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A new desiccant channel to be integrated in building façades

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ABSTRACT

Desiccant systems are useful to remove latent load from ventilation air in HVAC systems. Sometimes, desiccant wheels complement the treatment in dedicated outdoor units.

This paper proposes a new system that incorporates two layers of solid desiccant inside each side of a ventilated façade. The regeneration of the desiccant is achieved by passing hot air, given by a solar collector module also incorporated into the facade.

A detailed mathematical model, based on the water mass and heat transfer equations, gives the capacity of the system. In a Mediterranean climate, the maximum latent load that can be removed by the system reaches 30 W per linear meter of façade. The main variable that determines the capacity of the system is solar radiation, although the humidity ratio and the dry temperature of the outside air have also to be considered.

Finally, a very simple model based on an efficiency is developed. The relative error of the simple model ranges between 10% and 20%, depending on climatic conditions

1. Introduction

Improving the indoor air quality in occupied spaces involves increased ventilation levels. The energy that is required to condition the ventilation air from the outside conditions to the zone conditions is the ventilation load. The ventilation load increases as the outside flow increases.

Air conditioning systems can remove both sensible load (change the dry-bulb temperature of the air) and latent load (change the water content of the air). In most applications, the humidity of the air is not directly controlled by the HVAC system. In the process of meeting the sensible load, the air is cooled below its dew-point temperature, which coincidentally provides some degree of dehumidification. Under these circumstances, the latent load removed by the cooling coil depends on the sensible load being met. The ratio of sensible load to total load is the sensible heat ratio (SHR) of the cooling coil. The SHR depends on the geometric and operational parameters of the coil. During the operation period, the SHR of the coil must be equal to the SHR of the ventilation load, if both sensible and latent ventilation loads are to be satisfied.

When using a dedicated outdoor air unit (DOA), ventilation air increases the water content of the zone when the dry temperature of the outside air is near or below the comfort temperature of the zone. In this case, the cooling coil does not reduce the air temperature, neither the water content of the supply air. This effect occurs in temperate climates, but with high humidity, such as in the Mediterranean or tropical climates.

The development of systems able to control both, latent and sensible ventilation load, is interesting when looking for improved thermal comfort, especially if moisture levels in occupied spaces are mandatory. One option to disengage the sensible and latent treatments is the use of solid desiccants. Sometimes, air handling units (AHU) incorporates desiccant wheels for this purpose. Many authors have studied AHUs with desiccant wheels. In Baniyounes et al. [1] a conventional AHU is compared with one that uses a desiccant wheel for the treatment of outside air. We can also find numerous models of desiccant wheels in the literature, for example, Ruivo et al. [2] discuss the validity of the constant effectiveness model compared with more detailed models. Ghazal et al. [3], Sheng et al. [4] and De Antonellis et al. [5] propose models of desiccant wheels based on experimental analysis.

The energy for drying the wheel can be gas or electricity [6]. Sometimes solar energy is used for the regeneration process [7]. In such a case, regeneration temperatures are lower but the operating cost is reduced. A major drawback of the desiccant wheel is the

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Nomenclature

A_c	Solar collector surface per unit length of façade (m^2/m)
A_{c-s}	cross-sectional area of the channel (m^2)
c_{pf}	specific heat of humid air (J/(kg$_{da}$ K))
D	diffusion coefficient (m^2/s)
D_h	hydraulic diameter
e	width of finishing layer (m)
E_{lat}	latent energy removed over a complete cycle per sq. meter of façade (J/m^2)
f	friction factor
h_{ads}	adsorption heat (J/kg$_{water}$)
h_m	mass transfer coefficient (m/s)
h_h	heat transfer coefficient (W/(m^2 K))
h_{cr}	convective-radiant coefficient outside the façade (W/(m^2 K))
h_{fg}	latent heat (J/kg$_{water}$)
I_T	solar radiation impinging the façade (W/m^2)
j_h	heat flow (W/m^2)
j_m	water massflow (kg$_{water}$/(m^{2}s))
j_h	heat flow (W/m^2)
k	conductivity (W/(m K))
L	channel length (m)
Le	lewis number
$\dot{m}$	air mass flow per meter of façade (kg$_{wet\ air}$/(sm))
Nu	nusselt number
Q_{lat}	latent load removed per sq. meter of façade (W/m^2)
Q_{max}	maximum theoretical latent load per sq. meter of façade (W/m^2)
Pr	Prandtl number
P_w	wetted perimeter of the channel (m)
Re	Reynolds number
Rv	gas constant for the water vapor (J/(kg$_{vapor}$ K))
r	mean pore radius (m)
S_l	thermal starting length (m)
T	temperature (°C)
X	desiccant water content (kg$_{water}$/kg$_{dry\ desiccant}$).
x	direction normal to the façade (m)
w	width of the desiccant layer (m) or water content (kg$_{water}$/kg$_{dry\ air}$)

Greek letters

α	thermal difussivity
δ	channel width (m)
ε_w	void fraction in the desiccant with adsorbed water.
ε_d	void fraction in the dry desiccant
μ_f	dynamic viscosity of humid air (kg$_{wet\ air}$/(ms))
η	solar collector efficiency (–)
φ	air specific humidity (kg$_{vapor}$/kg$_{airehúmedo}$)
ρ_d^*	apparent density of dry desiccant (kg$_{dry\ desiccant}$/m^3$_{desiccant}$)
ρ_f	air density (kg$_{wet\ air/}$m^3)
ρ_l	density of water adsorbed by the desiccant (kg/m^3)
ρ_v^*	apparent density of water vapor in the desiccant (kg$_{wet\ air}$/m^3$_{desiccant}$)
τ_d	mass diffusion characteristic time (s)
τ_h	heat diffusion characteristic time (s)
τ_l	tortuosity for the adsorbed water (–)
τ_w	tortuosity for the water vapor (–)

Subscripts:

c	collector
d	desiccant
e	exterior
es	interface air-desiccant at the exterior side of the façade
eff	effective
f	fluid, air in the channel
is	interface air-desiccant at the interior side of the façade
l	liquid
m	mass or mass transfer
o	output
p	external finishing
r	room
reg	regeneration
T	tilted
v	water vapor inside the pores

pressure loss it causes. Goldsworthy and White [8] analyze this aspect by calculating the electric COP of the whole system. The increased consumption of the fans could offset the benefits of using desiccant wheel.

Since the publication of the NZEB [9] directive, buildings must generate the energy they consume. This has promoted, particularly in Europe, the incorporation of the systems into the façade of the buildings, so that the envelope of the buildings is no longer a passive element to but becomes an active one.

This paper proposes a new façade system that incorporates the desiccant. Taking advantage of the use of ventilated facades, we add a small desiccant layer to each side of the channel. The regeneration of the desiccant is achieved by passing hot air given by a solar collector module, also incorporated into the facade.

The proposed system has the advantages of separating the latent and sensible ventilation loads, reduces the pressure drop compared to conventional desiccant wheel systems, and transforms the façade into an active system.

The aim of the study is to assess the ability of this system to reduce the ventilation latent load.

2. The desiccant channel

The desiccant channel is installed inside the ventilated façade, and is formed by two layers of desiccant material, for example silica gel. The side of the channel in contact with the building is insulated and it is adiabatic (see Fig. 1). A fan forces the air movement.

There are two modes of operation: drying and regeneration. During the drying mode, the outside air is first dried inside the channel and then is supplied to a dedicated outdoor air system. In this period, solar collectors work as a conventional ventilated façade without communication with the desiccant channel neither with the zone. During the heating season, solar collectors preheat the outside air before it enters into the AHU.

In the regeneration phase, the outside air enters the solar collectors and then goes into the desiccant channel. It absorbs the humidity of the desiccant material and exits hotter and more humid. Modules desiccant + collector, occupying each floor of the building, make up the façade.

The external finishing of the facade modifies the temperature of the desiccant material and thus the absorption capacity: when the temperature increases, the water content of the desiccant in equilibrium with the air in the channel decreases.

The mathematical model of the channel considers the following design parameters:

- Air mass flow treated in the channel ($\dot{m}$).
- Channel dimensions: width (δ) and height (L).