Energy and Buildings 42 (2010) 522–533

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Quantifying and predicting performance of the solar dynamic buffer zone (SDBZ) curtain wall through experimentation and numerical modeling

R. Richman [a,*], K.D. Pressnail [b]

[a] Department of Architectural Science, Faculty of Engineering, Architecture and Science, Ryerson University, 350 Victoria St., Toronto, Ontario, Canada M5B 2K3
[b] Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, Ontario, Canada M5S 1A4

ARTICLE INFO

Article history:
Received 5 August 2008
Received in revised form 16 October 2009
Accepted 24 October 2009

Keywords:
Energy efficiency
Sustainability
Curtain wall
Solar air collectors
Low-energy buildings
Spandrel panels
Advanced cladding
Building envelope

ABSTRACT

The recent rise in the environmental and economic costs of energy demands a need to design and build more sustainable building systems. Curtain wall assemblies show great promise—the spandrel panels within them can be natural solar collectors. By using a solar dynamic buffer zone (SDBZ) in the spandrel cavity, solar energy can be efficiently gathered using the movement of air. There is a need for a numerical model capable of predicting performance of this system. This paper presents the quantification of a prototype SDBZ curtain wall system through experimental testing in a laboratory environment. Results from the experimental testing were used to validate a one-dimensional numerical model of the prototype.

This research shows a SDBZ curtain wall system as an effective means of reducing building heating energy consumption. The numerical model showed good correlation with experimental results in the expected operating range of the system. Given the lack of published literature for similar systems, this research acts to validate a simple, innovative approach to collect solar energy that would otherwise be lost to the exterior using already existing components within a curtain wall. This research shows the SDBZ curtain wall has the potential to act as a significant solar collector.

1. Introduction

The primary function of exterior building skins is to separate the interior and exterior environments, sustaining an acceptable level of indoor climatic conditions that facilitate society's modern standard of living. Specifically, the exterior skin must manage the flow of heat, moisture and air across itself. As technology advances, the gradients associated with these variables increase, making it more and more of a challenge for an exterior wall assembly to successfully perform its task. Generally, building skins have become more thin with advances in technology making it more challenging to act as an adequate separator. In addition to achieving its primary function as a building skin, a façade system capable of collecting heat from the exterior has been developed, constructed and tested—the solar dynamic buffer zone (SDBZ) curtain wall.

Curtain walls comprise a large majority of low, mid and high-rise commercial and residential buildings in urban areas. Traditional curtain wall assemblies act to minimize the transfer of heat across the building envelope. In an effort to produce "energy efficient" systems, much research has been focussed on the vision areas with the introduction of improved spacers, spectrally selective glass coatings and high performance glazing units [1–3]. The spandrel panels have been ignored. The authors recognized energy that would otherwise be lost back to the exterior during the heating season couldbe harnessed to pre-heat exterior fresh-air required for building occupancy.

The SDBZ curtain wall is an innovative system coupling the concepts of dynamic buffer zone and solar architecture. This approach has not been documented to date and represents state-of-the-art technology in the field of façade engineering. Through simple modifications during the manufacturing stage, an SDBZ curtain wall can act to transport pre-heated fresh-air to a building's air handling system or be installed as a separate modular component.

A previous paper presented the SDBZ curtain wall concept [4] concluding the need for laboratory study to quantify performance. This articlepresents the experimental apparatus and experimental results of the SDBZ curtain wall tested at the Building Science Laboratory (Department of Civil Engineering) at the University of Toronto, Toronto, Canada. This is followed by a presentation of results from numerical modelling and the ability to predict performance for practical applications.

2. The SDBZ curtain wall numerical model

Fig. 1 shows a schematic representation of the SDBZ curtain wall. The prototype was approximately 1.0 m in width by 1.2 m in height, equally split between vision and spandrel areas. The

* Corresponding author. Tel.: +1 416 979 5000; fax: +1 416 979 5353.
E-mail address: richman@ryerson.ca (R. Richman).

0378-7788/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2009.10.021

Nomenclature

A_g	area of the glass surface (m^2)
A_s	effective area of the receiving surface (m^2)
A_w	cross-sectional area of the wall components (i.e. insulation and metal back-pan) (m^2)
C_p	specific heat of air (kJ/kg °C)
G	incoming radiation normal to the glass (W/m^2)
h_{c1}	convective heat transfer coefficient between interior glass surface and cavity air (W/m^2 K)
h_{c2}	convective heat transfer coefficient between collector surface and cavity air (W/m^2 K)
$h_{c,ext}$	convective heat transfer coefficient between exterior glass surface and exterior environment (W/m^2 K)
$h_{c,int}$	convective heat transfer coefficient between interior metal back-pan surface and interior (W/m^2 K)
h_{k1}	conductive heat transfer coefficient between the interior and exterior glass surfaces (W/m^2 K)
h_{r1}	radiative heat transfer coefficient between collector surface and interior glass surface (W/m^2 K)
$h_{r,air}$	radiative heat transfer coefficient between exterior glass and exterior air (W/m^2 K)
$h_{r,int}$	radiative heat transfer coefficient between interior metal back-pan surface and interior (W/m^2 K)
$h_{r,gr}$	radiative heat transfer coefficient between exterior glass and ground (W/m^2 K)
$h_{r,sky}$	radiative heat transfer coefficient between exterior glass and sky (W/m^2 K)
$\dot{m}$	mass flow rate of cavity air (kg/s)
T_a	temperature of cavity air (K)
T_{ext}	temperature of exterior (K)
T_{g_i}	temperature of interior glass surface (K)
T_{g_e}	temperature of the exterior glass surface (K)
T_{g_o}	temperature of exterior glass surface (K)
T_{inlet}	temperature of the air at the inlet opening (K)
T_{int}	temperature of the interior (K)
T_{outlet}	temperature of the air at the outlet opening (K)
T_s	temperature of the collecting surface (K)
T_w	temperature of the interior metal back-pan surface (K)
U_1	conductive heat transfer coefficient between the collector surface and the interior metal back-pan (W/m^2 K)
α_g	absorptance of the glass
α_s	absorptance of the collector surface
τ_g	transmittance of the glass
ε	emissivity of the glass
V_{amb}	ambient velocity
V	cavity velocity
Fe	emissivity factor
Q	cavity flow in cubic metres per hour per square metre of collector surface (m^3/m^2 h)
$\eta = \dfrac{\dot{m}c_p(t_{outlet} - t_{inlet})}{AG_{solar}}$	SDBZ experimental thermal energy efficiency

numerical model utilized in this study is shown below along with the critical underlying assumption. A full discussion of assumptions along with preliminary research and development can be found elsewhere [4,5].

2.1. Numerical model

Glass cover—exterior

$$\frac{GA_g\alpha_g}{2} + h_{k1}A_g(T_{g_i} - T_{g_o}) = h_{r,gr}A_g(T_{g_o} - T_{gr}) + h_{r,sky}A_g(T_{g_o} - T_{sky}) + h_{r,air}A_g(T_{g_o} - T_{ext}) + h_{c,ext}A_g(T_{g_o} - T_{ext}) \quad (1)$$

Glass cover—interior

$$\frac{GA_g\alpha_g}{2} + h_{r1}A_s(T_s - T_{g_i}) + h_{c1}A_g(T_a - T_{g_i}) = h_{k1}A_g(T_{g_i} - T_{g_o}) \quad (2)$$

Cavity air

$$h_{c2}A_s(T_s - T_a) = \dot{m}C_p(T_{outlet} - T_{inlet}) + h_{c1}A_g(T_a - T_{g_i}) \quad (3)$$

Collector surface

$$GA_s\tau_g\alpha_s = h_{c2}A_s(T_s - T_a) + h_{r1}A_s(T_s - T_{g_i}) + U_1A_w(T_s - T_w) \quad (4)$$

Metal back-pan surface—interior

$$U_1A_w(T_s - T_w) = h_{r,\mathrm{int}}A_w(T_w - T_{\mathrm{int}}) + h_{c,\mathrm{int}}A_w(T_w - T_{\mathrm{int}}) \quad (5)$$

Relationship between inlet, outlet and cavity air temperatures

$$T_a = 0.75T_{outlet} + 0.25T_{inlet} \quad (6)$$

2.2. Critical assumptions

•Steady-state conditions	•The glass layer is opaque to infrared radiation
•Inlet air temperature equal to ambientair temperature	•Absorbed short wave radiation absorbed in a glass layer can be apportioned equally to the two surfaces
•Minimal stratification of surface temperatures	•Thermal storage was negligible
•Cavity air is completely mixed	

The relationship between inlet and outlet temperatures stated in Eq. (6) represents a common validated assumption found in the literature [6–10]. The above six equations include six unknowns (knowing T_{ext} and T_{int} as boundary conditions for a simulation) and can be solved using a standard Newton–Rhapson method. The heat transfer coefficients were solved using accepted empirical relationships published in the literature [6,7,9,10]. Table 1 summarizes the heat transfer coefficients and model input used to obtain the results.

3. Experimental apparatus

Testing for a curtain wall of this design had not been completed prior to this research. Although the testing varied from any standard available to suit the specific characteristics of the SDBZ curtain wall, an industry accepted testing foundation was sought and found—ASHRAE Standard 93 [11]. The standard provided the necessary foundation for design and development of the experimental method used during this research. Due to the current state of the SDBZ curtain wall, the preliminary stage of development and the limitations of the Building Science Laboratory (BSL) at the University of Toronto, several modifications were necessary to successfully carry out the experiments.

Table 2 lists the equipment and instrumentation used to perform the experiments in the BSL. Inlet and outlet points for air flow through the SDBZ were constructed so that flow entered the sample through a series of openings in the spandrel sill snap-on-cap and pressure plate. The exit point was a 25 mm high manifold across the entire width of the metal back-pan. Air flow manipula-