D. Rogdakis, Irene P. Koronaki, Dimitrios Nik. Tertipis (2014) Experimental and computational evaluation of a Maisotsenko evaporative cooler at Greek climate, Energy and Buildings, vol. 70, pp. 497–506

[12] Joohyun Lee, Dae-Young Lee (2013) Experimental study of a counter flow regenerative evaporative cooler with finned channels, International Journal of Heat and Mass Transfer, vol. 65, pp. 173–179

[13] Aftab Ahmad, Shafiqur Rehman, Luai M. Al-Hadhrami (2013) Performance evaluation of an indirect evaporative cooler under controlled environmental conditions, Energy and Buildings, vol. 62, pp. 278–285

[14] Frank Bruno (2011) On-site experimental testing of a novel dew point evaporative cooler, Energy and Buildings, vol. 43, pp. 3475–3483

[15] B. Naticchia, M. D‘Orazio, A. Carbonari, I. Persico (2010) Energy performance evaluation of a novel evaporative cooling technique, Energy and Buildings, vol. 42, pp. 1926–1938

[16] B. Riangvilaikul , S. Kumar (2010) An experimental study of a novel dew point evaporative cooling system, Energy and Buildings, vol. 42, pp. 637–644

[17] Xuan Y.M., Xiaoa F., NiuaX.F. ,Huang X., Wang S.W ―Research and application of evaporative cooling in China: A review (I) – Research‖ Renewable and Sustainable Energy Reviews,16,3535– 3546,2012.

[18] Suvarna V.Mehere, Krunal P.Mudafale, Dr.Sunil.V.Prayagi, Review of Direct Evaporative Cooling System With Its Applications.

[19] Bilal Ahmed Qureshi, Syed M.Zubai A unified approach to predict evaporation losses in evaporative heat exchangers.