International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 3, Issue 5, December 2014)

Energy Efficient Cooling Techniques As A Substitute To Air Conditioners For Major Cities Of Maharashtra

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***Abstract*— This paper proposes methodology of utilizing advanced evaporative techniques for energy efficient cooling in five major cities of Maharashtra for replacement air conditioners. It presents the basic principles of direct and indirect evaporative cooling and defines the effectiveness of the system. Later on, it determines feasibility index for all months for five major 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 five cities for all months except for month of July and August. It is observed that use of direct and indirect evaporative cooling along with combination can lead to comfort conditions in terms of temperature and humidity as per recommendations of ASHRAE standards. Temperature achieved is in the range of 12°C to 25°C for the various months of the year with humidity in the range of 50 %to 70%. Therefore, it can be concluded that evaporative cooling can replace air conditioners for major period of year in all cities leading to substantial saving in energy without compromising indoor air quality that is presently achieved by air conditioners.**

***Keywords*— Air Conditioning, Aurangabad, Evaporative Cooling, Dew point indirect cooler, Feasibility Index, Kolhapur, Nagpur, Nashik, Solapur**

I. INTRODUCTION

India, a fast growing developing nation is being successful of maintaining good pace of industrialization. Over the last two decades, India has witnessed increased rate of urbanization. The growing economy has stepped up lifestyle of common man. Maharashtra is one of the pioneer states in India. It has gained all round development in all sectors. The net effect is increased life style demanding more energy. Air conditioning now has become necessity and not the luxury. Air conditioning put huge bourdon on electricity demand. Hence some kind of replacement which is energy and environmental friendly is an urgent call. One alternative in the form of evaporative cooling is known to mankind since centuries. It has certain potential to provide comfort condition under specific climatic conditions. It is energy efficient, does not use harmful gases, and provides fresh supply air, easy to use. The power consumption of evaporative cooling is around 30 % as that of air conditioner. These benefits attract our attention in the era of energy crisis.

This paper describes chances of evaporative cooling application in certain climatic location. The term known as feasibility index is used to find suitability of EC. The five fast developing cities of Maharashtra are taken for consideration. Their climatic condition over entire year are studied and suitable method of EC is recommended.[1]

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II. Recent developments

Being a very old technology known to mankind, many researchers have recently shown interest for development of direct indirect and indirect direct combination evaporative cooling system. The first recorded work done by watt for analysis of Direct and Indirect Evaporative system. He proposed feasibility index number which is a indicative number for scope evaporative cooling in various climates

Watt in 1963 developed the first practical direct and in direct evaporative cooling system to attain substantial cooling. He evaluated feasibility of evaporative cooler by using term feasibility index. He proposed if feasibility index is less than 10 evaporative cooling is highly efficient. [1]

Egbal Ahemed evaluated local evaporative cooling pad for green house in Sudan and found that use of different types of evaporative cooling pad does not lead any significant change in temperature. The pads used were Celdek pads, straw pads and sliced wood pads. [2]

Cardoso checked the performance of evaporative cooling using feasibility index method, vector cooling process method and namograph and template method for Brazilian cities and found that evaporative cooling is useful when wet bulb temperatures recorded are below 24ºC. [3]

R. Boukhanouf and M. Kanzari used evaporative cooler for hot and dry climates having temperature 45ºC DBT and Humidity upto 50%. They found that supply air can be successfully cooled below wet bulb temperature of air and wet bulb effectiveness is greater than unity. The achieved temperatures are well below the comfort conditions required for air conditioning and hence are the attractive option. [4]

J.K.Jain and DA Hindoliya performed experimentation for new evaporative cooling pad materials namely Palash roots and Coconut fibers. They compared the performance with regularly used evaporative cooling materials like Aspen and Khus pads and found that there is rise of average 20% in effectiveness for Palash and average 10% for coconut fiber. They also found there is reduction in pressure drop for newly invented materials. [5]

X Cui studied performance of improved dew point evaporative cooler. He found that simulation results indicated 132% wet bulb effectiveness and 93% dew point effectiveness. They suggested the length of channel passage shall be 200 times the height of channel and air velocity shall be greater than 1.5 m/sec for efficient cooling. [6]

Moien worked on increasing effectiveness of evaporative cooling using precooled nocturnally stored water. For two stage evaporative cooling for four cities. He found that multistep system is economical and has higher effectiveness than conventional two stage evaporative cooling system. He also found energy saving potential varies between 75% to 79% compared to vapour compression refrigerated system. [7]

Samar jabber worked on Indirect evaporative cooling for mediterrian region for green practices of cooling. They come with outcome can be covered for total annual load and can be utilized for 5 million residential building. The annual saving in electricity is 1084GWHr and payback period was found to be less than 2 years.[8]

Ebrahim used direct evaporative cooling to improve performance of condenser of window air conditioner. The conventional condenser was air cooled which he converted into evaporative cooled condenser. He found that new system gives reduced power consumption by 16% and COP stepped up by 55%. [9]

Al hasan attempted a method to achieve subwet bulb temperature without using vapor compression cycle and developed a model of effectiveness NTU method. The model result showed good agreement with experimental result. [10]

Frank Bruno worked on noval due point evaporative cooler for commercial residential applications. He obtains average EER in the range of 7.22 to 11.5. The lowest temperature achieved by cooler is 14.7ºC and average temperature delivered was 17.3ºC. The Wet bulb effectiveness range from 93% to 106% and Dew point Effectiveness range from 65% to 83%. Annual energy saving range from 55% to 60%. [11]

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III. Evaporative Cooling Methods

Evaporative cooling can be used in two ways to achieve cooling of air.

A. *Direct evaporative cooling*

Firstly, hot outside air is directly allowed to flow over wetted cooling pads over which water is sprayed. The water is evaporated in air. The heat required for evaporation is taken from air. During this process, air is cooled and humidified. The limit of such cooling depends on wet bulb temperature of air.

In the second design which is recent, air is cooled below the wet bulb temperature and close to dew point temperature..

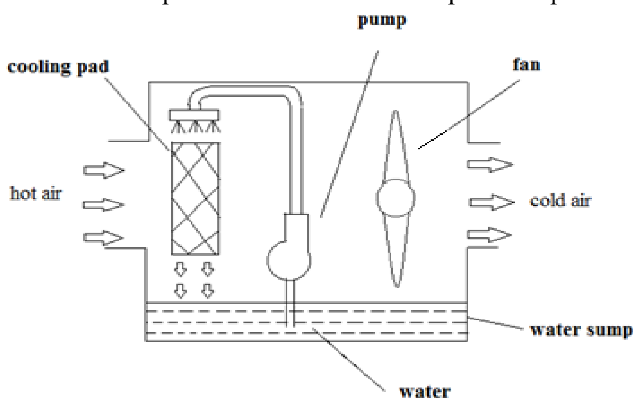

Figure 1: Direct Evaporative Cooling (DEC)

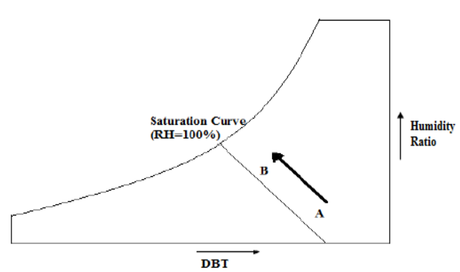

Figure 2: Direct Evaporative Cooling on Psychometric chart

fig 1 and fig 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:

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

The effectiveness depends upon air velocity, pas material, arrangement of pad material, outside air temperature and wet bulb temperature of air. Generally effectiveness vary from 0.8 to 0.9 for direct type and 06 to 0.7 for indirect type.

B. *Indirect evaporative cooling (Wet bulb approach design)*

In Indirect method, outside air is cooled sensibly, that is without adding moisture. Thus, specific humidity of air remains constant but relative humidity of air is brought in desired comfort limit. There are two ways of indirect evaporative cooling. In the first method, outside air is forced on a heat exchanger in which cooled humid air is flowing. This method has the limit of cooling air 60 to 70 % of wet bulb temperature of outside air.

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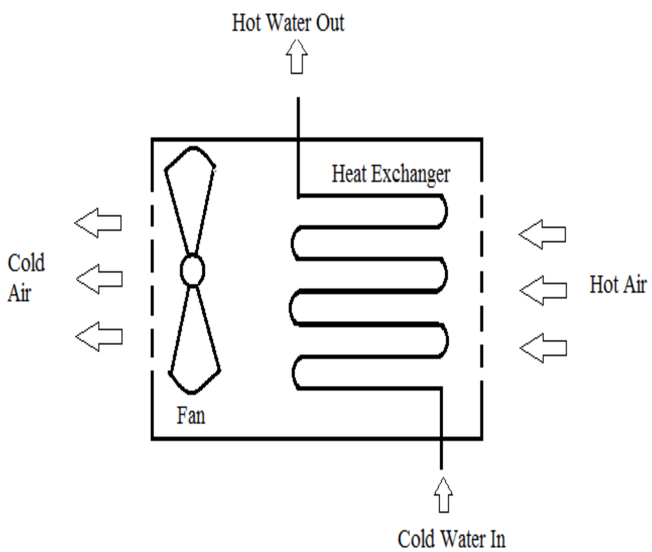

Figure 3 : Indirect Evaporative Cooling

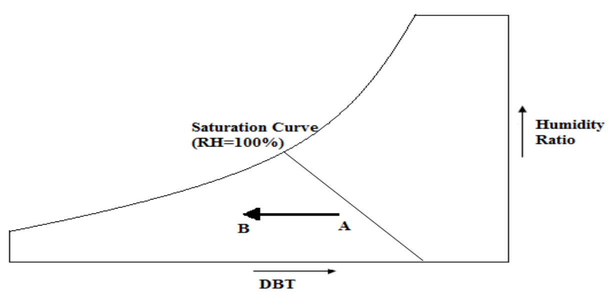

Figure 4: Indirect Evaporative cooling on Psychometric chart

C. Indirect Evaporative Cooling (Dew Point Approach Design)

The indirect coolers discussed till has potential to cool air up to close to wet bulb temperature. In Five cities in Maharashtra, the wet bulb temperature is recorded above 24° C to 28° C almost throughout the year. Hence it is not useful 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 is available. This cooler can produce temperature between wet bulb temperature and corresponding dew point temperature of the air.

. 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
The effectiveness of cooler is defined as

Effectiveness is defined by:

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

. In this cooler arrangement, the air streams are separated into dry channel for supply air and wet channel for rejecting spent working air. The supply air in the dry channel is cooled indirectly by transferring its heat to the working air in the wet channel through a thin non-permeable channel.

IV. METHOD OF FEASIBILITY INDEX

A simple method to evaluate quickly the potential of the evaporative cooling is based on the

Feasibility Index (FI), defined as

FI= WBT-ΔT

TABLE I
FEASIBILITY INDEX OF CITIES

	SOLAPUR	*KOLHAPUR*	*NASHIK*	*NAGPUR*	*AURANGABAD*
JAN	7.8	6.9	6.6	9.8	10.8
FEB	12.3	6.4	4.6	6.2	8.6
MAR	9.2	7.2	3.5	4.9	8.8
APR	6.3	12.5	2.9	14.4	6.3
MAY	7.5	14.8	8.3	9.6	10.9
JUN	14.8	20.7	16.1	16.8	18.3
JUL	15.6	20.6	20.2	22.6	19.4
AUG	17.2	20.8	19.8	22.6	19.5
SEP	18	19	20.4	22.2	19.7
OCT	13.6	17.1	13.8	18.4	11.8
NOV	14.4	10.4	8.8	17.2	10.8
DEC	9.3	9.6	7.3	16	11.3

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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 FI smaller value indicates better scope of EC in that climate. FI with value less than 10 indicates that EC can be used to provide comfort condition. If FI ranges from 10 to 15, relief cooling can be achieved while FI value more than 15 rejects use of EC.

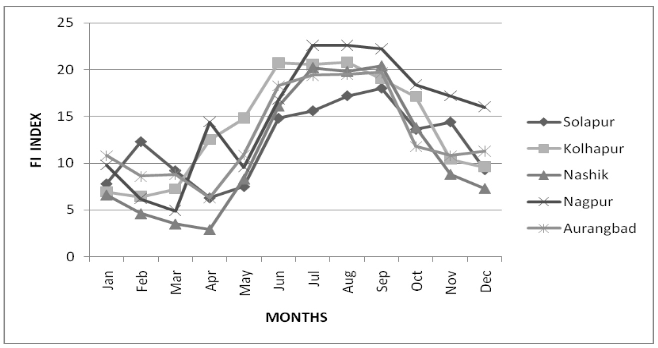

Figure 5: FI Index for Five Cities of Maharashtra

The five major cities of Maharashtra are compared to understand scope and significance of evaporative cooling technology.

TABLE III
ACCEPTANCE OF E.C. IN MONTHS FOR VARIOUS CITIES

Sr. No	City	Feasibility Index		
		Below 10	0-15	Above15
1	Solapur	5	4	3
2	Kolhapur	4	3	5
3	Nashik	7	1	4
4	Nagpur	4	1	7
5	Aurangabad	4	4	4

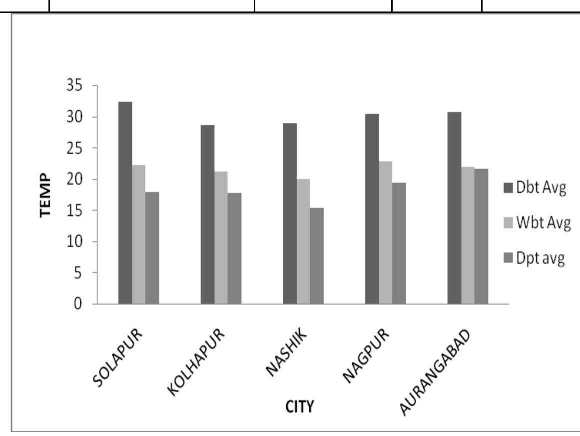

Figure 6 : Average Temprature for Five Cities of Maharashtra

TABLE III
CLIMATIC AND GEOGRAPHIC PARAMETERS OF CITIES

Sr. No.	Parameter	Solapur	Kolhapur	Nashik	Nagpur	Aurangabad
1	DBT maximum	40.1°C	33.8°C	35.7°C	41.2°C	37.9°C
2	DBT average	33.76°C	28.83°C	28.82°C	30.40°C	30.75°C
3	DBT minimum	20.3°C	25°C	23.8°C	24°C	27.3°C
4	RH range		28-81	18-84	19-81	23-72
5	Rainfall (mm)	680.9	1500	2800	1205	734
6	Solar flux (MJ/m² per day)	19.224	19.845	18.324	18.324	19.08
7	Wind Speed average (Kmph)	2.71	5	3.89	3.58	2.62
8	Geographic Location	17.68°N 75.92°E	16°41′30”N 74°14′00″E	20.00°N 73.78°E	21.15°N 79.09°E	19.88°N 75.32°E
9	Population	951,118	549,293	1.077 million	2.052 million	1,137,426
10	Area	148.9 km²	66.82 km²	360 km²	217.6 km²	123 km²
11	Elevation from mean sea level (m)	550	545	570	312.42	561

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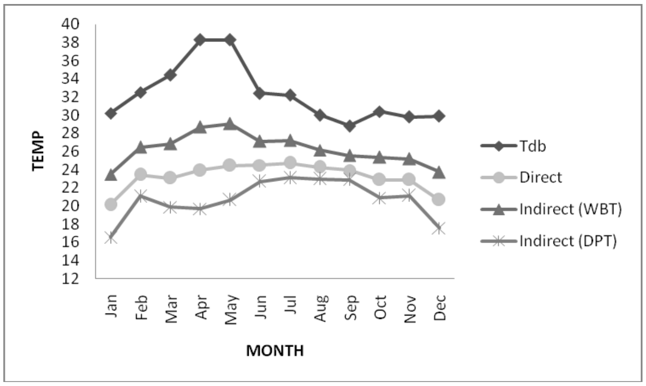

Figure 7: Possible Temperatures Achieved in SOLAPUR

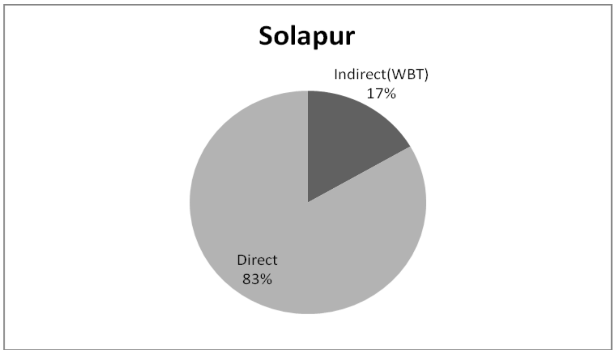

Figure 8: Scope of Evaporative Cooling For SOLAPUR

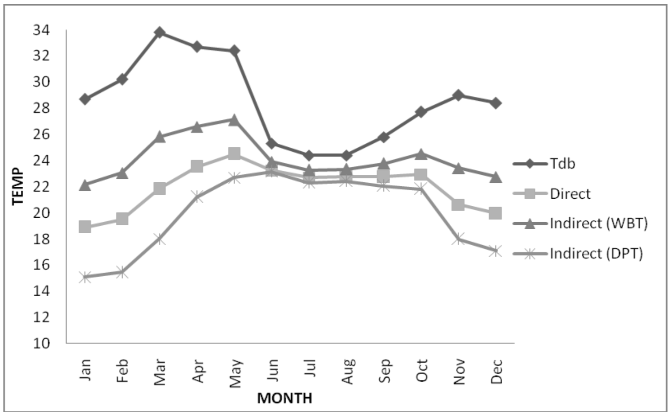

Figure 9: Possible Temperatures Achieved in KOLHAPUR

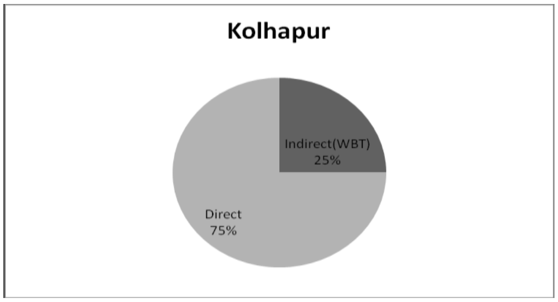

Figure 10: Scope of Evaporative Cooling For KOLHAPUR

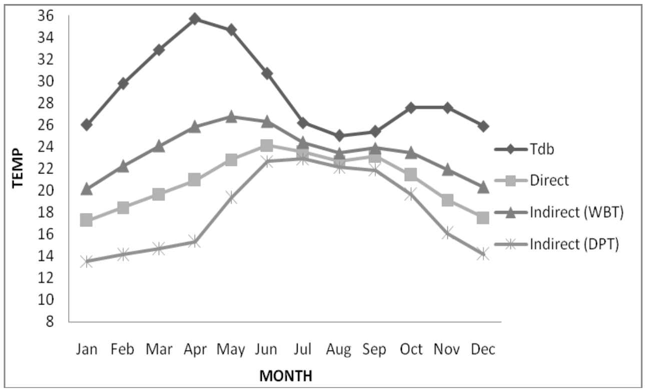

Figure 11: Possible Temperatures Achieved in NASHIK

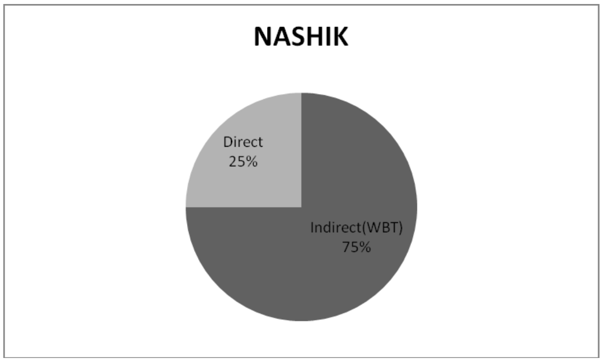

Figure 12: Scope of Evaporative Cooling For NASHIK

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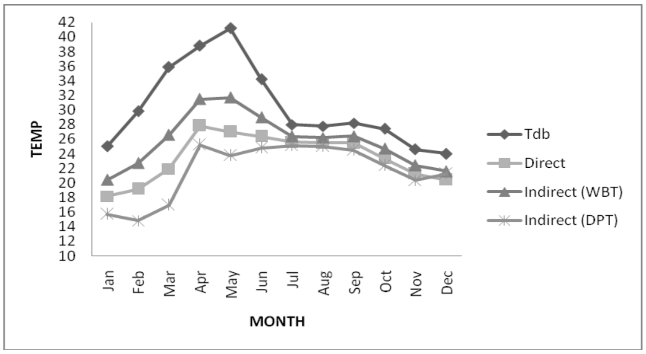

Figure 13: Possible Temperatures Achieved in NAGPUR.

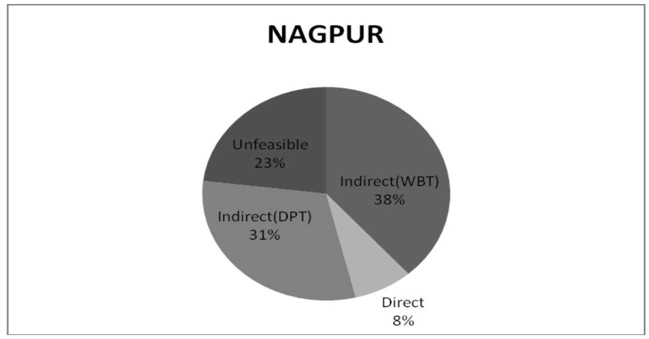

Figure 14: Scope of Evaporative Cooling For NAGPUR

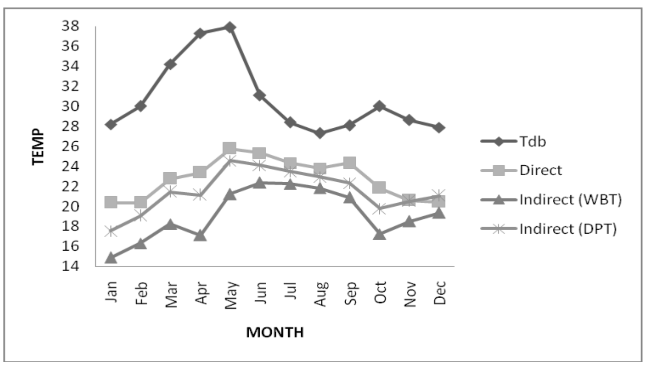

Figure 15: Possible Temperatures Achieved in AURANGABAD

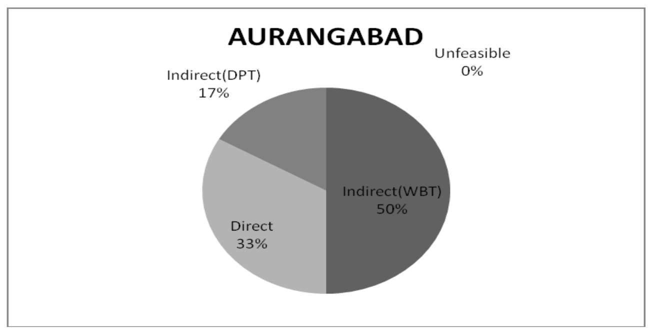

Figure 16: Scope of Evaporative Cooling For AURANGABAD

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V. CONCLUSIONS

Evaporative cooling technique is found to be capable of providing comfort conditions in all cities under consideration for the most of the time of the year as a replacement to air conditioner. The scope and potential of using EC for human comfort with the help of FI method is investigated using 2014 surface data for five major cities of Maharashtra namely Solapur, Kolhapur ,Nashik ,Nagpur, Aurangabad.

It is found that evaporative cooling systems can be recommended to use for all five cities in Maharashtra except 2 months in a year. It is found that evaporative cooling systems alone have a very high potential to provide thermal comfort in these cities as the climate is hot and dry nature in most of the period of the year.. As per feasibility index, technique evaporative cooling can be used for Solapur for 9 months, Kolhapur for 7 months, Nashik for 8 months, and Nagpur for 5 months, and Aurangabad for 8 months. 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 16°C to 22°C, 15°C to 23°C , 14°C to 22°C ,11 °C to 24°C and 15 °C to 23°C for Solapur, Kolhapur ,Nashik ,Nagpur and Aurangabad respectively. Thus temperature achieved lies in comfort zone as per prescription of ASHRAE standards also amount of power consumed per ton of refrigeration is about one third as of window air conditioner. Energy efficient air conditioning system can be achieved almost 80 % of the time in year in all cities thereby replacing conventional air conditioners. Fortunately these cities have no issues of availability of water. Hence, it can be concluded that there is tremendous reduction in energy demand caused by existing air conditioners and comfort conditions can be achieved in terms of air temperature, humidity without compromising indoor air quality using this green practice of air conditioning.

NOMENCLATURES

AC	Air Conditioner
CFC	Chloro- Floro Carbon
HFC	Hydro Floro Carbon
DBT	Dry Bulb Temperature ° C
WBT	Wet Bulb Temperature ° C
DPT	Dew Point Temperature ° C
WBD	Wet Bulb Depression ° C
EC	Evaporative cooling
DEC	Direct Evaporative Cooling
IDEC	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

REFERENCES:

1. Watt, J.R., 1963, "Evaporative air conditioning", The Industrial Press, New York. Watt, J. R., Brown, W. K., 1997.
2. Egbal Ahmed , Osama Abaas: Performance evaluation of three different types of local evaporative cooling pads in greenhouses in sudan. *Saudi Jouranal of Biological Sciences* (2011) 18,45-51
3. J. R. Camargoa, C. D. Ebinumaand S. cardosoa: Three methods to evaluate the use of evaporative cooling for human thermal comfort. Thermal Engg, Vol.5, No.02, December 2006, Page 9-15.
4. R. Boukhanouf, H. G. Ibrahim, A. Alharbi, and M. Kanzari investigation of an evaporative cooler for buildings in hot and dry climates *Journal of Clean Energy Technologies, Vol. 2, No. 3, July 2014*
5. J.K. Jain,D.A. Hindoliya Experimental performance of new evaporative cooling pad materials. *Sustainable Cities and Society* 1 (2011) 252– 256
6. X. Cui, K.J.Chua: Studying the performance of and improved dew-point evaporative design for cooling application. *Applied Thermal Engineering* 63 (2014) 624-633.
7. Moien Farmahini, Ghassem Heidarinejad: Increasing effectiveness of evaporative cooling pre-cooling using nocturnally stored water. *Applied Thermal Engineering* 38 (2012) 117-123.
8. Samar Jaber, Salman Ajib: Evaporative cooling as an efficient system in Mediterranean region. *Applied Thermal Engineering* 31 (2011) 2590-2596.
9. Ebrahim Hajidavalloo: Application of evaporative cooling on the condenser of window-air-conditioner. *Applied Thermal Engineering* 27 (2007) 1937-1943.
10. Ala Hasan: Going below the wet-bulb temperature by indirect evaporative cooling: analysis using a modified ε-NTU method. *Applied Energy* 89 (2012) 237-245
11. F. Bruno, On-site experimental testing of a novel dew point evaporative cooler, *Energy and Buildings*. 43 (2011) 3475-3483.