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Applicability of a heat and moisture transfer panel (HAMP) for maintaining space relative humidity in an office building using TRNSYS

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ABSTRACT

Radiant panel systems have one of the highest technical energy savings compared to other HVAC systems and they achieve high comfort levels. However, they are unable to maintain the indoor relative humidity as they only transfer sensible heat. In order to overcome this problem, a novel heat and moisture transfer panel (HAMP) is developed and tested. In this paper, the applicability of the HAMP is tested using the TRNSYS simulation program. The impact of the HAMP on space relative humidity is investigated by modeling a one-storey office building in four North American cities (Chicago, Miami, Phoenix, and Saskatoon) as representatives of four major climatic conditions. The validity of the HAMP and resulting energy savings is represented and compared against the same building operating with two other HVAC systems: a conventional all-air system and a radiant ceiling panel (RCP) system with 100% outdoor air. The HAMP is able to control the relative humidity in the building between 25% RH and 60% RH in Chicago, Saskatoon, and Phoenix, and between 40% RH and 62% RH in Miami. The results also show the potential of the RCP system with the HAMP to reduce the total energy consumed by the conventional all-air system in different climates.

1. Introduction

Since a large portion of primary energy is consumed in buildings and this is where people spend most of their time, the design of effective heating, ventilating, and air conditioning (HVAC) systems is necessary. Radiant panels are temperature controlled indoor surfaces placed on ceilings, floors or walls having 50% or more of the design heat transfer taking place by thermal radiation. Temperature is maintained by circulating water, air, or electric current. Radiant panels provide better comfort conditions and consume less energy than conventional HVAC systems [1]. The panels transfer heat to the space by radiation and convection. Convection heat transfer takes place between the panels and the room air, while radiation heat transfer takes place between the surface of the panels and the room surfaces and objects. Radiant panels are already available commercially but they are not able to control latent loads. It is important to control indoor relative humidity in buildings between 30% RH and 70% RH as suggested by ISO Standard 7730 [2] to achieve the required comfort levels and avoid condensation problems. Several researchers including Bornehag et al. [3] and Kosonen and Tan [4] reported that indoor humidity levels outside this range leads to discomfort, and lower productivity.

1.1. Radiant panels

Many papers in the literature discuss and document the theory and performance of radiant cooling regarding its comfort, efficiency, and cost effectiveness. Radiant panel systems have been used in Europe for over 25 years in facilities such as hospitals, museums, office buildings, and stores [5–7]. Simmonds [6] studied the first cost and long term energy savings of radiant ceiling cooling panels compared to conventional air conditioning systems (or all-air systems) and concluded that the first cost is 15% less with experienced contractors, the long term energy savings due to using smaller chillers and reduced fan power is 20–30%, there are less moving parts showing a potential for lower operational and maintenance costs, and the testing and balancing at commissioning is simpler and less expensive.

Simmonds [6] presented a comparison between floor and ceiling systems. This comparison showed that floor systems are favorable for buoyancy ventilation where the heated air in contact with the floor panels becomes less dense and replaces the colder air which is denser and thus allows air movement in the space. On the other hand, ceiling systems free up the floor space for electrical cabling. Simmonds [6] also mentioned that ceiling systems respond faster

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Nomenclature

Symbols

A	floor area [m^2]
D_{AB}	diffusivity [m^2/s]
H	Moisture added or removed from the building [kg]
h_c	convective heat transfer coefficient between HAMP external surface and space air [W/(m^2 K)]
h_{fg}	latent heat of vaporization of air [kJ/kg]
L	characteristic length [m]
Nu	Nusselt number
Pr	Prandtl number
Q	heating or cooling load [kW]
Sc	Schmidt number
Sh	Sherwood number
T	temperature [°C]
W	humidity ratio
ρ	density [kg/m^3]

Subscripts

a	space air
cooling	cooling
dryair	air without water vapor
heating	heating
p	panel
s	surface

to load changes than floor systems. However, whether floor systems or ceiling systems are used, the choice of the radiant panels' position depends on the specific case, location, and architectural concerns of the building.

Kulpmann [8] studied a space with cooled ceiling and found that the system achieved good thermal comfort. Different researchers [9–12] have shown that radiant panels consume less energy than all air systems. Sodec [9] used a numerical simulation and the weather data of Essen, Germany, to compare an all air VAV system with a radiant ceiling system regarding the energy costs, first costs, and the space requirements. Sodec [9] concluded that as the energy removed per unit area increases, the energy costs, first costs and space requirements decrease. It is also concluded that at the cooling energy of 45–55 W/m^2, the energy savings using free cooling can be up to 10–20% in cooling, the first costs can be reduced by up to 20%, and the space requirements can be reduced by 40–55%.

Miriel et al. [10] performed an experimental study to verify the results obtained using a computer simulation on the energy performance of radiant heating and cooling panels. Experimental results were obtained from two winters and one summer in a test room in an experimental house built in Rennes in western France. The study showed the ability of the panels to perform heating and cooling provided that the loads are low and the minimum ceiling temperature is 17 °C to avoid condensation and mold formation. Vangtook and Chirarattananon [11,12] tested radiant cooling in a hot and humid climate using a test room equipped with radiant cooling panels for experimentation [11] and a numerical simulation program [12] using weather data of Southeast Asia. The experimental and numerical results both proved that radiant cooling can achieve good thermal comfort indoor environment in hot humid climates. The experiments show that to avoid condensation on the surface of the panels, the supply water temperature should be kept to 24–25 °C which limits the cooling capacity to 40 W/m^2.

With proper selection and installation of the ceiling panels, the only problem faced by this system is condensation. To overcome this problem, many researchers have introduced the idea of using radiant ceiling panels integrated with other all air systems. Conroy and Mumma [13] reported the use of radiant ceiling panels to control sensible loads only, while a dedicated outdoor air system (DOAS) controlled 100% of the space latent load so that the dew point temperature of the space could be controlled. Busweiler [14] introduced the first system that used desiccant cooling with a cooled ceiling system. Due to limited space in the plenum above the suspended ceilings in a hotel in Bremen, a conventional all-air HVAC system could not be installed. This led to the selection and installation of a cooled ceiling system with ventilation air supplied from diffusers near the floor. A desiccant wheel was used to dehumidify a 100% outdoor air stream, and an evaporative cooler was used to cool and humidify the outdoor air according to the air conditions. The system ran successfully for a year and saved energy and reduced the peak electric consumption. In general, ceiling panels with their different applications are more widely used in Europe than in North America [5].

1.2. Heat and moisture transfer panel (HAMP)

A novel heat and moisture transfer panel (HAMP) has been developed as another solution to handle the latent load directly from the space and avoid condensation on chilled surfaces. The HAMP has been investigated by Fauchoux et al. [15,16]. Fig. 1 shows a sketch of the side view of the HAMP when applied as a ceiling panel and a picture of the HAMP prototype used in testing. A HAMP is a panel constructed from a semi-permeable membrane and uses a salt solution as the transfer media so that it can control both temperature and relative humidity of the space air. The salt solution is held by retaining walls on the top and sides and the semi-permeable membrane on the bottom (Fig. 1(a)). The semi-permeable membrane is impermeable to the liquid salt solution but permeable to water vapor. The salt solution is circulated to maintain its temperature and salt concentration.

The experiments done by Fauchoux [16] showed the ability of the HAMP to transfer heat and moisture to/from a space. The findings showed that the HAMP is able to heat, cool, humidify,

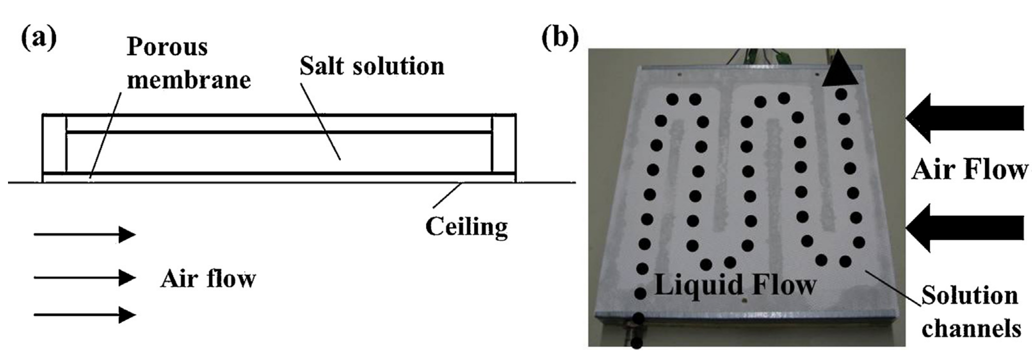

Fig. 1. The (a) side view and (b) top view of the HAMP used in testing.