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Energy Saving Potential of a Novel Dew Point Evaporative Air Conditioning System for Indian Buildings

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Abstract

A novel dew point evaporative cooler (DPEC) can sensibly cool the incoming air close to its dew point temperature. This paper presents potential energy savings of a novel DPEC for various cities during the summer season (April-June) for Indian buildings with the help of meteorological data. Energy savings are calculated by comparing the power required to run a DPEC with that of a conventional compression based refrigerant air conditioning system to produce the same cooling effect. The analysis is done for an office space of 200m^2 with an average cooling load of 90 W/m^2 assuming that the system is operated during 8 working hours from 9.00a.m. to 5.00p.m. It was found that energy savings is higher for the cities where climate is relatively drier during the summer season.

Keywords: dew point evaporative cooler,

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]

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[2]. Conventional heating ventilation and air conditioning systems (HVAC) consume approximately 50% of the building energy [3]. Conventional refrigeration based vapor 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 [4].

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 10^0C.

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 [5-6] 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 45^0C in many parts of the country [7-8]

A novel dew point evaporative cooler developed by Valeriy Maisotsenko 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 [9-10].

This paper presents analytical evaluation of potential energy savings by using DPEC for office buildings when compared with that of a conventional compression based air conditioning system to produce the same cooling effect during the summer season for different cities of India.[11]

Working principle of Dew Point Evaporative Cooling System

2.1 Construction

The heat exchanger as shown in fig.1 consists f a series of cellulose porous membrane coated with impermeable polythene on one side of it. The laminated portion facing each other forms dry channel as it doesn’t allow moisture to enter from the other side. Similarly plate facing each other with porous membrane on which water is sprayed is called wet channel. The air flow arrangement is cross flow as it is easier to manufacture although counterflow is advantageous but is difficult to construct.

2.2 Working

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 air is continuous from inlet of dry channel to exit and air at the end of dry channel reaches its dew point temperature of the inlet conditions.

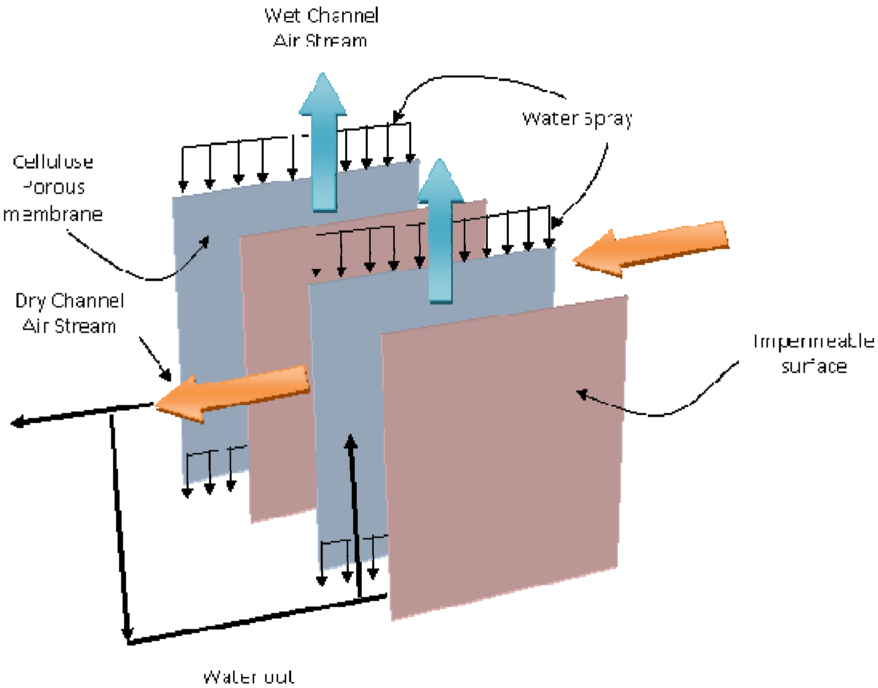

Fig 1: Cellulose porous stack heat exchanger configuration of a novel DPEC

Water is sprayed into the wet channel having cellulose porous surface. As air flow through wet channel, the evaporation of water takes away heat from the air in the dry channel. The thickness of the membrane is less than 0.5 mm. Thus the thermal resistance is negligible and can be used effectively without heat losses. Hot and dry air enters the dry channel and because of continuous cooling by wet channel, its temperature approaches a few degrees near to its dew point temperature of inlet air. 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. Various solid and liquid desiccants can be used to enhance its efficiency in achieving dew point temperatures or even lower temperatures.

2.3 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 neighboring 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. In this case the cooling capacity of the DPEC is zero as no air is extracted from state.

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 shoots up ideally up to state 6. Rest of the air flows into the neighboring 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. The real condition of this process is represented by 1-2-4-7 instead of 1-3-6.

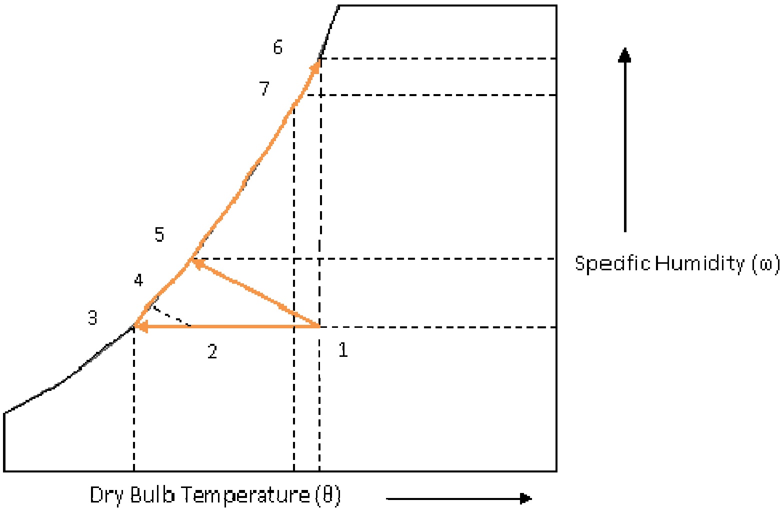

Fig. 2 Psychometric Representation of working of a DPEC

3. Mathematical Analysis of the Performance of DPEC System

The cooling capacity of a novel DPEC can be evaluated as follows:

$$Q = 60\rho\upsilon(i_1 - i_2) \quad \ldots\ldots\ldots(1)$$

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

$$\upsilon_1(i_1 - i_2) = \upsilon_3(i_3 - i_2) \quad \ldots\ldots\ldots\ldots(2)$$

From the definition of dew point effectiveness we have

$$i_2 = i_1 - \varepsilon_{dp}(i_1 - i_{dp}) \quad \ldots\ldots.(3)$$

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

$$\text{Since } \omega_2 = \omega_1, \quad \ldots\ldots.(5)$$

$$\text{Therefore, } i_3 = i_2 + \frac{\upsilon_1}{\upsilon_3}(i_1 - i_2) \ldots\ldots\ldots.(6)$$

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:

$$Q_c = c_p\rho\upsilon_2(\theta_1 - \theta_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Assuming a 200 m^2 office building space is operated between 9.00 a.m. to 5.00 p.m. with 90 W/m^2 cooling load amounts to 144 and 4320kWh of required total energy daily and monthly respectively.
The power rating of a compression based refrigerant air conditioning system (CRAC) according to [12] is given by:

$$R_{cac} = 0.212 + 0.026 * \theta_{dbt} + 0.42 \quad \text{kW/ton} \qquad \ldots\ldots\ldots(8)$$

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

$$E_{cac} = \frac{Q_c \text{ x } R_{cac}}{3.52} \qquad \ldots\ldots\ldots(9)$$

Now, the potential energy savings is the difference between the power required to run a CRAC and that for a DPEC.

$$E_s = E_{cac} - E_{dpec} \qquad \ldots\ldots\ldots(10)$$

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

Cooling capacity of the DPEC system were calculated using equations (1)-(7) with the assumption of supply air flow rate of 1 m^3/hr. The calculations gave the output cooling capacity and water consumption rate required on hourly basis. The effective cooling capacity is dependent on the outside weather conditions particularly dry bulb, wet bulb and dew point temperature of the ambient air and therefore it varies from location to location.

Results and Discussion

A novel DPEC system for summer season for Indian weather conditions was analyzed an expression for energy saving potential has been developed by comparing its performance with conventional air conditioning.

The cooling capacity of a novel DPEC for 4 cities is compared in fig 3 for a typical meteorological day (12^{th} June) for duration of 24 hours. It is observed that the cooling capacity is highest during 900-1300 hrs. This is because of larger difference between dry and wet bulb temperature during this time.

During night time as the wet bulb depression decreases so is the cooling capacity. And in some cities like Chennai it takes negative values because of high humidity content.

Energy savings potential of a novel DPEC for 4 major cities of India during summer season (April – June) is calculated using equations (1)-(8) and compared as shown in figure 4. The DPEC gives the highest energy savings if located at New Delhi and particularly in the month of May up to 5806kWh as its climate is hot and dry. Whereas in Chennai it gives the least energy savings up to 280kWh as is situated near sea. In Nagpur and Lucknow the performance is in between.

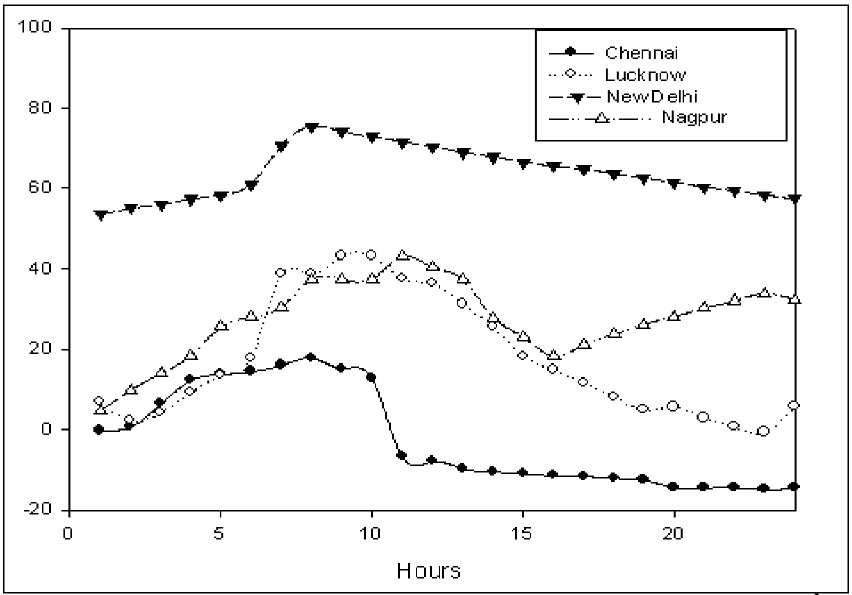

Fig 3: Cooling Capacity of a novel DPEC for various cities on 12th June

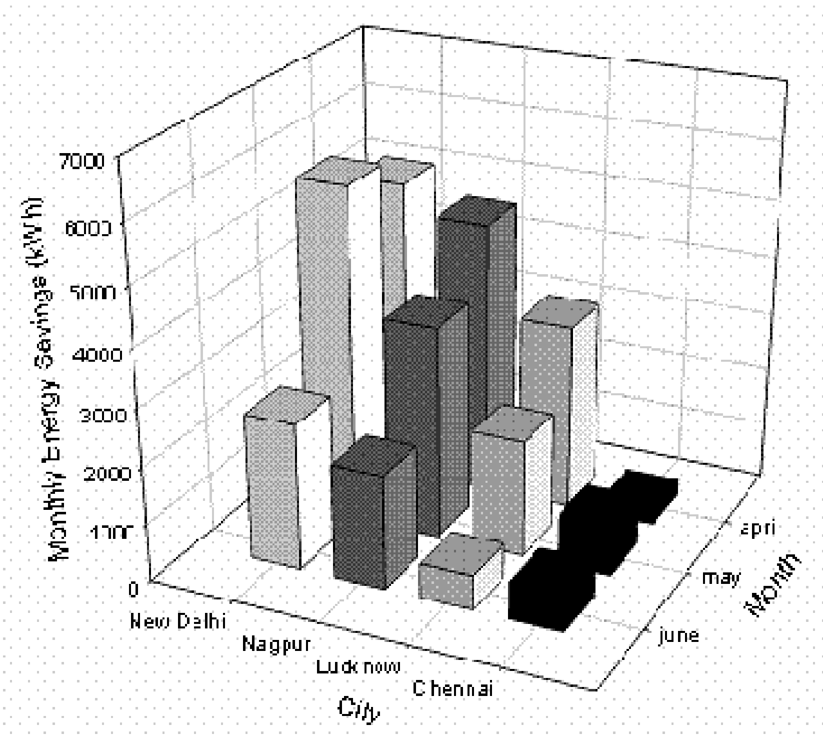

Fig. 4: Potential energy savings of a novel DPEC in various cities during summer season (April-June)

The novel dew point evaporative cooling system is compact and uses only water as refrigerant unlike harmful chlorofluorocarbons used in conventional air conditioning systems. This kind of cooling system is easy to manufacture and cost effective. The porous cellulose membrane has natural capillary action which breaks the surface tension of water resulting in high heat and mass transfer rate. Polythene coating on one side of the membrane prevents moisture entering into the air supplied to the conditioned space.

Conclusion

Potential energy savings of a novel dew point evaporative cooling system (DPEC) was analyzed using Engineering Equation Solver (EES) for different weather conditions of India. Three cities namely, New Delhi, Nagpur, Lucknow and Chennai were selected for the analysis. The water consumption rate and cooling capacity was examined for these cities for the summer season (April – June) for a typical meteorological year (TMY).

DPEC gives high cooling capacity when the relative humidity is the ambient air is low whereas it becomes less effective in reducing the temperature in humid climates. In such case it should be accompanied with dehumidification.

Tap water can easily be used without any trouble for DPEC. The cooling capacity varies from 5-26W/m^3/hr air flow. Taking a 200m^2 of building with 90W/m^2 cooling load during daytime working hours the DPEC consumes water in the range of 11.2-16 l/day. The system consumes more water in dry and hot climate regions like New Delhi and Nagpur than mild and humid regions like Chennai and Lucknow.

The DPEC is a good option against conventional air conditioning systems for air conditioning of buildings in India.

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