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# Analysis of a non-calorimetric method for assessment of in-situ thermal transmittance and solar factor of glazed systems

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ABSTRACT

The performance of glazing systems is usually assessed through the thermal transmittance and the solar factor, two metrics characterised either through calorimetric laboratory tests or calculations. In this paper, the analysis of the performance of a non-calorimetric method for obtaining the in-situ thermal transmittance and solar factor of glazing systems is presented. This method, developed as a trade-off between accurate (and expensive) laboratory tests (which characterise the systems under standardised, "averaged" conditions), and easy and less expensive tests on systems installed in real buildings (under real operative conditions), has been previously adopted for the characterisation of different glazed systems, but never presented and discussed in full detail.

The method, suitable for full-scale glazing systems installed in buildings or in test cells, is based on the acquisition of temperature, heat flux, and solar irradiance values. Experimental data are then processed through simple equations and linear regressions to determine the thermal transmittance and the solar factor under real boundary conditions. In this paper, a detailed description of the method, the experimental test rig, and the related expected accuracy is reported. The method is then applied to a case study (a conventional double glazed unit) to give an example of the proposed procedure and to validate it.

The results of the case study show the capability of the assessed in-situ thermal transmittance and solar factor to replicate the thermophysical behaviour of the glazing system within a satisfactory degree of accuracy. An in-depth discussion on the observed outcomes from the case study deepens the understanding of the method's performance and the results' significance.

## 1. Introduction

Glazing systems play an important role in the building envelope in assuring not only a high energy performance, but also high user satisfaction when it comes to visual environment and comfort. It is therefore not surprising that the trend in architecture is to have more and more glazed surfaces in buildings, and the corresponding vibrant research and development activity to assure that highly transparent building envelops can be realised without impairing, and even enhancing, the energy and environmental performance of the façade.

The characterisation of the behaviour of glazed system is therefore an important part of the assessment of the overall performance of the building. When it comes to energy performance characterisation, a glazed system is conventionally modelled through two steady-state, simplified performance parameters: the thermal transmittance (*U-value*, [W/$m^2$ K]) and the solar factor[1] (*g-value*, [-]). These two values can be obtained through laboratory tests and sub sequential calculations, or through software tools that integrate databases of glass panes.

The aim of these metrics, which are calculated assuming a standardised, average situation for glazing in practice, is to allow a fair comparison between different products to be made. Furthermore, they are widely used in calculation methods for the assessment of the annual energy use for space heating and the cooling of a residential or a non-residential building (ISO 13790, 2008), which form the basis for the energy performance certificate of a building in many European countries.

On the one hand, these simplified metrics are useful during the design phase to select among different alternatives, based on the expected performance pictured by the U-value and the g-value. On the other hand, it is important to highlight that heat and solar transmission through a glazed system when placed under real operative conditions may differ to a relatively large extent from those pictured through the standardised metrics. This fact can be explained considering the following simplifications adopted in the standardised calculation procedures.

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[1] Also called Total Solar Energy Transmittance (TSET), or Solar Heat Gain Coefficient (SHGC).

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**Nomenclature**

| | |
|---|---|
| A | surface area, $m^2$ |
| DD | degree day, °C day |
| dq | specific heat flux, $W/m^2$ |
| e | experimental value, $W/m^2$ or $Wh/m^2$ |
| E | specific solar irradiance, $W/m^2$ |
| $e_n$ | normalised residual, – |
| g (g-value) | solar factor, – |
| $G_{24}$ | specific daily solar irradiation, $J/m^2$ |
| h | heat transfer coefficient, $W/(m^2 K)$ |
| q | specific heat, $J/m^2$ |
| R | thermal resistance, $(m^2 K)/W$ |
| $R^2$ | coefficient of determination, – |
| RMSE | Root Mean Square Error, $W/m^2$ or $Wh/m^2$ |
| s | simulated value, $W/m^2$ or $Wh/m^2$ |
| t | time, s |
| T | temperature, °C |
| U (U-value) | thermal transmittance, $W/(m^2 K)$ |

*Greek symbol*

| | |
|---|---|
| $\lvert\varepsilon_{\%}\rvert$ | absolute percentage error, % |
| $\Delta t$ | time interval, s |
| $\Delta T$ | temperature gradient, °C |
| $\Lambda$ | thermal conductance, $W/(m^2 K)$ |
| $\rho$ | reflectance, – |
| $\tau$ | transmittance, – |

*Superscript*

| | |
|---|---|
| $\bar{a}$ | referred to the in-situ quantity |
| $\hat{a}$ | referred to the expected value |

*Subscript*

| | |
|---|---|
| c | referred to convection |
| diff | referred to the diffuse component |
| $\Delta T$ | referred to the temperature gradient |
| esp | referred to the experimental datum |
| e | referred to the outdoor/solar spectrum |
| g | referred to the solar irradiation or to the glazed surface |
| i | referred to the indoor/secondary transmission/i-element of a summation |
| E | referred to the secondary transmission |
| in | referred to the indoor |
| ind | referred to the indirect component |
| op | referred to the opaque surfaces |
| out | referred to the outdoor |
| r | referred to radiation |
| sim | referred to the simulated datum |
| TOT | referred to the total quantity |

– Steady state heat flux; which in the characterisation/calculation of the thermal transmittance leads to neglecting thermal inertia effect of the glazed layer(s). If this assumption is quite reasonable for a thin, single glass pane, multiple glazing characterised by thicker panes (e.g. with security, laminated glass panes) may present non-negligible dynamic heat transfer phenomena, which can lead to a shift in the peak transmitted heat flow higher than 1 h.
– Standardised and constant convective and radiative heat transfer coefficients towards the outdoor and indoor environment, which impact on both the value of the thermal transmittance and on the secondary heat transfer factor towards the inside, a quantity necessary in the calculation of the solar factor. In particular, the wind velocity on the outside surface is set to 4 m/s, a value that corresponds to quite high windy conditions. These assumptions lead to a value for $h_e$ in the range 23–25 $W/(m^2 K)$ and for $h_i$ in the range 7.7–8 $W/(m^2 K)$ for a vertical window, depending on the adopted standard.
– Electromagnetic (solar) radiation (nearly) impinging perpendicularly on the glazed system. This assumption disregards any angle-dependent feature of radiation transfer through the transparent component. While this assumption is reasonable within a certain range of impinging angles close enough to the normal to the pane's surface, it may differ substantially when the real geometric relationship between a (vertical) window and the sun (and the sky dome) are considered. This is particularly true in moderate and low latitude locations, and especially in summer time.

The discrepancy between the boundary conditions registered in-situ and standardised values may lead to substantial differences between the calculated and in-situ energy performance of the glazed system, especially when the transparent envelope's performance is obtained through simplified metrics and not fully dynamic calculation methods.

In this paper, a non-calorimetric method for the characterisation of in-situ thermal transmittance and solar factor of glazed systems is reported. This procedure has been previously adopted in experimental campaigns on triple glazed units with an integrated shading system (Favoino et al., 2016) and on triple glazed units with/without smart glass panes (Bianco et al., 2017a, 2017b), to assess both the in-situ thermal transmittance and solar factor; and on a double glazed system (Goia et al., 2014b) to assess the in-situ thermal transmittance, and on thermotropic glass panes (Bianco et al., 2015). Furthermore, parts of this methodology have also been previously used for assessing the different energy performance of advanced glazed façades in office buildings (Bianco et al., 2013; Goia et al., 2014a). However, this methodology has never been presented with full details nor its potentials and limitations have been discussed. The aim of this non-calorimetric method is to provide an experimental procedure, which presents a trade-off between complexity, costs, and accuracy, to assess the energy performance of full-scale glazed system installed either in outdoor test cells or in a real building. The target accuracy of the method lies around of ± 10% to 15%, and costs in the range of EUR 2000 to EUR 3000 for the entire measurement chain (sensors and data acquisition system).

In the context of this paper, the terms thermal transmittance and solar factor, where not differently specified, refer to the values derived under in-situ conditions, and therefore not according to the standardised assumptions described above – and provided in the long list of relevant international technical standards (EN 410, 2011; EN 673, 2011; EN 674, 2011; EN 675, 2011; ISO 9050, 2003; ISO 10077, 2017; ISO 10291, 1994; ISO 10292, 1994; ISO 10293, 1997). In order to highlight that the values of the metrics obtained in this paper refer to real, in-situ boundary conditions, both the thermal transmittance and the solar factor are identified with a bar above the usual symbol: $\overline{U}$ [$W/m^2 K$] for the in-situ (or equivalent) thermal transmittance and $\overline{g}$ [–] for the in-situ (or equivalent) solar factor.

The reason to develop a simple, yet robust procedure to identify the in-situ, equivalent thermal transmittance, $\overline{U}$ and the in-situ, equivalent solar factor, $\overline{g}$ lies in the need of establishing experimental methods that allow the assessment of envelope technologies under real operations to be carried out. This is particularly useful not only for R&D activities on glazed systems, but also in the framework of building energy audit procedures and post-construction monitoring of energy and environmental performance of a building.