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IMPACT OF THE SCHAPE OF THE CASEMENT ON THE INSIDE SURFACE TEPERATURE AT WOOD-ALUMINIUM WINDOWS

Roman Nôta – Stanislav Jochim - René Baďura

ABSTRACT

The work is dedicated to the analysis of the impact of the five basic structures of window frames and its three shapes for indoor surface temperature areas and bottlenecks. Area of interest is the surface area of the casement and line sites where glazing details are and contact between window frame and casement. For the analysis the two edge outdoor temperatures (θ_e) are determined, wherein the first is 0°C and the second is −10° C. The analysis is followed by assessing the risk of condensation and possible mold formation

The results of analysing the surface temperatures of basic window frame shapes and their modifications show that the frame shape modifications have no significant effect on surface temperatures either accross the surface of the casement or the critical points. The differences in temperature decreases varied on the average in the range of values approx. $\Delta\theta_{si}$ = 0.23 °C for both two edge outdoor temperatures. Shape modifications represent an added aesthetic value for casement but without significant reduction in surface temperature and without increasing the risk of formation of condensation and mold.

Key words: wood-aluminium windows, window design, passive house, surface temperature.

INTRODUCTION

“To evaluate building designs, there are several advanced standards, as Ecohomes (BRE, UK), Passivhaus (Germany), AECB (UK), and LEED (USA). These standards use different rating scale while assessing energy efficiency (or zero energy use) in buildings“ (BÚRYOVÁ, SEDLÁK 2016). The basic thermal technical requirements for the building as well as for the windows are the heat transfer coefficient so called *U*-value and the minimum temperature of the surface of the window $\theta_{si,w}$, to be above the dew point θ_{dp}. According to the standards of the institute Passivhaus the *U*-value for the unincorporated construction of the entire window should be 0.80 W/m^{2}K and for the window built-in to the building structure the value should be *U*-value 0.85 W/m^{2}K. (PASSIVHAUS INSTITUT 2016). The reasons for this are the maximal possible ways of preventing heat loss and elimination of condensation of water vapour on the surface of each part.

Condensation of water vapour on the surfaces of window frames and casement is undesirable due to creation of favourable conditions for mould formation and for damages of the wood coating and biotic degradation of wood. When designing the construction and shape of the window frames it is important to verify the surface temperatures, what can be nowadays accurately achieved by various simulation programmes.

It is expected windows with U_w= 0.10 Btu/(hr.ft2-°F) will be used in the future (ARASTEH *et al.* 2006), this represents a value of about 0.57 W/m^{2}K. However, generally favourable U_w does not mean that there will be no places where the condensation can occur. These possible risk temperature places need to be analysed to assess whether they meet e.g. the minimum requirement for the temperature above the dew point according to the STN 73 0540-2:2012/Z1/2016, which is θ_{dp} = 9.26 °C for the standard housing conditinos.

The scientific papers dealing with thermal properties of windows are only marginally concerned with surface temperatures on the window frames. The major variable monitored is particularly the overall thermal transmittance of the window U_w (VAN DEN BOSSCHE *et al.* 2015, MALVONI *et al.* 2016, ĆEHLIĆ, OMER 2016) or the studies focus mainly on the surface temperature of the glazing unit (ELEK, KOVÁCS 2014, YONN *et al.* 2014, VAN DEN BERGH *et al.* 2013).

The aim of this paper is to determine the impact of three various shape modifications of the construction of five window frames on the surface temperatures of the whole surfaces and critical points, such as the glazing detail and contact of the window frame with the casement. Further aim is to analyse the temperatures of the casement and evaluate the risk of condensation formation and mould growth.

THEORETICAL – EXPERIMENTAL PART

Calculation of thermal transmittance through window frame was made and based on EN ISO 10077 Thermal performance of windows, doors and shutters — Calculation of thermal transmittance. Part 1: General and Part 2: Numerical method for frames. When assessing the surface temperatures the insulating panel according to STN EN ISO was replaced by insulation triple glazing in the configuration 4-18-4-18-4 (48 mm) with U_g modelled using the value 0.606 W/m^{2}K, i.e. 0.6 W/m^{2}K after rounding. Glazing model is derived from the programme WINDOW (HUIZENGA *et al.* 2015B). The model Swisspacer® Ultimate was used as the distance spacer. (AUTORS 2014).

It has been done by simulation in computer programme THERM (HUIZENGA *et al.* 2015A). Boundary conditions for the calculation were according to the EN ISO 10077-2. Due to using the windows in less favourable conditions, also the temperature -10°C was selected for the analysis.

Reference temperature:	internal	θ_i = 20 °C
	external A	θ_{eA} = 0 °C
	external B	θ_{eB} = −10 °C
Reference surface resistance:	internal	R_{si} = 0.13 m^2·K /W
	increased surface	R_{si} = 0.20 m^2·K /W
	external	R_{se} = 0.04 m^2·K/W

To calculate the θ_{si} materials with the thermal conductivity (λ [W/m·K]) according to the Tab. 1 and Tab. 2 were used. The values are taken from STN EN ISO 10077-2:2012 which gives us the characteristics of the materials most commonly used for production of windows.

“Five wood-aluminium window profiles intended for passive houses for comparison between geometric change and subsequent change of interior surface temperature (θ_{si}) (see Tab. 3) were selected. The four sections are the additional thermal insulation of the highly-resistant PS-foam (MH, MR, MN, AR) and one of the additional plastic profile (WG)" see Fig. 1 (NÔTA *et al*. 2017).

Geometry changes concerned mainly the inner side of the wooden casement. Three variants were designed (V1, V2, V3) according to NÔTA *et al*. 2017.

Tab. 1 Coefficient of thermal conductivity of frame materials (STN EN ISO 10077-2:2012).

Material	Thermal conductivity (λ [W/m·K])
ethylene propylene diene monomer (EPDM)	0.25
steel	50.00
Picea Abies (L.)	0.11
polysulfide	0.40
silicone	0.35
alloy aluminium	160.00
polyvinylchloride (PVC)	0.17
acrylonitrile butadiene styrene (ABS)	0.20
highly resistant PS-foam*	0.04

Equivalent thermal conductivity (λ_{eq}) air cavities has been determined according to the algorithms in the software program THERM, modelled using the ISO 15099 (Thermal performance of windows, doors and shading devices – Detailed calculations) cavity Model

* COMPACFOAM: CF 150, from COMPACFOAM GmbH, Porzellangasse 22/1/11, 1090 Wien

Tab. 2 Coefficient of thermal conductivity of distance spacer and insulating glass.

Material	Thermal conductivity (λ [W/m·K])
Styrene-acrylo-nitrile whit 35% fiberglass*	0.17
Silicagel	0.13
Polyisobutilene (PIB)	0.20
Polyethylene (High destiny)	0.50
Silicone sealant (DC 3362)**	0.27
Glass	1.00
Gas – gap 1 (10% air- 90% argon - EN 673) ***	λ_{eq} 0.024
Gas – gap 2 (10% air- 90% argon - EN 673) ***	λ_{eq} 0.025

* Autors,2014, **Product Information, Dow Corning® 3362 Insulating glass sealant, *** λ_{eq} by HUIZENGA *et al.* 2015B

Tab. 3 List of studied frames.

No.	Frame	Mark	Frame depth [mm] / wood [%]	Country of origin
1.	Wood-aluminium with additional and integrated PS-foam	MW	131.50 / 48.4	Slovakia (SR)
2.	Wood-aluminium with additional PS-foam	MR	141.50 / 58.4	Slovakia (SR)
3.	Wood-aluminium with additional PS-foam	MN	140.50 / 56.2	Slovakia (SR)
4.	Wood-aluminium with additional PS-foam	AL	131.50 / 54.0	Poland (PL)
5.	Wood-aluminium with plastic profile	WG	150.50 / 57.9	Germany (DE)

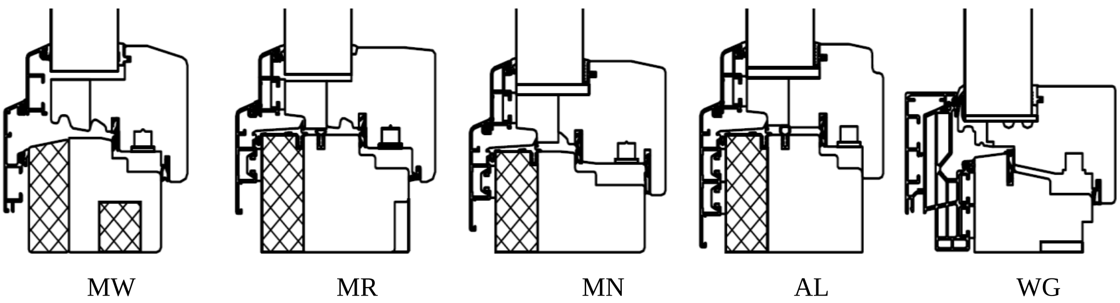


Fig. 1 Profiles of wood aluminium windows with marks (NÔTA *et al*. 2017).

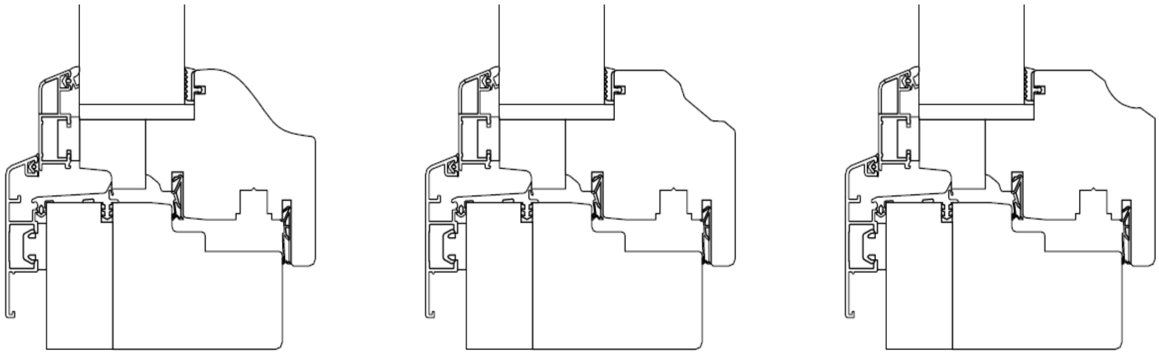
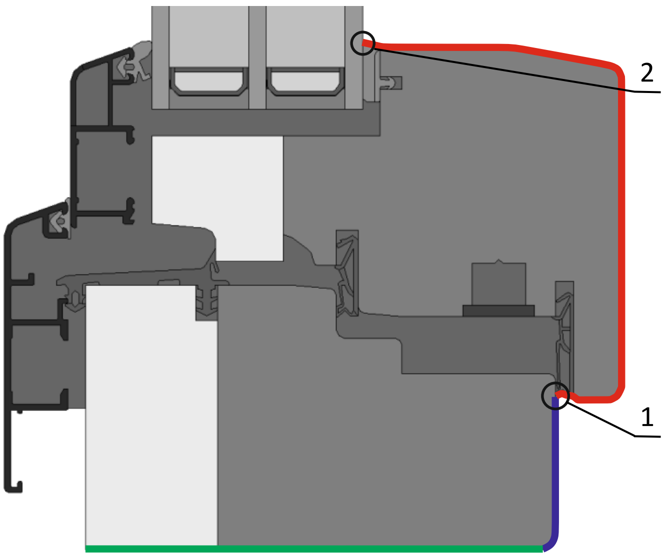


Fig. 2 Modified MN profiles (NÔTA *et al*. 2017).

Verification and evaluation of the temperature is carried out on the surface of the window frame and on the window casement and the two liner places which are also critical (glazing detail and the contact detail of the windows casement and the frame), as described in Fig. 3.



Red line: **Temperature Area of the Casement**
Blue line: **Temperature Area of the Frame**
Green line: **Adiabatic Boundary Condition**
Point 1:
Detail of the window frame – casement
Point 2:
Glazing detail

Fig. 3 Places of evaluation of surface temperatures.

RESULTS AND DISCUSSION

Results of the analysing the window surface temperatures are summarized in Tab. 4 and in Fig. 4. The course of the surface temperatures on the window constructions from the adiabatic edge model to the bottom does not change substantially until the casement. In this point the temperature decreases, due to the change in the shape modification, until it reaches the point where it returns to the original casement construction.

Tab. 4. The average surface temperature of window frame and casement and surface temperature on the critical details.

Profile	Average temp. of the Frame θ_{is}[°C]		Detail Frame – Casement θ_{is}[°C]		Average temp. of Casement θ_{is}[°C]		detail of glazing θ_{is}[°C]	
	θ_{eA}	θ_{eB}	θ_{eA}	θ_{eB}	θ_{eA}	θ_{eB}	θ_{eA}	θ_{eB}
MW OR	18.00	17.05	17.97	15.92	17.93	17.32	14.40	13.18
MW V1	18.00	17.10	17.26	16.06	17.76	17.09	14.41	13.20
MW V2	18.00	17.06	17.18	15.94	17.78	17.11	14.43	13.22
MW V3	17.99	17.07	17.19	15.94	17.76	17.10	14.38	13.16
MN OR	17.84	16.90	17.62	16.61	18.18	17.70	14.28	13.04
MN V1	17.86	16.93	17.66	16.65	17.83	17.21	14.30	13.07
MN V2	17.85	16.91	17.63	16.63	18.02	17.39	14.31	13.06
MN V3	17.84	16.91	17.63	16.62	18.09	17.48	14.31	13.05
MR OR	17.85	16.90	17.93	17.07	18.28	17.82	14.45	13.38
MR V1	17.88	16.94	17.98	17.13	18.12	17.62	14.50	13.45
MR V2	17.86	16.91	17.94	17.08	18.06	17.54	14.46	13.39
MR V3	17.85	16.91	17.93	17.07	18.13	17.63	14.45	13.38
AL OR	17.86	16.89	17.62	16.60	18.04	17.44	14.39	13.13
AL V1	17.86	16.91	17.59	16.54	17.77	17.02	14.44	13.17
AL V2	17.87	16.91	17.61	16.58	17.81	17.13	14.32	13.25
AL V3	17.86	16.90	17.59	16.55	17.88	17.22	14.34	13.19
WG OR	17.61	16.68	17.83	17.01	17.95	17.45	14.39	13.33
WG V1	17.66	16.74	17.89	17.09	17.63	17.02	14.50	13.44
WG V2	17.63	16.69	17.87	17.06	18.00	17.48	14.49	13.44
WG V3	17.60	16.67	17.86	17.05	18.13	17.63	14.47	13.41

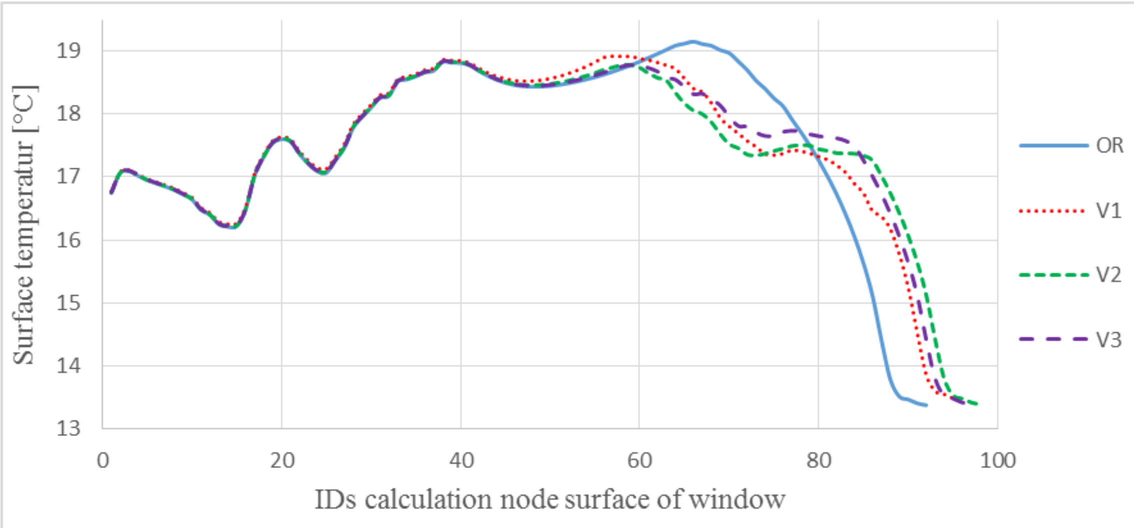


Fig. 4 Surface temperature of MR windows.

The temperature field in the cross section of the construction changes due to the shape change only in places where the volume of the wood mass was reduced. This is shown for the frame profile MR in Fig. 5. The overall change is not significant. The same is valid also for all other studied profiles (like MW, MN, AL and WG).

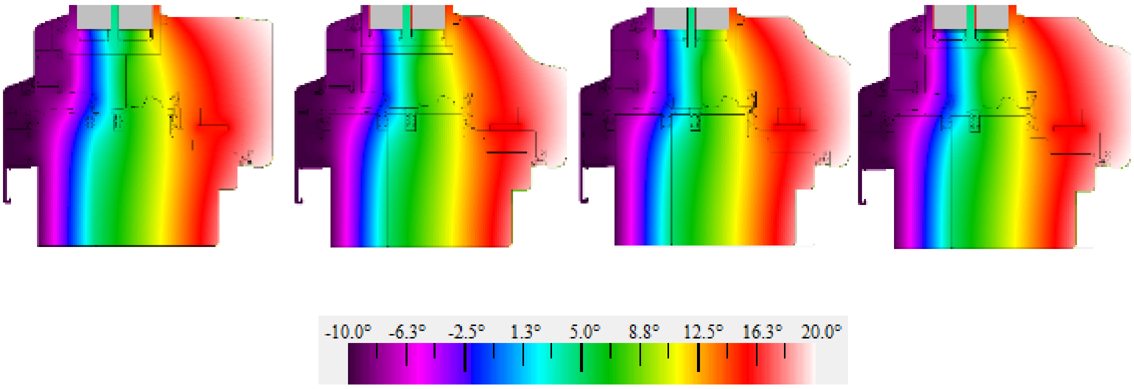


Fig. 5 Infrared display of temperature field in the cross section of MR window construction type.

Surface progressions of temperatures from the casement bottom edge to the glazing detail (red line in Fig. 3) are showed in Fig. 6, 8, 10, 12 and 14. Subsequently Fig. 7, 9, 11, 13 and 15 illustrate the progresses of the isotherms on the casement part with shape modification and highlighted isotherms with the value of approx. 13°C at $\theta_{eB} = -10°C$.

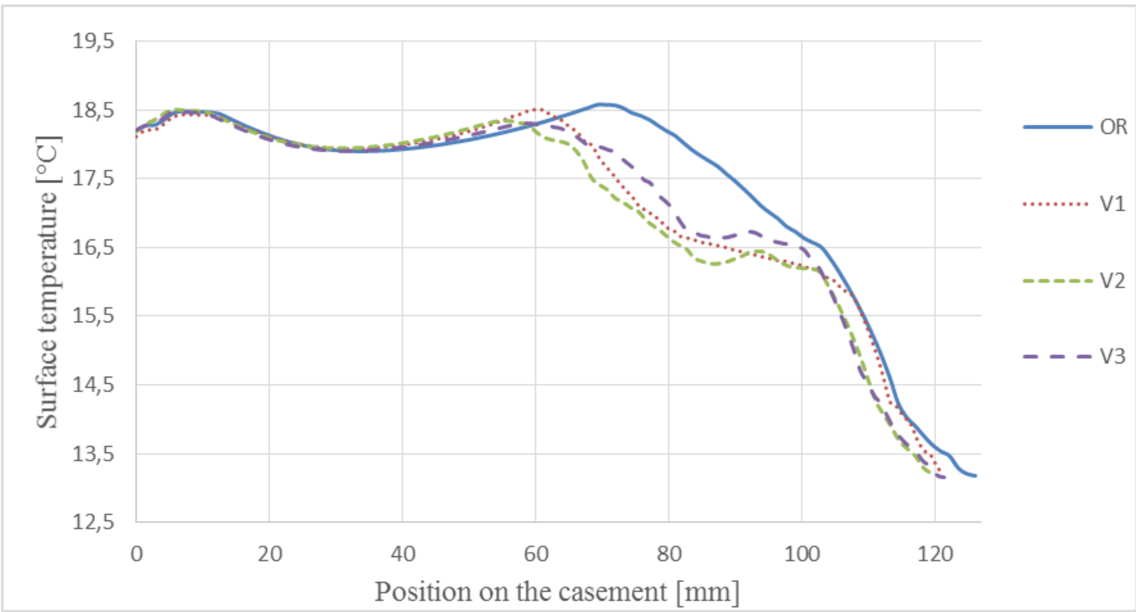
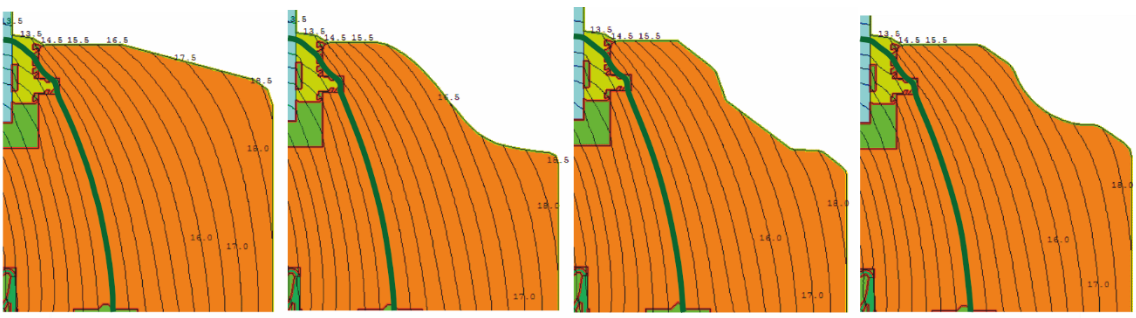


Fig. 6 Surface temperature on the casement of MW windows.



OR V1 V2 V3

Fig. 7 Isotherm on the original casement compared with the variant for profile MW.

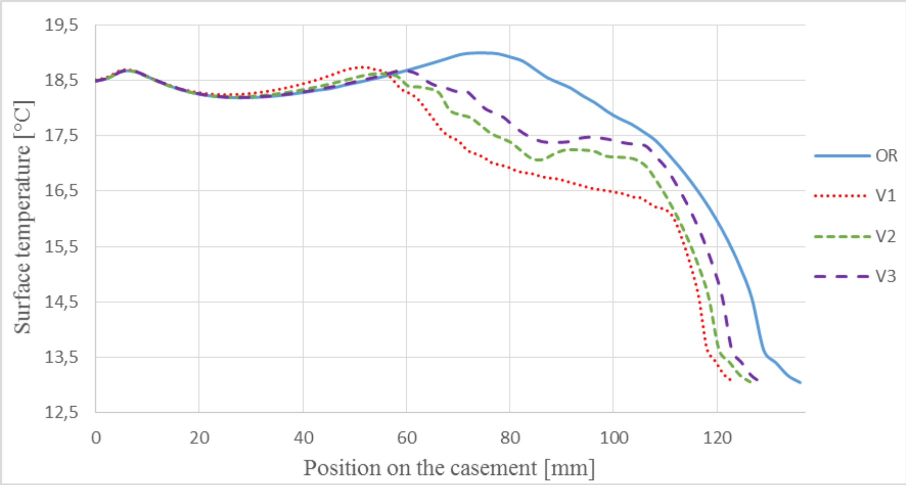


Fig. 8 Surface temperature on the casement of MN windows.

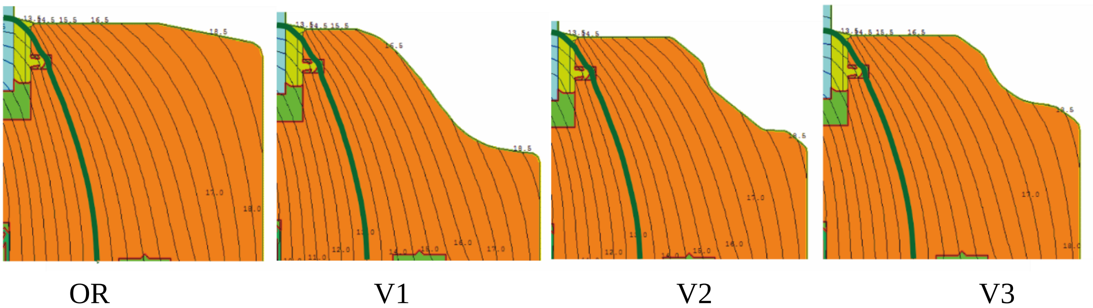


Fig. 9 Isotherm on the original casement compared with the variant for profile MN.

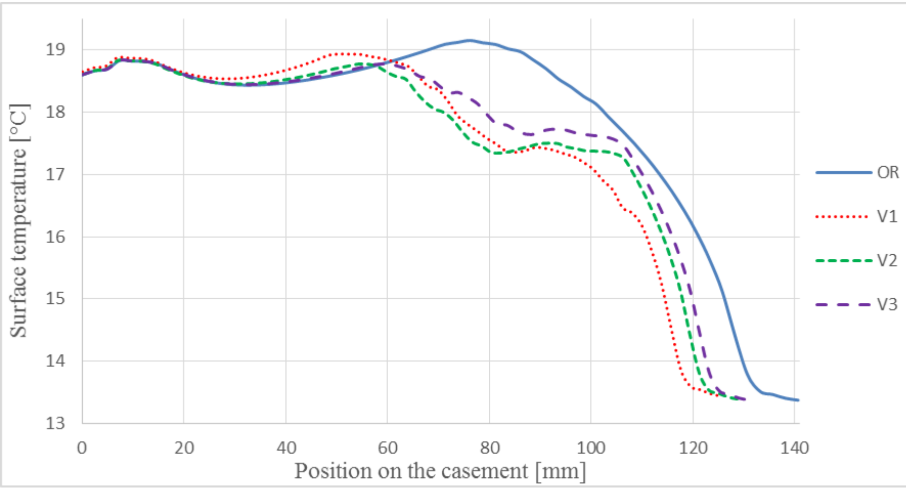


Fig. 10. Surface temperature on the casement of MR windows.

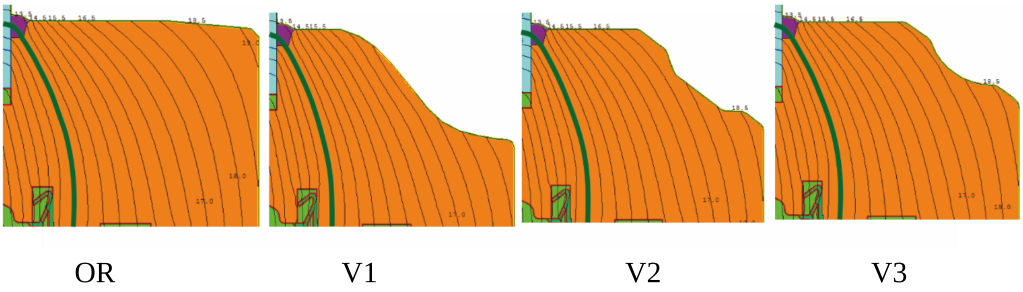


Fig. 11 Isotherm on the original casement compared with the variant for profile MR.

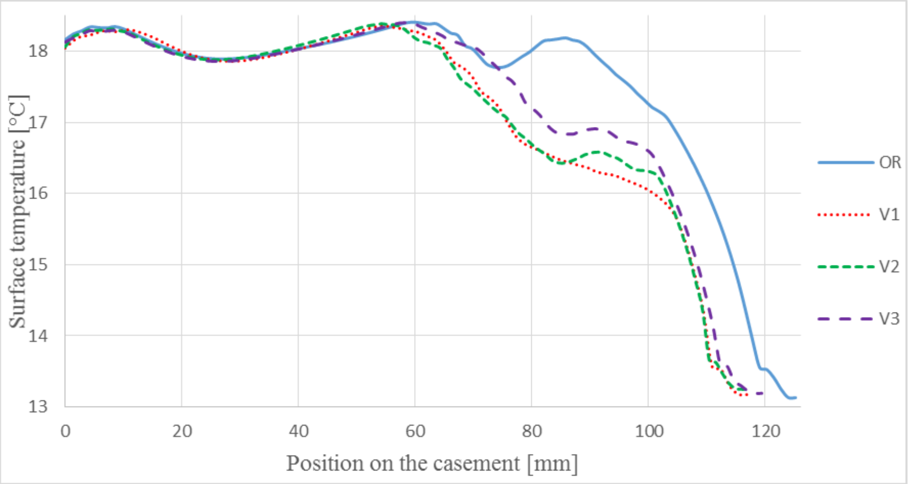


Fig. 12 Surface temperature on the casement of AL windows.

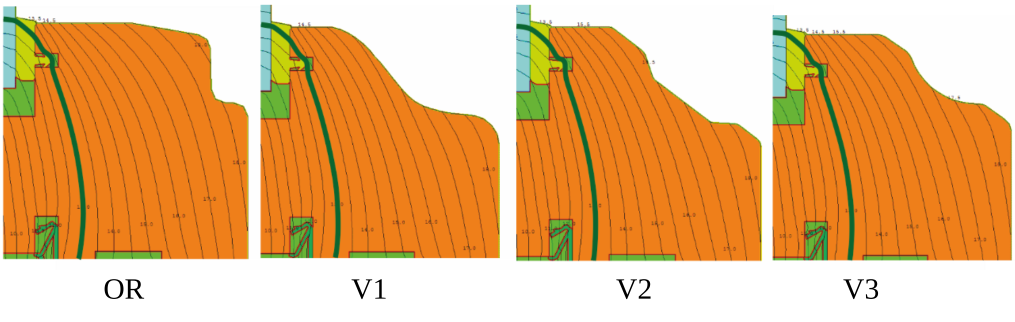


Fig. 13 Isotherm on the original casement compared with the variant for profile AL.

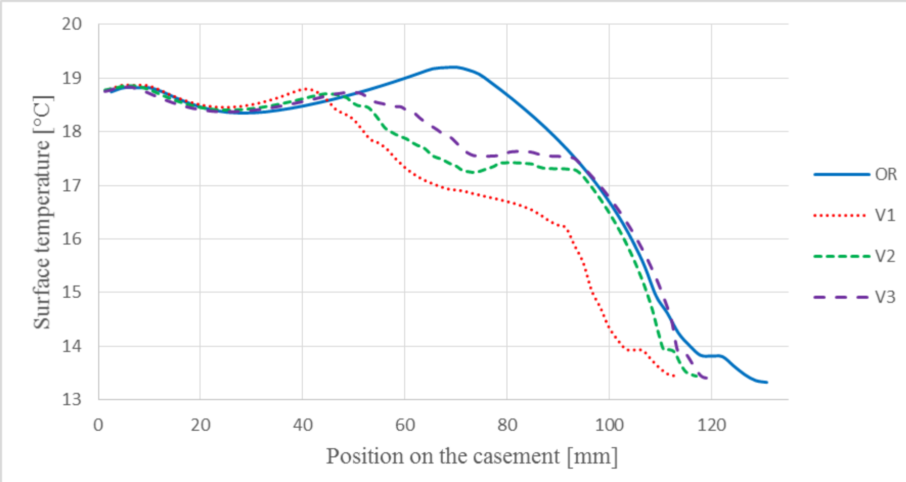


Fig. 14 Surface temperature on the casement of WG windows.

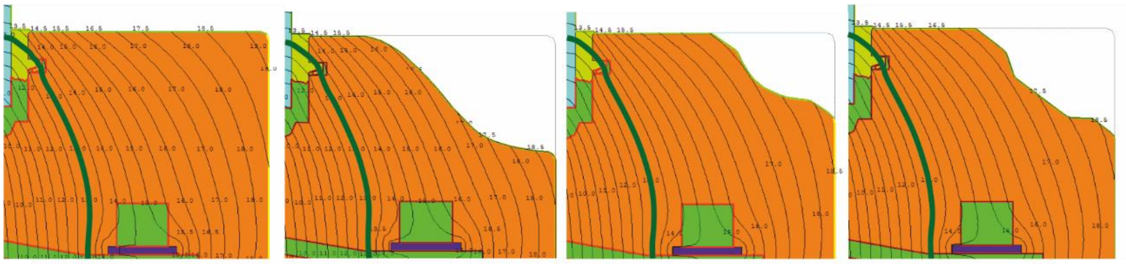


Fig. 15 Isotherm on the original casement compared with the variant for profile WG

According to the above mentioned graphs (Fig. 8, 10, 12 and 14) the surface temperature of variants V1, V2, V3 of all casement changes, i.e. decreases in places of wood material removal.

Isotherms on the modified profiles have, in a simplified perception, the same progress as isotherms on original profile; however, these are interrupted at the point of the shape changes. Highlighted isotherm with the value of 13°C represents the approximate critical temperature for the formation of mould. As apparent, this temperature does not reach the surface of the construction. Therefore it can be said that mould forming should not occur at an external temperature of −10°C.

The measured surface temperatures of all-wooden window frames with the profile thickness of 78 and 88 mm are on average in the range of 14.05°C for window frame, 16.30°C for casement and 10.40 °C in detail of glazing at temperature conditions θ_i = 22.50 °C and θ_e = −11.15 °C, according to NÔTA (2009). In case of frame constructions with the profile thickness 100 mm with additional insulation and with closed air cavity, the surface temperatures measured were: 16.0°C for window frame, 18.0 °C for the casement and 10.8°C in glazing detail at temperature conditions θ_i = 22.30 °C and θ_e = −11.20 °C. Insulation glass U_g = 0.5 was used for the verification for the profiles with the thickness of100 mm and 78 mm and with stainless spacer frame and for a window with the thickness of 88 mm and with a frame "warm edge" as well. For all-wood 92 mm profile with not exactly specified triple glazing, the measured surface temperatures ranged in the values of

17.03 °C for the window frame, 18.84 °C for the casement (PALKO *et al*. 2012). Surface temperatures for window constructions simulated in our study ranged in 16.67–17.01°C for window frames and for the casement they ranged between 17.02–17.82 °C. These values sufficiently in accordance with the experimentally measured values in our window constructions and the simulated boundary conditions as well.

Tab. 5 quantifies the absolute values of changes in surface temperature on the casement as well as in the glazing detail. These are used due to the highest temperature changes (casement) and the lowest reached surface temperature (detail of glazing).

Tab. 5 Absolute and percentage description of surface temperature changes on the casement and in glazing detail.

profile	Casement $\Delta\theta_{is}$				Detail of glazing $\Delta\theta_{is}$			
	θ_{eA} = 0°C		θ_{eB} = -10°C		θ_{eA} = 0°C		θ_{eB} = -10°C	
	°C	%	°C	%	°C	%	°C	%
MW OR								
MW V1	0.17	0.95%	0.23	1.33%	0.01	0.07%	0.02	0.15%
MW V2	0.15	0.84%	0.21	1.21%	0.03	0.21%	0.04	0.30%
MW V3	0.17	0.95%	0.22	1.27%	0.02	0.14%	0.02	0.15%
MN OR								
MN V1	0.35	1.93%	0.49	2.77%	0.02	0.14%	0.03	0.23%
MN V2	0.16	0.88%	0.31	1.75%	0.03	0.21%	0.02	0.15%
MN V3	0.09	0.50%	0.22	1.24%	0.03	0.21%	0.01	0.08%
MR OR								
MR V1	0.16	0.88%	0.20	1.12%	0.05	0.35%	0.07	0.52%
MR V2	0.22	1.20%	0.28	1.57%	0.01	0.07%	0.01	0.07%
MR V3	0.15	0.82%	0.19	1.07%	0.00	0.00%	0.00	0.00%
AL OR								
AL V1	0.27	1.50%	0.42	2.41%	0.05	0.35%	0.04	0.30%
AL V2	0.23	1.27%	0.31	1.78%	0.07	0.49%	0.12	0.91%
AL V3	0.16	0.89%	0.22	1.26%	0.05	0.35%	0.06	0.46%
WG OR								
WG V1	0.32	1.78%	0.43	2.46%	0.11	0.76%	0.11	0.83%
WG V2	0.05	0.28%	0.03	0.17%	0.10	0.69%	0.11	0.83%
WG V3	0.18	1.00%	0.18	1.03%	0.08	0.56%	0.08	0.60%
Average	**0.19**	**1.04%**	**0.26**	**1.50%**	**0.04**	**0.31%**	**0.05**	**0.37%**

When comparing the changes in surface temperature of the individual modifications and original construction, it is apparent that these changes do not affect the average surface temperature of the casement significantly, and their effect on the temperature in the glazing detail is negligible. On average, these changes fluctuated between 0.19°C (1.04%) and 0.04°C (0.31%) for θ_{eA} or 0.26 °C (1.5%) and 0.05°C (0.37%) for θ_{eB}.

CONCLUSIONS

It has been proven, by using simulation analysis, that the shape modification of the wooden casement that is in intentions of geometry considered in the paper (Fig. 2), affects the temperature in the shape of the treated area, however this of temperature change - drop is only minimal to 2.77% relative to the temperature of original frame structure. The reason is that only relatively small amount of material is removed from the casement to achieve the desired shape. In critical areas of glazing detail and in the contact of the casement with the window frame, the temperature decrease was even less important up to 0.91%. Based on these findings and the findings published in the article NÔTA *et al*. (2017) it can be said that the shape and volume change of the casement has no significant influence on the deterioration of the window *U*-value and surface temperature on the casement. It is safe regarding the required dew point temperature and is not a risk factor for condensation and mould forming. The added value is more attractive aesthetic impression of the shape.

REFERENCES

ARASTEH D., SELKOWITZ S., APTE J. 2006. Zero Energy Windows. In: 2006 ACEEE Summer study on energy efficiency in buildings. Volume 3 - Commercial Buildings: Technologies, Design, Performance Analysis and Building Industry Trends. Online: http://aceee.org/files/proceedings /2006/data/index.htm [cit.: 15.3.2017]. ACEEE. Washington. D.C., 2006.

AUTORS 2014. Vitrages Isolants avec espaceur SGG SWISSPACER® ULTIMATE. Document Technigue d´Applocation. Référence á l´Avis Technique 6/13-2124*01 Add, CSTB, Champs-sur-Marne, France. 2014.

ĆEHIĆ M., OMER S. E. 2016. Justifiability Installation of New Type of Window. Journal of Materials Science and Engineering B(1–2): 40–47, David publishing, 2016, ISSN: 2161-6221. Doi: 10.17265/2161-6221/2016.1-2.004.

BÚRYOVÁ D., SEDLÁK P. 2016. Wood log house – comprehensive thermal prediction and energy consumption quantification. In The Path Forward for Wood Products: A Global Perspective - Proceedings of Scientific Papers, p. 157–165, Baton Rouge, Louisiana, USA. WoodEMA. i.a. 2016. ISBN 978-0-692-76612-5.

ELEK L., KOVÁCS Z. 2014. Impact of the Glazing System on the U-factor and Inside Surface Temperature of Windows. Acta polytechnic Hungarica, 11(8), 2014. ISSN: 1785-8860.

HUIZENGA CH. *et al*. 2015A. THERM Fine Element Simulator v7.4.3.0: Program description. A PC program for analysing the two-dimensional heat transfer through building products. Berkeley. California: University of California 2015.

HUIZENGA CH. *et al*. 2015B: BERKELY LAB WINDOW v7.4.6.0: Program description. A PC program for NFRC Certification and modelling Complex Glazing Systems. Berkeley. California: University of California 2015.

MALVONI M., BAGLIVO C., CONGEDO P.M., LAFORGIA D. 2016. CFD modelling to evaluate the thermal performances of window frames in accordance whit the ISO 10077. Energy. 111. Elsevier Masson SAS. 2016. ISSN: 0360-5442.

NÔTA R., KAŠTIEROVÁ J., BAĎURA R. 2017. Thermal performance and aesthetics of wood-aluminium windows for passive houses. Acta Fakultatis Xylologiae Zvolen. 59(1): 131–140. 2017. ISSN 1336-3824, DOI:10.17423/afx.2017.59.1.13.

NÔTA R. 2009. Okenné otvorové výplne na báze dreva pre energeticky pasívne domy. (Wood based windows aperture fillers for energy-efficient houses). Doctoral Dissertation. Department of Furniture and Wood Products. Section of wood building constructions. Zvolen : Technical University in Zvolen. 2009.

PALKO M., PALKOVA A., PUŠKÁR A. 2012. Analysis of water vapour condensation in gap between casement and window frame of wooden windows. Wood Research. 57(4): 581–590. ISSN 1336-4561.

PASSIVHAUS INSTITUT 2016. Information. Criteria and Algorithms for Certified Passive House Components: Transparent Building Components and Opening Elements in the Building Envelope. Version 5.0, 01.12.2016, Passive House Institute, Dr. Wolfgang Feist, Rheinstr, Darmstadt, Germany, 2016.

STN EN ISO 1077-1:2012. Thermal performance of windows, doors and shutters — Calculation of thermal transmittance. Part 1: General.

STN EN ISO 1077-2:2012. Thermal performance of windows, doors and shutters — Calculation of thermal transmittance. Part 2: Numerical method for frames.

STN 73 0540-2:2012 - Z1/2016 Thermal protection of buildings. Thermal performance of buildings and components. Part 2: Functional requirements

PROMOTIONAL MATERIALS FROM COMPANIES: Ľubomír Svetlík - Mirador; MINTAL s.r.o; Makrowin s.r.o., Aluron Sp.z o.o.; Wiegand Fensterbaum; COMPACFOAM GmbH., Dow Corning Corporation.

VAN DEN BERGH S. 2014.Window Spacers and Edge Seals in Insulating Glass Units: A State-of-the-Art Review and Future Perspectives. Energy and Buildings. 2013. 58: 263–280. Lawrence Berkeley National Laboratory: Lawrence Berkeley National Laboratory. LBNL Paper LBNL-6122E. Retrieved from: http://escholarship.org/uc/item/14d1s1rf.

VAN DEN BERGH S., HART R., PETTER JELLE B., GUSTAVSEN A. 2013.Window Spacer and Edge Seals in Insulating Glass Units. A state-of-the-Art review and Future Perspective. Energy and Buildings 58: 263–280. Elsevier B.V. 2013 ISNN: 0378-7788.

VAN DEN BOSSCHE N., BUFFEL L., JANSSENS A. 2015. Thermal optimization of window frames. In Energy Procedia. Volume 78. 6th International Building Physics Conference. IBPC 2015. Energy Procedia 78. Elsevier Ltd. 2015. ISSN: 1876-6102.

YONN S.H., YONN Y.B., LEE K.H., 2014. Inside air and surface temperature characteristics of window systems depending on low-E coating and blind location during cool period. In: Materials research Innovations. Taylor & Francis. 2014. Print ISSN: 1432-8917 Online ISSN: 1433-075X. DOI: 10.1179/1432891714Z.000000000446.

Addresses of the authors

Dipl. Ing. Roman Nôta, PhD.
Assoc-Prof. Mgr.art. René Baďura
Technical University in Zvolen
Department of Furniture and Interior Design
T.G. Masaryka 24
960 53 Zvolen
nota@tuzvo.sk
badura@tuzvo.sk

Dipl. Ing. Stanislav Jochim, PhD.
Technical University in Zvolen
Department of Wooden Constructions
T.G. Masaryka 24
960 53 Zvolen
jochim@tuzvo.sk