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SCOPE AND POTENTIAL OF ADVANCED EVAPORATIVE COOLING TECHNIQUES FOR ENERGY EFFICIENT COOLING IN COASTAL MEGA CITIES OF INDIA

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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. And then it is applied to three coastal mega cities in India, characterized by different climatic conditions over entire months of the year. Initially, it represents the principles of direct and indirect evaporative cooling and effectiveness of the system. Later on, it determines feasibility index for all months for three cities and decides whether the system is efficient for particular city and its weather for particular month. It is found that evaporative cooling technique can replace air conditioners in all three cities only for January and February and for rest of months it can work as pre cooler achieving sensible heat drop followed by air conditioner rendering energy efficient cooling as compared to use of sole air conditioners. The advancement of dew point evaporative indirect cooler has ability to work as precooler and can provide outlet air temperature in the range of 17°C to 26°C, 20°C to 28°C and 12 °C to 28°C for Mumbai, Chennai and Kolkata respectively. It can be concluded that energy efficient air conditioning system that is a combination of indirect evaporative cooling which is capable of taking sensible heat almost throughout year and air conditioner that only takes latent heat loads can be developed for these cities resulting reduced power consumptions for building cooling.

KEYWORDS: Air Conditioning, Chennai, Dew Point Indirect Cooler, Evaporative Cooling, Feasibility Index, Kolkata, Mumbai

INTRODUCTION

The exponential growth in industrialization and increasing rate of urbanization is being witnessed by developing country like India from last three decades. India has three mega coastal cities namely Mumbai, Chennai and Kolkata representing capitals of progressive states. These cities are fast developing resulting high energy demands caused by growing industrialization, construction, population growth, increased lifestyle. The cooling load of these cities have stepped up due to construction of sky high multi-storeyed buildings, mega shops, malls, multiplexes, BPOs and call centres, software companies, sophisticated factories of automation and hospitals, all demanding compulsory air conditioning. This cooling load is presently taken care by window air conditioners and central air conditioners that are driven by mechanical refrigeration systems.. For India, the energy demands are elevated from 150,000 MW in 2007 to 230,000 MW in 2014. The major contribution of increased demand has come from air conditioning industry. Domestic as well as commercial places have been air conditioned. In India by 2022, about 1.3 million window air conditioners using

R-22 as refrigerant is expected to be in operation. 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.[1]

The existing practice of air conditioning uses mechanical refrigeration systems using air conditioners of 1TR to 10 TR capacities for domestic air conditioning and central air conditioners utilizing 50 TR to 500 TR capacities.

One substitute in the form of evaporative cooling is definitely an attractive option. Evaporative cooling systems have been used to condition facilities before refrigerated cooling was invented. Evaporative cooling is a process in which water is injected into outdoor air stream causing a heat and mass transfer that cools the outside air close to the wet bulb temperature. Conventional air conditioner has an average EER of 12 while Evaporative cooling may achieve EER of 24 to 48 depending upon climatic conditions over entire year.

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, reduced initial and running cost, simple maintenance, installation, silent operation practices. [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 provide comfort indoor temperature conditions. Various methods of EC and their combinations are discussed and methods which are capable of maintaining comfort conditions are subsequently recommended. Paper describes operational efficiency of E.C. systems and, for this, feasibility index method proposed by Watt and J. R. Camargoa is presented in order to establish references, applied to Indian costal mega cities to determine scope of evaporative cooling, characterized by different climates.[2][3]

RECENT DEVELOPMENTS

Several researchers have shown interest for the development of direct, indirect and regenerative evaporative cooling systems. Watt (1963) developed the first serious analyses of direct and indirect evaporative systems. [2]

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.

The evaporative cooling pad materials that holds the water is key functioning element in the performance of evaporative cooler. Various material are being used like aspen, khus, cellulose paper, metal foams organic impregnated material, Celdek paper and fired- clay. Wet media used in evaporative coolers is necessity of an evaporative cooler. It is made of a porous material with large surface area and capacity to hold liquid water. The selection of wet media materials is based on their effectiveness, availability, cost, safety. [5]

Zhao et al investigated various types of porous materials such as metal and plastic foams, zeolite and found that pressure drop and effectiveness vary with material selection.. [6]

Musa found that the use of aspen pads materials for indirect evaporative cooling system.[7]

Riffat and Zhu employed ceramic materials for indirect evaporative cooling systems. [8]

J.K. Jain a, D.A. Hindoliya used two new materials as coconut fibre and palash fiber as cooling pads materials.

They reported that 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. While effectiveness of coconut fibers was found to be 8.15% more than that of khus. The pressure drop was found minimum for palash followed by khus pads.[9]

Several studies have been reported on dew-point cooling Hsu et al. investigated three types of wet-surface heat exchangers for evaporative cooling. He found that the air can be easily cooled below wet-bulb temperature and the maximum wet bulb effectiveness was 1.3 for counter flow, closed-loop configuration was reported. [10]

Zhao et al. indicated that cooling effectiveness of the cooler was largely dependent on the air velocity, dimension of the air flow passages and working-to-intake-air ratio. The exchanger could obtain wet bulb effectiveness of up to 1.3 under a typical UK summer condition. [11]

Riangvilaikul and Kumar studied the performance of the cooler under different inlet air conditions. Key results have indicated that the range of the achievable wet bulb effectiveness spanned 92%e114% and the dew-point effectiveness between 58% and 84%.[12]

Frank Bruno conducted an on-site experimental testing of a prototype dew-point evaporative cooler installed in both a commercial and residential application. The cooler in the commercial application, with average wet bulb effectiveness 106%, was used to pre-cool the fresh air supplied to an existing conventional mechanical vapour compression refrigeration air conditioning system of a building. For the cooler in residential application, the average wet bulb effectiveness was 124 %. [13]

EVAPORATIVE COOLING METHODS

There are two types of evaporative cooling techniques: direct and indirect. The direct evaporative cooling is used where outside air is dry and hot. In direct mode, air is cooled by cooling and humidification process. The limitation of this process is that it cannot be used in places where air specific humidity is higher especially in coastal area where average relative humidity is in the range of 65% to 85 % In this case an indirect evaporative cooling system is used. The air can be cooled to wet bulb temperature but with recent developments air can also be cooled close to dew point temperature of air.

Direct Evaporative Cooling

In direct evaporative cooling, the outside air with relatively low humidity is cooled by injecting water through the wet pads causing a temperature drop and increasing the specific humidity of air. Figure 1 and figure 2 show arrangement of direct evaporative cooling process and its representation on psychometric chart. The performance of system is expressed in the form of effectiveness.

Effectiveness is defined by:

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

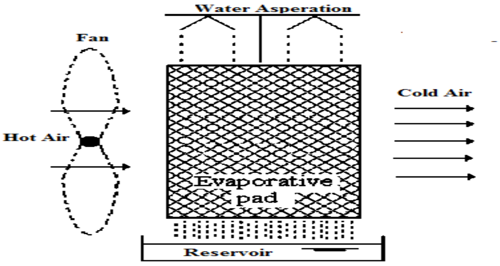

Figure 1: Direct Evaporative Cooling Method

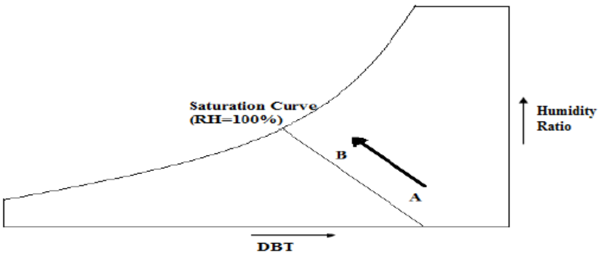

Figure 2: Direct Evaporative Cooling on Psychometric Chart

Indirect Evaporative Cooling (Wet Bulb Approach Design)

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.

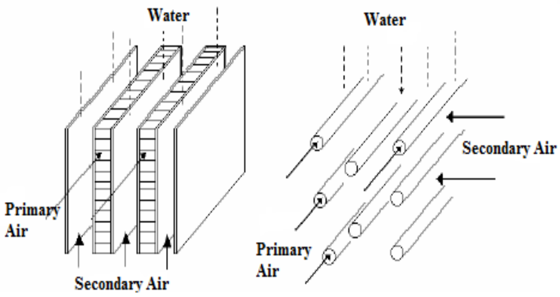

Figure 3: Indirect Evaporative Cooling Method

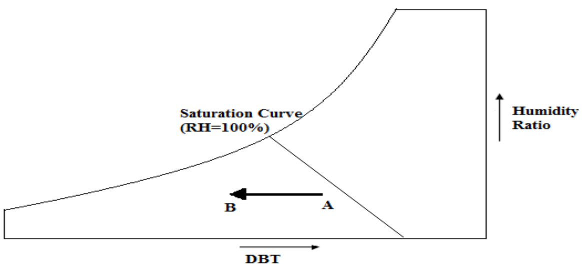

Figure 4: Indirect Evaporative Cooling on Psychometric Chart

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. Figure 3 and figure 4 show arrangement of indirect evaporative cooling process and its representation on psychometric 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%. The limitation of this method is reduced effectiveness causing higher air outlet temperature because it can cool air close to wet bulb temperature. In coastal cities of India, climatic conditions are such that WBT of air is above comfort temperature throughout the year and hence some advancement in this technique is essential.

Indirect Evaporative Cooling (Dew Point Approach Design)

The indirect wet bulb coolers have potential to cool air close to wet bulb temperature. In costal megacities in India, the wet bulb temperature is recorded between 24° C to 28° C almost throughout the year. Hence it is not beneficial to use indirect cooler that operates in these cities as comfort temperature cannot be achieved. The new attractive option in the form of indirect cooler operating at lower temperature than wet bulb temperature has been recently developed. This cooler can produce temperature between wet bulb temperature and corresponding dew point temperature of the air. It is based on the “Maisotsenko cycle (M-cycle)” which was developed to reduce the supply air temperature compared with conventional IEC systems. The M-cycle is able to cool the air below the wet bulb temperature (the limit for conventional evaporative cooling) and approaching the dew-point temperature.

Effectiveness is defined by

$$\epsilon = \frac{t_{db,1} - t_{db,2}}{t_{db,1} - t_{dp,1}}$$

Normally the effectiveness of such cooler is found in the range of 75 to 80 % providing air outlet temperature in the range of 15° C to 22° C. Thus a direct sensible drop of 20° C to 25° C is possible with new system

METHOD OF FEASIBILITY INDEX

Feasibility Index (FI), defined as

FI= WBT-ΔT

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. The lower value of FI indicates attractive chances of cooling through evaporative technique. If F.I. is found less than 10, it represents comfortable cooling. While if F.I. lies between 10 to 15 it represents manageable cooling and if F.I. is more than 15, climatic conditions are not suitable to adopt evaporative cooling technology.

The mega coastal cities of India are compared to understand scope and significance of evaporative cooling technology.

Table 1: Climatic and Geographic Parameters for Mega Cities

Sr.	Parameter	Mumbai	Calcutta	Chennai
1	DBT maximum	42.2°C	35°C	40°C
	DBT average	32°C	33 °C	33°C
	DBT minimum	13°C	12°C	11°C
2	RH range	65 - 85	60 - 80	40 – 80
3	Rainfall	242.2 cm	158.2	140 cm
4	Solar flux (MJ/m^2 per day)	18.25	16.17	19.34

Table 1: Contd.,

5	Wind speed average in kmph	1.5	1.15	2.1
6	Geographic location	18.9750° N, 72.8258° E	22.56° N, 88.36° E	13.083° N, 80.270° E
7	Population	12,655,220	4,486,679	8,917,749 (4th)
8	Area	603 KM^2	185 km^2	426 km^2
9	Energy demand	3288 MW	1900 MW	2450 MW
10	Cost of energy (in INR)	3.36 - 6.05	4.46 - 5.86	1 - 1.5
11	Elevation from mean sea level	14 m	9 m	6 m

Feasibility Index of Cities

As shown in Table 2, Feasibility Index based upon watts formula is calculated for the year 2013-14 for cities .It is observed that FI for all three cities is above 15 except for months of January, February and March. Hence EC is not suitable for rest of the months in the year.

Table 2: Year-Round Feasibility Index of Cities

	CALCUTTA	MUMBAI	CHENNAI
JAN	9.4	12.5	15.6
FEB	11.2	13.1	15
MAR	12.7	14	15.3
APR	18.3	20.3	22.3
MAY	23.9	21.4	18.9
JUN	24.6	23.6	22.6
JUL	24.8	24.2	23.6
AUG	24.6	23.6	22.6
SEP	24	22.2	20.4
OCT	23.1	19.8	16.5
NOV	16.3	16.2	18
DEC	14.6	16.2	20

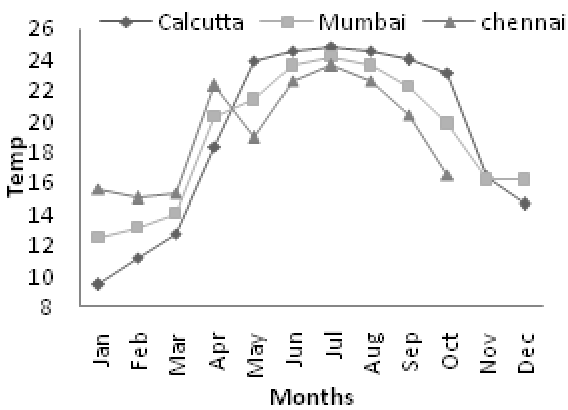

Figure 5: FI Index for Various Coastal Mega Cities

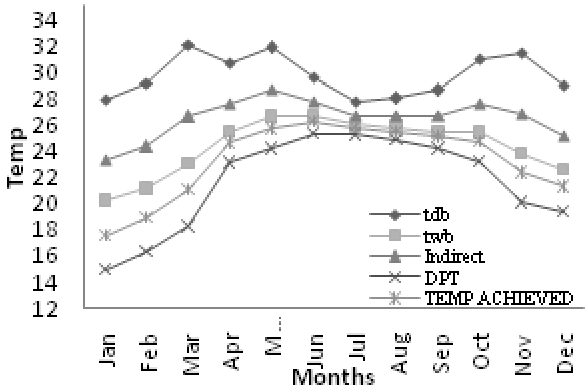

Figure 6: Possible Temperatures Achieved in Mumbai

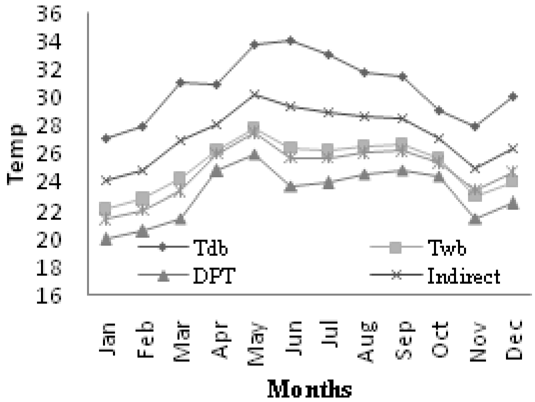

Figure 7: Possible Temperatures Achieved in Chennai

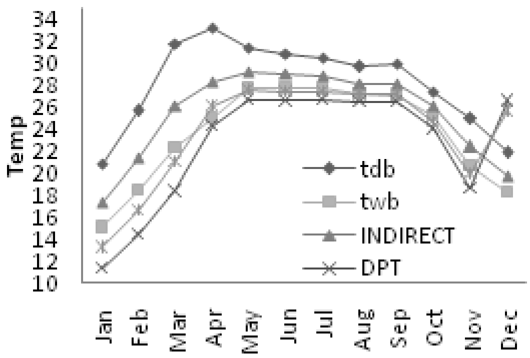

Figure 8: Possible Temperatures Achieved in Kolkata

CONCLUSIONS

Feasibility of use of evaporative cooling system for human comfort with the help of FI method is investigated using 2014 surface data for Indian mega coastal cities namely Mumbai, Chennai and Kolkata.

It is found that evaporative cooling systems can be recommended for only 2 months in a year in these city regions when the design wet bulb temperature is under 24ºC. It concludes that evaporative cooling systems alone have a very small potential to provide thermal comfort as wet bulb temperature is near and above 24ºC throughout the year for all three cities.

Feasibility index for all cities lies within limits 10 to 15 that indicates a relief cooling and for rest of months evaporative cooling cannot replace air conditioners. However, the advancement of dew point evaporative indirect cooler has ability to work as precooler and can provide outlet air temperature in the range of 17°C to 26°C, 20°C to 28°C and 12 °C to 28°C for Mumbai, Chennai and Kolkata respectively with an effectiveness of 0.7 .It can be concluded that a hybrid Air Conditioning system with Mechanical Refrigeration system and evaporative cooler have great scope in energy saving and in these climates rendering long term benefits.

NOMENCLATURES

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**	
tdb1	**Dry bulb temperature of outside air**	**° C**
tdb2	**Dry bulb temperature of conditioned Air**	**° C**
twb1	**Wet bulb temperature of outside air**	**° C**
ϵ	**Effectiveness**	

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