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Testing and modelling of a novel ceiling panel for maintaining space relative humidity by moisture transfer

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ABSTRACT

Radiant ceiling panels are preferred over all-air systems because of their ability to lower energy consumption and maintain better comfort conditions. One disadvantage is their inability to moderate indoor humidity. To overcome this limitation, a new panel that can transfer heat and moisture is being developed. This research determines the performance of this panel under different temperature and humidity conditions. The effectiveness of the panel ranges from 15% to 28%, depending on the conditions. A computational fluid dynamics model of the panel has been developed using the commercial software, FLUENT. Good agreement is seen between experiments and the model for most cases. Comparing the change in humidity ratio of the air, the average difference is 5%.

1. Introduction

Occupant comfort is an important aspect of building design. An occupant's health and productivity are affected by the comfort conditions in a building. Poor comfort conditions can result in a loss of productivity [1,2], which can result in a financial loss for a company. People naturally produce heat, based on their metabolic rate and the physical activity that they are engaged in. Occupant comfort relates to the ability of the environment to remove that heat. The heat transfer between an occupant and their environment is affected by several factors: air temperature, mean radiative temperature of the space, air speed, space relative humidity (RH), the activity level of the occupant and the amount of clothing worn [3]. The focus of this research is on improving RH conditions in a space, to improve overall comfort for occupants.

When a person is hot, the body cools itself by sweating. This moisture evaporates to the surrounding air, cooling the body. If the surroundings are very humid (high RH), little moisture is able to evaporate to the surrounding air, resulting in less cooling of the body. In high humidity conditions people often feel hotter than the actual temperature would suggest, due to this lack of cooling. Also, the presence of excess moisture on the skin can result in the skin feeling wet and increased friction between skin and clothing, all things that add to the occupant's discomfort. The opposite happens in a space with low humidity levels, where too much moisture is removed from the body. This leaves the occupant with dry skin and mucous surfaces (inside the nose, mouth and eyes). CEN EN 15251 [4] recommends that the relative humidity be kept between 25%RH and 60%RH for new buildings. ISO Standard 7730 [5] suggests the indoor RH should be between 30%RH and 70%RH.

The typical method used to moderate indoor RH is to precondition the air that enters the occupied space, usually a mixture of outdoor air and return air from the space. All-air systems use this supply air to maintain both the indoor temperature and RH. These systems require large fans to move the air and often require large airflow rates to meet the heating or cooling loads. They tend to consume large amounts of energy, through heating, cooling and fan power.

Another technology that is being used in new buildings is radiant ceiling panels. These panels consist of a lightweight metal panel that is installed into the ceiling of a space. On the back of the metal panel is a series of pipes, through which water is pumped. The front surface of the panel is exposed to the space below. The water that is pumped through the pipes is heated or chilled, as required by the space conditions. Heat is transferred between the water and the space air, by a combination of radiation and convection, thus heating or cooling the space, as required.

When radiant ceiling panels are used, the amount of air supplied to the space can be reduced drastically. Since maintaining the space temperature is accomplished with the panels, the supply air is required only for ventilation and humidity purposes. Since

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Nomenclature

C_p	specific heat [J/(kg K)]
D_h	hydraulic diameter of duct (m)
E	energy (J/kg)
H	height of duct (m)
h	enthalpy (J/kg)
$\vec{J}$	diffusion flux (kg s/m^2)
k	thermal conductivity [W/(m K)]
m, n	indices
P	pressure (N/m^2)
Re	Reynolds number
RH	relative humidity (%RH)
s_{ij}	stress tensor (1/s)
T	temperature (°C or K)
u, v	velocity (m/s)
W	humidity ratio ($g_{moisture}/kg_{dryair}$)
W_d	width of duct (m)
Y	mass fraction
y, z	distance along y-axis or z-axis

Greek symbols

ε	effectiveness (%)
φ	porosity of medium
γ	aspect ratio of the duct
μ	dynamic viscosity (N s/m^2)
ρ	density (kg/m^3)

Subscripts

eff	effective property
f	fluid phase
s	solid phase

the airflow rates are lower, smaller ducts and fans can be used. This creates both cost and space savings, as smaller plenums can be used in new constructions. As well, there is less draft in the spaces due to the lower airflow rates and less noise, due to the smaller fan sizes [6]. Radiant panels directly control the operative temperature (combination of the dry-bulb temperature and mean radiant temperature) of a space, which leads to better thermal comfort conditions in the space [7–10]. By controlling the mean radiant temperature of the space, the dry-bulb temperature may be set slightly lower (heating) or higher (cooling) resulting in the same operative temperature, which reduces sensible heating and cooling loads of a building.

Although radiant ceiling panels have been shown to improve thermal comfort and reduce energy consumption in buildings, a disadvantage is the lack of control of the indoor RH. In order to achieve acceptable indoor RH levels, the ventilation air that is brought into the space must be preconditioned to the appropriate RH level before it is supplied to the space. The current work focuses on the development of a ceiling panel that will be able to transfer moisture, as well as heat to a space, thus moderating the indoor RH and temperature together.

1.1. Heat and moisture transfer panel (HAMP)

The HAMP is similar to existing radiant panels, with the exception that it can transfer moisture, as well as heat. Fig. 1 shows a schematic of the HAMP used in the experiments. The surface of the HAMP is a porous membrane, which is permeable to water vapour but not to liquids. The membrane is attached to an acrylic tray which is divided into channels. A liquid is pumped through the channels, and heat and moisture are transferred between the liquid and the building air.

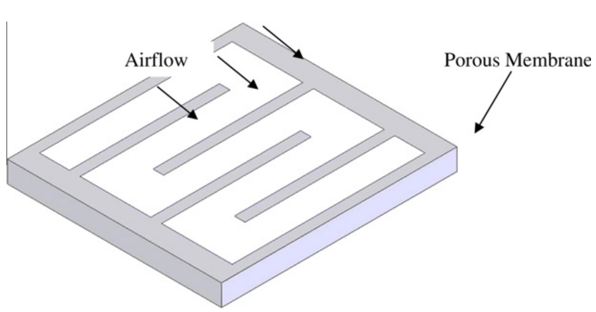

Fig. 1. Schematic of the HAMP used in the experiments.

Unlike radiant panels which use water as the circulating liquid, the HAMP uses a salt solution. Salt solutions have a lower surface RH than water (100%RH), which gives them the ability to dehumidify, as well as humidify, the space air. Water can only be used for humidification. A mixture of lithium chloride (LiCl) and water is used for the salt solution. A saturated LiCl solution (50% concentration) results in a surface RH of ~11%RH [11]. To avoid possible crystallization of the salt on the apparatus, the salt solution used is not at saturated conditions. Instead, a concentration of 35% is chosen, which results in a surface RH of ~30%RH.

2. Description of the test facility

The HAMP is tested in a small facility at the University of Saskatchewan. A complete description of the test facility is given by Fauchoux et al. [12,13]. The facility consists of an entrance section, test section and exit section. Air enters the facility through a small hose, with a high velocity. The purpose of the entrance section is to ensure that the air enters the test section as a uniform flow, filling the whole duct, rather than a jet. This is accomplished with an expansion, contraction and several screens. The temperature and RH of the air are measured at the end of the entrance section, just before the test section. The test section is shown in Fig. 2a and b. The HAMP can be tested either as a floor panel (Fig. 2a) or a ceiling panel (Fig. 2b). The test section is 0.23 m wide, 0.15 m high and 0.23 m long. Air entering the test section is conditioned to a temperature and RH set by the user. The conditioned air flows past the HAMP and heat and moisture are transferred between the air stream and the liquid in the HAMP. The exit section consists of a nozzle, which reduces the volume of the air. This allows the bulk temperature and RH of the air to be measured as the values will be non-uniform after the test section.

The flow rate of the air is controlled by two Type 1559A Mass-Flo® Controllers (MKS, Massachusetts). One has a range of 20 L/min and the other 50 L/min. The temperature and RH of the air are measured using two HMP 233 sensors (Vaisala, Helsinki, Finland). One is located upstream and one downstream of the test section. The uncertainty in these measurements is ±0.5 °C and ±2%RH. The temperature of the liquid in the HAMP is measured in each of the five channels, using T-type thermocouple wire. All measurements are collected using a SCXI 1000 chassis (National Instruments, Texas) connected to a 16-bit data acquisition card. The experimental data