Experimental Study of Heat Pipe Heat Exchanger in Hospital HVAC System for Energy Conservation

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***Abstract*— The hospitals Heating, Ventilating, and Air Conditioning (HVAC) systems consume large amounts of energy due to the specific requirements that must be met to ensure environmental conditions are healthy, convenient, and safe. Therefore, to reduce electricity consumption without sacrificing comfort and improving indoor air quality, the utilizing of heat pipe heat exchanger (HPHE) is necessary and highly recommended. An experimental study was conducted to investigate the thermal performance of heat pipe in recovering the heat of an exhaust air from a room simulator. HPHE consists of several tubular heat pipes with water as a working fluid and staggered by up to six rows. The outer diameter of each heat pipe is 13 mm and length of 700 mm with fins mounted on each heat pipe. A series of experiments was conducted to determine the effect of inlet air temperature. The influence of the number of heat pipe rows and air velocity was also investigated. The experiments show that the higher inlet air temperature, the more effective the HPHE performance has become. The cooling capacity of the system has increased. It was indicated by the decrease of air temperature entering the evaporator by 2.4 °C with the effectiveness of 0.15. This result was achieved when using six rows HPHE, air velocity 1 m/s, and evaporator inlet air temperature 45 °C. When air velocity was double to 2 m/s, the system reaches the largest amount of heat recovered of 1404.29 kJ/hour. The overall use of energy in HVAC system from the annual prediction of heat recovery for 8 h/day and 365 days/year will decrease significantly 0.6-4.1 GJ/yr.**

***Keywords*— heat pipe; heat recovery; HVAC; effectiveness.**

I. INTRODUCTION

Energy consumption in Indonesia increased by 3.1% in 2014, has doubled over the last 16 years [1]. The hospital is one of the commercial buildings with a high level of energy demands. The high consumption is due to the need for heating, cooling, ventilation and high load that must operate during 24 hours for most facilities, coupled with much medical equipment [2].

Energy Consumption Index for hospitals according to SNI 05-3052-1992 is 380 kWh/m2.year. Based on the results of the survey and energy audit conducted by BPPT and JICA with a sample of buildings in Jakarta show that the energy intensity of buildings hospitals reached 239 kWh/m2 per year [3].

The Heating, Ventilating, and Air Conditioning (HVAC) system is the largest energy consumer in the hospital, which contributed for nearly 60% of total energy costs that must be paid. The HVAC system (mainly cooling and ventilation) have a significant role in the electric power consumption [4]. Hu et al. stated that if the absorption chiller was not used, then the air conditioning system will consume about 70% of the total electricity used [5].

The large amounts of energy consumption by HVAC systems in hospitals, particularly the operating room is needed regarding to the accuracy control of the aseptic environment. Improperly control of hospital indoor air quality can cause infection and disease [6]. Hospital operating rooms require an installation of air conditioning to ensure healthy indoor environmental conditions so that the patient and medical personnel are more comfortable and safe. It can be done by keeping the environmental parameters within decided ranges and also to ensure acceptable indoor air quality with control, filter or reduce air contaminants [7, 8].

The indoor air quality in the operating room must be sterile, temperature and humidity are relatively constant and has a relatively low speed to avoid airflow and rotation that can cause recirculation microbes and can interrupt the procedure during surgery. Indoor air that flows out of the operating room should not be mixed up with the supply of fresh air from the outside (without recirculation) [2, 9]. The critical room, such as surgical operating room, usually requires air supply about 15-25 ACH, temperature 20 °C to 24 °C, relative humidity between 20% - 60% and a positive air pressure must be maintained [10, 11].

Therefore, it takes a method and equipment that support energy conservation efforts to reduce energy consumption without sacrificing comfort and at the same time improving the quality of the air that is clean and sterile. Using heat pipe heat exchanger (HPHE) as a sensible heat recovery is the right solution.

HPHE is the most effective tools for heat recovery [12]. Evaporator section of HPHE was used as the precooling the air before passing through the coil [13]. In conditions where the building needed more fresh air to generate positive pressure in the room, such as the operating room, the use of a heat recovery system is the best option. There is no mixing of the two airflows and thus no transfer of any pollutants that might be carried in the exhaust air of indoor environments [2].

The thermal energy flow from exhaust air could be used to recover sensible heat from the outside air resulting in reduced load on the cooling coil. This application is highly recommended for a system where the indoor and outdoor air is not mixed as in a hospital operating room, as well as biological and chemical laboratories [14, 15].

Several studies have been done on the effectiveness of HPHE especially their application to the HVAC system and can be found in many references [16, 17]. Another researcher such as Firouzfar E. et al. [13] conducted research to determine the effectiveness of HPHE with the use of nanofluid as working fluid. Thermal performance investigation of HPHE studied experimentally and theoretically by M. A. M. Hassan [18] used working fluid R410A, R134a, R22, and R407C. The result showed that the effectiveness HPHE more than 25% to 72% by increasing evaporator inlet air temperature up to 55 °C with the air velocity of 1.5 m/s. The use of R410A as a working fluid was recommended because it give a good result on the performance of HPHE and their effect on the environment was better than the R22 and R134a. Abd El-Baky and Mohamed [15] have conducted experimentally the effectiveness HPHE in waste heat recovery process to reduce the cooling load. The result showed that the heat transfer effectiveness was increased by 48% when the inlet air temperature 40 °C. The increase in inlet air temperature causes an increase in heat recovery up to 85%. SH Noie-Baghban and G.R. Majideian [12] have examined the use HPHE for heat recovery in hospital operating rooms and laboratories at a low temperature operating conditions (15-55 °C) and using methanol as the working fluid. The result showed that the minimum value of heat transfer rate obtained still far above the rate of heat transfer was needed. Furthermore, to improve the effectiveness HPHE, the area should have been coupled with fins installing on heat pipes or by increasing the number of heat pipes. Y.H. Yau dan A.S. Tucker [19] have used computer simulations to predict the performance of 6 rows HPHE without a wick on a tropical building HVAC system with a variety of operating conditions. The results obtained showed that the heat transfer increases with the addition of HPHE inclination angle, and by raising the air velocity in the evaporator with the effectiveness value ranges between 0.2-0.6.

Heat pipe heat exchangers have the potential to be applied to hospitals HVAC system, particularly operating room as heat recovery equipment. Therefore, the objectives of this study were to examine the thermal performance of HPHE for hospital HVAC systems applications and the amount of heat recovery experimentally.

II. Methodology

A. Design and Specifications

The detail specifications of HPHE used in this study were shown in Table 1.

TABLE I
HPHE Specification

OD tube	13 mm
Length of tube	700 mm
Tube spacing	transverse: 50 mm longitudinal: 58 mm
Fin	Copper plate, 30 fins of each heat pipe, thickness: 0.1 mm
Number of tube	2 row = 13 tubes 4 rows = 26 tubes 6 rows = 39 tubes
Tubes arrangement	staggered

In this study, the tubular heat pipe will be arranged staggered with vertical position and placed in the ducting before the cooling coil or evaporator of the air conditioning system. Evaporator section of HPHE installed on the bottom of the duct, condenser section of HPHE located on the top of the duct, and the adiabatic section inserted in the space between ducting. The rows number of HPHE will be varied and causing changes the number of a heat pipe that was used.

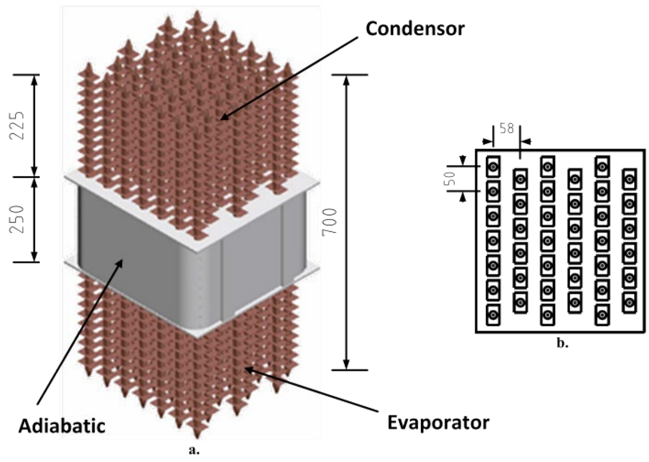

Fig. 1 (a). Dimensions of HPHE with fins are arranged staggered; (b). The distance between the HPHE tubes

Heat pipes made of the copper material, which uses water as working fluid with a ratio of 50% and added 30 sheets fins in each heat pipe to increase the heat transfer area. Each heat pipe has a length of 22.5 cm on each part of the evaporator and condenser, whereas the adiabatic section has a length of 25 cm as shown in Fig. 1 (a). Fig. 1 (b) illustrates the distance between the pipes in HPHE, transversal direction by 50 mm by 58 mm in the longitudinal direction.

B. Experimental Setup

Fig. 2 shows the test rig. It consists of some equipment such as fan on the inlet and outlet side, HPHE, cooling coil (evaporator of the air conditioner), condensers, the room simulator, and several measuring devices that are connected to ducting with dimensions of 30 cm x 47 cm. The placement of heat pipes in the ducting and direction of airflow in and out also shown in Fig. 2.

HPHE evaporator installed inside the ducting before the cooling coil of commercial air conditioning with a capacity of 9000 BTU. Commercial air conditioning was expected to be able to condition the room with length 310 cm, width 150 cm, and height 150 cm. The setting of evaporator inlet air temperature was done in the air heating chamber using the temperature control.

Temperature control (ON/OFF switch) on the 6 kW heating element using PID control (Proportional Integral Derivative) with a temperature tolerance ± 0.3 °C of the setting value was used in this experiment. Inlet fan flows fresh air into the ducting where the mass flow rate can be set, and an airflow rate was measured using a hot wire anemometer. Inlet air to be cooled (pre-cooled) came in contact with the evaporator HPHE. Furthermore, cooling process was conducted by cooling the coil to decrease the temperature of room simulator. Exhaust air from the room simulator flows into the upper side of ducting with a lower temperature than the temperature of the inlet air as it would be used to cool the condenser HPHE.

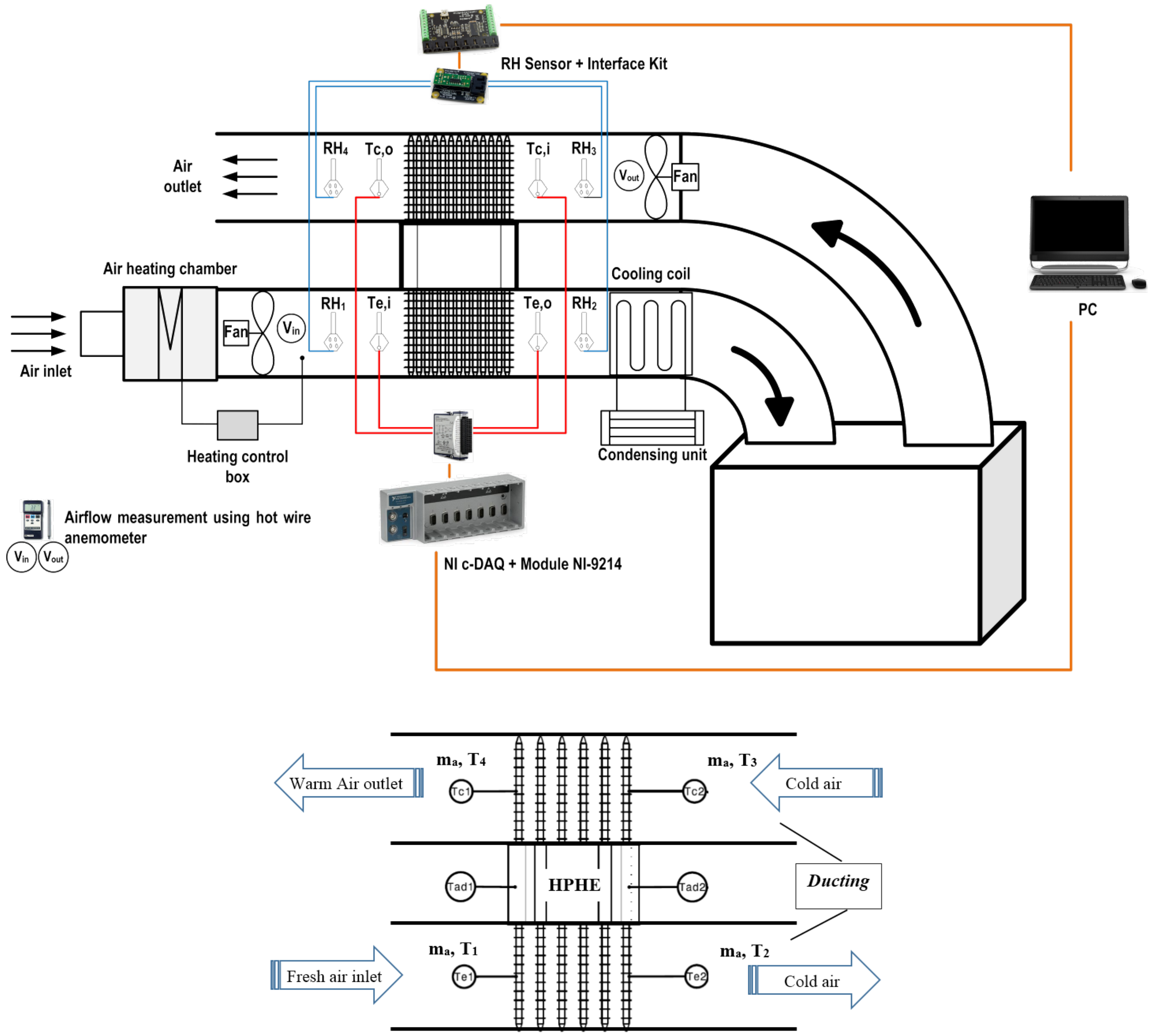

Fig. 2. Test Rig

Temperature measurement using the K-type thermocouple with a total of five thermocouples mounted on ducting, and in the ambient. Four thermocouples are installed in the ducting (before and after HPHE) to measure the air temperature and one thermocouple to measure ambient temperature. The measurement system was equipped with NI DAQ modules 9213 and 9211 are attached to the chassis NI cDAQ 9172 to measure the temperature. The measurement of relative humidity using four RH sensors Phidget Inc. and connected with the interface kit was installed in the ducting (before and after HPHE) and one sensor to measure ambient conditions.

Fig. 3 (a) presents the test rig simulator of HVAC system in the Heat Transfer Laboratory UI. Fig. 3 (b) shows the placement of the heat pipe in the ducting.

(a).

(b).

Fig. 3 (a). Equipment Test Simulator;
(b). HPHE placement in the ducting

The sensible effectiveness could be used to determine the thermal performance of HPHE from the air side. Effectiveness is the most relevant parameter to describe the performance HPHE. Effectiveness in Equation (1) is defined as the ratio of the actual heat transfer to the maximum heat transfer in a heat exchanger.

$$\varepsilon = \frac{Q_{act}}{Q_{\max}} \quad (1)$$

$$\varepsilon = \left(\frac{T_{e,i} - T_{e,o}}{T_{e,i} - T_{c,i}} \right) \quad (2)$$

III. Results and Discussion

A. Heat Pipe Heat Exchanger Performance

The thermal performance of HPHE can be determined from the value of its effectiveness. Results of experiment are to determine the effectiveness HPHE with variations or operating parameters as shown in Fig. 4. It illustrates that the greatest effectiveness 0.15 is obtained when using six rows HPHE with the air velocity 1 m/s at a temperature of 45 °C. At the same condition showed that the evaporator inlet air temperature has decreased to 2.4 °C indicating that HPHE already working. During the air velocity 1 m/s, the value of effectiveness was better than the airflow velocity of 1.5 m/s and 2 m/s due to decrease airflow causes the absorption of heat by HPHE become maximal. The result shows that the effectiveness of HPHE has increased systematically by increasing the evaporator inlet air temperature and the number of rows HPHE as well as a decrease in airflow velocity.

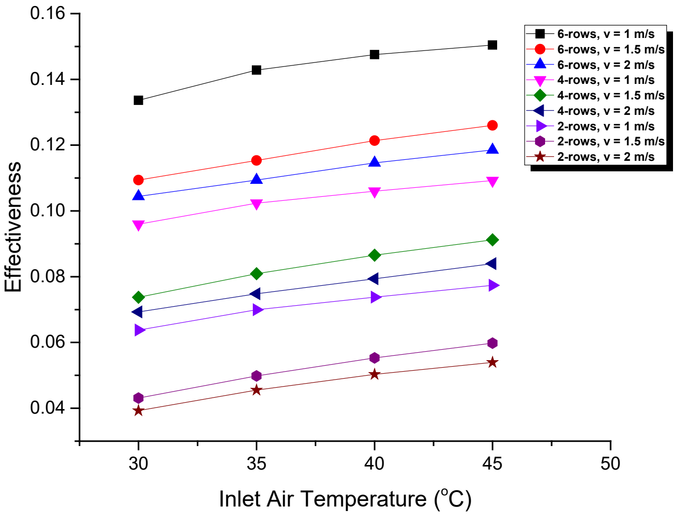

Fig. 4 The effectiveness of heat pipe heat exchanger

B. Heat Recovery

In this experiment, heat recovery was only observed in the precooling (evaporator HPHE) because it provides a direct impact on the reduction in the energy consumption of the system. The amount of heat recovery can be achieved in the use of HPHE in the HVAC system with several variations of the experiment was shown in Fig. 5. It presents that the greatest value of heat recovery was obtained equal to 1404.29 kJ/hour when using six rows HPHE at the evaporator inlet air temperature 45 °C and the air velocity 2 m/s. Whereas for the smallest value of the heat recovery was obtained when using two rows HPHE at the evaporator inlet air temperature of 30 °C and the air velocity of 1.5 m/s was equal to 204.72 kJ/hour.

Increasing the number of rows and evaporator inlet air temperature significantly influences the increase in heat recovery from HPHE. However, the magnitude of the maximum and minimum heat recovery did not change significantly when the evaporator inlet air velocity was increased at the condition two or four rows HPHE.

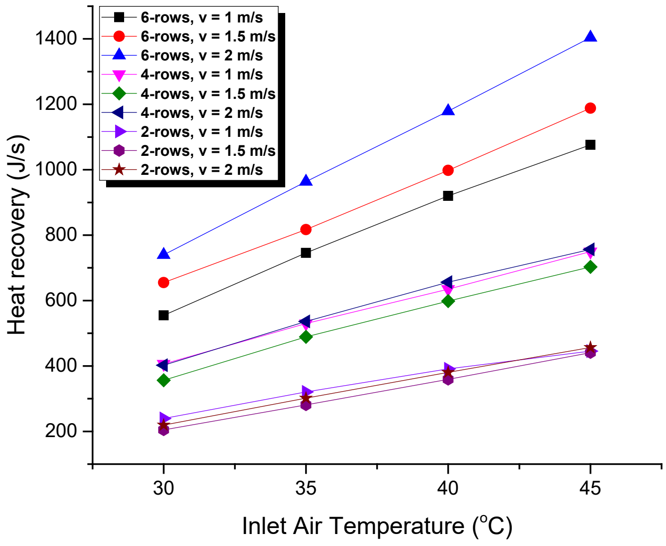

Fig. 5 Heat recovery on evaporator HPHE

From these results, it can be concluded that the use of six rows HPHE was an optimum design compared to the use of two or four rows. The addition of air velocity will increase the mass flow rate of air that can increase the heat transfer rate between the air and HPHE thus increasing the value of heat recovery.

IV. Conclusions

HPHE could work well. The cooling capacity of the system increased as a result of the precooling process. It was indicated by a decrease in the temperature of air entering the evaporator up to 2.4 °C with the effectiveness 0.15 when using six rows HPHE, air velocity of 1 m/s, and the evaporator inlet air temperature of 45 °C. HPHE thermal performance increase in line with the rise in the HPHE rows number and evaporator inlet air temperature and a decrease in airflow velocity. The largest amount of heat recovery achieved 1404.29 kJ/hour when using six rows HPHE, the evaporator inlet air temperature of 45 °C, and an air velocity of 2 m/s. Whereas for the smallest value of heat recovery was obtained equal to 204.72 kJ/hour when using two rows HPHE, the evaporator inlet air temperature of 30 °C, and an air velocity of 1.5 m/s. If the operating room to operating for 8 hours/day and 365 days/year, the reduction in energy consumption at the hospital HVAC system can be seen from the predicted amount of heat recovery which reached 4.1 GJ/year.

Nomenclature

Q	heat transfer rate	W
T	temperature	°C

Greek letters

ε	effectiveness

Subscripts

act	actual
max	maximum
c	condenser
e	evaporator
i	inlet
o	outlet

Acknowledgment

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