NUMERICAL ANALYSIS OF A POOR-QUALITY GLAZING SYSTEM IN A COMPUTER SOFTWARE

Marek Bartko*[,1], Pavol Durica[1]

*marek.bartko@uniza.sk
[1]Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia

Abstract
Following the current topic in the construction industry of improving energy performance of buildings, this paper discusses a numerical analysis of a glazing system. The performed analysis is based on the results of a particular type of glazing during measurements in a pavilion laboratory and in a set of climatic chambers which have been the focus of previous research papers. Fifteen glazing cases were made in the analysis and their glazing properties were monitored - the filling gas and the position of the low-emissivity layers were changed and observed. The results indicate that the values obtained from experimental measurements are greatly influenced by a degraded or missing low-emissivity layer and a missing or incorrect filler gas.

Keywords
Glazing system, window, U-value, solar transmittance

1 INTRODUCTION

Glazing forms a substantial part of the overall window structure. Due to the fact that glazing is transparent, window structures belong to the so-called transparent part of the building envelope. The current market offers a large number of products in terms of material base or composition of the glazing system. In terms of thermal and visual comfort, glazing is one of the most important elements of a window structure[1], [2]. Glazing has evolved from classical single glazing up to today's types of glass systems [3], [4], which include, for example, insulating double and triple glazing [5], low-emissivity glazing [6], [7], electrochromic glazing [8], thermochromic glazing [9], and aerogel materials [10]. An important part of glazing systems is also the filler gases [11], or the spacer frame, which provides an interaction between the window frame and the glazing [12]. All these elements that make up a glazing system are developed and designed to ensure that they meet thermal protection requirements of the glazing system itself or the window structure as a whole. Thermal protection in the Slovak Republic is defined in STN 73 0540-2Z1+Z2: 2019 [13]. Thermal protection of buildings is a key factor to achieve thermal comfort of the occupants and to reduce heat losses, which should result in a reduction of heating and cooling energy consumption [14]. Heating and cooling is where energy reduction is needed, as it accounts for approximately 40% of all energy consumed in the EU. The Energy Performance of Buildings Directive 2010/31/EU addresses this problem in the EU area as amended [15]. This Directive targets reducing energy consumption in buildings by 20% by 2020 and up to 50% by 2050 compared to 1990 values. To achieve high energy savings in new construction or renovation of existing buildings, it is necessary to calculate the energy performance of a building to guarantee the right indoor environmental conditions for the occupants. An essential factor in the calculation of energy performance of buildings at the design stage is solar heat gain, which causes overheating of the interior, especially in summer, and heat loss through the envelope in winter. One of the parameters needed for the calculation of the energy performance of buildings is the U-value, whose calculated value differs from the actual value after the construction is built into the building [16], [17]. This study deals with a numerical analysis of the glazing system, which is part of two plastic window structures which were the subject of experimental measurements in the pavilion laboratory at the Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Žilina, Slovakia and in the system of climatic chambers, which are part of the Research Centre of the University of Žilina where the method of measuring heat flux by sensors was used to measure the U_g. These measurements were not taken into account inthis study but are part of several previous studies [18], [19], [20]. Since the results of the earlier studies were found rather unfavourable (up to 90% difference in U_g values between measurement and manufacturer), fifteen alternative solutions for a specific glazing system were created in this study to explain the measured unfavourable results. The numerical analysis was performed in Berkeley Lab WINDOW software and the results are shown and discussed in this study.

DOI 10.13164/juniorstav.2024.24013

2 METHODOLOGY

The subject of this study is a numerical analysis of a particular glazing system. The numerical analysis was based on the unfavourable results in the above-mentioned studies, which represent up to 90% difference between the measured parameters and the parameters specified by the manufacturer of the glazing. The purpose is to find out the reason for such a significant difference between these parameters. Fig. 1 shows the analysis process of this study.

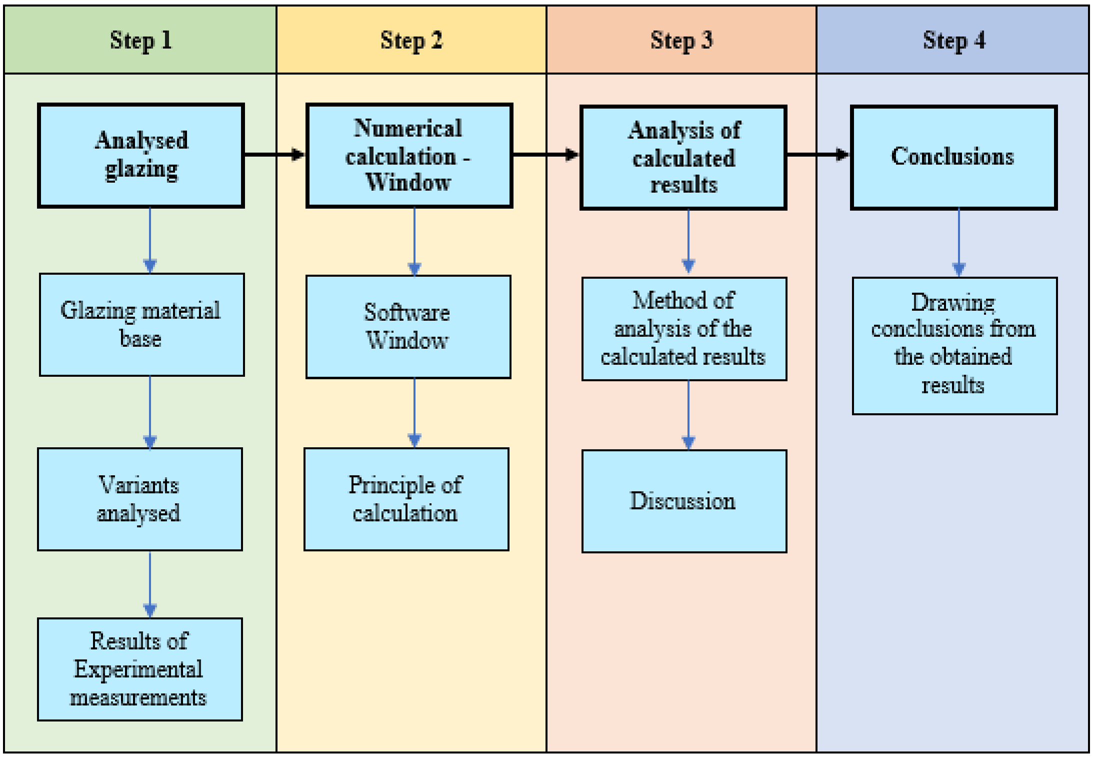


Fig. 1 Flowchart of the analysis process.

Analysed glazing

The numerical analysis deals with the Saint-Gobain Glass (SGG) Climatop Max glazing system [21], which, according to the manufacturer, is part of the aforementioned plastic windows. This glazing system is an insulating triple glazing unit and consists of an outer and an inner pane of SGG Planitherm Max glass, with a pane of Diamant glass placed between them. The gaps between the panes of glass are 16 mm wide and filled with Krypton. A detailed description of the characteristics of the glazing system is presented in Tab. 1.

Tab. 1 Glazing Parameters.

External plate glass	SGG Planitherm Max (coating – position 2)
Middle plate glass	SGG Diamant
Internal plate glass	SGG Planitherm Max (coating – position 5)
Glazing thickness (mm)	4-16-4-16-4
Luminous transmittance (%)	74
Luminance reflection (%)	15
Solar transmittance τ (%)	54
Total solar energy transmittance g (-)	0.60
Heat transfer coefficient of glazing U_g (W/(m^2.K))	0.5

For the numerical analysis, 15 different cases of the Climatop Max glazing system were created to determine what caused such a significant difference between the parameters that the glazing system is supposed to meet

DOI 10.13164/juniorstav.2024.24013

according to the manufacturer and the parameters that were measured in the pavilion laboratory and the climate chamber system.

Case 1 presents a basic glazing system based on the parameters set by the manufacturer, which specifies the gaps between the panes of glass filled with krypton, together with low-emissivity layers that are located on the inside of the outer glass and the inside of the inner glass, which means that the low-emissivity layers are in positions 2 and 5. Case 2 presents a change in the positioning of the low-emission layers. One is placed on the inside of the outer glass and the other on the outside of the inner glass. The low-emission layers are therefore at positions 2 and 6. In Case 3, the low-emission layers are located on the outside of the outer glass and on the inside of the inner glass, which are positions 1 and 5. In Case 4, there is only one low-emission layer which is located at position 2. Case 5 also shows only one low-emission layer, at position 5. Case 6 presents a glazing system using krypton as a filler gas but with no low-emissivity layers.

Cases 7 to 12 consider glazing systems using low-emission layers in the same order and the same positions as Cases 1 to 6. The difference is the use of the filler gas between the panes of glass, which in the case of these variants is argon.

Case 13 shows a glazing system using low-emissivity layers at positions 2 and 5; however, the gap filler between the panes is air. Case 14 considers a low-emissivity layer only at position 2 and Case 15 is a low-emissivity layer only at position 5. In both variants, air is considered as the gap filler between the glass panes. A graphical representation of the location of the low-emissivity layers in the glazing system is shown in Fig. 2. Tab. 2 presents an overview of the alternative solutions of the numerical analysis.

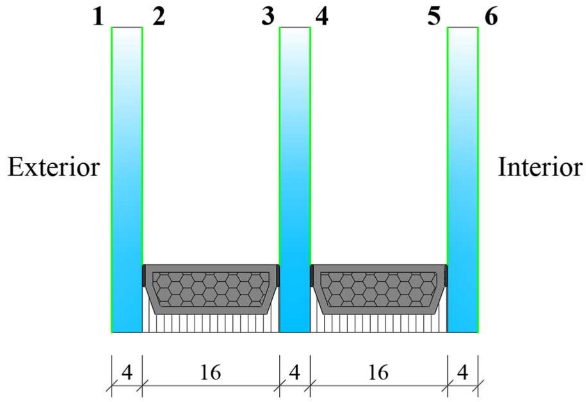
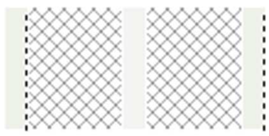


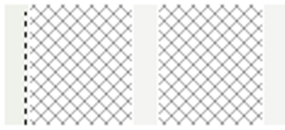
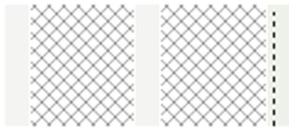
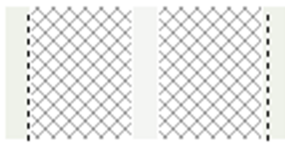
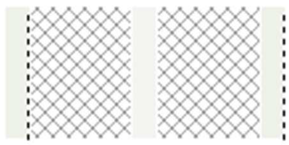
Fig. 2 Positions of the low-emission layer.

Tab. 2 Glazing cases analysed.

Layer	Material	Thickness (mm)	Film position	Graphic representation
		Case 1		
Glass	Planitherm max SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	2, 5	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 2		
Glass	Planitherm max SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	2, 6	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Planitherm max SGG	4.0		

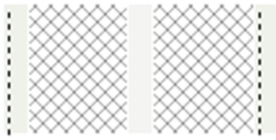
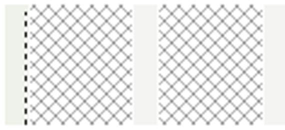
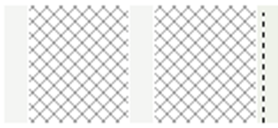
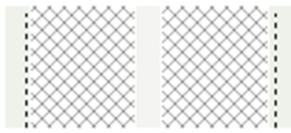
DOI 10.13164/juniorstav.2024.24013

Tab. 2 (Continued).

		Case 3		
Glass	Planitherm max SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	1, 5	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 4		
Glass	Planitherm max SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	2	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0		
		Case 5		
Glass	Diamant SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	5	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 6		
Glass	Diamant SGG	4.0		
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0	0	
Gap	Air (5%) / Krypton (95%)	16.0		
Glass	Diamant SGG	4.0		
		Case 7		
Glass	Planitherm max SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	2, 5	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 8		
Glass	Planitherm max SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	2, 6	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Planitherm max SGG	4.0		

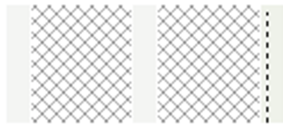
DOI 10.13164/juniorstav.2024.24013

Tab. 2 (Continued).

		Case 9		
Glass	Planitherm max SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	1, 5	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 10		
Glass	Planitherm max SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	2	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0		
		Case 11		
Glass	Diamant SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	5	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 12		
Glass	Diamant SGG	4.0		
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0	0	
Gap	Air (10%) / Argon (90%)	16.0		
Glass	Diamant SGG	4.0		
		Case 13		
Glass	Planitherm max SGG	4.0		
Gap	Air (100%)	16.0		
Glass	Diamant SGG	4.0	2, 5	
Gap	Air (100%)	16.0		
Glass	Planitherm max SGG	4.0		
		Case 14		
Glass	Planitherm max SGG	4.0		
Gap	Air (100%)	16.0		
Glass	Diamant SGG	4.0	2	
Gap	Air (100%)	16.0		
Glass	Diamant SGG	4.0		

DOI 10.13164/juniorstav.2024.24013

Tab. 2 (Continued).

		Case 15		
Glass	Diamant SGG	4.0		
Gap	Air (100%)	16.0		
Glass	Diamant SGG	4.0	5	
Gap	Air (100%)	16.0		
Glass	Planitherm max SGG	4.0		

Numerical calculation – Berkeley Lab Window

The numerical analysis of the glazing system was carried out in the Berkeley Lab WINDOW computer program [22], which is designed to calculate thermal and solar-optical properties of windows represented by the U- value, the total solar energy transmittance g, the direct solar transmittance τ, the light transmittance τ_v and the shading coefficient SC. The algorithms for determining thermal and solar-optical performance of glazing systems are based on the TARCOG mathematical models designed to calculate thermal performance of glazing systems with or without shading devices. The calculations are based on ISO 15099 [23] and STN EN ISO [24], and include other parameters such as visible solar reflectance, absorption of layers, UV transmittance, etc. During the calculation, the algorithms consider the glazing system as a system of layers and gaps, where some layers may also be in direct contact. Since windows as a whole are three-dimensional structures, the algorithms for determining thermal and solar-optical performance of whole window structures are based on area-weighted averages of one-dimensional calculations at the centre of the glazing and two-dimensional calculations at the interaction of the frame with the edge of the glazing.

Result analysis method

The WINDOW software contains a library of elements where glazing systems, individual glasses, filler gases, spacer frames, frame materials, etc. from the individual manufacturers of these elements can be found. The elements in the library have all the properties necessary for the calculation of U_g and τ. At the beginning of the analysis, the authors create fifteen glazing cases from the elements selected from the program library. For each case, the program calculates a heat transfer coefficient through the glazing U_g and the direct solar transmittance τ, which is then compared with the parameters measured in the pavilion laboratory and in a set of climatic chambers. The final step is to determine the cases that are similar to the measured parameters. On this basis, the authors determine the possible reason for the degradation of the glazing system shown by the measurements from the pavilion laboratory and the climate chamber array.

3 RESULTS

In the numerical study, the U-value and direct solar transmittance values were determined for each case, which is shown in Tab. 3 along with the values from the experimental measurements.

Tab. 3 Results of numerical analysis.

Case	U_g (W/(m^2.K))	τ (-)	U_g* (W/(m^2.K))	τ* (-)	$U_{g,P}$ (W/(m^2.K))	τ_P (-)	$U_{g,K,V1}$ (W/(m^2.K))	τ_K (-)
1	0.54	0.45						
2	0.88	0.44						
3	0.86	0.44						
4	0.88	0.54						
5	0.86	0.54	0.5	0.54	0.96	0.44	0.94	0.45
6	1.61	0.74						
7	0.63	0.45						
8	0.96	0.44						
9	0.93	0.44						

DOI 10.13164/juniorstav.2024.24013

Tab. 3 (Continued).

10	0.96	0.54
11	0.94	0.54
12	1.68	0.74
13	0.79	0.45
14	1.13	0.54
15	1.11	0.54

Fig. 3 presents a comparison of the U-values calculated in the numerical analysis with those obtained from previous studies from experimental measurements in the pavilion laboratory and in a set of climate chambers, and with those determined by the manufacturer. Green – Values from the numerical analysis, Yellow – Values determined by the manufacturer [21], Blue – Values measured in the pavilion laboratory [19], Red – Values measured in the climatic chamber [20].

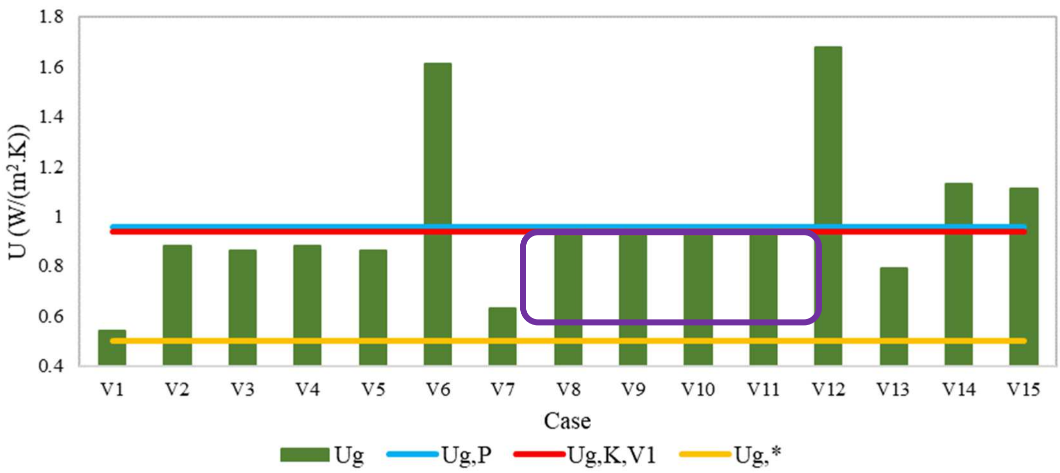


Fig. 3 U-value glazing. Green – Values from the numerical analysis, Yellow – Values determined by the manufacturer, Blue – Values measured in the pavilion laboratory, Red – Values measured in the climatic chamber.

Fig. 4 presents a comparison of the direct solar transmittance values calculated in the numerical analysis with the values obtained from experimental measurements and with the values specified by the manufacturer.

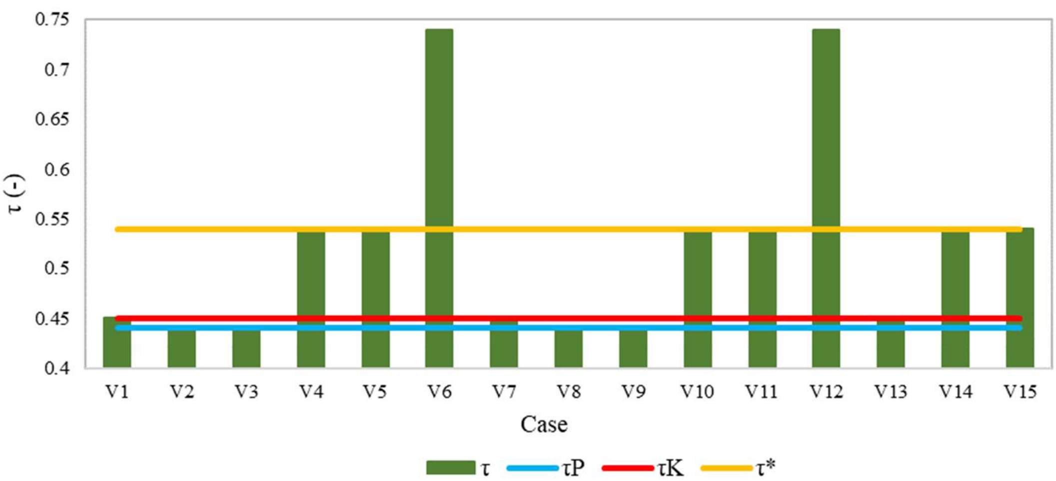


Fig. 4 Solar transmittance. Green – Values from the numerical analysis, Yellow – Values determined by the manufacturer, Blue – Values measured in the pavilion laboratory, Red – Values measured in the climatic chamber.

DOI 10.13164/juniorstav.2024.24013

4 DISCUSSION

Experimental studies, which are mentioned in Chapter 2, have shown a significant difference in the measured thermo-technical parameters of the glazing under study compared to the parameters set by the manufacturer of the glazing. In this study, the authors produced fifteen glazing cases, including a baseline, to verify the possibility of glazing degradation or the possibility that an error had already occurred during the production of the glazing.

Case 1 presents the glazing system as specified by the manufacturer. In this variant, there is an 8% difference between the calculated Ug value and the U_g value specified by the manufacturer. For Cases 2 to 5, where krypton was considered a filler gas in the glazing system and the positions of the low-emissivity layer were changed, the difference between the calculated U_g value and the U_g value specified by the manufacturer is approximately 72~76%. Case 6 was a glazing system with krypton as the filler gas but without low-emissivity layers. In this case, there is a difference between the calculated and declared U_g values of up to 220%. Case 7, in which the filler gas was changed from krypton to argon compared to the original glazing system, shows a difference between the calculated and declared U_g values of 26%. Cases 8 to 11, in which argon filler gas was considered with changing positions of the low-emissivity layer, show a difference between the manufacturer's stated U_g and the calculated U_g values of 86~92%. In Case 12, argon was considered a filler gas yet the glazing system did not have low-emissivity layers. In this case, there was a difference between the declared and calculated U_g values of up to 235%. Case 13, similarly to case 7, represented a change in the filler gas compared to the original krypton, in this case, it was pure air. The difference between the calculated and declared U_g values was 58%. The last two variants (14 and 15) include air as a filler between the panes of glass together with a change in the position of the low-emissivity layer. The difference between the declared and calculated U_g values that occur in these cases is between 122~126%. These results are shown in Fig. 3. Having analysed the values of the individual variants shown in this figure, it can be stated that Cases 8 to 11 are closest to the measured values from the experimental measurements. These cases have argon filler gas and contain at least one low-emission layer. However, when changing the filler gas from krypton to argon and keeping the positions of the low-emission layers at positions 2 and 5, we observe a decrease in the Ug values by about 16%. Nevertheless, when we start to manipulate the positions of the low-emission layers, there is a decrease in U_g values of 35 to 40%. Based on this analysis, it is therefore possible to say that the unfavourable results from the experimental measurements may be due to an error in the manufactur of the glazing when instead of the declared filler gas in the form of Krypton, Argon was filled into the glazing, and at the same time the correct order of the low-emissivity layers was not observed. Or the low-emission layers were in the correct sequence but degradation of one of them occurred, making it unable to perform its function properly anymore.

The study further compared the values of direct solar transmittance τ, (see Fig. 4) where it was found that changing the filler gas or changing the position of the low-emissivity layer does not affect the value of the direct solar transmittance τ. However, if one of the layers is degraded or not applied at all, either one or both of the layers are significantly altered by 20 to 40% in the value of the direct solar transmittance τ.

5 CONCLUSION

This study focuses on thermal-technical qualities of a glazing system, which exhibited values in experimental measurements that were notably lower than those specified by the manufacturer. The authors conducted fifteen experiments on the glazing system, altering the filler gas and the placements of the low-emissivity layers. The examination and analysis of the results led to the following conclusions:

- If there was a leakage of the fill gas in the form of krypton in the glazing system, there would be a deterioration of U_g values of approximately 58%.
- If the gaps between the panes of glass were filled with argon instead of the original krypton during manufacture, the U_g values of the glazing system would deteriorate by approximately 16%.
- Changing the position of the low-emissivity layers results in a deterioration of U_g values of 35 to 40%.
- Cases 8 to 11 correspond to the measured values from the experimental measurements, where there is a difference of about 86 to 92 % between the measured and calculated values compared to the values provided by the manufacturer.
- The corresponding difference between measured and calculated values of 92% occurs in the case where the position of the low emission layer was changed from 5 to 6, or this layer was completely absent from the interior side and argon was considered the filler gas.
- A difference of 88% occurred when the low-emission layer on the exterior side of the glass was completely absent and argon was considered the filler gas.

- A difference of 86% occurred when the position of the low emission layer was changed from 2 to 1 and again argon was considered as the filler gas.
- These statements show that the unfavourable results from the experimental measurements can be due to:
    - Either an error in the manufacturing process of the glazing where argon was injected into the glazing system instead of krypton and at the same time the low-emissivity layers were not in the correct positions.
    - Or again, wrong gas was injected and some of the low-emissivity layers gradually degraded.
- A change in the position of the low-emissivity layer or its complete absence has a more significant effect on the thermal-technical properties of the glazing than a change or absence of the filler gas.
- A change in the position of the low-emissivity layer or the absence of the filler gas does not affect the direct transmittance of solar radiation; however, the absence of the low-emissivity layer already adversely affects the direct transmittance of solar radiation.

The results presented in this study should serve as a basis for manufacturers of glazing systems and for designers of window structures for proper design, application and installation.

The authors plan to follow up on the completed study with further research in the form of additional experimental measurements and simulation of the glazing system.

Acknowledgement

The research is supported by the grant project VEGA No. 1/0673/20 and KEGA No. 023ŽU-4/2023.

References

[1] URIBE, Daniel and Sergio VERA. Assessment of the Effect of Phase Change Material (PCM) Glazing on the Energy Consumption and Indoor Comfort of an Office in a Semiarid Climate. *Applied Sciences* [online]. 2021. 11(20). ISSN 2076-3417. DOI 10.3390/app11209597

[2] REZAEI, Soroosh Daqiqeh, Santiranjan SHANNIGRAHI and Seeram RAMAKRISHNA. A review of conventional, advanced, and smart glazing technologies and materials for improving indoor environment. *Solar Energy Materials and Solar Cells* [online]. 2017, 159, 26–51 [accessed 2023-03-23]. ISSN 0927-0248. DOI 10.1016/J.SOLMAT.2016.08.026

[3] HEE, W. J., M. A. ALGHOUL, B. BAKHTYAR, Omkalthum ELAYEB, M. A. SHAMERI, M. S. ALRUBAIH and K. SOPIAN. The role of window glazing on daylighting and energy saving in buildings. *Renewable and Sustainable Energy Reviews* [online]. 2015, 42, 323–343 [accessed 2023-03-23]. ISSN 1364-0321. DOI 10.1016/J.RSER.2014.09.020

[4] PEREIRA, Júlia, Henriqueta TEIXEIRA, Maria da Glória GOMES and António MORET RODRIGUES. Performance of Solar Control Films on Building Glazing: A Literature Review. *Applied Sciences* [online]. 2022, 12(12). ISSN 2076-3417. DOI 10.3390/app12125923

[5] MANZ, Heinrich. On minimizing heat transport in architectural glazing. *Renewable Energy* [online]. 2008, 33(1), 119–128 [accessed 2023-03-23]. ISSN 0960-1481. DOI 10.1016/J.RENENE.2007.01.007

[6] RYDZEK, M., M. REIDINGER, M. ARDUINI-SCHUSTER and J. MANARA. Low-emitting surfaces prepared by applying transparent aluminum-doped zinc oxide coatings via a sol-gel process. *Thin Solid Films* [online]. 2012, 520(12), 41144118 [accessed 2023-03-23]. ISSN 0040-6090. DOI 10.1016/J.TSF.2011.04.105

[7] KHALED, Khaled and Umberto BERARDI. Current and future coating technologies for architectural glazing applications. *Energy and Buildings* [online]. 2021, 244, 111022 [accessed 2023-03-23]. ISSN 0378-7788. DOI 10.1016/J.ENBUILD.2021.111022

[8] BAETENS, Ruben, Bjørn Petter JELLE and Arild GUSTAVSEN. Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review. *Solar Energy Materials and Solar Cells* [online]. 2010, 94(2), 87105 [accessed 2023-03-23]. ISSN 0927-0248. DOI 10.1016/J.SOLMAT.2009.08.021

[9] ABURAS, Marina, Veronica SOEBARTO, Terence WILLIAMSON, Runqi LIANG, Heike EBENDORFF-HEIDEPRIEM and Yupeng WU. Thermochromic smart window technologies for building application: A review. *Applied Energy* [online]. 2019, 255, 113522 [accessed 2023-03-23]. ISSN 0306-2619. DOI 10.1016/J.APENERGY.2019.113522

[10] BAETENS, Ruben, Bjørn Petter JELLE and Arild GUSTAVSEN. Aerogel insulation for building applications: A state-of-the-art review. *Energy and Buildings* [online]. 2011, 43(4), 761769 [accessed 2023-03-23]. ISSN 0378-7788. DOI 10.1016/J.ENBUILD.2010.12.012

[11] AGUILAR-SANTANA, Jorge Luis, Hasila JARIMI, Mariana VELASCO-CARRASCO and Saffa RIFFAT. Review on window-glazing technologies and future prospects. *International Journal of Low-Carbon Technologies* [online]. 2019. ISSN 17481325. DOI 10.1093/ijlct/ctz032
[12] SHIN, Mi Su, Kyu Nam RHEE, Ji Yong YU and Gun Joo JUNG. Determination of equivalent thermal conductivity of window spacers in consideration of condensation prevention and energy saving performance. *Energies* [online]. 2017, 10(5). ISSN 19961073. DOI 10.3390/en10050717
[13] STN 73 0540-2+Z1+Z2: 2019 Thermal Protection of Buildings. Thermal Performance of Buildings and Components. Part 2: Functional Requirements; Slovak Office of Standards, Metrology and Testing 2019
[14] ASDRUBALI, Francesco, Francesco D'ALESSANDRO, Giorgio BALDINELLI and Francesco BIANCHI. Evaluating in situ thermal transmittance of green buildings masonries: A case study. *Case Studies in Construction Materials* [online]. 2014, 1. ISSN 22145095. DOI 10.1016/j.cscm.2014.04.004
[15] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) [online]. B.m.: European Parliament, Council of the European Union, 2021. Available from: http://data.europa.eu/eli/dir/2010/31/oj
[16] ALBATICI, Rossano and Arnaldo M. TONELLI. Infrared thermovision technique for the assessment of thermal transmittance value of opaque building elements on site. *Energy and Buildings* [online]. 2010, 42(11). ISSN 03787788. DOI 10.1016/j.enbuild.2010.07.010
[17] GASPAR, Katia, Miquel CASALS and Marta GANGOLELLS. A comparison of standardized calculation methods for in situ measurements of façades U-value. *Energy and Buildings* [online]. 2016, 130, 592599 [accessed 2023-02-24]. ISSN 0378-7788. DOI 10.1016/J.ENBUILD.2016.08.072
[18] JURAS, P. Comparison of triple glazed windows based on long-term measurement. In: *IOP Conference Series: Materials Science and Engineering* [online]. 2018. ISSN 1757899X. DOI 10.1088/1757-899X/415/1/012020
[19] BARTKO, Marek and Pavol DURICA. Experimental Analysis of Thermo-Technical Parameters of Windows Glazing in the Pavilion Laboratory. *Buildings* [online]. 2023, 13(4). ISSN 2075-5309. DOI 10.3390/buildings13041026
[20] BARTKO, Marek and Pavol DURICA. Verification of window properties after 10 years of exploitation: results of measurements in the pavilion laboratory and the climate chamber. *Acta Polytechnica CTU Proceedings* [online]. 2022, 38, 509515. ISSN 2336-5382. DOI 10.14311/APP.2022.38.0509
[21] SGG CLIMATOP MAX [online]. [accessed 2024-01-09]. Available from: https://fliphtml5.com/bjmn/raer/SGG_CLIMATOP%C2%AE_MAX/
[22] Window & Daylighting. Berkeley Lab [online]. [accessed 2024-01-09]. Available from: https://windows.lbl.gov/window-software-downloads
[23] ISO 15099:2003 Thermal performance of windows, doors and shading devices — Detailed calculations. B.m.: International Organization for Standardization, 2003.
[24] STN EN ISO 10077-1:2020 Thermal Performance of Windows, Doors and Shutters – Calculation of Thermal Transmittance – Part 1: General (ISO 10077-1:2017); Slovak Office of Standards, Metrology and Testing: Bratislava, 2020