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STUDY ON THE PERFORMANCE PARAMETERS OF TWO STAGE EVAPORATIVE COOLING SYSTEM

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ABSTRACT

The Evaporative cooling systems are continuously going modifications for increased efficiency and reduced energy consumption. It is the demand of time to develop energy efficient technology as far as environmental aspects and economic dependency on unconventional sources is concerned. Due to this, the evaporative cooling systems are used for commercial cooling and humidification control of buildings, cold storages, green houses, etc. Two stage indirect/direct evaporative air cooler can provide summer comfort conditions as an environmentally clean, fresh supply air and energy efficient cooling system for the regions where direct system alone is not suitable. In this paper, the performance parameters of Indirect/Direct evaporative cooling system are studied. Effects of various operational and geometrical parameters on cooling performance of this cooling system also have been studied. Results show that indirect/direct cooling systems can provide comfort conditions, which use only water as cooling media and consume much less energy in comparison with conventional vapour compression systems. Additionaly, in certain localities having high humidity the use of evaporative cooling is having limited use. In these situations when evaporative cooling systems are used in conjuction with mechanical vapour compression systems for the precooling of the air, these systems can also have potential to save considerable amount of energy and there by the cost of operation of the equipment.

INTRODUCTION

The evaporative cooling technology is energy efficient and eco-friendly technology hence used in hot and dry climates. The evaporative cooling systems are classified as direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) systems. Direct evaporative cooling is popular method of conditioning the atmospheric air. The direct evaporative cooling system uses fan to pass outside warm air through porous wetted pad. The heat is absorbed by the water as the water evaporates from the porous pads. The leaving air is cooled to lower temperature. Here the dry bulb temperature of incoming air gets reduced as its wetted in the adiabatic saturation process. In direct evaporative cooling, the sensible heat gets converted latent heat. Thus the direct evaporative cooling systems have two drawbacks: the moisture content of the space to be cooled increases, since water vapour is added to air; and the air can be cooled to the ambient air wet bulb temperature. Whereas in indirect evaporative cooling, non-adiabatic evaporation takes place over the wet surface heat exchanger. There are dry and wet alternate flow passages for air and are separated from each other. The product or primary air flows inside the dry flow passages and the supply or secondary air on the wet flow passages which absorbs and carries the heat of primary air. The water spray is provided for efficient wetting of the wet surface, so that there is evaporation of water in to the secondary air, which reduces the temperature of the wall. Thus, the heat is transferred from primary to secondary air without the addition of moisture in to the primary air. The resulting cooled air temperature is lower than the ambient wet bulb temperature. The direct and indirect evaporative cooling systems are efficient but there is considerable water consumption in indirect evaporative cooling.

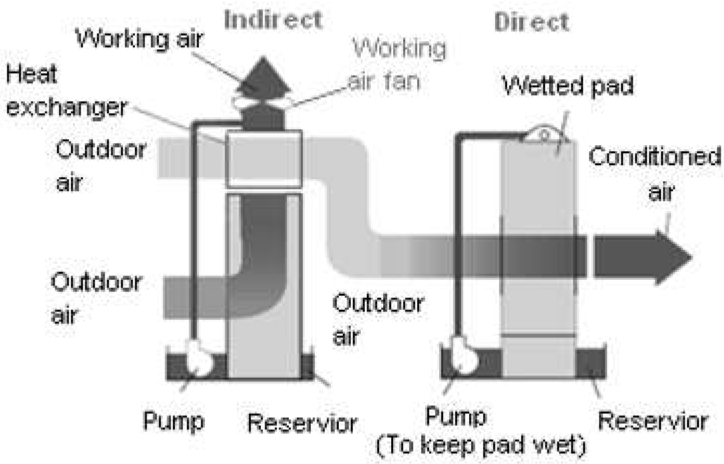

Figure 1 Concept of Indirect-Direct evaporative cooling system. [1]

In the two stage indirect - direct evaporative system, as shown in figure 1 above; the dry bulb and wet bulb temperatures of air are reduced at constant absolute humidity before passing to the direct evaporative cooler. The two stage indirect direct stage evaporative air conditioner is useful for places where lower inside temperetures are not able to be achieved because of high wet bulb temperatures resulting high humidity. In particular situations where the atmosphereic wet bulb temperatures are higher.Normally about 65% effciency at indirect can be achieved which permits an ambient wet bulb temperature of about 25^{0}C to provide the comfort conditions.[1] Thus in two stage IEC/DEC system, primary air is precooled without adding any moisture before it gets cooled evaporatively in the direct evaporative system. Using this system, the dry bulb temperature and the absolute humidity of the conditioned air can be reduced, as compared with the direct evaporative cooling system.

LITERATURE REVIEW

El-Dessouky et.al; [1996]; done the experimentation on the two stage indirect – direct evaporative cooler to determine the thermal and hydraulic performance. The performance parameters considered are mode of operation, the thickness of the cooling pad, mass flow rate of the water flowing to the indirect evaporative cooler, and the mass flux of the water flowing over the direct evaporative cooler. The types of the packing materials used are sheathy leaf, natural fibre and structured packing. The various pad thickness used are 0.1,0.15, and 0.2m, mass flux of the water that is flowing over the direct evaporative cooler packing 8,6,4,2.5 and 1.25 kg/m²s, mass flow rate of water flowing to the indirect evaporative system 0.038,0.0296,0.0216 and 0.0127 kg/s. When there is no water flow to the indirect evaporative cooler, then the unit works as direct evaporative cooler.

The length and width of pad material used is 0.5m each. The indirect evaporative cooler has 3 rows each having 36 nos. tubes, the size of the cooler is 480x480x70mm. 433nos.fins per meter are provided having height of about 16mm. High density structured polythene packing used having specific area density of 420 m²/m³ volume. The other two materials are sheathy leaf base and natural fibre from coconut trees. The results showed that, the increased mass flow rate to the indirect evaporative cooler increases the effectiveness that is for low water flow rate the rate of effectiveness increase is high. When in direct evaporative cooler operation, the effectiveness is almost independent of the mass flux rate to the packing material. For two stage mode of operation, effectiveness of the evaporative unit reduces uniformly for increased water mass flux. With increase in the thickness of the packing material; the effectiveness of the system increases, also when structured pad material is used its higher as compared with sheathy leaf or natural fibre. Its also observed that the air side pressure drop increases for sheathy leaf and natural fibre at steady rate of mass flux of water to the packing material. The structured packing is having minimum air side pressure drop in comparison to other two.[2]

Faisal Al-Juwayhel, et.al; [1997], carried out the experimentation on two different arrangements of two stage evaporative cooling system, in order to find out the thermal effectiveness and the pressure drop for the air side of the arrangement. In first set up, the cooling tower was used to cool the water before its sprayed above the tube type indirect evaporative cooler for cooling of air, where as in the second arrangement, the cooled water from the thick pad of direct evaporative cooling system, was used for the cooling of air in indirect evaporative cooler. The variables which were used are the thickness of the pad material, mass flow rate of the water to the indirect evaporative cooler, and mass flux rate of water to the pad material. The various pad thickness used are 0.1,0.15, and 0.2m, mass flux of the water that is flowing over the direct evaporative cooler packing 1.25, 2.5, 4, 6, 8, and kg/m²s, mass flow rate of water flowing to the indirect evaporative system 0.0127,0.0216,0.0296 and 0.038 kg/s. When there is no water flow to the indirect evaporative cooler, then the unit works as direct evaporative cooler.

The length and width of pad material used is 0.5m each. The indirect evaporative cooler has 3 rows each having 36 nos. tubes, the size of the cooler is 480x480x70mm. 433nos.fins per meter are provided having height of about 16mm. High density structured polythene packing used having specific area density of 420 m²/m³ volume. The counter current wet cooling tower is used, for testing with cooling tower. The air flow needed is maintained by fan at the air outlet. The diameter of the fan is 0.78m with power requirement of 3kW, and power required for the circulation pump is 0.75 kW. The steady state measurements taken, the results shown that the arrangement having cooling tower is having high effectiveness as compared with the cooling water from direct evaporative cooling sump, also better than the only direct stage evaporative cooling operation. Higher mass flow rate of water to the indirect evaporator in two stage mode operation, increases its effectiveness. For the effectiveness of the arrangement with no cooling tower, uniform increase of the mass flux rate of water sprayed above pad material of thickness. When cooling tower is used for the single stage and two stage arrangement, the effectiveness has no relation with the mass flux of the water sprayed above pad material. For all the three categories tested, it's concluded that the thermal performance increases with the thickness of the pad material and the air side pressure drop is approximately steady.[3]

El-Dessouky et.al; [2004]; experimented on indirect direct evaporative cooling unit. The parameters studied are the packing thickness, rate of water flow to the indirect and direct evaporative cooling system, and mode of operation for IEC system. The set up includes two identical indirect evaporative coolers, each having 18 nos. copper tubes and the dimension 0.89 x 0.6 x 0.16 m. Each tube is 'U' shaped with diameter 0.0254m and wall thickness of 1.5mm. The total surface area is 4 m². In order to maintain steady state condition, the basin water content of the system is maintained at 0.15 cubic metres. In DEC, structured packing material of size 10, 20 and 40 cm thickness and made of high density polythene having wetted surface area of 420m²/m³ is used. The pad material is light weight, having high specific surface area, and low pressure drop per unit length. Low pressure drop results low power requirement for air blower. The efficiency of the indirect/direct evaporative cooler found between 90 – 120%. The results shown that IEC has less efficiency than DEC, but when used in combination can bring down the temperature of incoming air below its wet bulb temperature. [4].

Faisal Al-Juwayhel, et.al; [2004]; carried out the experimental evaluation on four different arrangements of evaporative cooling systems. The various arrangements are Single stage direct evaporative cooling, Single stage indirect evaporative cooling with cooling tower, Two stage indirect/direct evaporative cooling and three stage evaporative cooling system comprising of indirect-direct and mechanical vapour compression system. The evaluation of thermal performance is done for thermal effectiveness and energy efficiency ratio. From the experimentation, IEC/DEC system found having higher energy efficiency ratio, the direct evaporative cooling; the IEC/DEC-mechanical vapour compression; and the indirect evaporative system are followed order for higher to lower energy efficiency ratio. The effectiveness of IEC/DEC-mechanical vapour compression system is higher followed by IEC/DEC system; IEC system; direct evaporative cooling system which is having the lowest effectiveness. The IEC/DEC system when used in conjunction with mechanical vapour compression system, can cool the dry bulb temperature in the range of 40 to 15 deg C, for any value of ambient wet bulb temperature. Two experimental relations were developed for each of the tested system. One is effectiveness as related to water to air mass flow ratio (liquid /Gas ratio), the other is energy efficiency ratio with effectiveness and water to air mass flow rate.

The experimental set up includes forced draft axial fan with motor 0.9kW, indirect cooler is fin tube type air to water unit, 0.81x0.12 x 0.125 thickness, having 18 finned tubes; fixed in four rows. The direct unit is having structured pad material with spray nozzles. High density polyphone pad thickness is 20mm with specific surface area of 420m2/m3, the length and height of the pad are 0.79 m and 0.81 m respectively. The 2T capacity mechanical vapour compression window air conditioner is used. The effectiveness and energy efficiency ratio increases with water to air mass flow (L/G) ratio for direct evaporative cooling system and Reynolds number of indirect evaporative cooler water flow for the systems under consideration.[5]

Jain [2006], developed and tested two stage evaporative cooler for high humidity and low temperature application needed for the storage of fruits and vegetables, which can increase the shelf life of agro products at moderate respiration rates. There is a plate heat exchanger and two evaporative coolers. In this cooler, wooden shave used as packing material to increase the efficiency. The performance evaluation done in terms of temperature drop, efficiency of the evaporative cooling and effectiveness of two stage cooler over single evaporation. Return air used effectively cooled in heat exchanger channel with dry air, resulting in effectiveness from 110 – 120%. This resulted in to favourable conditions for safe storage of tomatoes for 14 days. [6].

Heidarinejad G.et.al; [2009] experimented on a indirect direct type two stage evaporative cooler with simulated conditions for primary and secondary air, to simulate different climatic conditions for different regions of Iran. 0.15 m thick cellulose evaporative pad for plastic wet surface heat exchanger used in the direct evaporative cooler. In spite of different climatic conditions, it's found that the effectiveness of indirect evaporative cooler varied from 56 – 60% and for two stage cooler from 107 – 110%. Also concluded that the water consumption is more than direct evaporative cooler and power requirement of mechanical cooling systems. As compared to mechanical vapour compression system; more than 60% power saving is possible with approx. 55% high water consumption in direct evaporative cooling system. The power consumption is 33% of the mechanical vapour compression system. During the experimentation, its found that the energy efficiency ratio for the room cooling is in the range of 28 – 31, whereas that for mechanical vapour compression system is about 10. For the various climatic conditions in Iran, where the direct evaporative cooling system alone are not able for comfort air conditioning, the two stage evaporative cooling can be the effective solution. Hence the two stage evaporative cooling system can provide comfort conditions where the wet bulb temperatures are higher. Thereby reducing the power consumption. [7]

Sam C.M.Hui and Ms.Y.W.Cheung [2009], assessed the performance of the two stage indirect-direct evaporative cooling system, for the hot and humid climate of Hong Kong. For this purpose, the year round readings were collected for dry bulb temperatures, wet bulb temperatures, relative humidity, and wet bulb depression which is the difference in dry bulb and wet bulb temperature, for the reference year of 1989 for Hong Kong. Annual Relative humidity observed to be higher at 78 %, annual absolute maximum and minimum temperatures of 33.7 and 7.6 deg. When the system is used along with mechanical vapour compression system, the total cooling needs can be reduced in the range of 40 – 85% depending upon the location, system arrangement and nature of load or load characteristics. The experimentation done on two stage indirect direct evaporative cooling system in order to find out product air temperature, cooling effects and energy efficiency ratio. Effectiveness for DEC and IEC presumed to be 90% and 70%, building air is taken as secondary air, input power is 0.65kW, and mass flow rate of air is 600 LPS. Hourly and monthly data was collected and found ambient air maximum dry bulb temperature 28.9 deg and minimum of 15.7 deg C. The product air maximum and minimum temperatures of 12.1 – 24 deg C, max and min cooling capacity of 3904 – 2041 W. Recorded max and min EER of 2.77 to 6.0 W/W. Results indicated that, due to high humidity in climate under consideration during the year, the use of evaporative cooling systems on regular basis is not possible. If used in to precool the ambient or outside air considerable energy savings will be possible for air conditioning systems. The efficiency of the system will be depending upon the control strategies, system configuration and design considerations for various parts of the system.[8]

R.S.Kulkarni et.al; [2011], analysed the performance of indirect direct two stage evaporative cooler, theoretically. The experimental set up consisted of wet surface type plate heat exchanger and direct evaporative cooler; which tested using cellulose and Aspen pads of various shapes for hot and dry climate at Bhopal. During experimentation the secondary air flow kept constant. The performance parameters include effectiveness of indirect evaporative cooler, saturation efficiency of direct evaporative cooler, air outlet temperature, cooling capacity in direct and indirect-direct mode and overall cooling efficiency. The effectiveness obtained with this combination was 0.9 to 0.5. Hence during this experimentation, the secondary air flow is assumed to be constant at 1.15 kg/s and the primary air flow is assumed to vary from 0.3 to 1.25 kg/s for various shapes of pad material. After the experimentation the result has shown the effectiveness of indirect unit in between 0.95 and 0.82. The higher effectiveness is due to the assumption of operation under ideal condition and low primary to secondary air ratio. Also the efficiency of the direct unit varies from 89.1 to 63.4% for the primary air flow in the range of 0.3 to 1.25 kg/s with different pad shapes and combination of materials. The primary air outlet temperature found between 22.5 to 24.6^{0}C. Different pad shapes viz, rectangular, hexagonal, and cylindrical tested in direct evaporative cooler. The overall cooling efficiency of the two stage unit varies between 121.5 and 106.7%. The overall cooling capacity of the two stage unit varies 18244 kJ per hr to 73809 kJ per hr. when tested with different combinations.[9]

R.S.Kulkarni, S.P.S.Rajput [2011], carried out the experimentation on the indirect/direct two stage evaporative cooler and evaluated the performance using different materials and cooling media in the later or direct stage of the two stage cooler. The configration of various shapes includes rectangular, semi cylindrical, and semi hexagonal and having cooling pad shapes constructed out of wood wool, rigid cellulose and aspen fibre are examined in direct and in two stage system. The secondary air flow was kept constant at 1 kg /sec whereas primary air flow varied from 0.08 to 1.01 kg/sec. Average dry bulb temperature at inlet varying from 39 to 43 deg, and relative humidity from 37 to 46%. They concluded, that the saturation efficiency for the direct stage in the range of 98 to 72 %, whereas in combined mode, its found varying from 119 to 74 %, and final temperature of air between 27 to 32 degrees. The range of cooling capacities for the direct mode obtained between 3200 to 45500 kJ/hr, and for combined stage in the range of 4700 to 44000 kJ/hr for various configurations. The result indicates that with the combined system the cooling efficiency can be improved and the inlet air temperature can get reduced below its wet bulb temperature. The use of rectangular shapes of cooling media in direct stage of the two stage system has the maximum efficiency for low mass flow rates of air, and low air velocity. Where the mass flow rates are higher, semi cylindrical and semi hexagonal shapes of cooling pads are found appropriate. The power consmption for the direct stage is 203W where as for the two stage its 408W. The consumption pattern of water ranges from 3 to 6 litres per hour, based on the mode of operation.[10]

A.K.Mohammed [2013]; performed experimentation of two stage indirect direct type evaporative cooling system under various simulated air conditions at Erbil, Iraq. The results show that for different ambient conditions the effectiveness of indirect evaporative system remains from 55 to 65 % and that for two stage evaporative system its found to be 90 to 110%. The results shown, as compared to conventional vapour compression system; more than 60% power saving at the expense of 40 % water consumption as compared with direct evpaorative cooler can be obtained. The performance parameters include dry bulb temperature, effectivness, water consumption and power consumption.[11]

A.M.Alklaibi, [2015], carried out the experimental performance comparison of the internal two stage evaporative cooler with direct evaporative cooler and theoretical comparison with direct and external two stage evaporative cooler. In comparison to direct evaporative cooler the efficiency of internal two stage evaporative cooler is less sensitive to air speed. When the fan switches from high to low speed; for internal two stage evaporative cooler the increase in efficiency is 5%, compared to DEC having increase of 12%. He also concluded that intenal two stage evaporative cooling system is having high humidity as compared to direct evaporative cooler, which makes it good choice to be used for cold storages, requiring humidity near to saturation. In case of internal two stage evaporative system, its not possible to increase efficiency above 100%, where as it can be; in case of external two stage evaporative cooling system relative to direct evaporative cooler. [12]

Mohammad Ul Hassan [2016], carried out experimentation and evaluated perfoemance of the two stage indirect direct evaporative cooler, for the variation of the speed at high medium and low speed. The result shown that the COP is about more than 13 as compared to conventional cooler and window air conditioner, which is close to 7 and 3 respectively. The change in the enthalpy at the inlet and outlet of two stage evaporative system is more than that with direct evaporative arrangement. The refrigeration effect and energy consumption is more in comparison with conventiona l direct evaporative cooler. The make up water consumption is less for the combined unit of indirect direct system. [13]

Stefano De Antonellis, et.al, [2017], carried out the experimentation on the cross flow indirect evaporative system, to find out the cooling capacity for different operating conditions. The performance evaluation is done for the wet bulb effectiveness, supply air temperature, and the amount of water evaporated during operation. Inlet temperature and relative humidity of the primary and secondary air represented the operating conditions during summer for air conditioning applications in commercial and residential applications. Also assumed that the primary air is at outside air temperature while secondary air is exhaust from the room. The various components used in experimentation includes cross flow plate type heat exchanger, exhaust air stream used as secondary air wherein 8 nozzles are fixed, and mechanism to increase the pressure of water supply to nozzles. Aluminium plates with semi spherical dimples, the plates are vertically oriented, The number of aluminium plates is 119 with thickness of 0.14mm,the pitch being 3.35 mm, the length and the width of the plates is 0.485m each. The water at 20 ºC is supplied at the secondary stream and water flow variation between 30 and 65 lph. The results shows that the higher rate of water flow higher fraction of evaporated water or the evaporation rate of water. The high primary air temperature at inlet, slightly influences the wet bulb effectiveness, since the plates are at higher temperature. Variation of inlet secondary air slightly influences the wet bulb effectiveness and fraction of evaporated water. The reduction of supply air temperature varies between 8 to 14ºC. [14]

THE TWO STAGE INDIRECT DIRECT EVAPORATIVE COOLING SYSTEM PERFORMANCE

1. The effectiveness of the evaporative cooling systems is given by the ratio of the actual temperature drop to the maximum temperature drop. Hence the cooling efficiency or the effectiveness of indirect direct cooling system is given by: [5]

$$\varepsilon = (DBTi - DBTo) / (DBTi - WBTi) \quad (1)$$

$$= (DBTi - DBTo) / (WBDi) \quad (2)$$

$$= R / (R + A) \quad (3)$$

Wherein ε is the effectiveness (%) , DBTi and DBTo - the inlet and outlet dry bulb temperatures of the air (°C); WBTi is the inlet wet bulb temperature of the air (°C),WBDi is the wet-bulb depression of the inlet air (°C), R is the cooling range (°C) (= DBTi – DBTo) A is the cooling approach (°C) (= DBTo – WBTi)
Energy Efficiency Ratio

2. The energy efficiency ratio (EER) – the term EER is often used for determining the efficiency of air cooling systems and is defined by equation as follows:

$$EER = [\text{Cooling output (Btu/h or W)}] / [\text{Input power (W)}] \quad (4)$$

The cooling output, Q, in kW, for discussed evaporative cooling systems, [5]

(a) Direct Evaporative Cooling (DEC)

$$QDEC = ma(Wi - Wo)\,\lambda \quad (5)$$

(b) Indirect Evaporative Cooling (IEC) $QIEC = maCpa\,(DBTi - DBTo)$ (6)

(c) Two-Stage Evaporative Cooler

$$QIEC/IEC = QIEC + QDEC$$
$$= maCpa(DBTi - DBTo) + ma(Wi - Wi)\,\lambda \quad (7)$$

where Wi and Wo = Absolute humidity at inlet and outlet (kg/kg),
ma = mass flow rate of air (kg/s),
λ = latent heat of evaporation evaluated at 0°C (kJ/kg),
DBTi and DBTo = inlet and outlet DBT (°C),
Cpa = Specific heat of air at constant pressure (kJ/kg/K)

In short; above information is summarised as follows:

Sr. No	Researcher	Parameters	Results
1	El Dessouky, et.al, (1996)	Mode of operation, type of cooling pad, Pad thickness, mass flow rate of water to IEC, Mass flux of water.	Low water flow, high effectiveness. High mass flux-reduced effectiveness. Structured packing – high effectiveness.
2	Faisal I .Al-Juwayhel, et.al,(1997)	Effectiveness, Mass flux of water to pad material, Air side pressure drop.	With cooling tower effectiveness is high; with increase in mass flux of water effectiveness reduces; pressure drop for air side is approximately steady.
3	El Dessouky (2004)	Packing thickness, water flow rate to DEC and IEC, mode of operating IEC unit, Efficiency.	Efficiency of IEC/DEC varied from 90 – 120%, higher efficiency even if intake air temperature is high.
4	Faisal Al-Juwayhel et.al;(2004)	Effectiveness, EER,	For the four arrangements tested; IEC/DEC-MVC has high effectiveness, followed by IEC, IEC/DEC, and DEC. IEC/DEC has best EER.
5.	Jain (2006)	Performance evaluation in terms of temperature drop, efficiency, and effectiveness.	Effectivenss ranging from 110 to 120 %. temperature drop from 17 – 25 ^{0} C, with 50 – 75 % relative humidity, suitable for increasing the shelf life of fruits and vegetables.
6.	Heidarinejad G (2009)	Effectiveness, performance.	Effectiveness of Indirect evaporative system varies from 56 – 60% and for two stage system 107 – 110%.
7	Dr.Sam C.M.Hui and Ms.W.Y.Cheung (2009)	Outlet air DBT, Performance, EER	Outlet air DBT 12.1 – 24 deg. Cooling capacity-1803 – 3904 W,EER – 2.77-6.0W/W
8	R.S.Kulkarni, S.P.S.Rajput [2011]	Effectivness of IEC, DBT, Saturation efficiency, cooling capacity and overall cooling efficiency.	Effectiveness of IEC 0.82 – 0.95, Saturation efficiency from 63.4 to 89.1%, Overall cooling efficency varies from 121.5 % and 106.7 %, Primary air outlet temperature 22.5 and 24.6^{0}C, Cooling capacity ranges from 18244 and 73809 kJ/h for Two stage operation.
9	R.S.Kulkarni, S.P.S.Rajput [2011]	Saturation efficiency, Cooling capacity, power consumption	Saturation efficiency 98 to 72 %(direct), 119 to 74 (two stage), Cooling capacity 3200-45000kJ/hr(direct),4700-44000kJ/hr(two stage), Power Consumption 203W and 418W for direct and two stage respectively.
10	A.K.Mohammed (2013)	Dry bulb temperature, effectiveness, power and water consumption.	Effectivness ranges 90 – 110%. Power saving of 33% as compared with vapor compression.40% more water consumption as compared to DEC.
11	A.M.Alkalibi (2015)	Performance & efficiency comparison.	Efficiency less than two stage external evaporative system but more than DEC system.High humidity than DEC system. Suitable for cold staorages.
12.	Mohammad Ul Hassan (2016)	Air velocity, Enthalpy, refrigeration effect, COP, Energy consumption.	COP is more than 13 against about 7 in conventional cooler, Change in enthalpy is more than DEC.

CONCLUSION

From above study it can be concluded :

1. The evaporative cooling technology is energy efficient and enviornment friendly, since uses water as working fluid in contrast to vapor compression system which uses harmful refrigerents affecting ozone layer and causing global warming.
2. Factors affecting the effectiveness of the evaporative cooling systems are pad material, pad thickness, air velocity, water flow.
3. In order to balance the rate of evaporation and pressure drop; the pad thickness is imporatant parameter.
4. From studies; it is understood that higher water flow does not ensure higher effectiveness of cooling, resulting in energy consumption to be imporatant aspect.
5. For the hot and humid regions, two stage evaporative cooling systems are energy efficient compared with conventional air conditioning systems.
6. COP of two stage evaporative cooling systems is higher than that of conventional direct evaporative cooler.
7. In high humidity regions in certain climates, where only direct evaporative cooling systems can not be used due to high outlet moisture; two stage systems can be used in conjuction with mechanical vapour compression systems to precool the outside air to gain considerable energy savings in air conditioning.

REFERENCES

1) Ghasem Heiderinejad,et.al, ‘Heat and mass transfer modelling of two stage indirect/direct evaporative cooler’, ASHARE Journal, ASHRAE Thailand Chapter,2007-2008.
2) Hisham El-Dessouky, et.al, ‘Thermal and hydraulic performance of a modified Two stage vaporative cooler’, Renewal Energy Journal, Vol.7, No.2, pp 175-176, (1996)
3) Faisal I..Al-Juwayhel,et al. ‘Experimental investigation of the performance of two stage evaporative coolers’- Heat transfer engineering, vol.18, No.2, (1997)
4) Hisham El-Dessouky,Hisham Ettouney,Ajeel El-Zeefari, ‘Performance analysis of Two stage evaporative coolers’ – Chemical Engineering Journal, (2004) 102 : 255-266.
5) Faisal Al-Juwayhel,et.al; ‘Experimental evaluation of one, two and three stage evaporative cooling systems’-Heat Transfer Engineering,25(6):72-86 vol.25,No.6, (2004).
6) Dilip Jain, ‘Development and testing of two stage evporative cooler’-Building and Enviornment (2007) 42: 2549-2554.
7) Ghaseem Heidarinejad, Mojtaba Bozorgmehr,Shahram Delfani,Jafer Esmaeelian, ‘Experimental investigation of two stage indirect/direct evaporative cooling system in various climatic conditions’ – Building and Enviornment, (2009),44:2073-2079.
8) Dr.Sam C.M.Hui and Ms.W.Y.Cheung, ‘Two stage evaporative cooling systems in hot and humid climate’- Tianjin-Hong Kong Joint Symposium 2009, 29-30 Jun 2009, Tianjin, China, pp. 64-76.
9) R.K.Kulkarni, S.P.S.Rajput, ‘Theoretical performance analysis of indirect/direct evaporative cooler in hot and dry climates’- International Journal of Engineering Science and Technology,ISSN : 0975-5462,vol.3,No.2,Feb 2011.
10) R.K.Kulkarni, S.P.S.Rajput, ‘Performance evaluation of two stage indirect/direct evaporative cooler with alternative shapes and cooling media in direct stage’, International Journal of Applied Enginering Research, ISSN 0976 – 4259,Vol 1, No.4,2011
11) A.K.Mohammed, ‘Experimental performance of two stage evaporative cooling system’-Scholars Journal of Engineering and Technology, ISSN 2321-435X, 2013;1(3),122-127.
12) A.M.Alkalaibi, ‘Experimental and Theoretical investigation of internal two stage evaporative cooler’-Energy Conversion and Management, (2015) 95:140-148.
13) Mohammad Ul Hassan, ‘Performance evaluation of two stage air cooler in different speeds’-International Journal of Mechanical Engineering and Technology, 2016: vol 7,issue 3,329-341, ISSN 0976-6340.
14) Stefano De Antonellis, et.al, ‘Indirect evaporative cooling systems: An experimental analysis in summer conditions.’ Energy Procedia 140 (2017) 467 – 474.