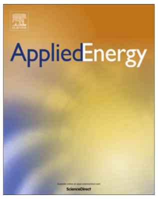
Applied Energy 194 (2017) 440–453

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



Parameter sensitivity analysis and configuration optimization of indirect evaporative cooler (IEC) considering condensation

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

[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 of Institute of Hong Kong, Hong Kong*

HIGHLIGHTS

- Numerical model of IEC considering condensation were established and validated.
- Sensitivity analysis was conducted among seven parameters.
- Influence rank of seven parameters were obtained by orthogonal test.
- The channel gap and NTU of IEC were optimized.

ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form 20 June 2016
Accepted 25 June 2016
Available online 2 July 2016

Keywords:
Indirect evaporative cooler
Condensation
Orthogonal test
Sensitivity analysis
Optimization

ABSTRACT

The indirect evaporative cooler (IEC) is a low-carbon device which cools the air with water evaporation. Its performances in dry regions have been investigated intensively. However, its application in hot and humid regions, where the IEC is used as a pre-cooling device in an air-conditioning system, is still at developing stage. The exhausted air from air-conditioned space is humidified and used as secondary air to pre-cool the fresh air. As the dew point temperature of the fresh air is high, condensation may occur in the dry channels. However, the parameter sensitivity analysis of IEC with condensation is lacking. Besides, the optimized IEC configuration may be different from that of dry regions because of distinguished air handling process. So the sensitivity analysis among seven parameters by orthogonal test was conducted based on the experimental-validated IEC model emphasizing on condensation condition. The optimization was then conducted to the most influential and engineering controllable parameters. The results indicate the channel gap and cooler height are the key influential factors on IEC thermal performance. The optimized channel gap is 2–3 mm and 3–4 mm under condensation and non-condensation state, respectively. The optimized NTU_p is 4–7 and 3–5, respectively.

1. Introduction

Indirect evaporative cooler (IEC) is an energy efficient and environmental friendly cooling device which uses water evaporation to produce cooling air [1,2]. The IEC has been regarded as a promising energy-saving technology in the near future for its high efficient, low energy consumption, pollution-free and easy maintenance features [3–5]. The most commonly used plate-type IEC consists of alternative wet and dry channels which are separated by thin plates. In the wet channels, the spraying water drops form a thin water film on the plate surface and consistently evaporates into the main stream of secondary air. The primary air in the adjacent dry channels is sensibly cooled by the low temperature wall without change in moisture content [6]. The schematic diagram of a typical plate type counter flow IEC is shown in Fig. 1. The channel gap is an important geometric parameter which refers to the gap between adjacent plates in IEC.

The air with lower humidity provides larger evaporation driving force, so larger cooling capacity can be achieved when IEC applied in hot and dry regions. The cooled primary air is supplied to the interior directly in these regions [7–9]. But in hot and humid regions, its application is restricted because the supplied primary air temperature is limited to the high wet-bulb temperature of ambient air. However, in recent years, a new hybrid air-conditioning system consisted of IEC and mechanical cooling is proposed for IEC application in hot and humid regions [10–15]. The IEC, installed before an AHU or cooling coil, is used to pre-cool the fresh air for energy conservation. The exhausted air with

---

* Corresponding authors.
E-mail addresses: hong-xing.yang@polyu.edu.hk (H. Yang), yimo.luo@vtc.edu.hk (Y. Luo).

http://dx.doi.org/10.1016/j.apenergy.2016.06.121

Nomenclature

A	heat transfer area, m^2
H	cooler height, m
L	cooler length, m
P	pressure, pa
Pr	Prandtl number
NTU	number of heat transfer unit
c_{pa}	specific heat of air, J/kg °C
c_{pw}	specific heat of water, J/kg °C
d_e	hydraulic diameter of channel, m
h	heat transfer coefficient, W/m^2 °C
h_m	mass transfer coefficient, kg/m^2 s
h_{fg}	latent heat of vaporization of water, J/kg
i	enthalpy of air, J/kg °C
m	mass flow rate, kg/s
n	number of channels
s	channel gap, m
t	Celsius temperature, °C
u	air velocity, m/s

Greek symbols

ω	moisture content of air, kg/kg
σ	wettability
η	efficiency
ε	enlargement coefficient
μ	dynamic viscosity, Pa s
υ	kinematic viscosity, m^2/s
λ	thermal conductivity, W/m °C

Subscripts

c	condensation
e	evaporation
p	primary/fresh air
s	secondary/exhaust air
w	wall
cw	condensate water
ew	evaporation water
in	air inlet
out	air outlet
wb	wet-bulb
lat	latent heat transfer

Abbreviation

RH	relative humidity
IEC	indirect evaporative cooler
RIEC	regenerative indirect evaporative cooler
COP	coefficient of performance

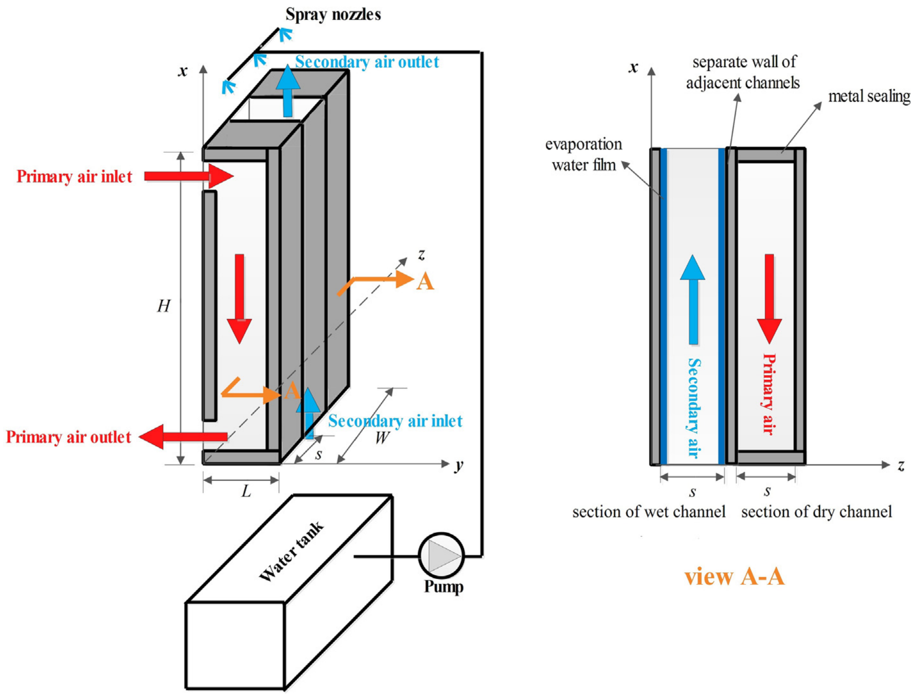


Fig. 1. Schematic diagram of plate type counter flow IEC.

lower temperature and humidity from air-conditioned space is used as secondary air for enhancing the evaporation process. Unlike the normal cases in which the IEC operates for only sensible cooling in dry regions, condensation from high humidity primary air may occurs when IEC applied in humid regions, resulting in not only sensible cooling but also dehumidification effect. However, it is found that relevant study on IEC with condensation is still at developing stage [16].

For high efficient cooling system, the parameter study, sensitivity analysis and configuration optimization are crucial because they could provide valuable guidance for favorable operating conditions and system design. A lot of such studies have been conducted to IEC under its non-condensation state. The models of IEC including traditional IEC, RIEC, M-cycle IEC (a dew-point IEC proposed by Maisotsenko et al. [17]) and other dew-point IEC [18] were established and solved numerically or analytically to