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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 $1 \text{ m}^3/\text{s}$, 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.

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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)

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

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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