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Experimental analysis of a cross flow indirect evaporative cooling system

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ABSTRACT

Indirect evaporative cooling is an effective way to increase energy efficiency of air conditioning systems. This technology is particularly suitable for data centers applications, where the indoor temperature can be higher than the one adopted in residential and commercial buildings. In this work an indirect evaporative cooling system based on a cross flow heat exchanger has been widely tested. The system has been designed in order to minimize water consumption, with water mass flow rate between 0.4% and 4% of the secondary air one. On the whole, 112 experiments have been carried out in different working conditions of data centers. The effects of variation of water flow rate, humidification nozzles setup and secondary air temperature, humidity and flow rate have been widely investigated. Results put in evidence that performance is slightly dependent on nozzles number and size but it is strongly influenced by the water flow rate. In addition, nozzles in counter flow arrangement perform better than in parallel flow configuration. Depending on working conditions and equipment setup, the wet bulb effectiveness varies between 50% and 85%.

1. Introduction

In the last 15 years data centers, which consist of specific facilities containing ICT devices as well as cooling and power equipment, quickly increased in number and size [1]. As a result, in 2010 the total electricity used by data centers was 1.3% of world consumption and, in particular, in the US it increases from 0.13% in 2005 to 2% in 2010 [2]. Heat fluxes dissipated in data centers vary between 0.5 kW m^{-2} to 10 kW m^{-2}: as a consequence electricity consumption for cooling is relevant and it can reach 50% of the total consumption [1,2]. Therefore, at present design, manufacturing and management of cooling system is one of the most challenging aspects of data centers. Many research activities deal with the reduction of primary energy consumption in data centers, and in particular with energy efficiency measures and the integration of renewable sources [3], with waste heat recovery [1] and with free cooling options [2].

Recently ASHRAE updated the thermal guidelines for data centers [4], suggesting appropriate temperature and humidity ranges for IT equipment operation. On the whole 4 classes are defined, namely A1, A2, A3 and A4. Classes A1 and A2 are identical to class 1 and 2 reported in the previous edition of guidelines [5], instead classes A3 and A4 are new and represent an extension of suggested temperature and humidity limits. More precisely, in class A3 and A4 the maximum allowable temperature is respectively 40 °C and 45 °C. The appropriate class is selected by data center' operators in order to achieve desired energy savings and IT equipment reliability.

It is well known that an increase in the indoor data center temperature leads to an increase in free cooling working hours and, therefore, to relevant energy savings [2,6]. As a consequence, research activities about free cooling technologies and energy efficiency measures in data centers are rapidly increasing. One of the most promising technologies is based on the indirect evaporative cooling (IEC) principle. In IEC systems an air stream is first cooled through an adiabatic humidifier, and then it is used to cool a working fluid, typically a water stream [7] or an air stream [8]. The second configuration is of particular interest, because the process air stream is directly supplied to the data center facility.

It is put in evidence that in case of data centers applications, the system is arranged in recirculation mode: the primary (or process) air stream is extracted from the building, it is cooled in the indi-

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Nomenclature

A_{HE}	Heat exchanger cross area [m^2]
A, B, C	Test conditions
cp	Specific heat [kJ kg^{-1} K^{-1}]
h	Net channel height [m]
L	Gross plates length and width [m]
L^*	Net plates length and width [m]
$\dot{m}$	Specific flow rate [kg s^{-1} m^{-2}]
$\dot{M}$	Flow rate [kg s^{-1}]
M	Mass [kg]
N_{HE}	Number of heat exchanger plate [-]
pt	Plates pitch [mm]
$\dot{Q}$	Volumetric flow rate [m^3 h^{-1}]
t	Time [s]
T	Dry bulb temperature [°C]
T_{wb}	Wet bulb temperature [°C]
v	Channel air velocity [m s^{-1}]
x_i	Measured quantity [-]
X	Humidity ratio [kg kg^{-1}]
y	Calculated quantity [-]
Greek letters	
ΔP	Pressure drop [Pa]
ΔT	Temperature difference [°C]
ΔX	Humidity ratio difference [kg kg^{-1}]
ε_{db}	Dry bulb effectiveness [-]
ε_{wb}	Wet bulb effectiveness [-]
δ	Plates thickness [m]
Superscripts	
N	Nominal condition (ρ = 1.2 kg m^{-3})
Subscripts	
a	Air
eva	Evaporated water
in	Inlet
net	Net
out	Outlet
p	Primary air stream
s	Secondary air stream
w	Water
x_i	Measured quantity
y	Calculated quantity
Acronyms	
IEC	Indirect evaporative cooling

rect evaporative cooling system and, finally, it is supplied back to the facility. Instead a secondary air stream at outdoor conditions is humidified and used to cool the previous one. In addition, a conventional cooling system should be installed in order to provide backup and peak load cooling capacity.

Ongoing researches about IEC systems mainly deal with new thermodynamic cycles, heat exchanger materials and geometries, humidification systems and evaluation of energy savings compared to conventional devices [9]. In particular, experimental works are mainly focused on performance evaluation of different prototypes [10–16], of heat exchanger orientation [16] and of flows configuration [17–20].

In data centers applications, as previously described, the primary air flow of the IEC system is recirculated and it is completely separated from the secondary air stream. Therefore, indirect evaporative coolers based on M-cycle heat exchangers [12] or in regenerative configurations [13] are not suitable for the investigated application. In fact, in such systems the primary air is split in two streams: the first one is supplied to the building and the second one is humidified and used as secondary air stream. As a consequence, only systems with independent air flows can be considered [21].

At present there is a lack of extensive experimental studies of such indirect evaporative cooling systems, especially in typical data center working conditions. Based on the aforementioned considerations, the aim of this work is:

- To provide a detailed experimental analysis of the indirect evaporative cooling system in typical working conditions of data centers.
- To evaluate the effect of water nozzle arrangement on IEC performance.
- To analyze the effect of water mass flow rate on IEC performance.

The apparatus has been designed in order to minimize water consumption, with water mass flow rate between 0.4% and 4% of the secondary air one. It is shown in many operating conditions a high fraction of evaporated water is achieved $\left(\dot{M}_{eva}/\dot{M}_{w,in} > 40\%\right)$: in those cases such system can be manufactured without a pump for water recirculation, leading to a compact apparatus and minimizing risks of bacterial contamination.

2. Experimental set up

2.1. Description of the investigated indirect evaporative cooling system

The analyzed indirect evaporative cooling system consists of (Fig. 1):

- A commercial cross-flow plate heat exchanger.
- Water spray nozzles installed in the upper part of the system.
- An apparatus to increase pressure of water supplied to the nozzles.

The heat exchanger is made of aluminium plates with cross flow arrangement. Main characteristics are:

- Number of plates N_{HE} = 119.
- Plates thickness δ = 0.14 mm.
- Plates pitch pt = 3.35 mm.
- Net channel height $h = pt - \delta$ = 3.21 mm.
- Gross plate length and width L = 500 mm.
- Net plate length and width L^* = 470 mm.
- The plates spacing is obtained through dimples with semi-spherical shape.

As shown in Fig. 1, two horizontal water manifolds are symmetrically installed in the upper part of the heat exchanger casing. In each of them up to 4 nozzles (n° 8 in total) can be installed: the distance between each nozzle along the water manifold is around 8 cm. Instead the distance between the two manifolds is 18 cm and both of them are installed 15 cm from the heat exchanger face.

Two different axial flow—full cone nozzles, characterized by a different orifice diameter, have been adopted. Nominal data provided by manufacturer are:

- Nozzle A: water flow of each nozzle equal to 3.52 l h^{-1} at 10 bar.
- Nozzle B: water flow of each nozzle equal to 7.50 l h^{-1} at 9 bar.