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Advancements In Evaporative Cooling Technology As A Substitute To Air Conditioners For Pune Weather

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Abstract

This paper presents feasibility index method that indicates scope and potential of evaporative cooling systems for replacement of high power consuming air conditioners, partially or completely for maintaining thermal comfort in multi climatic locations without compromising indoor air quality. Later on, it is applied to Pune city, characterized by different climatic conditions over entire months of the year. Initially, it presents the basic principles of direct and indirect evaporative cooling and defines the effectiveness of the system. It is seen that, the various combinations of direct and indirect methods of evaporative cooling have ability to provide temperature and humidity of supply air within comfort limits. Later on, it determines feasibility index for all months for Pune city and decides whether the system is efficient for Pune weather for particular month. It concludes that evaporative cooling systems have a very large potential to provide thermal comfort and can still be used as an alternative to conventional systems in Pune regions when the design wet bulb temperature is under 24ºC.It is found that evaporative cooling can replace conventional air- conditioners for eight months in a year resulting environmental friendly energy efficient cooling.
Keywords: *Evaporative Cooling, Air Conditioning, Thermal Comfort Feasibility Index, Pune City.*

1. Introduction

Air conditioning is one of the fastest growing sectors in India with annual growth of 20% per annum since 1990. In India, it is estimated that in year 2020, about 1.5 million room air conditioners will be manufactured with HCFC-22 every year, comprising approximately 75% of the window units. Thus, the energy demand due to air conditioning usage alone will be in the range of an extra 750,000 GWh by the year 2025. As shown in *figure1*, air conditioner consumes maximum energy at domestic and office. [1]

Therefore, in the future, with higher Air Conditioning penetration levels, energy demand will prove to be a significant challenge for the country

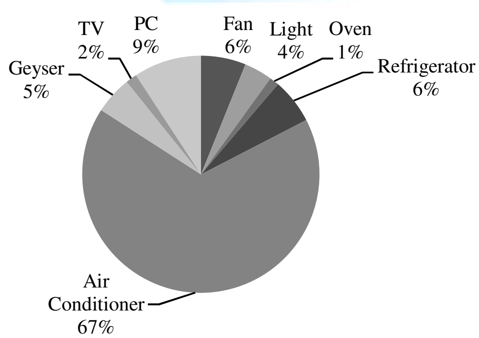

Fig 1: Domestic Power Consumption Distribution for typical Indian house

As per ASHRAE standards, the comfort conditions lies in the limits of 22 ºC to 25 ºC DBT and 40% to 60% RH Even though, window air conditioners serve the purpose but in the focus of energy and environment, it has certain issues like higher electricity demand, use of CFC refrigerant, air quality being 100% recirculation, higher initial and operating cost due to electric tariff plans, health problems associated due to supply of no outside fresh air and humidity control. .These issues call upon some alternate method which can partially or completely eliminate use of air conditioner without compromising the indoor air quality and able to maintain comfort conditions. One substitute in the form of evaporative cooling is definitely an attractive option.

Evaporative cooling operates utilizing natural phenomena through induced process where water and air are the working fluids. It consists in the utilization of water evaporation through the passage of airflow, decreasing the air temperature. The main characteristic of this process is the fact that it is more efficient at higher temperatures, i.e. at the times when more cooling is actually needed. Moreover, in the dry regions, increase of humidity is salutary while in some others, with increase of humidity of the air supplied avoids air dehumidification, a typical discomfort present in conventional systems.

Evaporative cooling has the several causes of attraction over conventional air conditioning viz. reduced energy consumption per ton of cooling capacity, absence CFC and HFC gases causing absolutely no environmental harm, provision of 100% fresh supply air, no recirculation of air avoiding proliferation of fungi and bacteria, a constant problem in conventional air conditioning systems, reduced initial and running cost, simple maintenance, installation, silent operation practices. Due to its characteristics, the evaporative cooling is more efficient in places where the climate is hot and dry but it can also be used under other climatic conditions. [2]

This paper proposes a methodology that enables user to determine scope and potential of evaporative cooling in particular location. It tells user, the months in a year, when evaporative cooling has potential to replace conventional air conditioner by all means. Various methods of EC and their combinations are discussed and methods which are capable to maintaining comfort conditions are subsequently recommended. Paper describes where, when, how and what is the operational efficiency of EC systems and, for this, feasibility index method proposed by J. R. Camargoa is presented in order to establish references, applied to Pune city to determine scope of evaporative cooling, characterized by different climates.[3]

2. Recent developments

Several authors dedicated their researches to the development of direct, indirect and regenerative evaporative cooling systems. Watt (1963) developed the first serious analyses of direct and indirect evaporative systems.

Watt used the dry and wet bulb temperature to determine the "feasibility index" through which is possible to classify the weather conditions, related to comfort gain by evaporative cooling. It is a fast method to evaluate the potential of evaporative cooling. [4]

Victor O. Aimiuwu carried out investigation of performance of evaporative cooling for dry and arid climates and found that use of evaporative cooling becomes more efficient as dry bulb temperature rises above 40 °C and humidity 20 to 35%.[5]

Juan M. Rod investigated the potential of indirect evaporative cooling as effective means of providing comfort conditions is evaluated for 20 Mexican cities. He found that in all instances this cooling process will provide for better comfort when compared to direct evaporative cooling. [6]

S Datta, P.N Sahgal, showed that the potential energy savings envisaged by replacing conventional refrigerated systems by evaporative systems is ≈75%. Indirect systems can achieve comfort conditions similar to refrigerated systems in climatic zones where the wet bulb temperature is usually < 25°C. [7]

Khalid A. Joudi showed that indirect evaporative cooling would result in a comfortable indoor condition for most periods of system operation in many locations. Also, the results have shown that the coefficient of performance tends to be very high because the system consumes only fan and water pumping power. [8]

J.K. Jain, D.A. Hindoliya carried out analysis of two new evaporative cooling pad materials. Normally evaporative cooling pads are commonly made from aspen and khus fibers. The effectiveness of pad with Palash fibers was found to be 13.2% and 26.31% more than that of aspen and khus pads respectively. Whereas the effectiveness of coconut fiber was found to be 8.15% more than that of khus and it was comparable with that of aspen pads. Khus pad offers lowest pressure drop whereas aspen pad (most commonly used) offers highest pressure drop among the four materials tested. [9]

Varun Jain, studied performance of EC and VCC hybrid mode operation and concluded that it is financially attractive for Movie Theater and waiting hall building applications for all the climatic conditions considered in the present study. [10]

Ala Hassan studied indirect evaporative cooling performance and found that the wet bulb cooling effectiveness (E_{wb}) for the examples studied is 1.26, 1.09 and 1.31 for the two-stage counter flow, parallel flow and combined parallel-regenerative cooler, respectively, and it is 1.16 for the single-stage counter flow regenerative cooler. Such a method extends the potential of useful utilization of evaporative coolers for cooling of buildings as well as other industrial applications. [11]

3. Evaporative cooling methods

3.1. Direct evaporative cooling

With direct evaporative cooling, outside air is blown through a water-saturated medium (usually cellulose) and cooled by evaporation. The cooled air is circulated by a blower

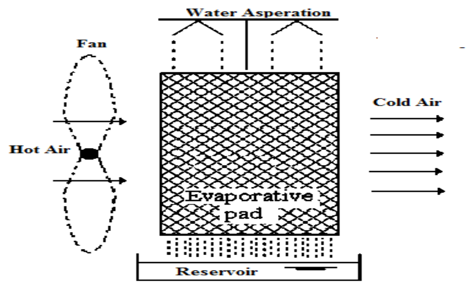

Fig 2: Direct Evaporative Cooling (DEC)

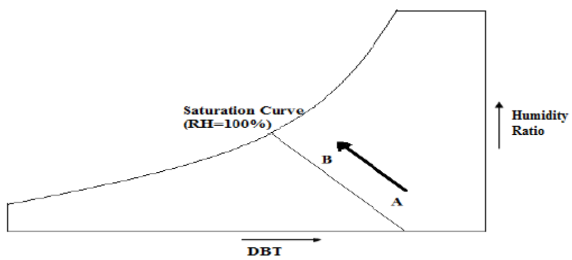

Fig 3: Direct Evaporative Cooling on Psychrometry chart

Direct evaporative cooling adds moisture to the air stream until the air stream is close to saturation. The dry bulb temperature is reduced, while the wet bulb temperature remains the same. Direct evaporative cooling, commonly used with residential systems, cools the air by evaporating water to increase the moisture content of the air. Standard residential systems use evaporative media of shredded aspen fibers, typically 1 to 2 inches thick.

Fig 2 and fig *3* show arrangement of direct evaporative cooling process and its representation on psychrometric chart

Effectiveness is defined by:

$$\in = \frac{t_{db,1} - t_{db,2}}{t_{db,1} - t_{wb,1}} \qquad (1)$$

The thickness of the media and air velocity contribute to the effectiveness. More advanced systems use a rigid medium 8 to 12 inches thick and have an effectiveness of 80% to 90%. Direct evaporative cooling systems are suitable for hot and dry climates where the design wet-bulb temperature is 20°C or lower. In other climates, outdoor humidity levels are too high to allow for sufficient cooling.

3.2. Indirect evaporative cooling

With indirect evaporative cooling, a secondary (scavenger) air stream is cooled by water. The cooled secondary air stream goes through a heat exchanger, where it cools the primary air stream. The cooled primary air stream is circulated by a blower.

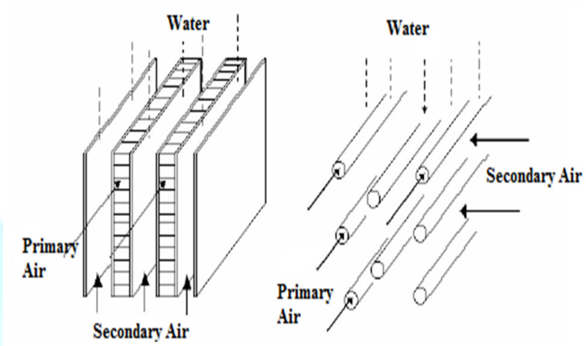

Fig 4 : Indirect Evaporative Cooling

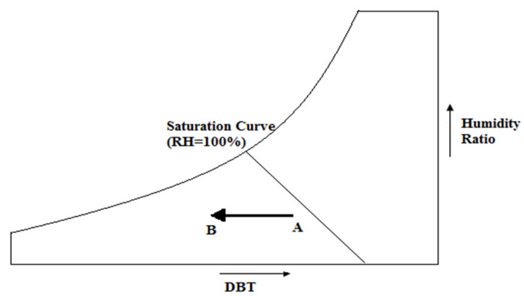

Fig 5: Indirect Evaporative cooling on Psychometric chart

Indirect evaporative cooling does not add moisture to the primary air stream. Both the dry bulb and wet bulb temperatures are reduced. This method is used when direct addition of moisture in air is not permitted. *Fig 4* and *fig 5* show arrangement of indirect evaporative cooling process and its representation on psychrometric chart. It has effectiveness of 0.6 to 0.7 and it can be used for precooling of air before air conditioner to achieve energy saving. This method finds good potential of cooling in case when air humidity is more than 70%.

3.3. Indirect/direct evaporative cooling

With indirect/direct evaporative cooling, the primary air stream is cooled first with indirect evaporative cooling and then cooled further with direct evaporative cooling.

In this method, the advantage of direct and indirect EC is separately derived in order to achieve additional cooling and maintaining humidity of outlet air within comfort limits. As outside air is cooled in first stage by IEC, WBT is reduced. This air enters then enters DEC where its moisture absorbing capacity is reduced, still it gets cooled. *Fig 6* and *fig 7* show arrangement of direct/indirect evaporative cooling process and its representation on psychrometric chart.

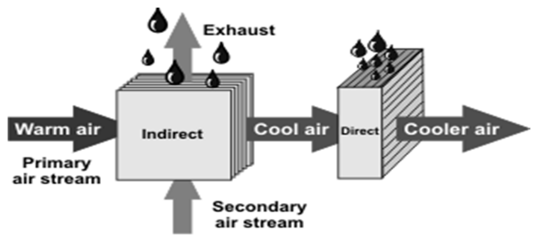

Fig 6: Indirect/Direct Evaporative Cooling

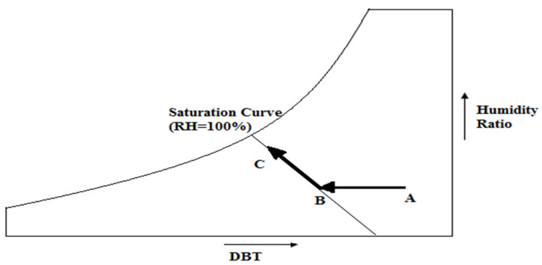

Fig 7: Indirect/Direct cooling on psychrometry

3.4. Indirect/indirect evaporative cooling

In first stage, the primary air stream is cooled by indirect evaporative cooling

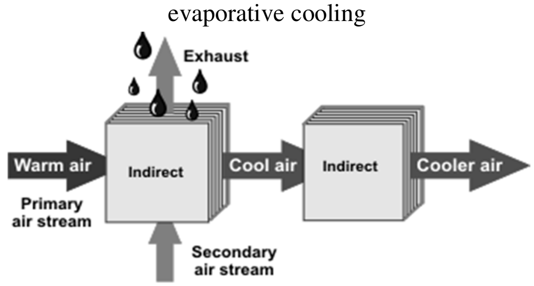

Fig 8: Indirect/Indirect evaporative cooling

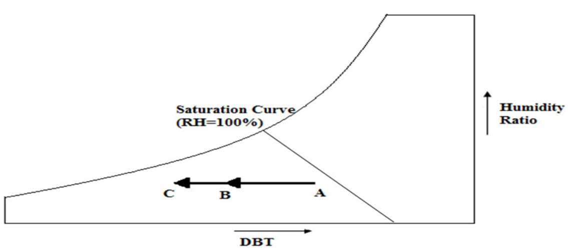

Fig 9: Indirect/Indirect evaporative cooling

Fig 8 and fig 9 show arrangement of IDIDC process and its representation on psychrometric chart. Combined effectiveness of 0.7 to 0.8 is possible with this arrangement.

4. Method of Feasibility index

A fast method to evaluate approximately the potential of the evaporative cooling is based on the

Feasibility Index (FI), defined as

$$FI= WBT-\Delta T \qquad (2)$$

Where ΔT = (DBT – WBT) is the wet bulb depression. DBT and WBT are, respectively the dry bulb temperature and the wet bulb temperature of the outside air. This index decreases as the difference between dry bulb and wet bulb temperature increases, i.e. as air relative humidity decreases. It shows that, the smaller FI is, more efficient the evaporative cooling will be. Thus, this number indicates the evaporative cooling potential to give thermal comfort. Watt (1963) recommend that indices that are under or equal to 10 indicate a comfort cooling, indices between 11 and 16 ,indicate lenitive cooling (relief) and indices above 16 classify the place as not recommended for use evaporative cooling systems. From these limits, it is possible to conclude that, to reach a comfort recommended performance index, a wet bulb depression should be at least 12 ºC. It corresponds, e.g. to a DBT of 34ºC with WBT of 22ºC, characterizing a region with relative humidity of approximately 35%. [6]

5. Feasibility Index for Pune City

Pune is a metropolitan city in the state of Maharashtra, India with very high industrialization practices. Pune city has experienced exponential growth in industrialization and maintains very high living standards over last three decades, resulting high electric demands .Pune geographical location is such that the city lies between 18 degree 32' N latitude and 73 degree 51' E longitude. Situated near the western margin of the Deccan plateau, it stands bordered by hills on the west as well as the south. Pune is approximately 50 km from the Western Ghats and 100 km to the east of the Konkan i.e. the west coast. At an altitude of 560 m above sea level, it falls on the leeward side of the Sahyadri Mountains.
In order to estimate feasibility index of city, data from Indian Metrological Department Shivajinagar, Pune is collected for the specified reference year 2010.

Based on the surface data, following plots are developed. It is found that feasibility index lies between 10 to 15 from February to June, close to11 to 16 from October to January and above 16 for rest of months. So evaporative cooling will give comfort cooling between February to June and relief cooling for January, February and October. So it is recommended to use evaporative cooling for almost 7 to 8 months as shown in fig. 10.fig 11 shows maximum DBT during the months of years 2010.fig. 12 shows corresponding WBT .It is seen that higher the wet bulb depression greater is the scope for EC.fig.13. indicates humidity corresponding to maximum DBT.

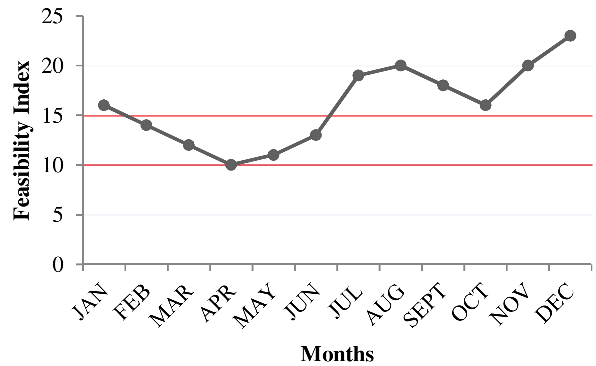

Fig 10: Feasibility index for Pune city in year 2010

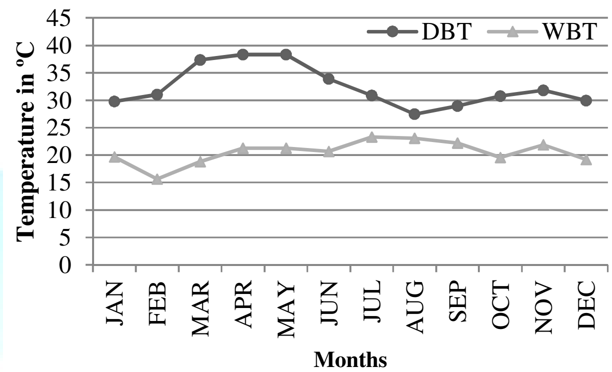

Fig 12: Monthly DBT and WBT variation

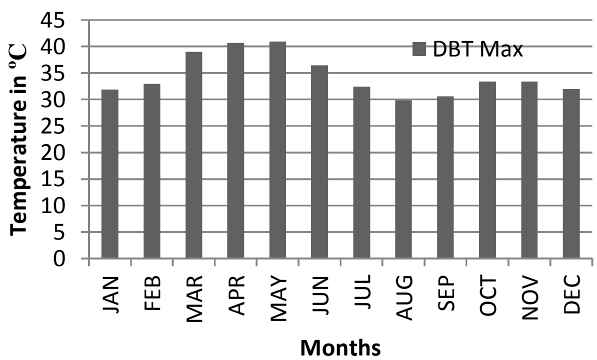

Fig 11: Maximum monthly DBT variation for year 2010

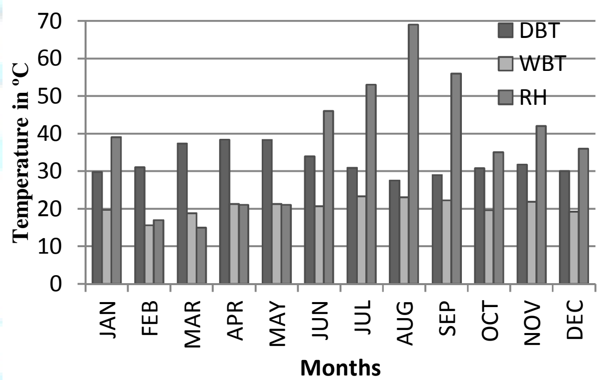

Fig 13: Variation in DBT, WBT and humidity of outside air over year for maximum DBT conditions

Table 1: Air Outlet Temperatures obtained by employing various methods of evaporative cooling

Month	*DBT(°C)*	*WBT(°C)*	*DEC(°C)*	*IDEC(°C)*	*DIDEC(°C)*	*IDIDC(°C)*
January	30	19.5	20.5	22.65	16.48	19
February	31	16	17.5	20.5	11.95	16
March	38	19	20.9	24.7	14.17	18.75
April	39	21.5	23.25	26.75	19.32	22.62
May	39	21.5	22.8	26.75	19.32	22.62
June	34	20.5	21.85	24.55	18.25	20.87
July	31	24	24.7	26.1	22.86	24.3
August	28	23	23.5	24.5	24.3	23.25
September	29	22	22.7	24.1	20.86	22.8
October	31	19	20.2	22.6	18.41	19.3
November	32	21	22.1	25	18.7	21.25
December	30	19	20.1	22.3	15.73	18.9

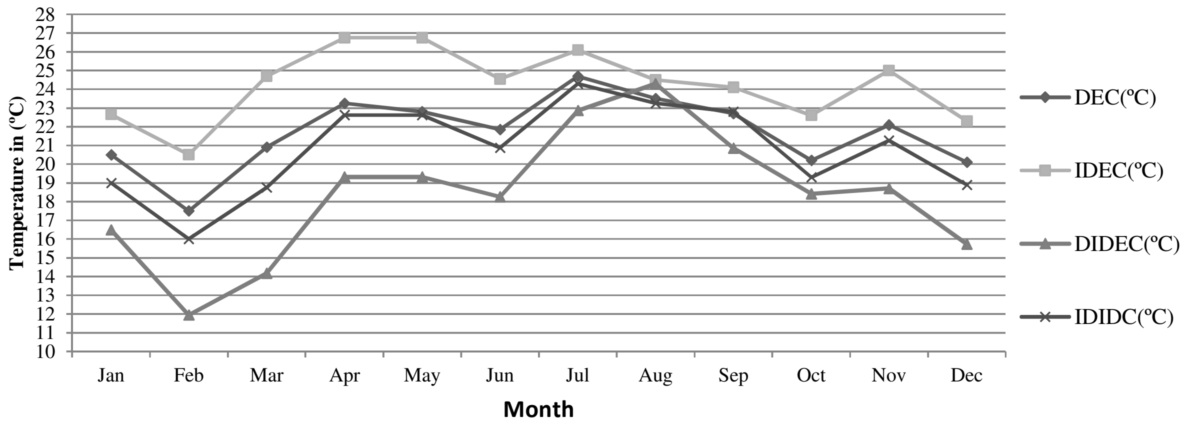

Fig 5: Theoretical Air Outlet Temperatures obtained by various methods of evaporative cooling

6. Conclusions

Feasibility of use of evaporative cooling system for human comfort with the help of FI method it is investigated using 2010 surface data for Pune city.
It is found that evaporative cooling systems can be recommended to use for 7 to 8 months in a year in Pune regions when the design wet bulb temperature is under 24°C.
The highest temperature drop is achieved by DIDIC systems while lowest temperature drop is achieved by IDEC systems .Considering energy efficiency, outside air temperature and humidity and feasibility, one particular system out of four proposed systems is more effective and it is recommended. For January and February, IDEC systems are suitable while from March to June DEC serves the purpose as it adds the moisture in a dry air. The relative humidity of air being on higher side in the months of monsoon viz. July, August and September,, IDIDC systems are favorable. Even though, the desired drop in air DBT is achieved , air conditioning is must in these months to dehumidify air so as to bring relative humidity within comfortable limits. Months October, November and December IDEC systems are recommended as outside air DBT is low and relative humidity being lies within normal limits, air conditioning is not really essential
The combinations of DEC and IEDC is always more effective than single system because they give supply air temperature less than WBT of entering air, thus reduces the relative humidity of process air. It is used in case lower indoor temperature is desired. The key factor for use of EC is availability of water which fortunately is in abundance in Pune.
Thus, evaporative cooling systems have great potential to replace conventional air conditioners either fully or partially for Pune city for eight months in a year, which render benefits of substantial saving in power consumption.

Appendix

AC	Air Conditioner	
CFC	Chloro- Floro Carbon	
HFC	Hydro Floro Carbon	
DBT	Dry Bulb Temperature	° C
WBT	Wet Bulb Temperature	° C
WBD	Wet Bulb Depression	° C
EC	Evaporative cooling	
DEC	Direct Evaporative Cooling	
IDEC	Indirect Evaporative Cooling	
DIDEC	Direct Indirect Evaporative Cooling	
IDIDC	Indirect, Indirect Evaporative Cooling	
FI	Feasibility index	
t_{db1}	Dry bulb temperature of outside air	° C
t_{db2}	Dry bulb temperature of conditioned Air	° C
t_{wb1}	Wet bulb temperature of outside air	° C
ϵ	Effectiveness	

Acknowledgement

The authors acknowledge The Indian Metrological Department Shivajinagar, Pune for providing surface data for Pune city for the specified reference year 2010.

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