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Thermal performances comparison between dry-coil and wet-coil indirect evaporative cooler under the same configuration

Yi CHEN, Hongxing YANG*

Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

Abstract

The indirect evaporative cooling (IEC) is an energy efficiency and environmental friendly air-conditioning device which cools the air by water evaporation. In the market, there're two kinds of IEC units, namely dry-coil IEC and wet-coil IEC. The only differences between them lie in the sequence of air humidification process and heat exchange process. In dry-coil IEC, the two processes are separated. The working air firstly being humidified and then proceed sensible heat exchange with the fresh air; while in wet-coil IEC, the two processes are simultaneous. The different arrangement may result in distinction of thermal performance. The paper presents the analytical models for dry-coil IEC and wet-coil IEC and compares their supply air temperature and cooling efficiency under the same configuration. The condensation and non-condensation statuses for both IEC types were discussed by simulation under a wide range of fresh air inlet parameters. The results show that the wet-coil IEC owns a higher efficiency and can provide lower temperature supply air either in condensation or non-condensation statuses. Besides, the efficiency of both types of IEC will be lowered once condensation occurs.

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Keywords: wet-coil IEC; dry-coil IEC; simulation; comparison; condensation; efficiency.

1. Introduction

The indirect evaporative cooling (IEC) is an energy efficiency and environmental friendly air-conditioning device which cools the air by water evaporation. Typically, a plate type IEC unit consists of a series of thin parallel plates assembled to form a multi-layer sandwich of alternating dry and wet channels [1], which are also called fresh air and secondary air channels. The water constantly evaporates from the wet surface of the secondary air channel owing to the vapor pressure difference. At the same

* Corresponding author. Tel.: +852 2766 5816; Fax: +852 2765 7198
E-mail address:behxyang@polyu.edu.hk (H. Yang)

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time, the sensible heat will transfer from the fresh air side to the secondary air side. In this way, the fresh air can be cooled without adding moisture.

Owing to the high coefficient of performance (COP) and CFCs-free characteristic, IEC has become an increasingly popular cooling technology applied in industry, public air-conditioning (A/C) system and civil air-conditioner [2].

Nowadays in the market, there're two kinds of IEC products available with different air handling sequences, which are called dry-coil IEC and wet-coil IEC, as shown in Fig.1. In dry-coil IEC, the secondary air firstly being humidified before enters to the heat exchanger, so the humidification and sensible heat exchange proceed separately, while in wet-coil IEC, they processes simultaneously.

Though the thermal performances of both types of IEC have been widely studied, the investigation into their condensation performances has received little attention, especially the thermal performance of the wet-coil IEC under totally condensation, partially condensation and non-condensation statues. Besides, the performances comparison between them is still lacking. The paper establishes the analytical models for the dry-coil and wet-coil IEC and compares their performance under the same configuration in both condensation and non-condensation conditions. The results can provide guidance for choosing a better IEC product in engineering field and designing the similar heat exchanger with spraying configuration.

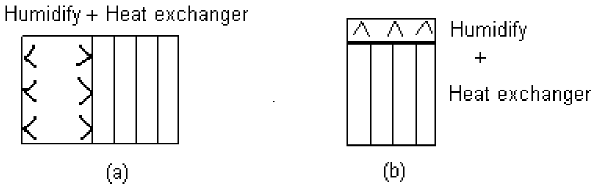

Fig. 1. (a) dry-coil IEC; (b) wet-coil IEC.

Nomenclature

c	specific heat capacity of air, kJ/kg·°C	K	total heat transfer coefficient, kJ/m^2·°C
t	air temperature, °C	m	mass flow rate of the air, kg/s
h	enthalpy of air, kJ/kg	α	sensible heat transfer coefficient, kJ/m^2·°C
e	slope of the saturated wet air	ζ	wet factor coefficient
w	moisture content of the air, kg/kg	Cr	heat capacity ratio
F	heat transfer area, m^2	NTU	heat transfer unit
Subscript			
1	fresh air	2	secondary/working air
w	wet surface	in	indoor/return air
$surf$	plate surface		
Superscript			
‘	inlet air	‘’	outlet air

2. Methodology

2.1. Method of judging condensation statuses

According to different inlet conditions of the fresh air and secondary air, the IEC unit can be either non-condensation or condensation depending on the relationship between the temperature of the plate surface and dew point temperature of the moisture air. In order to distinguish the condensation statuses of IEC unit, a pre-judging code was programmed for wet-coil IEC and dry-coil IEC by 'supposing and verifying' method, as shown in Fig.2.

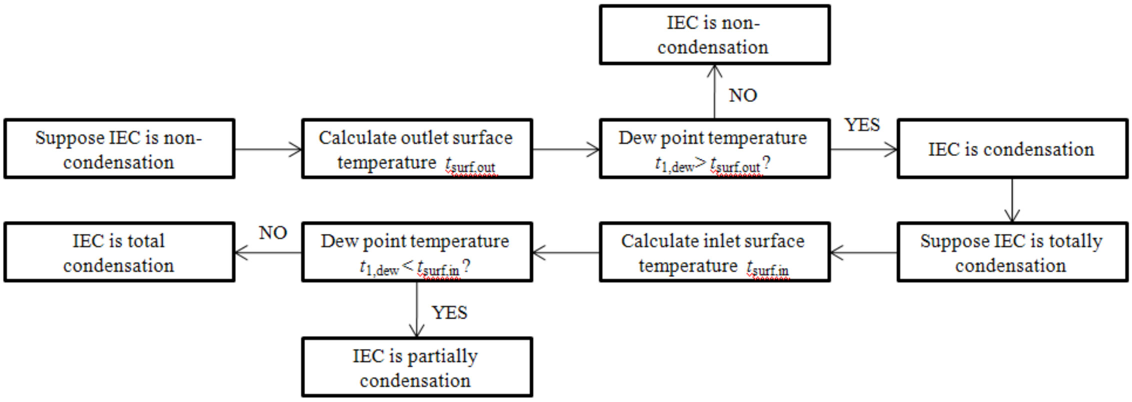

Fig. 2. Procedure of judging condensation statuses of IEC

2.2. Models for dry-coil IEC

The traditional ε-NTU method can be used directly for dry-coil IEC, in which the two air flows are: humidified secondary air and outdoor fresh air. The temperature of the humidified secondary air depends on the wet-bulb temperature of secondary air $t_{wb,in}$ and humidify efficiency η_1.

$$t_2' = t_{in} - \eta_1 \cdot (t_{in} - t_{wb,in}) \quad (1)$$

Under the non-condensation status, the heat capacity ratio Cr and heat transfer unit NTU can be calculated as:

$$Cr = \frac{(c_p m)_{\min}}{(c_p m)_{\max}} \quad (2)$$

$$\varepsilon = \frac{1-\exp\left[-NTU\cdot(1-Cr)\right]}{1-Cr\cdot\exp\left[-NTU\cdot(1-Cr)\right]}\left(NTU = \frac{KF}{(MC_P)_{\min}}\right) \quad (3)$$

When condensation occurs in the dry-coil IEC, the wet factor coefficient ζ should be induced for calculating the enlarged heat transfer rate bought by the wet surface as equation (4). Based on heat balance principle, the total heat transfer rate of the fresh air side and secondary air side are listed as Equation (5) and (6). The LMTD method should be used for calculating the temperature difference Δt. The surface temperature of the heat exchanger can be calculated by electricity analogy method. On partially condensation condition, the moving boundary method can be adopted by separating the whole heat exchange area into dry part and wet part.

$$\xi = \frac{\bar{h}_1 - h_{surf}}{C_p \cdot (\bar{t} - t_{surf})} \quad (4)$$

$$Q_1 = m_1 \cdot \left(h_1^{'} - h_1^{''}\right) = \zeta \cdot \alpha_1 \cdot F \cdot \Delta t_1 \quad (5)$$

$$Q_2 = m_2 \cdot c_p \cdot \left(t_2^{''} - t_2^{'}\right) = \alpha_2 \cdot F \cdot \Delta t_2 \quad (6)$$

2.3. Models for wet-coil IEC

As the heat and mass transfer process occurs simultaneously in the secondary air channels in the wet-coil IEC, the modeling can be very complicated. Maclaine-Cross & Bank [3] proposed a calculation method for the heat transfer coefficient on the wet surface by assuming the enthalpy of the moist air is in direct proportion to the wet-bulb temperature. In that way, the analogy ε-NTU method can be applied into wet-coil IEC modeling by introducing two revised parameters: heat transfer coefficient of the wet surface α_w and specific heat capacity of the wet surface c_{pw}, both based on the wet-bulb temperature of the moisture air.

$$\alpha_w = \alpha \left(1 + \frac{h_{fg}}{c_p e}\right) \quad (7)$$

$$c_{pw} = c_p + \frac{1}{e}\left(r + 1.84 t_{wb}\right) = c_p + \frac{h_{fg}}{e} \quad (8)$$

On non-condensation status, the heat balance equation can be expressed as equation (9). The efficiency of the wet-coil IEC is defined as equation (10).

$$M_1 C_p \left(t_1^{'} - t_1^{''}\right) = M_2 C_{pw} (t_{wb,2}^{''} - t_{wb,2}^{'}) \quad (9)$$

$$\varepsilon = \frac{t_1^{'} - t_1^{''}}{t_1^{'} - t_{wb,2}^{'}} \quad (10)$$

By adopting the revised α_w and c_{pw}, the heat capacity ratio *Cr* and heat transfer unit *NTU* in the ε-NTU method can be still used as Equation(2) and (3). In the condensation status, both the fresh air channels and secondary air channels contain wet surface. As the evaporation and condensation are reversed process, the concept of the revised α_w and c_{pw}, can still be used for calculating the condensation areas.

Similarly, in partially wet condition of the wet-coil IEC, the turning point separates the whole heat exchange area into dry part and wet part. On the turning point, the plate surface temperature must be equal to the dew point temperature of the fresh air, so the heat balance equation is as follows.

$$a_1 \cdot \left(t_{1,turn} - t_{1,dew}^{'}\right) = a_{2d} \cdot \left(t_{1,dew}^{'} - t_{wb,2,turn}\right) \quad (11)$$

$$d_{1,\mathrm{turn}} = d_1^{'} = f(t_1^{'}, t_{wb,1}^{'}) \quad (12)$$

2.4. Basic simulation parameters

The IEC thermal performance is mainly influenced by the structure parameters and inlet air parameters. In order to compare the thermal performance between the wet-coil and dry-coil IEC under the same configuration, the construction parameters and inlet air conditions should be set as the same in the simulation. In this study, the channel gap of the IEC is 5mm. The secondary inlet air condition is set constant to be 24℃ with 50% relatively humidity, for the reason that the exhaust air from indoor A/C space is usually used as the secondary air. The inlet fresh air parameters were selected on a wide range of temperature and humidity. The selected inlet air parameters were summarized as Table 1.

Table 1. The selected inlet fresh air and secondary air parameters

Item	Fresh air condition	Secondary air condition
Temperature (℃)	20, 22, …, 38	24
Relative humidity (%)	20, 30, …, 90	50
Mass flow rate (kg/s)	0.28	0.20

3. Results and discussion

By adopting the method of judging condensation statuses of IEC as Fig.2, the condensation regions of the dry-coil IEC and wet-coil IEC under the wide range of inlet fresh air conditions were plotted in Fig.3.

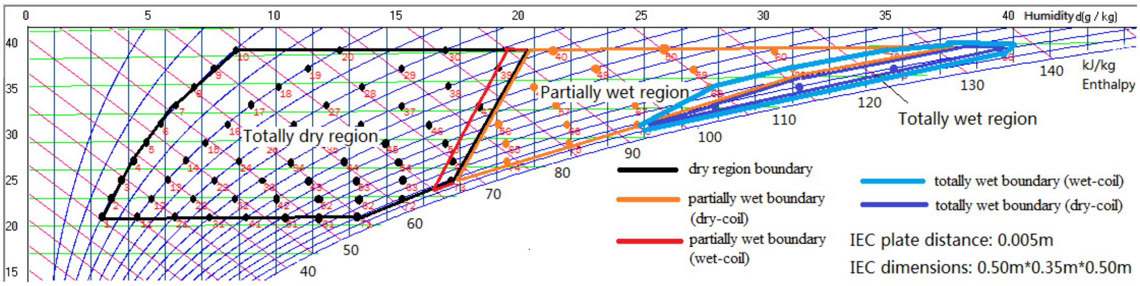

Fig.3. Condensation regions of the dry-coil IEC

It can be seen that the condensation trend of the dry-coil and wet-coil IEC is similar under the same configurations, which tends to be condensing at higher inlet air humidity. When the absolute moisture content of the fresh air exceeds 0.02 kg/kg·dry air, condensation will occur in both kinds of IEC units. The totally condensation will even happen if the inlet fresh air moisture content is too high (>0.035 kg/kg·dry air) or the relatively humidity is high (>90%) but the dry-bulb temperature is low.

However, the wet-coil IEC is more likely to be condensate and the condensation region is a little larger than that of dry-coil IEC, which may contribute to the lower plate surface temperature at the very beginning of the secondary air channels owing to the water evaporation.

Fig.4 and Fig.5 present the thermal efficiency and cooled fresh air outlet temperature of the dry-coil IEC and wet-coil IEC under condensation status (RH=70%) and non-condensation status (RH=30%). The turning points in the figures represent the transformation from non-condensation to condensation under RH=70% condition. When condensation occurs, the sensible cooling efficiency of both types of heat exchangers would be lowered to some extents because the moisture releases the latent heat. The supplied fresh air temperature will increase, but it can bring dehumidification effect to the fresh air.

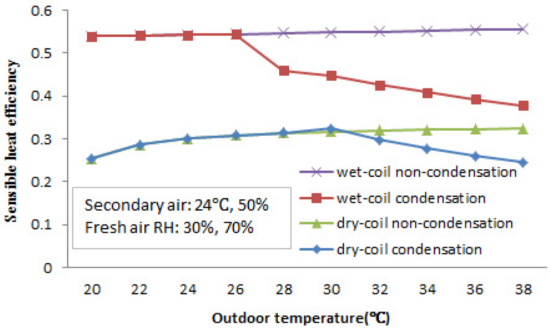

Fig.4. Sensible efficiency of dry-coil and wet-coil IEC

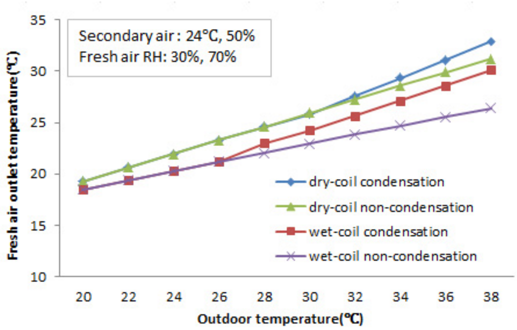

Fig.5. Fresh air outlet temperature of dry-coil and wet-coil IEC

It can be concluded that the efficiency of the wet-coil IEC is always higher than the dry-coil IEC in either status under the same configuration and with lower supplied temperature of the fresh air. The average sensible efficiency of the wet-coil IEC is 24% higher than that of dry-coil IEC in non-condensation statues and 13% higher in condensation statues. This can be attributed to the reason that water evaporation dramatically enhances the heat transfer rate between the two channels in the heat exchanger. Owing to the higher efficiency, the wet-coil IEC is more compact than the dry-coil IEC to achieve the same cooling effect.

4. Conclusion

The paper presents the analytical models for dry-coil IEC and wet-coil-IEC and compares their thermal performance under the same configuration. The simulation results show that: 1.when the absolute moisture content of the fresh air exceeds 0.02 kg/kg•dry air, condensation will occur in both wet-coil and dry-coil IEC units; 2. The efficiency of the wet-coil IEC is always higher than the dry-coil IEC in either non-condensation or condensation status under the same configuration; 3. The efficiency of IEC will be lowered when condensation occurs.

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Biography

Yi CHEN, PhD student from Building Service Engineering of Hong Kong Polytechnic University. The major research interests lie in the analysis of heat and mass transfer process in indirect evaporative cooling as well as the system dynamic simulation.