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Cooling Capacity and Energy Saving Potential of Dew Point Evaporative Cooling System for Indian Buildings

T. Ravi Kiran*[‡], S.P.S. Rajput**

*Centre for Energy Studies, Gyan Ganga Institute of Technology & Management

**Department of Mechanical Engineering, Maulana Azad National Institute of Technology

travikiran108@gmail.com, spsrajput@gmail.com

[‡]Corresponding Author; T. Ravi Kiran, Centre for Energy Studies, Gyan Ganga Institute of Technology & Management, Bhopal- 462021, India, +91 942 446 6604,travikiran108@gmail.com

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Abstract-Energy consumption all over the world is increasing rapidly and there is a pressing need to develop ways to conserve energy for future generations. Researchers are forced to look for renewable sources of energy and ways to use available sources of energy in a more efficient way. Conventional refrigeration based vapour compression air conditioning systems consume a large portion of electrical energy produced mostly by fossil fuel. A novel dew point evaporative cooler (DPEC) can sensibly cool the incoming air close to its dew point temperature. In this paper feasibility of DPEC system is investigated for various Indian cities for office buildings during day time. Firstly the weather data of different cities of India is used to find the suitability of dew point technology for Indian buildings by estimating the cooling capacity of the cooling system for each city. Secondly energy saving potential of the dew point cooling system w. r. t. to the conventional compression based air conditioning system for different cities of India is estimated.

Keywords-dew point evaporative cooling system, cooling capacity.

1. Introduction

India’s energy demands are expected to be more than double by 2030, and there is a pressing need to develop ways to conserve energy for future generations. This implies that we have to look for renewable sources of energy and use available sources of energy in a more efficient way. Thus energy consumption can be reduced drastically by using energy efficient appliances [1-2].

In India, the Union ministry of power's research pointed out that about 20-25% of the total electricity utilized in government buildings in India is wasted due to unproductive design, resulting in an annual energy related financial loss of about Rs 1.5 billion [3]. Conventional heating ventilation and air conditioning systems (HVAC) consume approximately 50% of the building energy [4]. Conventional refrigeration based vapour compression air conditioning systems consume a large portion of electrical energy produced mostly by fossil fuel. This type of air conditioning is therefore neither eco-friendly nor sustainable. Selection of proper air conditioning system for buildings can not only help the country save electrical energy but also reduce green house emissions.

Evaporative cooling, being used by mankind for centuries is based on a very simple principle. When a hot and dry air is allowed to pass through a wet pad, the temperature of incoming air is reduced with an increase in specific humidity as some water from the pads is evaporated taking the latent heat of vaporization from the incoming air. Thus direct evaporative cooling adds moisture to room air which is unpleasant to the occupants. Also outlet temperature by this type of air conditioning is limited ideally to wet bulb temperature of the incoming air [5].

In an indirect evaporative cooler the primary air is sensibly cooled by the evaporative cooling of the secondary outside air with the help of an air-to-air heat exchanger. The advantage of using this type of air conditioning is that no moisture is added to the incoming air. But the cooling effect through this process is limited to less than 10^{o}C.

A number of authors have worked with two stage evaporative cooling system utilizing the advantages of both these methods and achieved temperature reduction to a few degrees below the wet bulb temperature of incoming air etc. But these methods are not at all sufficient to provide air conditioning in buildings especially during summer seasons in India where the ambient air temperature shoots above 45^{o}C in many parts of the country [6-7].

A novel dew point evaporative cooler developed by V. Maisotsenko [8] based on the principles of indirect cooling has broken the limit of cooling to beyond wet bulb temperature up to a few degrees above the dew point temperature of the incoming air.

Although a great deal of initial research work has been carried out on the dew point cooling technology, a gap still exists between the research results and practical application, which mainly lies in the study of the suitability of the novel dew point technology for India climate and building construction.

In this paper firstly the weather data of different cities of India is used to find the suitability of dew point technology for Indian buildings by estimating the cooling capacity of the cooling system for each city. Secondly energy saving potential of the dew point cooling system w. r. t. to the conventional compression based air conditioning system for different cities of India is estimated.

2. Dew Point Evaporative Cooling System

2.1. Working Principle

Water is sprayed into the wet channel having porous surface with one of its face laminated with coating or polyethylene sheet. As air flow through wet channel, the evaporation of water takes away heat from the air in the dry channel. The thermal resistance of the polyethylene sheet is negligible and therefore can be used effectively without heat losses.

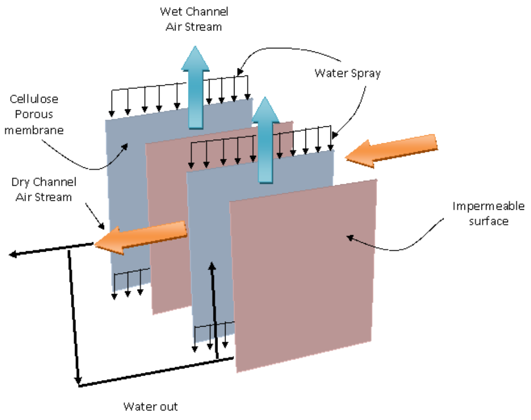

Fig. 1. Porous stack heat exchanger configuration of a novel DPEC

The heat exchange through the plates between wet and dry channels helps in removing heat from the intake air by evaporation of water in the wet channel. This cooling of hot and dry air is continuous from inlet of dry channel to exit and air at the end of dry channel reaches approximately to the dew point temperature limit of the inlet air conditions.

A portion of this air is diverted to conditioned space for air conditioning purposes. The remaining air is then redirected to the wet channel which takes away heat of dry channel and comes out as exhaust air as hot and humid air.

2.2. Psychometric Representation

Fig 2 shows a psychometric representation of the dew point evaporative cooling process. The outdoor air, 1 is pushed into the dry channels, where it exchanges heat from its neighbouring wet channels, and is cooled from state 1 to 3 ideally, without any inclusion of moisture to the air. When whole of the air at state 3 is passed through wet channels, the air becomes hot and saturated absorbing the heat from dry channel and exits at state 5.

A portion of the air at state 3 is delivered to the conditioned space of the building for cooling purposes. As the mass flow rate of air from wet channel decreases, its temperature goes up ideally up to state 6. Rest of the air flows into the neighbouring wet channel, where it absorbs moisture from the channel surface and thus becomes saturated because of heat transfer between the dry and wet channels; utilizing the latent heat of vaporization of water from the wet surface. The hot and saturated air, 6 is finally discharged to the atmosphere from the wet channel. A real condition of this process is represented by 1-2-4-7 instead of 1-3-6.

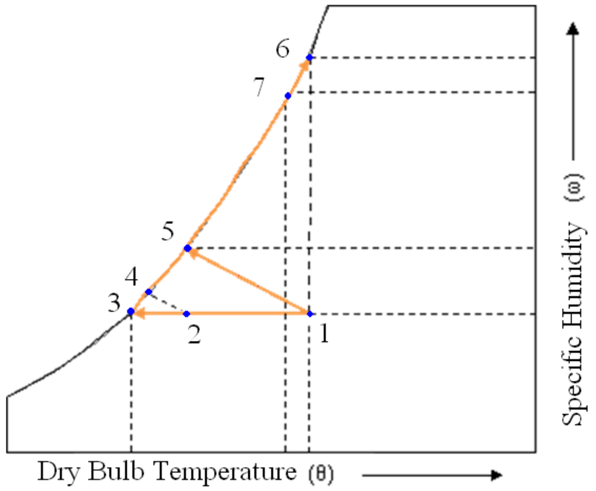

Fig. 2. Psychometric Representation of working of a DPEC

3. Mathematical Analysis of the Cooling Performance of DPEC System

The cooling capacity (Q) of a novel DPEC can be evaluated as follows [9]:

$$Q = 60\rho\upsilon(i_1 - i_2) \tag{1}$$

where, ρ is the density, υ is the volume flow rate and i is the enthalpy of air stream.

Neglecting fan, pump, heat losses and the heat balance can be given as

$$\upsilon_1(i_1 - i_2) = \upsilon_4(i_4 - i_2) \tag{2}$$

From the definition of dew point effectiveness (ε) we have

$$i_2 = i_1 - \varepsilon_{dp}(i_1 - i_{dp}) \tag{3}$$

$$\text{or, } \theta_2 = \theta_1 - \varepsilon_{dp}(\theta_1 - \theta_{dp}) \tag{4}$$

where, θ is the dry bulb temperature and subscript 'dp' represents dew point limit of air stream.

$$\text{Since } \omega_2 = \omega_1 \tag{5}$$

(ω = specific humidity of air stream, kg/kg of dry air)

$$\text{Therefore, } i_4 = i_2 + \frac{\upsilon_1}{\upsilon_4}(i_1 - i_2) \tag{6}$$

The system is designed with 100% recirculation or fresh outdoor air. Thus the cooling capacity of the system can be calculated using the following equation:

$$Q_c = c_p\rho\upsilon_2(\theta_1 - \theta_2) \tag{7}$$

Assuming a 200 m^2 office building space is operated between 9.00 a.m. to 5.00 p.m. with 100 W/m^2 cooling load amounts to 160 and 4800 kWh of required total energy daily and monthly respectively. Cooling capacity of the DPEC system were calculated using equations (1)-(7) with the assumption of supply air flow rate of 250m^3/hr.

4. Analysis of Weather Data of Various Indian Cities

Weather data of various locations of India were analyzed. Ten locations including Ahmedabad, Amritsar, Chennai, Hyderabad, Jaipur, Lucknow, Nagpur, New Delhi, Patna and Varanasi were selected which represent all parts of climatic conditions in Indian regions. Hourly based weather data in the summer season (April to June) of a typical year, including dry bulb, wet bulb and dew point of ambient air, were examined and studied during day time. Higher value of temperature difference between the dry-bulb and dew point temperatures results in higher cooling capacity of the dew point system. This temperature difference would generate a significant amount of cooling energy to conduct air conditioning of the conditioned space. For most regions of India, the air relative humidity is below 70%. This allows air to be treated by the dew point system directly without the need for prior dehumidification.

Table 1. Statistical Data of Dry Bulb And Difference Between Dry Bulb and Dew Point for Selected Indian Cities

Location	Dry Bulb (DB), °C			Difference between DB and DP (dew point), °C		
	Max	Min	Average	Max	Min	Average
Ahmedabad	46.5	18.0	33.9	35.4	1.0	14.6
Amritsar	46.0	12.0	29.2	32.8	0.8	14.9
Chennai	39.0	22.0	30.4	32.0	0.6	7.8
Hyderabad	40.0	21.5	31.1	35.5	0.1	12.5
Jaipur	45.8	18.2	32.2	44.0	0.0	17.6
Lucknow	44.0	20.0	31.6	33.0	0.0	12.0
Nagpur	45.0	21.0	33.3	36.0	0.0	15.0
New Delhi	43.0	16.0	33.4	39.0	0.0	21.7
Patna	46.0	17.7	29.7	41.0	0.0	8.9
Varanasi	46.0	19.0	32.3	22.8	0.0	8.8

The drier the ambient air is in a region, the better is the performance of the dew point cooling system. The ideal regions for this application are Ahmedabad, Amritsar, Jaipur, Nagpur, New Delhi, Patna and Varansi, where the climate remains dry and hot in the summer season. In some regions of India, such as Chennai dew point cooling is unsuitable for use, as the relative humidity of the outdoor air is more than 70%, which leaves very little room for utilizing the benefit of the dew point cooling, i.e., temperature difference between the dry bulb and dew point. However, implementing a pre-dehumidification device will allow the dew point system to be used in these humid areas. The pre-dehumidification could also be used in other areas in order to obtain the controlled inlet fresh air dew point, enhanced cooling output and controlled room temperature and humidity.

5. Cooling Capacity of the DPEC System

Cooling capacity of the dew point evaporative cooling system was calculated using (1)-(7). Assuming the dew point efficiency, ε_{dp} to be 0.8 for the an air supply/discharge flow rate of 250m^3/hour, the calculations yielded the system's total cooling capacity, as well as the ventilation load associated with the system operation, which is the energy used for bringing temperature of fresh air from outdoor down to indoor level. As a result, the net cooling output, known as the effective cooling capacity, is a figure of total cooling capacity subtracted by the ventilation load.

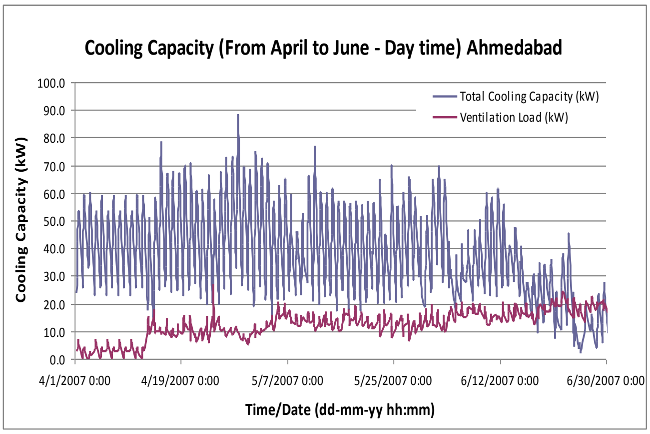

Fig. 3. Effective Cooling capacity of DPEC system for Ahmedabad

The effective cooling capacity is dependent on the weather condition, particularly dry bulb, wet bulb and dew point of the ambient air, and therefore varies from location to location. Fig 3 shows the effective cooling capacity of the DPEC system for Ahmedabad. Authors are unable to present the estimation of the other cities due to space limitations of the paper. It was found that in the summer duration of Ahmedabad, the effective cooling capacity is in the range 0-9.5 W per m^3/h air flow rate, and its average is 2.97. In 90% of summer time, the effective cooling capacity fell into the cooling band of 1-5 W per m^3/h air flow.

A summary of average cooling capacity of India cities over the summer duration is given in table 2. Comparison among the selected Indian cities indicates that the effective unit cooling capacity of the dew point system varies from city to city. Higher ambient temperature leads to a lower effective cooling capacity as a larger part of cooling energy generated from the system is used for removing the ventilation load.

Table 2. Cooling Capacity of the DPEC System in Selected Indian Cities.

City	Cooling Capacity (kW)
Ahmedabad	28.9
Amritsar	23.7
Chennai	15.1
Hyderabad	22.4
Jaipur	29.2
Lucknow	22.5
Nagpur	28.9
New Delhi	35.4
Patna	15.8
Varanasi	24.2

Higher ambient humidity also reduces the system's cooling capacity due to the smaller temperature difference between its dry bulb and dew point. In India, New Delhi has the highest effective cooling capacity, which is as high as 35.4 kW and therefore is the place most suitable for application of the dew point system.

Ahmedabad, Jaipur and Nagpur have cooling capacities of 28.9, 29.2 and 28.9 respectively, which are slightly less than in New Delhi. Chennai and Patna get the lowest cooling capacities, i.e., 15.1 and 15.8 which means that the system is less effective in these two cities.

6. Energy Saving Potential of the DPEC System

Power requirements of a conventional packaged air-conditioner of 250 m^3/hour and providing the same cooling as that of the DPEC were considered to estimate the power saving potential. The power rating (R_{cac}) of a VCRS according to [10] is given by (including power consumed by compressor, and condenser fans):

$$R_{cac} = 0.212+0.026*\theta_{dbt} + 0.42 \text{ kW/ ton} \qquad (9)$$

The power required to run a conventional VCRS of the same cooling capacity of DPEC can be expressed as

$$E_{cac} = \frac{Q_c \text{ x } R_{cac}}{3.52} \qquad (10)$$

Assuming a pressure drop of 200 Pa and fan and motor efficiencies of 70 and 80% respectively to deliver 250 m^3/hour of conditioned air with air filter the DPEC would approximately consume 0.50 kW of electrical energy per hour. The potential energy savings is the difference between the power required to run a VCRS and that for a DPEC of same capacity

$$E_s = E_{cac} - E_{dpec} \qquad (11)$$

where, E_s is the energy saving

E_{cac}=Electrical Energy required to run a conventional compression based air conditioning

system, kW

E_{dpec}= Electrical energy required to run a novel DPEC, kW.

The potential seasonal energy savings (PSES) of the dew point evaporative cooling system (DPEC) was analyzed using Engineering Equation Solver (EES) [11] for different locations in India assuming a conditioned space of 200 m^2 office building space is operated between 9.00 a.m. to 5.00 p.m. with 100 W/m^2 cooling load. PSES is obtained by integrating equation 6.11 over the entire summer season using the hourly weather data available in the form of a typical meteorological year.

$$PSES = \sum E_S \quad \text{kW/month} \qquad (12)$$

This analysis procedure is adopted. Saving in energy is based on continuous operation of the DPEC with a steady power of 0.5 kW. Fig. 4 shows the monthly energy savings for different locations in India during summer season.

The highest energy savings of the DPEC during April is with cities Nagpur followed by Ahmedabad which is 6037 and 5998 kWhr respectively. Whereas the lowest energy savings during this month is with Chennai followed by Amritsar which is 2459 and 2604 kWhr respectively. The drier and hotter te air is the greater is the cooling capacity of the DPEC and thus higher is the seasonal energy savings. Due to high relative humidity of the ambient air in Chennai as it is sitated in the coastal region of India, the DPEC performs poorly giving the lowest cooling capacity and seasonal energy saving as well.

During the May month the highest energy savings of the DPEC is with Nagpur followed by New Delhi, Ahmedabad and Jaipur which amounts to 6818, 6585, 5659 and 5420 kWhr respectively. Chennai gives the lowest energy savings during this month whch is 1915 kWhr.

New Delhi gets the highest energy saving during June followed by Amritsar which is 5897 and 5072 kWhr respectively. During this month Patna gives the lowest energy savings of 1319 kWhr.

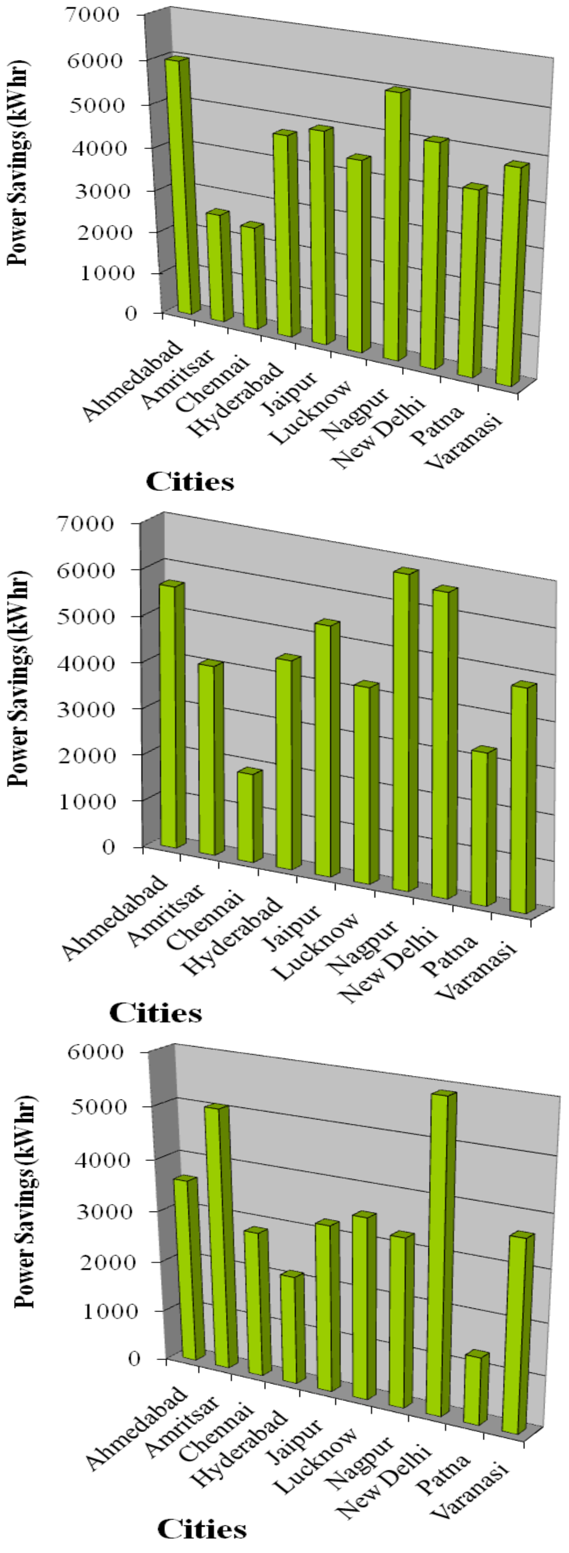

Fig. 4. Energy savings of the DPEC during April-June month of a TMY for different Indian cities.

7. Conclusion

The DPEC system used for air conditioning of office buildings offers the advantages of (i) reduced power consumption over conventional air conditioning system based on VCRS and (ii) environment friendly as it operates on water and doesn't use harmful CFC's which deplete ozone layer.

The feasibility of DPEC system is investigated through the following: (1) Weather data of different regions of India was used to estimate the cooling potential of DPEC system and the suitability of this technology for India buildings was identified (2) energy saving potential of the DPEC system w. r. t. the conventional compression based air conditioning system was estimated.

The dew point air conditioning system is suitable for most India regions, particularly Ahmedabad, Amritsar, Nagpur, New Delhi, Jaipur and Varanasi where the climate conditions are hot and dry. The system is unsuitable for some regions in India, such as Chennai, where the air is too humid to be dealt with. However, implementing a pre-dehumidification device will allow the dew point system to be used in these humid areas.

Lower relative humidity results in higher temperature differences between the dry bulb and dew point temperatures, and higher cooling capacity of the dew point system. If air is at a relative humidity of 70% or below, the dew point system could be used for cooling of buildings.

The cooling output of the DPEC varies with the region where the system applies, but is usually in the range 60 to 140 W per m^3/hour air flow. Higher ambient temperature leads to a lower effective cooling capacity as a larger part of cooling energy generated from the system is used for removing the ventilation load. Higher ambient humidity also reduces the system's cooling capacity due to the smaller temperature difference between its dry bulb and dew point. To retain a comfortable indoor air condition, the intake air should be kept at a humidity level of 70% and below. This is unachievable in Chennai in India, and a moisture removal practice should be taken into consideration for this particular application.

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