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A parametric analysis on the regeneration performance of silica gel in a proposed comfort provision strategy for a typical office space in Harare, Zimbabwe

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ABSTRACT

This paper reports the influence, design and climate parameters have on the regeneration performance of a proposed strategy for passive comfort provision for an office space. Solar regeneration of an external silica gel bed is later followed by regeneration of internal surfaces laden with silica gel. The internal surfaces regeneration is effected utilizing air dried by the external bed. External bed regenerating air conditions are evaluated based on simple energy balance and buoyancy models. Thermal efficiency is formulated based on its fundamental definition. Silica gel drying models are obtained from literature. MS Excel Spreadsheet program is applied in the present simulations. Internal surfaces regeneration depends largely on; ventilation rate, initial dryness and mass of external silica gel bed. There is an optimum ventilation rate for a given mass of silica gel in the external bed for particular initial moisture content. Channel depth is quite critical to the regeneration effect on the external silica gel bed, with an average influence coefficient of 200%. The specific humidity of the regenerating air has the least coefficient of influence of 82%. Considering the foregoing, the design of the proposed system calls for simulation to estimate performance.

1. Introduction

Vapor compression based air conditioning systems have been the means for comfort provision in built environments for a long time. These mechanical systems are effective if properly designed. The challenges associated with these systems however are the high energy requirement and the adverse environmental impacts of the refrigerants used. Efforts towards environmental friendly refrigerants saw the development of less harming refrigerants, though more efforts are still required. On the other hand the energy demand largely remains unresolved because of the low efficiency of the systems applying the new refrigerants [1].

Research into comfort provision at low or near-zero energy use has become quite topical. Major parameters in a thermal comfort provision are temperature and humidity [2]. Application of phase change materials (PCMs) to building envelope components has been and is still being studied for temperature control in buildings. PCMs are largely being recommended for peak cooling load reduction and shifting [3–5], thus cannot provide full answer to a thermal comfort provision let alone the indoor air quality [6]. Adverse health effects can be minimizing if the relative humidity is maintained between 40% and 70% [6]. Some building envelope materials have been investigated for moisture buffering [7–9]. While some degree of buffering is achieved, need for improving the buffering capacity is evident [10]. Moisture capacity enhancement of the interior surfaces of the building envelope can be attained through the integration of desiccants to building interior construction [11,12]. One other way is the development of new hygroscopic materials applicable to building interior construction [13]. The application of envelope materials in such passive temperature and moisture buffering brings the issue of regeneration. The materials naturally get to saturation, at saturation state, mass or heat transfer required in the buffering process becomes impossible. Regeneration of PCMs for office space is easily achieved, thanks to the usually low enough temperatures during night time. For an office space, interior surfaces (laden with e.g. silica gel) regeneration requires some strategy that can be applied to effect the drying of the surfaces when the building is not in use, night time. A novel strategy has been proposed [14] that involve; solar drying of an external silica gel 'bed'

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Nomenclature

A_c	Channel surface area (m^2)
A_b	Channel transverse area (m^2)
b	Air gap depth (m^2)
C_f	Specific heat of air at constant pressure (J/kg K)
c_p	Specific heat of air at constant pressure (J/kg K)
g	Acceleration due to gravity (m/s^2)
h	Convective heat transfer coefficient (W/m^2 K)
I	Solar radiation incident on the channel surface (W/m^2)
I'	Equivalent heat flux (W/m^2)
k	Drying constant (–)
L	Height of channel (m)
m	Mass of desiccant, silica gel (kg)
$\dot{m}_a$	Mass flow rate of air (kg/s)
$\dot{m}_w$	Moisture transfer rate (kg/s)
Q_s	Sorption heat (W)
t	Time (s)
T_a	Ambient temperature (°C)
T_f	Regenerating air temperature (°C)
u	Air velocity (m/s)
X	Moisture content ratio (kg water/kg silica gel)
X_a^*	Air humidity ratio at equilibrium (kg water/kg dry air)
X_{ai}	Air humidity ratio at regenerator inlet (kg water/kg dry air)
X_{ao}	Air humidity ratio at regenerator outlet (kg water/kg dry air)
X_e	Equilibrium moisture content ratio (kg water/kg silica gel)
Greek letters	
β	Coefficient of thermal expansion
ϕ	Relative humidity (–)
η	Thermal efficiency (–)
ρ	Mass density (kg/m^3)
τ	Time (hr)

during day time, during night time air is then passed through the dried bed into the room space. The dried air from the external silica gel bed then dries the interior surface.

The main objective of this study is to determine and highlight the influence of design and environmental parameters on the possible regeneration of the external bed as well as the internal surfaces. The regeneration process is a function of a number of parameters and it is important to evaluate the dependence of performance on a parametric basis; this will inform the design process and performance prediction of such passive systems. The critical performance factors assessed ultimately are the final moisture content at the end of regeneration and the regeneration time. The feasibility and effectiveness of the proposed novel passive comfort provision strategy depends on the responsiveness of system design to the intermittent environmental conditions (that determine the regenerating conditions) and such responsiveness is not yet known.

2. Methods

A solar channel incorporated to a hypothetical office is considered. The solar channel has a silica gel bed as its absorber surface while the interior surfaces are considered to be having a PCM/Desiccant finish. To effect ventilation at night another solar channel with a PCM absorber surface is incorporated onto one of the other walls. The hypothetical office is a 3×3 m^2 in floor plan and a height of 3 m with a 1.8 m^2 window area and a 1.6 m^2 door which results to an internal wall surface area of approximately 30 m^2. The internal surface area of 30 m^2 gives a mass of silica gel within the surfaces of 7.5 kg (2.5 kg per 1 m width of external silica gel bed) when considering 0.25 kg/m^2. Solar radiation flux falling onto the channel is simulated for the cardinal orientations to establish a most favorable orientation in terms of solar radiation receivable. With the chosen orientation further simulations are then carried out to establish the impact of each of the parameters to the regeneration performance of the system.

2.1. Mathematical modeling

2.1.1. Modeling assumptions

a. Absorption of solar energy by the glass cover is negligible.
b. An efficiency correlation is formulated from basic principles to account for losses.
c. Lumped air mass is assumed.
d. Properties of air are considered to be independent of temperature.
e. Air is assumed to be non-absorbent of radiation.
f. Thin-layer drying model is considered for silica gel regeneration.

2.1.2. Developed models

Solar radiation modeling was necessary to process available radiation which is received on a horizontal surface to that which is received on a vertical surface. Sun-earth geometry is used to produce a radiation simulator for a surface of any orientation, and this was applied on the available solar radiation data. Shading effects were not taken into account.

Assuming uniform temperature and applying energy balance, the regenerating air temperatureT_f is given by:

$$T_f = T_a + \frac{\eta I A_c + Q_s}{2\dot{m}_a c_p} \tag{1}$$

Eq. (1) assumes a linear variation of temperature with distance along the flow direction. In Eq. (1), $T_a$is the environmental air temperature, $\eta$is the efficiency of converting solar radiation to useful thermal regenerating energy, $I$is the normal solar radiation received by the channel, c_p is specific heat capacity of air and Q_s is the sorption heat of silica gel. Air mass flow rate $\dot{m}_a$, is given by $\dot{m}_a = \rho u A_b$where $\rho$is air mass density, u, the air velocity and $A_b$is the transverse area of the air gap of the channel. The air velocity$u$, is given by Eq. (2) [15];

$$u = \frac{b^2}{24\mu}\left[\rho g \beta\left(\frac{I'L}{\rho u b c_p + hL/2}\right)\right] \tag{2}$$

$I'$is the equivalent flux that takes into consideration the channel efficiency and the sorption heat. Neglecting the wind effect, Eq. (2) can be approximated to;

$$u = \left(\frac{g\beta I' L b}{24\mu c_p}\right)^{\frac{1}{2}} \tag{3}$$

for assumed laminar flow over the silica gel surface in the channel.

According to the definition of efficiency, Eq. (4) can result.

$$\eta = \frac{2\rho u b c_p}{L}\frac{(T_f - T_a)}{I} - \frac{Q_s}{IL} \tag{4}$$

In Eq. (4) $I$is the perceived normal solar radiation on the solar channel. Noting that$Q_s << IL$, the last term in Eq. (4) can be neglected such that the efficiency equation becomes;

$$\eta = \frac{2\rho u b c_p}{L}\frac{(T_f - T_a)}{I} \tag{5}$$