SURFACE CONDENSATION ON WINDOWS AND THE POSSIBILITIES OF ITS ELIMINATION

Petra Vorlíčková[*,1], Miloš Kalousek[1], Slávka Pobucká[1], Tomáš Žajdlík[1]

[*]167550@vutbr.cz
[1]Brno University of Technology, Faculty of Civil Engineering, Veveří 331, 602 00 Brno, Czech Republic

Abstract
The largest thermal bridges are formed at the window joints. As a result of the increased heat flux, the internal surface temperature drops below the air saturation point. A conductive material applied on the interior side can be used as a remediation product. The correct choice of conductive material, type of masonry, and type of adhesive can affect the actual performance of the preparation. Using Ansys Steady-State Thermal software, the window sill detail of a double-glazed window with a wooden frame was analysed at the connection joint of the glazing and the frame.

Keywords
Surface condensation, lowest internal surface temperature, window glazing, connection joint

1 INTRODUCTION

The issue of surface condensation involves a wide range of factors. In addition to inconsistent or no ventilation on the use side of the building, there may be poor thermal-technical properties of the structures under consideration, where the high-temperature gradient between the interior and exterior results in excessive cooling of the structure. As a consequence, mould can begin to grow inside in weakened areas, or moisture can appear in the form of surface condensation. Remedial measures can be taken before replacing the entire structure and insulating it to remedy localised dampness disturbances.

The aim of the work is to demonstrate the effectiveness of the application of conductive material on the interior side with a focus on window openings. In the presented paper, a detail of a wooden window frame with double glazing installed on uninsulated masonry was analysed. Evaluated was the lowest internal surface temperature observed on the bottom of the glazing and the window sill at the connection joint.

2 METHODOLOGY

Surface condensation

Condensation occurs at the locations of the lowest surface temperatures, i.e. the locations with the highest heat flux. In the case of windows, this is the window frame-to-wall joint and the glazing to the frame. Condensation problems occur to a greater extent on the north side of buildings [1]. In general, condensation arises due to poor thermal properties of individual elements and materials used in the designed detail, and inconsistent ventilation, often associated with attenuation of the heating at night [2], [3].

At the glazing site, this disorder can be mostly observed in the lower cheek. Although this may not be degrading to the window product, it is at least an uncomfortable defect for the user, and, in addition, condensate runoff can damage the sill connection joint. This phenomenon can be explained by the effect of airflow in the room [4]. Not enough heat flows is transferred to the window either by wide sills, other obstructions, or low performance of the heating system, e.g. in the case of underfloor heating.. As a result, cool air remains on the sill, and moisture can condense [5], [6]. Another consequence of the occurrence of surface condensation at the bottom of the glazing is the flow of air or rare gas in the space between the glazing. This phenomenon is more produced in double glazing, where the gas is directly exposed to interior and exterior conditions through the glass. The influence of the spacer frame as the weakest element of the insulating glazing [7] can be added to this phenomenon. At the point where the window frame is mounted on the wall, the location of the frame on the wall, the design of the connection joint, and any external insulation of the lining are decisive factors [8].

DOI 10.13164/juniorstav.2024.24037

Equations

According to the theory of conduction, the bar placed on the interior side constantly balances the temperature gradient acting on it (i.e. heat received from the interior environment and simultaneous cooling from the structures in which the bar is built). A steady-state temperature analysis was chosen for the solution, where the only property required for the calculation is the thermal conductivity. The transient thermal analysis did not prove to be significant. Due to the high thermal conductivity of the bar, steady-state conditions occur very quickly.

The general equation of heat transfer in a solid with constant thermal conductivity (1) can be expressed for one-dimensional heat conduction as follows [9], [10]

$$\rho c_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} + \dot{q} \tag{1}$$

where ρ is density, c_p is specific heat capacity, T is temperature, t is time, x is distance, k is thermal conductivity, and q is internal heat generation.

In the steady state, the temperature and time derivatives are zero. Thus, we only get partial derivatives of the temperature and space as a function of the heat flux rate (2). This relationship is called Fourier's law. Written in its one-dimensional form [11]

$$q = -k \frac{\partial T}{\partial x} \tag{2}$$

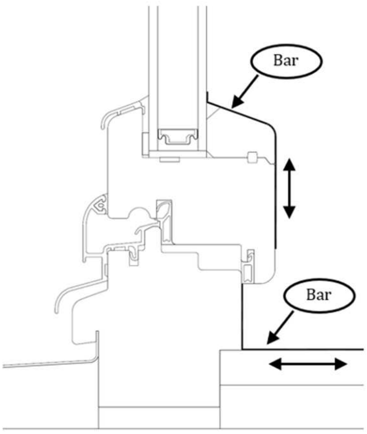
where q is the heat flux (heat flow Q divided by area A), k is the thermal conductivity and $\partial T/\partial x$ is the temperature gradient (change of the temperature with position).

Detail evaluation

A detail of the sill of a double-glazing wooden window, mounted on uninsulated brickwork made of solid brick, 600 mm thick, was selected for evaluation in the temperature field (see Fig. 1). The evaluation monitors the surface temperatures at the glazing and the sill. The material characteristics of the bar (conductive metals and coatings) and the length developed of the bar were varied.

Furthermore, a 100 mm long aluminium bar 0.6 mm thick was selected for the glazing and 180 mm for the sill and placed on the same wooden window. Masonry types and thicknesses were varied. The frame was always placed in the centre of the wall. The choice of load-bearing masonry in the envelope was considered with regard to the construction systems and materials used in the Czech Republic in the 1970s–1980s.

The glazing was also studied in more detail to better understand the behaviour of the bar. The selected bar, the same as in the previous case, was placed at the bottom of the double glazing. The type of spacer frame and the filling between the panes were changed. Finally, the contact layer (adhesive) between the bar and the structure was studied according to its conductivity and thickness. The values entering into the calculation are given in Fig. 1. The results are loosely related to the previous publication at the Young Scientist 2022 conference [12].



Name	Thermal conductivity coefficient [W/mK]
Window frame	0.13
Plaster	0.87
Bar	
Copper	300
Aluminium	160
TiZn	100
Galvanized sheet	50
Graphene	4000
Graphite	2000
Masonry	
Solid fired brick	0.84
Hollow brick	0.73
Aerated concrete	0.3
Glazing	
Dry air	0.034
Argon	0.018
Krypton	0.009
Adhesive	
PUR foam	0.05
Silicone	0.35
Conductive adhesive	0.8

Fig. 1 Diagram of the window frame under evaluation with the location of the bar and the material characteristics used in the calculation.

3 RESULTS

Choice of conductive material as the cover bar

The chart in Fig. 2 shows the dependence of the temperature on the glazing on the total length of the bar for different material solutions of the remediation product. Conductive sheets with a thickness of 0.6 mm were modelled as well as carbon sprayed on the frame with a thickness of 0.01 mm. The thermal conductivity of the different materials is shown in the graph.

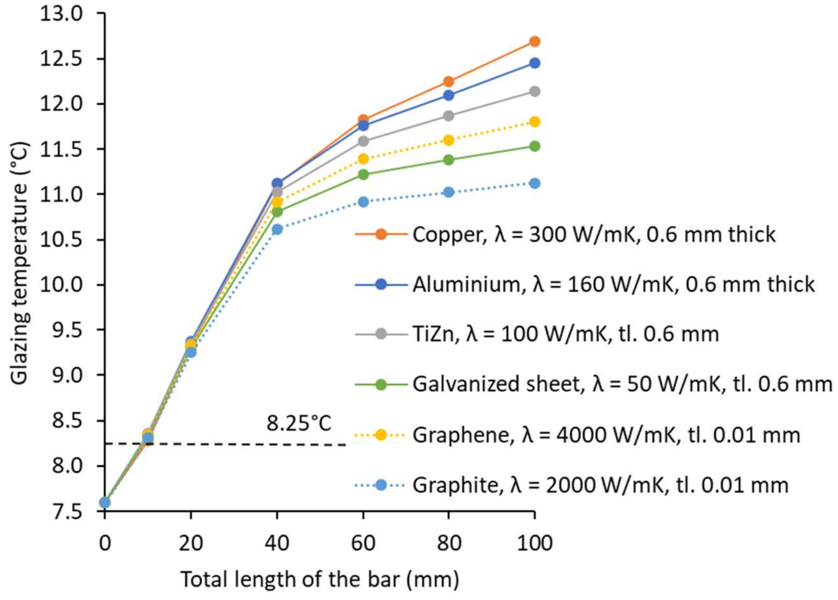


Fig. 2 The temperature dependence on the glazing on the total length of the bar.

Fig. 3 shows the dependence of the surface temperatures at the sill connection joint on the total (developed) length of the sill. 4 variants of conductive sheets and 2 variants of sprayed sheets were tested as with the previous results, the specification is shown next to the chart in Fig. 3.

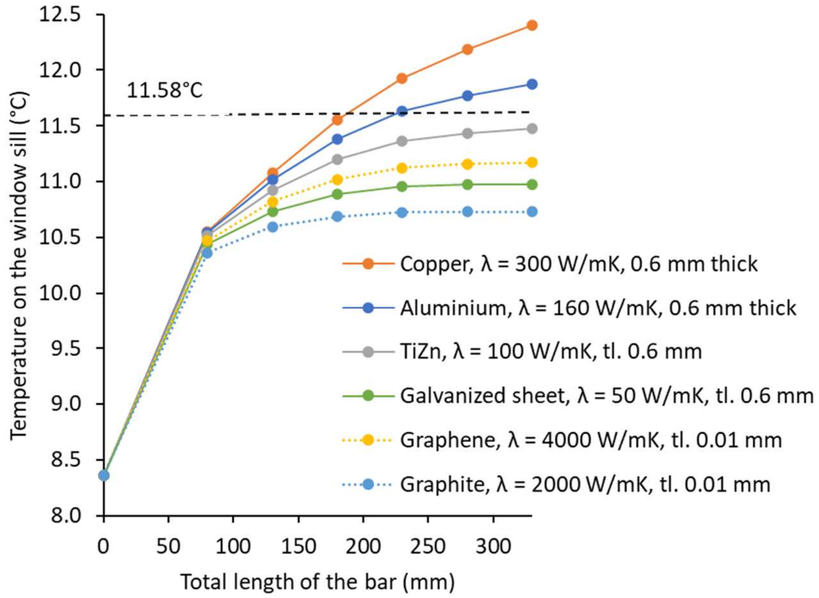


Fig. 3 The temperature dependence on the window sill on the total length of the bar.

DOI 10.13164/juniorstav.2024.24037

Effect of masonry type and its thickness on the effectiveness of the bar

The selected aluminium bar, 0.6 mm thick, 100 mm long on the glazing, 180 mm on the sill, was placed on the wooden window frame. The types and thicknesses were varied. The specifications along with the results are shown in Fig. 4.

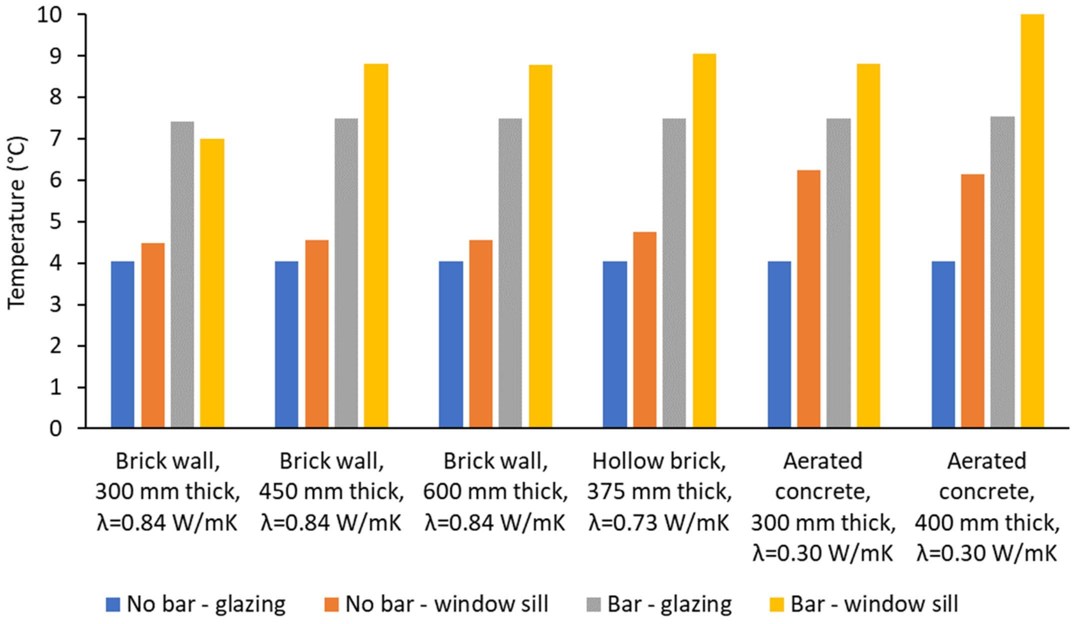


Fig. 4 Temperature on the glazing and the window sill for the window without a bar and with an applied bar.

Influence of a spacer type and an air space at glazing on bar efficiency

Warm and cold spacer frames and different types of air space between the panes were considered when evaluating different variants of insulating glazing. The temperature results for the bottom of the glazing can be seen in Fig. 5.

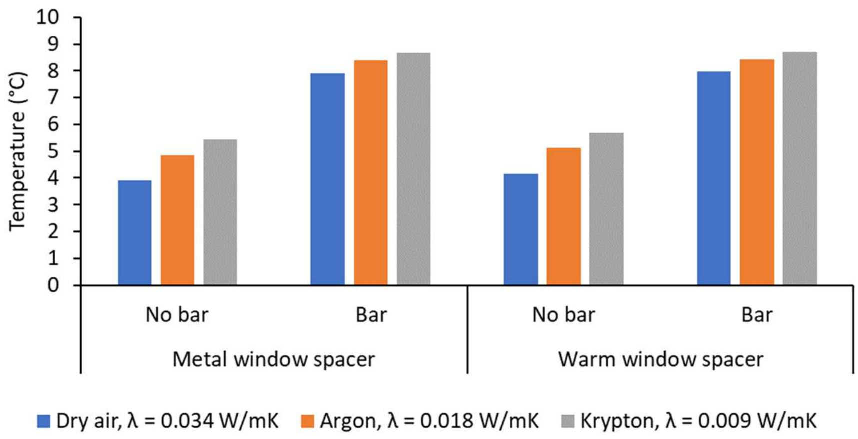


Fig. 5 Temperature on the glazing for different types of glazing.

Effect of contact material on bar efficiency

The effect of the contact layer between the bar and the substrate can be seen in Fig. 6. The charts show the dependence of surface temperature on glazing/window sill and adhesive thickness.

DOI 10.13164/juniorstav.2024.24037

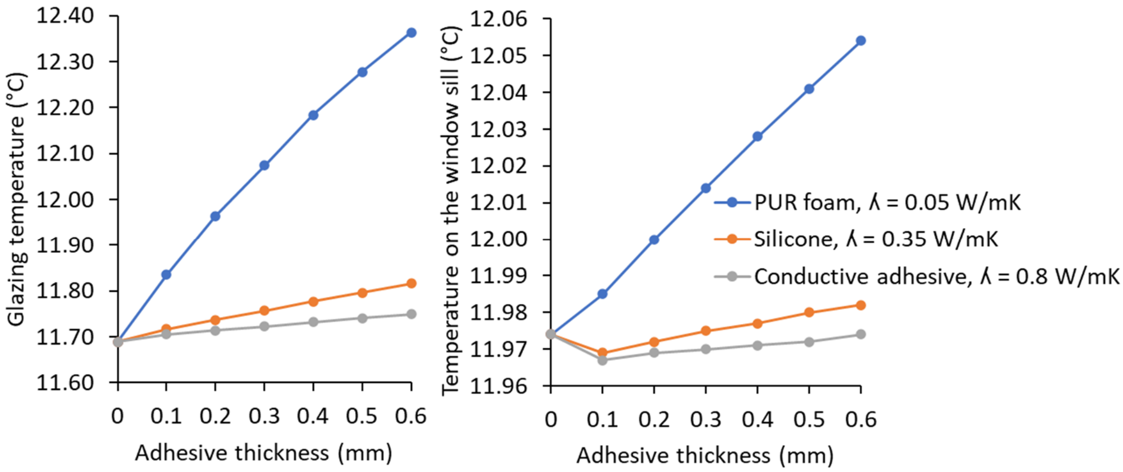


Fig. 6 The temperature dependence on the glazing and the window sill on the thickness of the contact layer.

Validation of thermal imaging results

The white sprayed aluminium bar was shaped and placed on the glazing and the sill. It is a timber window frame with double glazing placed on solid brickwork. Fig. 7 shoes a photograph of the site and a thermal image with an outside temperature of 0 °C.

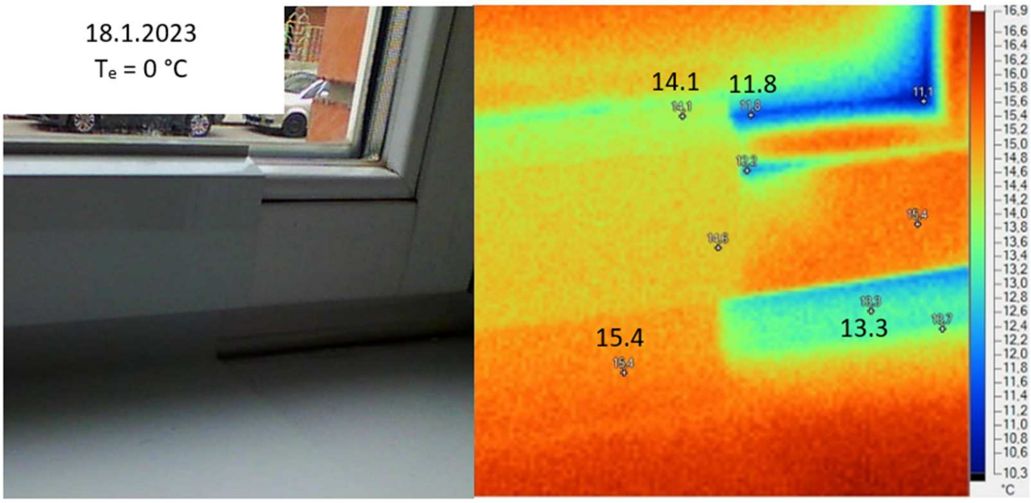


Fig. 7 Photographs of the experimental window with the glazing bar and the sill in place and a thermal image taken on 18/01/2023 with an external temperature of 0 °C.

4 DISCUSSION

Choice of conductive material for a cover bar

The results show that as the conductivity of the bar increases and the self-developed length increases, the lowest internal surface temperature increases. For glazing, the effect is seen in the conductivity of the bar material from a length of 40 mm, and for the sill from a length of 80 mm. The solid waveform corresponds to sheets and the dotted waveform corresponds to injection mouldings. The aluminium and copper bar meet the requirements for the temperature rise above the dew point on the sill from the developed length of 230 mm, for glazing even in the shortest variant.

Effect of masonry type and its thickness on bar effectiveness

The blue and orange waveforms correspond to the detail of the sill without the application of the bar, and the grey and yellow waveforms correspond to the detail with the bar. There was an increase in temperature of 3.5 °C on the glazing and the highest increase in temperature of 4 °C was recorded on the sill for the 1960 metric bricks for a wall 375 mm thick. In contrast, the lowest temperature increase, 2.5 °C, was on the sill for the 300 mm thick solid brick wall. This suggests that the bar works more effectively under more favourable initial conditions. The absolute highest temperatures are exhibited by the porous concrete detail, 400 mm thick masonry.

Influence of spacer type and air space at glazing on bar efficiency

In general, the warm spacer achieved better values than the cold spacer. The best results were achieved for the glazing bar with air-dried infill, i.e., the highest temperature difference was 4 °C. It can be observed that the highest efficiency was achieved by the bar at the lowest initial conditions.

Effect of contact material on bar efficiency

The surface temperature scale was set as very fine. The results show that the contact layer had very little effect on the resulting surface temperatures. The PUR foam achieved the highest temperature increase when it acted as an insulator to protect the bar from the structure cooling. It is desirable to keep the thickness of the contact layer as small as possible to ensure the best bar performance. Air could built up behind the bar, and thus created space for moisture.

Validation of thermal imaging results

As can be seen in the photo of the in-situ measuring, the bar is sprayed in the colour of the frame (Fig. 7). For this reason, no modification of the emissivity of the surface is necessary for the thermal camera measurement due to the high reflectivity of the aluminium material. The thermal resistance of the surface on the internal side of the construction was interpolated to 0.2 m^{2}K/W to validate the results and performance of the model. The results were consistent with each other under these conditions (see Fig. 8).

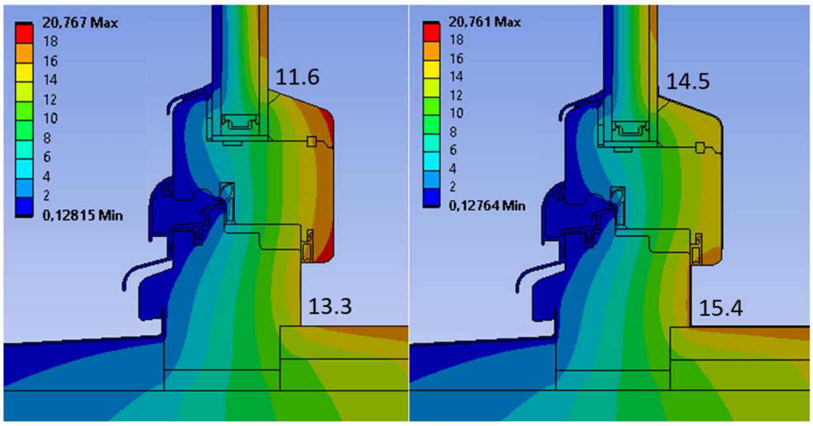


Fig. 8 Validation of results – window sill model without a bar and with a bar on the glazing and connection joint.

5 CONCLUSIONS

The aim of the research was to determine the suitability of using a product to increase the surface temperature in non-compliant conditions on the window glazing and frame. After replacing the window infill with tight solutions, the lining details may show failures at weakened points and the connection joints. The bar acts as a remediation agent on the interior side and protects the central part of the frame-to-wall connection joint.

Different variants of the bar design (material and sheet length) were tested in the analysis on a wooden window frame at the point of the sill where failures occur most frequently. Furthermore, the uninsulated masonry of different thicknesses, the types of glazing and the contact layer between the bar and the substrate were varied. All this was crried out for the selected aluminium bar.

It was shown by both steady-state computer models and thermocouple measurements that a conductive product applied to the interior side increases the lowest interior surface temperature. In all cases, not enough temperature was reached to eliminate condensation. However, due to the high diffusion resistance factor, the bar can also serve as a vapour barrier on the interior side.

References

[1] KIM, Soojung, ZADEH, Puyan A., STAUB-FRENCH, Sheryl, FROESE, Thomas and CAVKA, Belgin Terim. Assessment of the Impact of Window Size, Position and Orientation on Building Energy Load Using BIM. *Procedia Engineering* [online]. 2016, **145**, pp. 1424–1431. Available at: https://doi.org/10.1016/j.proeng.2016.04.179

[2] CAPPELLETTI, Francesca, GASPARELLA, Andrea, ROMAGNONI, Piercarlo and BAGGIO, Paolo. Analysis of the influence of installation thermal bridges on windows performance: The case of clay block walls. *Energy and Buildings* [online]. 2011, **43**(6), pp. 1435–1442. Available at: https://doi.org/10.1016/j.enbuild.2011.02.004

[3] LUCAS, Franck; ADELARD, Laetitia; GARDE, François and BOYER, Harry. Study of moisture in buildings for hot humid climates. *Energy and Buildings* [online]. 2002, **34**(4), pp. 345–355. Available at: https://doi.org/10.1016/S0378-7788(01)00115-3

[4] CUEVAS, Cristian; FISSORE, Adelqui and FONSECA, Nestor. Natural convection at an indoor glazing surface with different window blinds. *Energy and Buildings* [online]. 2010, **42**(10), pp. 1685–1691. Available at: https://doi.org/10.1016/j.enbuild.2010.05.003

[5] IZADI, Mohammad Javad and MAKAREMI, Kamyar. CFD Simulation of Temperature Distribution in a Room With Various Under Floor Heating System Models [online]. FEDSM2009. 2010, **1**(1), pp. 2319–2329. Available at: https://doi.org/10.1115/FEDSM2009-78545

[6] MYHREN, Jonn Are and HOLMBERG, Sture. Flow patterns and thermal comfort in a room with panel, floor and wall heating. Energy and Buildings [online]. 2008, **40**(4), pp. 524–536. Available at: https://doi.org/10.1016/j.enbuild.2007.04.011

[7] ARICI, Müslüm; KARABAY, Hasan and KAN, Miraç. Flow and heat transfer in double, triple and quadruple pane windows. Energy and Buildings [online]. 2015, **86**, pp. 394–402. Available at: https://doi.org/10.1016/j.enbuild.2014.10.043

[8] MISIOPECKI, Cezary; BOUQUIN, Marine; GUSTAVSEN, Arild and JELLE, Bjørn Petter. Thermal modeling and investigation of the most energy-efficient window position. Energy and Buildings [online]. 2018, **158**, pp. 1079–1086. Available at: https://doi.org/https://doi.org/10.1016/j.enbuild.2017.10.021

[9] GREENE, George Alanson,. Heat Transfer. In: *Encyclopedia of Physical Science and Technology* [online]. Third Edition. Academic Press, 2003, pp. 279–292. ISBN 9780122274107. Available at: https://doi.org/10.1016/B0-12-227410-5/00312-4

[10] DINCER, Ibrahim and SIDDIQUI, Osamah,. Heat Transfer Aspects of Energy. In: Comprehensive Energy Systems. 1. *Elsevier* [online]. 2018, pp. 422–477. ISBN 9780128149256. Available at: https://doi.org/10.1016/B978-0-12-809597-3.00109-7

[11] ARFKEN, George B., GRIFFING, David F., KELLY, Donald C. and PRIEST, Joseph. HEAT TRANSFER. In: International Edition University Physics. [online] 1. Academic Press, 1984, pp. 430–443. ISBN 978012059858. Available at: https://doi.org/10.1016/B978-0-12-059858-8.50028-5

[12] VORLÍČKOVÁ, Petra and KALOUSEK, Miloš. Elimination of surface condensation on window glazing and connecting joints. *AIP Conf. Proc.* [online]. 2023, **2887** (1). Available at: https://doi.org/10.1063/5.0158837