Application of heat pipes in HVAC systems: A review

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ABSTRACT

The recent investigations show that the application of heat pipes in HVAC systems such as pre cooling the return air, reheating the supply air on the evaporator side and heat recovery from the condenser side result in more energy savings. Heat pipes incorporated in HVAC systems control the humidity at an optimum level which results in better comfort and optimum utilization of energy resource. A literature review on the studies and applications of heat pipes in HVAC system has been conducted. Based on the investigation of theoretical and experimental studies, it is found that the heat pipes are more suitable as an effective way to recover heat, control humidification and for reducing the heat load on HVAC systems and thereby saving precious energy.

KEYWORDS: Humidity control, Pre cooling, Reheating, Indoor air quality, passive cooling, Energy resource, Green building, Global warming

INTRODUCTION

Heat pipes are heat transfer devices with very high effective thermal conductivity. They handle high heat fluxes with small temperature difference over long distance. These heat pipe heat exchangers are very compact due to the above reason in comparison with the conventional heat exchangers. These devices utilize the latent heat of evaporation as a means of heat transport. Heat transfer is achieved when heat is applied at the evaporator section, which is partially filled with a suitable working fluid to a required fill ratio, causing the working fluid to become vapor and travel to the condenser section of the heat pipe. Due to heat rejection at the condenser the vapor working medium condenses back to liquid and the closed circulation continues. Heat pipes with wick structures [Fig. 1] are used widely for anti-gravity applications. Whereas the wickless heat pipes find wide applications in gravity assisted areas. Wickless heat pipes which are designed and fabricated with ease comparing the wicked ones find wider applications in heat transfer.

Heat pipes are used in many applications viz. waste heat recovery systems, air pre-heaters, cooling of electronic instruments, solar energy collection systems, space shuttle thermal management systems, cooling of gas turbine rotor blades etc. Heat pipes incorporated in the HVAC systems pre cools the return air, reheats the supply air and controls the room humidity to an optimum level. These results in energy savings due to higher thermostat settings and hence lower running cost. The heat pipes also recover the heat from the exhaust air from the condenser side. This energy recovered from the condenser side can be used for industrial and domestic pre heating purposes, which results in less fuel supply and hence less impact on the environment. This paper groups the related papers on application of heat pipes in HVAC systems in two group viz. experimental investigations and theoretical studies.

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Fig. 1: Heat pipe

2. Experimental studies:

Many experimental investigations have been reported on applications of heat pipes in HVAC systems. Relative humidity control in air conditioning system is one of the important aspects in maintaining better indoor air quality.

Table 1: Summary of experimental studies on applications of heat pipes in HVAC System

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Type of heat pipe</th>
<th>Application area</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiao Ping Wu et al. [1]</td>
<td>Wickless thermostyphon vertical HPHX, R22 working fluid</td>
<td>HVAC humidity control</td>
<td>Enhancement of cooling capacity by 20-32.7%, humidity reduced to 70-74% from 92-100%, increased air circulation pressure loss.</td>
</tr>
<tr>
<td>Mostafa A. Abd El Baky et al. [3]</td>
<td>Brass wicked, aluminium finned copper HPHX, R-11 working fluid,</td>
<td>HVAC coolness recovery</td>
<td>Enhancement of heat transfer effectiveness</td>
</tr>
<tr>
<td>Yau[4]</td>
<td>Inclined wick less HPHX</td>
<td>HVAC in tropical climate</td>
<td>Heat transfer effectiveness not affected due to HPHX configuration</td>
</tr>
<tr>
<td>Guiyin Fang et al.[5]</td>
<td>Separate helical heat pipe, R-22 working medium</td>
<td>HVAC ice storage air-conditioner</td>
<td>Cool thermal energy storage</td>
</tr>
<tr>
<td>Hussam Jouhar[6]</td>
<td>Finned wickless loop heat pipe, R-134a working fluid</td>
<td>Humidity control in HVAC</td>
<td>Energy savings due to pre cooling and reheating, enhanced dehumidification</td>
</tr>
<tr>
<td>Suprirattanaku et al.[7]</td>
<td>Closed loop oscillating heat pipe, R-134a working medium</td>
<td>HVAC room air conditioning</td>
<td>Increased COP and EER</td>
</tr>
<tr>
<td>Ahmadzadehtalatapeh[8]</td>
<td>Vertical HPHX, aluminium finned, stainless steel meshed</td>
<td>HVAC system</td>
<td>Energy conservation</td>
</tr>
<tr>
<td>Yau et al.[9]</td>
<td>Wick less, R134a, R22, R410a, revolving copper heat pipes</td>
<td>HVAC heat recovery</td>
<td>Dehumidification, heat recovery and cooling of rotating machinery</td>
</tr>
</tbody>
</table>
Conventional air conditioning systems require considerable amount of reheat energy by way of reheating coils. But by using a thermosyphon [Fig.2] or a heat pipe, one may eliminate the usage of reheat coils without compromising on indoor air quality. Xiao Ping Wu et al. [1] investigated the application of a HPHX to control humidity in air conditioning system. They reported that if the RH level is higher than 70% in living space, a disease called Legionella can spread and sustain.

They also quote the Section 5.11 of ASHRAE Standard 62-1989 which states “Relative humidity in habitable spaces should be preferably maintained between 30 and 60%, to minimize the growth of allergenic or pathogenic organisms”.

![Fig. 2: Schematic of thermosyphon [1]](image)

They experimentally investigated the incorporation of HPHX to pre cool the return air and reheat the supply air in the normal air conditioning system to save the precious reheat energy and also to maintain the required level of RH as shown in the Fig. 3 and Fig.4.

![Fig. 3: HVAC system with HPHX [1].](image)

ma: mass of air entering the system, h1: enthalpy before the pre cooling section of heat pipe, hp: enthalpy after pre cooling section of heat pipe, h2: enthalpy after the cooling coil of A/C unit, h3: enthalpy at the exit of reheating section of heat pipe.
Fig. 4: Psychometric chart representing the air conditioning process with (solid line) and without (dotted line) HPHX [1]. 1: return air, 1p: pre cooling section of heat pipe, p2: conventional cooling process, 23: reheating section of heat pipe, 12a: conventional cooling process, 2a3a: conventional reheating process

They concluded that with the incorporation of the above HPHX, the cooling capacity of the system is enhanced by 20 to 32.7% and the RH level maintained below 70%.

Khanh Dinh [2] has invented a serpentine heat pipe and reported its application in dehumidification through patent no US5845702. In his discovery, he connected several heat pipes with U bends to form a continuous heat pipe with integral condenser and evaporator portions to form a single section heat exchanger. He claims that these types of heat pipe are superior in dehumidification than the conventional heat pipes.

Mostafa et al. [3] carried out an experimental study on HPHX for heat recovery in air conditioning. They have reported the application of HPHX for pre-cooling the incoming fresh air in an HVAC system. For various ratios of mass flow rate (between return and fresh air) of 1, 1.5 and 2.3 the heat transfer and the temperature change of fresh air were calculated. They report that the effectiveness and heat transfer for both evaporator and condenser sections are found to increase by about 48% when the inlet fresh air temperature is increased to 40 °C. They also report that the effect of mass flow rate ratio on effectiveness is positive for evaporator side and negative for condenser side. Further they report that the enthalpy ratio between heat recovery and conventional air mixing has increased to about 85% with increase in fresh air inlet temperature. On comparison of the optimum effectiveness of the HPHX with the experimental data, the reported results showed that the effectiveness is close to the optimum effectiveness with the fresh air inlet temperature nearing the refrigerant operating temperature of heat pipes.

Yau [4] carried out an experimental thermal performance study of an inclined HPHX operating in high humid tropical HVAC systems. The condensation formation on the evaporator section of HPHX impedes the effectiveness and also the mass transfer effect reduces the dry bulb temperature difference between the return air and the supply air. He used an experimental set up to study the thermal performance in which the HPHX were tilted to 30 degree. As a result, the gravitational force is exerted to increase drainage of condensation on the HPHX evaporator section, and hence the effectiveness of the HPHX is expected to be better than the vertical configuration. They reported that the results suggested, the influence of condensate formation on the fins of the inclined HPHX was negligible, and the HPHX in vertical configuration performs as good as that of the HPHX installed in an inclined position.

Guiyin Fang et al. [5] carried out an experimental investigation on performance of ice storage air conditioning system with separate heat pipes. Cool thermal energy storage (CTES) plays a crucial role in energy conservation by shifting on-peak demand to off-peak period. On investigation of several parameters like the vaporization, condensation pressure of refrigeration system, the refrigeration capacity and the COP of the system, they reported that the ice storage air conditioning system worked steady and stable during charging and discharging periods. Hussam jouhara et al.[6] conducted an experimental investigation of wrap around loop HPHX used in energy efficient air handling units. Pre cooling and dehumidifying functions of HPHX in hot and humid climates are major contributors to reduce the running costs of the HVAC system. They experimented with a bundle of 7 loop heat pipes with finned evaporator and condenser sections, to test the variation of heat load and the air velocity on the overall thermal resistance of the loops.
Supirattanakul et al. [7] carried out an experimental study on application of a closed-loop oscillating heat pipe (CLOHP) with check valves [Fig. 5] on performance enhancement in air conditioning system.

![Fig. 5: Arrangement of CLOHP/CV.1: Outdoor air, 2: return air, 3: pre cooled air, 4: Cooling coil, 5: cooled and dehumidified air, 6: reheated air, 7: Evaporating section, 8: condensing section, 9: Insulator, 10: check valves.]

With R134a and R22 as working fluids and for the given indoor and outdoor conditions, the performance of the air conditioning unit with CLOHP/CV was experimented and compared with the conventional air-conditioner. The results have shown that the cooling capacity had increased by 3.6%, the COP by 14.9% and the EER improved by 17.6%.

Ahmadzadehtalatapeh et al. [8] carried out an experimental study and prediction on energy conservation potential of the heat pipe heat exchangers in air conditioning chamber. For the given face velocity and the indoor temperature, the performance curves of a eight row HPHX were obtained based on a weeklong operation. Based on the performance characteristics and the empirical equations, the energy conservation potential of the HPHX for the years of 2000, 2020, and 2050 for Kuala Lampur were predicted. As per the predictions, 6794 kWh, 1278 kWh and 14132 kWh of energy could be conserved in the years 2000, 2020 and 2050 respectively. They also reported that the study showed that the overall SHR was reduced from 0.688 to 0.188 while the dehumidification capacity improved from 22 to 42%.

High heat transfer rate due to enhanced return of condensate in the rotating heat pipe due to centrifugal force was reported by Yau and Foo [9]. A comparison of heat transfer characteristics of working fluids R134a, R22 and R410a was reported using the RHP with various radial displacements. They reported that more the radial displacement more the heat transfer due to higher centrifugal forces generated and better distribution of working medium. Heat transfer characteristics for different rotational speeds for the above working fluids were compared in their study.

2.1 Inferences from the experimental investigations:

The comparison of various experimental reports (Table 1) show that the role of heat pipes in HVAC applications by way of heat recovery, indoor air quality control, pre cooling, adsorption refrigeration, non-conventional refrigeration, coolness recovery, dehumidification are encouraging. Still the application of heat pipes in domestic and commercial areas viz. green buildings, passive cooling mechanisms, buildings with in-built heat pipes and thermal energy storage systems need further investigation.

3. Theoretical Investigations:

Michael et al.[10] carried out a theoretical investigation on optimizing 100% outside air systems with heat pipes. To meet the stringent building codes and ASHRAE standards, which do not permit reheating the cooled air, 100% outside air conditioning systems are the need of the hour. They also reported that ASHRAE standard 90.1.2010 stipulates effective ventilation with fresh air in the dwelling spaces.
This (DOAS) dedicated outside air conditioning system is well addressed by heat pipes which pre cools the return air and reheels the supply air by eliminating conventional heater. Richard Meskimmon [11] has published notes on application of heat pipes in displacement ventilation cum chilled ceiling systems. Unlike in the conventional ventilation technique, where fresh air and return air mixture is supplied at a temperature of 12 to 15 °C from high level at a velocity of 1 to 1.5 m/s, in displacement ventilation air is introduced at low level occupied zone at 18 to 19 °C. As the cold air is denser than the humid air, it easily ventilates the occupants and transfers the hot and humid air upwards.

Wan et al.[12] carried out a study on the effect of heat pipe air conditioning coil on energy consumption in central air conditioning system. They reported that for a typical 20-26°C, 50% RH indoor condition, the rate of energy saving (RES) for the heat pipe equipped air-conditioning is 23.5 to 25.7% for cooling load and 38.1-40.9% for total energy consumption. They also reported that the RES is governed by both indoor temperature and RH.

Yau[13] carried out a theoretical investigation on potential of HPHX on coolness recovery in tropical buildings. They reported a novel concept of using double HPHX to recover the coolness from the contaminated exhaust air of hospitals and operation theatres etc. The first HPHX recovers the coolness from the contaminated exhaust air and pre cools the fresh air. This pre-cooled fresh air is passed over the second HPHX to get the pre cooled air further cooled. This further cooled air is passed through the cooling coil for getting over cooled (i.e nearer to saturation curve). This three step cooling process enhances the dehumidification capacity of the cooling coil. After the dehumidification the air moves to the condenser section of the second HPHX, where the supply air is reheated partially and further reheated at a conventional heater to the required level and finally delivered to the distribution grills.

Yau[14] carried out a full year energy consumption model simulation of a double HPHX system for reducing energy consumption of treating ventilation air in an operating theatre. His report consists of a case study on energy consumption of an operation theatre in Kuala Lumpur, Malaysia. He carried out a simulation study with a custom built Trane Air Handler Unit(AHU) 0704 2.2mb. After retrofitting the existing HVAC system with double HPHX to compare the energy consumption pattern on hour by hour basis using TRANSYS, the results showed that the payback period of the retrofitted HVAC system is reduced to 3.9 years as compared to that of the normal one of 4.5 years due to improved COP of the former.

Alklaibi[15] carried out a theoretical investigations on evaluating the possible configurations [Fig. 6]

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<th>Effect</th>
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<tr>
<td>Ahmadadehtalatapeh[2011]</td>
<td>HPHX horizontal heat pipe</td>
<td>Hospital ward energy saving</td>
<td>Recommended for meeting ASRHE standard on Indoor air quality.</td>
</tr>
<tr>
<td>Ehsan Firozfar et al.[2009]</td>
<td>Wickless heat pipes(thermosyphons)</td>
<td>HVAC</td>
<td>HVAC systems, controlled RH, energy saving</td>
</tr>
<tr>
<td>Yau[2010]</td>
<td>Horizontal heat pipes</td>
<td>Cool and heat recovery, HVAC in tropics HVAC-IAQ</td>
<td>Dehumidification, energy saving, less sized equipments. Energy savings, dehumidification, recommended for commercial usage to increase energy savings</td>
</tr>
<tr>
<td>Ehsan Firozfar et al.[2011]</td>
<td>HPHX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAN et al.[2007]</td>
<td>HPHX</td>
<td>HVAC- central air conditioning applications</td>
<td>Rate of energy savings compared with and without incorporation of HPHX</td>
</tr>
<tr>
<td>Richard Meskimmon[2004]</td>
<td>Wraparound heat pipes</td>
<td>HVAC- ventiliation</td>
<td>Low air treating costs, energy saving</td>
</tr>
<tr>
<td>Alklaibi[2008]</td>
<td>Double HPHX vertical type</td>
<td>Operation theatre air ventilation</td>
<td>Reduced energy consumption, low pay back period of HVAC systems</td>
</tr>
<tr>
<td>Michael et al.[2010]</td>
<td>Wraparound loop heat pipes</td>
<td>HVAC- Dedicated outside air conditioning systems(DOAS)</td>
<td>Simplified recirculating HVAC system, Improvement of Indoor Air Quality(IQA)</td>
</tr>
</tbody>
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Table 2: Summary of theoretical studies on applications of heat pipes in HVAC systems
of incorporating the loop heat pipe into the air conditioning system. He reports that due to precooling and reheating effect of the loop heat pipe, the LHP incorporated air conditioning system has 2.1 times more COP than the conventional one and consumes lesser compressor work. He also reports that out of the several configurations, the LHP evaporator which is placed in the supply air stream gives the highest COP.

Ehsan Firouzfar et al.[16] presented a research paper on applications of wickless heat pipe heat exchangers in HVAC systems. They report that application of thermosyphon HPHX in conventional air-conditioning system not only maintains the indoor humidity within the acceptable level but also reduces the power demand. They also report that the incorporation of HPHX in HVAC system reduces the indoor humidity to the required level that leads to reduction in latent heat load on the compressor and also helps to maintain the indoor air quality standards particularly in tropical climates.

Yau et al. [17] carried out a review on the applications of horizontal HPHX in air conditioning systems in the tropics. They report that though the horizontal and vertical configurations of HPHX are implemented in subtropical climates for recovery of coolness, heat and dehumidification purposes and to maintain better indoor air quality standards, the benefits of the same are yet to be familiarized in the tropical countries like Malaysia and other Middle East countries.

A review on application of HPHXs in heating, ventilation and air conditioning systems was presented by Ehsan Firozfar et al.[18]. They grouped the recent experimental and theoretical studies and reported that conventional air conditioning systems fitted with HPHX or thermosyphon heat exchangers are effective in saving energy and also providing acceptable indoor air quality by reducing humidity level of the conditioned space by 10%, which results in significant reduction in latent heat load.

Ahmadadehtalatapeh et al.[19] carried out a simulation study on the applications of HPHX to improve the air quality and to reduce the energy consumption of the air conditioning system in a hospital ward. They employed the transient system simulation software (TRANSYS) to monitor the hour-by-hour energy consumption, indoor humidity and air quality. The result shows that on comparison of the retrofitted (with HPHX) HVAC system with the conventional one the retrofitted HVAC system gives better indoor air quality on pair with ASHRAE standards, better energy savings and better humidity control. They also report that this study as fitting case for justification for retrofitting the conventional HVAC systems in tropical regions.

3.1 Inferences from the theoretical investigations:

The observations based on the theoretical literature reviews (Table 2) show that the single HPHX and double HPHX are widely applied in the HVAC systems to control humidity, improve Indoor Air Quality, conserve and recover cool and heat energy by way of precooling and reheating. Air cooled and evaporative cooled condensers are investigated to enhance the effectiveness of the HPHX. The theoretical investigations reveal limited applications of HPHX in the areas of green buildings, naturally ventilated buildings and thermal energy storage.

Conclusions:

This paper presents an overview of the research results of applications of heat pipes in HVAC systems. The results show that the heat pipes have great potential of heat transfer and also the following conclusions can be drawn upon analyzing the experimental and theoretical investigations that
1. The HVAC systems which are incorporated with heat pipes conserve energy in one way or the other as evident from the above review.

2. The heat pipes are widely applied in the HVAC systems to recover coolness and heat. They are also used for dehumidification purpose, which enhances the COP and hence the energy savings, shorter payback period and better Indoor Air Quality Standards.

3. The HPHX are also used along with PCM to improve the heat transfer rate to enhance the performance of the thermal storage systems.

4. Further it is found that the theoretical and experimental investigations are limited in the areas of Green buildings, Passive cooling mechanisms, Buildings with inbuilt heat pipes, Non-conventional refrigeration and Thermal energy storage systems.

REFERENCES


