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Fully Fresh Air Air-conditioning System Equipped with Double Heat Pipe Based Heat Recovery Technology

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ABSTRACT

Using of double heat pipe based heat exchanger (HPHX) in a conventional fully fresh air air-conditioning (AC) system was examined in the present study. The fabricated HPHXs were tested under the actual conditions and the measured data were used to study the performance of the existing AC system (System A) and AC system equipped with the double HPHXs (System B) for a yearly operation through modeling in the TRNSYS software. Simulation results showed that the System B with the six and eight-row HPHXs, could maintain the air conditions within the recommendations. However, it was found that the System B with the double eight-row HPHXs is superior in terms of energy savings.

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1. INTRODUCTION

During the last two decades primary energy has grown by 49% with an average annual increase of 2% [1]. In addition, predictions shows that this growing trend is expected to continue; therefore, the increasing trend of energy demand has raised concerns over sustainable energy supply, environmental effects, and exhaustion of energy resources.

Globally, buildings consume about 40% of the total world annual energy consumption [2]. In addition, energy consumption of air-conditioning (AC) systems is considerable and it is mostly higher than 50% of total building energy consumption [3]. Hospitals and health care facilities are the most energy demanding spaces. In hospitals and health care facilities the air needs to be changed at least 20 times per hour and the exhaust air is not allowed to be mixed with fresh outdoor air [4]. Therefore, significant amount of energy can be recovered if AC systems are equipped with the heat recovery devices. This objective can be achieved by employing heat recovery technologies such as heat pipe based heat exchangers (HPHXs). HPHXs are made of sealed heat pipe tubes containing a refrigerant as a working fluid. Heat pipes are passive heat transfer devices (no external power requirement) that allow transferring high amounts of heat over medium distances. The heat transferring capability of heat pipes is several orders of magnitude greater than solid metals [5]. HPHXs advantages over conventional heat recovery devices such as: high efficiency, no external power requirement, no moving parts, and easy manufacturing make the engineers to use this heat transfer device for energy recovery purposes [6]. Apart from the energy issues, not suitable air quality in the operating theaters can affect the health and safety of the medical staff. Air relative humidity (RH) must be controlled at acceptable range, and it is related to space hygiene, since some sorts of diseases mostly occurs in high humid conditions. ASHRAE standards recommend 20-24$^{\circ}C$ and 30-60% RH for the operating theaters [4]. In addition, a RH higher than 70% in low velocity air ducts can cause the accumulation of the moisture on the duct lining and subsequently microbial growth and fungal contamination [7]. Therefore, it is strongly recommended to maintain the supply duct air RH lower than 70% [8].

In a previous study, application of the double eight-row HPHX on the existing AC system of an operating theater was examined by Yau [9] (see Figure 1). The

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existing system was redesigned as in Figure 2 and the effect of added HPHXs was determined for a whole year of operation. For this study [9], series of tests were conducted on an eight-row HPHX under controlled conditions to obtain the performance of the HPHX empirically for the simulation purposes [10].

The eight-row HPHX was installed in an environmental control chamber and the inside air, which was received by the HPHX evaporator section, was controlled in the district points (see Figure 3). The temperature and RH of the environmental control chamber was set at district amounts as the representative for the out side air conditions.

As it is shown in Figure 3, the evaporator side of the HPHX receives the air from the control chamber and the condenser section of the HPHX is exposed to the off cool air. Then, the empirical performance of the eight-row HPHX based on the categorized evaporator inlet air RH was obtained and used to represent the eight-row HPHX component mathematically for the simulation process in TRNSYS software.

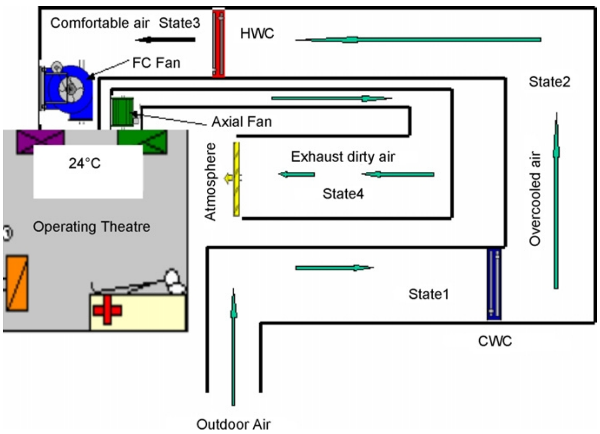

Figure 1. AC system schematic diagram, [9]

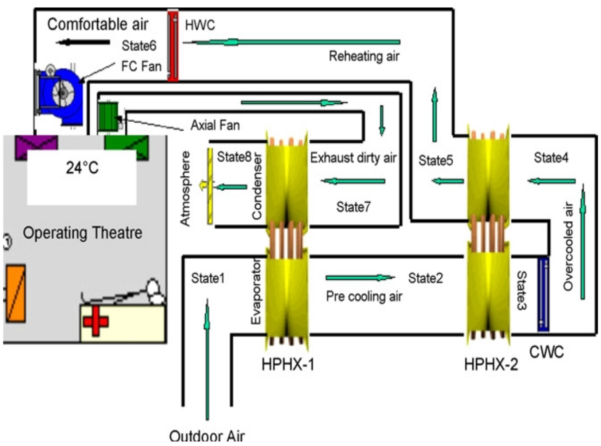

Figure 2. AC system modified by the HPHXs, [9]

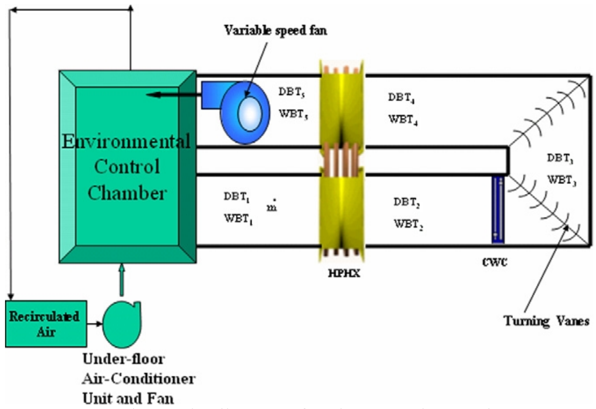

Figure 3. Schematic diagram for the experimental set-up, [10]

It is clear that in this research, the environmental control chamber was employed to simulate the tropical outdoor air rather than using the actual outdoor air. Moreover, the empirical performance of the HPHX was obtained based on the steady state performance of the HPHX in the test setup. However, in the actual conditions, the HPHX is expected to receive the real outdoor air and operates under the transient operation conditions. These limitations may lead to some uncertainty on the simulated findings. Therefore, the present study was performed and the same design, i.e. double HPHX was employed for the study. On the other hand, this time the performance characteristics of four different HPHX with two, four, six, and eight-row achieved under the actual test conditions during the period of one week (168 hour) and were used for the simulation purposes.

In the two earlier papers [11, 12], the author examined a two and four-row HPHX in a climate chamber under the situations close to the situations. They would expected to experience in the actual AC system. In these series of test runs, the HPHXs were placed in a climate chamber to determine the real performance characteristics of the fabricated HPHXs in the tropical climate of the Kuala Lumpur, Malaysia. In the experiments, the evaporator side of the HPHX receives the fresh outdoor air and the condenser side of the HPHX receives the return indoor air. The indoor air temperature and coil face velocity was set to the amounts recommended and mostly expected to occur in practice. Then, the performance of the HPHXs was monitored and recorded hourly during the period of at least one week. The above mentioned procedure was conducted for two, four, six, and eight-row HPHX and the performance of the HPHXs was used for the simulation of the new configuration, i.e. the AC system equipped with the double HPHXs. More details regarding the tests may be found in Ref. [11, 12].

This time, the operating theater at the Putrajaya Hospital, Kuala Lumpur, Malaysia (OTPH) was chosen as the case study. TRNSYS software was employed to determine the hourly performance of the systems in terms of the provided air conditions and energy consumption level. This study makes to achieve more realistic and reliable estimations of the impact of the double HPHX configuration on the existing AC system.

2. TRNSYS DESCRIPTION

TRNSYS software is a Transient System Simulation Software (TRNSYS) and applied in this study for simulation of the AC system in order to understand the hourly performance in terms of provided air conditions and energy consumption. This program requires the Typical Meteorological Year (TMY) weather files to simulate the hour-by-hour performance for the whole year of 8760 hours.

3. SYSTEM A, EXISTING AC SYSTEM

In this research, operating theatre number three was chosen for the research case study. As a requirement for the operating theaters, AC system of the OTPH is a fully fresh air system and exhaust air is not permitted to be recycled and be mixed with the fresh air. In the existing AC system, an energy recovery wheel has already been used for energy recovery purposes. With this device, energy recovery is achieved with placing the recovery device between the fresh hot outdoor and cool exhaust air. In order to understand the situation of the provided air conditions by the existing AC system, the physical parameter of the space i.e. temperature and RH were recorded. The measurements showed that the mean room temperature and RH is 20.4 $^{\circ}C$ and 60.5%, respectively.

4. SYSTEM A SIMULATION IN TRNSYS

In order to study the effect of double HPHXs on the existing AC system, the existing system, System A, must be simulated first in TRNSYS studio. The standard AC components are available in the software library and can be used. However, the performance characteristics of the non-standard equipment can be written as FORTRAN source code and defined as a new component in the software library. The OTPH building was defined as a single thermal zone (Type 56a) and the internal and architectural conditions of the space and building was obtained and defined in Type 56a component. Figures 4 and 5 show the System A schematic diagram and simulation layout, respectively. The TRNSYS components, processes, and functions are tabulated and described in Table 1.

TABLE 1. The processes and functions in Figures 5 and 7

Code or label	Description of the components	Function
Type109-TMY2	Kuala Lumpur Weather Data	This component reads TRNSYS TMY2 format weather file to determine the outdoor condition.
Type56a	OTPH	This component takes the inlet DBT, RH and air flow and calculates the space DBT and RH.
Type265	HPHX	This component takes the inlet air properties to evaporate and condenser to calculate the HPHX evaporator and condenser leaving air properties.
TYPE206	Energy recovery wheel	This component takes the on coil dry and wet bulb temperature to calculate the off coil air conditions.
TYPE202	Cooling Coil	This component takes the inlet air properties to calculate the cooling coil outlet air properties.
TYPE207	Blower	This component takes the inlet air DBT and RH to calculate the leaving air DBT and RH.
TYPE209	Heater	This component takes the entering air properties, air flow, and power input to calculate the leaving air properties and power consumed.
TYPE218	Chiller	This component takes the total load of the air handling unit to calculate the power consumption.
Type33	Psychrometric Calculator	This component takes any two properties of moist air to calculate all other properties of moist air.
Type25c	Printer	This component saves the simulated data into a specified file.

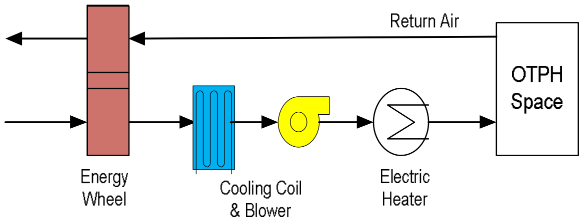

Figure 4. Schematic diagram of the System A at OTPH

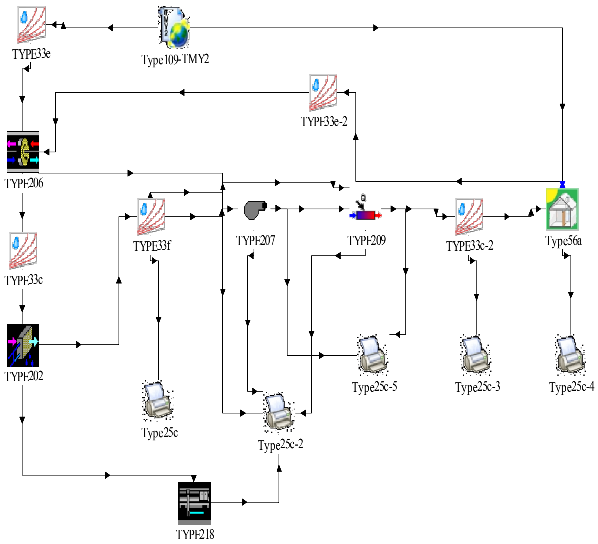

Figure 5. Simulation layout for the System A

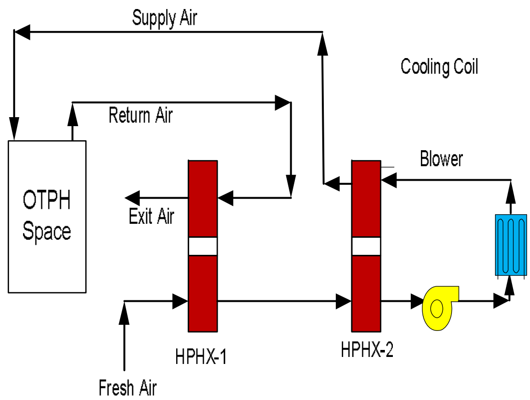

Figure 6. Schematic diagram of the System B

5. SYSTEM B, REDESIGNED AC SYSTEM

The existing AC system is equipped with the energy recovery wheel. However, because of the operational principles of this energy recovery device, the cross contamination of the fresh and return air are expected, which is strongly prohibited for the operating theatres as the clean spaces. Therefore, the system was reconfigured as System B with the added double HPHXs, as illustrated in Figure 6. The HPHXs were defined as a new component and added into the TRNSYS studio (see Figure 7). The System B performance was obtained and compared with the System A. HPHXs with two, four, six and eight-row were examined in the System B to determine the most proper configuration in terms of the provided air conditions and energy consumption level.

6. SIMULATION RESULTS AND DISCUSSION

The comparison of the Systems A and B performances are presented in this section. The provided space air conditions by the systems will be reviewed first in Section 6.1 and annual energy consumption of the systems will be discussed in Section 6.2.

6. 1. Space Conditions for the Systems A and B

The existing AC system was simulated and the provided air conditions were obtained for a yearly operation, as shown in Figure 8. According to the simulation results, the indoor temperature fluctuates between 18.54$^\circ C$ and 20.68$^\circ C$ with the mean value of 19.54$^\circ C$ and RH varies from 58.24% to 62.46% with the mean value of 59.03%. The System A simulation results were compared with the filed measurements and acceptable agreement was found between the field measurements and simulation values (see Table 2).

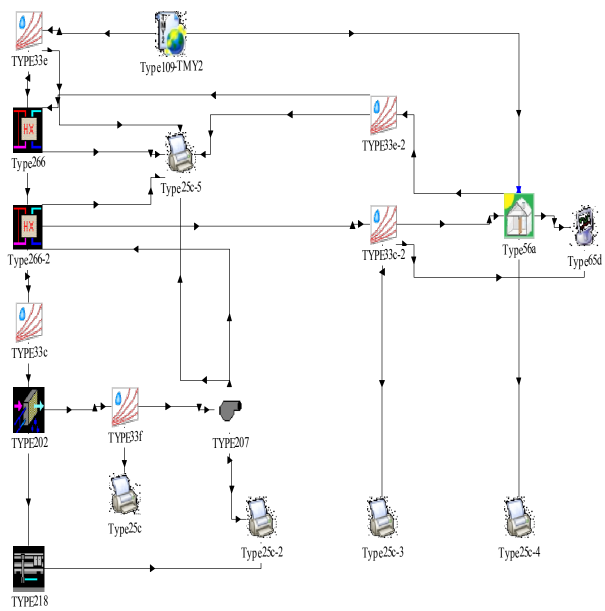

Figure 7. Simulation layout for the System B

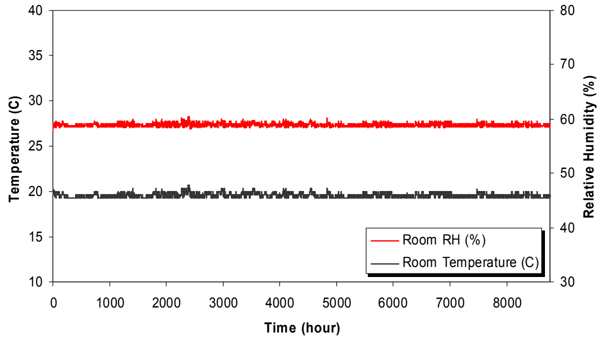

Figure 8. Hourly provided air conditions by the System A

TABLE 2. Space air conditions for the System A: Existing AC system

	Space Temperature (°C)	Space RH (%)
Field measurements	20.4	60.5
Simulation values	19.6	58.9
Deviation (%)	3.9	2.6

Figure 9 shows the simulation responses for the double eight-row HPHX configuration as a representative of the HPHXs examined. The simulation results showed that the System B could keep the indoor air conditions within the recommendations by the ASHRAE standard. Based on the results, the room temperature would be at $20.3^{\circ}C$, $21^{\circ}C$, $21.4^{\circ}C$, and $21.6^{\circ}C$ with the added double two, four, six and eight row HPHXs, respectively. In addition, the indoor air RH would be at 61.2%, 55.1%, 52.8%, and 51.5% with the HPHXs, as tabulated in Table 3. However, the provided supply duct air by the double two and six-row HPHX configurations are not within the recommendation. As it is shown in Table 3, the supply duct air RH is 80.3% and 71.3% with the double two and four-row HPHXs configurations, respectively. Therefore, only the six and eight-row configurations are capable of providing the desired air conditions for the space.

6. 2. Annual Energy Consumption for the Systems A and B

The annual energy consumption by the System A components are tabulated in Table 4. As tabulated in Table 4, it is clear that the chiller and heater are the main energy consuming equipment at 47% and 42%, respectively.

Based on the previous section, the double six and eight-row HPHX configurations could provide the most proper air conditions to the space; therefore, the double HPHX with six and eight-row were considered for energy analysis. However, the annual energy consumption by the System B configurations are tabulated in Table 5. Figure 10 shows the yearly energy consumption comparison between the Systems A and B. The systems performance in terms of energy consumption level were estimated and compared in Table 6. The yearly energy consumption comparison between Systems A and B indicates that the system with double eight-row HPHX is superior in terms of energy saving in comparison to the six-row double HPHX configuration. The estimations showed that the double eight-row HPHXs configuration have the potential to save a total amount of 27.48 MWh in a yearly operation. Figure 9 also illustrates the supply duct air RH for the double eight-row configuration. The simulation results shows that this configuration can provide the supply duct air in less that 70%, which is desirable for the supply duct air RH [7, 8].

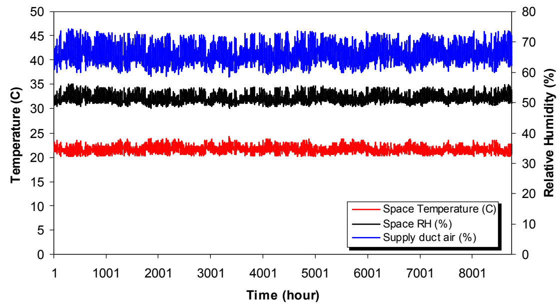

Figure 9. Hourly provided air conditions by the System B

TABLE 3. Space air conditions for the System B

System B configurations	Space Temperature (°C)	Space RH (%)	Supply RH (%)
Double two-row HPHX	20.3	61.2	80.3
Double four-row HPHX	21.0	55.1	71.3
Double six-row HPHX	21.4	52.8	67.9
Double eight-row HPHX	21.6	51.5	66.0

TABLE 4. Energy consumption of the System A: Existing AC system

Equipment	Energy Consumption (kWh)	Percentage (%)
Chiller	34,016.24	47.07
Heater	30,660	42.42
Energy Recovery Wheel	1,629.36	2.25
Blower	5,956.8	8.23
Total	72,262.4	

TABLE 5. Energy consumption of the System B

System B configurations	Energy consumption of the equipment (MWh)				
	Chiller	**Heater**	**Energy Recovery Wheel**	**Blower**	**Total**
Double two-row HPHX	44.2	-	-	7.84	52.04
Double four-row HPHX	36.8	-	-	9.03	45.83
Double six-row HPHX	34.3	-	-	10.66	44.96
Double eight-row HPHX	33.1	-	-	11.68	44.78

TABLE 6. Energy consumption and saved energy for the entire year (MWh)

System	Chiller	Heater	Energy Recovery Wheel	Blower	Total	Saved Energy (MWh)
System A	34.02	30.66	1.63	6	72.26	
System B: Double eight-row HPHX	33.1	-	-	11.68	44.78	27.48

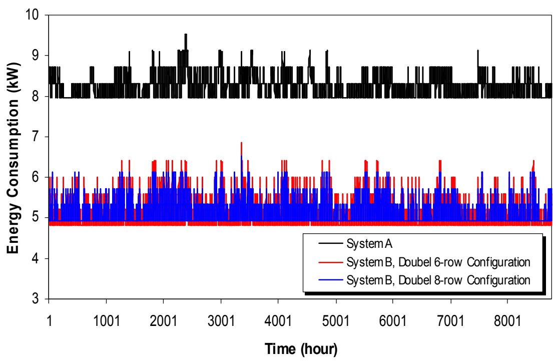

Figure 10. Yearly energy consumptions of Systems A and B

7. CONCLUSIONS

In this study, the hourly effect of double HPHX configuration on a tropical AC system was investigated empirically for a whole year of operation. The findings showed that the application of double HPHX in the existing AC system significantly improved the existing system performance in terms of energy consumption level and provided air conditions. The main conclusions from this research study are as follows:

1. System B configuration could maintain the indoor air conditions within the range recommended by the ASHRAE standard.
2. The cooling load of the existing system is significantly redistributed by the pre-cooling effect of the double six and eight-row HPHX. Therefore, the supply air RH is less than maximum 70% suitable for the supply duct air. However, the supply duct air RH provided by the double two and four-row HPHX configuration is out of the recommendations.
3. As expected, System B consumes less energy in comparison to System A. Since in System B, the heater elements was replaced by the condenser sections of the added double HPHX, which is providing free heating, and evaporator sections pre-cools the outdoor air before entering into the cooling coils.
4. The energy consumption of the Systems A and B was compared and it was revealed that System B configuration with the double eight-row HPHX is superior configuration in terms of energy savings capability and has the potential to save a total amount of 27.48 MWh energy in a year; thereorfe, the double eight-row HPHX configuration is recommended to be used in the system.

8. ACKNOWLEDGMENTS

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Fully Fresh Air Air-conditioning System Equipped with Double Heat Pipe Based Heat Recovery Technology

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چکیده

در تحقیق حاضر کاربرد دو مبدل حرارتی لوله ای همزمان در یک سیستم تهویه مطبوع معمول مورد بررسی قـرار گرفتـه است. مبدلهای حرارتی لوله ایی ساخته شده در شرایط کارکرد واقعی تست و داده های بدست آمده برای مطالعه اثر مبدلها در سیستم تهویه موجود مورد استفاده قرار گرفته است. به این منظور عملکرد سیستم موجود (سیستم A) و سیستم مجهز به دو مبدل حرارتی لوله ای (سیستم B) در طول عملکرد یک ساله توسط نرم افزار شبیه ساز سیستمها در محیط نرم افزار TRNSYS مورد ارزیابی قرار گرفته است. نتایج شبیه سازی نشان می دهد که سیستم B مجهز به دو مبدل حرارتی لوله ای شش و هشت ردیفه شرایط هوا را منطبق با استانداردها فراهم می نمایند. عملکرد سیستمها از نظر میزان مصرف انرژی نشان می دهد که سیستم B با دو مبدل حرارتی هشت ردیفه عملکرد بهتری نسبت به دو مبدل شش ردیفه داشته و قابلیت صرفه جویی بیشتری در انرژی را دارد.

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