Energy 109 (2016) 876–885

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Analysis of annual energy savings in air conditioning using different heat pipe heat exchanger configurations integrated with and without evaporative cooling

T.S. Jadhav [a, *], M.M. Lele [b]

[a] Research Centre, Sinhgad COE, Pune and SOPRIM, National Institute of Construction, Management and Research, Pune, 411045, Maharashtra, India
[b] Department of Mechanical Engineering, MAEER's MIT College of Engineering, Pune, 411038, Maharashtra, India

ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form
28 March 2016
Accepted 4 May 2016

Keywords:
Heat pipe heat exchanger
Water
Air conditioning
Evaporative cooling
Energy savings

ABSTRACT

The three HPHX (heat pipe heat exchanger) configurations in the present investigation include HPHX with single wick structure (HPHX 1), HPHX with composite wick structure (HPHX 2) and hybrid HPHX (HPHX 3) which is the combination of HPHX 1 and HPHX 2. The experimental correlations obtained are used for investigating annual energy savings in air conditioning using HPHX integrated with and without evaporative cooling, for Indian climatic zones. A representative city for each Indian climatic zone is selected for the analysis involving sensible heat recovery between outdoor air and conditioned return air. The investigation reveals that for HPHX without evaporative cooling, HPHX 1 becomes favourable choice for cities such as Bengaluru (representing temperate Indian climatic zone), Chennai (warm and humid Indian climatic zone) and Guwahati (cold Indian climatic zone). For cities such as Ahmedabad (hot and dry Indian climatic zone), Gwalior (composite Indian climatic zone) and Chennai, the use of HPHX integrated with evaporative cooling is found more promising for HPHX 3 followed by HPHX 2, whereas for cities such as Bengaluru and Guwahati, HPHX 1 becomes the popular choice. The present research gives an insight towards the performance and selection of HPHX with different configurations, for Indian climatic zone.

1. Introduction

With increasing demand in air conditioning, the use of heat recovery devices such as HPHX (heat pipe heat exchanger) becomes significant for achieving better energy savings. 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 [1]. A literature review is conducted to investigate the work done by the past researchers in energy saving analysis using heat pipe for air conditioning applications. In the earlier investigations the authors [2] have studied the theoretical energy saving analysis of air conditioning system using HPHX for Indian climatic zones. The analysis was carried out for total 25 Indian cities representing different Indian climatic zones. The maximum energy saving potential was revealed for hot and dry, warm and humid and composite Indian climatic zones. In the present study, the experimental correlation for each HPHX configuration is used to estimate the actual energy saving analysis in air conditioning system using HPHX integrated with and without evaporative cooling. A representative city for each Indian climatic zone is considered for the analysis involving only sensible heat recovery between outdoor air and conditioned return air. G.D. Mathur [3] investigated the impact of HPHX on the energy consumption and the peak demand of an existing air conditioning system. A detailed performance investigation was carried out by using the climate conditions for St. Louis, Missouri for year round operation of the HVAC system with HPHX. J.W. Wan et al. [4] investigated the effect of heat pipe 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 and M. Ahmadzadehtalatapeh [5] studied the effect of an air-to-air heat pipe heat exchanger on the energy recovery and

* Corresponding author. Tel.: +91 20 66859307; fax: +91 20 27390057.
E-mail addresses: tushar01031978@gmail.com (T.S. Jadhav), anuman7@gmail.com (M.M. Lele).

http://dx.doi.org/10.1016/j.energy.2016.05.017
0360-5442/

Nomenclature

C_{pa}	Specific heat for air, J/kg·K
R_a	Gas constant for air, J/kg·K
η_{elect}	Electrical efficiency, %
η_{mech}	Mechanical efficiency, %
AHU	Air handling unit
DBT	Dry bulb temperature, °C
ESCC	Energy savings across cooling coil, kW
HPHX	Heat pipe heat exchanger
HPHX 1	HPHX with single wick structure
HPHX 2	HPHX with composite wick structure
HPHX 3	Hybrid HPHX (combination of HPHX 1 and 2)
INR	Indian rupee
OA	Outdoor air
OA_{DBT}	Dry bulb temperature of outdoor air entering the evaporator section of HPHX, °C
p_a	Atmospheric pressure, Pa
PID	Proportional-integral-derivative
$Power_{compressor}$	Compressor power consumption, kW/TR
RA	Return or room air
RA_{DBT}	Dry bulb temperature of return or room air entering the condenser section of HPHX, °C
RTD	Resistance temperature detectors
SCCC	Savings in cooling coil capacity, TR
$SSHR_{HPHX}$	Savings in sensible heat recovery using HPHX, kW
T_{OA}	Dry bulb temperature of outdoor air, °C
TR	Ton of refrigeration
V	Velocity, m/s
WBT	Wet bulb temperature, °C
ω	Humidity ratio, kg of moisture per kg of dry air
ΔTe	Temperature drop across the evaporator section of HPHX, °C
ΔTc	Temperature rise across the condenser section of HPHX, °C

Subscripts

c	Condenser
e	Evaporator

dehumidification enhancement of the air conditioning system in tropical climates. The investigation revealed that the heat pipe heat exchanger can pay for itself in period of two years. The authors also observed that the dehumidification capability of the cooling coil can enhance up to 6% with the added heat pipe heat exchanger. In another investigation the authors [6] simulated the performance of HPHX to improve the air quality and reduce the energy consumption of the air conditioning system in a hospital ward located in Malaysia. The performance characteristics of a typical eight-row HPHX [7] was used to develop the relevant empirical performance equations and subsequent energy conservation potential of HPHX for the years of 2000, 2020 and 2050. Firouzfar et al. [8] made comparative experimental investigations between methanol – silver nanofluid and pure methanol as HPHX working fluid, to study HPHX effectiveness and its energy saving potential in air conditioning. It was observed that methanol–silver nanofluid leads to energy saving around 8.8–31.5% for cooling and 18–100% for reheating the supply air stream in an air conditioning system. Lian Zhang and W.L. Lee [9] evaluated the use of heat pipe for dedicated ventilation of office buildings in Hong Kong. The feasible use of heat pipe at the air handler dedicated for outdoor air treatment for improved indoor air quality and reduced energy consumption was investigated. Heat exchanger comprising of nine thermosyphons in a modified inline configuration filled with water was experimentally investigated by Jouhara and Merchant [10]. Different sets of experimental tests were carried out by varying the heat load as well as the inclination angle of the heat exchanger. The authors also developed empirical mathematical correlations to predict the effectiveness of the thermosyphon based heat exchanger.

Surprisingly though water is a natural and ecofriendly fluid and has a good figure of merit due to its high latent heat and surface tension [11], yet information on use of water as working fluid in HPHX (heat pipe heat exchanger) for air conditioning application is limited. The present research focuses on the experimental investigation on HPHX with distilled water as the working fluid for air conditioning application. In addition, the comparative investigations on annual energy savings in air conditioning using different configurations of HPHX with and without evaporative cooling are reported in the present study.

2. Methodology

The methodology for the present study involves experimental investigations on HPHX and subsequent predictions in annual energy savings for air conditioning application.

The investigation on use of HPHX for air conditioning application is studied for three different configurations as mentioned in Table 1. The investigations are performed only for sensible heat recovery between outdoor air and return air.

2.1. Experimental set up

The experimental performance of HPHX (HPHX 1, 2 and 3) is determined by testing the HPHX in an environment test chamber as shown in Figs. 1 and 2.

The specifications of environment test chamber are summarized in Table 2.

The evaporator section of HPHX is located in outdoor room (room 1) and the condenser section of HPHX is located in indoor room (room 2) of the environment test chamber, as shown in Fig. 1. Fig. 2 shows the arrangements of HPHX and the measuring instruments in outdoor and indoor room of environment test chamber. The air sampler is provided at the inlet of evaporator (outdoor room) and condenser (indoor room) section of HPHX to measure the DBT and WBT of entering air. The measurement of air sampler readings is in accordance with ANSI/ASHRAE Standard 41.1–1986 (RA 2001). The HPHX seen in Fig. 1 performs the role as a precooler i.e. sensible cooling of the air flowing over the evaporator section of HPHX. Nevertheless, the WBT measurement is just an additional reading and is not required in the analysis. The temperatures of air leaving the evaporator and condenser section of HPHX are measured with calibrated RTD type PT – 100 (range: 0–100 °C and accuracy: ±0.1 °C). The outdoor air flow is measured with code tester tunnel as well as thermal anemometer (range: 0–30 m/s and accuracy: ±5%). The measurement of air flow with code tester tunnel is as per ANSI/ASHRAE Standard 41.2–1987 (RA