G-box: a transportable device for in-situ measure of window's Solar Heat Gain Coefficient

Peter Gallinelli, Reto Camponovo, Dimitri Crivellin, Sylvie Margot
LEEA – HEPIA – HESSO, 4 rue de la Prairie, 1202 Genève, www.leea.ch

Daniel Pahud, Marco Belliardi
ISAAC – DACD – SUPSI, Campus Trevano, 6952 Canobbio, www.supsi.ch/isaac

Zusammenfassung Résumé Abstract

L'objectif principal de ce projet est le développement d'un calorimètre transportable, facilement reproductible sur la base d'un prototype, qui permette de mesurer le coefficient g d'un vitrage, i.e. la fraction de l'ensoleillement solaire incident qui est transmise à l'intérieur. Contrairement aux bancs de mesure fixe (test en laboratoire), le dispositif est monté temporairement sur une façade existante pour mesurer son comportement réel (simple peau, double-peau, façade en verre opaque), incluant éventuellement une protection solaire. Le projet comprend la mesure de façades représentatives en conditions réelles d'exploitation. Les avantages et les limitations du dispositif g-box sont établis. L'effet d'ombrage dynamique sur le coefficient g, comme celui des lamelles d'un store, peut être mis en évidence par le dispositif. Toutefois une surestimation du coefficient g requiert des études spécifiques pour améliorer le dispositif. Ce dernier présente déjà de très bonnes caractéristiques.

The main objective of the project is the development of a transportable calorimeter, easily reproducible on the basis of a prototype, which allows for the assessment of the g-value of glazing and window systems, i.e. the fraction of incident solar energy that is transmitted inside. Unlike standard calorimeters for laboratory Solar Heat Gain Coefficient (SHGC or g-value) assessment, the device is temporarily mounted on existing facades to measure their real behavior (single skin, double skin, opaque glass facades), including their possible solar protections. The project includes measurements on representative facades in real operating conditions. Advantages and limitations of the g-box device are characterized. Dynamic effect of shadows, such as the slat position of a venetian blind, can be shown by the g-box. An overestimation of the g-value makes more in-depth studies necessary to improve the measurement and analysis procedure of the device. This latter already presents very good and satisfactory characteristics.

1. Scope of the project

Contemporary architectural style is characterized by an increasing use of glass in construction. In summer, this may result in overheating situations which require the use of air conditioning. Despite numerous efforts to improve the characteristics of glass, the problem persists and is, in certain cases, amplified due to the fact that theoretical performance established in laboratory is hardly found in actual construction. It appears therefore essential to have the possibility to assess the actual thermal loads of a building. It is thus an advantage to have a portable device which allows on site measurements of the transmission of solar energy through both transparent and translucent facades.

From the thermal point of view glass is still a weak element. In winter the transmission heat losses are always 5 to 10 times superior to that of an opaque wall. In summer the passive solar gains are often causing overheating.

The g-box project consists in the development of a monitoring device that allows evaluating the thermal performances of transparent or translucent building elements.

In the framework of this SFOE (Swiss Federal Office of Energy) project, two independent units with each two calorimetric boxes were assembled in the hepia workshops. They allow for the simultaneous measurement of two glazing systems, enabling thus the assessment of the effect of a solar protection or any intervention aiming at optimizing solar gains. One of the devices has been delivered and installed at SUPSI and the other one has been used in Geneva for two years.

2. Operating principle and g-box control

A g-box device includes two insulated boxes that are opened on 1 side. The box aperture is placed against the glazing to be measured. The solar gains from the glazing are absorbed inside the box and drawn by a heat exchanger through which circulates water from a cold water tank. Heat removal is controlled by a three-way valve and a PID controller (Proportional-Integral-Derivative), which maintains the inside air temperature of the box to that of the ambient room. A small fan inside the box is mixing the air to equalize the temperatures. Heat flow is essentially derived from temperature difference and mass flow through the exchanger.

A simplified thermal model of a box is shown in figure 1. The two temperature nodes are T_{water}, the water temperature of the radiator, defined as the average between inlet and outlet, and T_{in}, the air temperature inside the box.

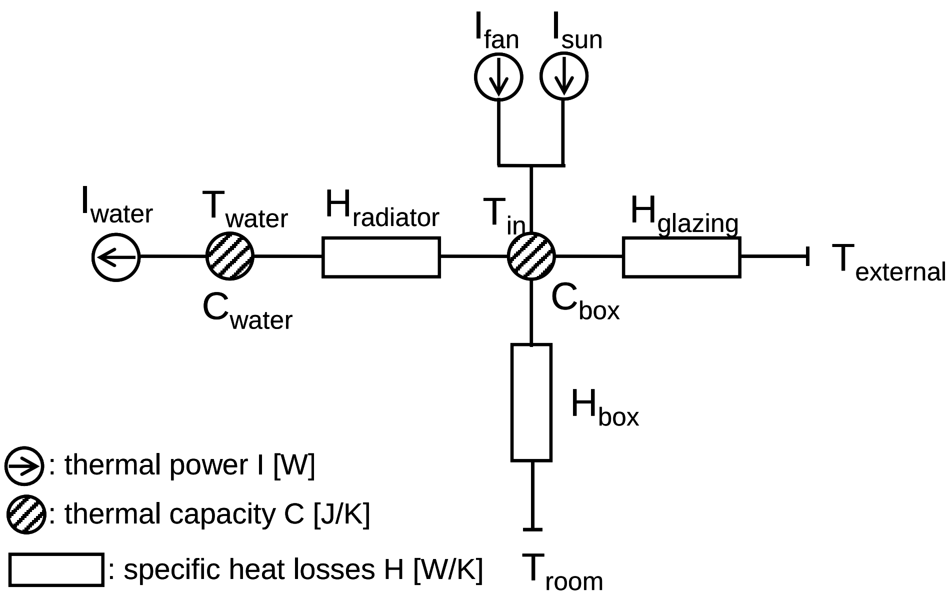

Figure 1 Simplified thermal model of a box with two temperature nodes

The measure of the heat removed from the box (I_{water}), the outside ($T_{external}$) and inside (T_{room}) air temperatures, the incident solar radiation in the window plane, the knowledge of the heat gains from the fan (I_{fan}), the U-value of the glazing and the various thermal caracteristics of the box (H_{box}, C_{box}, $H_{radiator}$, C_{water}) make it possible to calculate a thermal heat balance of the box in which the only unknown is the g-value.

An opening of the three-way valve has an effect on the inside air temperature of a box after a delay of 4 to 5 minutes. As a result the air temperature of a box oscillates around its set point value, defined as the room air temperature. It is illustrated in figure 2 with the best tuning of the PID controller.

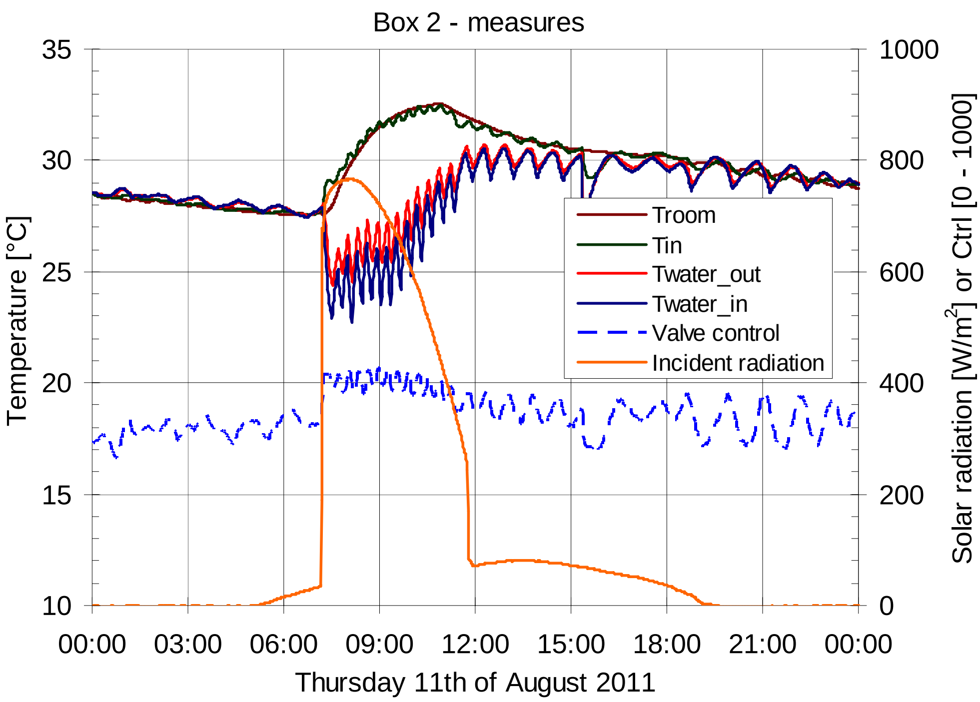

Figure 2 *Typical measurements with the PID controller regulating the inside air temperature of the box (T_{in}) on the room air temperature (T_{room})*

The extracted heat gains exhibit oscilliations that have a period of about 20 minutes. This is the main reason why the analysis of the measurements are performed with running averages of 40 minutes (see section 4.3).

3. Construction of a g-box device

Except temperature, flow measurement and a laboratory grade datalogger and control system, the calorimeter is designed to be built from standard industry components. The system can be divided into four distinctive parts: the chiller, the buffer tank, the calorimeter and the controller.

The whole system is designed to be easily transportable to allow on-site measurements. As such, each part of equipment can be easily transported by 1-2 persons. Only a 230V power supply is required. Additional access to Ethernet allows for optional remote access and control.

Figure 3 gives a synoptic overview of the g-box. It can be seen from left to right:

- standard industrial water chiller
- cold water circuit
- cold water buffer tank
- secondary water circuit including monitoring, regulation and circulation
- calorimeter box

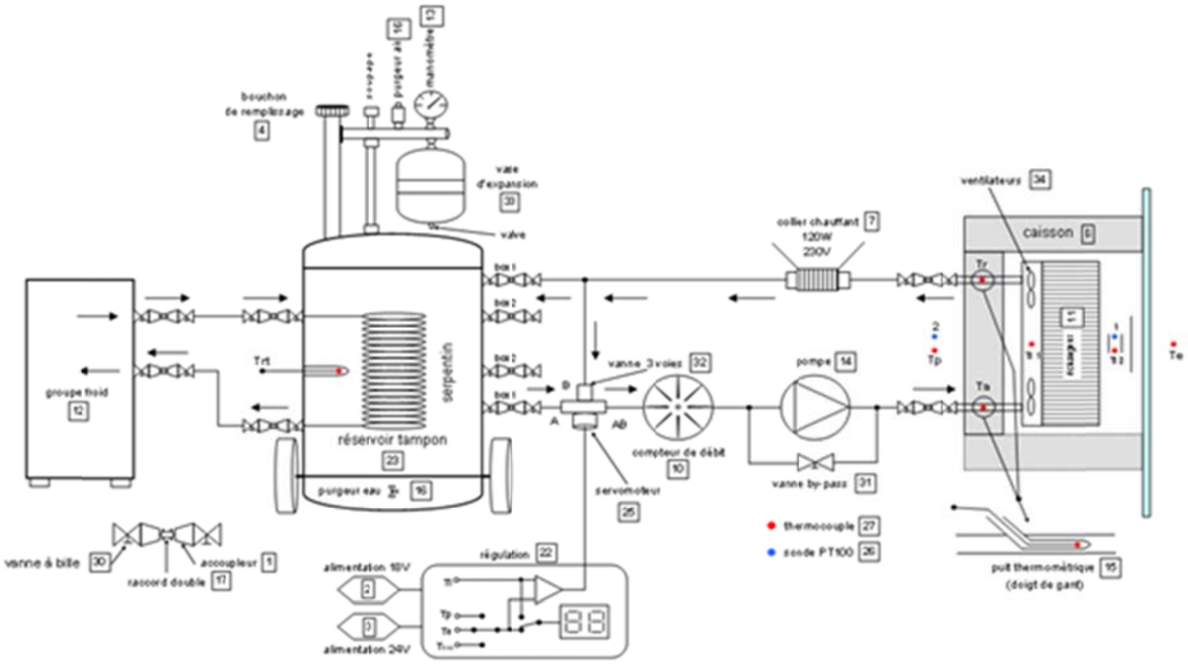

Figure 3 Synoptic overview of the g-box

3.1 The calorimeter box

The glazing sample is applied against an insulated box made of expanded polystyrene foam. The internal dimensions are 500x500x500mm^3 and contain the inside temperature reference probe and an air/water heat exchanger. Inside air is stirred using micro-ventilators in order to maintain a homogeneous temperature inside the box.

Figure 4: Assembly of prototype calorimeter

3.2 The buffer tank

The buffer tank contains approximately 100 liters of water, a heat exchanger for the chiller circuit and connections for two calorimeter circuits.

3.3 The controller

The controller and measurement unit is made of a programmable datalogger used to control and monitor data. The CR1000 based unit controls à servo 3-way valve to maintain setpoint temperature inside the calorimeter via a PID algorithm. Depending on the measurement protocol either ambient, building or constant temperature can be regulated.

Figure 5: Buffer tank (left) and climatic data probes.

3.4 Real time climatic data

Weather data is monitored, essentially ambient temperature and incident (vertical) global solar radiation with WMO grade equipment temperature probe and pyrometer.

4. Measurements and data analysis

4.1 Measurements and data acquisition

Incident solar radiation and outdoor air temperature are measured, as well as forward and return water temperature and mass flow rate through each box, indoor air temperature and inside air temperature of the box. Temperature measurements are made with laboratory calibrated K type thermocouples. A calibrated pyranometer is used for measurement of solar radiation and the and mass flow is measures by high precision factory calibrated flow meters. The CR1000 datalogger controls the g-box operation and makes measurements every 2 seconds. One minute averages or integrals are recorded for further data analysis.

4.2 G-box thermal characteristics

The parameters of the g-box thermal model (see figure 1 in chapter 2) are determined with measurements in stagnation and relaxation conditions as well as punctual measurements. They are shown in table 1.

Thermal parameter	Box 1	Box 2
Dissipated power by the fan I_{fan}	3.0 ± 0.1 [W]	2.9 ± 0.1 [W]
Box specific heat loss coefficient H_{box}	1.0 ± 0.2 [W/K]	1.0 ± 0.2 [W/K]
Radiator heat transfer coefficient $H_{radiator}$	16.5 ± 2.0 [W/K]	16.5 ± 2.0 [W/K]
Box thermal capacity C_{box}	4’500 ± 400 [J/K]	4’500 ± 400 [J/K]
Water thermal capacity in radiator C_{water}	5’000 ± 400 [J/K]	5’000 ± 400 [J/K]

Table 1 Estimation of the thermal parameters for the two boxes of the ISAAC

The stagnation measurements can be used to increase the accuracy of the thermal power exchanged by the g-box radiator. This leads to the “secondary calibration” procedure, which can be done before each measurement campaign.

4.3 Data analysis and accuracy

The estimation of the g-value is realized with running averages of 40 minutes. This has the advantage to smooth the oscillations of the extracted thermal power from the box radiator and limit the statistical error to negligible values. An analysis of the systematical error has been conducted to evaluate its magnitude due to typical error measurements. For a g-value of 0.38 [-], the systematic error was assessed to be ±0.03 [-].

Greater variations or deviations of the g-value, observed with the various measurements done, are caused by parasitic effects that are not taken into account in the simplified model (see figure 1) used to analyze the measures.

5. Measurements results

The two g-box devices were used at SUPSI in Lugano and HEPIA in Geneva. Various types of glazing were measured for several positions of solar protections and different orientations (see [1] for details). Each g-box device has two boxes and makes possible comparative measurements.

5.1 Instantaneous g-value

In figure 6 the measured g-value is reported for a clear sunny day in Lugano. The incident solar radiation decreases to the diffuse component at midday, as the orientation of the façade is east. At the beginning of the day the solar radiation is increasing stepwise at about 7h30, due to a high horizon due to nearby mountains.

Box 1 reports the g-value resulting from a glazing with an external venetian blind whose slats are inclined to be in a horizontal position. Box 2 shows the g-value of the glazing without solar protection. This latter is a triple glazing whose g-value, according to the manufacturer, is 0.38 [-].

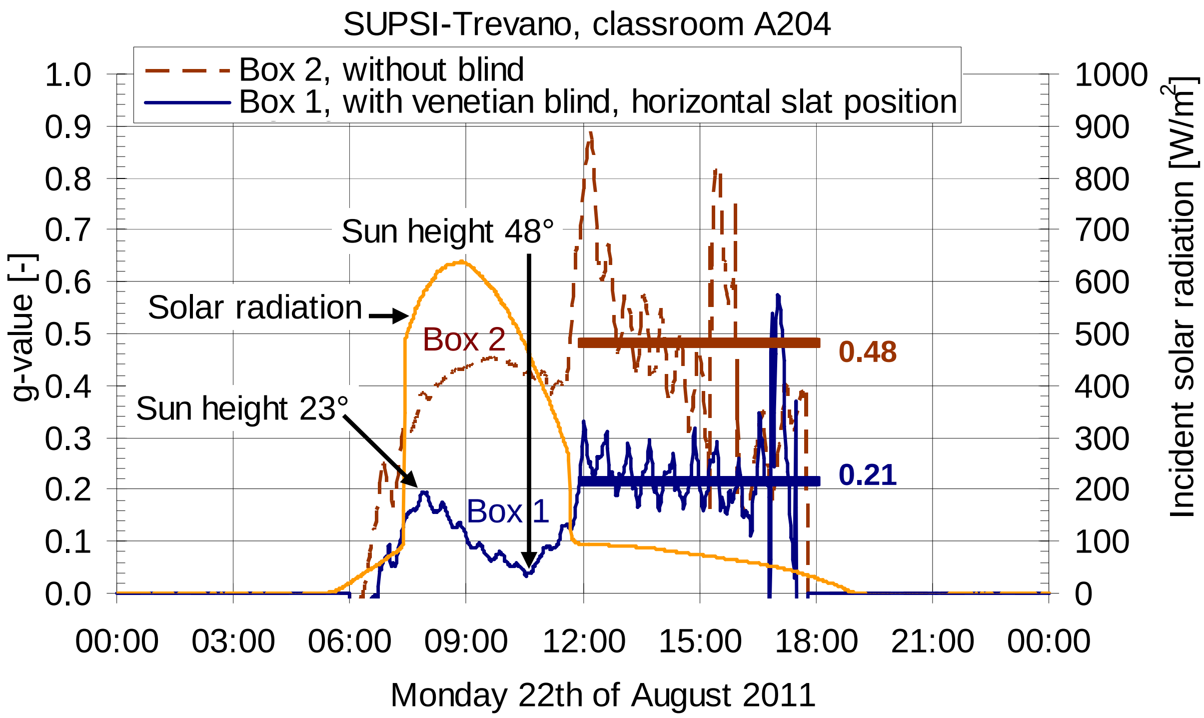

Figure 6 *Evolution of the measured g-value for a clear sunny day in Lugano. A triple glazing with an external venetian blind is measured by Box 1. Box 2 report the measured g-value of the triple glazing without solar protection*

The slats of the venetian blind, set to a horizontal position, create a dynamical effect on the g-value. Measurements from 8h to 10h30 show a clear dependency with the height of the sun.

The oscillation of the extracted thermal power of the box can still be observed with a data analysis based on 40-minutes running means. This is particularly obvious with the afternoon measurements, as the thermal loads resulting from diffuse radiation are extremely low.

It can be observed how the g-value of Box 2 is decreasing from 12h to 15h, indicating a heat capacitive effect due to the cooling of the glazing. This effect is much weaker with Box 1, as the glazing was already shadowed when the sun passed behind the façade.

The perturbations after 15h for Box 2 and at about 17h for Box 1 are due to unwanted full opening of the three-way valve that controls the cooling of the box. These events happen at regular time intervals and override the valve control. They are manufactory set to avoid a blocking of the valve that may occur after a long still period.

The instant g-value, as shown by measurements of Box 2, appears to be greater than the nominal value given by the manufacturer.

5.2 Daily g-value

The g-value values, obtained with 40-minutes running means, are selected for large enough incident solar radiation (greater than 200 W/m^2 in the plane of the façade), and small enough incidence angle (smaller than 50°), in order to make incidence angle effects negligible. An average of the selected values is done day per day. In this way it is possible to compare the g-value from one day to the other, or between the two boxes when they measure the same situation.

In figure 7 the daily g-values are reported for the triple glazing considered in the previous section. A quality of the day and the measures is defined on the basis of qualitative criteria. Three categories are defined: sunny day, average day and poor day. A poor day is characterized by a week insolation, short periods of data for the evaluation of the g-value and a prevalence of diffuse solar radiation. In figure 7, only the sunny and average days are shown.

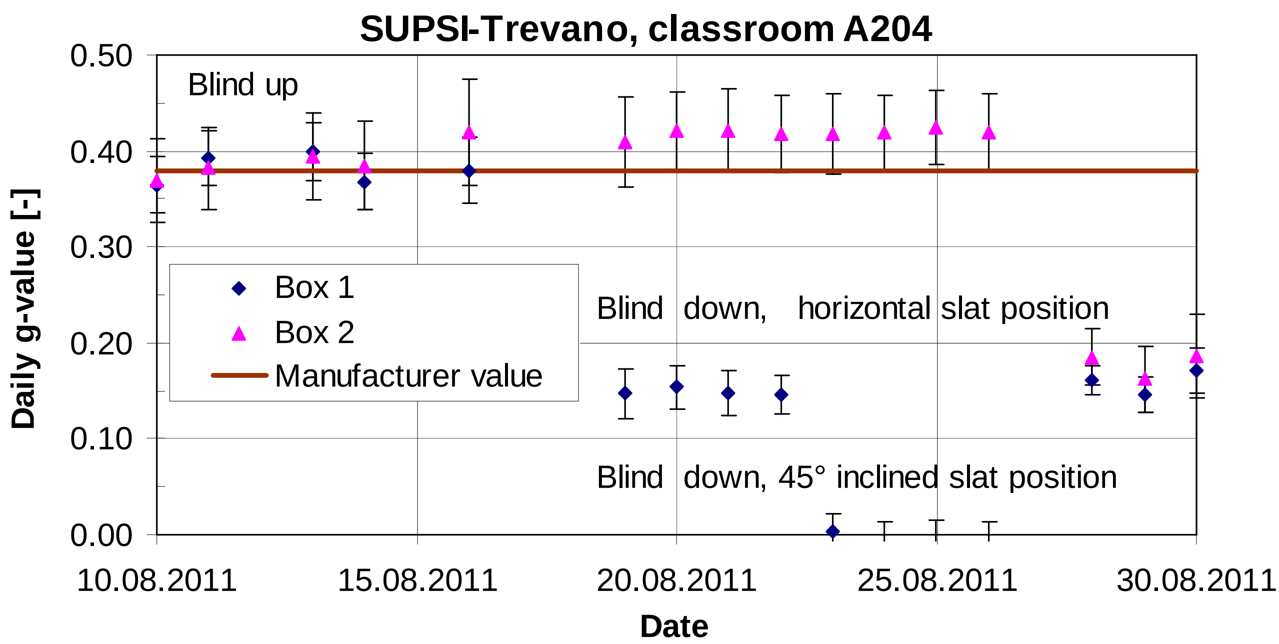

Figure 7 *Daily g-value measured in the classroom A204 of SUPSI in Lugano-Trevano. Three positions of the blinds are tested: blind up, blind down with horizonzal slat position and blind down with 45° inclined slat position*

The average daily g-values are summarized in table 2 for a confidence interval of 95%.

Average daily g-value	Box 1	Box 2
Blind up	0.38 ± 0.03 [-]	0.41 ± 0.04 [-]
Blind down, horizontal slat position	0.15 ± 0.02 [-]	0.18 ± 0.04 [-]
Blind down, 45° inclined slat position	0.00 ± 0.02 [-]	-

Table 2 Average daily g-values assessed for a confidence interval of 95%

The g-values provided by box 1 are systematically slightly lower than those of box 2. Taking into account the uncertainty, the measured g-values are compatible with the manufacturer one.

With the 45° inclined slat position, only diffuse solar radiation cross the window. The g-value appears to be low and of the same order of magnitude of the uncertainty.

5.3 Overestimation of the g-value

Daily g-values were also established with measurements made on building integrated photovoltaic (BiPV) modules and various types of double glazing windows (in Geneva). These measurements clearly indicated that the obtained g-value was larger than it should be. This overestimating effect is caused by the g-box border. It is about 10 cm large and is positioned against the glazing. When the sun is striking the border, it creates an undesired heating of the glazing and part of it ends up in the g-box, increasing the indirect component of the g-value.

6. Discussion

Two g-box devices have been developed and constructed for the in situ measure of glazing g-value with or without an external solar protection. Two boxes per device allow for the simultaneous measurement of two glazing types and the assessment of the benefit, for example, of a solar protection by comparison.

Measurements were performed on various types of glazing, with or without a solar protection, for different orientations and in two different climates (Lugano and Geneva), in order to test de g-box device. A test procedure has been designed to calibrate temperature sensors and increase the measurements' accuracy. A statistical data analysis has been developed to assess the g-value and limit statistical uncertainties related to the sensors.

Data analysis showed that the measured g-value was generally overestimated. The overestimation is very variable and depends on the type of glazing and the conditions in which the measurements are performed. It has been found that the aperture border of the box that is placed against the glazing disturbs the results. Solar radiation that strikes the border makes its temperature rise, which, in turn, warms up the glazing that is in contact with the border. As a result part of these solar gains ends up inside the box and increases the g-value.

7. Perspectives

Detailed studies are still to be carried out to improve the measurements method and analysis. The developed g-box device has already very good characteristics and presents a great improvement potential. Continuous measurements permit to calculate a daily heat balance of a glazing, which opens new perspectives to take into account the influence of the solar protection control or the inhabitant behavior in the solar passive gains evaluation.

Literature/references

[1] D. PAHUD, P. GALLINELLI, D. CRIVELLIN, S. MARGOT, R. CAMPONOVO et M. BELLIARDI (2013) G-box. Mesure in situ des performances énergétiques de façades transparentes et translucides. Rapport final, Office Fédéral de l'Energie, Bern, Switzerland. www.bfe.admin.ch/dokumentation/energieforschung publication number 290963