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Theoretical energy saving analysis of air conditioning system using heat pipe heat exchanger for Indian climatic zones

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ABSTRACT

Heat pipe heat exchanger (HPHX) is an excellent device used for heat recovery in air conditioning systems. The Energy Conservation Building Code (ECBC) – Bureau of Energy Efficiency (BEE) India classifies Indian climatic zones into five categories viz., Hot and Dry (e.g. Ahmedabad, Jodhpur etc), Warm and Humid (e.g. Mumbai, Chennai etc), Composite (e.g. Nagpur, Jaipur etc), Cold (e.g. Guwahati etc) and Temperate (e.g. Bengaluru etc). The literature review indicated that very limited information is available on annual energy saving analysis of air conditioning system with HPHX for Indian climatic zones. The paper investigates the possible energy savings using HPHX for heat recovery in air conditioning system for Indian climatic zones. The analysis is carried out for total 25 Indian cities representing different climatic zones. The analysis is performed for a 6 row HPHX and assuming outdoor air quantity as 1 m^3/s, return air dry bulb temperature as 23 °C and compressor power as 1 kW/TR. This paper discusses the use of HPHX only for the heat recovery application (exchange of sensible heat between fresh outdoor air and conditioned return air). The annual energy savings with HPHX for a particular city is calculated for number of hours when outdoor air dry bulb temperature exceeds 25 °C. The maximum energy saving potential is revealed for hot and dry, warm and humid and composite Indian climatic zones.

1. Introduction

In the last six decades, India's energy use has increased 16 times and the installed electricity capacity by 84 times. In 2008, India's energy use was the fifth highest in the world [1]. The air conditioning contributes towards significant energy usage of a building. The building sector represents about 33% of electricity consumption in India, with commercial sector and residential sector accounting for 8% and 25% respectively [2]. There exists tremendous potential for energy savings in air conditioning systems in developing country like India. In air conditioning facilities with high outside air requirements such as cleanroom air conditioning systems, considerable energy savings is possible by heat recovery using heat pipe heat exchanger (HPHX). Heat pipe heat exchanger (HPHX) is an excellent device used for heat recovery in air conditioning systems. Among the many outstanding advantages of using the heat pipe as a heat transmission device are constructional simplicity, exceptional flexibility, accessibility to control and ability to transport heat at high rate over considerable distance with extremely small temperature drop [3]. A literature review on the application of horizontal heat pipe heat exchangers for air conditioning in tropical climates was conducted by Y.H. Yau and M. Ahmadzadehtalatapeh [4]. The authors investigated the energy saving and dehumidification enhancement aspects of HPHXs and made a summary of experimental and theoretical studies on HPHXs. G.D. Mathur [5] simulated energy savings using HPHX on the existing air conditioning systems. The investigation was carried out for 33 United States cities with widely different

Abbreviations: DBT, dry bulb temperature; HPHX, heat pipe heat exchanger; OA, outdoor air; OA_{DBT}, dry bulb temperature of outdoor air; $Power_{compressor}$, compressor power consumption; RA, return (room) air; RA_{DBT}, dry bulb temperature of return (room) air; RH, relative humidity; $SSHR_{HPHX}$, savings in sensible heat recovery using HPHX; SCCC, savings in cooling coil capacity; AES, annual energy savings; T_{LA}, DBT of air leaving the HPHX and entering the cooling coil; T_{OA}, DBT of outdoor air entering the HPHX; TR, ton of refrigeration; T_{RA}, DBT of return (room) air; ε_{HPHX}, effectiveness of heat pipe heat exchanger.

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climatic conditions. T.S. Jadhav and M.M. Lele [6] investigated the possible energy savings using HPHX in air conditioning system for a process air conditioning facility in Pune city, India. The impact of number of rows of HPHX and variations in the operating air conditions on the savings in cooling coil capacity were studied. The comparative analysis of annual energy savings with number of rows of HPHX for Pune weather conditions was also investigated. The authors J.W. Wan et al. [7] investigated the effect of heat pipe air handling coil on energy consumption in a central air conditioning system. The study indicated that a central air conditioning system can significantly reduce its energy consumption and improve both the indoor thermal comfort and air quality when HPHX is employed in the air conditioning process. Y.H. Yau studied the experimental performance of HVAC system for tropical climates equipped with 8 row thermosyphon HPHX [8]. The author studied the influence of inlet air parameters such as dry bulb temperature, relative humidity and air velocity on sensible heat ratio of HPHX. Y.H. Yau and M. Ahmadzadehtalatapeh investigated the effect of HPHX on energy savings in air conditioning applications [9–11] and strongly recommended the use of HPHX for air conditioning applications. M. A. Abd. El – Baky and M.M. Mohamed [12] investigated the use of HPHXs for heat recovery in air conditioning applications. The authors studied the performance of HPHX for different ratios of mass flow rate between return and fresh air and for different temperature of fresh air. Di Liu et al. [13] designed and tested a looped separate heat pipe as a waste heat recovery facility for the air-conditioning exhaust system and performed a parametric analysis to investigate the effects of the length of the evaporator, vapor temperature and power throughput on the critical values of the upper and lower boundaries. The literature review indicated that very limited information is available on annual energy saving analysis of air conditioning system with HPHX for Indian climatic zones. The paper investigates the possible energy savings using HPHX for heat recovery in air conditioning system for Indian climatic zones. Total 25 Indian cities representing different climatic zones are considered for the analysis.

2. Indian climatic zones as per ECBC guidelines

The Energy Conservation Building Code (ECBC) – Bureau of Energy Efficiency (BEE) India [2]classifies Indian climatic zones into five categories viz., Hot and Dry (e.g. Ahmedabad, Jodhpur etc), Warm and Humid (e.g. Mumbai, Chennai etc), Composite (e.g. Nagpur, Jaipur etc), Cold (e.g. Guwahati etc) and Temperate (e.g. Bengaluru etc). The details of each climatic zone are summarized in Table 1.

3. Research methodology

The methodology used for investigations on energy savings in air conditioning system using HPHX for Indian climatic zones is as shown in Fig. 1.

In air conditioning system, HPHX can be used for i) exchange of heat between fresh outdoor air and conditioned return air (heat recovery application) and ii) enhancing the dehumidification capability of cooling coil as well as reheat savings (dehumidification enhancement with reheat application) [6]. However, the second application of dehumidification with reheat is beneficial in situation wherein reheating is necessary for maintaining required indoor air conditions. This paper discusses the use of HPHX only for the heat recovery application (exchange of sensible heat between fresh outdoor air and conditioned return air), as it can be used for all the air conditioning applications. The sensible heat recovery in air conditioning system using HPHX is as shown in Fig. 2.

In the present analysis, since the HPHX involves recovery of only sensible heat therefore the effectiveness of HPHX can also be defined as ratio of actual temperature drop to maximum possible temperature drop [5,6]. The ε_{HPHX} can be evaluated by using Equation (1)

$$\varepsilon_{HPHX} = \frac{T_{OA} - T_{LA}}{T_{OA} - T_{RA}} \quad (1)$$

Rearranging the above terms,

Table 1
Indian climatic zones [2].

Sr. No.	Climatic zone	Description	Dry bulb temperature				Relative humidity
			Summer mid day (high) °C	Summer night (low) °C	Winter mid day (high) °C	Winter night (low) °C	%
1	Hot and dry	High temperature. low humidity and rainfall. Intense solar radiation and generally a clear sky.	40 to 45	20 to 30	5 to 25	0 to 10	Very low, 25 to 40
2	Warm and humid	Temperature is moderately high during day and night. Very high humidity and rainfall. Diffused solar radiation if the cloud cover is high and intense if the sky is clear.	30 to 35	25 to 30	25 to 30	20 to 25	High, 70 to 90
3	Composite	This applies when 6 months or more do not fall within any of the other climatic zones. High temperatures in summer and cold in winter. Low humidity in summer and high in monsoons. High direct solar radiation in all seasons except monsoons high diffused radiations.	32 to 43	27 to 32	10 to 25	4 to 10	Variable dry periods, 20 to 50. Variable wet periods, 50 to 95
4	Cold (sunny/cloudy)	Moderate summer temperatures and very low in winter. Low humidity in cold and sunny climate and high humidity in cold and cloudy. High solar radiation in cold and sunny climate and low solar radiation in cold and cloudy climate.	17 to 24/20 to 30	4 to 11/17 to 21	−7 to 8/ 4 to 8	−14 to 0/−3 to 4	10 to 50/70 to 80
5	Temperate	Moderate temperature, moderate humidity and rainfall. Solar radiation same throughout the year and sky is generally clear.	30 to 34	17 to 24	27 to 33	16 to 18	High, 60 to 85

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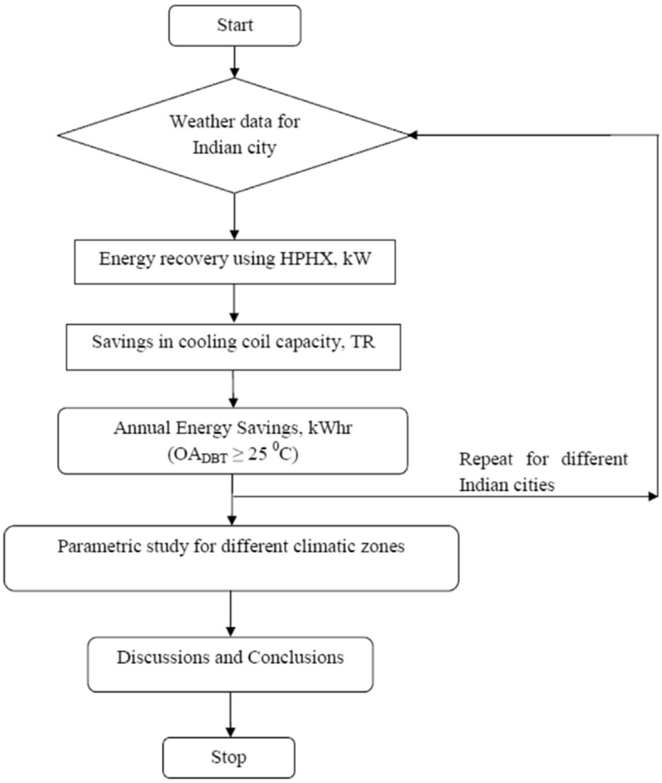

Fig. 1. Flow chart for energy saving analysis.

$$T_{LA} = \{T_{OA} - \varepsilon_{HPHX}(T_{OA} - T_{RA})\} \tag{2}$$

The value of effectiveness for a 6 row HPHX is referred using product catalogue of S & P Coil Products Limited [14].

Savings in sensible heat recovery using HPHX ($SSHR_{HPHX}$) [6,15] is evaluated by using Equation (3)

$$SSHR_{HPHX},\ kW = 0.02044 \times OA_{m^3/s} \times 60 \times (T_{OA} - T_{LA}) \tag{3}$$

Savings in cooling coil capacity (SCCC) is calculated by using Equation (4)

$$SCCC_{TR} = \frac{SSHR_{HPHX},\ kW}{3.517} \tag{4}$$

The annual energy savings (AES) in cooling coil capacity is estimated by using Equation (5)

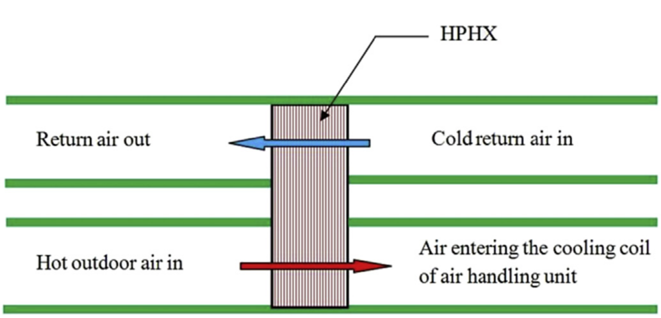

Fig. 2. Sensible heat recovery in air conditioning system using HPHX.

$$AES\ in\ cooling\ coil\ capacity_{kWhr} = \Sigma\left[SCCC_{TR} \times Power_{compresor}\ in\ \frac{kW}{TR} \times Operating\ hours\ (hr)\right] \tag{5}$$

The annual energy savings analysis is performed for a particular city with $OA_{DBT} \geq 25\ ^\circ C$.

Table 2 indicates the input parameters used for energy saving analysis of different Indian cities. The values of input parameters are assumed based on the data available from open literature.

Table 3 summarizes the 25 Indian cities (representing different climatic zones) used for the analysis.

The available weather data is limited for Temperature and Cold climatic zones [16], hence only one city representing these zones is considered for the analysis.

The sample calculation for Ahmedabad city is as shown below.

For $T_{OA} = 40\ ^\circ C$, $T_{RA} = 23\ ^\circ C$ and $\varepsilon_{HPHX} = 0.75$,
$T_{LA} = 27.25\ ^\circ C$.

$$SSHR_{HPHX},\ kW = 0.02044 \times 1 \times 60 \times (40 - 27.25) = 15.64\ kW$$

$$SCCC_{TR} = \frac{15.64}{3.517} = 4.44\ TR$$

The annual energy savings when $OA_{DBT} \geq 25\ ^\circ C$ will be

$$AES\ in\ cooling\ coil\ capacity_{kWhr} = \Sigma\left[SCCC_{TR} \times Power_{compresor}\ in\ \frac{kW}{TR} \times Operating\ hours\ (hr)\right] = 12604 \times 1 \times 1 = 12604\ \text{kWhr}$$

The AES in cooling coil capacity, kWhr is calculated considering $\Sigma[SCCC_{TR}]$, therefore the operating hours becomes 1 in the above formula.

Table 2
Input parameters.

Input parameter	Value
OA quantity	1 m^3/s
RA_{DBT}	23 °C
$Power_{compressor}$	1 kW/TR
Plant operation	24 h

Table 3
Summary of Indian cities for energy saving analysis [2].

Sr. No.	Cities representing Indian climatic zones				
	Hot and dry	Warm and humid	Composite	Cold	Temperate
1	Ahmedabad	Chennai	Gwalior	Guwahati	Bengaluru
2	Jaisalmer	Vishakhapatnam	Nagpur		
3	Jodhpur	Trivandrum	Jaipur		
4	Solapur	Mumbai	Allahabad		
5	Aurangabad	Bhubaneshwar	Delhi		
6		Kolkata	Hyderabad		
7		Panjim	Lucknow		
8		Pune	Bhopal		
9			Amritsar		
10			Indore		

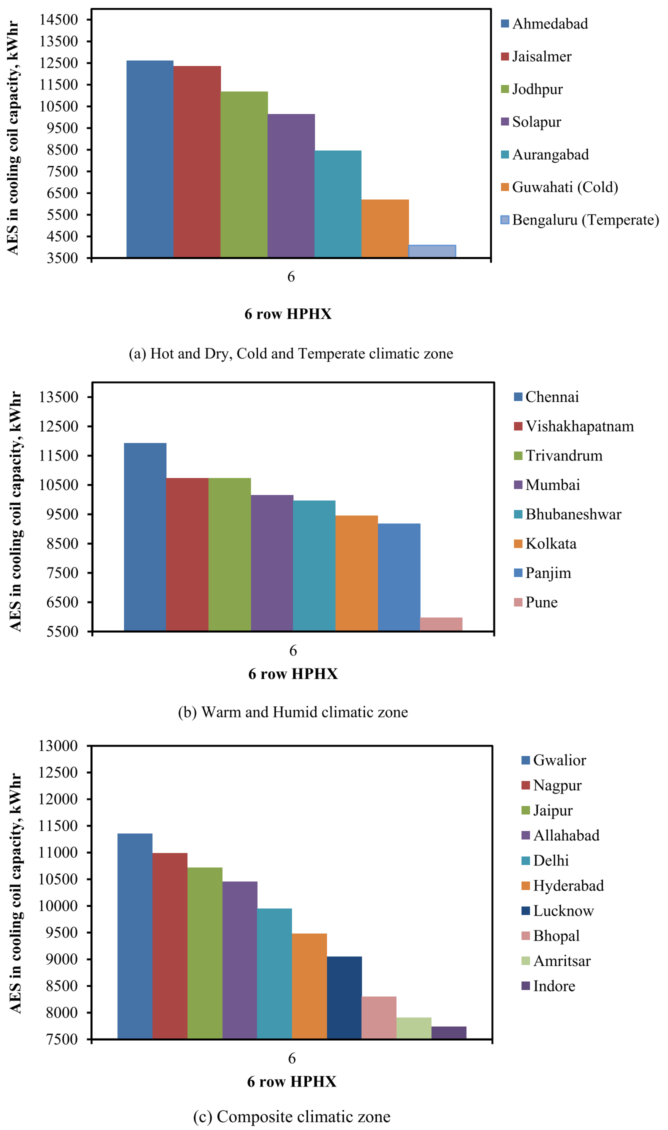

Fig. 3. Comparative analysis of energy savings for different Indian climatic zones with a 6 row HPHX.

4. Results and discussions

Fig. 3 reveals the comparative analysis of energy savings for different Indian climatic zones with a 6 row HPHX.

The maximum energy savings are observed for Ahmedabad city which represents hot and dry climatic zone and minimum energy savings are observed for Bengaluru city representing temperate climatic zone. Chennai represents maximum savings amongst warm and humid climatic zone and Gwalior amongst composite climatic zone. OA_{DBT} and its occurrence are the influencing parameters for the trend in energy savings as observed in Fig. 3.

Table 4 summarizes the annual percentage number of hours when $OA_{DBT} \geq 25$ °C for a particular city.

Table 4 indicates that the annual percentage number of hours when $OA_{DBT} \geq 25$ °C is highest for cities like Mumbai, Vishakhapatnam and Panjim representing warm and humid climatic zone. However in terms of energy saving, Fig. 3 shows that these are not the leading cities. This leads to an interesting fact that only the total number of hours when $OA_{DBT} \geq 25$ °C is not sufficient to understand the energy savings scenario. Therefore the further investigations are carried out by considering the number of hours for different range of OA_{DBT} as.

1. $OA_{DBT\ R1}$– OA DBT 35 °C and above.
2. $OA_{DBT\ R2}$ – OA DBT 34.9 °C to 30 °C
3. $OA_{DBT\ R3}$ – OA DBT 29.9 °C to 25 °C

The occurrence of OA_{DBT} for various Indian climatic zones is summarized in Table 5.

It is evident that higher OA_{DBT} will result in more effectiveness value of HPHX and that leads to more energy savings. However, Table 5 helps us to understand the most important fact that for majority of the cities studied, the occurrence of OA_{DBT} exceeding 35 °C ($OA_{DBT\ R1}$) is not more than 10% of the annual period. This point must be taken into consideration during design and selection of HPHX for a particular city. Fig. 4 shows the comparison of energy savings with 6 row HPHX, amongst the typical cities predominating each climatic zone.

The energy savings for Ahmedabad city are more for in $OA_{DBT\ R2}$ (OA_{DBT} between 34.9 °C to 30 °C) and have decreased for $OA_{DBT\ R3}$ (OA_{DBT} between 29.9 °C to 25 °C). Chennai has more savings than Ahmedabad for $OA_{DBT\ R2}$ and $OA_{DBT\ R3}$. The energy savings for different OA_{DBT} range shows decreasing trend for Gwalior and increasing trend for Guwahati and Bengaluru. The variation in the energy savings for OA_{DBT} range for a particular city is dependent upon the magnitude of OA_{DBT} and its occurrence. Therefore it reveals that for energy saving analysis for a particular air conditioning facility, the most influencing parameters are the total plant operating hours as well as the schedule of daily operating hours. This consideration is thus significant for HPHX selection for a particular application.

5. Conclusions

The maximum energy saving potential is revealed for hot and dry, warm and humid and composite Indian climatic zones. The

Table 4
Summary of annual number of hours when $OA_{DBT} \geq 25$ °C for a particular city.

Sr. No.	Cities representing Indian climatic zones (Annual no. of hours when $OA_{DBT} \geq 25$ °C, %)				
	Hot and Dry	Warm and Humid	Composite	Cold	Temperate
1	Ahmedabad (70.84)	Chennai (81.08)	Gwalior (58.97)	Guwahati (52.87)	Bengaluru (34.52)
2	Jaisalmer (62.56)	Vishakhapatnam (78.12)	Nagpur (62.02)		
3	Jodhpur (62.10)	Trivandrum (65.97)	Jaipur (58.79)		
4	Solapur (63.58)	Mumbai (78.73)	Allahabad (59.64)		
5	Aurangabad (53.56)	Bhubaneshwar (72.12)	Delhi (55.43)		
6		Kolkata (68.85)	Hyderabad (63.10)		
7		Panjim (77.04)	Lucknow (56.24)		
8		Pune (41.89)	Bhopal (52.68)		
9			Amritsar (45.26)		
10			Indore (48.99)		

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Table 5
Occurrence of OA_{DBT} for various Indian climatic zones. (a) Hot and Dry climatic zones. (b) Warm and Humid climatic zones. (c) Composite climatic zones. (d) Cold climatic zone. (e) Temperate climatic zone.

(a)

Sr. No.	City	Annual % hours OA_{DBT} is			
		25 °C and above	$OA_{DBT\ R1}$	$OA_{DBT\ R2}$	$OA_{DBT\ R3}$
1.	Ahmedabad	70.84	11.45	24.06	35.33
2.	Jaisalmer	62.56	15.56	20.18	26.83
3.	Jodhpur	62.10	10.27	22.90	28.93
4.	Solapur	63.58	7.87	18.96	36.76
5.	Aurangabad	53.56	6.86	14.93	31.77

(b)

Sr. No.	City	Annual % hours OA_{DBT} is			
		25 °C and above	$OA_{DBT\ R1}$	$OA_{DBT\ R2}$	$OA_{DBT\ R3}$
1.	Chennai	81.08	4.45	25.82	50.81
2.	Vishakhapatnam	78.12	1.86	23.80	52.47
3.	Trivandrum	65.97	9.00	19.39	37.58
4.	Mumbai	78.73	0.45	21.48	56.80
5.	Bhubaneshwar	72.12	4.65	17.76	49.71
6.	Kolkata	68.85	2.16	19.52	47.18
7.	Panjim	77.04	0.01	17.63	59.41
8.	Pune	41.89	4.29	9.19	28.41

(c)

Sr. No.	City	Annual % hours OA_{DBT} is			
		25 °C and above	$OA_{DBT\ R1}$	$OA_{DBT\ R2}$	$OA_{DBT\ R3}$
1.	Gwalior	58.97	12.56	20.45	25.97
2.	Nagpur	62.02	10.45	19.94	31.63
3.	Jaipur	58.79	11.00	20.63	27.16
4.	Allahabad	59.64	9.08	20.38	30.19
5.	Delhi	55.43	8.32	21.07	26.04
6.	Hyderabad	63.1	7.00	15.79	40.32
7.	Lucknow	56.24	6.26	17.88	32.11
8.	Bhopal	52.68	7.01	13.52	32.16
9.	Amritsar	45.26	7.51	14.19	23.56
10.	Indore	48.99	6.32	24.08	25.69

(d)

Sr. No.	City	Annual % hours OA_{DBT} is			
		25 °C and above	$OA_{DBT\ R1}$	$OA_{DBT\ R2}$	$OA_{DBT\ R3}$
1.	Guwahati	52.87	0.26	11.42	41.20

(e)

Sr. No.	City	Annual % hours OA_{DBT} is			
		25 °C and above	$OA_{DBT\ R1}$	$OA_{DBT\ R2}$	$OA_{DBT\ R3}$
1.	Bengaluru	34.52	0.25	8.22	26.05

energy savings will vary with the variation in the input parameters such as outdoor air quantity, outdoor air temperature, return air temperature, compressor power consumption and plant operating hours. However, the energy savings will still be significant where the air conditioning plant is operating for more than 12 h. The biggest advantage of HPHX is that it does not require any external power for its operation. Hence for further analysis, additional thrust must be given on experimental investigations with parameters

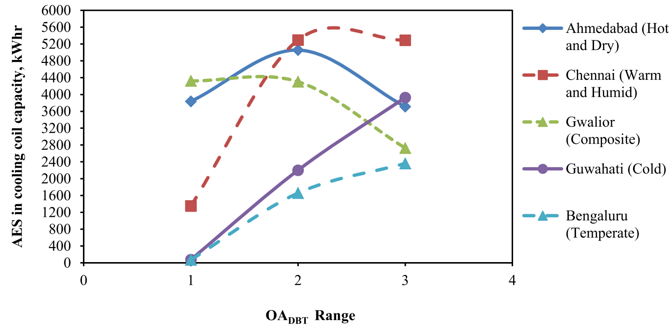

Fig. 4. Comparative analysis of energy savings with a 6 row HPHX amongst typical Indian cities.

such as plant operating conditions, HPHX working fluid, pressure drop calculations, additional fan power consumption and payback period.

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