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VERIFICATION OF WINDOW PROPERTIES AFTER 10 YEARS OF EXPLOITATION: RESULTS OF MEASUREMENTS IN THE PAVILION LABORATORY AND THE CLIMATE CHAMBER

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Abstract. The article will deal with the analysis of measured data on a plastic window with thermal insulating triple glazing, which is suitable for low-energy or passive houses. The window was installed in 2011 in the test laboratory of the Department of Building Engineering and Urban planning, Faculty of Civil Engineering, University of Žilina (Slovakia), where it was tested under standard indoor climate conditions and real outdoor climate conditions. Surface temperatures on the frame friezes and glass system and heat flux density were recorded at a five-minute time step. In 2020, the window was removed from the laboratory and subsequently tested in a climate chamber. This paper will present the results of these measurements in terms of heat flow density waveforms, heat transfer coefficient, and total solar transmittance through the glazing. Subsequently, a simulation model of this window will be created in the environment of a computational program and its verification based on the measurements will be carried out. A series of calculations will be performed on the tuned model and analyses of the results and comparisons will be presented under the same climatic conditions as during the real measurements recorded by the meteorological station.

Keywords: Window, triple glazing, climate chamber, pavilion measurement, building physics.

1. Introduction

Windows are an integral part of the envelope of almost all buildings. They are the most used transparent system in building envelopes. The main function of windows is to protect the indoor environment from the external climate. Other important functions are daylighting and insolation of the space [1], fresh air supply by natural ventilation, contact with the outdoors, etc. With increasing demands for thermal protection, window constructions are constantly evolving. Physical criteria such as thermal-technical, acoustic, lighting, and hygiene are important. Another important aspect of the proper functioning of windows is their installation in envelope construction. Window constructions are the most problematic point of the building envelope in terms of thermal insulation and construction design. Therefore, continuous research and development of window constructions are essential. A significant problem that needs to be addressed more than in the past is overheating in summer [2]. Another problem is the elimination of thermal bridges in window construction. For example, by using triple glazing we limit the formation of water vapor condensation at the bottom of the glazing.

In Slovakia, thermal protection is dealt with in STN 730540:2019 [3], which follows the EC Energy Performance of Buildings Directive (EPBD) 2010/31/EU. Valid values for window constructions are $U_w = 1.0\,\mathrm{W/(m^2\,K)}$ from 2016 and from 2021 the recommended value is $U_w = 0.65\,\mathrm{W/(m^2\,K)}$.

Since 2011, three different windows have been monitored in the laboratory of the Department of Building Engineering and Urban planning. It is a so-called pavilion laboratory. The indoor environment is controlled by a heating system and an air conditioning unit. The outdoor environment is represented by the real climate, which is recorded by a weather station [4]. From the research conducted so far, several results related to temperature, heat flux, and U-value measurements have been published. Comparisons have been made with the model in the FEM Therm software and result from different years were analyzed. During autumn 2020, the laboratory building envelope was renovated and insulated with a new ETICS system, while one of the measured windows was dismantled and taken for measurement in the climate chamber [5, 6]. A comparison of the measured results from the pavilion laboratory and the climate chamber after ten years of window exploitation at the same boundary conditions is described in this paper.

2. Methods of measurement

The analyzed plastic window has been installed in the department testing laboratory since 2011 (Figure 1). The window was oriented to the south with a slight inclination to the west (15°). From the exterior side, the window was exposed to real outdoor climate conditions, which are monitored and recorded by a mobile experimental weather station [7], located on the roof of a nearby building. The indoor climate is provided

Figure 1. External and internal view of the built-in plastic window in the test laboratory.

Material	Number of chambers	Glazing	Gas	Total solar energy transmittance g [%]	U_w [W/(m^2·K)]	U_f [W/(m^2·K)]	U_g [W/(m^2·K)]
Plastic	6	Triple	Ar	36	0.80	1.00	0.50

Table 1. Properties of the measured plastic window given by the manufacturer.

by an air-conditioning unit, which maintains it based on the Slovak standard boundary conditions: 20 °C and 50 % humidity [8].

The sensors used for the measurements consist of NiCR-Ni [9] thermocouples and heat flux density plates (HFP), also equipped with a correction thermocouple (standard 120 × 120 mm) and a half-sized (120 × 60 mm) for window frames and sashes [10]. The monitoring points are the frame, sash, and glazing. The datalogger and both types of sensors are from Ahlborn. The data logging interval in this case was five minutes. The heat flux density was only recorded at the glazing, as measuring the heat flux density through the window frame requires different input conditions – the glazing must be replaced by a full panel. For this reason, the degradation of the glazing system will be mainly evaluated in this paper.

Subsequently, the window was dismantled in 2020 during the reconstruction of the facade of the pavilion laboratory. However, it is not at the end of its life. After dismantling, the window was removed and installed in the climate chamber, where it has been and will continue to be tested and measured. The purpose was to compare the parameters of the window measured in the pavilion laboratory with those measured in the climate chamber.

For the measurements in the climate chamber, two variants of indoor climate modeling were used, one with a constant indoor temperature and a measurement with a hotbox, the other without the application of a hotbox and with the same temperature waveform as was recorded in the pavilion. For the measurement of the climate chamber was chosen 1st March 2018. The outside temperature ranges from -3.4 °C on a sunny day to -16.7 °C at night. The indoor air temperature was also used. This method was chosen to compare the behavior of the window under the same boundary conditions in the pavilion laboratory and the climate chamber. Instead of thermocouples, PT100 and NTC sensors were used to measure temperature. The HFP used is of similar types to those used in the pavilion measurements.

When the window was initially installed in the pavilion laboratory, not all the parameters that we now measure in the laboratory were measured. For this reason, the measured values from the pavilion laboratory and the climate chamber are compared with the values set and declared by the manufacturer. The declared values of the window parameters from the manufacturer are summarized in Table 1.

2.1. U-value

The heat transfer coefficient U of a structural element describes the amount of heat energy that passes through it from one side to the other per second in a square meter of the area at a constant ambient temperature difference of 1 °C. The relation for calculating the heat transfer coefficient U is shown in Equation (1):

$$U = \frac{1}{R_0} = \frac{1}{(R_{si} + R + R_{se})} = \frac{1}{\frac{1}{h_i} + \frac{1}{\Lambda} + \frac{1}{h_e}} = \frac{q}{\theta_{ai} - \theta_{ae}}, \quad (1)$$

U heat transfer coefficient [W/(m^2 K)],

R_0 structure resistance to heat transfer [(m^2 K)/W],

R_{si} internal surface resistance [(m^2 K)/W],

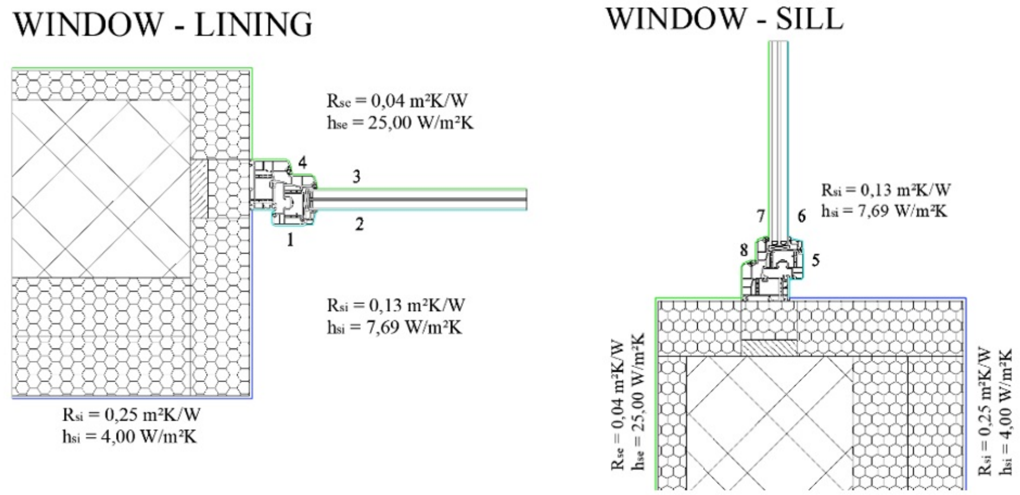

Figure 2. Detail of the window in the wall of the laboratory. Marked positions for comparison of surface temperatures.

Surface transfer coefficient [W/(m² · K)]	**STN 73 0540**	**Glazing pavilion**	**Glazing clim. chamber with hotbox**	**Glazing clim. chamber without hotbox**
h_i	7.62	10.47	10.92	16.51
h_e	25	14.56	15.92	15.66

Table 2. The surface transfer coefficient is defined in STN 73 0540 and calculated using Equations (2) and (3).

R_{se} external surface resistance [(m^2 K)/W],

R thermal resistance of the structure [(m^2 K)/W],

h_i surface transfer coefficient at internal surface [W/(m^2 K)],

h_e surface transfer coefficient at external surface [W/(m^2 K)],

Λ thermal conductance [W/(m^2 K)].

The surface transfer coefficient can be calculated according to the Equations (2) and (3):

$$h_i = \frac{q}{\theta_{si} - \theta_{ai}}, \tag{2}$$

$$h_e = \frac{q}{\theta_{se} - \theta_{ae}}. \tag{3}$$

2.2. Solar transmittance

For transparent and translucent constructions such as window constructions, besides the thermal quantification, the optical properties, especially the solar transmittance, are equally important parameters [11]. There are several ways, to measure solar transmittance. In our case, measuring devices in the form of two pyranometers were used, one of which was mounted on the interior side of the measured window and the other on the exterior side as part of a mobile meteorological station. From the values measured in this way, the solar transmittance is finally determined as the ratio of the observed solar radiation intensities behind (from the interior side) and in front (from the exterior side) of the measured window located in the pavilion laboratory and subsequently in the climatic chamber.

2.3. Window simulation in simulation software

In the design and planning process of a building, thermal bridges are analyzed for several construction fragments, including the window frame detail and the window fitting into the opening. The analysis can be carried out using various simulations, however, modeling different window construction is quite time-consuming [12].

In the field of two-dimensional modeling of heat transfer in buildings, several software is available. This article used Therm software, developed by Lawrence Berkeley National Laboratory. The simulation results in the form of surface temperatures were compared with the actual measured surface temperatures in the pavilion laboratory. A detailed view of the modeled window is shown in Figure 2. These windows were placed in the same composition as in the laboratory to achieve the best possible temperature match. The simulation was carried out in the lining and the sill.

3. Results of measurements

For the calculation of the surface transfer coefficient were used Equations (2) and (3). Results are summarised in Table 2. The results show in some cases (especially outdoors) a large difference between the

Heat transfer coefficient [W/(m² · K)]	Specified by the manufacturer	Glazing pavilion	Glazing clim. chamber with hotbox	Glazing clim. chamber without hotbox
U_g	0.5	0.92	0.94	0.96
U_w	0.8	1.12	1.13	1.15

Table 3. Heat transfer coefficient window U_w and glazing U_g.

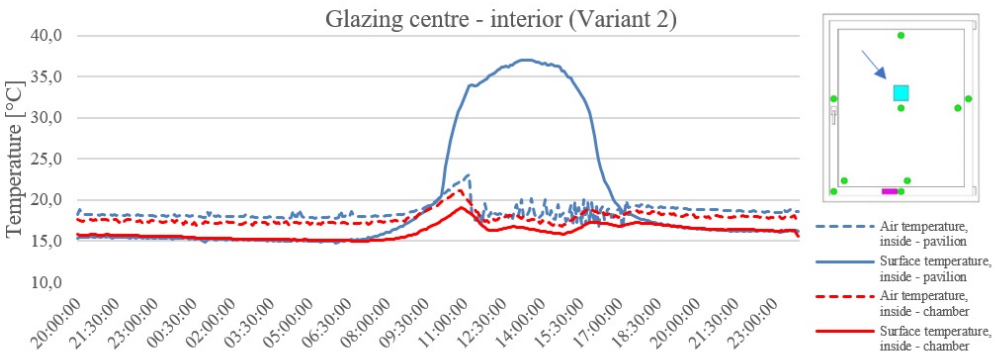

Figure 3. Temperature courses for the Centre of glazing. Very good match of courses at the night (without solar radiation).

measured values and the standard values. The difference could be due to the measurement method itself, a non-stationary state, lower accuracy of the thermocouples, or imperfect contact between the sensor and the surface. In the case of the outdoor coefficient, the non-stationary state of the external environment: solar radiation, wind, and rain. The calculated values of the surface transfer coefficient based on the measured heat fluxes are given in Table 2 and the heat transfer coefficient glazing in Table 3.

The measured surface temperature values at each position are shown in Figures 3–6. In this case, the temperature waveforms for a selected time interval were compared (from 20:00 28$^{\text{th}}$ February 2018 to 23:59 1$^{\text{st}}$ March 2018). Although there are 6 (10) positions displayed within the window, only 3 specific positions are compared. In other positions the results are similar.

Figure 3 shows the temperature waveforms at the center of the glazing from the inside. Temperatures were measured using HFP. Figure 4 and Figure 5 show a comparison of the different internal temperatures. In the first case, the steady – constant air temperature is measured with a hotbox in the climate chamber. In the second figure, the non-stationary temperature was used as the boundary condition in the chamber. Figure 6 shows the surface temperatures at the window sash location.

In Table 4 we can see the solar transmittance calculated as the ratio of the observed solar intensities behind (from the interior side) and in front (from the exterior side) of the measured window. Measurements were carried out in the pavilion laboratory and the climate chamber.

In Table 5 we can see a comparison of the surface temperatures measured in the climate chamber and pavilion laboratory with the surface temperatures from the Therm simulation software (Figure 7). The boundary conditions in the simulation were set approximately according to the real conditions from the measurements in the pavilion. Outdoor temperature -10 °C and indoor temperature 20 °C.

4. Conclusion

This article deals with the comparison of measured parameters of a plastic window after its ten-year exploitation. The measured parameters were compared only with the data given by the manufacturer. The measured window was installed in the pavilion laboratory where it was exposed to the real outdoor climate. It was later dismantled and used for measurements in the climate chamber with the same boundary conditions set as on the selected winter day in 2018. For comparison, a simulation was also created but in the stationary environment of the Therm software.

The results showed a very good agreement in the shape of the temperature waveform and for the position in the center of the glazing also in the values where the difference is relatively small. In other positions, there is a different temperature approx. 3–4 °C. Daily temperatures in the pavilion laboratory are strongly influenced by solar radiation, wind, and rain. Discrepancies in the sill results require further analysis, such as the impact of the masking panel compared to the wall. The glazing heat transfer coefficients calculated from the measured heat fluxes in the pavilion laboratory and the climate chamber show similar values but differ significantly from the values given by the manufacturers. The heat transfer coefficient glazing

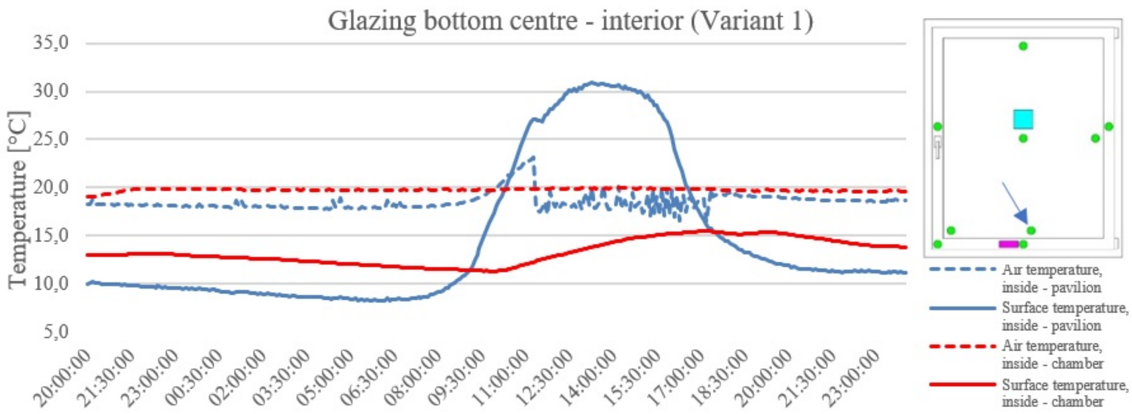

Figure 4. Temperature courses for the bottom of glazing. Variant 1 with constant indoor temperature. Difference of about 3 °C in surface temperatures.

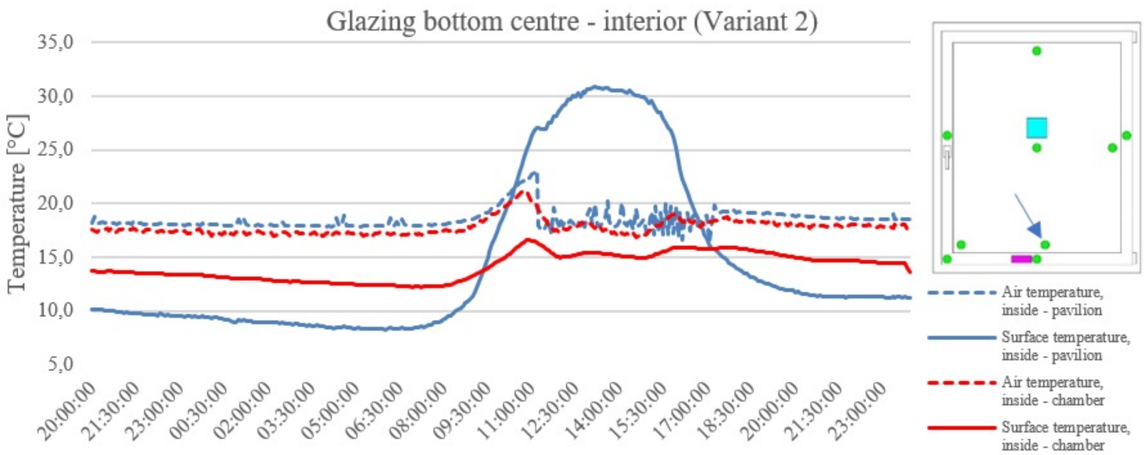

Figure 5. Temperatures courses for the bottom of glazing. Variant 2 with non-steady indoor temperature. Difference of about 4 °C in surface temperatures.

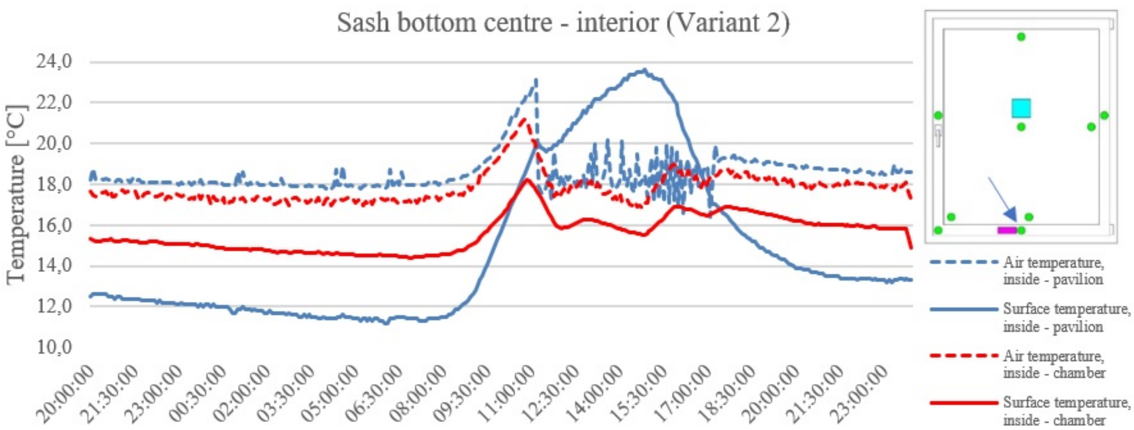

Figure 6. Temperature courses for the bottom of windows sash. Difference of about 3 °C in surface temperatures.

	Specified by the manufacturer	**Pavilion**	**Climatic chamber**
Total solar energy transmittance g [-]	0.36	0.34	0.31

Table 4. Total solar energy transmittance g.

	Position	Temperature [°C]		Therm	Pavilion	Chamber
Plastic window	1	Outdoor -10	Indoor 20	17.3	15.1	15.0
	2			16.5	14.9	13.3
	3			-9.1	-8.3	-8.9
	4			-8.5	-8.3	-9.0
	5			17.5	9.9	15.4
	6			15.9	12.5	16.9
	7			-8.7	-10.6	-
	8			-8.9	-10.6	-

TABLE 5. Comparison of surface temperatures measured in the pavilion and climate chamber with temperatures from the Therm simulation software.

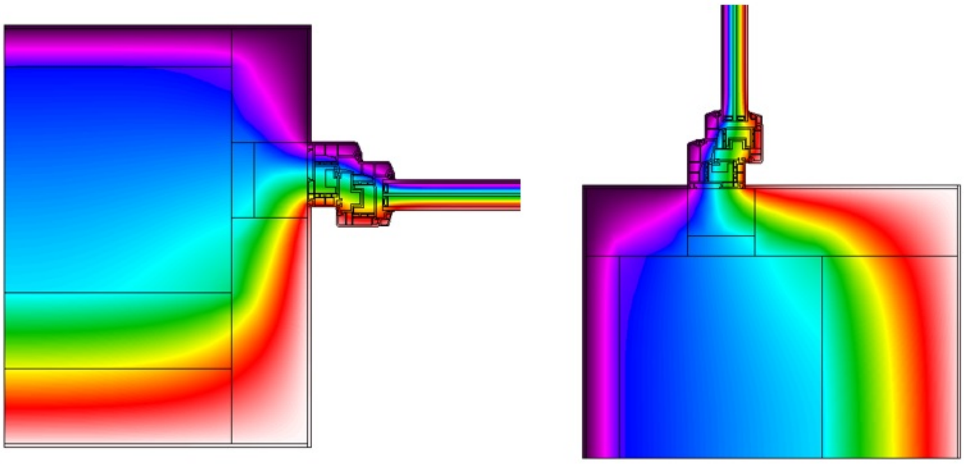

FIGURE 7. Temperature waveforms according to the Therm software simulation at the lining and sill location.

shows a difference compared to the manufacturer's values of about 90 %. The values of the total solar energy transmittance compared to the manufacturer's value is quite similar. The value measured in the pavilion laboratory compared to the manufacturer's value show a deterioration of only about 5.5 %. For the values measured in the climate chamber, a deterioration of 14 % occurs. Based on these findings, we can say that the thermal-technical properties of the plastic window after 10 years of exploitation show deterioration. This deterioration of the parameters is influenced by possible leakage of filler gas from the glazing system, non-stationary conditions, especially from the exterior side (solar radiation, wind, rain), and airflow in the vicinity of the construction.

The surface temperatures obtained from the simulation were then compared with the surface temperatures measured in the pavilion and the climate chamber. The results showed a slight overestimation of the temperatures in the lining area, however, there is a large difference between the temperatures in the sill area, which may be due to the airflow in the sill area and the stationary environment of the Therm software.

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REFERENCES

[1] M. Glória Gomes, A. J. Santos, A. Moret Rodrigues. Solar and visible optical properties of glazing systems with venetian blinds: Numerical, experimental and blind control study. *Building and Environment* **71**:47–59, 2014. `https://doi.org/10.1016/j.buildenv.2013.09.003`

[2] R. Ponechal. Increasing thermal mass in low carbon dwelling. *Procedia Engineering* **111**:645–651, 2015. `https://doi.org/10.1016/j.proeng.2015.07.062`

[3] STN 73 0540:2019: Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.

[4] P. Juras, D. Jurasova. Influence analysis of climate data time-step on the accuracy of HAM simulation. *MATEC Web of Conferences* **196**:02029, 2018. `https://doi.org/10.1051/matecconf/201819602029`

[5] P. Juras, P. Durica, M. Bartko. Long-term window evaluation: Comparison of pavilion laboratory and climate chamber measurement. In P. Akimov, N. Vatin (eds.), *XXX Russian-Polish-Slovak Seminar Theoretical Foundation of Civil Engineering (RSP 2021)*, pp. 132–140. Springer International Publishing, Cham, 2022. `https://doi.org/10.1007/978-3-030-86001-1_16`

[6] K. Banionis, J. Kumžienė, A. Burlingis, et al. The changes in thermal transmittance of window insulating glass units depending on outdoor temperatures in cold

climate countries. *Energies* **14**(6):1694, 2021. https://doi.org/10.3390/en14061694

[7] P. Juras, D. Jurasova. Outdoor climate change analysis in university campus: Case study with heat-air-moisture simulation. *Civil and Environmental Engineering* **16**(2):370–378, 2020. https://doi.org/10.2478/cee-2020-0037

[8] P. Juras. Comparison of triple glazed windows based on long-term measurement. *IOP Conference Series: Materials Science and Engineering* **415**(1):012020, 2018. https://doi.org/10.1088/1757-899X/415/1/012020

[9] NiCr-Ni thermocouple T190-0. [2022-04-20]. https://www.ahlborn.com/download/pdfs/kap07/05draehted.pdf

[10] Thermal flux plates. [2022-04-20]. http://www.ahlborn.com/download/pdfs/kap13/WflPlatten.pdf

[11] M. Čekon, R. Slávik. Total solar transmittance quantifying of transparent insulation building materials based on real climate outdoor measurements. *Energy Procedia* **132**:243–248, 2017. https://doi.org/10.1016/j.egypro.2017.09.694

[12] P. Juras. Analysis of window model accuracy and its influence on the results compared to the measurement. *MATEC Web of Conferences* **196**:02028, 2018. https://doi.org/10.1051/matecconf/201819602028