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STUDYING THE PERFORMANCE OF AN EVAPORATIVE PRE-COOLED AIR CONDITIONING SYSTEM IN HUMID TROPICAL CLIMATE

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ABSTRACT

The evaporative cooling technique has gained growing attention for use in air conditioning systems. A hybrid evaporative pre-cooled air-conditioning system has been proposed. An indirect evaporative heat exchanger (IEHX) is adopted as a pre-cooling device before the conventional mechanical vapour compression unit. The present work aims to develop a numerical model for the IEHX to study the pre-cooling performance by using the room exhaust air as the working air. A computational model has been developed to investigate the heat and mass transfer in the indirect evaporative heat exchanger. It can be inferred that the evaporative pre-cooling unit is able to reduce the air temperature and condense water through the IEHX. Consequently, the hybrid evaporative pre-cooled air-conditioning system is able to achieve a potential energy saving due the pre-cooling effect and the improvement of the chiller's efficiency.

Keywords: Indirect evaporative cooling, Air-conditioning, Mathematical model, Heat and mass transfer.

NONMENCLATURE

Abbreviations	
RH	Relative Humidity
Symbols	
T	temperature (°C)
α	thermal diffusivity (m^2/s)
u	incoming air velocity (m/s)
D	diffusivity (m^2/s)
m	mass flow rate of air [kg/s]
ω	humidity ratio [g/kg]

1. INTRODUCTION

Plate type heat exchangers are commonly used for indirect evaporative cooling systems [1]. For a typical indirect evaporative heat exchanger (IEHX), the product air usually flows along the alternatively arranged dry channels, while the working air acts as the heat sink due to the evaporation process in wet channels [2].

Since the air temperature is reduced by vaporizing water, the IEHX is generally suitable for hot and dry areas [3]. However, a single IEHX is often insufficient to maintain comfort indoor thermal conditions for building in humid tropical cli-mates [4]. Fig. 1. schematically shows the design for the hybrid indirect evaporative pre-cooling system. The ambient air is first treated through an IEHX. The exhaust air from the indoor is adopted as the working air in order to promote the cooling performance of the IEHX. Thereafter, the ambient air is further conditioned by the conventional mechanical vapor compression unit before supplying to the building.

The pre-cooling IEHX is associated with a complicated air treatment process. In humid tropical climates, the ambient air generally has a higher temperature and a higher humidity ratio compared with the indoor air conditions [5]. As a result, the working air temperature in the pre-cooling IEHX for this hybrid system may be lower than the dew-point temperature of the ambient air [6]. In other words, the intake ambient air in the pre-cooling unit has a possibility to condense water in the product channel. The aim of the work is to evaluate the energy performance of the hybrid system with pre-cooling air treatment process.

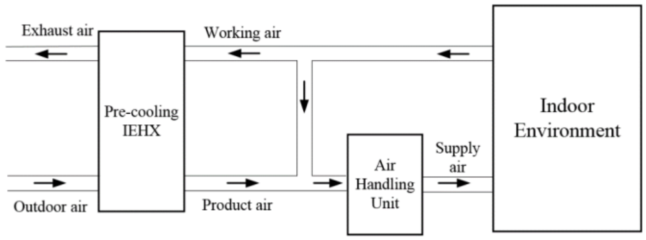

Fig 1 Schematic of the hybrid indirect evaporative pre-cooling system.

2. THEORY

The mathematical formulation for the IEHX has been established to study the pre-cooling performance. The key governing equations are expressed as follows:

$$\frac{\partial u_a}{\partial x}+\frac{\partial v_a}{\partial y}=0 \quad (1)$$

$$u_a\frac{\partial u_a}{\partial x}+v_a\frac{\partial u_a}{\partial y}=-\frac{1}{\rho_a}\frac{dp}{dx}+v_a\frac{\partial^2 u_a}{\partial y^2} \quad (2)$$

$$\frac{\partial}{\partial x}(u_aT_a)+\frac{\partial}{\partial y}(v_aT_a)=\alpha_a\frac{\partial^2 T_a}{\partial y^2} \quad (3)$$

$$u_a\frac{\partial c_a}{\partial x}+v_a\frac{\partial c_a}{\partial y}=D_a\frac{\partial^2 c_a}{\partial y^2} \quad (4)$$

The interfacial boundary condition at the working channel surface is given as:

$$-k_w\frac{dT_w}{dy}=-k_a\frac{dT_a}{dy}+M_{H_2O}h_{fg}D_a\frac{\partial c_a}{\partial y} \quad (5)$$

After the treatment of the pre-cooling IEHX, the product air is further conditioned through the cooling coil in the conventional AHU. A mathematical model was also developed for the cooling coil as follows.

The total heat transfer for the chilled water and the air

$$\Delta Q_{(i,j)}=m_wc_{pw}\left(T_{w(i,j+1)}-T_{w(i,j)}\right) \quad (6)$$

$$\Delta Q_{(i,j)}=m_a\left(i_{a(i,j)}-i_{a(i+1,j)}\right) \quad (7)$$

By considering the convective heat transfer, we obtain:

$$\Delta Q_{(i,j)}=h_i\Delta A_i\left(T_{s,m(i,j)}-T_{w,m(i,j)}\right) \quad (8)$$

$$\Delta Q_{(i,j)}=h_o\Delta A_o\eta_s\left(T_{a,m(i,j)}-T_{s,m(i,j)}\right)+h_{fg}h_m\Delta A_o\eta_s\left(\omega_{a,m(i,j)}-\omega_{s,m(i,j)}\right) \quad (9)$$

3. RESULTS

The computational model is first validated against experimental data. Thereafter, the model is employed to theoretically study the performance of the proposed hybrid system operating under humid tropical climates.

3.1 *Validation*

Firstly, the validation of the model is carried out based on the experimental data of an IEHX. The simulation has been conducted under the experimental conditions [7]. The calculated outlet air temperature is compared with the experimental measurement as illustrated in Fig. 2. It is observed from the figure that the developed model shows a good agreement compared with the experimental data with a maximum discrepancy around 5%.

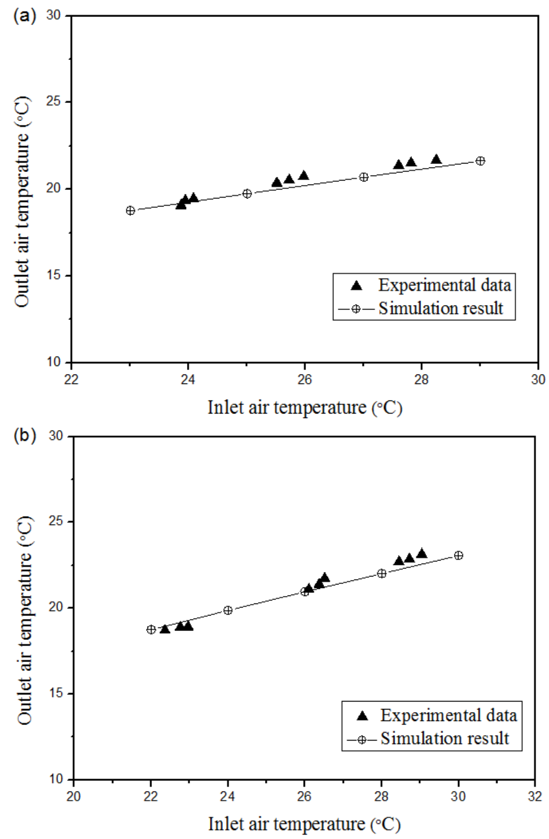

Fig 2 Validation of the model for a counter-flow IEHX (a) the intake air flow rate is 4.5 L/s; (b) the intake air flow rate is 6.0 L/s.

3.2 *Pre-cooled air-treatment profiles*

For the pre-cooling IEHX, the validated model has been employed the predict the air stream conditions profiles. The intake air condition is assumed as a typical ambient air condition in humid tropical climates ($T_{a,in}$=35°C, and $RH_{a,in}$=80%). The working air in the IEHX utilizes the room exhaust air ($T_{a,in}$=25°C, and $RH_{a,in}$ =50%).

Fig. 3 shows the profiles of the product air in terms of the temperature and humidity ratio along the flow passages. It can be inferred from the figure that the product air temperature decrease along the flow direction. The product air humidity ratio is kept constant when the interface temperature of the plate is higher than its dew point temperature. Once the plate temperature is reduced to below dew point temperature, the product air humidity ratio decreases accordingly. In other words, the condensation process occurs in this region of the product channel.

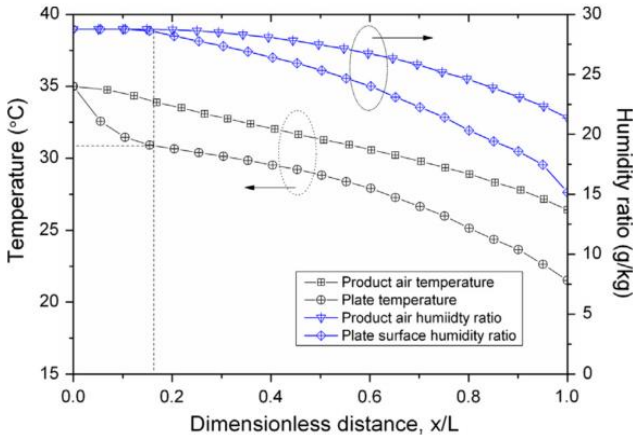

Fig 3 Temperature and humidity ratio profiles in the pre-cooling IEHX.

3.3 Impact of the pre-cooling on the chiller

Fig. 4 illustrates an example of the calculated air treatment conditions for the hybrid system. On the psychrometric chart, the point O represents the selected outdoor air condition (*T*=33 °C, *RH* = 80%), and the point R shows the assumed indoor air condition (*T*=24 °C, *RH* = 60%).

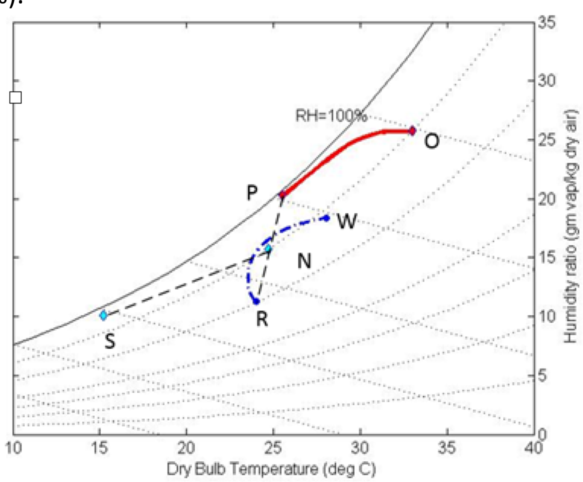

Fig 4 Description of air treatment conditions on psychrometric chart for the hybrid indirect evaporative pre-cooling system.

In Fig. 4, the outdoor air (O) and the exhaust air (R) are first treated in the IEHX. The product air in the IEHX is cooled and dehumidified as the condition is varied from point O to point P. The exhaust air absorbs heat and moist in the working channel resulting in a final condition at point W. The product air and the return air are then mixed to point N. In addition, a higher chilled water supply temperature (10 °C) can be employed in the hybrid system for achieving a similar supply air condition at point S compared with the conventional air handling unit.

Fig. 5 shows the impact of the chilled water temperature on the chiller's coefficient of performance (COP) [5]. It is observed that the chiller's efficiency can be improved by increasing the supply temperature of the chilled water [8]. For example, the average COP is ranged from 3.6 to 4.4 due to the increase of chilled water temperature. The enhanced chiller's performance can potentially reduce the energy consumption.

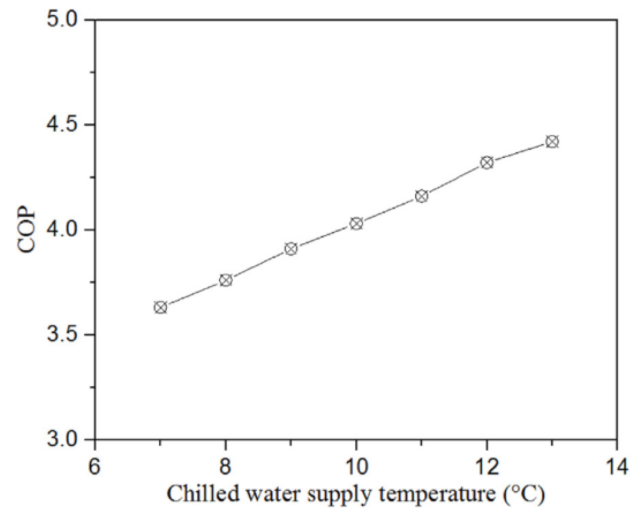

Fig 5 Influence of the chilled water temperature on the COP of the chiller.

4. CONCLUSIONS

The present work has introduced a hybrid air-conditioning system by using an IEHX as a pre-cooling unit. Mathematical model has been established for both the IEHX and the cooling coil. The pre-cooling IEHX employs the room exhaust in the working channel to enhance the cooling performance for the ambient intake air. The temperature and humidity distribution along the passages have been evaluated for the IEHX. Simulation results have illustrated the capability of the IEHX to cool and dehumidify the intake air. An energy saving potential can be achieved due to the application of the energy-efficient IEHX, reduced cooling load and improved chiller's performance.

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