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Development of a calorimeter for determination of the solar factor of architectural glass and fenestrations

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ABSTRACT

This work presents the development of a calorimeter used to determine the Solar Factor of glazing and windows, including shading devices or not. Solar Factor is an index used around the world for comparing the thermal performance of fenestrations. The development of the calorimeter includes its project, construction, instrumentation particularities and calibration. The calorimeter has two systems of thermal gain measurement: the first one depends on the temperature difference of the fluid used for refrigeration of the main cavity (employed in tests with elements in full-scale); the second system is applied in a secondary cavity, where heat flow transducers are used to measure the solar gain through fenestrations. During the calibration stage, a new formulation for the determination of the Solar Factor was proposed and applied. After this, a reference glass sample (3 mm clear monolithic glass) was tested simultaneously in the two cavities. All tests were conducted under outdoor conditions. The measurement surface was always maintained in vertical position and facing north. The results of Solar Factor measurements were compared to theoretical values determined by ISO 9050. The uncertainty of measurement (absolute) was on average ±0.04 for the secondary cavity, and ranged between ±0.10 and ±0.16 in the main cavity. In general, experimental values showed good agreement with theoretical values. Therefore, the calorimeter can be used for research purposes or as an alternative to determine the Solar Factor of new products, which are not covered by the calculation procedures presented in the existing standardization.

1. Introduction

In hot-climate countries like Brazil, solar heat gain through fenestrations is largely responsible for the increase of thermal load inside buildings. Apart from implicating on users' comfort, this thermal gain influences power consumption. Considering that houses and buildings are increasingly being built with air conditioning systems, the control of solar heat gain through fenestrations is important to make buildings more efficient, reducing individual energy consumption and demand peaks in the electrical system, especially during the summer.

In Brazil the concern about the impact that fenestrations cause on energy consumption is still incipient. Most of the regulations directed to the sector are related to the constructive aspects of windows and there are practically no national regulations related to their energy efficiency. It was only in 2009 that an official resolution was applied in this field, when the Brazilian government instituted a regulation, initially voluntary, for the certification of energy efficiency levels in commercial and public buildings [1,2]. With this regulation, the knowledge over properties of windows and their components has become essential for a global evaluation of the energy efficiency of buildings.

One of the window properties mentioned above is the Solar Factor (*SF*), also known as Solar Heat Gain Coefficient (SHGC). The Solar Factor is one of the most important indexes of energy performance of windows and fenestrations. It represents the fraction of heat gain due to solar radiation that the fenestration directly transmits, added to the portion that is absorbed and re-emitted to the interior of the building by the fenestration itself. Its definition is expressed in Eq. (1), where τ and α are the optical properties (transmittance and absorptance) of each element, and N is the fraction of absorbed heat flow that reaches the interior of the

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building [3]. These optical properties are, in turn, dependent on the incidence angle (θ) and wavelength. The Solar Factor is given as a dimensionless number between zero and 1, which can be specified only for glass or be indicated for the whole of the window. This information, associated with computer simulation and other analytical processes, enables the elaboration of better and more efficient building designs.

$$SF(\theta,\lambda) = \tau(\theta,\lambda) + N\alpha(\theta,\lambda) \qquad (1)$$

During the last decades, research centers around the world have engaged in efforts to characterize the phenomenon of the passage of solar radiation through windows, especially for situations in which shades are used [4–8]. The creation of mathematical models for some situations is difficult due to the large number of variables involved, since each type of window and shade has specific characteristics. Nevertheless, some of these calculation mathematical models have been implemented in computer programs [9,10], in spite of their limitations. Direct measurements continue to be important, therefore, to compare and validate calculated results [7,11,12].

Calorimeters are devices commonly used in researches related to the evaluation of the thermal performance of windows [8,11,13–17]. Through these devices, it is possible to perform measurements to determine the amount of heat that crosses the glazing under real use conditions or test-specific situations. In some cases, measurement results are used to assist the certification process of windows [18].

In Brazil, the Federal University of Santa Catarina (UFSC) has continuously dedicated efforts for the development of experimental devices to determine the Solar Factor, aiming to characterize fenestration systems [19–21]. Marinoski [22,23] continued this line of research, presenting an improvement to the existing tests. These last studies were used as a basis for the construction of a new measuring device [24].

This paper describes the project and assembly of a calorimeter developed in Brazil for the test of glazing samples and real-size windows. The method for determination of the Solar Factor applied to the equipment and calibration tests performed in field using a reference glass sample are also presented.

2. Project and manufacturing of components

Due to the complexity of the project of the final device, subprojects were prepared for each of the basic components of the equipment (shelter trailer, heat absorbers, cooling system, electrical and hydraulic system, and monitoring system), which are presented below.

2.1. Shelter trailer

Since the assembly of a calorimeter involves the use of various components, it was determined that these components would be sheltered in a trailer (towing-type vehicle). The decision for the trailer was based on the ease of handling that this type of vehicle allows and also because it enables weather protection. Apart from this, the manufacturing cost of this type of shelter for the system is reduced, since the trailer is produced on commercial scale.

The dimensions adopted for the trailer were determined based on the definition of the characteristics of the internal components. The need for internal movement during the installation, operation and maintenance of the systems was also taken in consideration. Thus, the project and construction of a vehicle with internal dimensions of 3.50 m × 1.60 m × 1.90 m and with a load capacity of approximately 350 kg was chosen. Fig. 1 presents a scheme of the arrangement envisioned for the various components of the calorimeter that are stored inside and also on the outside platform of the trailer.

The project includes two rear access doors, two side fenestrations (for the absorbers) and a front platform. Under the floor of the back part two holders were included for leveling, and in the front part an auxiliary wheel was added to facilitate movement. For the fixation of glazing samples, wooden frames were designed to cover the entire perimeter of measurement fenestrations. The use of wood is intended to provide mechanical resistance and thermal isolation for the contact in the fixation of the sample and other components.

2.2. Heat absorbers

Absorbers are cavities placed on the inside of the window. They absorb solar radiation that penetrates through the window and from the elements that are part of it, allowing heat to be quantified and removed by a cooling system. For the construction of the proposed calorimeter, the use of two different heat absorbers was defined. The first absorber was called “main cavity” (MC), with a measuring fenestration of 1500 mm × 1200 mm and depth of 300 mm. The MC can be used for measurements of complete

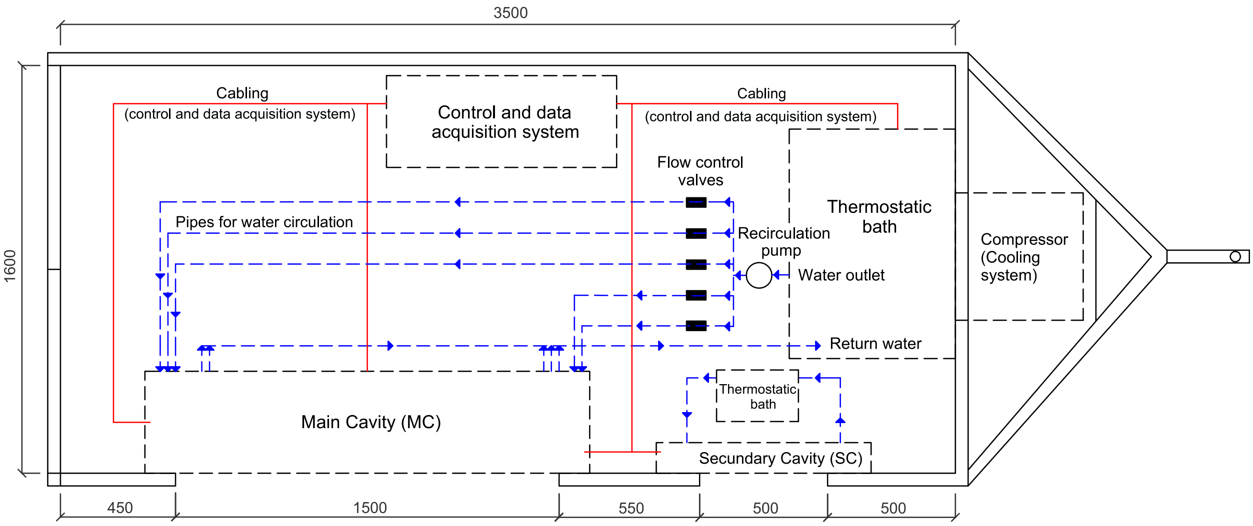

Fig. 1. Distribution scheme of internal components (without scale, dimensions in millimeters).