EXPERIMENTAL AND FEASIBILITY STUDY OF THE UTILIZATION OF U-SHAPED HEAT PIPES FOR REDUCING AIR HUMIDITY IN HVAC SYSTEMS

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Abstract

Along with various activities carried out in the building, an HVAC system is needed to provide a comfortable room in terms of temperature and humidity control for its occupants. Operating an HVAC system requires a large amount of energy, which is around 30% of the total energy consumption in the building, so it is important to reduce its energy consumption. To meet room temperature set point in conventional HVAC system, overcooling the fresh air and heating it back to achieve the needed room humidity is inevitable. This research has investigated the effect of utilization of U-shape heat pipe for reducing supply air humidity by reheating process before entering a conditioned room. The U-Shaped heat pipe experiments were varied using one row and two rows with six heat pipe in each row. The inlet air temperature in the evaporator section was varied of 35°C, 40 °C, and 45 °C, while the inlet air velocity varied of 1.5 m/s, 2.0 m/s and 2.5 m/s. The results showed that the two-row of U-shaped heat pipes can reduce the relative humidity as much of 21.31%. The highest effectiveness of 46 % was obtained when using the two-row U-shaped heat pipes at inlet air temperature of 35 °C and air velocity of 1.5 m/s. The highest energy saving in reducing air humidity was 647 W, which was achieved with the two-row U-shaped heat pipes at inlet air temperature of 45 °C and air velocity of 2.5 m/s. With that amount of energy-saving value, the fastest payback time can be achieved by using the two rows U-shaped heat pipe for 0.5 years (six months), respectively.
Keywords: *HVAC, U-shape heat pipe, feasibility study, energy saving*

1. Introduction

The population in Southeast Asian countries currently continues to grow, including Indonesia, and as such growth, dependence on fossil fuels as the primary fuel for transportation and electricity also increases[1]. In 2010, as Indonesia's population growth continues to increase, the domestic energy consumption is expected to be tripled by 2030[2]. The Indonesian government is targeting an increase in the optimal use of renewable energy aimed at reducing energy dependency on oil, gas, and coal which is almost gone[1]. Along with the current climate change, a rapid increase in building energy consumption has become a concern for reducing the use of energy by buildings and their components. Among the factors related to building components, the HVAC system has accounted for the most significant portion of the total building energy consumption and nearly 40 - 60% of global energy consumption and energy consumed by buildings[3-5].

In the subtropics (hottest and humid) area, humidity control is a common problem in providing comfortable and healthy conditions for controlled air space[6]. Referring to the ASHRAE standard, the air temperature to provide comfort to human occupancy is approximately between 20 °C – 28 °C[7] and relative humidity less than 65% [8]. In the conventional HVAC system, in order to meet the standard room condition, overcooling the fresh air and heating it back are inevitable [9]. In addition, reducing humidity can also be achieved by using a desiccant rotary wheel[10].

The efforts to recover exhaust heat from the conditioned room to reduce energy consumption in HVAC systems by using heat pipes have been carried out [11-13]. A heat pipe is a simple device consisting of a closed pipe that has a very high thermal

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conductivity, which can transfer large amounts of heat efficiently without the need for external electrical input[14, 15]. Putra et al. (2017) used a straight heat pipe heat exchanger consisting of 2, 4, and 6 rows as a precooling device in an HVAC system. From the results, the highest amount of heat recovery was 1404.29 kJ/hour [16]. Then Kusumah et al. (2019) investigated the use of U-shaped heat pipe heat exchangers with the aim of pre-cooling air before entering the cooling coil device and reheating air to reduce air humidity. Their experimental results showed that the highest effectiveness was 7.64% and the highest amount of heat recovery was 2190.43 kJ/hour[17]. Jauhara, investigated the use of a wraparound heat pipe heat exchanger (U-shaped loop heat pipe) to reduce air humidity. The heat pipe used was thermosyphon. The results showed an annual saving of nearly 134 MWh [6]. The literature review shows that heat pipes are very effective in reducing energy consumption in HVAC systems. However, various efforts to improve the performance of the HVAC system need to be carried out continuously. In the HVAC for the recovery system, the straight heat pipe can be mounted vertically or horizontally [18].

The main objective of this research was to investigate the effect of the utilization of a U-shaped heat pipe for reducing energy consumption, and its feasibility in the HVAC system. The U-shaped heat pipe was installed around the cooling coil in the ducting system, where the evaporator side of the heat pipe was positioned before the cooling coil and its condenser side positioned after the cooling coil. The adiabatic side was then above the cooling coil.

2. Methodology

This paper discusses the utilization of the U-Shaped heat pipe for reducing energy consumption and investigate the feasibility of this equipment in the HVAC application.

2.1. Experimental designs

The design of the U-shaped heat pipe heat exchanger is shown in fig.1. The U-Shaped Heat Pipe was varied into two configurations, one row and two rows with six heat pipe for each row. In two rows, the U-shaped heat pipes was arranged in a staggered configuration. The heat pipe was made of a copper with an outer diameter of 10 mm and length of tube 710 mm, with sintered copper wick and used water as a working fluid. The heat pipe consisted of three parts, namely the evaporator at one end, the condenser part at the other end, and adiabatic part in between.

Table 1. U-shape Heat pipe specifications

The outer diameter of tube	10 mm
Length of tube	710 mm
Length of evaporator	150 mm
Length of adiabatic	410 mm
Length of condenser	150 mm
Tube arrangement	One row and two rows (staggered) with six heat pipe for each row

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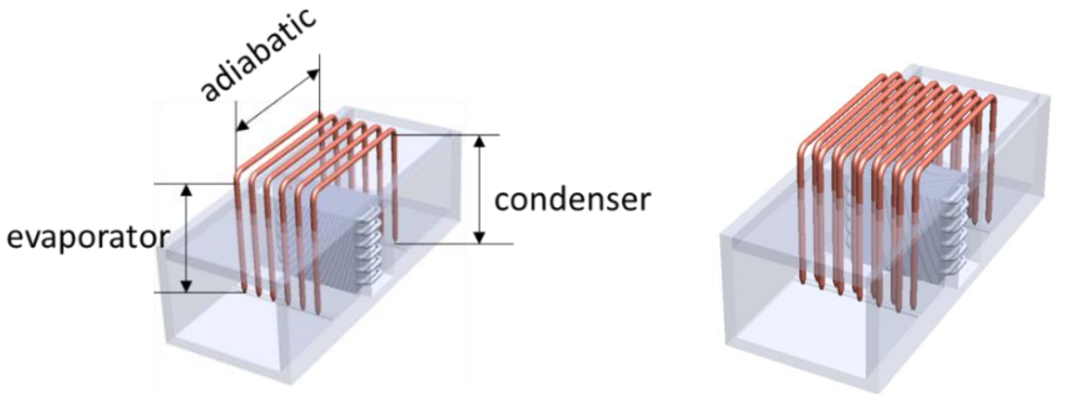

(a) (b)

Figure 1. (a) U-shaped Heat Pipe 1 Row; (b) U-shaped Heat Pipe 2 Row in a staggered configuration

2.2. Experimental setup

The experimental setup in this study is shown in Figure 2. A 6000 W heater controlled with a Proportional-Integral-Derivative Controller (PID) was used to vary the entering air temperature in the evaporator side of the heat pipe. Inlet air was varied at 35 °C, 40 °C and 45 °C. An axial fan was used to supply fresh air into the inlet side of the room at a velocity of 1.5, 2.0, and 2.5 m/s. The air velocity was measured using the Lutron AM-4204 wire anemometer water. Type K thermocouple connected with module NI9214 was used to measure the air temperature, while for the measurement of relative humidity an Autonic sensor connected with Module NI9207 was used.

Inside the ducting, before flowing into the cooling coil device, the air entered the evaporator side of the U-shaped heat pipe. So the precooling process occured. After the cooling coil cooled the air, the air will flow to the condenser side of the heat pipe, so that the reheating process will occur.

In this research, we focused on the utilization of U-shaped heat pipes that were applied in HVAC systems. There are 5 measurement points for temperature and relative humidity, i.e :(Te, in), (Teu, in), (Teu, Out), (Tcu, in), and (Tcu, out) as shown in Figure 3.

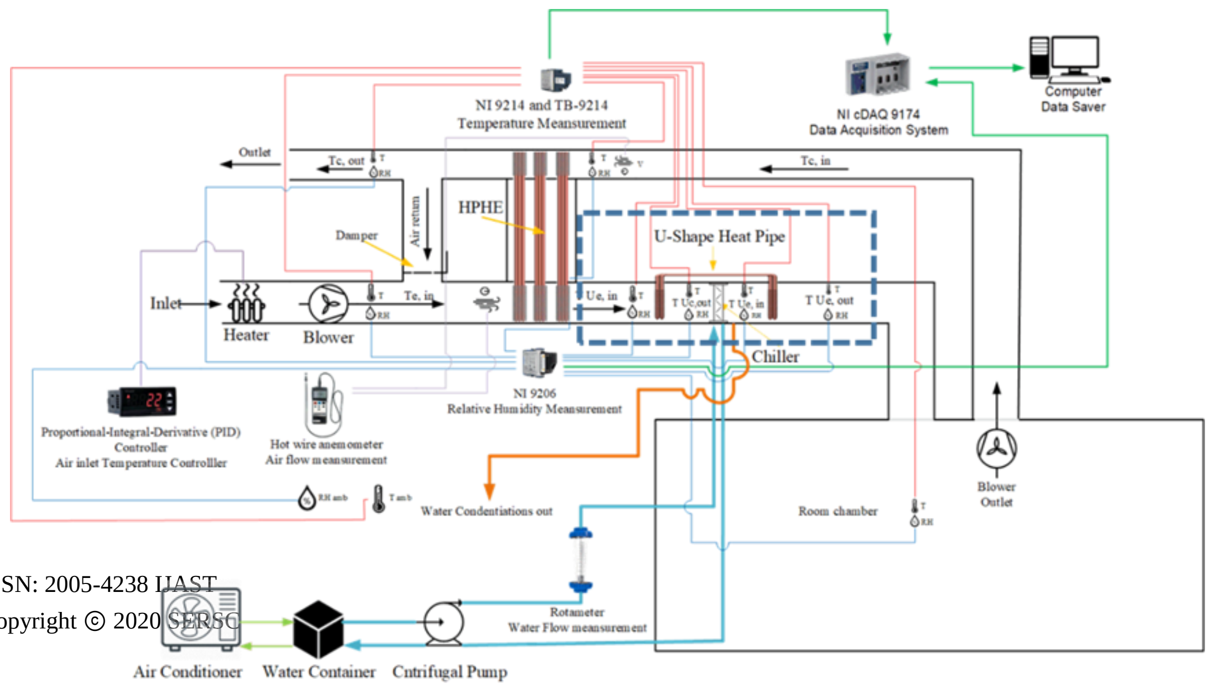

Figure 2. U-shaped Heat Pipe Experimental Setup

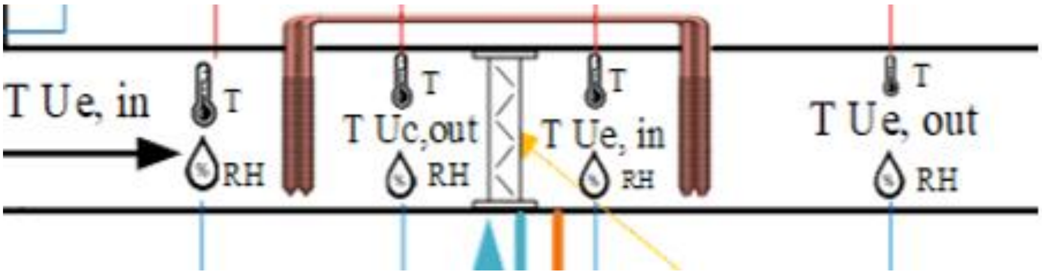

Figure 3. Position of Temperature and RH sensor

2.3. Effectiveness Calculation

The performance of the U-shaped heat pipe used in the HVAC system was investigated using thermal effectiveness as in equation 1. The effectiveness of the U- shaped heat pipe is defined as the ratio of actual to the highest heat transfer [16, 19-23].

$$\varepsilon = \frac{T_{c\ U,out} - T_{c\ U,in}}{T_{e\ U,in} - T_{c\ U,in}} \qquad (1)$$

2.4. Energy Saving Calculation

Inside the ducting, before flowing into the cooling coil device, the air entered the evaporator side of the U-shaped heat pipe. So the precooling process occured. After the cooling coil cooled the air, the air will flow to the condenser side of the heat pipe, so that the reheating process will occur.

$$Q_{Reheat} = \dot{m}_a \cdot C_p \left(T_{C\ U,out} - T_{c\ U,in}\right) \qquad (2)$$

$$Energy_{Saving} = Q_{reheat} \qquad (3)$$

$$Cost\ Saving = Energy_{saving\ per\ year}\ (kWh)\ x\ Electrical\ Cost\left(\frac{IDR}{kWh}\right) \qquad (4)$$

2.5. Feasibility Evaluation

Payback Periods from investments of using U-shaped heat pipes can be determined by dividing total investment by energy-saving, as shown in equation 5.[13, 24, 25]. The price of one U-shape Heat pipe was Rp.300,000 so that one-row of six heat pipes costed Rp.1,800,000 and two-row with twelve heat pipes costed Rp.3,600,000.

$$Payback\ Periods = \frac{total\ investment\ (IDR)}{Cost\ Saving\left(\frac{IDR}{year}\right)} \qquad (5)$$

3. Result and discussions

3.1. Temperatures and Relative Humidity Profile

Figure 4 shows the temperature profile of the U-shape heat pipe with two rows configuration at 2.5 m/s inlet air velocity. Air entered straight heat pipe (Te, in) and then exited from straight heat pipe heat exchanger (Te,U in), where this point was the same with inlet air side of U-shaped heat pipe. On the evaporator side of U-shape heat pipe (Te, U out) there was a decrease in temperature. It indicated that precooling had occurred on the evaporator side. Then, after the air exited the cooling coil or on the inlet side of the condenser (Tc, U in) he air then experiences an increase (Tc, U out) which meant the reheating process had occurred. At the inlet air temperature of 45°C and air velocity of 2.5 m/s, by using two rows U-shaped heat pipes an increase in temperature on the condenser side was 6.8°C. At the same time, the relative humidity as shown in Figure 5 had decreased from 82.8% to 61.5%. It showed that U-Shaped Heat Pipe was able to reduce the relative humidity as much as 21.31%.

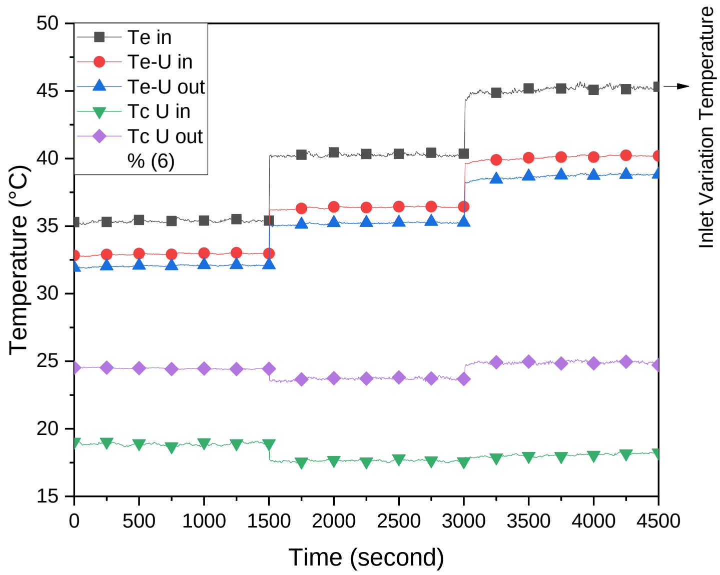

Figure 4. The temperature profile of two-row U-shaped heat pipe with inlet air velocity of 2.5 m/s

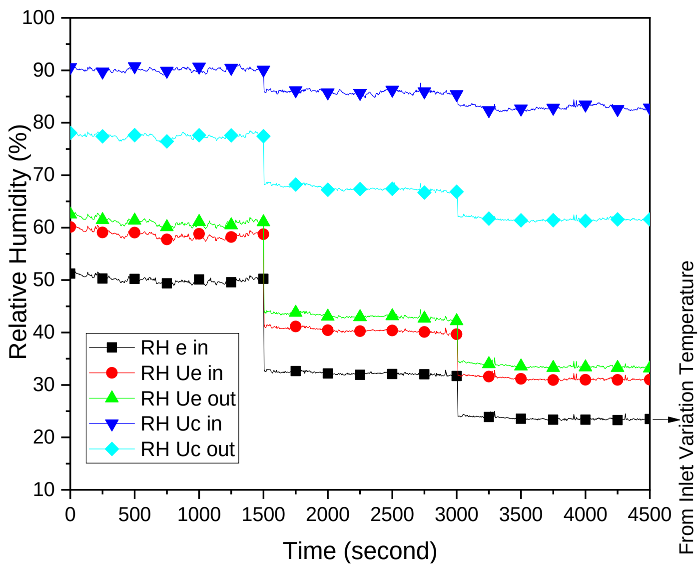

Figure 5. The relative humidity of two-row U-shaped heat pipe with inlet air velocity of 2.5 m/s

3.2. Effectiveness and Difference of Relative Humidity Profile

Figure 6 shows that the highest effectiveness of the U-shaped Heat pipe configuration was realized by using two rows at 46% when the inlet air temperature was 35 °C and air velocity of 1.5 m/s. However, in this condition, the decrease in relative air humidity was only 12%. Figure 7 shows the different relative humidity or decrease in relative humidity on the condenser side of the U-shaped heat pipe. The highest difference in relative humidity is 21% at inlet air temperature of 45 ° C and air velocity of 2.5m/s. At this condition, the effectiveness of the U-shaped Heat pipe was 31%

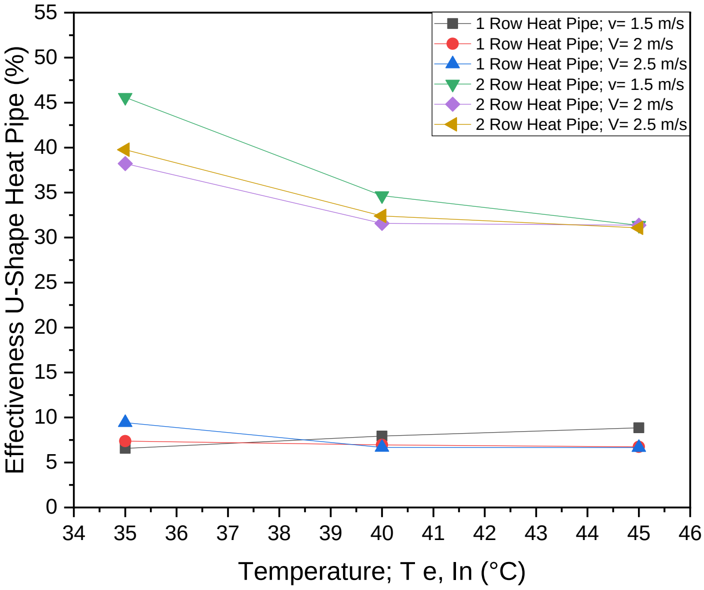

Figure 6. The effectiveness of the U-shaped Heat Pipe

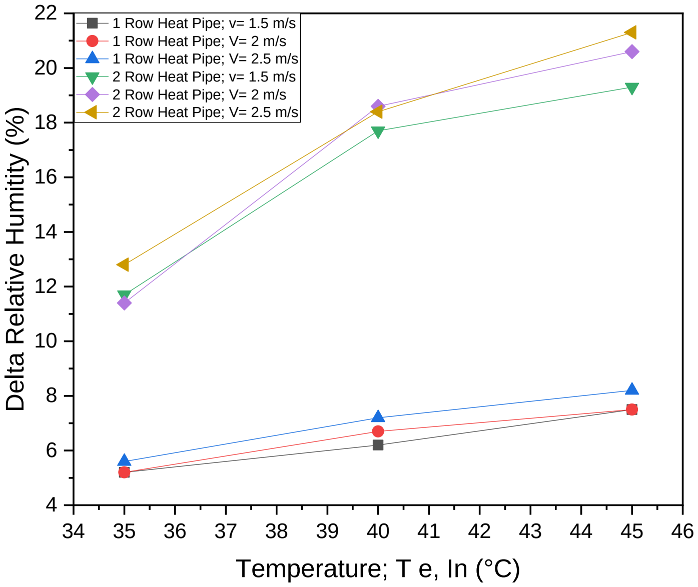

Figure 7. The difference of Relative Humidity in the condenser section of the U-shaped Heat Pipe

3.3. The Energy-Saving and Payback Periods Profile

Figure 8. shows the energy-saving profile of the utilization of U-shaped heat pipes in the HVAC system. The highest energy savings of 647.7 W occurred in a two-row configuration, with inlet air velocity of 2.5 m/s and inlet air temperature of 45 °C. While the lowest energy savings of 51.8 W occurred in a one-row configuration, at air inlet temperature of 35 ° C and inlet air velocity of 1.5 m/s.

Figure 9 shows the comparison of payback periods of one and two rows configuration of U-shaped heat pipe. It can be shown from the figure that the fastest payback time can be achieved by using the two rows U-shaped heat pipe for 0.5 years (six months), respectively.

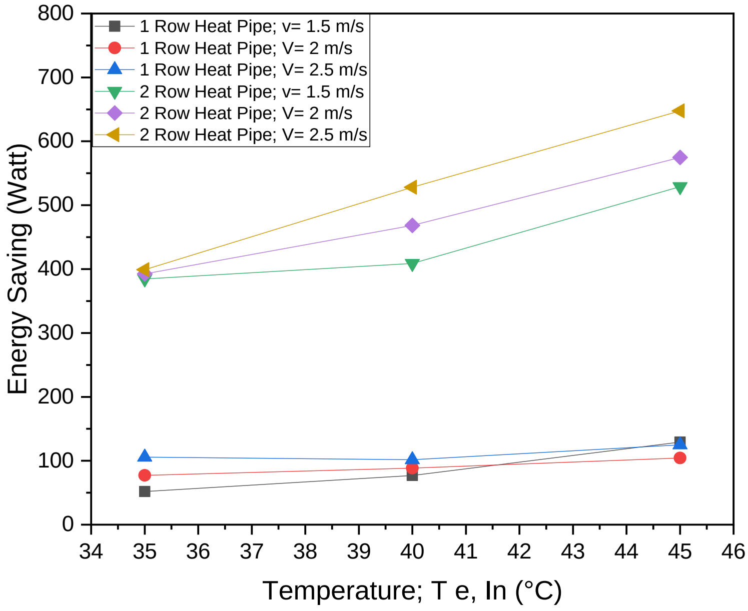

Figure 8. The Energy-Saving of U-shaped Heat Pipe

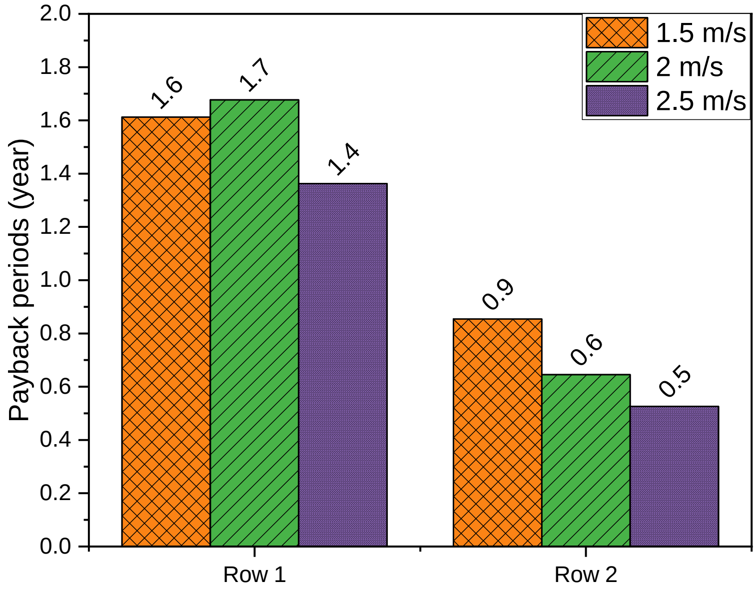

Figure 9. The Payback Periods of U-shaped Heat Pipe

4. Conclusions

The utilization of U-shaped heat pipes has proven to be very effective as a precooling as well as preheating media in the HVAC system. The highest effectiveness of 46 % was achieved when two-row U-shaped heat pipes was used at inlet air temperature of 35°C and air velocity of 1.5 m/s. The highest difference in relative humidity is 21% at inlet air temperature of 45 ° C and air velocity of 2.5m/s with resulted the effectiveness of 31%. The highest energy saving for reducing air humidity of 647 W was achieved with two-row U-shaped heat pipe at inlet air temperature of

45°C and air velocity of 2.5 m/s. With that amount of energy-saving value, the fastest payback time can be achieved by using the two rows U-shaped heat pipe for 0.5 years (six months), respectively.

Appendix

$T_{e,in}$	Inlet air temperature,°C
$T_{e\ U,in}$	Inlet air temperature in the evaporator section of U-Shape heat pipe,°C
$T_{e\ U,out}$	Outlet air temperature in the evaporator section of U-Shape heat pipe,°C
$T_{c\ U,out}$	Inlet air temperature in the condenser section of U-Shape heat pipe,°C
$T_{c\ U,in}$	Outlet air temperature in the condenser section of U-Shape heat pipe,°C
ε	Effectiveness
Q_{Reheat}	Heat transfer in the condenser section (Watt)
$\dot{m}_a$	air mass flow rate(kg/s)
C_p	Specific heat in the condenser section (J/kg K)
$Energy_{Saving}$	Electrical energy saving (Watt)

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