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# Lab-based validation of glass-floor systems for zero-energy buildings

**Radoslav Ponechal**[1]* (*orcid id: 0000-0002-4865-739X*)
**Peter Kysela**[1] (*orcid id: 0000-0002-0580-6332*)
**Jakub Jura**[2] (*orcid id: 0000-0003-2538-0014*)
**Miroslav Fabian**[3]
[1] University of Žilina, Slovakia
[2] Czestochowa University of Technology, Poland
[3] Heliobus AG, Switzerland

Abstract: The subject of this study is experimenting with a procedure to verify a prototype walkable glazing module in the laboratories belonging to the University of Žilina. A square-shaped specimen with sides of length 800 mm, incorporating a triple-glazed insulated glass unit within a thermally broken stainless-steel frame, was conditioned and tested under rigorously controlled conditions. Air permeability was assessed following EN 1026 and EN 12207 by mounting the specimen in a special sealed test frame, applying stepwise pressure differentials up to 600 Pa, and recording steady-state volumetric flow rates. Watertightness testing conformed to EN 1027/EN 12208 protocols, using an oscillating rain simulator delivering 5 L/m$^2$·min and internal pressurization in incremental steps, with leak detection via absorbent-paper inspection. For completeness, the measurements were supplemented by thermal-transmittance evaluations as per the ISO 12567-2 employed hot-box method. The measurement results showed that the product is capable of withstanding several extreme weather conditions.

Keywords: watertightness, air permeability, climatic chamber, glass-floor

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## Introduction

Climate chambers are used in many industries to ensure stable temperature and humidity conditions when testing samples. In addition to temperature and humidity,

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[*] Corresponding author: radoslav.ponechal@uniza.sk

other meteorological conditions can be artificially created, such as high wind speeds and overpressure caused by wind or heavy rain. Such adverse conditions tend to be particularly severe for construction products incorporated in the building envelope. In this way, not only the resistance of the materials to extreme temperatures is tested, but also the overall structural design to ensure thermal resistance, airtightness and watertightness. This applies in particular to façade elements and windows, and as such, there has been quite a lot of development in this area in recent years.

Attention can be drawn to such developments in Central Europe. In Slovakia, this problem of air and moisture transport was discussed by a collective from the Slovak Technical University in Bratislava on the example of wooden windows (Palkova et al., 2018). In the Czech Republic, the team of J. Tywoniak, from the Czech Technical University in Prague, solved the problem of optimizing roof windows for the building of ultra-low-energy passive houses (Tywoniak et al., 2019). Long-term research in the field of windows also stemmed from the collaboration of Polish and Ukrainian researchers (Pavlenko & Sadko, 2023). Currently, climate chambers with their additional equipment are used not only for measuring windows but also for green façades (De Groeve et al., 2023; Juras & Durica, 2022) or thermally active façades (Čekon et al., 2018; Vanaga et al., 2022).

Another perspective on measurements in climate chambers could be in terms of sample size. ISO 8990-96, similar to EN 14351-1, requires the size of the opening into which the sample is inserted to be at least 1 $m^2$. Smaller samples are easier to handle, although they may have certain shortcomings in terms of measurement accuracy (Smith, 2016). A similar method for testing windows is Twin Rooms. They still have a lot in common with climate chambers, but the exterior conditions are not created artificially (Dankova et al., 2024; Lee, 2020). In Twin Rooms, the sample is exposed to real outdoor climatic conditions. The performance of building structures and façades in the summer season is most often evaluated using this method, precisely because of solar radiation, which is difficult to simulate in climatic chambers. In addition to the full spectrum of radiation, it also involves the dynamics of radiation during the day, including the angle at which the radiation is incident on the sample, as Čekon described in detail in an older experimental analysis of a transparent insulation façade (Čekon & Čurpek, 2019). Likewise, there is an effort to develop a device that would be able to measure the watertightness of façade elements in in-situ conditions (Andreotti et al., 2020; Bielek et al., 2022). One of the main problems today is coping with extreme weather conditions (Pastori & Mazzucchelli, 2023). Testing new products for all weather extremes is often a costly and organizationally demanding task. This article shows how the resistance of building components can be tested relatively effortlessly using a single method.

## 1. Methodology

The essence of this paper is to describe the methodology, starting the preparation of test specimens, the environmental conditioning, the instrumentation employed, and the execution of air permeability, watertightness and thermal-transmittance tests.

All listed below measurements were carried out in the laboratories of the Department of Building Engineering and Urban Planning in the University of Žilina (UNIZA) according to relevant European standards to ensure reproducibility and compliance.

### 1.1. Test specimen preparation

The subject of the investigation was a walkable skylight Glassfloor® Pure (nominal size 800 mm × 800 mm, glazing 720 mm × 720 mm) delivered as a finished product by the Swiss company Heliobus®. In this product there is a triple-glazed insulated glass unit fitted into a thermally broken stainless-steel frame with a 5 mm sightline (Fig. 1). Before testing, the module of the Glassfloor® Pure system was mounted on thicker plywood with dimensions 1200 mm × 1400 mm, which are the dimensions of the opening in the test wall between the climate chambers. EPDM foil was used as an air and watertight plane connecting the steel edge of the skylight with the edge of the masking panel, and glued to the steel sheets with high-quality window tape.

The sample, thus prepared, was exposed to 23 °C and 50 % relative humidity for 72 hours on both sides. This initial steady state was necessary to stabilize the temperature and humidity conditions in the sample and also to eliminate mechanical stress. This was done the same way each time after each test.

**Fig. 1.** Glassfloor® Pure skylight sketch (Heliobus®)

### 1.2. Air permeability measurement procedure

The airtightness measurements were carried out in accordance with EN 1026 at an overpressure in the outdoor climate chamber in the range of 0 Pa to 600 Pa in 50 Pa steps. Each step increase in pressure was followed by a stabilisation phase lasting at least 60 s. This procedure was repeated 3 times and the measured values were averaged. A metal cover panel with a thin tube was created to measure air flow during overpressure. The cover dimensions were slightly larger than the opening in the masking panel to properly anchor and seal the structures dividing the two climatic chambers. In this atypical method of measurement a thermo-anemometric probe was placed in the tube to measure the flow speed measuring in the range of 0.2 m/s to 20 m/s with an accuracy of ±1.5 %, from which the air flow through the sample was secondarily derived.

## 1.3. Watertightness measurement procedure

The large climatic chamber at UNIZA also contains water nozzles designed for the needs of watertightness testing according to EN 1027. Here, water is sprayed and flows evenly over the sample surface, with a simulated oblique rain rate of 5 L/m$^2$ per minute. During spraying, the pressure was changed rapidly, but this time at greater intervals, namely to pressure values of 150 Pa, 300 Pa, 450 Pa, 600 Pa. Each pressure level was maintained for 10 minutes while visual inspection and leak detection (paper wipe method) were performed on the interior surface in the indoor chamber. Figure 2 shows the sample during spraying.

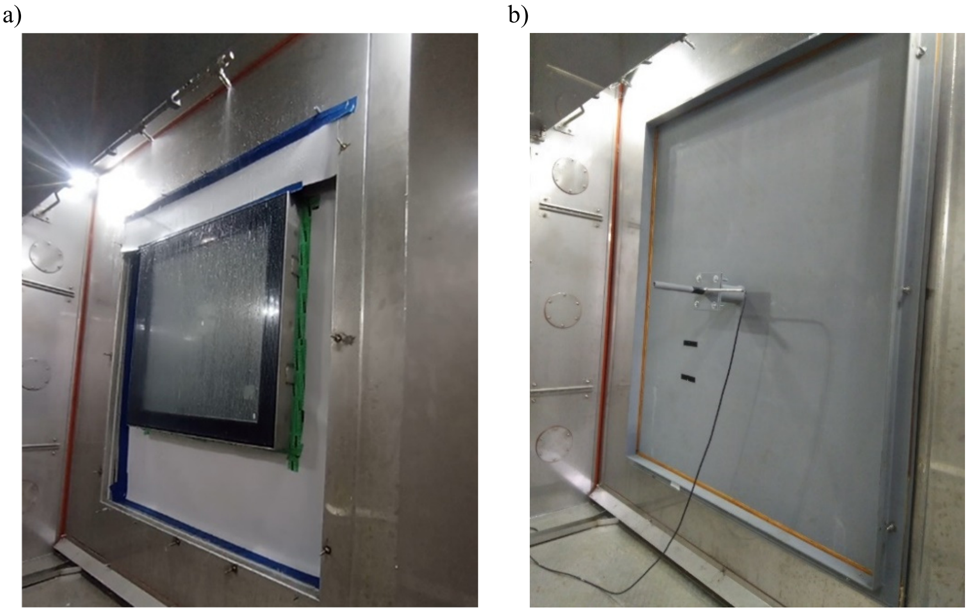
a)
b)

**Fig. 2.** View of the sample in the outdoor chamber: a) during the water resistance test, b) during the air permeability test (*own research*)

## 1.4. Thermal transmittance measurement procedure

In order to properly measure the heat flux through the sample without unnecessary thermal bridges, the wooden board (15 mm OSB + 15 mm laminated plywood) was insulated. The insulation was implemented on the interior side with 40 mm thick extruded polystyrene EXP. Thermal-transmittance (U-value) measurements were conducted in a two-chambered hot-box per EN ISO 12567-2. The warm side was maintained at 21.7 °C; the cold side at –11 °C. Surface temperatures were measured at nine points on each glazing face and four points on the frame, ensuring representative sampling. Heat flux sensors were mounted centrally on the inner pane. After a 12-hour stabilization period, data was collected for 24 hours. Due to the sample being smaller than the width and height of the hot-box, it was necessary to determine the heat flux through the edge of the sample to determine the particular U-value of the skylight. The heat balance in climatic chambers with a hotbox can be written with following formula:

$$\phi_{hb} = \phi_1 + \phi_2 + \phi_3 + \phi_4 \tag{1}$$

where:

$\phi_{hb}$ – power supply to the hotbox measured with a wattmeter [W],
$\phi_1$ – heat flow rate through the metering area of the skylight [W],
$\phi_2$ – heat flow rate through the metering area of the wall around skylight [W],
$\phi_3$ – heat flow rate through the hotbox walls [W],
$\phi_4$ – heat flow rate through the edge of the metering area [W].

## 2. Results and discussion

### 2.1. Air permeability performance

Figure 3 shows the results of the air permeability measurements in $m^3/h \cdot m^2$. The Glassfloor® Pure specimen achieved an air-permeability classification of Class 4, with a relatively high reserve. This indicates exceptionally low leakage rates even in higher buildings (up to 50 m building height).

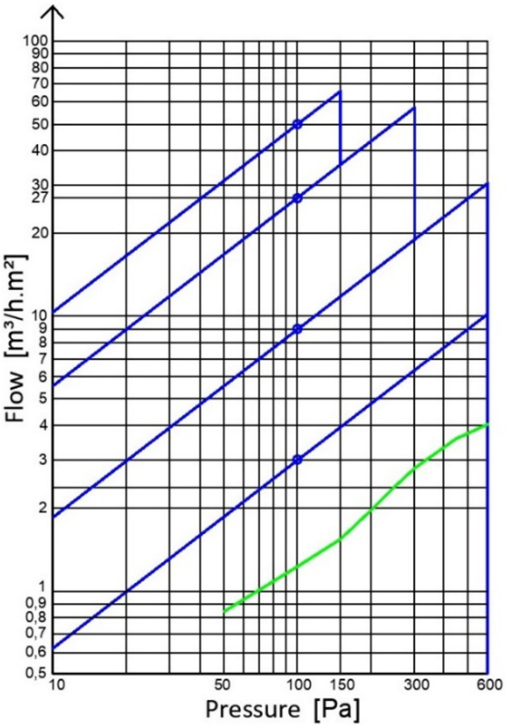

**Fig. 3.** Air permeability chart under pressure – average measurement values marked in green – the blue lines define the various airtightness classes (*own research*)

The stability of flow rates across three pressure cycles also demonstrates the reliability of the stainless-steel frame and gasket system under cyclic loading. Such performance suggests minimal risk of drafts or moisture ingress in both residential and commercial installations.

## 2.2. Watertightness performance

During the spraying of the sample (55 minutes exactly) and the overpressure in the range of 0 Pa to 600 Pa, no water leakage was observed at sight through the sample under investigation. Pressures higher than 600 Pa could no longer be generated in the test apparatus. This limitation is related to the design of the climatic chamber. Nevertheless, under these conditions the sample already meets the requirements for the highest rating of Class 9A according to EN 12208. Designers can therefore specify this system in exposed roofs without additional secondary drainage measures.

## 2.3. Thermal transmittance performance

The combination of triple glazing and a thermally broken stainless steel frame resulted in a relatively low U-value of 0.60 W/(m$^2$·K). Details of other measured parameters such as ambient temperature, surface temperatures, heat transfer coefficients and others are given in Table 1.

**Table 1.** Calculation of the thermal transmittance of the window (*own research*)

| Physical quantity | Unit | Value |
|---|---|---|
| Temperature mean surrounding panel | °C | 4.0 |
| Thermal resistance of the surrounding panel | (m$^2$·K)/W | 1.7 |
| Thermal conductivity of surrounding panel | W/(m·K) | 0.035 |
| $\Psi$ edge for w = 40 mm | W/(m·K) | 0.0262 |
| Temperature difference surface, surrounding panel | K | 28.1 |
| Temperature difference air | K | 32.7 |
| Input power to hot box | W | 31.5 |
| Power through surrounding panel | W | 16.5 |
| Edge zone heat flow | W | 2.5 |
| Heat flow density through specimen | W/m$^2$ | 19.5 |
| Warm side convective fraction | – | 0.3 |
| Cold side convective fraction | – | 0.85 |
| Mean radiant temperature warm side | °C | 21.2 |
| Mean radiant temperature cold side | °C | –11.0 |
| Warm side environmental temperature | °C | 21.3 |
| Cold side environmental temperature | °C | –11.0 |
| **U-value measured** | **W/(m$^2$·K)** | **0.60** |

The resulting heat transfer coefficient value was determined as the average of two measurements. The measurement of the temperature difference between the chamber environments had a combined standard uncertainty of 0.7 K. The heat flux measurement had a combined standard uncertainty of 0.98 W in both cases. The overall accuracy of the resulting heat transfer coefficient of the skylight was 7.1 %, which was based solely on the accuracy of the temperature and heat flux meters; thanks to the exceptional stability, the noise in the results was minimal (0.05 % max.).

The values obtained during the measurement of thermal transmittance were in the vertical installation of the sample. For a building product such as a skylight, it is typical to install it in a horizontal direction. It is assumed there, that the value of thermal transmittance on the glazing will deteriorate. During the hot-box test, the heat flux in the centre of the glazing was also measured. Based on this, the U-value of the glass was found to be about 0.5 W/($m^2 \cdot K$). In colder climates, this performance minimizes surface condensation and heat loss, while in temperate zones it can contribute to net energy gains through solar passive heating. It confirms that walkable glass need not compromise thermal comfort and water vapour condensation problems.

### 2.4. Limitations and further research

We emphasize that these results were obtained from a specimen in an elevated position, which is not typical for such a product installed in a building. It was a measurement of a new product. However, the walk-on skylight very often comes into contact with shoes, tires and other objects in practice, which can cause degradation of the glass seal. Thus, further research will focus on testing the degraded product and the possibilities of bringing back its original properties.

## Conclusions

The measurements made in the climate chambers confirmed the high expectations in the airtightness and watertightness of the walk-on skylight. In both tests it received the highest classification and can therefore be considered a good choice for installations in even demanding applications such as high-rise buildings. The measured low heat loss also qualifies this product for installation in zero energy buildings. However, the unanswered question is how long it will maintain these properties under realistic conditions of use. In future research it would be useful to measure the product with this methodology after several years of use.

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