Energy and Buildings 104 (2015) 57–64

Contents lists available at ScienceDirect

Energy and Buildings

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

A new method for the thermal characterization of transparent and semi-transparent materials using outdoor measurements and dynamic simulation

Cristina Cornaro[a,b,*], Francesco Bucci[a], Marco Pierro[a], Maria Elena Bonadonna[a], Guglielmo Siniscalco[a]

[a] Department of Enterprise Engineering, University of Rome "Tor Vergata", Via del Politecnico, 1, 00133 Rome, Italy
[b] CHOSE, University of Rome "Tor Vergata", Via del Politecnico, 1, 00133 Rome, Italy

ARTICLE INFO

Article history:
Received 30 January 2015
Received in revised form 11 June 2015
Accepted 23 June 2015
Available online 8 July 2015

Keywords:
Thermal characterization
Solar Heat Gain Coefficient
U-value
Innovative semi-transparent materials
Solar test box
Dynamic building simulation
IDA ICE

ABSTRACT

The work presents a new method to evaluate the thermal performance of transparent and semi-transparent materials under real operating conditions. The methodology could be particularly useful to test innovative materials and composites whose thermal properties are not known. It is easily reproducible, low cost, with a low technical impact. The proposed method uses experimental devices named "Solar Test Boxes" (STB) and a dynamic simulation software: IDA Indoor Climate and Energy. The outdoor measurements inside and outside the test boxes are used to accurately calibrate the dynamic simulation model of STB with the objective to obtain the global thermal transmittance (*U*) and Solar Heat Gain Coefficient (SHGC) of the test sample.

The paper illustrates the methodology and the application of the method for the determination of the thermal characteristics of a light diffusing insulating glass. The application of the method to the case study allowed estimating SHGC with accuracy below ±10%. The *U*-value yields a poor result due to the lack of measurement range (required temperature difference) to assess this parameter.

1. Introduction

Windows and glazing can offer to building occupants visual relief, insulation against heat and cold, control of light and ventilation. Windows and other fenestrations are of great importance adding esthetic qualities and beauty to the building design. However, in recent decades, fenestrations have been often considered for another type of concern: their influence on the building energy consumption. This aspect may have a direct influence on the design and performance of lighting and air-conditioning systems. For this reason, research on new materials and their properties have grown recently, as for example glazing with the integration of silica aerogel in monolithic form or the use of electro-chromic smart windows.

A problem of these new technologies is that the semi-transparent part is composed by different materials with different physical properties that sometime are not yet defined. To know the behavior of the materials under real operating conditions is primarily important to determine the actual efficiency of the device.

External thermal loads in buildings depend mainly on thermal transmittance (*U*) of the envelope. In addition to *U* value, another parameter named Solar Heat Gain Coefficient (SHGC) has to be considered to identify the thermal behavior of glazing systems. SHGC is defined as the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. It is expressed as a number between 0 and 1. Usually, the center-of-glass SHGC is considered, which describes the effect of the glazing alone. Moreover, the manufacturer referenced values are given considering solar irradiance at normal incidence on the glazing.

In this paper a method is proposed to use Solar Test Boxes (STB) to evaluate the overall energy performance of innovative glazing systems suitable for energy saving purposes, consisting of layers of different materials whose thermal characteristics cannot be easily retrieved.

To prove the capability of the method the thermal characteristics of a light diffusing insulating glass (LDIG) were evaluated. The method consists in a short-term outdoor monitoring of STB thermal behavior and in the construction of a calibrated dynamic

* Corresponding author at: Department of Enterprise Engineering, University of Rome "Tor Vergata", Via del Politecnico, 1, 00133 Rome, Italy.
E-mail address: cornaro@uniroma2.it (C. Cornaro).

http://dx.doi.org/10.1016/j.enbuild.2015.06.081
0378-7788/

simulation model for the boxes. The thermal properties, *U* and SHGC, can be evaluated finding the best match between the experimental data and the calibrated model simulation data. Section 2 gives an overview of the actual methods and models. In Section 3 the STB are described and the short-term monitoring campaign is reported. Section 4 briefly describes the dynamic building simulation program used by the method while in Section 5 the measurement methodology is described. Finally, Section 6 presents the results obtained during the outdoor campaign and describes the data analysis for the implementation of the method.

2. Models and measurement methods overview

Many modeling attempts have been made to characterize fenestrations with particular characteristics. Indeed many variables such as thermal properties (thermal conductivity, specific heat, thermal diffusivity) of the various materials that constitute the glaze system and their optical characteristics (transmittance, absorbance and reflectance at short wavelengths) are involved in the calculation and it is difficult to build mathematical models to determine the solar heat gain through different fenestration systems. This is particularly true when innovative transparent materials are integrated in the windows or building integrated photovoltaic (BIPV) glazing is used. Klems [1–3] and Collins et al. [4,5] have developed calculation methods to predict solar heat gain through fenestrations with shade devices. A theoretical study was conducted by Fung and Yang [6] to build a model to simulate the total heat gain of BIPV glazing.

For many complex systems and realistic radiation distributions, mathematical models, may have limitations due to their abstract formulation [7]. For this reason direct measurements are important in order to compare and validate the results [5,8,9]. Most of the research presently conducted is performed in the laboratory using calorimetric test boxes [10,11] and lamps that simulate the solar radiation.

An apparatus used to measure the amount of heat transferred in a process is called calorimeter. In the considered application calorimetric test boxes allow to measure the thermal parameters of a material through the measurement of the heat flux across it.

Chen et al. [12] developed a calorimetric hot box to measure both the thermal transmittance and the Solar Heat Gain Coefficient of five different semi-transparent PV glazing. They found that when the PV glazing produced electricity (i.e., it was connected to an electric load) the SHGC could be reduced by only 3–6%. Moreover they studied the effect of angle of incidence (AOI) on the variation of SHGC and they found that this parameter was almost constant for AOI between 0° and 45° while from 45° to 70° a reduction of 20% was observed. The indoor calorimetric method is used in the norms to evaluate the windows conductance [13,14].

However, controlled laboratory methods often cannot completely highlight the real behavior of a complex glazing system so that it is certainly beneficial to carry on studies and research on outdoor methods.

Recently, some authors used the calorimetric principle testing the system in real environmental conditions. For example, Piccolo [15] used this method to evaluate the performance of electro chromic smart windows. Infield et al. [16] proposed a simplified approach for the characterization of BIPV facades in outdoor. Han et al. [17] made a comparative analysis of the outdoor performance of a semi-transparent PV façade with a conventional clear glass façade. Marinoski et al. [18,19] built two different outdoor devices to evaluate the thermal characteristics of small sample and real size fenestrations, respectively. In both cases they evaluated the SHGC. In the first case they obtained and average difference of 5.4% between the measured and reference SHGC values. Oliviero et al. [20] proposed an integral energy performance characterization of semi-transparent PV elements under real operating conditions. They built up a device able to evaluate the thermal, electric and lighting performance of the sample during the same test. They simultaneously tested a reference glass and a semi-transparent PV glass and they evaluated the Heat Gain Coefficient, defined as the ratio between the solar heat gain into the room and the solar irradiance measured on the vertical plane, using the daytime data. Using the nighttime measurements they calculated the Heat Loss Ratio, defined as the ratio between the heat loss from the box with the PV material and the heat loss from the reference glass.

All the presented studies used calorimetric boxes to evaluate thermal parameters of the samples. The main drawback of the calorimetric method is that steady state conditions need to be reached using cooling devices, mainly heat exchangers that use water as cooling fluid. The introduction of these devices in the test beds adds a certain amount of complexity and costs.

In the literature, small test boxes were used principally as physical thermal models of rooms with particular fenestration systems to study passive solar building design. This kind of Solar Test Boxes (STB) were used in the past by Grimmer et al. [21] to simulate the behavior of passive solar building: in this case the physical models were not scaled for the architectural model of the building but rather for its thermal behavior. More recently Solar Test Boxes were used by Entrop et al. [22] to test the thermal behavior of phase chance materials (PCM) integrated into concrete floors. A comparative analysis of four STB was carried out to evidence the advance of using PCM together with solar radiation to reduce temperature gradients in the environment.

In this work small test boxes are used to evaluate thermal characteristics of glazing in the real environment avoiding the use of cooling devices using transient measurements.

3. Experimental activity

3.1. STB description

Two Solar Test Boxes (STBs) were built at the ESTER laboratory of the University of Rome "Tor Vergata" [23] with the objective of making comparative analysis of thermal and lighting performance of innovative transparent material with respect to a double glass reference pane and to investigate the possibility of a complete thermal characterization of an unknown sample. The boxes were designed with a linear scale factor of 1:5 and a surface scale factor of 1:25 with respect to a real room. The STBs have the dimensions of 1.00 m × 0.60 m × 0.55 m. Fig. 1 shows the two devices exposed outdoor at the ESTER lab.

The main objective of the construction was to maximize the thermal contribution of the transparent material allocated on the short side of the box. For this reason, each box has five out of six faces heavily insulated to guarantee adiabatic conditions and one face shaped in order to host different kinds of transparent or semi-transparent samples of dimension of approximately 50 cm × 50 cm. The STBs exterior was manufactured with plywood panels of 8 mm thickness. The plywood offers excellent thermal insulation performance, which is useful for experimentation; trying to approximate the best possible conditions of insulation from the outside, the STBs were then painted entirely white, to make them highly reflective. The entire not glazed inner surface of the boxes, also comprising the portion of the area behind the frame of the window, was heavily insulated with a lightweight rigid insulating material of 80 mm thickness, Stiferite GT, specific for thermal insulation in buildings. The panel is made of polyurethane foam (88%$_w$ of which 6%$_w$ is pentane) and multi-layer coating Duotwin® (12%$_w$).