Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2125 – 2130

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Energy saving potential of hybrid liquid desiccant and evaporative cooling air-conditioning system in Hong Kong

Yi Chen[a], Yimo Luo[b], Hongxing Yang[a,*]

[a]*Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong*
[b]*Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Hong Kong*

Abstract

The hybrid liquid desiccant dehumidification and evaporative cooling system, short for LDD-EC system, is regarded as a promising energy-saving air-conditioning (A/C) scheme for hot and humid regions. Unlike most previous reported LDD-EC system based on traditional indirect evaporative cooler (IEC) and 100% fresh air system, the LDD-EC system with partial circulation air was explored by fully making use of dry return air from air-conditioned space. The regenerative indirect evaporative cooler (RIEC) is used to sensibly cool the return air. The outdoor fresh air is firstly dehumidified in the LDD unit to have the latent heat removed, and then further cooled by RIEC. The LDD model, EC model and space model were established separately to facilitate the hybrid system simulation under the typical hot and humid condition in Hong Kong. The energy saving potential of the proposed system is quantitatively evaluated with respect to the conventional vapor compression A/C system. The results show an attractive energy saving ratio of 23.5% under Hong Kong weather condition. The energy saving ratio increases to 70% if the waste heat could be utilized.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: liquid desiccant; evaporative cooling; hybird cooling system; energy saving; hot and humid

1. Introduction

Evaporative cooler (EC) is a device that cools air by water evaporation. Because of water's large enthalpy of vaporization, the air temperature can be reduced significantly by the phase transition from liquid to vapour. The EC is regarded as promising for its high efficient, low energy consumption, pollution-free and easy maintenance features. However, its wide applications are found only in dry

* Corresponding author. Tel.:+00852-27665863
E-mail address: hong-xing.yang@polyu.edu.hk

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.601

regions because the supply air temperature is limited to the high wet-bulb temperature of ambient air in humid areas.

In the subtropical areas, such as Hong Kong, the cooling season is long around the year. It was reported the energy consumption of the air-conditioning (A/C) system accounted for about 54% and 23% of the total building energy consumption in Hong Kong's typical office and residential buildings. Therefore, there is great potential of energy saving for A/C system. It is found the exhaust dry air from air-conditioned space instead of outdoor air can be used as the secondary air to render the EC application in Hong Kong, providing a good breach for A/C energy conservation.

In the vast majority of cases, EC is well-recognized for effectively handling the sensible heat load. The latent heat load, however, also needs to be removed as the indoor relative humidity (RH) needs to be kept in the range of 40-60% to meet the requirements of human comfort. In a traditional vapour compression A/C system, it consumes around 30-50% of the total energy to remove the latent heat with the condensation dehumidification. The proportion is even higher in very humid areas, such as Hong Kong. To deal with the latent heat, the liquid desiccant dehumidification (LDD) stands out as an effective technology. The LDD is unnecessary to reduce the air temperature below the dew-point one for moisture removal and avoids re-heat energy waste. Besides, the LDD could be driven by low grade heat sources, such as solar energy and waste heat, for further energy saving.

Based on the above review, the hybrid LDD and EC system, short for LDD-EC system, is regarded as a potential energy-saving A/C system for the hot and humid regions. The outdoor fresh air is firstly dehumidified in the LDD unit to have the latent heat removed, and then cooled by EC for sensible load. The system advantages are: 1) There is not mechanical refrigeration so it has low energy consumption; 2) It is environmentally friendly as no CFCs used; 3) It is easier to achieve independent control of temperature and humidity.

Several papers have studied this kind of system and good performance was reported [1, 2]. However, most of the studies focus either on the 100% outdoor air systems which have limited application, or based on traditional IEC which has limited wet-bulb efficiency. In the paper, the LDD-EC A/C system with partial circulation air system was explored with fully utilize of regenerative IEC (RIEC) and indoor return air. The energy saving potential of the proposed system is quantitatively evaluated with respect to a conventional vapour compression A/C system.

Nomenclature

Symbols	
A	heat and mass transfer area, m
c_{pa}	specific heat of air, J/kg·℃
c_{pw}	specific heat of water, J/kg·℃
h	heat transfer coefficient, W/m^2·℃
h_m	mass transfer coefficient, kg/m^2·s
h_{fg}	heat capacity of vaporization, J/kg
i	enthalpy of air, J/kg
m	mass flow rate, kg/s
t	celsius temperature, ℃
u	air velocity, m/s
ω	moisture content of air, kg/kg
Subscript	
sat	air in equilibrium with solution/water at solution/water temperature
p	primary/fresh air
s	secondary air

sol	solution
w	wall
ew	evaporation water
wb	wet-bulb temperature
SA	supply air
RA	return air

2. Proposed system

The schematic diagram of the proposed LDD-EC A/C system is shown as Fig.1. The RIEC (a kind of IEC can cool the air close to its dew-point temperature) is used to sensibly cool the return air (25℃, 50%). The outdoor air (32.4℃, 70%, Hong Kong weather condition) is firstly dehumidified in the LDD unit to have the latent heat removed, and then further sensibly cooled by RIEC. The processed return air and fresh air are mixed. A part of the mixed air is supplied to the DEC to achieve lower temperature and the rest part is by-passed before finally mixed as supply air with desired temperature and humidity.

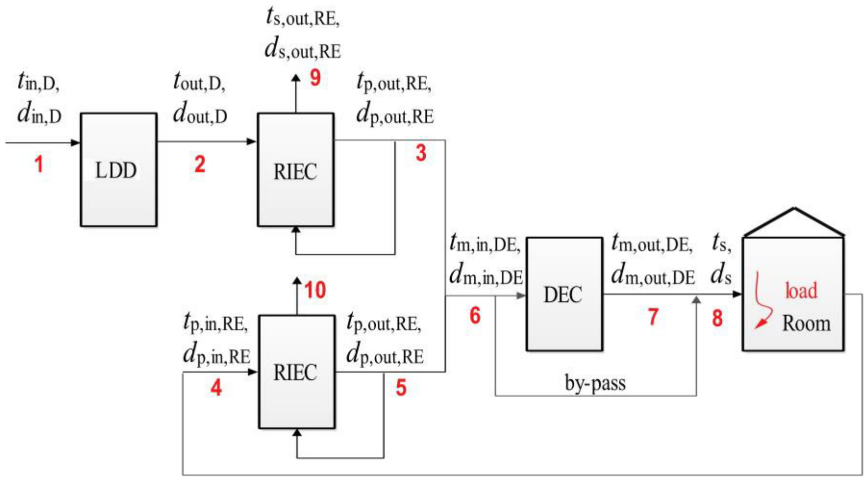

Fig.1 LDD-EC A/C system

3. Simulation models

The LDD model, EC model and space model were established separately to facilitate the hybrid system simulation under Hong Kong weather data.

3.1. Liquid desiccant dehumidifier (LDD))model

A one-dimensional finite difference model was employed for analysis. The dehumidifier was meshed to 100 microelements uniformly. For each microelement, the heat and mass transfer process follows the energy and mass conservation equations, listed as follows:

1) Mass conservation equation

$$m_p d\omega_p + dm_{sol} = 0 \tag{1}$$

2) Energy conservation equation

$$m_p di_p + d(i_{sol} m_{sol}) = 0 \tag{2}$$

3) Sensible heat exchange equation

$$m_p c_{pa} dt_p = h(t_{sol} - t_p)dA \tag{3}$$

4) Overall heat exchange equation

$$m_p di_p = h_m[(i_{a,sat} - i_p) - (1 - \frac{h}{h_m c_{pa}})c_{pa}(t_{sol} - t_p)]dA \tag{4}$$

In this work, the mass and heat transfer coefficients are calculated by the following equations [1~2]:

$$h_m = 25.9u^{0.833} / 3600 \tag{5}$$

$$h = h_m \times c_{pa} \tag{6}$$

3.2. Evaporative cooler (EC) model

There are two kinds of EC in the LDD-EC system, namely RIEC and DEC. The model of RIEC is established based on the energy and mass balance in the two channels, listed as follows:

1) Heat balance of the secondary air

$$h_s(t_w - t_s)dA = c_{pa} m_s dt_s \tag{7}$$

2) Mass balance of the secondary air

$$h_{ms}(\omega_{sat} - \omega_s)dA = m_s d\omega_s \tag{8}$$

3) Heat balance equation of the primary air (As the moist air is dehumidified by the LDD, no condensation would take place)

$$h_p(t_p - t_w)dA = c_{pa} m_p dt_p \tag{9}$$

4) Mass balance of evaporation water film

$$dm_e = m_s d\omega_s \tag{10}$$

5) Energy balance equation

$$m_s di_s - c_{pa} m_p dt_p = d(c_{pw} t_{ew} m_e) \tag{11}$$

The mass transfer coefficient (h_{ms}) can be obtained accordingly by assuming Lewis relationship is satisfied and Lewis number is unity in air-water interaction surfaces. For RIEC, the boundary conditions are: $x=H$, $t_p=t_{p,in}$,; $x=0$, $t_s=t_{p,out}$; $x=0$, $\omega_s=\omega_{p,in}$; $x=H$, $m_e=m_{e,in}$. The mass flow rates of primary air and secondary air satisfy the relationship: $m_s=rm_p$, in which r=0.3 is the optimized regeneration flow rate.

The governing equations can be written in ordinary differential equations. Then, the differential term is discretized into algebraic form by finite difference method and numerical simulation results at each discretize node can be obtained by solving a set of algebraic equations simultaneously.

For DEC, the air inhaled by the fan is cooled and humidified inside the pads following an approximately constant enthalpy. In theory, the leaving air can approach its wet-bulb temperature.

However, most of the commercial DEC in the market can reach a saturation efficiency of 70% ~ 95%. In this paper, a saturation efficiency of 90% is chosen for simulation.

3.3. Space model

The design supply air flow rate is determined by Eq. (12) once the sensible heating load, indoor setting and supply air temperature are known. The design supply air humidity is determined by Eq. (13).

$$Q_{sen} = m_{SA} \cdot c_{pa} \cdot (t_{RA} - t_{SA}) \quad (12)$$

$$Q_{lat} = m_{SA} \cdot h_{fg} \cdot (\omega_{RA} - \omega_{SA}) \quad (13)$$

4. Results and discussion

The simulation was conducted under the typical design air conditions of Hong Kong (outdoor: 32.4℃, 70%, indoor: 25℃, 50%) using the models developed above. The fresh air ratio is 30% and regenerative air flow rate in RIEC is also 30%. The air handling process of LDD-EC system is illustrated in the psychrometric chart in Fig.2. The point numbers in Fig. 2 are consistent with that of Fig. 1. The air conditions of each point refer to Table 1.

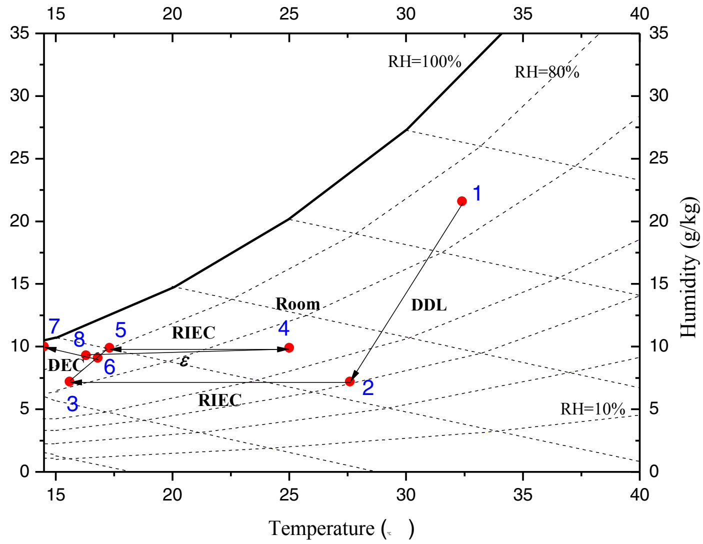

Fig.2 Psychrometric chart illustrated air handling process of LDD-EC system

It can be seen that the supply air is 16.34℃ and 9.28 g/kg, which near the supply air conditions (15 ~16℃, 90~95% RH) in traditional mechanical cooling system. Therefore, the LDD-EC system can take place of the mechanical cooling system in term of cooling performance. Take a case with sensible heat load of 3568 W and moisture load of 0.254 g/s as an example. The supply air flow rate is calculated to be 0.41 kg/s. The energy consumption of the LDD-EC system consists of regeneration heat, solution pump and fan. The regeneration heat is calculated to be 6.3 kW (0.176×2500×(21.6-7.2)) and regeneration power consumption is 1.58 kW (suppose heat to power ratio is 4). The energy consumption by the solution pump and fan is usually no more than 10% of the regeneration heat. Thus, the energy consumption of the pump and fan is estimated to be 0.6 kW. The energy consumption by RIEC and DEC include water circulation pumps and fans, which is estimated to be 0.42 kW (10% of the energy saving). In sum, the total power consumption of the LDD-EC system is 2.6 kW.

Table 1 Air conditions of each point

Point	*t* (°C)	*RH*	*ω (g/kg)*	*i* (kJ/kg)	t_{wb} (°C)	*m (kg/s)*
1	32.4	0.70	21.6	88.0	27.7	0.176
2	27.6	0.31	7.2	46.1	16.7	0.176
3	15.6	0.66	7.2	33.9	12.0	0.123
4	25.0	0.50	9.9	50.3	18.0	0.410
5	17.3	0.81	9.9	42.5	15.2	0.287
6	16.8	0.77	9.1	39.9	14.3	0.410
7	14.5	0.97	10.0	39.9	14.3	0.205
8	16.3	0.80	9.3	39.9	14.3	0.410
*9**	14.0	0.93	9.3	37.7	13.4	0.410

* Machine dew point in mechanical cooling air-conditioning system.

If the traditional central A/C system with primary return air is adopted, the total cooling capacity is calculated as 10.7 kW, of which fresh air cooling load is 6.2 kW, return air cooling load is 3.6 kW and reheat load is 0.9 kW. The power consumption of the mechanical cooling system is around 3.4 kW if the COP (coefficient of performance) of the chiller is 4.0. Thus, the energy saving ratio of LDD-EC system is 23.5% compared with that of traditional mechanical cooling system. In addition, if the waste heat is used for regeneration process in LDD unit, the energy saving ratio can be as high as 70%.

5. Conclusions

The hybrid liquid desiccant dehumidification and evaporative cooling (LDD-EC) system with partial circulation air was explored by fully making use of dry return air from air-conditioned space and high efficient regenerative indirect evaporative cooler (RIEC). The LDD-EC system can fully take place of the mechanical cooling system in term of cooling performance with an attractive energy saving ratio of 23.5% under Hong Kong weather condition.

Acknowledgements

The author would like to express appreciation to The Hong Kong Housing Authority for providing financial support for this study.

References

[1] Kim, M. H., Park, J. S., & Jeong, J. W. (2013). Energy saving potential of liquid desiccant in evaporative-cooling-assisted 100% outdoor air system. Energy, 59, 726-736.

[2] Goldsworthy, M., & White, S. (2011). Optimisation of a desiccant cooling system design with indirect evaporative cooler. International Journal of refrigeration, 34(1), 148-158.

Biography

Dr. Yi CHEN was graduated from the Building Service Engineering of The Hong Kong Polytechnic University. Her research interests lie in the heat and mass transfer modeling of indirect evaporative cooling (IEC), IEC system simulation and CCHP system optimization.