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EFFECT OF UTILIZING DIFFERENT PERMEABLE MATERIAL IN AIR-TO-AIR FIXED PLATE ENERGY RECOVERY HEAT EXCHANGERON ENERGY SAVING

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ABSTRACT

The performance of air-to-air fixed plate energy recovery heat exchanger utilizing porous paper and Mylar film as the heat and moisture transfer media used in ventilation energy recovery systems is presented. This performance is represented by the heat exchanger sensible and latent effectiveness. A simplified air conditioning system which is represented by cooling coil that incorporates air-to-air fixed plate heat exchanger to cool office space is developed. Energy analysis for tropical climate shows that utilizing paper surface heat exchanger in a standard air conditioning system will lead to 78% energy saving as compared with utilizing Mylar plastic film which recovers only sensible heat.

Keywords: energy saving, air-to-air fixed plate, recovery heat.

INTRODUCTION

In the last few decades, many countries have adopted new standards for building ventilation that specify higher indoor air quality by supplying 100% fresh air. Thus, more energy is required to condition the outdoor air where, the air conditioning load constitutes 20% to 40% of the thermal load for commercial buildings [1]. To reduce the increase in load, energy recovery systems are used which can recover a large fraction of this load. This can be achieved by utilizing the room exhaust air to pre-cool or heat the fresh air before it enters the air conditioning system. This will save a large fraction of energy which in return will reduce the HVAC required operating cost [2]. In tropical climates, treating the latent load is important due to high humidity levels that require more energy for the air conditioner to reduce this load.

This led to an increased attention on energy recovery systems to recover both latent and sensible energy. Heat and mass transfer are in fact analogous to each other and whenever there is a gradient in heat or mass concentration; heat and mass will be transferred from the hot and higher concentration side to the colder and lower concentration side. This phenomenon is used in ventilation energy recovery systems, where the ambient hot and humid supply air is passed over one side of a porous surface heat exchanger and in the other stream the room exhaust air, which is cold and less humid is passed.

Due to the gradient in the heat and moisture concentration, heat and moisture are transferred across the membrane surface, causing a decrease in temperature and humidity of the supply air stream before it enters the evaporator unit, hence both sensible and latent energy are recovered.

Zhang and Jiang [3], investigated the performance of such systems and for simplicity they used a cross flow heat exchanger. They investigated the improvement of the energy recovery ventilator effectiveness using different types of membranes and different airflow arrangements. Their results show that the highest sensible and latent effectiveness occurred when the counter flow heat exchanger is used. However in a real application of a heat exchanger, it is difficult to implement a counter flow arrangement, as both inlet and outlet ducts are located on the same side of the heat exchanger.

Nasif *et al.* [1] performed energy comparison between an air conditioner coupled with Z-flow configuration energy recovery exchanger who uses 60gsm Kraft paper as heat and moisture transfer surface and a conventional air conditioning system that operates based on mixing fresh air with room exhaust air.

Nasif *et al*. energy analysis have showed that an air conditioning system coupled with an enthalpy heat exchanger consumed 8% less energy throughout the year than the conventional air conditioning system in tropical climates.

Al-Waked *et al*. [4] performed CFD simulation analysis of a membrane heat exchanger and noted the significant effect of permeable surface characteristic on the heat exchanger total performance.

Most of the published research have been performed on cross flow heat exchanger. The main outcome of the research performed showed the superiority of the membrane heat exchanger in humid climate over 100% fresh air HVAC systems. Furthermore, researchers have focused on determining the efficiency of an air conditioner that incorporates different energy recovery systems including an enthalpy heat exchanger and compared it with a 100% fresh air system [5-9].

Zhang [8] conducted a theoretical simulation of an air conditioning system and performed energy analysis

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on different energy recovery systems. The results showed that a system that incorporates a cross-flow enthalpy heat exchanger consumes less energy than other energy recovery systems.

Liang *et al.* [9] modelled an air conditioner that incorporates a cross-flow membrane heat exchanger. Their modelled system performance was validated against experimental measurements. They reported that under hot and humid conditions an air conditioner coupled with membrane heat exchanger improves the air conditioner performance significantly in comparison with a 100% fresh air supplied system

Nasif and Al- Waked [10] performed energy analysis of an air conditioner coupled with Z-flow configuration energy recovery exchanger which uses 70gsm Kraft paper as heat and moisture transfer surface under different seasonal weather conditions. They reported thata seasonal saving of up to 1.4GJ in energy consumption and 900kg annual reduction of CO_2 gas emission could be achieved when Z-flow heat exchanger is utilized instead of a conventional air mixing conditioning system that operates based on mixing fresh air with room exhaust air. There results also showed that the heat exchanger performance is more superior in hot and humid weather conditions.

The aim of this research is to evaluate experimentally the performance of a Z type flow air-to-air heat exchanger (Figure-1) using paper and Mylar film as the heat transfer surface. This Z flow configuration will provide a counter flow arrangement. Therefore, heat and moisture transfer will improve relative to the counter flow arrangement over a substantial part of the heat exchanger surface resulting in an increase in the amount of energy recovered. In this study, three different heat and mass transfer surfaces for the Z shaped heat exchangers are used and tested experimentally, which are Mylar, 45gsm paper and 60gsm paper to investigate the effect of changing the heat and mass transfer surface on the amount of energy recovered by the heat exchanger.

Heat exchanger effectiveness

Heat exchanger effectiveness was calculated using equations 1 and 2:

Sensible Effectiveness

$$\varepsilon_s = \frac{(\dot{m}c_{pa})_s (T_{hi} - T_{ho})}{(\dot{m}c_{pa})_{\min} (T_{si} - T_{Ci})} \quad (1)$$

Latent Effectiveness

$$\varepsilon_L = \frac{\dot{m}_s H_{fg} (\omega_{hi} - \omega_{ho})}{\dot{m}_{\min} H_{fg} (\omega_{hi} - \omega_{Ci})} \quad (2)$$

where $\dot{m}$ is air mass flow rate, T_{hi} and ω_{hi} are ambient air inlet temperature and humidity ratio, T_{ho} and $\omega_{ho}$are air outlet temperature and humidity ratio which enters the cooling coil, $T_{ci}$and $\omega_{ci}$is room exhaust air temperature and humidity ratio, and H_{fg} represents air enthalpy of evaporation.

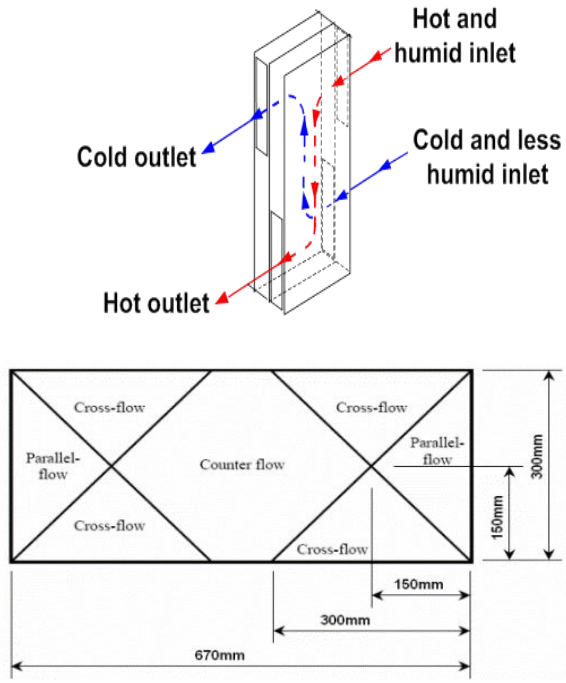

Figure-1. Z type flow air-to-air heat exchanger.

Experimental setup

The experimental rig consists of two separate air ducts arranged in parallel (Figure-2). At the duct entry, two centrifugal fans are mounted to supply variable airflow. In the hot air stream, steam is injected and air is heated. As for the cold air stream, air is supplied at ambient temperature.

The performance is evaluated by calculating the sensible and latent effectiveness of the heat exchanger, through flow rate, humidity and wet and dry bulb temperature measurements at the inlets and outlets of the heat exchanger.

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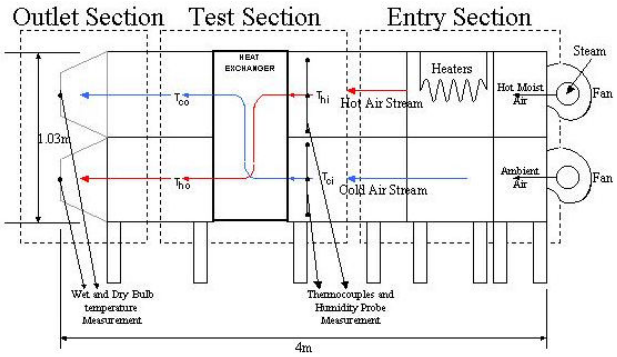

Figure-2. Experimental rig.

The heat exchanger is made of 98 plastic frames with 49-inlet air passages in each of the air streams. Three different types of heat and mass transfer surfaces are tested in this experiment which are23µm thick Mylar plastic surface which does not transfer moisture, 78µm thick porous 45gsm Kraft paper with porosity of 0.0027, and 98µm thick 60gsm Kraft paper with porosity of 0.0029.

Figures 3 and 4 show the measured performance of the heat exchanger. As seen, the sensible effectiveness is almost the same for the three different surfaces. This is due to conduction thermal resistance of the surfaces which are thin and hence it has minor effect on the overall heat transfer resistance. Therefore, the effectiveness of the three surfaces is almost the same.

However, the latent effectiveness values were different for 45 and 60gsm papers, where 60gsm paper recorded higher latent effectiveness values than 45gsm. It can also be seen that the sensible effectiveness values were higher than the latent effectiveness and this is due to the high moisture resistance of the paper.

Where, paper moisture transfer resistance affect the total mass moisture transfer process and hence affected the latent effectiveness values, unlike the conduction thermal resistance which is very small and has only a minor effect on the overall heat transfer resistance of the paper and can be ignored due to the small thickness of the paper.

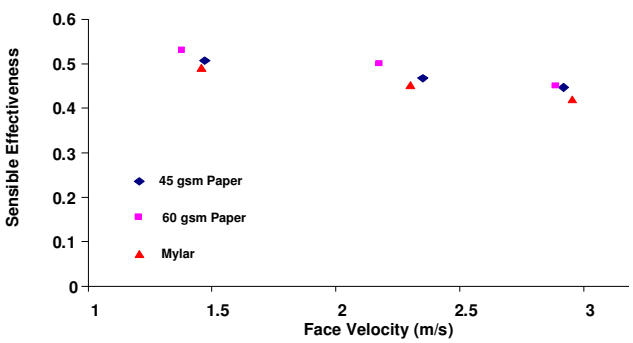

Figure-3. Sensible effectiveness.

The results also show that the effectiveness decreases as the air flow rate increases, which is attributed to the air residence time in the heat exchanger. When the velocity is high the residence time is short and the amount of heat and moisture transferred per kilogram of airflow will be less than when the air velocity is low.

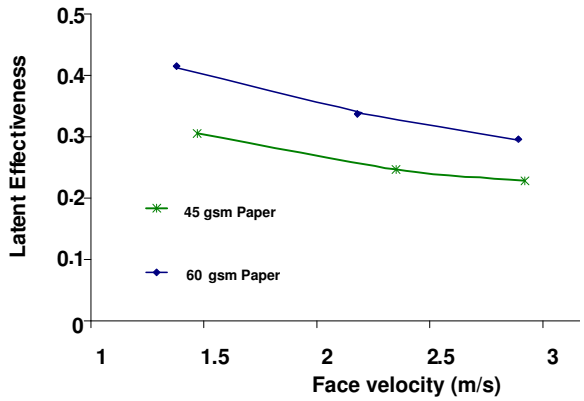

Figure-4. Latent effectiveness.

The pressure drop across the heat exchanger has to be considered because it will contribute to the additional fan power. The static pressure difference was measured between the inlet and outlet for both streams using static pressure tapping points drilled through the test rig walls to connect the manometer tubes located 50mm from the heat exchanger inlets and outlets. Figure 5 shows the pressure drop variation across the heat exchanger with respect to air velocity.

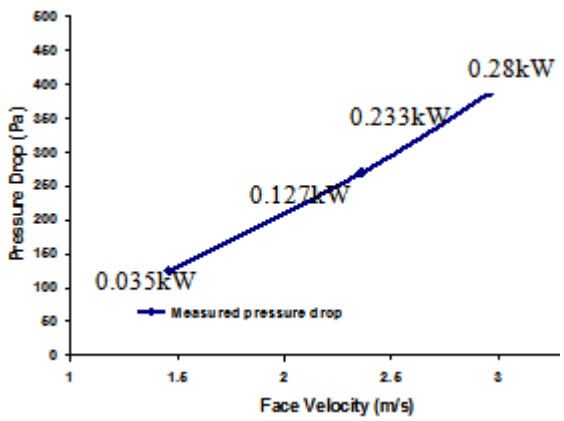

Figure-5. Pressure drop.

HEAT RECOVERY ANALYSIS

The model

The heat exchanger measured performance is incorporated in an office space cooling system by using

the heat exchanger as a pre-cooling device. Figure-6 shows the model which represents a 300m^2 office space.

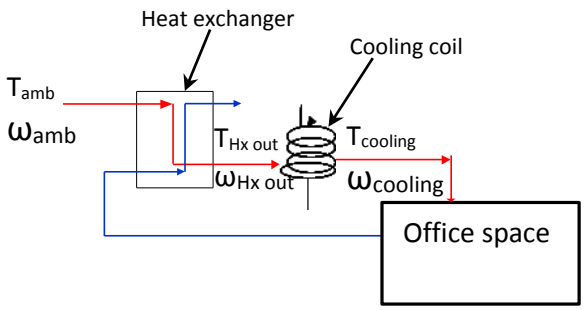

Figure-6. Schematic diagrams of Z shaped heat exchanger air conditioning model.

The sensible and humidity loads and office details are listed in Table-1.

Table-1. Model conditions.

Office AU	**0.98 kW/K**
Office area and height	300m^2 , 3.5m
Office indoor temperature and humidity conditions	22°C, 0.0087kg/kg
Ambient temperature and humidity	35°C, 0.0244kg/kg
Office sensible load	20kW

The temperature at the cooling coil air - off is calculated from the energy balance between heat transferred from ambient to the office space and the cooling provided by the air conditioner as follows:

$$Q_{heat} = Q_{cooling} + Q_{load} \quad (3)$$

$$AU(T_{amb} - T_{room}) = \dot{m}Cp(T_{room} - T_{cooling}) + Q_{load} \quad (4)$$

where A represent the overall office surface area and U is the office wall heat transfer coefficient.

The temperature and moisture content at the heat exchanger out let is calculated from

$$T_{Hx\ out} = T_{amb} - \varepsilon_s(T_{amb} - T_{ci}) \quad (5)$$

$$\omega_{Hx\ out} = \omega_{amb} - \varepsilon_s(\omega_{amb} - \omega_{ci}) \quad (6)$$

The amount of sensible heat saved is calculated from

$$Q_{sensible\ saved} = \dot{m}Cp(T_{amb} - T_{cooling}) - \dot{m}Cp(T_{HX\ out} - T_{cooling})$$

which leads t

$$Q_{sensible\ saved} = \dot{m}Cp(T_{amb} - T_{HX\ out}) \quad (7)$$

and the amount of latent heat saved is calculated as

$$Q_{latent\ saved} = \dot{m}H_{fg}(\omega_{amb} - \omega_{cooling}) - \dot{m}H_{fg}(\omega_{HX\ out} - \omega_{cooling})$$

Which leads to

$$Q_{latent\ saved} = \dot{mH_{fg}}(\omega_{amb} - \omega_{HX\ out}) \quad (8)$$

The above saving in heat do not include the pressure drop through the heat exchanger which requires additional power as shown in Figure-5.

The total heat saved takes into consideration the pressure drop effect and it is calculated as follows:

$$Q_{total} = Q_{sensible} + Q_{latent} - P_{pressure\ drop} \quad (9)$$

Energy for cooling recovered

Figure-7 shows the amount of sensible and latent heat saved. As see, the variation in sensible heat values are the same due to the small thickness of the papers and Mylar.

However, the variation in the latent heat is significant where 60gsm paper recorded the highest energy saving as compared with 45gsm paper. It should be noted that Mylar does not transfer moisture and hence only sensible heat will be saved.

It can also be seen that, 60gsm paper provided up to 15.3 kW of energy saving, whereas 45gsm paper achieved maximum saving of 11.9 kW.

Figure-8 shows the total amount of energy saved for Mylar, 45gsm, and 60gsm papers. The results shows that Mylar recovered only sensible heat and hence it recorded the lowest energy saving. However, 60gsm paper provided up to 19.7 kW of energy for cooling saving. Whereas, 45gsm paper achieved up to 16.3kW energy for cooling saving.

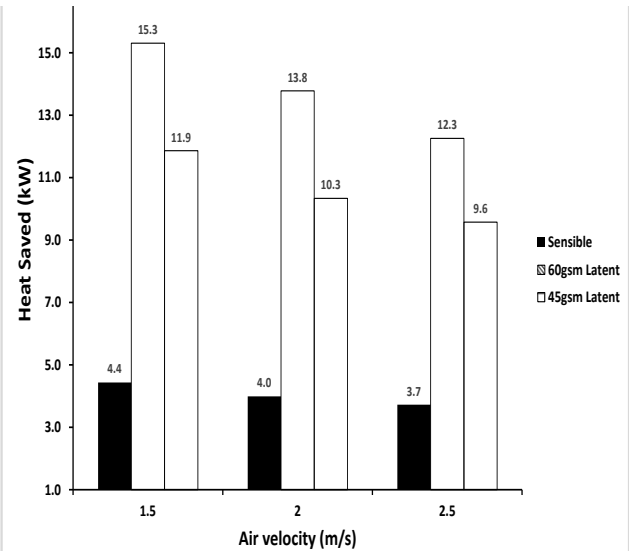

Figure-7. Sensible and latent energy for cooling saving for 45gsm, 60gsm and Mylar.

From the above results, it can be concluded that although the paper thickness for both 45 and 60gsm is small, however, due to the slightly higher porosity of 60gsm paper which consequently recorded higher latent effectiveness, 60gsm paper energy saving for cooling was 18% higher than 45gsm paper and 78% higher than Mylar. The above results also show the importance of latent moisture recovery in tropical weather conditions, where Figure-8 shows that 60gsm and 45gsm papers provided significantly higher energy for cooling saving as compared with Mylar which can only recover sensible heat.

It can be concluded that changing the heat and moisture transfer material in air to air fixed plate energy recovery heat exchanger has significant effect on the amount of energy saving in buildings' air conditioning systems.

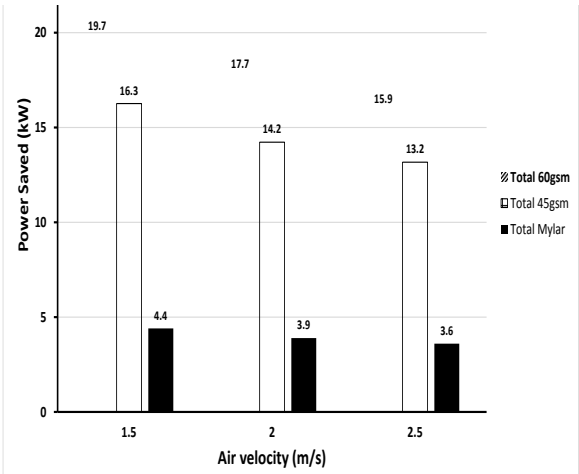

Figure-8. Total energy for cooling saving for 45gsm, 60gsm and Mylar.

CONCLUSIONS

The performance of Z shaped air to air fixed plate heat exchanger which is used in building' HVAC energy recovery system is experimentally investigated. The test was conducted by using 45gsm, 60gsm papers and Mylar plastic film as the heat exchanger heat and moisture transfer surfaces. Measurements showed that 60gsm recorded higher latent effectiveness than the 45gsm heat exchanger. Whereas, the sensible effectiveness was same for the three surfaces. A simplified air conditioning model is developed which incorporates the heat exchanger under tropical weather conditions. The heat exchanger effectiveness is included in the model. Energy analysis showed that it is very important to recover latent heat in tropical climate where 60gsm and 45gsm paper heat exchanger recorded higher energy for cooling saving as compared with Mylar which recovers sensible heat only. Results also revealed that 60gsm paper heat exchanger energy saving for cooling was 18% higher than 45gsm paper and 78% higher than Mylar which is attributed to the higher porosity of the 60gsm paper which attains higher latent effectiveness values.

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