PERFORMANCE ANALYSIS OF AIR-CONDITIONING SYSTEM WITH FIXED-PLATE HEAT EXCHANGER IN TROPICAL CLIMATE

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ABSTRACT

Electrical energy consumption of air-conditioning systems has escalated. Its performance can be enhanced using integrated systems - systems that combine the air-conditioning system and the fixed plate heat exchanger. Various integrated and non-integrated systems have been investigated in cold climate countries while researches on such systems in hot and humid countries are limited. This study was carried out to determine and compare the performance of an integrated system with stand-alone air-conditioning system by varying the temperature inlet. The results showed that the cooling capacity and Coefficient of Performance (COP) for integrated system were 1.5-2.8 kW and 1.8-3.1 respectively which were higher than stand-alone system with 0.9-1.8 kW of cooling capacity and 1.2-2.2. One-way ANOVA was conducted. The results were shown that the performance of integrated system was statistically better than stand-alone air-conditioning system.

Keywords*:* COP, cooling capacity, fixed plate heat exchanger, energy recovery system, hot-humid climate.

INTRODUCTION

The global energy use is escalating at an alarming rate which has raised concerns over depletion of energy resources and accelerating environmental impacts such as ozone layer depletion and climate change [1]. Over 50 % and 30 % of electricity bills are contributed by the power consumption of the air-conditioning system in commercial building and residential areas respectively. As a result, electrical consumption in 2011 has exceeded 100,000 GW h in Malaysia [2]. Thus, reducing energy consumption in buildings is the priority for global energy policy makers [1].

Energy recovery system has been broadly employed in buildings which recovers sensible and latent load from exhaust stale air to pre-condition the outdoor fresh air [3]. Fixed-plate heat exchanger utilize its corrugated structure to transfer thermal energy from outgoing to incoming air streams. By applying energy recovery unit of fixed-plate heat exchanger in conventional air-conditioning system, the waste condensing heat from air-conditioning system can be recovered [4].

Many studies have been carried out on performance of air-conditioning system. However, there is the problem of waste condensing heat, causing the air-conditioning system to be inefficient. Several approaches have been conducted to conserve the energy of air-conditioning system. For instance, Jadhav and Lee [5] employed heat pipe heat exchanger for energy recovery in air-conditioning system in different climatic zones of India. Yau [6] investigated the performance of 8-row heat pipe heat exchanger for building heating, ventilating and air-conditioning (HVAC) systems by taking into account inlet air state. He found that maximum of 0.856 can be achieved in sensible heat ratio active cooling which implies a strong moisture removal as relative humidity inlet increased. Wan et al. [7] found out that heat pipe heat exchanger can significantly reduce energy consumption of central air-conditioning system. Liang et al. [8] concluded that membrane heat exchanger in HVAC system improves the performance of air-conditioning system significantly. Nasif et al. [9] compared annual energy consumption of an air-conditioner coupled with Z-flow heat exchanger with a conventional air-conditioning system using HPRate software. It was found that 8 % of annual energy savings can be achieved in integrated system.

On the other hand, numerous researches have been paid close attention to seasonal weather but less on hot-humid climate which has constant outdoor temperatures with high humidity annually. For instance, Fan et al. [10] evaluated the energy conservation performance of real office space with an energy recovery ventilator and air conditioner in Japan by adopting computational fluid dynamics (CFD) program with building energy simulation (BES) software. Yang et al. [11] conducted the performance and energy saving analysis of energy recovery ventilator with air-conditioning system in both cold and hot seasons in China. Delfani et al. [12] combined energy recovery with cooling coil to study the effect of energy recovery on sensible and latent load in various climates of Iran. They found out that there is about 11-32 % of energy consumption can be reduced by using energy recovery with air-conditioning system. Beccali and Finocchiaro [13] compared the performance of a cross flow heat exchanger for air handling process in wet and dry operation. Mathur [14] simulated energy savings using heat pipe heat exchanger on the existing air-conditioning systems in different climatic conditions. In another study, Zhang and Zhang [15] found out over 80% of the energy during the hours of operation of air conditioning can be saved by applying heat pipe heat exchanger in the air handler in Southern China with long, hot and humid summers.

Despite many investigations related to integrated system, the application of fixed plate heat exchanger in tropical climates is still limited. Thus, to narrow this gap, this study focuses on performance analysis of air-conditioning integrated with fixed-plate heat exchanger in tropical climate, where hot and humid climate conditions could justify the use of energy recovery systems. This research applies a cross flow configuration of fixed-plate heat exchanger with numerous corrugated channels to increase its surface area for heat and mass transfer. The primary objective is to evaluate and compare the performance of integrated system with stand-alone air-conditioning system by varying inlet conditions. The results are analyzed based on cooling capacity and coefficient of performance (COP).

METHODOLOGY

An aluminum box of dimension 0.8 m x 0.5 m x 0.2 m was built to provide sufficient fresh air requirement for air-conditioning (AC) system [16]. The split-wall AC system with indoor unit size of 0.8 m x 0.19 m x 0.28 m and outdoor unit size of 0.7 m x 0.24 m x 0.54 m were studied in this research. Besides that, an aluminum box of size 0.6 m x 0.2 m x 0.4 m was constructed to house a fixed-plate heat exchanger of size 0.25 m x 0.25 m x 0.1 m with two separate air ducts of diameter 0.185 m. The core was formed by hydrophilic polymeric membrane layers which were made of cellulose paper with corrugated structures. The membrane layers were organized in cross-flow manner to allow both heat and moisture to be transferred simultaneously.

The experiments were set up as shown in Figure 1. Two centrifugal blowers were installed in energy recovery unit to assist good distribution of airflow through fixed plate heat exchanger. To create heat and humid condition, heater and humidifier were utilized at inlet air ducts in hot stream. Portable air-conditioning unit was employed to condition the return air [16].

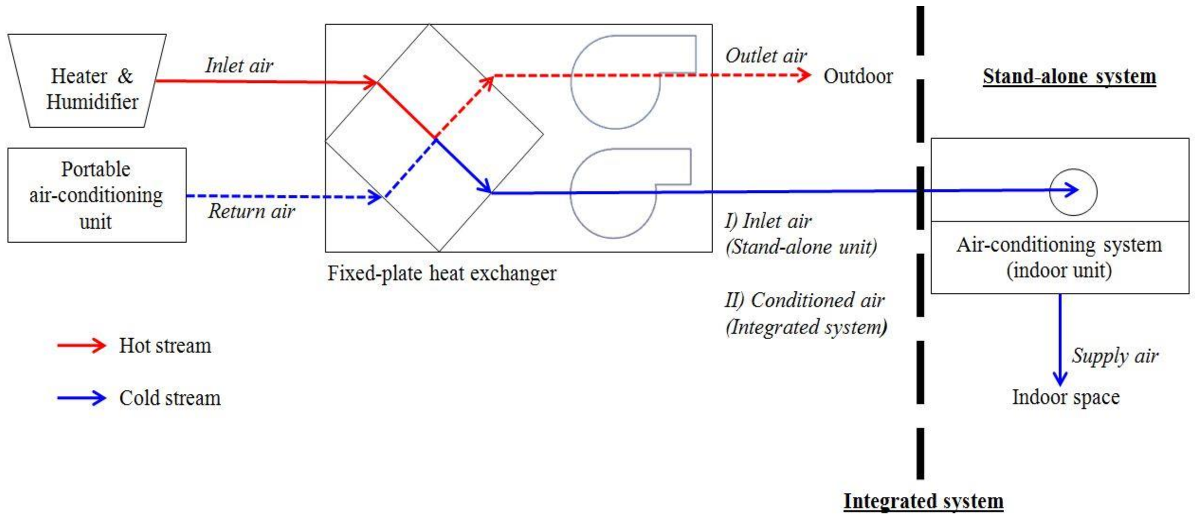

Figure 1 Experimental set up of stand-alone and integrated system.

Parameters of temperature, relative humidity and air velocity were taken with HD9817T1 temperature and humidity transmitters as well as Digi-Sense 20250-16 hot-wire thermoanemometer. Measurements were carried out for 2 h after reaching steady state of 20 min. The data was recorded with datataker DT80 using DtUsb software. Inlet air were conditioned at temperature of 28 ºC, 31 ºC, 34 ºC and 40 ºC according to the average dry bulb temperatures for several cities in hot-humid climate zone [12, 17].

Cooling capacity, coefficient of performance (COP) and percentage energy saved were evaluated with Equation 1-3 as shown below [18]:

$$Cooling\ capacity = \dot{m}\ (H_{iah} - H_{sac}) \tag{1}$$

$$COP = \frac{cooling\ capacity}{power} \tag{2}$$

where,
$\dot{m}$ = mass flow rate, g/s
H_{iah} = Enthalpy of inlet air in hot air stream, kJ/kg
H_{sac} = Enthalpy of supply air in cold air stream, kJ/kg

The data were analyzed with statistical analysis independent t-test using software IBM SPSS Statistics 20. T-test was applied to determine whether there are statistically significant differences between the means of two independent groups. Assumptions were performed before running analysis of t-test.

RESULTS & DISCUSSION

Cooling Capacity

Figure 2 shows that cooling capacity for temperature inlet of 40 ºC is 2.8 kW which is higher than 34 ºC with 1.8 kW, 31 ºC with 1.7 kW and 28 ºC with 1.5 kW in integrated system. In stand-alone air-conditioning (AC) system, cooling capacity for temperature inlet of 40 ºC was 1.8 kW which was higher than 34 ºC with 1.2 kW, 31 ºC with 1.1 kW and 28 ºC with 0.9 kW respectively. The largest difference between two systems was 1 kW at temperature inlet of 40 ºC. Cooling capacity in integrated system is higher than stand-alone air-conditioning system when temperature inlet increases.

Cooling capacity shows how much the heat load of the AC system can remove within a certain time frame [2]. From Figure 3, cooling capacity increases when the temperature inlet escalates, causing heat load to be removed is high. As FPHE precondition the inlet air, the enthalpy condition of supply air is low and thus the heat load is high in integrated system. Therefore, cooling capacity for integrated system is larger than stand-alone AC.

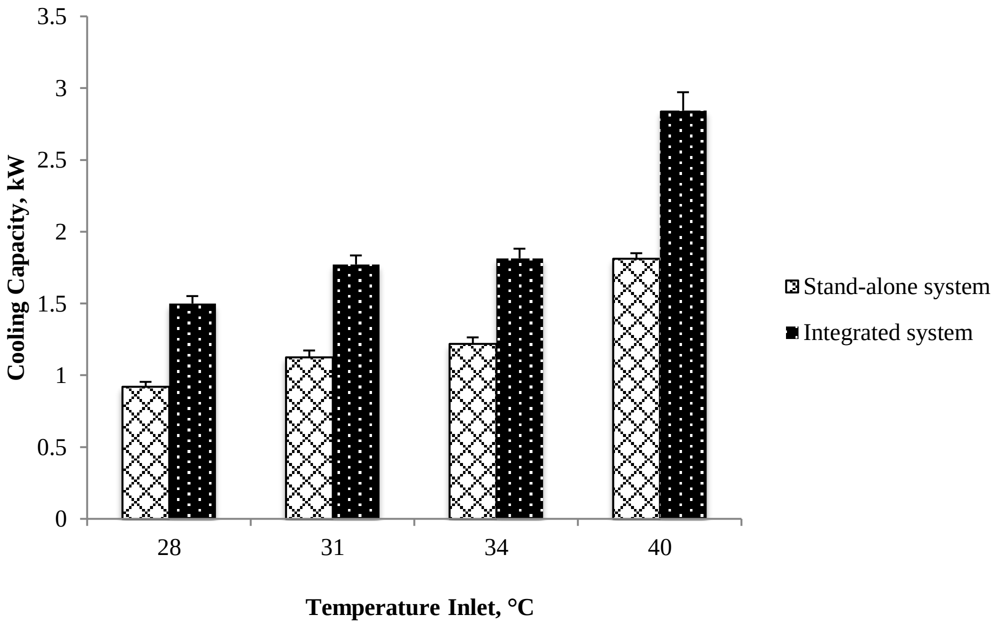

Figure 2 Comparison of cooling capacity between stand-alone and integrated system.

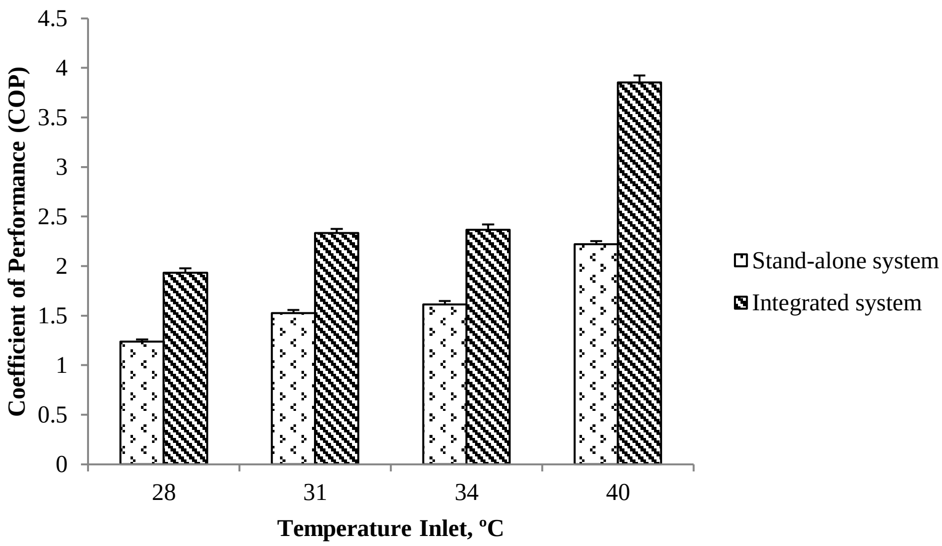

Figure 3 Comparison of coefficient of performance (COP) between stand-alone and integrated system.

Coefficient of Performance (COP)

The comparison of both systems is displayed in Figure 3. COP for temperature inlet of 40 ºC was the highest which was 3.9, followed by 34 ºC with 2.4, 31 ºC with 2.3 and 28 ºC with 1.9 in integrated system. In stand-alone air-conditioning (AC) system, COP for temperature inlet of 28 ºC was the smallest which was 1.2, followed by 31 ºC with 1.5, 34 ºC with 1.6 and 40 ºC with 2.2 accordingly. The higher the temperature inlet, the larger is the value of COP. Integrated system has better performance than stand-alone air-conditioning system.

COP indicates the efficiency of the systems using the lowest power consumptions to produce the highest cooling capacity [2]. When temperature inlet increases, the COP increases from Figure 4. Efficiency of the integrated system is higher when the temperature inlet escalates. High temperature inlet leads to the large heat transfer with the evaporator [19], causing COP to be increased. As the cooling capacity is larger in integrated system, the COP is higher than stand-alone AC.

Statistical Analysis (T-test)

An independent-samples t-test was conducted to compare COP of integrated system for both systems as shown in Table 1. There were significant difference for stand-alone air-conditioning system and integrated system for the operating parameter temperature inlet studied.

Table 1 Independent samples T-test

Temperature Inlet, ºC	System	Mean	Standard Deviation	p value
28	Stand-alone	1.24	0.03	$p<0.05$
	Integrated	1.93	0.05	$p<0.05$
31	Stand-alone	1.52	0.04	$p<0.05$
	Integrated	2.33	0.07	$p<0.05$
34	Stand-alone	1.61	0.03	$p<0.05$
	Integrated	2.37	0.05	$p<0.05$
40	Stand-alone	2.22	0.03	$p<0.05$
	Integrated	3.85	0.07	$p<0.05$

CONCLUSION

The performance of integrated system was studied and compared with stand-alone air-conditioning (AC) system. It was found that cooling capacity and COP for integrated system ranged 1.5-2.8 kW and 1.8-3.1 respectively. Both systems perform the best at high temperature inlet which is 40 ºC. Statistical analysis t-test showed that the COP for stand-alone and integrated system are statistically different. The performance of integrated system is better than stand-alone AC.

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