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Development of a new control strategy for improving the operation of multiple shades in a solarium

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Abstract

This paper presents a new control strategy for improving the performance of one interior and/or exterior planar shade(s). The control strategy is based on performing an energy balance on the fenestration system and calculating the total heat flow (i.e. solar gains + overall heat losses). The heat flow can be maximized or minimized depending on the needs of the space. A solarium model was developed in order to assess the performance of the proposed shading strategy. The solarium model can simulate passive and active thermal storage using sensible and phase change materials. A prototype solarium with motorized interior and exterior shadings has been instrumented and subjected to controlled conditions. The numerical simulations are in good agreement with experimental results.

The simulation model has then been used to perform annual simulations of an attached solarium for the location of Montreal, Canada. The year was divided in a heating mode and a mixed mode. During the heating mode (i.e. October through April), heating is provided to keep a minimum temperature of 10 °C and surplus heat is considered when the temperature reaches 28 °C. By using the proposed algorithm for the control of one interior and/or exterior shade(s) in the heating mode, heating requirements of the simulated solarium have been reduced by 3–9% and an additional 9–14% of surplus heat have been collected when compared to a control based on near optimum global horizontal solar radiation levels. During the mixed mode, thermal comfort can be improved significantly (+1822 h) when the interior shade is controlled with the proposed algorithm.

Keywords: Sunspace; Solarium; Greenhouse; Shading control; Fenestration system; Heating requirements

1. Introduction

Shading devices are commonly used in various building types such as residential buildings, offices buildings, solariums and greenhouses. They are mainly used for reducing solar gains and heat losses, controlling glare and improving daylight availability.

In solariums and greenhouses, the former two objectives typically prevail. Attached solariums are one of the most popular passive solar systems (Mihalakakou and Ferrante, 2000). Integrated to either new or existing houses, they are generally built to gain additional floor space with abundant daylight. In addition, solariums also have the potential to provide adequate conditions for growing plants and vegetables, as well as collecting solar heat. With their large glazing area, the use of shades and their control may affect significantly the energy requirements and thermal comfort in a solarium.

Generally in greenhouses, a shade whose main purpose is to reject near infrared radiation for temperature control is called a solar screen, while a shade whose main purpose

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Nomenclature

A_i	area of surface i, m^2
c_{eff}	effective specific heat capacity, J/(kg K)
c_p	specific heat capacity, J/(kg K)
C	capacitance, J/K
D_h	hydraulic diameter, m
DHR	diffuse horizontal radiation, W/m^2
DNR	direct normal radiation, W/m^2
$f_{w,i}$	portion of window area illuminating directly surface i, m^2
F_{ij}	view factor between surface i and j
F_{ij}^d	transfer factor
G_a	incoming solar radiation absorbed by glazing, W/m^2
G_b	transmitted beam solar radiation, W/m^2
G_d	transmitted diffuse solar radiation, W/m^2
G_{ij}	Gebhart coefficient
GHR	global horizontal radiation, W/m^2
h_c	convective coefficient, $W/(m^2 K)$
h_r	linearized radiative coefficient, $W/(m^2 K)$
I_b	incident beam solar radiation, W/m^2
I_{ds}	incident sky diffuse solar radiation, W/m^2
I_{dg}	incident ground diffuse solar radiation, W/m^2
I_d	total incident diffuse solar radiation, W/m^2
k	conductivity of air, W/(m K)
L	characteristic length, m
m	mass, kg
n	number of surfaces
Nu	Nusselt number
q	long wave radiative flux, W
Q	heat flux, W
$R_{i,j}$	thermal resistance between nodes i and j, K/W
$S_{b,i}$	total beam solar radiation absorbed by surface i, W
$S_{d,i}$	total diffuse solar radiation absorbed by surface i, W
S	solar radiation transmitted through a fenestration system and absorbed by interior surfaces, W
T_{in}	interior air temperature, K
T_i	temperature of surface i, K
t	time, s
U	thermal conductance, $W/(m^2 K)$
v	mean air velocity in a cavity, m/s
v_w	wind speed, m/s
α_i	absorptance of surface i
β	stability coefficient
ϵ_i	emittance of surface i
λ	latent heat of fusion, J/kg
ρ_j	reflectivity of surface j
σ	Stefan–Boltzmann constant, $W/(m^2 K^4)$
θ	incidence angle, °

is to reduce heat losses is called a thermal screen. Many studies reported significant energy savings due to the implementation of thermal screens in greenhouses. For different types of greenhouses and screens, the use of a thermal screen from sunset to sunrise has been shown to reduce the energy used by 27–43% (Meyer, 1981), 21–33% (Bailey, 1988) and 16% (Dieleman and Kempkes, 2006) for greenhouses located in Germany, England and Netherlands, respectively.

The addition of shades to the windows of residential buildings has been shown to be useful for reducing heat losses. Simulations carried out by Selkowitz and Bazjanac (1979) have shown that the net annual heating requirements of a house can be reduced by 18% when R10 shutters are closed twelve hours at night for equally distributed single pane windows (with a window to floor ratio of 15% in Minneapolis). When used with clear double glass, the net annual heating requirements can be reduced by 9%.

Simulations have shown that the use of roller shades in office buildings with continuously dimmable lights could lower the source energy consumption up to 7% while improving visual comfort (Tzempelikos and Shen, 2013). The use of more sophisticated devices like an actively controlled venetian blind was estimated to reduce the energy for heating, cooling and artificial lighting by up to 22% (Nielsen et al., 2011).

1.1. Existing shading control strategies

Many studies have been conducted about the operation of different types of movable shading devices and their associated energy performance. Studies on office buildings generally focus on reducing heating and cooling loads, artificial lighting and glare while providing adequate workplane illuminance.

Various shading control strategies for offices buildings have been investigated such as those based on

- Time clock operation (Yao, 2014).
- Incident solar irradiance (van Moeseke et al., 2007).
- Incident total or beam radiation (Lee and Selkowitz, 2006; Wienold, 2007; Tzempelikos and Shen, 2013).
- Incident or transmitted illuminance (Galasiu et al., 2004; Tzempelikos and Shen, 2013).
- Preventing direct sunlight from falling on the workplane (Tzempelikos and Shen, 2013).
- The illuminance level at the workplane (Wienold, 2007).
- Minimizing the total heat gains when in cooling mode (with additional criteria) (Tzempelikos and Shen, 2013).
- Fixed blind tilt angle (for venetian blinds) (Carbonari et al., 2001; Galasiu et al., 2004; Huang et al., 2014).