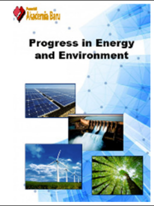
Penerbit Akademia Baru

Progress in Energy and Environment

Journal homepage: http://www.akademiabaru.com/progee.html
ISSN: 2600-7762



Model-based Performance Comparison of Different Configurations of Evaporative Cooling Systems in various Climates of Pakistan

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Muzaffar Ali[1,*], Zahida Yaqoob[1], Tanzeel-ur-Rashid[1], Abid Hussain[1], Zahid Suleman[1]

[1] Mechanical Engineering Department, University of Engineering and Technology Taxila, Pakistan

ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form 6 February 2018
Accepted 8 February 2018
Available online 30 April 2018

Keywords:
Direct evaporative systems, Indirect evaporative systems, falling film evaporation, Pakistan, MATLAB

ABSTRACT

The standard of living is continuously improving in all climatic areas of the world causing higher energy demands especially in building sector. The numerous cooling techniques that are being used are very energy intensive and also causing environmental hazards due to hydro chlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs). Therefore there is need to look for more energy efficient, cheaper, and environmental friendly cooling technologies such as evaporative cooling.The current study is focused on performance analysis of various configurations of evaporative cooling including direct evaporative cooling, indirect and falling film. Initially, a detailed mathematical model of these configurations is developed and then MATLAB code is developed for performance analysis under various operating conditions like air temperature and humidity. In view of performance dependence of these configurations on climatic conditions, comprehensive transient simulations are performed in five climatic zones of Pakistan including Islamabad, Peshawar, Lahore, Multan and Karachi considering their six month cooling duration data from April to September. The performance parameters considered are cooling capacity and outlet temperatures.The results obtained established that direct systems perform best in dry and hot weathers of Multan and Lahore even providing 2-3ºC more temperature reductions than falling film and indirect evaporative cooling systems and provide maximum cooling capacity of 2.4kW. Indirect system performs well in Islamabad and Peshawar providing 3-3.5ºC more reductions than direct and falling film configurations. Maximum cooling capacity of 2.29kW is required to meet the same outlet conditions, while falling film performs best than the other two configurations in all climates including humid climate of Karachi. Maximum temperature reduction of 26.1ºC is achieved in Lahore during the month of June. Maximum cooling capacity of 2.01kW is obtained to achieve outlet temperature equal to wet bulb.

1. Introduction

The building sector consumes a major part of world's whole energy. It has the leading sole potential for improving the efficiency of energy use. Cooling energy is a vital portion of this energy

* *E-mail address: Muzaffar.ali@uettaxila.edu.pk*

and the demand for cooling is incessantly increasing due to the rising demand for superior indoor ease conditions in buildings and the effects of global warming [1]. Air conditioning of buildings is currently subjugated by conventional compression refrigeration and air conditioning systems. Such types of systems are highly energy intensive and that's why, they are not very sustainable and even not environmentally friendly.

An alternative to conventional systems for low temperature applications as air conditioning during summers can be the phenomenon of low energy costs evaporative cooling, whose cooling air applications are being in use since the ancient years [2]. The phenomenon of evaporation is the conversion of liquid substance into gaseous state. Evaporation causes cooling of surfaces as it requires heat to change the liquid into vapour [3].

Dry bulb temperature of the surfaces is lowered when the air blows through them due to the transference of water to the air from the surface. The cooling effect is dependent on the temperature difference between dry and wet bulb temperatures, the air velocity, and the quality and condition of the medium [4].

Direct Evaporative cooling is the oldest, the simplest and the most prevalent form of air-conditioning [5]. Primary air in Direct Evaporative Cooling (DEC), comes directly into contact with water, which results in water evaporation and hence air temperature reduction. Evaporation of some of the water converts the sensible heat of air to the latent heat. Due to this evaporation, water vapours are added into the air, which results in an increase in humidity of air causing discomfort to the inhabitants [2].

Indirect Evaporative Cooling (IEC) systems cool the air without raising the indoor humidity, which makes them the most attractive preference over the direct ones [2]. In IEC the heat is transferred between the primary and the secondary air. Primary air is the air which is supplied from outside to the conditioned space. Tubes or plates are used as passages for the heat transfer, with the help of which the secondary air cools the primary air. The surface of passage through which secondary air is passed is sprayed by water which transfers the heat and mass between the wetted surface and the secondary air, reducing the temperature of both [6].

Evaporative coolers are the further group of this falling film apparatus in which water is sprayed over the bundle of tubes, where water flows around those tubes as a film and freely falls from one tube to the other. The falling film is typically open to an air flow; which is heated on tubes, and at the similar time, cooled primarily by evaporation at the water-air interface [7].

Fouda and Melikyan [8] established a basic mathematical model which describes the mass and heat transfer between water and air in a direct evaporative cooler. They concluded that the optimum frontal air velocity which provides higher efficiency should be assumed as 2.5 m/s and the cooling efficiency is augmented with the increase in the pad thickness, because of increased contact surface between water and air.

Similarly Kachhwaha and Prabhakar [9] work was related to the design of a household desert cooler. Parameters as input involved dry bulb temperature of inlet air, velocity of the air and geometrical properties for evaporative medium to predict the performance. During dry months up to10ºC of reduction in dry bulb temperature was seen in results by employing evaporative cooling. Present methodology could be used for size selection of an evaporative cooler design.

The impacts of the face velocity of inlet air, pad thickness and inlet air wet-bulb and dry bulb temperatures on the cooling efficiency of the evaporative cooler were also analyzed by Wu *et al.*, [10]. The results that were predicted showed that the direct evaporative cooler with higher performance pad material may be well applicable for the purpose of air conditioning with suitable pad thickness and inlet air face velocity.

Evaporative cooling systems can be used as a substitute to conventional systems in many tropical areas providing thermal comfort. Jose´ Rui Camargo *et al*., [11] has developed mathematical equations. From performance analyses temperature difference of up to 7.4ºC-8ºC between the external DBT and at the DEC outlet temperature was possible to obtain thus concluded that the evaporative cooler is more efficient when the temperatures are higher.

Tulsidasani *et al*., [12] researched on the thermal performance of a building that is non-air-conditioned and equipped with an IEC system. In India for three different climatic conditions (dry/hot, humid/hot, humid/warm), effects of various IEC parameters to thermal comfort of the building space was investigated. The results indicated that the IEC system is effective in improving the thermal comfort of the buildings in dry/ hot climatic condition.

Shariaty-Niassar and NGilani [13] also found that with respect to thermal comfort criteria, IECs can be effectively used in hot and humid climates. In another study, Jiang *et al*., [14] offered the viability to use a newly established indirect evaporative chiller for different parts of the world by analysing the design climatic data that was derived from the ASHRAE handbook 2001. The paper specified that the technology is appropriate for use in dry climatic areas of the world.

As the properties of the mass/heat exchanging medium (wall material) directly affects the performance so it is of great significance principally the cooling efficiency and effectiveness [2]. Zhao *et al*., [15] studied several IEC available materials, including fibres, metals ceramics, zeolite and carbon. It is concluded that the most appropriate material/structure are the wick (sintered, meshes, groves and whiskers) attained metals.

Armbruster, and Mitrovic [7] offered evaporative cooling of falling water film on smooth and unheated tubes having the difference of the water temperature in the flow direction which was exposed to upwardly streaming air. It was found that the main source of reduction in water temperature was the evaporation at the water-air interface. In another study, Gherhardt Ribatski, Anthony Jacobi [16] presented a state-of-the-art review of horizontal-tube, falling film evaporation. They developed mathematical models and empirical correlations for the heat transfer coefficient. It was found that liquid distribution has a dramatic impact on evaporator performance and the thermal performance of falling-film heat exchangers is excellent.

In view of above literature, it can be concluded that significant research has been done for implementation of different types of evaporative cooling systems in different climatic conditions of world. However, the performance of such systems is strongly dependent on local climate conditions. Therefore, there is dire need to analyse these systems in local climate of Pakistan and select the best system's type for each climate zone. Thus, the key objective of the current study is to initially design and develop 03 different types of evaporative cooling systems model including direct, indirect, and falling film systems. Afterwards, simulations are performed in 05 different climate zones of Pakistan for six months of cooling season. Finally, the best system type is suggested for each climate i.e. Islamabad, Lahore, Karachi, Multan, and Peshawar.

2. Mathematical Modelling of Evaporative Cooling Systems

In the current study, detailed mathematical models are developed for three different evaporative cooling systems including direct, indirect and falling film systems. Various parameters of each system are designed and same design is evaluated in different climates.

2.1 Mathematical Modelling of Direct Evaporative Cooling

Rigid cellulose pad material is chosen with wetted surface area (A_w) of $370 m^2/m^3$**.** Length, width and thickness of pad are taken as 610mm * 335mm * 152 mm [17].

2.1.1 Area of pad

Rectangular shape pad is conventional shape which is used by the most evaporative coolers. Area of rectangular pad is calculated by Eq. 1.

$$A_p = \mathrm{L} \times \mathrm{W} \tag{1}$$

2.1.2 Volume of pad

Volume of pad is found by Eq. 2.

$$V_p = L \times W \times T \tag{2}$$

2.1.3 Characteristic length

The Characteristic length is determined by Eq. 3 [18],

$$L_c = \frac{V_p}{A_w} \tag{3}$$

The wetted surface area of cellulose material is 370 m^2/m^3 so that the total wetted surface area of rectangular pad of this material is calculated by Eq. 4[19].

$$A_w = A_s \times V_p \tag{4}$$

2.1.4 Reynolds No.

Reynolds number is based on average velocity of air through the pad and characteristic dimension as describes in Eq. 5 [20]

$$Re = \frac{u \times L_c}{\upsilon} \tag{5}$$

2.1.5. Nusselt number

Following correlation of Nusselt number given in Eq. 6 is used to determinate the convective heat transfer co-efficient in a rigid cellulose evaporative media [13, 17,21];

$$Nu = 0.1 \times \left(\frac{L_c}{T}\right)^{0.12} \times Re^{0.8} \times Pr^{0.33} \tag{6}$$

2.1.6 Convection heat transfer coefficient

The convection co-efficient is determined from the Nusselt number (Nu) expressed as a function of the Reynolds number (Re) and Prandtl number (Pr) given in Eq. 7 [18].

$$h_{DEC} = \frac{Nu \times k}{L_c} \tag{7}$$

2.1.7 Effectiveness

Saturation efficiency is calculated based on the following relation given in Eq. 8 [22].

$$\varepsilon_{DEC} = 1 - exp\left[\frac{-h \times A_w}{M_a \times Cp_u}\right] \tag{8}$$

This equation shows that an effectiveness of 100% requires a combination of large area of heat transfer and a high heat transfer coefficient and low mass flow.

The mass flow rate of air is calculated by

$$M_a = \rho \times A_p \times u \tag{9}$$

2.1.8 Outlet temperature

Dry bulb temperature of outlet air is calculated by Eq. 10 [23],

$$T_{oDEC} = T_{di} - \varepsilon_{DEC} \times (T_{di} - T_{wi}) \tag{10}$$

where the wet bulb temperature is computed using the equations given below respectively[24,25].

$$T_{wi} = 2.265 \times [1.97 + (4.3 \times T_{di}) + (10^4 \times \omega)]^{\frac{1}{2}} - 14.85 \tag{11}$$

The humidity ratio and relative humidity are related in the following expression:

$$\omega = \frac{P_g \times 0.622 \times \emptyset}{101325} \tag{12}$$

where saturation pressure is calculated by [26];

$$lnP_g = \left[12.1929 - \left\{\frac{4109.1}{(T_{di} + 273.15) - 35.50}\right\}\right] \times 10^5 \tag{13}$$

2.1.9 Sensible cooling capacity

Sensible Cooling capacity is given by Eq. 14

$$Q_s = M_a \times Cp_a \times (T_{di} - T_{oDEC}) \tag{14}$$

2.1.10 Mass transfer coefficient

Based on the assumption of Le = 1, the mass transfer coefficient is approximated using an analogy between heat and mass transfer described in Eq. 15[27,28]:

$$h_m = \frac{h_{DEC}}{Cp_a} \tag{15}$$

2.1.11 Total mass transfer rate

If the specific humidity or concentrations of the air close to the surface (**ω_s**) is different from the one at the free stream velocity (**ω**), that is **$\omega_s \neq \omega$** then evaporative mass transfer will take place. The total evaporative mass transfer rate on an entire given surface is determined by the following expression of Eq. 16

$$m_v = h_m \times A_w \times (\omega_s - \omega) \tag{16}$$

where, specific humidity at saturation temperature can be expressed in terms of the absolute and vapor pressures as in the equation given below

$$\omega_s = \frac{(0.622 \times P_v)}{(101325 - P_v)} \tag{17}$$

The partial pressure of water vapor can be computed with the following equation.

$$P_v = P_{wb} - \frac{[(101325 - P_{wb}) \times (T_{di} - T_{wi})]}{[1532 - (1.3 \times T_{wi})]} \tag{18}$$

Here dry bulb and wet bulb temperatures are in Kelvin scale.

The saturation temperature in direct evaporative cooler is equal to wet bulb temperature, therefore, vapor pressure corresponding to a given wet bulb temperature is

$$Log\left(\frac{P_{wb}}{2337}\right) = 6789\left[\left(\frac{1}{293.15} - \frac{1}{T_{wi}}\right)\right] - 5.031 \times ln\left(\frac{T_{wi}}{293.15}\right) \tag{19}$$

2.1.12 Enthalpy of moist air

The enthalpy of humid air can be expressed in terms of dry bulb temperature and specific humidity as given in Eq. 20

$$H_{lvs} = C_{pa} \times T_{di} + \omega \times (2501 + 1.86 \times T_{di}) \tag{20}$$

2.1.13 Latent cooling capacity

Latent heat is determined by the relation given in Eq. 21.

$$Q_L = H_{lvs} \times m_v \tag{21}$$

2.1.14 Total cooling capacity

Total cooling capacity is obtained by combining latent and sensible cooling capacity as,

$$Q_T = Q_S + Q_L \tag{22}$$

The mathematical model of two other systems i.e. indirect and falling film are given the Appendices A and B. A MATLAB code is developed based on above mentioned equations and climate conditions in terms if ambient temperature, relative humidity, and wind velocity are varied for each system.

3. Results and Discussions

3.1 Climatic Analysis

In this study, Islamabad, Karachi, Lahore Multan and Peshawar are chosen as geographical locations for examination of the performance of the proposed systems.In order to investigate the applicability of proposed systems with different climates, data of ambient conditions is being taken from TMY files of each climate.

Köppen climate zone classifications are being used to divide climates of selected sites in different categories, to indicate that the selected five cities have different climate zones. Table 1 [29] shows selected cities and their classification.

Table 1
Selected Climatic zones and their Köppen climate classification

Sr. no	Location	Koppen climate classification
1	Islamabad	BShw
2	Karachi	BWhw
3	Lahore	BShw
4	Multan	BShw
5	Peshawar	BSh

Additionally, the selected cities are highlighted in Figure 1 on the map of Pakistan according to Köppen climate classification.

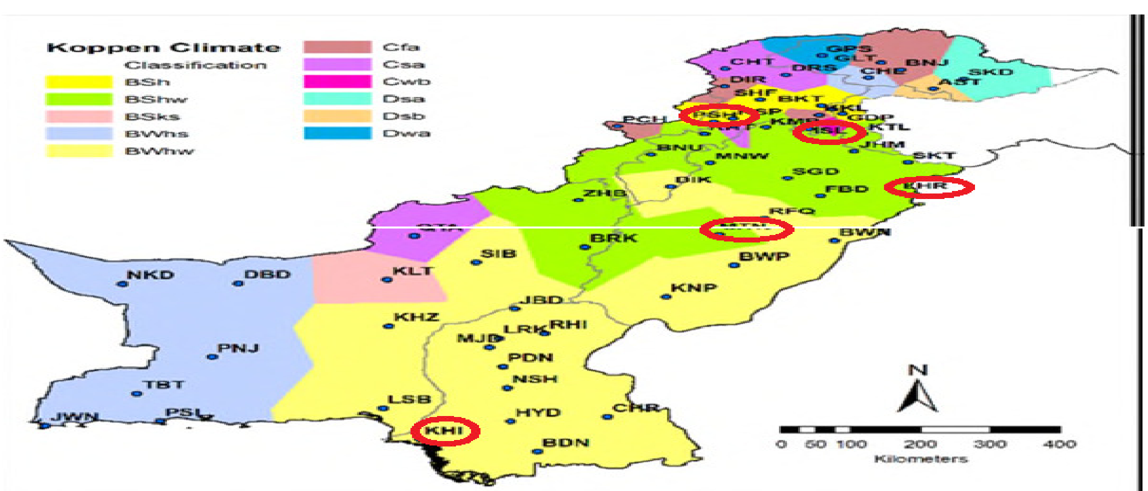

Fig. 1 Locations according to Köppen climate classifications

Figure 2 shows the inlet air temperature during six months of five chosen climates. Islamabad, Lahore, Multan Islamabad and Peshawar show the high temperatures during hottest month of June. But Karachi shows low air temperatures during the entire period of six months. Figure 3 shows the inlet relative humidity during six months of five chosen climates. Islamabad, Lahore, Multan and Peshawar show the lower relative humidity during hottest month of June. But Karachi shows relative humidity in the range of 70% to 90% during the entire period of six months.

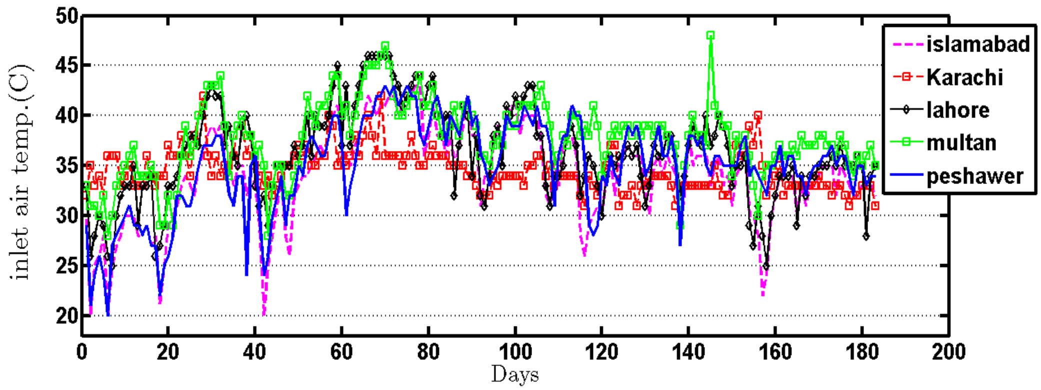

Fig. 2. Inlet air Temperature of selected regions for six months

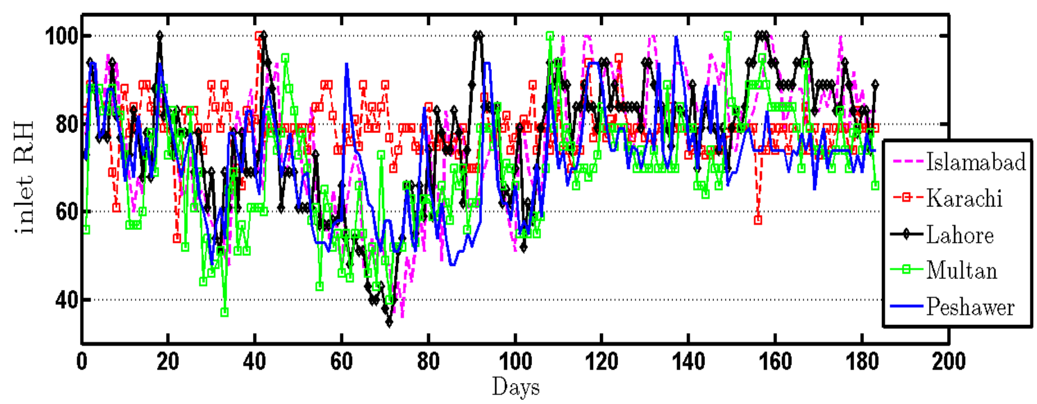

Fig. 3. Inlet relative humidity during six months of five chosen climates

3.2. Configuration Analysis

In the current study, the results represent a comparison based on the cooling capacity and outlet temperature of all three systems. Although, the analysis is performed for 06 months i.e. April to September, however, results of the hottest month June are discussed here.

3.2.1 Analysis of temperature reduction

In June, all four cities except Karachi have high inlet temperatures. But due to variations in inlet humidity, highest reductions in outlet temperatures are shared by Lahore and Multan shown in Figure 4. At approximately same highest inlet conditions in Islamabad and Peshawar, these configurations perform better in climate of Islamabad. Maximum temperature reduction of 11.88ºC is possible in direct, 22.7ºC in indirect and 26.1ºC by falling film in Lahore at 46ºC inlet temperature with 35% relative humidity.

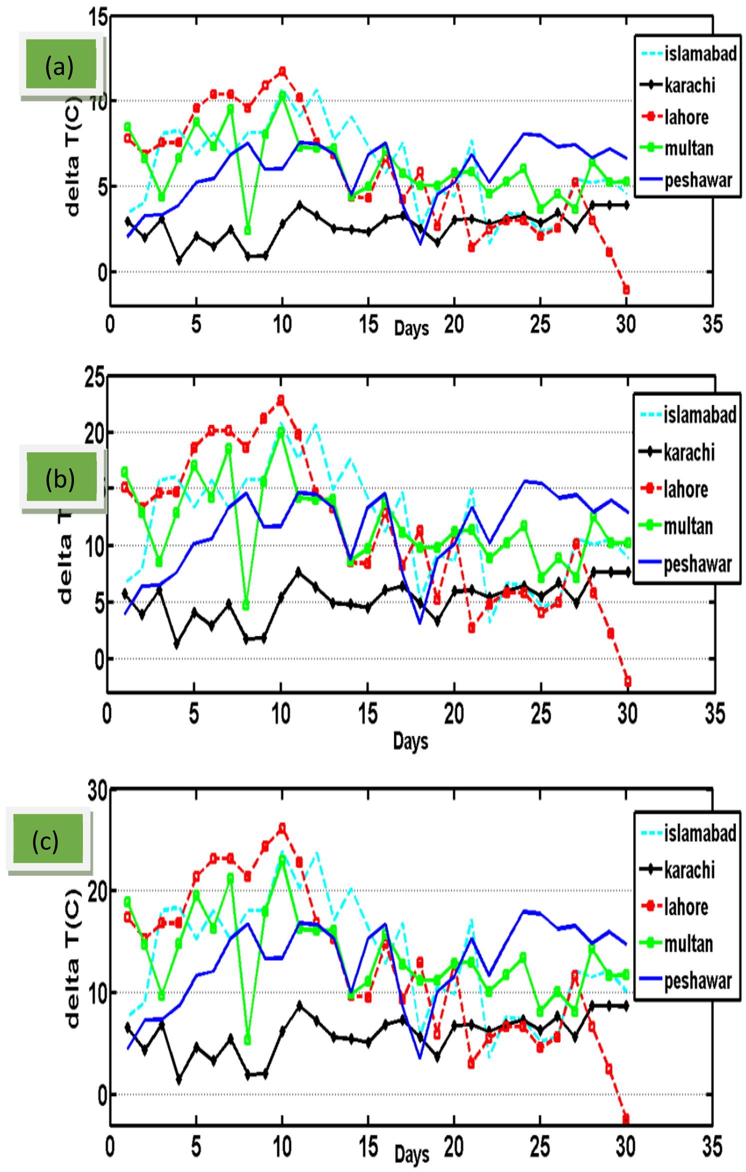

Fig. 4. Temperature reductions in the selected five regions during the month of June for (a) DEC system (b) IEC system (c) Falling Film Evaporative system

3.2.2 Analysis of cooling capacity

Cooling capacity for all the three configurations is taken by considering fixed outlet temperature difference between inlet air dry bulb temperature and its wet bulb temperature. It is seemed that cooling capacity is also influenced by inlet ambient temperatures but more by relative humidity.

During June highest input temperature among all climates is found to be in Lahore on its 10th day with 46ºC input air temperature and relative humidity of only 35%.So highest required cooling capacity is also on this day, by 2.4 kW with direct, 2.29 kW with indirect and 2.01kW with falling film to provide wet bulb temperature shown in Figure 5. Lowest cooling capacity is also found in Lahore on last day of June with 38ºC and 100% relative humidity with direct and indirect system providing 0.2 kW while falling film system 0.18 kW. Among all the climates, throughout the month Karachi shows lowest cooling capacities because of higher input relative humidity.

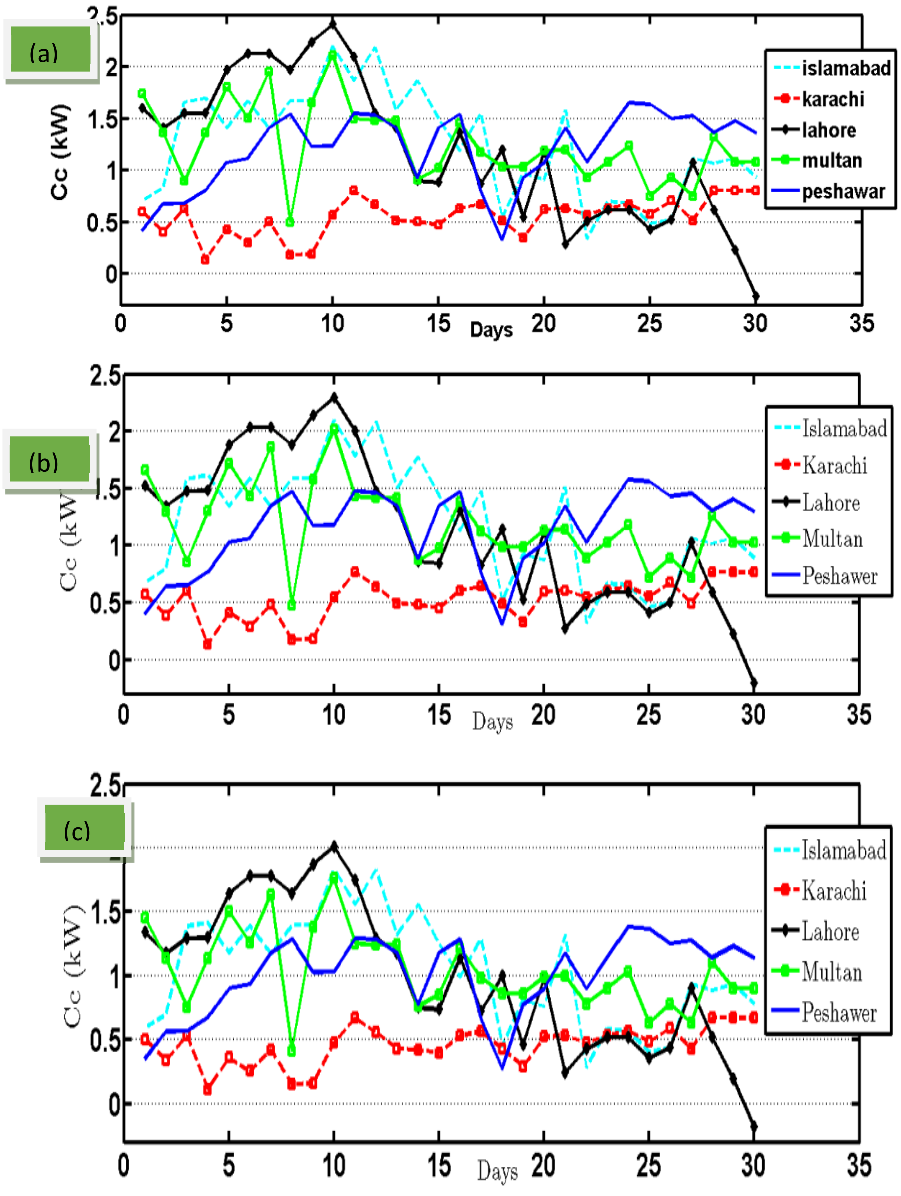

Fig. 5. Cooling capacity of the selected regions during the month of June for (a) DEC (b) IEC (c) Falling Film Evaporative cooling system

3.2.3 Effect of wind velocity on cooling capacity

The impact of air velocity on cooling capacity of all the three systems is shown in Fig 6. It can be observed that cooling capacity of direct evaporative cooling increase greatly with an increase in air velocity. Indirect evaporative cooling also shows a gradual increasing trend but less than direct one. Cooling capacity of falling film evaporative cooling show reverse trend with a decrease in cooling capacity because due to an increase in air velocity the overall heat transfer coefficient of falling film decreases.

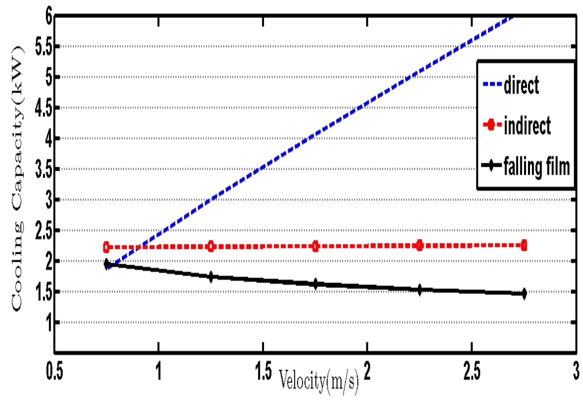

Fig. 6. Comparative Analysis of Cooling Capacities of all three systems

3.2.4 Effect of wind velocity on outlet temperature (ºC)

The effect of inlet air velocity on outlet air temperature from all thee evaporative systems is shown by Figure 7.The results indicate that the outlet temperature increases with increasing inlet air velocity in direct evaporative cooling system [20]. Same trend is found with indirect evaporative cooling but falling film evaporative cooling shows the reverse phenomenon of above two with a large decrease in outlet temperature.

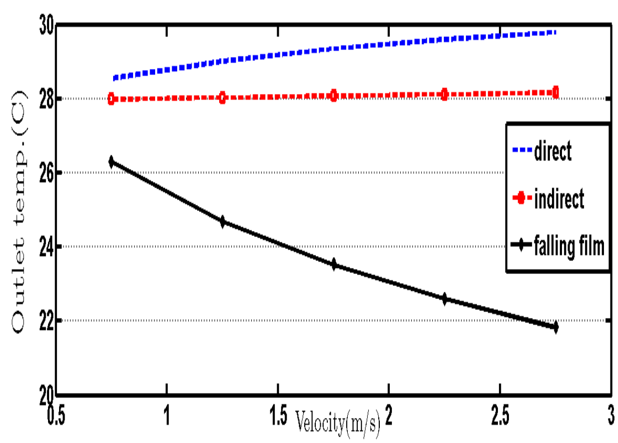

Fig. 7. Comparative Analysis of effect of air velocity on the outlet temperatures for all three systems

4. Conclusions

In the current study, the main aim was to suggest a suitable configuration of evaporative cooling system in a certain climate in view of its cooling capacity. Following results are summarized:

- Direct evaporative cooling systems perform best in hot and dry climates of Multan even providing 2-3ºC more temperature reductions than falling film and indirect evaporative cooling systems.
- Direct evaporative cooling systems provide maximum cooling capacity of 2.4kW in Lahore during the month of June to achieve fixed outlet temperature reductions.
- Indirect evaporative cooling systems performs better than direct evaporative cooling systems but their best performance regarding temperature reductions is achievable in hot and dry climates of Islamabad providing 3-3.5ºC more reductions than direct and falling film configurations
- Maximum cooling capacity of 2.29kW is obtained by indirect systems in Lahore during hot and dry month of June to meet fixed outlet conditions.
- Falling film configuration performs best than the other two regarding temperature reductions in all selected climates. Maximum temperature reduction of 26.1ºC is achieved in Lahore during the month of June.
- Maximum cooling capacity of 2.01kW is required to achieve the same outlet conditions as by direct and indirect systems during June in Lahore.
- In general cooling capacity increases with an increase in dry bulb temperature but temperature drops reduces with an increase in relative humidity.

References

[1] Hasan, Ala. "Indirect evaporative cooling of air to a sub-wet bulb temperature." *Applied Thermal Engineering* 30, no. 16 (2010): 2460-2468.

[2] Duan, Zhiyin, Changhong Zhan, Xingxing Zhang, Mahmud Mustafa, Xudong Zhao, Behrang Alimohammadisagvand, and Ala Hasan. "Indirect evaporative cooling: Past, present and future potentials." *Renewable and Sustainable Energy Reviews* 16, no. 9 (2012): 6823-6850.

[3] J. D. Palmer, P.E., C.E.M., EVAPORATIVE COOLING DESIGN GUIDELINES MANUAL. December 2002, NRG Engineering. p. 108.

[4] Larry Kinney, New Evaporative Cooling Systems: An Emerging Solution for Homes in Hot Dry Climates with Modest Cooling Loads. 2004, Midwest Research Institute.

[5] Gelit Jan Bom, R.F., Ebel Dijkstra, AMIaijTa ummer-, Evaporative Air-Conditioning. 1999, the world bank.

[6] T Ravi Kiran , S.P.S.R., Modeling of an Indirect Evaporative Cooler (IEC) using Artificial Neural Network (ANN) approach. 2009. 1(2): p. 327-343.

[7] Armbruster, R., and J. Mitrovic. "Evaporative cooling of a falling water film on horizontal tubes." *Experimental Thermal and Fluid Science* 18, no. 3 (1998): 183-194.

[8] Fouda, A., and Z. Melikyan. "A simplified model for analysis of heat and mass transfer in a direct evaporative cooler." *Applied Thermal Engineering* 31, no. 5 (2011): 932-936.

[9] Kachhwaha, S. S., and Suhas Prabhakar. "Heat and mass transfer study in a direct evaporative cooler." (2010).

[10] Wu, J. M., X. Huang, and H. Zhang. "Numerical investigation on the heat and mass transfer in a direct evaporative cooler." *Applied Thermal Engineering* 29, no. 1 (2009): 195-201.

[11] Camargo, Jose Rui, Carlos Daniel Ebinuma, and Jose Luz Silveira. "Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city." *International Journal of Refrigeration* 28, no. 7 (2005): 1124-1132.

[12] Singh, S. P., T. R. Tulsidasani, R. L. Sawhney, and M. S. Sodha. "Recent researches in indirect evaporative cooler V: relative thermal performance of buildings coupled to direct and indirect evaporative cooler." *International journal of energy research* 21, no. 15 (1997): 1413-1423.

[13] Shariaty-Niassar, M., and N. Gilani. "An investigation of indirect evaporative coolers, IEC with respect to thermal comfort criteria." *Iranian Journal of Chemical Engineering* 6, no. 2 (2009): 15.

[14] Jiang, Yi, and Xiaoyun Xie. "Theoretical and testing performance of an innovative indirect evaporative chiller." *Solar Energy* 84, no. 12 (2010): 2041-2055.

[16] Ribatski, Gherhardt, and Anthony M. Jacobi. "Falling-film evaporation on horizontal tubes—a critical review." *International journal of refrigeration* 28, no. 5 (2005): 635-653.

[17] Camargo, J. R., C. D. Ebinuma, and S. Cardoso. "A mathematical model for direct evaporative cooling air conditioning system." *Revista de Engenharia Térmica* 2, no. 2 (2003).
[18] Heidarinejad, Ghassem, and Shahab Moshari. "Novel modeling of an indirect evaporative cooling system with cross-flow configuration." *Energy and Buildings* 92 (2015): 351-362.
[19] Kulkarni, R. K., and S. P. S. Rajput. "Comparative performance analysis of evaporative cooling pads of alternative configurations and materials." *International Journal of Advances in Engineering & Technology* 6, no. 4 (2013): 1524.
[20] Chinenye, Ndukwu, and Seth Manuwa. "Heat transfer coefficient and concept of relaxation time in forced air direct evaporative cooling system." (2015).
[21] Heidarinejad, Ghassem, Vahid Khalajzadeh, and Shahram Delfani. "Performance analysis of a ground-assisted direct evaporative cooling air conditioner." *Building and Environment*45, no. 11 (2010): 2421-2429.
[22] Mohammad, Abdurrahman Th, S. B. Mat, M. Y. Sulaiman, K. Sopian, and A. Al-abidi. "Experimental performance of a direct evaporative cooler operating in Kuala Lumpur." *International journal of thermal & Environmental engineering* 6, no. 1 (2013): 15-20.
[23] Elmetenani, S., M. L. Yousfi, L. Merabeti, Z. Belgroun, and A. Chikouche. "Investigation of an evaporative air cooler using solar energy under Algerian climate." *Energy Procedia* 6 (2011): 573-582.
[24] Joudi, Khalid A., and Salah M. Mehdi. "Application of indirect evaporative cooling to variable domestic cooling load." *Energy Conversion and Management* 41, no. 17 (2000): 1931-1951.
[25] Khalid A. Joudi1, K.N.H., SIMULATION OF INDIRECT EVAPORATIVE COOLER HEAT EXCHANGER AT IRAQI CONDITIONS. Journal of Engineering, june 2011. 17.
[26] Musa, Mu'azu. "Novel evaporative cooling systems for building applications." PhD diss., University of Nottingham, 2009.
[27] Kloppers, Johannes C., and Detlev G. Kröger. "The Lewis factor and its influence on the performance prediction of wet-cooling towers." *International Journal of Thermal Sciences* 44, no. 9 (2005): 879-884.
[28] Wu, J. M., X. Huang, and H. Zhang. "Theoretical analysis on heat and mass transfer in a direct evaporative cooler." *Applied Thermal Engineering* 29, no. 5-6 (2009): 980-984.
[29] Sarfaraz, S. A. R. D. A. R., MUDASAR HASAN Arsalan, and H. I. R. A. Fatima. "Regionalizing the climate of Pakistan using Köppen classification system." *Pakistan Geogr Rev* 69 (2014): 111-132.