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Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city

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Abstract

This paper presents the basic principles of the evaporative cooling process for human thermal comfort, the principles of operation for the direct evaporative cooling system and the mathematical development of the equations of thermal exchanges, allowing the determination of the effectiveness of saturation. It also presents the results of experimental tests in a direct evaporative cooler that take place in the Air Conditioning Laboratory at the University of Taubaté Mechanical Engineering Department, and the experimental results are used to determinate the convective heat transfer co-efficient and to compare with the mathematical model.

Keywords: Brazil; Experiment; Air conditioning; Evaporative system

Refroidisseur à evaporation directe fonctionnant en été dans une ville brésilienne: performance expérimentale

Mots clés : Brésil ; Experimentation ; Conditionnement d'air ; Système évaporatif

1. Introduction

Evaporative cooling operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists, specifically, in water evaporation, induced by the passage of an air flow, thus decreasing the air temperature. When water evaporates into the air to be cooled, simultaneously humidifying it, that is called direct evaporative cooling (DEC) and the thermal process is the adiabatic saturation. The main characteristic of this process is the fact that it is more efficient when the temperatures are higher, that means, when more cooling is necessary for thermal comfort. It has the additional attractiveness of low energy consumption and easy maintenance. Due to use total airflow renewal, it eliminates the recirculation flow and proliferation of fungi and bacteria, a constant problem in conventional air conditioning systems. Due to its characteristics the evaporative cooling system is more efficient in places, where the climate is hot and dry but it can also be used under other climatic conditions.

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Nomenclature

A	area of the heat transfer surface; total wetted surface area (m^2)
C_{pa}	constant pressure specific heat of the dry air ($J\ kg^{-1}\ K^{-1}$)
C_{pu}	specific heat of the humid air ($J\ kg^{-1}\ K^{-1}$)
C_{pv}	constant pressure specific heat of the vapour ($J\ kg^{-1}\ K^{-1}$)
h_a	specific enthalpy of the air ($J\ kg^{-1}$)
h_c	convective heat transfer co-efficient ($W\ m^{-2}\ °C^{-1}$)
h_{LVS}	specific enthalpy of vaporization of the water at surface temperature ($J\ kg^{-1}$)
h_m	mass transfer co-efficient ($kg\ m^{-2}\ s^{-1}$)
h_{sa}	specific enthalpy of the leaving air ($J\ kg^{-1}$)
h_v	specific enthalpy of the vapour ($J\ kg^{-1}$)
h_{VS}	specific enthalpy of the vapour at surface temperature ($J\ kg^{-1}$)
l	pad thickness (m)
l_e	characteristic length (m)
m_a	air mass flow ($kg\ s^{-1}$)
m_v	mass flow of the water vapour ($kg\ s^{-1}$)
Nu	Nusselt number (dimensionless)
Pr	Prandtl number (dimensionless)
Re	Reynolds number (dimensionless)
R_{Le}	Lewis relationship (dimensionless)
T	bulk temperature (°C)
$T_{ext\ av}$	external average temperature (°C)
T_n	thermal neutrality temperature (°C)
T_s	surface temperature (°C)
w	absolute humidity of the draft ($kg_w\ kg_{air}^{-1}$)
w_s	absolute humidity of the air close the surface ($kg_w\ kg_{air}^{-1}$)
Greeks	
ε	cooling effectiveness (dimensionless)
ϑ	volume occupied by the evaporative pad (m^3)
ρ	specific mass ($kg\ m^{-3}$)

2. Recent developments

Several authors dedicated their researches to the development of direct and indirect evaporative cooling systems. Watt [1] developed the first serious analyses of direct and indirect evaporative systems; Leung [2] presents an experimental research of the forced convection between an air flow and an inner surface of a horizontal isosceles triangular duct; Halasz [3] presented a general dimensionless mathematical model to describe all evaporative cooling devices used today; Camargo, Cardoso and Travelho [4] developed a research, where a thermal balance study for direct and indirect cooling systems was developed; Camargo and Ebinuma [5] presented the principles of operation for direct and indirect evaporative cooling systems and the mathematical development of the equations of thermal exchanges, allowing for the determination of heat transfer convection co-efficients for primary and secondary air flow; Dai and Sumathy [6] investigated a cross-flow direct evaporative cooler, in which the wet honeycomb paper constitutes the packing material and the results indicate that there exists an optimum length of the air channel and the performance can be improved by optimizing some operation parameters; Liao and Chiu [7] developed a compact wind tunnel to simulate evaporative cooling pad-fan systems and tested two alternative materials; Al-Sulaiman [8] evaluated the performance of three natural fibers (palm fiber, jute and luffa) to be used as wetted pads in evaporative cooling; Camargo, Ebinuma and Silveira [9] presents a thermoeconomic analysis method based on the first and second law of thermodynamics and applied to an evaporative cooling system coupled to an adsorption dehumidifier; Hasan and Sirén [10] investigated the performance of two evaporatively heat exchangers operating under similar conditions of air flow and inlet water temperatures; Camargo, Ebinuma and Cardoso [11] presents the basic principles of the evaporative cooling processes for human thermal comfort and presents the mathematical development of the thermal exchanges equations, allowing the determination of the effectiveness of saturation.

This paper develops a mathematical model for direct evaporative cooling system and presents the experimental results of the tests performed in a direct evaporative cooler that took place in the Air Conditioning Laboratory at the University of Taubaté Mechanical Engineering Department, located in the city of Taubaté, State of São Paulo, Brazil.

3. Direct evaporative cooling

The principle underlying direct evaporative cooling is the conversion of sensible heat to latent heat. Non-saturated air is cooled by heat and mass transfer increases by forcing the movement of air through an enlarged liquid water surface area for evaporation by utilizing blowers or fans. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapor and diffuses into the air [12].

Fig. 1 shows a schematic direct evaporative cooling system, where water is running in a loop and the makeup water entering the sump to replace evaporated water must be at the same adiabatic saturation temperature of the incoming air. In a DEC, the heat and mass transferred between air and water decreases the air-dry bulb temperature (DBT) and increases its humidity, keeping the enthalpy constant