Green Practices Of Air Conditioning For Major Capital Cities Of India Using Advanced Evaporative Cooling

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Abstract-- In the present era of energy crisis, effective and energy efficient air conditioning is a need of time. Advanced evaporative cooling is able to replace conventional air conditioning. This paper identifies the major cities of India and investigates scope and potential of evaporative cooling over entire period of year using feasibility index method. Initially paper describes basic and advanced methods of evaporative cooling with the mechanism of cooling and its representation on psychometric chart. It is found that evaporative cooling is promising alternative for Delhi, Jaipur, Ahmedabad and Bangalore for 9, 7, 7 and 8 months of the year respectively. The temperature achieved are in range of 12 °C to 27 °C for Delhi, 14 °C to 27 °C for Jaipur, 17 °C to 27 °C for Ahmedabad and 16 °C to 22 °C for Bangalore. The paper concludes that evaporative cooling has great potential of replacing conventional air conditioning and still providing better quality of air resulting environmental friendly energy efficient cooling practice there by reducing energy burden in these cities.

Key Words: Air Conditioning, Ahmedabad, Bangalore, Delhi, Dew point indirect cooler, Direct Evaporative Cooling, Feasibility Index, Jaipur.

I. INTRODUCTION

Global warming caused by the rapid growth in industrialization, increased rate of urbanization extensive transportation has lead to discomfort able environmental conditions for human beings in terms of air temperature, air humidity and air quality. This has lead to increased use of air conditioner in developing nations. India being a developing country has witnessed favorable growth in economy resulting deep penetration of Air conditioning in all sectors of society. Before two decades, air conditioning was limited to rich class community as a luxury. However, in today’s scenario, even middle class of the society are able to afford air conditioning resulting very high demand. Sales of air conditioners are growing at a rate of 20% per annum in India due to rise in temperature with climatic changes. The major capital cities of India like Delhi, Bangalore, Ahmedabad and Jaipur have huge population with dense multistoried building requiring continuous demand of energy supply as being economic centers. The energy demand of these major capital cities has increased enormously, the cooling load of these cities has step up due the luxurious lifestyle of people in homes, office’s, hotels, theaters, auditorium halls, seminar halls, hospitals, malls and industries all demanding compulsory air conditioning. This cooling load is currently taken by central air conditioning and window conditioners that are driven by mechanical refrigeration systems. The major contribution in energy consumption is dominated by air conditioning in industry, domestic as well as commercial places.

Presently window air conditioners are available in capacities from 0.75 TR to 5 TR, while 50 TR to 1000 TR central air conditioners are used. Conventional air conditioners are inefficient in terms of energy use. They have 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. Thus there is a need of replacing air conditioners in efficient ways.

Evaporative cooling is an attractive option. Evaporative cooling is the oldest technology of cooling air known to the mankind. It uses evaporation of water in dry and hot air resulting cooling and humidification of air. The amount of water absorbed depends upon dry bulb and wet bulb temperature of air. Higher DBT and Lower WBT are favorable condition for evaporative cooling to be effective. 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. [1]

Evaporative cooling has many benefits over conventional air conditioning like less energy consumption, absence of harmful refrigerants like R-12 and R-22, supply of total fresh air, avoiding proliferation of fungi and bacteria, lesser initial and operating cost, minimum maintenance, quick installation. Hence the evaporative cooling is more efficient in places of dry and hot climate.

This paper proposes a feasibility study of using evaporative cooling in four major capital cities of India over the entire months of year. 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 are chances of providing thermal comfort and probability of replacing air conditioner by advanced evaporative cooling. And, for this, feasibility index method proposed by J. R. Camargoa is presented. [2]
II. RECENT DEVELOPMENTS

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]

J. R. Camarogo presented three methods to use evaporative cooling in Brazilian climate he concluded that evaporative cooling is capable of providing thermal comfort in region where WBT is less than 24 °C. [2]

A. Mohammad experimentally investigated performance of direct evaporative cooler for Kuala Lumpur he founded the temperature achievement in a range of 27.5°C to 29.4°C with cooling capacity 1.3 kW to 5.3 kW. [3]

In India Kulkarni and Rajput evaluated performance of direct evaporative cooler which varies pad material. They found that aspen pad material have highest efficiency of 87.5 % while rigid cellulose have lower efficiency of 77.5 %. The outlet temperature dropped between 26.5°C to 28.8°C. [4]

Azhar found that 60% power saving as compared to mechanical refrigeration system is achieved using Indirect-Direct evaporative cooling the effectiveness of direct varied from 5.6 to 6.5 while for indirect it varied from 0.9 to 1.1 the final outlet temperature of air for indirect and direct combination achieved between 23°C to 25°C. [5]

R Boukhanouf presented a computer model for space cooling in hot and dry climate with DBT 45°C and RH 50%. He used indirect innovative cooler with dew point effectiveness 0.712 and from that comfort condition can be achieved using dew point evaporative cooler to replace conventional air conditioners. [6]

Morgado Baca evaluated performance of evaporative cooling for Spain and found that evaporative cooling efficiency depends upon geographic location and developed methodology to apply direct evaporative cooling more efficiently in continental climate while indirect evaporative cooling is more efficient for Mediterranean coast location where humidity range is 60% to 80%. [7]

B Costello and D Finn proposed methodology of thermal effectiveness to be used as a measure of degree to which evaporative cooling can be used. They found there is the considerable scope of energy efficient control in cooling tower, fan and secondary pumps. [8]

Dilip Jain developed and tested two stage evaporative cooler for storage of foods and vegetable he found that the temperature drop depends upon relative humidity and ambient conditions. The effectiveness of cooler was founded in the range of 1.2 and the utility stored tomatoes successfully and safely for 14 days. [9]

Krishan kant examined possibility of space conditioning for multistoried building in delhi for summer using direct evaporative cooling. He found that if the temperature and relative humidity both of humid air are on upper side, evaporative cooling fails to provide thermal comfort. [10]

III. 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. There is direct injection of water in air stream and air undergoes cooling because heat required for evaporation is supplied by air resulting temperature drop. It cannot be used in regions where humidity range is 60% and above. In order to overcome this limitation indirect evaporative coolers are also used. Where heat exchange takes place without direct contact. Advanced evaporative techniques use a combination of direct and indirect EC methods which can achieve temperatures up to wet bulb temperatures.

A. Direct Evaporative Cooling

With direct evaporative cooling, unconditioned air is blown through saturated water medium using blower to get conditioned air with appropriate temperature and humidity.

Direct evaporative cooling continuously adds moisture to the air stream until it reaches close to saturation. The wet bulb temperature remains the same while dry bulb temperature is reduced. Air get cools by evaporating water which results in increase of moisture content in the air. Residential systems commonly use direct evaporative cooling. Typically 1 to 2 inches thick aspen fibers are used as evaporative cooling pad in residential systems.

![Fig. 1 Direct evaporative cooling](image1)

![Fig. 2 Direct evaporative cooling on psychrometric chart](image2)
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:

\[
\varepsilon = \frac{t_{db,1} - t_{db,2}}{t_{db,1} - t_{wb,1}}
\]

Effectiveness is a result of two important factors, thickness of material and air velocity. 8 to 12 inches thick pads having an effectiveness of 80\% to 90\% are used in advance evaporative cooling systems. Generally for hot and dry climates direct evaporative cooling systems are suitable where the wet-bulb temperature is 20°C or lower.

B. Indirect Evaporative Cooling

Fig 3 shows, in indirect evaporative cooling, a secondary air stream is cooled by water. The cooled secondary air stream is passed through a heat exchanger, where it cools the primary air stream.

Fig. 3 Indirect evaporative cooling by two air streams.

Fig. 4 shows, in indirect evaporative cooling cold water is allowed to flow through the tubes of heat exchanger and hot air stream is directed over the tubes, due to heat exchange air gets cool without increasing humidity. The effectiveness lies in the range of 0.6 to 0.7 depending upon design of heat exchanger, air velocity and arrangement.

Fig. 4 Indirect evaporative cooling by single air stream.

In Indirect evaporative cooling both DBT and WBT are reduced without significantly increasing the humidity. This method is used when direct addition of moisture in air is not permitted. Fig. 3, fig. 4 and fig. 5 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 pre-cooling of air before air conditioner to achieve energy saving. In cases where humidity is more than 70\% indirect evaporative cooling method is used. As air is cooled close to Wet bulb Temperature the effectiveness is reduced.

C. Indirect-Direct Evaporative Cooling

In this method combination of indirect and direct method of EC is used to achieve greater temperature drop. As shown in fig. 6 and fig. 7 the ambient hot air is initially forced on a heat exchanger and is sensibly cooled this pre cooled air enters in direct evaporative cooler where it is mixed with water to achieve further drop in temperature.

Fig. 5 Indirect evaporative cooling on psychometric chart

Fig. 6 Indirect-direct evaporative cooling
IV. METHOD OF FEASIBILITY INDEX

Feasibility index is a measure of using evaporative cooling in given climate. Feasibility Index (FI) defined as

$$\text{FI} = \text{WBT} - \Delta T$$

Where $\Delta T = (\text{DBT} - \text{WBT})$ is the wet bulb depression.

TABLE I

FEASIBILITY INDEX OF CITIES

<table>
<thead>
<tr>
<th>Month</th>
<th>Delhi</th>
<th>Jaipur</th>
<th>Ahmedabad</th>
<th>Bangalore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>9.5</td>
<td>6.1</td>
<td>7.1</td>
<td>6.4</td>
</tr>
<tr>
<td>Feb</td>
<td>8.7</td>
<td>3.4</td>
<td>6.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Mar</td>
<td>7.7</td>
<td>5.3</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Apr</td>
<td>4</td>
<td>5.6</td>
<td>7.8</td>
<td>9.2</td>
</tr>
<tr>
<td>May</td>
<td>8.2</td>
<td>10.6</td>
<td>6.2</td>
<td>13.0</td>
</tr>
</tbody>
</table>
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%.

Fig. 9 Seasonal variations in relative humidity for various cities

Fig. 9 shows, seasonal variation in relative humidity for four cities. It is seen that summer season has relative humidity in the range of 20% to 40% thus direct evaporative cooling is ideal method of cooling. Delhi, Jaipur are still favorable in monsoon for direct evaporative cooling while Ahmedabad and Bangalore can use indirect evaporative cooling to get sensible cooling. In winter except Ahmedabad all three cities can use direct evaporative cooling.

Fig. 10 shows, Average DBT, Average WBT and Average DPT for various cities. Delhi, Jaipur and Bangalore have average WBT (20ºC) well below the comfort condition temperature (25ºC). Hence direct and indirect evaporative cooling can serve the purpose also for all cities average DBT is 32ºC. Hence 7ºC to 8ºC drop in temperature is easily possible while in summer higher DBT is favorable for evaporative cooling

The four major cities of India are compared to understand scope and significance of evaporative cooling technology.

### TABLE III

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Parameter</th>
<th>Delhi</th>
<th>Jaipur</th>
<th>Ahmedabad</th>
<th>Bangalore</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DBT maximum (°C)</td>
<td>39.8</td>
<td>41.3</td>
<td>42.6</td>
<td>32.6</td>
</tr>
<tr>
<td>2</td>
<td>DBT average (°C)</td>
<td>27.45</td>
<td>30.6</td>
<td>34.15</td>
<td>29.15</td>
</tr>
<tr>
<td>3</td>
<td>DBT minimum (°C)</td>
<td>15.1</td>
<td>21.5</td>
<td>25.7</td>
<td>25.7</td>
</tr>
<tr>
<td>4</td>
<td>RH range (%)</td>
<td>22-73</td>
<td>17-62</td>
<td>36-75</td>
<td>21-72</td>
</tr>
<tr>
<td>5</td>
<td>Rainfall (mm)</td>
<td>797.3</td>
<td>650</td>
<td>772</td>
<td>859</td>
</tr>
</tbody>
</table>
6 Solar flux (MJ/m² per day) | 24.43 | 26.11 | 25.18 | 23.64
7 Energy consumption (Million KWH) | 25,559 | 16,468 | 16,097 | 21,219
8 Wind Speed average (Km/h) | 15 | 14.4 | 11 | 10
9 Geographic Location | 228.36°N 77°13'48"E | 26,926°N 73°823°E | 23.03°N 72.58°E | 12°8'N 77°37'E
10 Population | 11,007,835 | 6,663,971 | 5,570,585 | 8,236,654
11 Area (km²) | 1,484 | 645 | 720 | 740
12 Elevation from mean sea level (m) | 125 | 431 | 55 | 900

Fig. 11 Possible temperatures achieved in Delhi

Fig. 12 Scope and Potential of evaporative cooling methods for Delhi

Fig. 13 Possible temperatures achieved in Jaipur

Fig. 14 Scope and Potential of evaporative cooling methods for Jaipur
V. CONCLUSIONS

This paper is intended to study feasibility using advance evaporative cooling method as an alternative to Air conditioner for four major capital cities of India, in view with scope of reduction in electricity demands and environmental issues.

For this purpose feasibility index method is used and it is found that for all cities feasibility index lies within favorable limit for 8 months. Thus with direct, indirect and indirect-direct combination comfort conditions in terms of temperature and humidity can be obtained for these cities. For Delhi temperatures obtain are in range of 12°C to 25°C for 9 months and for the months of July, August and September evaporative cooling cannot be used. For Jaipur temperatures obtain are in range of 14°C to 25°C for 10 months and for the months of July and August evaporative cooling cannot be used. For Ahmedabad temperatures obtain are in range of 18°C to 25°C for 7 months and for the months of May, June, July, August and September evaporative cooling cannot be used. For Bangalore evaporative cooling can provide comfort conditions in terms of temperature throughout the year the temperature range is 18°C to 23°C, but for monsoon 4 months direct evaporative cannot be used as Relative Humidity of air is above 60%.

The use of evaporative cooling is energy efficient and can reduce heavy burden of electricity caused by air conditioners. Fortunately these cities have an abundant supply of water which adds to the benefit.

ACKNOWLEDGEMENT

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NOMENCLATURE

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

REFERENCES


