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Applications and Performance Analysis of Heat Pipe Heat Exchangers for Heat Recovery

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Abstract: The waste heat recovery by heat pipes is an excellent way to save energy. A study was performed on the applications of heat pipe heat exchangers for the heat recovery with energy saving and the effectiveness of the Conventional Heat Pipe (CHP) and Two-Phase Closed Thermosyphon (TPCT) heat exchangers. The relevant papers were analysed to support future works and the experimental studies were summarised. This study also provides the analysis of performance of heat pipe heat exchangers in the heat recovery system.

Key words: Heat pipe, Recovery, Effectiveness

I. INTRODUCTION

The use of Heat Pipe Heat Exchanger (HPHE) for waste heat recovery is one of the ways to save energy. It possesses many advantages, such as its heat recovery effectiveness, compactness, lack of moving parts, light weight, relative economy, small pressure drop on the air side, complete separation of hot and cold fluids and reliability. The HPHE has been applied in many industries(eg. Energy engineering, chemical engineering and metallurgical engineering) as waste heat recovery systems.

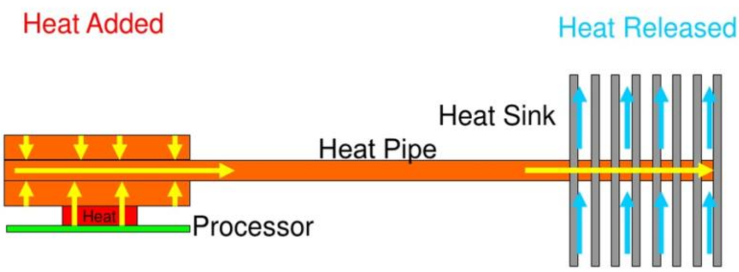

Fig 1. Transfer of heat

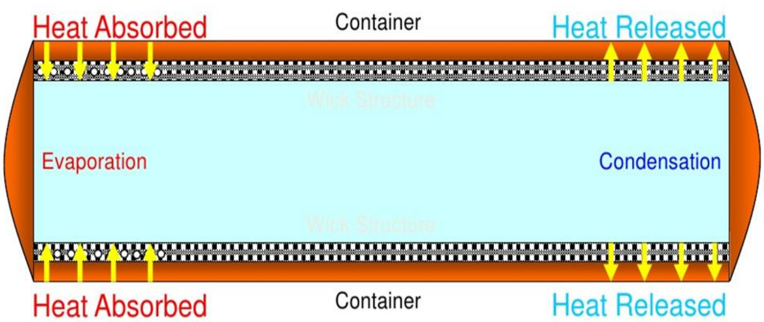

Fig 2. Heat transfer within a heat pipe

The recovery of heat from exhaust gases in a furnace stack by HPHE is illustrated in Fig. 3. In a conventional furnace (Fig. 3a), the exhaust gases enter directly into surrounding area, which not only wastes energy but also harms the environment. The use of a HPHE (Fig. 3b) reduces the primary energy consumption and protects the environment. This article provides the applications of the Conventional Heat Pipe (CHP) and Two-Phase Closed Thermosyphon (TPCT) heat exchangers for heat recovery along with the analysis of their performances.

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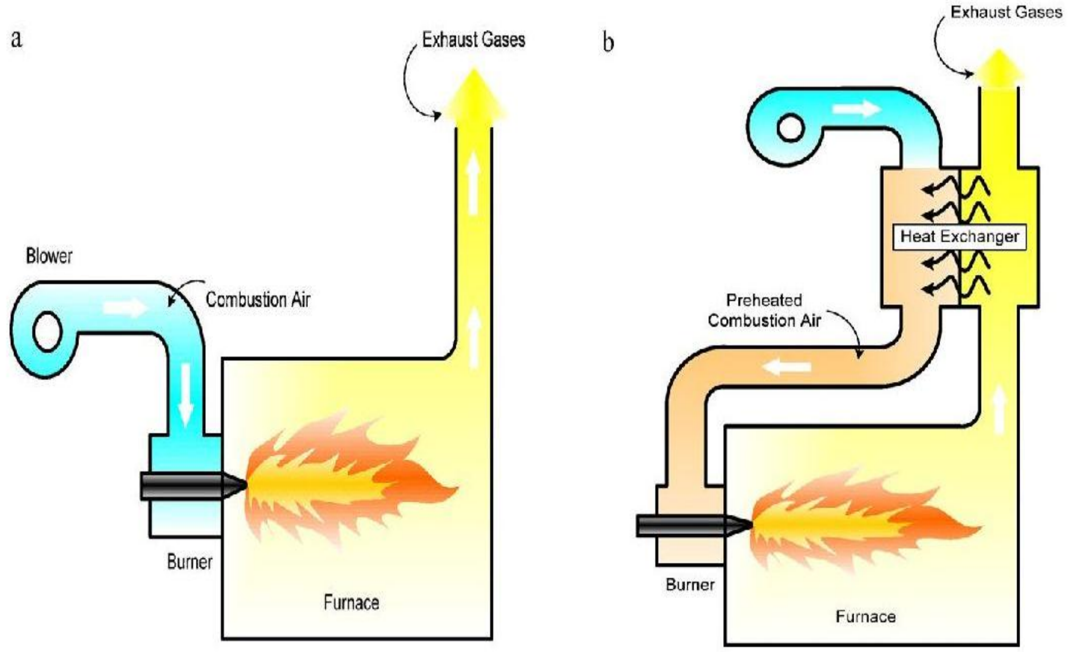

Fig 3. Heat recovery for preheated air before combustion of the furnace

1.1 CHP and TPCT

HPHEs are heat transfer devices in which the latent heat of vapourisation is utilised to transfer heat from one end to other with a corresponding small temperature difference. A working fluid is filled in a closed tube. A vapour at a slightly higher pressure and temperature is generated when heat enters the evaporator. Due to increased pressure the vapour flows along the pipe to the condenser section, where a slightly lower temperature causes the vapour to condense and release its latent heat of vapourisation.

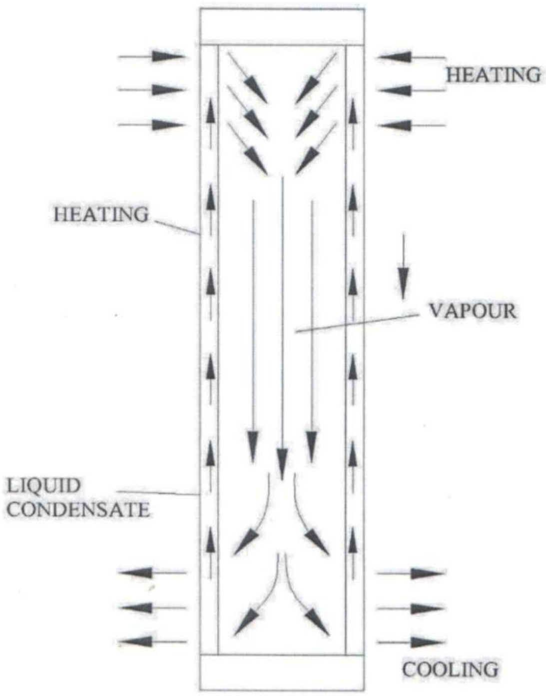

Fig 4 Conventional Heat Pipe(CHP)

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In CHP the condensed fluid returns to the evaporator due to the capillary action of the wick.In TPCT this is due to the gravitational force. TPCT heat pipe do not have the wick structure with evaporator section is situated below the condenser section. The working fluid evaporates, condenses in the condenser section and flows back to the evaporator section due to the gravitational force. Fig.4 represents CHP and Fig. 5 represents TPCT

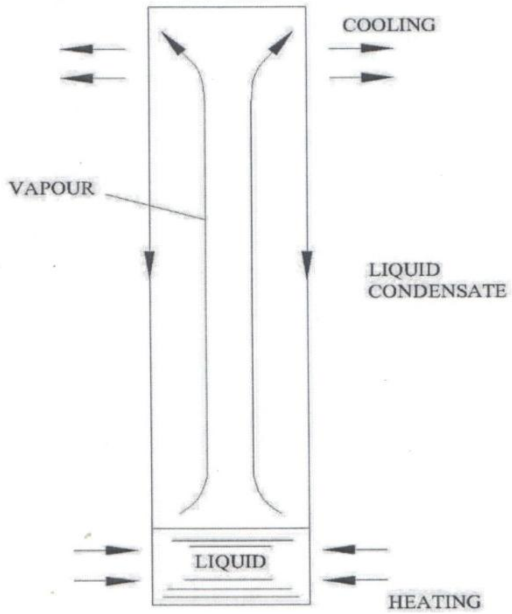

Fig 5 Two Phase Closed Thermosyphon(TPCT)

II. HEAT PIPE APPLICATIONS FOR HEAT RECOVERY

2.1 Heat Exchangers for heat recovery
2.2 Human body temperature control(medicine)
2.3 Space craft cooling
2.4 Electrical and Electronics equipments cooling

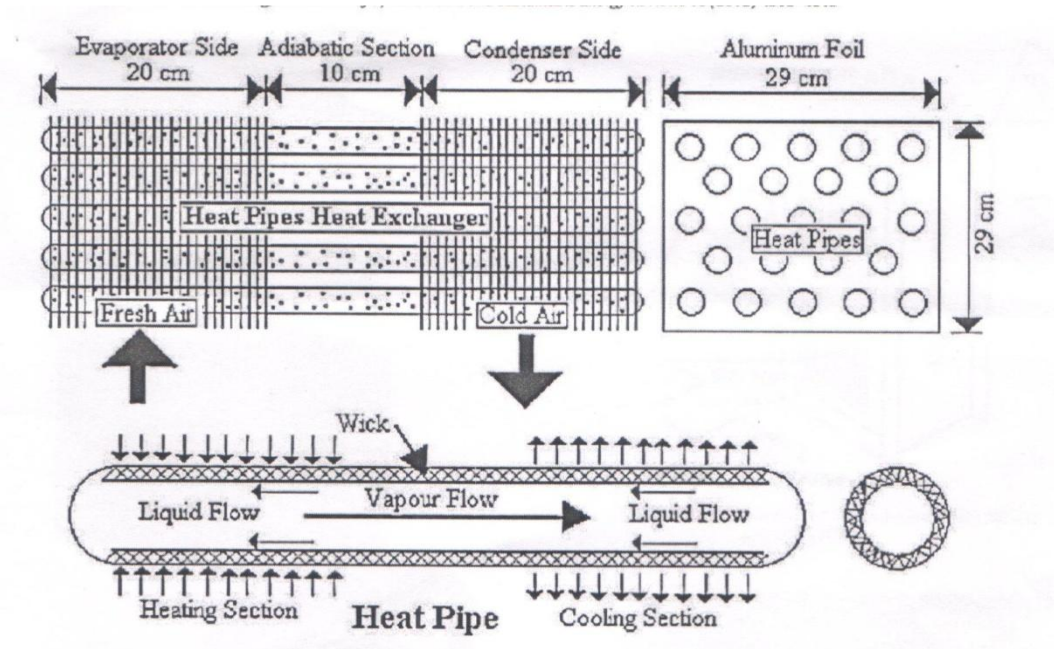

Fig 6 CHP heat exchanger for heat recovery

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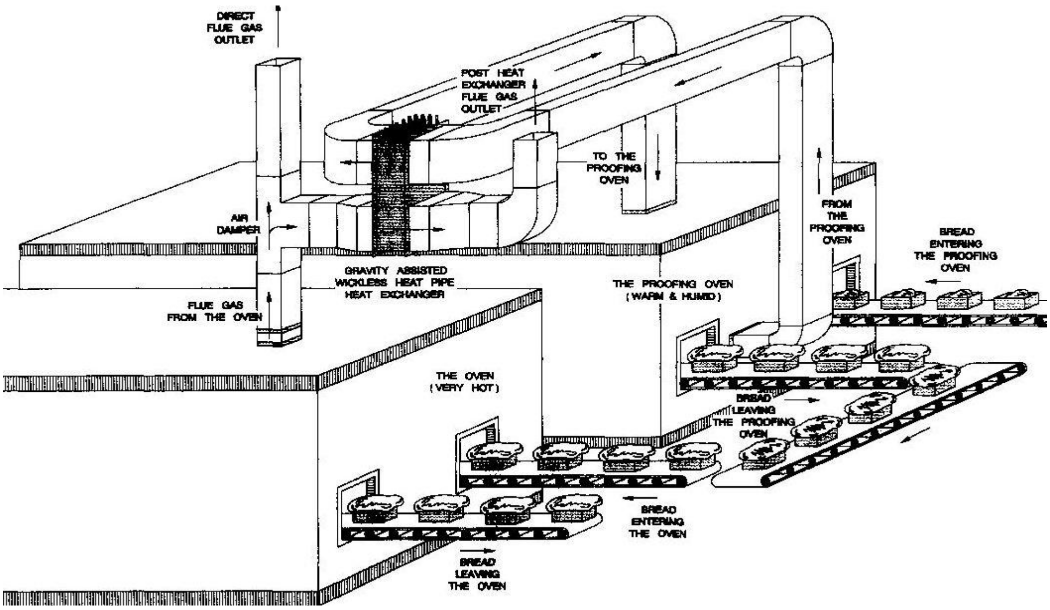

Fig 7 Recovery of flue gas energy of ovens

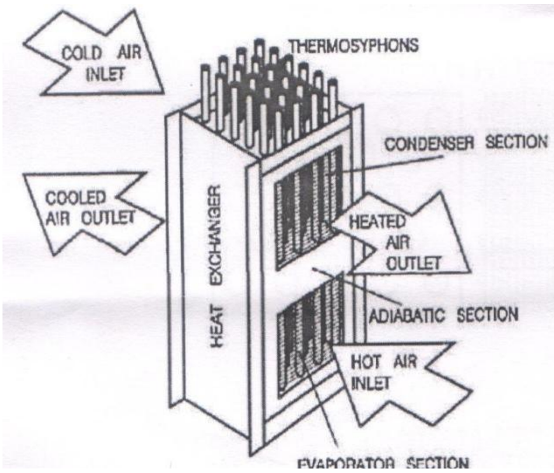

Fig 8 TPCT heat exchanger for heat recovery in a bakery

Fig: 9 Heat pipe in space craft

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Fig: 10 Heat pipe in Laptop

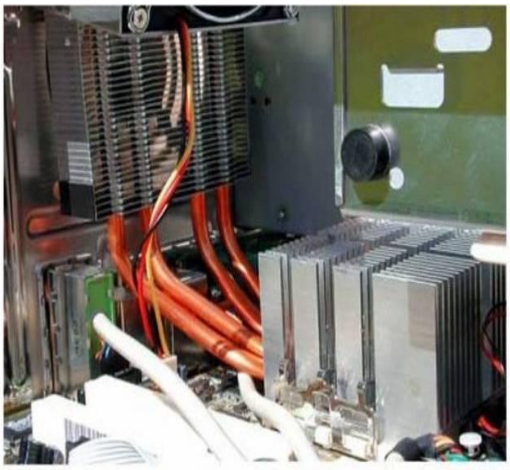

Fig: 11 Heat pipes used in processor

Fig 12 Heat pipe in CPU

III. LITERATURE REVIEW

W.Srimuang and P.Amatachaya[1] performed a review of the applications of heat pipe heat exchangers for heat recovery and concluded that heat pipes for heat recovery contains an efficient air-to-air heat recovery device that controls heat loss in both commercial and industrial applications to ensure both energy savings and environmental protection. It does not need input power for its operation and does not require cooling water and lubrication systems. Noie-Baghban and Majideian [2] examined the waste heat recovery using CHPs for surgery rooms in hospitals. The CHPs were designed for use with low-temperature sources (15-55 ^{o} C). The study found that the CHP effectiveness is 0.16, although it depends upon the diameter and the fin gap. The effectiveness value is very small because the CHP was designed for low-temperature operating conditions. Abd E1-Baky and Mohamed [3] applied the CHP to the heat recovery between two streams of fresh and return air in an air conditioning system, where the incoming fresh air could be cooled. The ratios of the mass flow rate between the return and fresh air (1, 1.5 and 2.3) were tested to validate the heat transfer and the temperature change of the fresh air. During the tests, the fresh air inlet temperature was controlled in the range of 32- 40 ^{o} C, while the inlet return air temperature was kept constant at approximately 26 ^{o} C. Martinez et al. [4] designed a mixed-energy recovery system consisting of two CHPs and indirect evaporative recuperators for the air conditioning. The energy characterisation of the mixed energy recovery system was performed with the experimental design techniques. A main conclusion was that by applying the mixed-energy recovery system in the air-air conditioning installations consisting of two CHPs and indirect evaporative systems, part of the energy from the return air flow could be recovered, thus improving the energy efficiency and reducing the environmental impact.

In the applications of TPCT, Lukitobudi et al. [5] designed, constructed and tested a TPCT heat exchanger for a medium-temperature heat recovery in bakeries. The TPCT was very efficient (65%). The authors commented that the overload pressure during the processes may damage the TPCT. Yang et al. [6] studied the possible application of a TPCT for the passengers in a large bus by recovering the heat from the exhaust gas of the engine. The study determined that TPCTs can be effectively used as a device for heat recovery and the experimental result agree well with numerical results. Riffat and Gan [7] explored the effectiveness of the TPCT heat exchangers for naturally ventilated buildings. In this research, the performances of three types of TPCT heat recovery units were tested in a two-zone chamber with a horizontal partition. The first TPCT heat exchanger consists of a bank seven externally finned heat pipes, the second has a cylindrical spine fins, and the third was made of 2 rows of staggered TPCTs. CFD modeling was used for the pressure loss characteristics of the units. According to the experimental result, the air velocity significantly influenced the effectiveness of the TPCT heat recovery units.

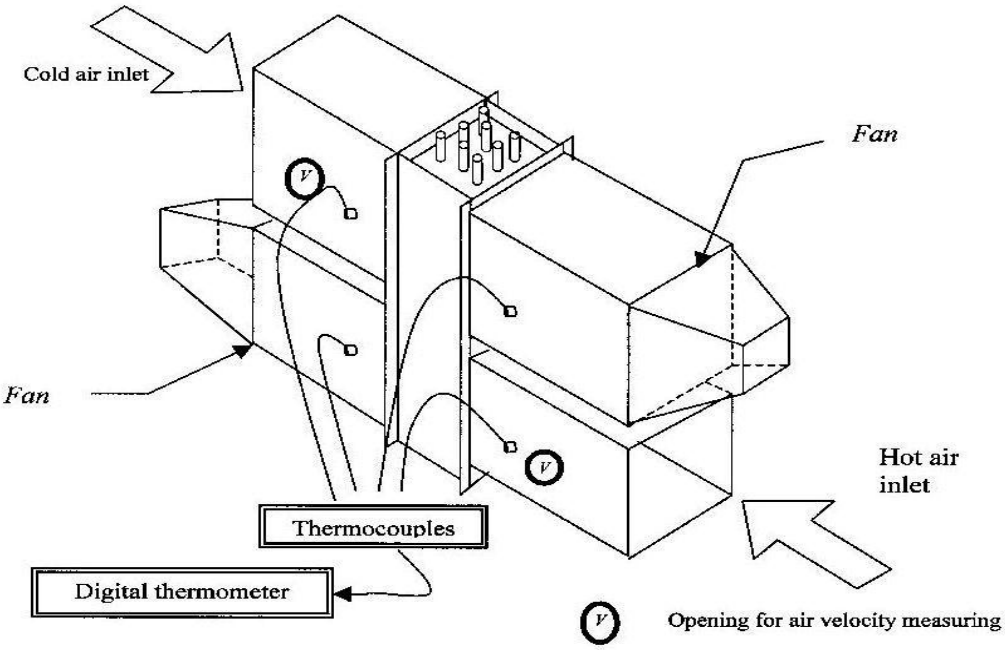

Fig 13 Test of thermal performance of CHP for heat recovery(application in surgery room in hospitals)

For the same velocity, the heat recovery was between 16% and 17% more efficient using two banks of TPCTs with plain fins instead of using one bank. Based on the CFD modeling results, at a velocity of 1m/s, the predictive pressure

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loss coefficient for a 2-row, parallel setup of six pipes was 3.3 compared with 4.2 for the staggered pipes and 3.7 for seven smaller parallel TPCTs. The study recommended that in naturally ventilated low-rise buildings without the influence of wind, the designed mean air velocity should be less than 1m/s. Wu et al [8] studied the applications of TPCT exchangers for humidity control in air conditioning systems. The conventional reheat coil can be replaced by this type of heat exchanger which results energy savings and enhanced cooling capability of the cooling coils.

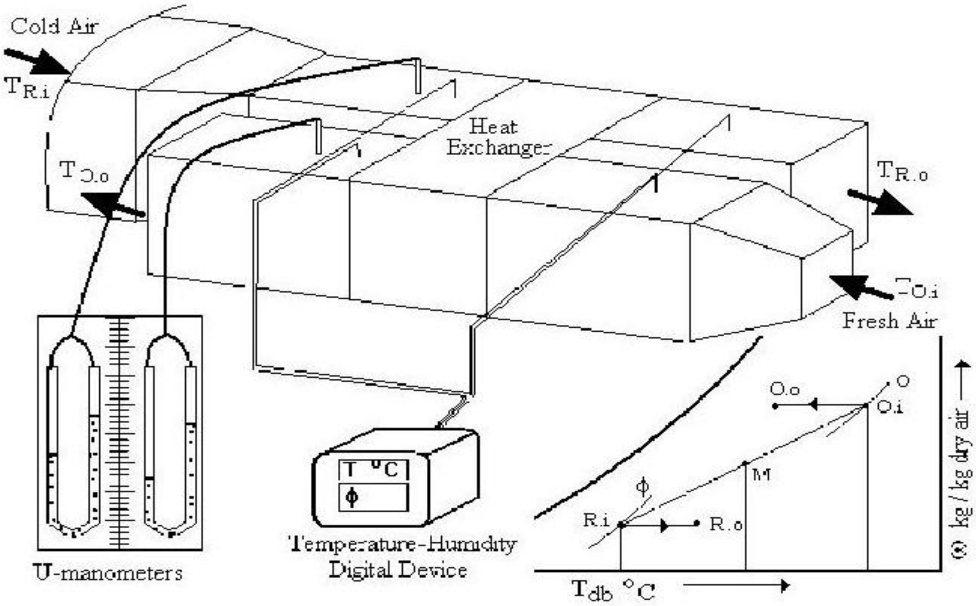

Fig 14 Test of thermal performance of CHP for heat recovery(application in Air conditioning)

IV. EXPERIMENTS, RESULTS AND DISCUSSION

Based on the survey of previous research, the CHP and TPCT were designed with different forms for heat recovery as shown in Fig. 6 to 12.

Fig. 9,10,11 and 12 represent heat recovery in spacecraft, Laptop, processor and CPU respectively. The experimental test rig of [2] (Fig. 13) consists of two fans that provide a flow rate of $0.103m^3/s$ through evaporator and condenser. The air velocities of both streams were measured by air velocity meters and were 2.3m/s. K type thermocouples were used and temperature measurement was processed by digital thermometer. The atmospheric air is heated by the three electric heating elements (total power 1500W). The air is discharged to the atmosphere after giving part of the heat to the evaporator

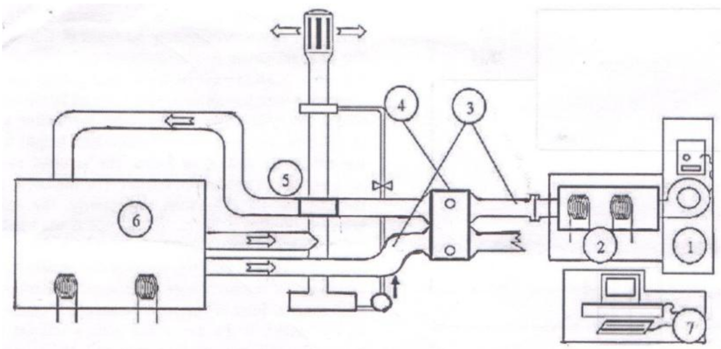

Fig 15 Application of Heat pipe with indirect evaporative recuperator

In the experimental setup of [3] (Fig. 14), the test section consists of two air ducts of 0.3m x0.22m section connected by finned tube HPHE.A refrigeration machine is provided to supply return cold air to the condenser side of HPHE.A blower of variable speed was installed before the cooling coil. The fresh air duct was equipped with a blower to supply

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air to the evaporator. The return-cold and fresh-warm air ducts were insulated with glass wool (50mm thick) to minimise the heat transfer to the surrounding air. The flow rates of air in both ducts were measured with a pitot-static tube. The fresh air was maintained constant as 0.4 kg/s, while the return air were varied, with values of 0.4, 0.6 and 0.933kg/s.

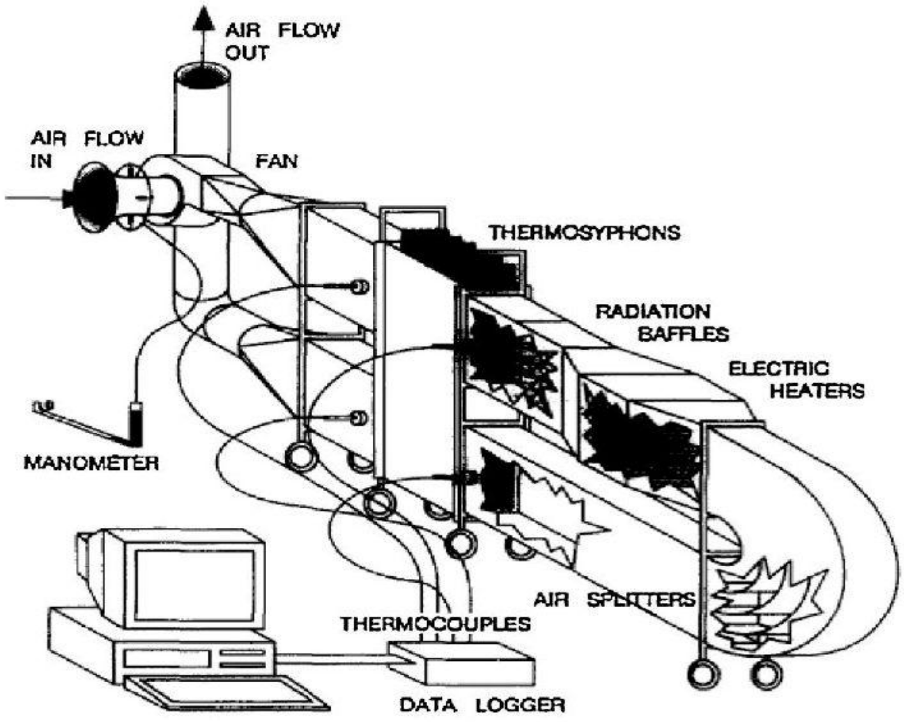

Fig 16 Test of TPCT's effectiveness

Fig 15 shows a schematic diagram of the experimental installation of [4] and comprised of the following components: (1) the air handle unit with variable flow air, which simulates the outside air (temperature, humidity and flow air), (2) a room maintaining the supply parameters, (3) air distribution ducts, (4) heat pipe recuperator, (5) indirect evaporative recuperator, (6) a room (1.2m x 1.2m x 1.5m) equipped with an air-air heat pump to maintain the comfort parameters and (7) a data acquisition computer (hardware and software) for monitoring.

The test rig of [5] was used to test the effectiveness of the TPCT (fig 16).Air heated in the upper condenser section is boosted by an electric heater and is returned as the heating air to the evaporator section in a counter flow configuration. A variable speed motor drives the fan.The air face velocity can vary between 1 and 5m/s. The heat input into the evaporator section inlet can vary between 4 and 20kW, depending on the number of activated heating elements. Thermocouple (type K) are used for the temperature monitoring. These measurements are processed by a computerised data logging system. Flow rate is measured by a pitot static tube.

Fig 17 shows the experimental setup of [6] where the hot fluid inlet of the heat exchanger(TPCT) is connected with the muffler outlet of the bus. A fan with a 100mm H_2O pressure head, 400m^3/h volume flow rate and 120W power supply is adopted to blow the air over the heat exchanger. The ambient temperature is 8^oC. The physical dimensions of the driver room and the carriage inlet are 1840mm x 2300mm x 1620mm and 1810mm x 2300mm x 7040mm, respectively. The carriage is an integral steel structure with a passenger gate. The maximum rotational speed of the petrol engine with six cylinders, is 3000 rpm, and the cylinder volume is 5.42 l.

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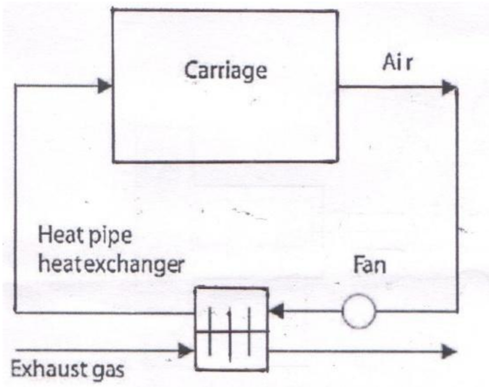

Fig 17 Warming passengers by recovery of heat from exhaust

In another study, Riffat and Gan [7] assessed the performance of the TPCT heat recovery units for naturally ventilated buildings. The test chamber made up of plywood insulated with a layer of polyurethane had an interior base area of 1.169x1.133 m and a height of 2.335 m. It was divided into two zones with a horizontal partition. There was an opening (0.215m x 0.215m) in the middle of the partition to allow air to flow from one zone to another. The net internal volume of the chamber was 3.09m^3. Supply and exhaust ducts were connected to the chamber on one of the vertical walls. The air ducts were also made of plywood.When air entered the lower zone via the supply duct and return air was extracted from the upper zone through the exhaust duct. A HPHE was provided in the supply and exhaust ducts for heat exchange between return and supply air.In the test rig of[8](Fig 18), the inlet air passing through th evaporator section of HPHE was heated by an electric heater and humidified by steam.The precooled air leaving the evaporator then passed through the cooling coil for further cooling and was returned to the condenser section.The air stream flow was in counter flow.A variable speed fan blew air through the ducts which has 25 cm square section at the lower duct and converted to a 25.4 cm diameter round duct at the return section.

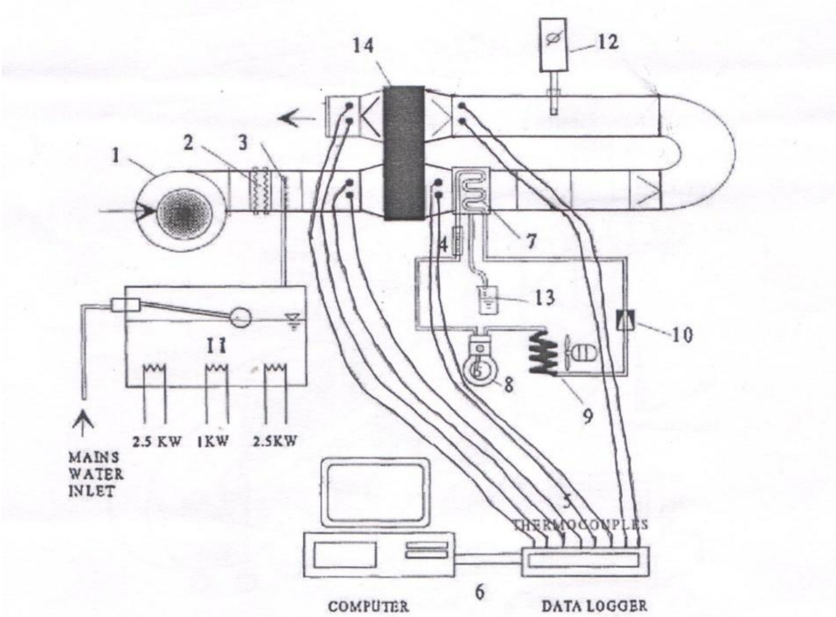

Fig 18 TPCT heat exchanger test rig- Test rig for enhancement of cooling capability

1.speed controlled fan 2.two air heaters 3. humidifier 4. Refrigerant flow meter
5. thermo couple 6. data logger 7. cooling coil 8. Compressor 9. condenser 10. Expansion valve
11. steam boiler 12. Air velocity meter 13. condensate measuring cylinder14. TPCT heat exchanger

These studies help the designers and researchers to select a test rig to investigate the thermal performance of HPHE of heat recovery system.

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4.1 PERFORMANCE

1. The effectiveness decreases with an increase in air velocities (Fig 20 and 22). This effect is reported by [1,5,7].
2. The rate of heat transfer increases with an increase in temperature. This effect is reported by [1,2,3,6] (Fig:19, 21)
3. The rate of heat transfer depends upon working fluids. If the working fluid changes from water to methanol to acetone, the heat transfer rate decreases for the same temperature. This effect is reported by [1,2],(Fig 19)
4. The geometry and number of pipes influence the effectiveness. These effects are reported by [1,5,6],(Fig 20, 22)

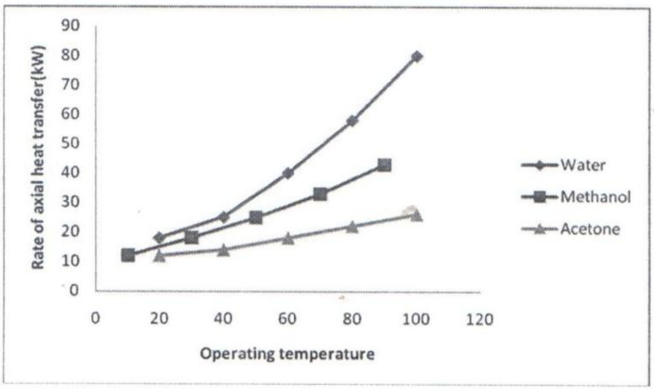

Fig 19 Variation of heat transfer with operating temperature

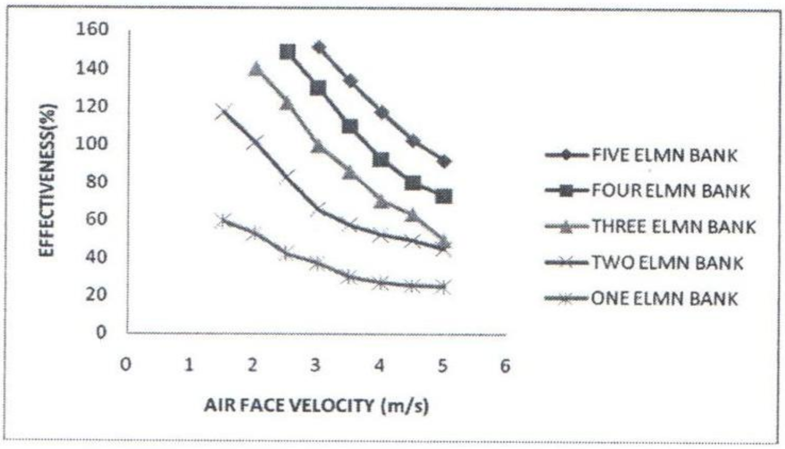

Fig 20 Variation of Effectiveness with velocity (effect of number of elements)

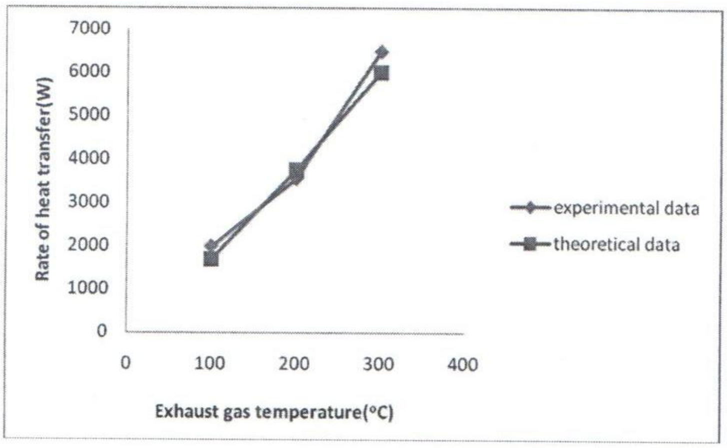

Fig 21 Variation of heat transfer with temperature

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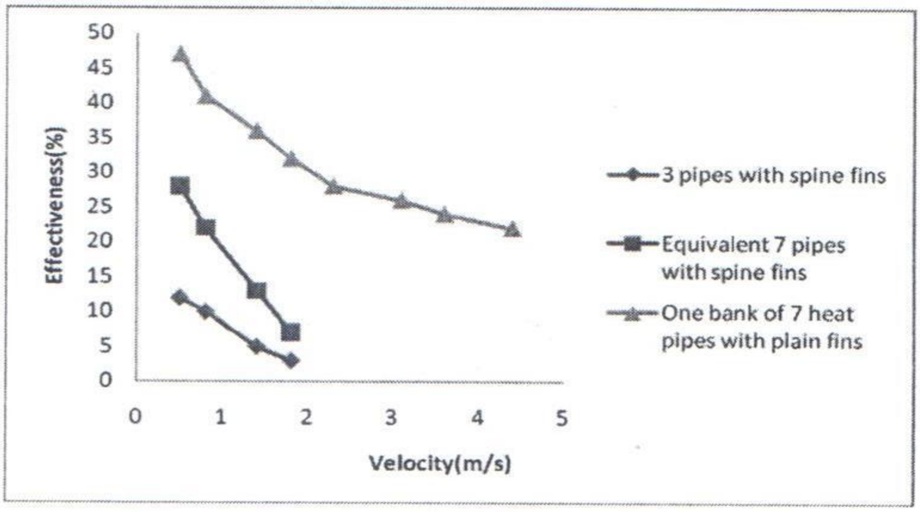

Fig 22 Variation of effectiveness with velocity (effect of geometry of pipes)

V. CONCLUSION

The HPHE units possess many advantages, such as heat recovery effectiveness, compactness, lack of parts, light weight, relative economy, smaller pressure drop of fluid flow across, complete separation of hot and cold fluids, and reliability. The thermal performance of HPHE can be enhanced by

1. Increasing the fluid flow time over the evaporator and condenser sections.
2. Providing modification of the surface or the dimension of the heat pipes.
3. Considering the working fluid–types, qualities.
4. Re-arranging the tubes of the heat pipe appropriately such that the fluid contacts the evaporator and condenser section.

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