Experimental investigation on the performance of an air-to-air energy recovery for building applications in hot-humid climate

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ABSTRACT

The aim of this study was to evaluate the performance of an air-to-air energy recovery system in terms of latent efficiency and recovered energy. Experimental investigations were carried out under controlled conditions in Energy and IEQ Testing Unit located in School of Industrial Technology, Universiti Sains Malaysia. Tests were performed under different airflow rates ranged from 1.0 to 3.0 m/s and intake relative humidity of 70 %, 80 % and 90 %. The latent efficiency and recovered energy of the system were calculated and evaluated by adopting calculation method by ASHRAE Standard. The latent efficiency of this system ranged from 40 to 74 % and the highest value of recovered energy of 1,456 W was achieved at 2.5 m/s and 90 %. Results indicate that the latent efficiency decreased and in contrast the recovered energy increased with increasing airflow rates.

Keywords: Air-to-air energy recovery, performance, hot-humid climate, experimental investigation

INTRODUCTION

Over the past century, there has been a dramatic increase in energy consumption of the world's energy usage. This phenomenon has resulted in the global rising pattern in building energy consumption reaching figures between 20% and 40% (Fan, & Ito, 2012). The main factors contribute to this increasing trend include:(i) the growing numbers in population; (ii) the higher demand for building services; (iii) the essentials for better comfort levels; and (iv) longer duration of time spent by people inside buildings [1]. Besides, energy usage for heating, ventilation and air-conditioning systems (HVAC) by building sector accounts about 40 to 50% of the total final energy demand [1]. It is predicted that these HVAC systems will continue to take a huge amount of total energy consumption in buildings as stated in [2]. Without any precautions taken into consideration, the upraising trend in energy demand will continue to increase in the future. Thus, improving energy efficiency in buildings becomes a prime objective for global energy policymakers nowadays. Thus, it is essential that technologies to reduce energy usage are designed to have the maximum impact of energy saving [3]. With this concern, air-to-air energy recovery system appears as one of the key solutions to produce energy saving [4]. According to Pavel [5], the application of air-to-air energy recovery system basically helps in reducing the energy impacts by 45% besides providing fresh outdoor air to an indoor space. Furthermore, the system also aids in reducing the level of indoor air contamination by providing a consistent and reliable level of ventilation, setting the

occupants in control of their indoor air conditions [6]. The system has been approved as one of the energy-efficient technologies that can save a large portion of thermal load since heat or energy would be transferred from the warmer airstream [5, 7].

The air-to-air energy recovery system is a mechanical system that operates based on a process of recovering energy (heat/mass) from a stream at a high temperature to a low-temperature stream through a core (heat exchanger) to maintain a comfortable temperature of indoor spaces [8]. The system able to remove polluted air from indoor spaces and replaces it with fresh outdoor air. In general, there are two general classifications of air-to-air energy recovery system; i) sensible air-to-air energy recovery system and; ii) total air-to-air energy recovery system [9-14]. Thorough reviews on air-to-air energy recovery technologies are reported in [9, 15]. Based on the reviews, a lot of works has been conducted with regard to numerical, simulation and experimental approaches of the system. However, a gap still exists between research results and practical applications and therefore, future investigation should be established in these areas to better evaluate the feasibility and reliability of the system in building services. Besides, most studies reported that the application of this system was prevalently designed for cold climate area [5, 16, 17]. This could be mainly because most studies in the field of air-to-air energy recovery system only focus on the countries with both summer and winter season [8, 18]. Only several studies can be found in the open literature pertaining to the application of this system in hot-humid climate [19] and most of them merely based on numerical study [20, 21] and lack of experimental approaches [19, 22, 23]. Thus, to close this gap, this study proposed a design of an air-to-air energy recovery system for potential application in hot-humid climate. Performance of the system in terms of efficiency and recovered energy was investigated and evaluated based on experimental approach.

METHODOLOGY

In this study, an air-to-air energy recovery core was developed and formed based on hydrophilic polymeric membrane layers. It was structured with 23 pieces of waveform stand channels, arranged in a cross-flow manner and with the capabilities to transfer both heat and moisture simultaneously. This configuration also allowed air to change direction in a manner that ensures sufficient air comes in contact with heat transfer surface prior leaving the core. The dimensions of the core were 0.2 m height, 0.2 m length and 0.1 m width with 0.002 m height of sinusoidal plate fin channels. A core shell was designed to house the core at the centre with two separate flexible air ducts (intake and exhaust) with a diameter of 0.015 m. The shell was made of 0.025 m thick polystyrene sandwich panels with thin aluminium sheet for insulation purpose. The shell helped to station and separate two airstreams (intake and exhaust) of the core (Figure 1). Two DC centrifugal fans with a maximum of 24 V were installed in the intake and exhaust ducts to assist airflow and distribute the air through the air-to-air energy recovery system. The air-to-air energy recovery system was designed to recover energy in hot-humid climate with the design parameters of: i) airflow ranged from 300 to 60,000 m^3/h; ii) intake temperatures ranged from 30 to 45 °C; room temperatures ranged from 20 to 25°C.

An air-to-air energy recovery system was tested in a controlled experimental chamber comprised of an indoor space with a dimension of 2.9 m x 4.6 m x 5 m, an insulated controlled test room with a dimension of 2 m x 2 m x 2 m, located in School of Industrial Technology, Universiti Sains Malaysia (Figure 2). The insulated test room was made of 0.045 m polyurethane foam sandwich panel to reduce the influence of

surroundings. An artificial heating system was used to generate heat in the test room. Meanwhile, air-conditioning equipment was placed to simulate cold temperature in the room. Measurements were carried out under different airflow rates ranged from 1.0 to 3.0 m/s using an established method by [24] as stated in [25].
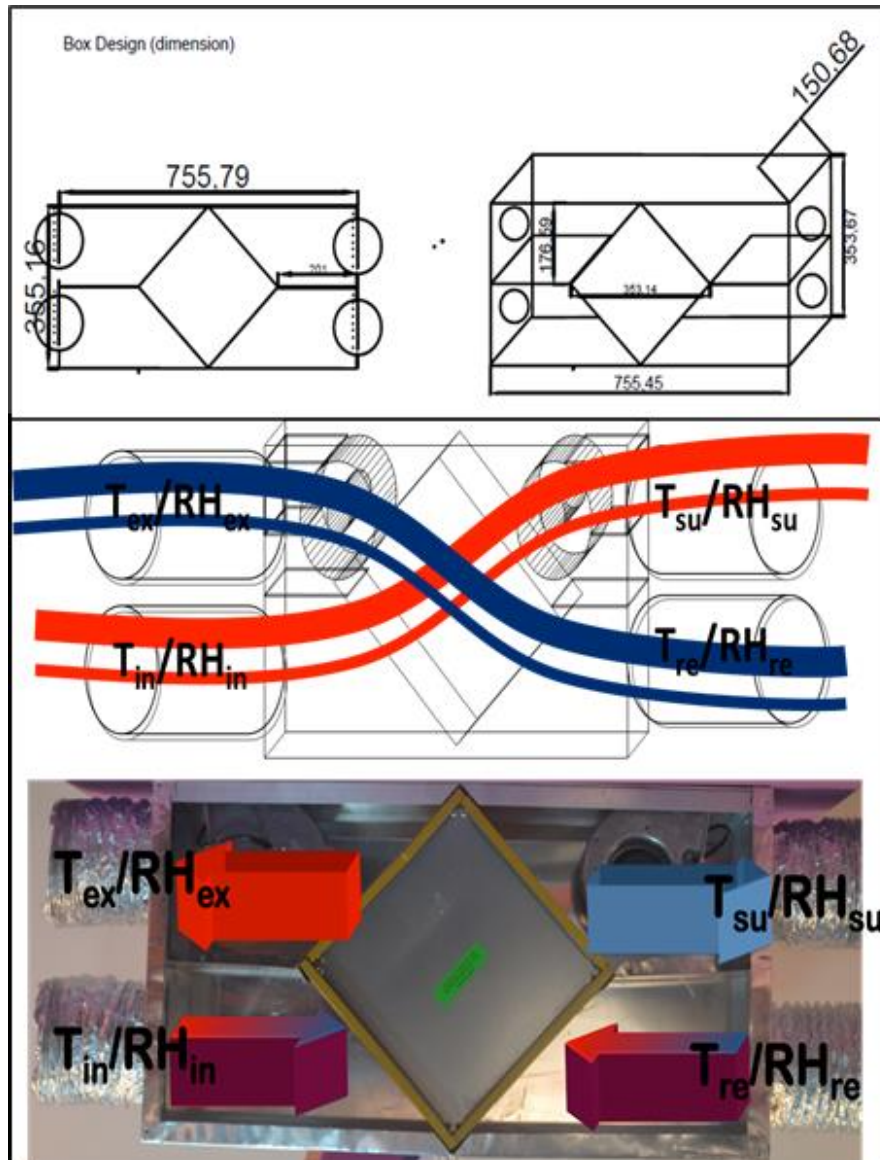

Figure 1. Design of an air-to-air energy recovery system

In order to test the efficiency of the system at different airflows, two speed controllers were connected to the DC centrifugal fans. Intake relative humidity before entering core (RH_i), intake relative humidity after entering core (RH_s), return relative humidity (RH_r) and exhaust relative humidity after entering core (RH_e) were recorded using Delta Ohm HD9817T1 dual sensor (+/- 0.21^{0}C or +/- 2.5%) and were placed at four (4) different points across the experimental chamber. Connection of a Hobo Data Receiver ZW-RCVR (temp: -20 to 50^{0}C and RH: 5 to 95 %) with a unit of Hobo ZW-003 Temperature/Relative humidity (RH) data ($\pm$0.54 ^{0}C and $\pm$ 2.5%) was placed to measure the room (R) conditions. Four thermocouples were positioned in the controlled test room, and five thermocouples were placed in the indoor space. For airflow

measurements, a hot-wire anemometer (±3% of reading, ±0.05 m/s) 0. 05 m/s was used to measure airflow rates of intake and exhaust airstreams at the same points of relative humidity measurement. Log-Tchebycheff method was applied in order to obtain accurate airflow rate values [26]. For each test, the experimental chamber was allowed to come to steady-state condition, which was attained after 45 minutes. The measurements were then performed after the experimental chamber reached the steady-state condition. Data was recorded using a data acquisition system comprising DT800 with DeLogger[TM] 5 Pro Software and was collected over a period of two (2) h for each test. Results were analysed to evaluate the efficiency and recovered energy of the system by adopting calculation method as suggested by ASHRAE Standard [9, 13, 27]. The tests were carried out at mean room conditions: temperature = 24°C; relative humidity = 52% and mean intake relative humidity (RH_i) of 70%, 80% and 90% with intake temperature T_i fixed at 35[0]C.
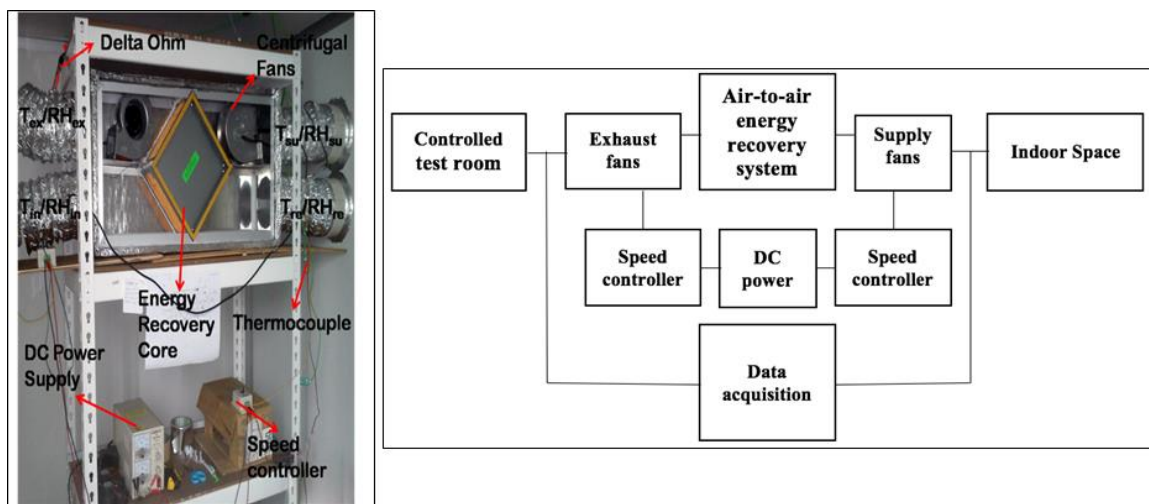

Figure 2. Experimental set up

RESULTS AND DISCUSSION

Table 1, 2 and 3 show the measured and calculated data of the air-to-air energy recovery system at mean intake mean intake relative humidity (RH_i) of 70%, 80% and 90% with intake temperature constant at 35[0]C, respectively for airflow rate ranged from 1.0 to 3.0 m/s (0.018 – 0.054 m³/s). From this data, it was calculated that the relative humidity difference (ΔRH) at intake relative humidity 70% was 3.75%, at 80% was 4.12% and at 90% was 3.75% for airflow rate of 1.0 m/s (0.018 m³/s). On the other hand, at airflow rate of 3.0 m/s (0.054 m³/s), ΔRH was found to be in a range of 1.30 to 3.05%.

Table 1. Measured and calculated data at 70 [0]C.

Intake air velocity, V_i (m/s)	Volumetric airflow rate, Q_i (m³/s)	Mass air flow rate, M_a (kg/s)	RH_i (%)	RH_s (%)	RH_r (%)	RH_e (%)
1.0	0.018	0.021	69.93	66.18	58.32	54.16
1.5	0.027	0.031	70.30	67.48	53.08	49.41
2.0	0.036	0.041	70.05	68.23	50.00	46.16
2.5	0.045	0.052	69.50	65.69	55.89	57.79
3.0	0.054	0.062	70.26	68.96	56.34	54.16

Table 2. Measured and calculated data at 80 ^{0}C.

Intake air velocity, V_i (m/s)	Volumetric airflow rate, Q_i (m³/s)	Mass air flow rate, M_a (kg/s)	RH_i (%)	RH_s (%)	RH_r (%)	RH_e (%)
1.0	0.018	0.021	80.32	76.20	56.87	73.54
1.5	0.027	0.031	80.10	74.82	55.33	55.57
2.0	0.036	0.041	79.91	74.06	55.99	65.56
2.5	0.045	0.052	81.81	76.94	55.86	65.32
3.0	0.054	0.062	80.57	78.99	60.63	69.19

Table 3. Measured and calculated data at 90 ^{0}C.

Intake air velocity, V_i (m/s)	Volumetric airflow rate, Q_i (m³/s)	Mass air flow rate, M_a (kg/s)	RH_i (%)	RH_s (%)	RH_r (%)	RH_e (%)
1.0	0.018	0.021	91.00	87.25	63.64	79.76
1.5	0.027	0.031	90.16	82.25	58.39	69.13
2.0	0.036	0.041	89.51	84.89	65.36	67.28
2.5	0.045	0.052	90.22	83.13	58.13	72.06
3.0	0.054	0.061	90.23	87.18	57.04	72.67

Figure 3 illustrates the efficiencies of the system based on the measured for airflow rates (V_i) ranged from 1.0 to 3.0 m/s (Q_i = 0.018 to 0.054 m³/s) and tested intake relative humidity (RH_i) of 70%, 80% and 90%. From the figure, it can be seen efficiency decreased with increasing airflow rates for every tested relative humidity. The relationship between efficiency and airflow rates at 70 %, 80 % and 90 % can be expressed by equation (1), (2) and (3), respectively.

$$y = -6.3x + 77.5 \tag{1}$$
$$y = -3.0x + 65.0 \tag{2}$$
$$y = -5.2x + 69.2 \tag{3}$$

This trend can be explained by a theory of residence time within the air-to-air energy recovery core, which is the average amount of time that a substance (air) spends in the core. The higher the residence time, the higher is the efficiency [26]. In contrast, efficiency decreases with increasing relative humidity. The efficiency ranged from 40 to 74%. The highest efficiency (74%) was achieved at 0.018 m³/s and 70 %. Meanwhile, the lower efficiency was achieved at (0.054 m³/s) and 90 %. Thus, intake air conditions give significant effects to the performance in terms of efficiency of energy recovery system as suggested in [28, 29]. In additional, the material properties of the air-to-air energy recovery have been claimed having significant impact on latent efficiency [30]. The variations of recovered energy with airflow rates are shown in Figure 4 for airflow rates (V_i) ranged from 1.0 to 3.0 m/s and tested intake relative humidity (RH_i) of 70%, 80% and 90%. From the study, it was found that the recovered energy of air-to-air energy recovery system increased with increasing airflow rates. The highest value of recovered energy of 1,456 W was achieved at 2.5 m/s and the lowest value was achieved at 1.0 m/s for intake relative humidity of 90%. Whilst, for intake relative humidity of 70%, the lowest value of recovered energy of 531 W was obtained at 1.0 m/s and the highest value

was obtained at 2.5 m/s. From these results, it was observed that the higher humidity difference between the indoor and outdoor gives the higher amount of recovered energy [30].
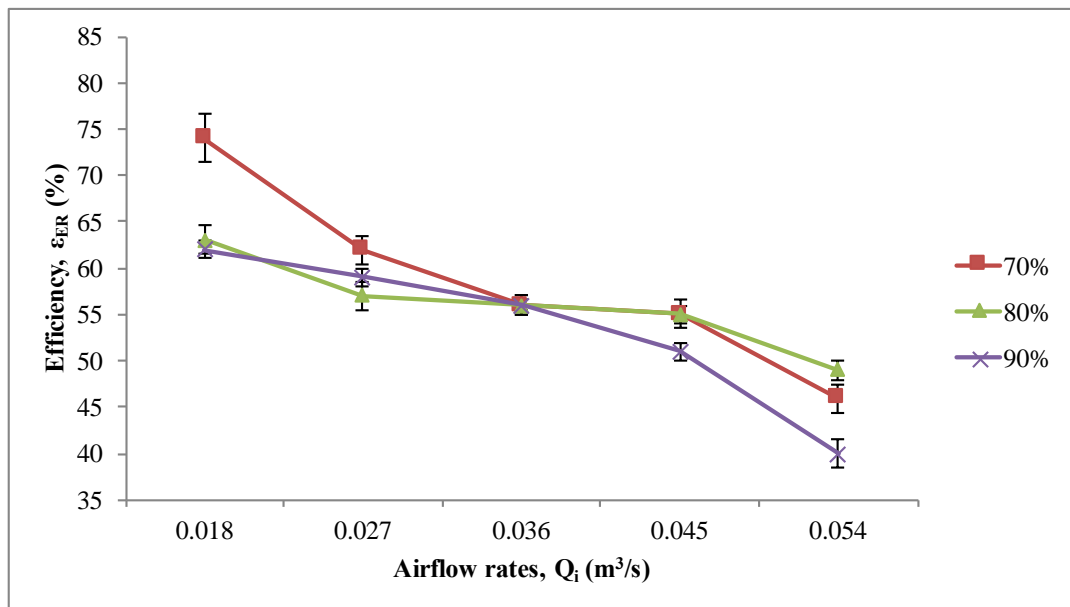

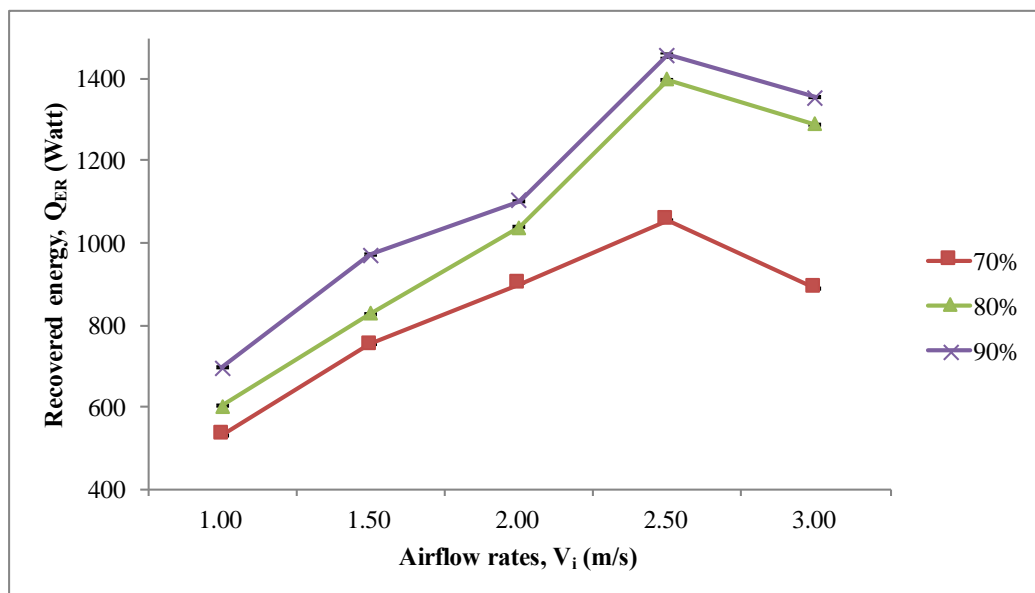Figure 3. Efficiency of the system versus airflow rate

Figure 4. Recovered energy of the system

CONCLUSIONS

The air-to-air energy recovery system was completely designed and tested to evaluate the performance of the system in terms of efficiency and recovered energy. In order to achieve its objectives, a series of experimental investigations were carried out at room condition of 24°C and 52% and intake relative humidity (RH_i) of 70%, 80% and 90% in School of Industrial Technology, Universiti Sains Malaysia. It was found that the

efficiency of the system decreased with increasing airflow rates and relative humidity. Meanwhile, when the airflow rate increased, the recovered energy increased. The efficiency of the system ranged from 40 to 74% with the highest recovered energy of 1,456 W. Thus, as a conclusion, the performance of the system was affected by the intake air conditions.

ACKNOWLEDGMENTS

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