Heat Pipe Technology as a Viable Option for HVAC Application: An Overview

***S. C Kaushik, *Amit Sharma and **S. Jain

Abstract

Heating, ventilating & Air Conditioning has traditionally been energy intensive industry, requiring exorbitant capital investment. Reclaiming waste heat undoubtedly gives a breather to the fastly depleting energy sources. Use of heat pipe technology in HVAC is a step in the direction of energy conservation. Heat pipe is a passive heat transport device that transfers heat most efficiently. This feature is utilized in various air-conditioning applications such as evaporative cooling, dehumidification in hot and humid climates, controlling humidity etc. Heat pipe based heat exchanger has emerged as an energy conservation device and proving to be boon for energy conversationalist. In this paper heat pipe's various HVAC applications are discussed.

Keywords: Heatpipe, Air-conditioning.

1. INTRODUCTION

In 1964, Grover [1], demonstrated the high effective thermal conductance device and named it "heat pipe". It is simple yet ingenious device. Heat pipe allows heat transfer by means of phase change of a medium (working fluid) enclosed in an envelope (container). The envelope consists of three sections: The Evaporator, Condenser and Adiabatic transport region. The working fluid in the evaporation section is evaporated by a hot fluid and is led to the condensation section, where it is condensed by a cold fluid. The condensed fluid returns to the evaporator section along the inside of the wall by gravity or by capillary forces created by the wick, in the container (heat pipe). Thus heat is transported passively from one location to the other. Fig. 1 explains the various elements of the heat pipe.

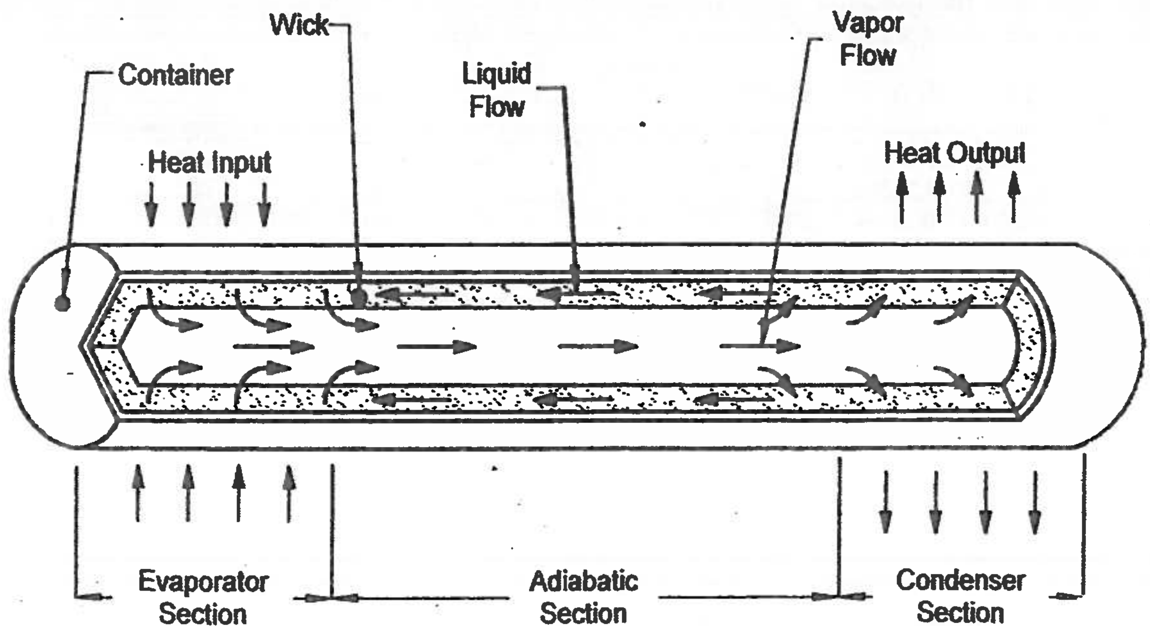

Fig. 1 Basic elements of heat pipe

Its working fluid undergoes a thermodynamic cycle [2]. Various heat transfer processes constituting the cycle shown on T-s diagram (Fig. 2) are: A-m-n-B (Heat supplied to the evaporator); B-C (Vapor flow from Evaporator to condenser through transport region); C-D (Constant pressure heat rejection in condenser region); D-A (Condensed liquid flows back to evaporator through the wick).

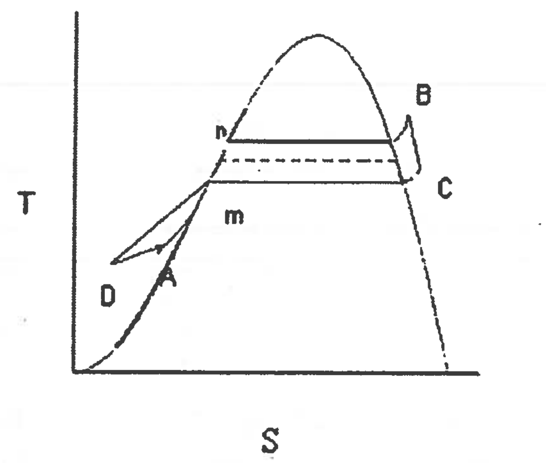

Fig 2 T-S Diagram of Heat pipe working fluid

Heat pipe has high thermal performance, high effective conductivity and slight temperature difference. It is rugged, reversible in nature and reliable. It needs no additional power requirement. These characteristics [3], qualify heat pipe to be a good heat exchanger system.

HVAC applications consume lot of energy [4] and the rejected large chunk of waste energy is burdening existing nonrenewable energy sources. Exploiting this secondary sources of energy i.e. waste heat as a part of waste air and flue gases, is of paramount importance. Their return to the technological process is the primary concern for desirable reduction of energetic claim in vast majority of industrial heat exploiting devices. Although, heat pipe technology exists since early seventies, but its use in energy recovery systems, is relatively new. Energy recovery using HPHE is done in various ways such as heat recovery from the process exhaust stream to preheat the air for space heating; heat recovery from the process exhaust stream to reuse in the process(heat recovery in A/C). Heat exchangers made up of heat pipes are the most effective devices for waste heat recovery [3].

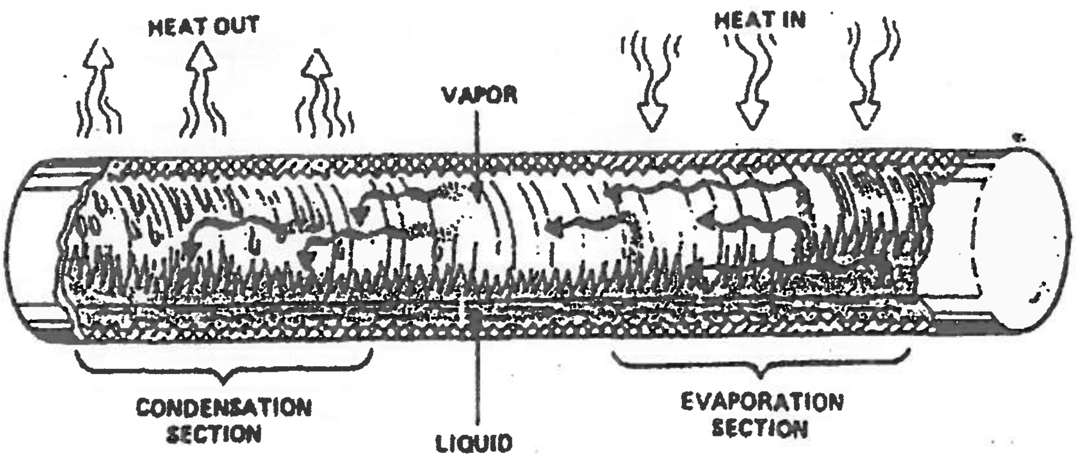

Fig 3 Heat Pipe

Unlike the conventional heat pipes, the heat pipes used in heat exchangers have no adiabatic section (or very small length separator plate). Figs. 3 and 4 give detailed view of heat pipe and heat pipe heat exchanger respectively.

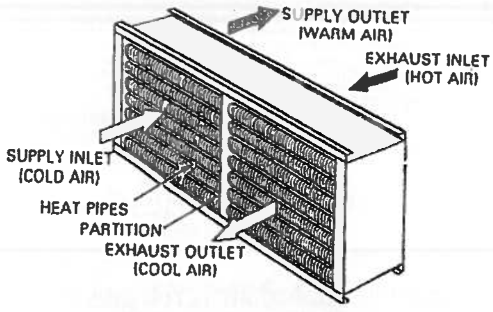

Fig 4 Heat Pipe Heat exchanger

The heat transfer in HPHE depends mainly on orientation of the exchanger relative to the horizontal; face velocity and wet bulb temperature of the entering air; state of the condenser section i.e. whether dry or wet. The wetted surface is the most preferred approach as it gives optimum performance.

In an A/C application, HPHE is used either as to retrofit or as a new installation. For retrofit applications, the operating cost is reduced because of the reduction in the energy consumption. For new installations the heating and cooling equipment can be downsized which will result in lower equipment and operating costs. During summer season, indirect evaporative cooling can also be used to further enhance the performance of A/C system. Various studies have reported the use of HPHE in HVAC systems [5, 6, 7], proving to be great energy saver.

HPHE is useful in operating theaters to maintain RH level [8, 9], commercial buildings (where reheat is employed), libraries (where humidity is a problem) etc. HPHE's based A/C in hot and humid climates help in preventing sick building syndrome. In solar space conditioning, HPHE offer viable option of storage of solar heat [4] and then transfer it for space conditioning when it is required. The Bottom line is that all these applications do involve savings in total energy consumption, yielding lower energy bills and healthier indoor air quality (IAQ).

In this paper, various heat pipe based A/C applications are discussed covering winter and summer air-conditioning schemes. A special application, for controlling humidity in the hot and humid climate by means of HPHE is also discussed. This includes a discussion on a novel heat pipe based dehumidifier/air conditioner and the use of HPHE in IDEC systems. Various schemes are discussed highlighting HPHE's emerging potential for HVAC applications.

2. HVAC applications

2.1 Operation of HPHE during summer and winter

During summer, requirement is of lowering down the temperature and in winter it is of elevating temperature at comfortable RH level. During summer time, the HPHE pre-cools the hot supply air stream before it enters the cooling coil. Thus reducing the size of the cooling coil as compared to what would have been used with HPHE. And during winter time, the HPHE preheats the cold supply air stream before it enters the heating coil, thus reducing the size of the heating coil. The section of HPHE that works as an evaporator in the winter will work as a condenser when the outside temperature of HPHE section exceeds the exhaust air temperature, thus reversing the roles of evaporator and the condenser. Similarly, the section of the HPHE that works as a condenser in the winter will work as an evaporator when the outside air temperature exceeds the exhaust air temperature. Hence, the existing ductwork used for the winter season will not have to be modified in any way for the system to operate in the summer season without a change in the flow direction [7]. For summer A/C, cooling coil is used to further lower down the temperature and RH. Evaporative cooler is also used. For winter A/C, heating coil is used in the same path of supply air. For both seasons HPHE can be used for energy saving in terms of electricity. Fig. 5 gives the block diagram of the operation of HPHE during summer and winter. This kind of HPHE basically can recover heat and help in reducing the cost of equipment by downsizing the system components.

2.2 Heat pipe based system for hot and humid climate

In certain regions of India (mainly south India), the summer dbt is $>35^{0}$C & RH level is > 70% [11]. Thus temperature as well as RH level is to be controlled. A typical A/C is useful in moderately humid environment but in monsoon season normal cooling coil is not effective. In hot and humid environment a typical air conditioner removes only a portion of the humidity during normal cooling coil operation, resulting in highly humid room air. To remove large amount of humidity in a hot and humid [5] environment, an A/C must operate longer & consume more energy, the RH is removed, but air is cooled. This overcooled air must be reheated to a comfortable level. Fig. 6 explains the processes [5]. This reheating consumes additional energy. For using heat pipes in an A/C, air is pre-cooled before it reaches the cooling coil. Then, cooling coil removes the heat & moisture. The over cooled air is reheated to a comfortable temperature by the condenser portion of HPHE. Fig. 7 describes the principle [5]. And Figs. 8 a) and b) explain the block diagram and component description respectively [7]. Psychrometric processes are shown in Fig. 9

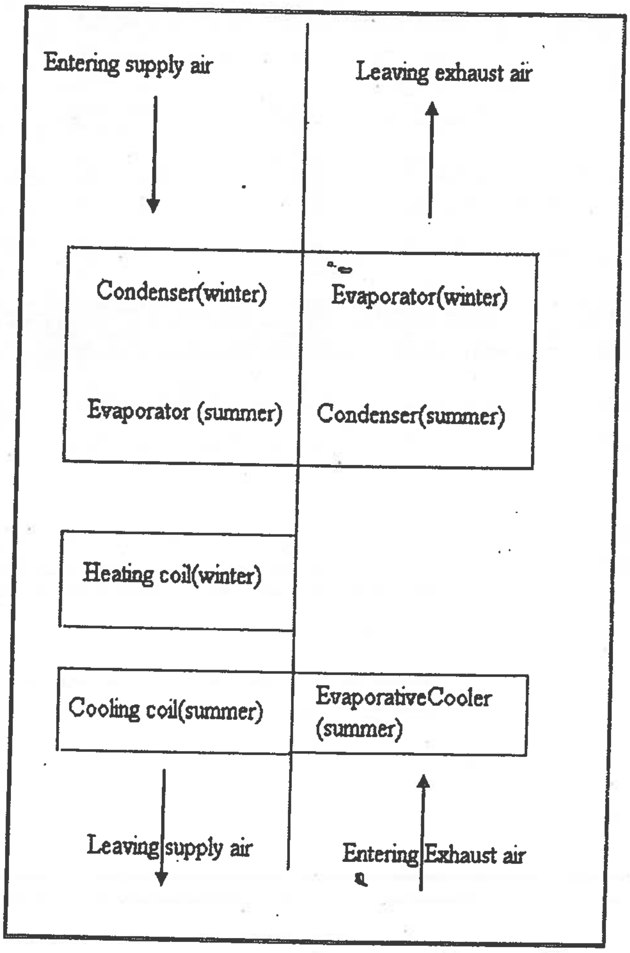

Fig 5 Summer / winter operation of HPHE

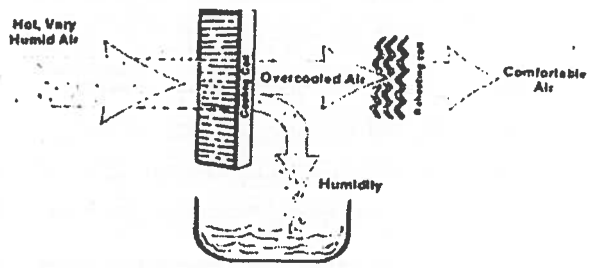

Fig 6 A/C and Reheating of over cooled air

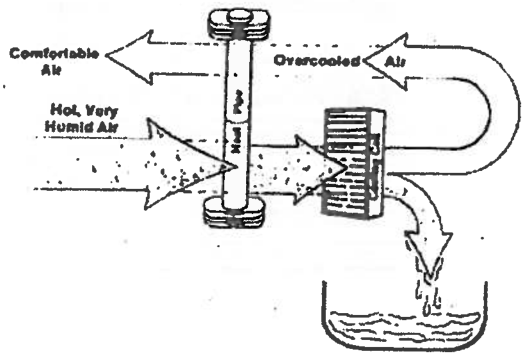

Fig 7 Principle of heat pipe based A/C

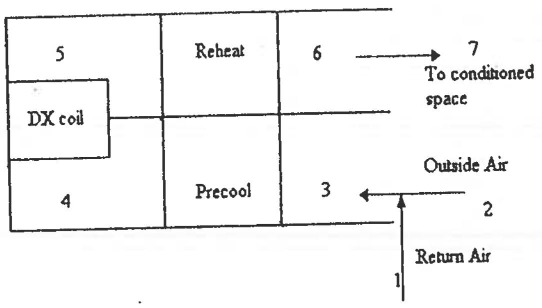

Fig 8 a) Block diagram the HPHE based Air conditioner/ dehumidifier

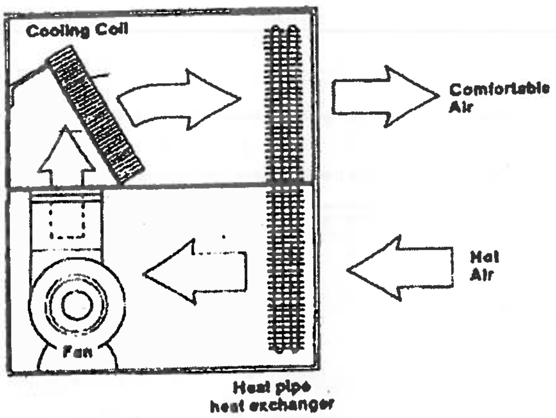

Fig 8 b) Air conditioner/Dehumidifier

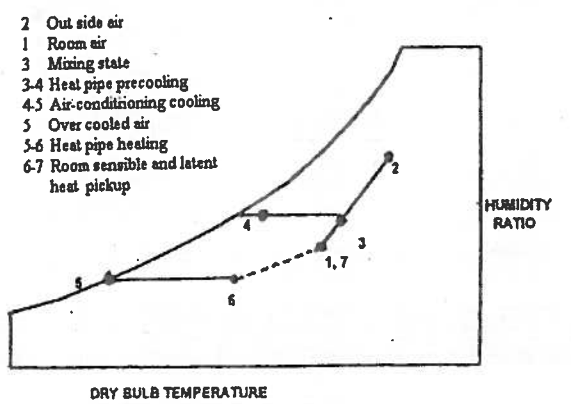

Fig 9 Psychrometrics of Heat pipe application to avoid overcooling and reheating

2.2.1 A novel design of air-conditioner/dehumidifier based on heat pipe

In this system heat pipes are wrapped around the cooling coil. Conditioned air is obtained in the three steps [5]: air is pre cooled; moisture and heat are removed from the air by the A/C coil; heat is added to the air by the heat pipe system. Fig. 10 explains all the processes and drop in temperature along the length of the arrangement.

Heat pipes can be used for dehumidification and reheating purposes in air conditioning. This is done by employing heat pipe heat exchanger around the cooling coil, the evaporator end placed in front of the coil and the condenser after the coil. As shown in Fig. 10, the incoming warm and moist air is pre-cooled as it flows over the evaporator section, before passing over the cooling coil. Some moisture is removed in the pre cooling section and rest is removed by cooling coil. Dry and low temperature air goes to condenser section. The condenser portion of heat pipe on the down stream side of the

Cooling coil, releases an equal amount of heat to that extracted from the upstream side of air resulting in raising the temperature of the air to comfortable level. Thus reheating is done in a novel way, without using external energy source, and it leads to saving in high grade energy. The pre cooling effect also reduces the temperature of air coming onto the cooling coil and reduces the total duty/load on the cooling coil.

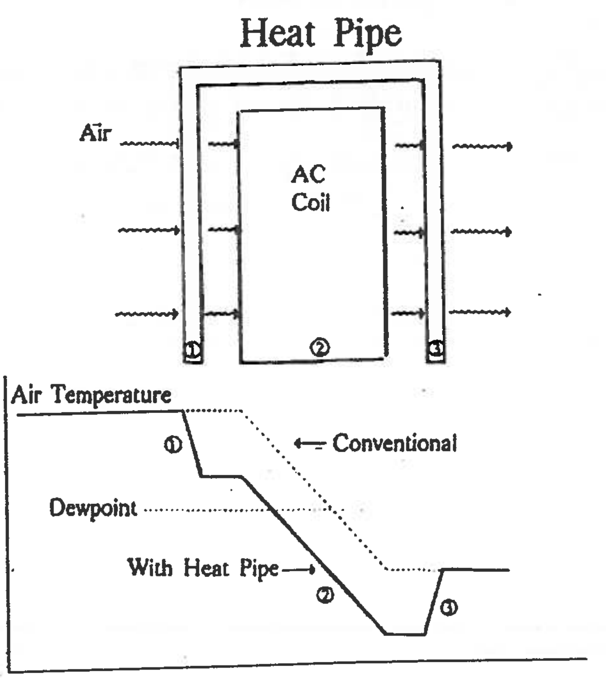

Fig 10 Heat Pipe Installed around AC coil & comparitive temperature drop

2.3 Indirect evaporative cooling systems with HPHE

IDEC system is the latest development in the use of HPHE [12]. It not only slashes the power consumption but also reduces the mechanical A/C equipment. At times, (depending on favorable wbt) even eliminating the need for mechanical A/C equipment.

2.3.1 Ventilation

In manufacturing shop areas, there is a need of reduction of temperature rather than area to be air conditioned. This drop in temperature is obtained using HPHE with IDEC. Fig.11 explains it's working [12].

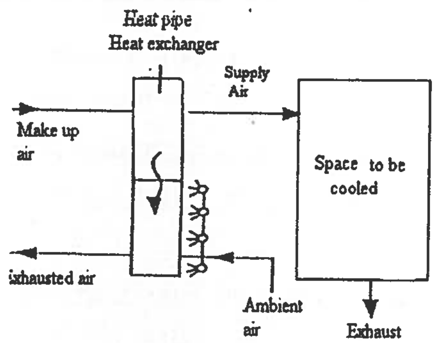

Fig 11 Indirect EvaporativeCooling Coupled with HPHE

2.3.2 Combination with Direct Evaporative cooler

The indirect evaporative cooler is used with direct evaporative cooler (desert cooler) to cool the space and add moisture where average humidity is low. Fig. 12 shows the schematic scheme of the system [12].

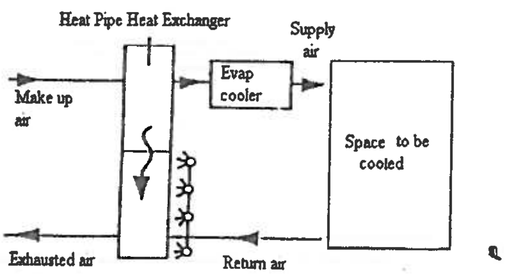

Fig 12 Direct and Indirect Evaporative cooling Coupled with HPHE

2.3.3 Coupled with standard Air Conditioning

Since, ventilation/makeup air is essential to meet the biological conditions for the required space, HPHE recovers energy from the return air & pre-cools the fresh air. This reduction in sensible heat of the fresh air enables design of more economically viable A/C plants with no extra input of energy. Fig.13 explains its working [12].

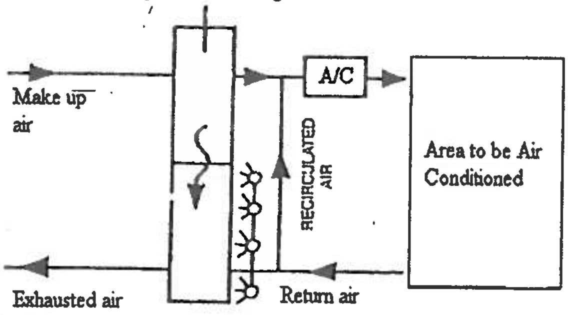

Fig 13 Indirect Evaporative Cooling
(coupled with standard Air conditioning)

Conclusion

HPHEs are versatile in their applicability and can be incorporated in many modes in HVAC systems. No external energy source is required and saving in energy results in high returns. Installation of an HPHE is easy for new as well as retrofit applications. The energy consumption is drastically reduced with these devices. HVAC industry is reaping the benefit from the passive heat pipe technology and this technology is emerging as a viable option for HVAC systems.

Acknowledgement

Author (Amit Sharma) SRF, is grateful to CSIR for providing financial support for undertaking the research work.

Nomenclature

A/C	Air conditioning /er	IAQ	Indoor air quality
HPHE	Heat pipe heat exchanger	IDEC	Indirect evaporative cooling
HVAC	Heating, Ventilating and air conditioning	W b t	wet bulb temperature

References

1. Grover, G.M., Cotter, T.P. and Erickson, G.F , "Structures of very high thermal conductance", *J. App. Phys.*, Vol. 35, 1964.

2. Juo ,Z. J and Faghri, A. , "A network thermodynamic analysis of the heat pipe", *Int. J. Heat Mass transfer*, Vol-41, No. 11, pp 1473-1484,1998.

3. Shah,R.K, and Giovannelli,A.D., "Heat pipe Heat Exchanger Design Theory", in Heat Transfer Equipment Design, Advanced study Institute book, Hemisphere publication corporation ,1988

4. Kaushik,S.C, M.K.Gupta and Amit Sharma, "Energy efficiency of thermal systems: an overview, Proceedings of National Conference on Recent Advances in Science and Technology,ISTE,4-12, 2006

5. Khattar, M , " Heat Pipe application " , Florida Solar Energy Centre,1994, www.owr.ehnr.state.nc.us/ref/12/11348.pdf, accessed on Dec 2006

6. Hancock, C.E., and Paul Reeves, " New Technology Demonstration Program Kennedy Space Center L Heat Pipe Project: Performance Evaluation report," NREL/TP-71024738, Goldan, Colorado, March 1999

7. Mathur, G.D., "Controlling space humidity with heat pipe heat exchangers", *AIAA* paper 2000-2949.

8. Noie-Baghban, S.H, Majideian, G.R, "Waste heat recovery using heat pipe heat exchanger (HPHE) for surgery rooms in hospitals" , *Applied Thermal Engineering*,20,pp 1271-1281,2000

9. Yau,Y.H, " Using heat pipe heat exchangers for reducing energy consumption of treating ventilation air in an operating theater in an tropical climate: a simplified model," *Building Serv. Eng. Res. technol*, 27,4, pp 297-310,2006

10. Kaushik,S.C & G Sujit kumar. "Heat transfer pipes and energy storage potential of ground for solar space conditioning" National seminar on heat pipe for rural and industrial application, NPL sep 1993.

11. Bansal, N.K & Minke,G, Climate zones and Rural Housing in India, Passive space conditioning,1988

12. Joshi, R. "Air to air waste heat recovery by using heat pipe concept" in National seminar on heat pipe for rural and industrial application, NPL sep 1993.

***Professor

Centre for Energy Studies, IIT Delhi, Delhi-110016(India)

kaushiksc@ces.iitd.ernet.in

*Senior Research Fellow

Centre For Energy Studies, IIT Delhi

*mech_amit_sharma@yahoo.co.in

**Associate Professor

**Mechanical Engineering Department, IIT Delhi, Delhi-110016 (India)

**sanjeevj@mech.iitd.ernet.in