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THE IMPACT OF THE SPACER ON THE INTERIOR SURFACE TEMPERATURE IN THE DETAIL OF WOOD WINDOW GLAZING

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ABSTRACT

The impact of the spacer of insulated glazing on the surface temperature in the glazing detail of a wooden window is discussed in the paper. Six warm edge profiles from three manufacturers were assessed in the study, the model glazing with parameters 4-12-4-12-4 with the U-factor of 0.7 W/m^{2}K. The detailed model of the spacer was compared also to the Two Box model. Subsequently, the Psi values of glazing (Ψ_g) for these spacers were determined and compared with the values from the Data sheet Psi values for windows (BUNDESVERBAND FLACHGLAS E.V.) and calculated values of U_w according to the STN EN ISO 10077. Following the calculation, minimum surface temperatures ranging from $\Delta\theta_{si}$ of approx. 0.10 °C for the detailed model to $\Delta\theta_{si}$ of approx. 0.15 °C for the Two Box model was observed. When comparing the detailed models with the Two Box models, the minimum surface temperatures were in the range from approx. 0.5 °C representing 3.40 %. This difference was also observed in case of the exterior temperature resulting in condensation on the test window. In such case the difference between the detailed and Two Box model was at the value of 16.94%, while the U_w value for all studied variants was the same 1.7 W/m^{2}K.

Key words: wood windows, surface temperature, IGU spacer, Psi values.

INTRODUCTION

Hygienic requirements affect the minimum required interior surface temperature of a window, since condensation can occur on the construction surface leading to mould growth on these surfaces. Condensed water on the material surfaces is more significant for the mould growth than the atmospheric humidity. Approximately 70−80 % of moulds occurring in the environment can produce mycotoxins affecting negatively the human health (UVZ SR, 2014).

Condensation on the material surface occurs when the surface temperature decreases below the dew point temperature. Moulds grow and develop with higher relative atmospheric humidity. The standard STN 73 0540-3 defines the critical surface temperature for mould development for various combinations of temperature and atmospheric humidity.

The coldest place on the surface of a window construction is the detail of glass system fitting. It is caused by the major thermal bridge created by the shape of the construction as well as by the impact of the spacer in the insulation glazing unit (IGU). It is a place on the glass where the surface temperature changes from the lowest value to the value which equals to the surface temperature in the centre of IGU. This region, according to VAN DER BERGH *et al.* (2013), can reach up to approx. 102 mm. It can be affected by a number of factors, from the thermal characteristics of the environment, glazing thickness, to the type and thickness of the window construction etc. However, the type of the used spacer affects the surface temperature in the glass fitting detail most. Its impact in calculating the window heat transfer coefficient U_W is expressed by the linear thermal transmittance of the glazing – Ψ_g (Psi value).

Nowadays, spacers with improved thermal performance, so called warm edge spacers, are used most often. These are according to the standard STN EN ISO 10077-1 defined by the equation:

$$\Sigma\,(d \times \lambda) \leq 0{,}007 \qquad (01)$$

Where d is the spacer wall thickness and λ is the thermal conductivity coefficient of the material.

For these spacers the Ψ_g value, for plastic window and insulation double glazing, is less than 0.051 W/mK (MEYER-QUEL 2017).

Due to the complex nature of calculating the thermal performance of the spacers and a number of materials a simplified calculation model Two Box model was created. The principle is in substituting the spacer by a pair of rectangles (box), where one represents the sealing substance (polysulfide) and the other one represents the spacer construction. The dimensions of the rectangles are the same as those of the spacer, and the thermal performance for the calculation is substituted by the equivalent value of the thermal conductivity coefficient (SVENSEN *et al.* 2005, IFT ROSENHAIM 2015).

THEORETICAL – EXPERIMENTAL PART

Calculation of thermal transmittance and surface temperature 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. Glazing model is derived from the programme WINDOW 7.6 (HUIZENGA *et al.* 2017B). It has been done by modelling in computer programme THERM 7.6 (HUIZENGA *et al.* 2017A). Boundary conditions for the calculation by EN ISO 10077-2. Reason for this is using windows in less favourable conditions.

Reference temperature:	internal	$\theta_i = 20$ °C
	external	$\theta_e = 0$ °C
Reference surface resistance:	internal	$R_{si} = 0.13\ \mathrm{m^2 \cdot K/W}$
	internal - reduced radiation	$R_{si} = 0.20\ \mathrm{m^2 \cdot K/W}$
	external	$R_{se} = 0.04\ \mathrm{m^2 \cdot K/W}$

To calculate the θ_{si} of materials, the values of thermal conductivity (λ [W/m·K]) according to the Tab. 1 and Tab. 2 were used. The values are taken from STN EN ISO 10077-2:2018 which gives us the characteristics of the materials most commonly used for production of windows.

A model of wooden window construction with construction depth of 88 mm was used for the modelling (see Fig. 1).

Tab. 1 Coefficient of thermal conductivity of window frame materials.

Material	Thermal conductivity (λ [W/m·K])
ethylene propylene diene monomer (EPDM)	0.25
steel (oxidized)	50.00
Picea Abies (L.)	0.11
silicone	0.35
alloy aluminium	160.00
polyvinylchloride (PVC) Flexible, with % softener	0.17

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

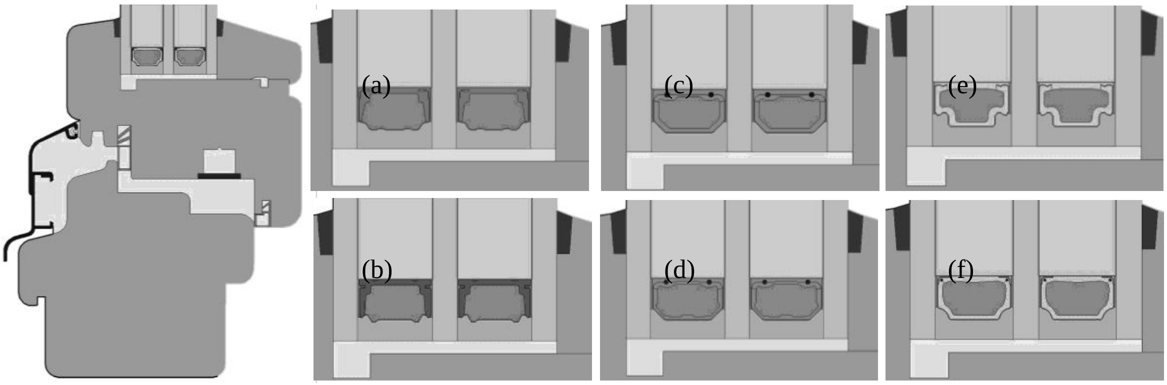

Fig. 1 Model of wooden window and detailed models of spacers ((a) Chromatech Ultra F, (b) Chromatech ultra S, (c) Thermix TX.N plus, (d) Thermix TX pro, (e) TGI Spacer, (f) TGI Spacer M).

Tab. 2 Coefficient of thermal conductivity of spacers.

Material	Thermal conductivity (λ) [W/m·K]
Desiccant - Silicagel *	0.13
Silicone sealant (DC 3362 HD)** - secondary seal	0.26
Polyisobutylene (PIB) * – primary seal	0.20
Glass	1.00
Gas – gap 1 (10% air- 90% argon - EN 673) ***	λ_{eq} 0.020
Gas – gap 2 (10% air- 90% argon - EN 673) ***	λ_{eq} 0.021
Chromatech Ultra F [1]	
Stainless steel 1.4372	15
Polyvinylchloride (PVC)	0.17
Chromatech Ultra S [2]	
Stainless steel 1.4372	15
Polypropylene (PP)	0.25
Thermix TX.N plus [3] Thermix TX Pro [4]	
Polypropylene (PP) - no glass fibers	0.22
Steel	50.00
Stainless steel 1.4372	15
TGI Spacer [5]	
Polypropylene (PP) with talcum powder	0.193
Stainless steel 1.4301	15
TGI Spacer M [6]	
Polypropylene (PP) with talcum powder	0.193
Steel C72D2	47.30
Stainless steel 1.4372	15

[1] Document Technique d´Application 6/15-2256, [2] Document Technique d´Application 6/17-2365_V1, [3,4] Document Technique d´Application 6/16-2348, [5,6] Document Technique d´Application 6/16-2305_V1, * STN EN ISO 10077-2, ** Product Information, Dow Corning® 3362 HD Insulating Glass Sealant, *** λ_{eq} by HUIZENGA *et al.* 2017B

After evaluating the minimum surface temperature, the temperature index calculated according to the equation (02) was established. *"The temperature index is non-dimensional, and represents the interior surface temperature relative to the interior and exterior air temperatures. The use of the temperature indexes offers the opportunity to compare the thermal performance of samples subjected to different boundary conditions."* (MAREF *et al.* 2011)

$$f_{\mathrm{Rsi}(\theta)} = \frac{\theta_{si}\text{-}\theta_e}{\theta_i\text{-}\theta_e} \tag{02}$$

Via its modification (Shin, 2017), the exterior temperature, which will cause condensation on the model window, can be determined (equation (03)).

$$\theta_{\mathrm{e,dp-min}} = \frac{\theta_{\mathrm{dp}} - f_{\mathrm{Rsi}(\theta)}\theta_i}{1 - f_{\mathrm{Rsi}(\theta)}} \tag{03}$$

Where θ_{dp} represents the dew point temperature corresponding to the calculation of the interior air temperature at its relative humidity. Our conditions correspond to the conditions of STN 730540-2 ($\theta_i = 20°C$ a $\varphi_i = 50\%$), while the dew point temperature in such conditions is $\theta_{\mathrm{dp}} = 9.26°C$.

The Ψ_g value calculations were performed according to the procedure outlined in "Calculating Fenestration Product Performance in WINDOW 6 and THERM 6 According to EN 673 and EN 10077" (LBNL 2012) and the associated spreadsheet, with the following exceptions. The surface transfer coefficient at internal/external surface used in the models was 25 W/m^{2}K for the external surface and 7.69 and 5 W/m^{2}K for the internal and internal - reduced radiation surface according to the ISO 10077, instead of 23 and 3.6+(4.4*ε/0.9) W/m^{2}K shown in the document.

RESULTS AND DISCUSSION

The interior surface temperature on the window structure obtained when modeling with the Chromatek Ultra F spacer is shown in the graphs in Fig. 2. For the other spacers the temperature course is the same. The lowest temperature is in the place of IGU contact with the window frame. This place is represented by 0 on the x axis (see fig. 3). In this place, condensation occurs most often causing a high risk of mould creation. The temperature in this place can be seen in Table 3. The table provides the temperatures for the detailed model of the spacer as well as for the Two Box model.

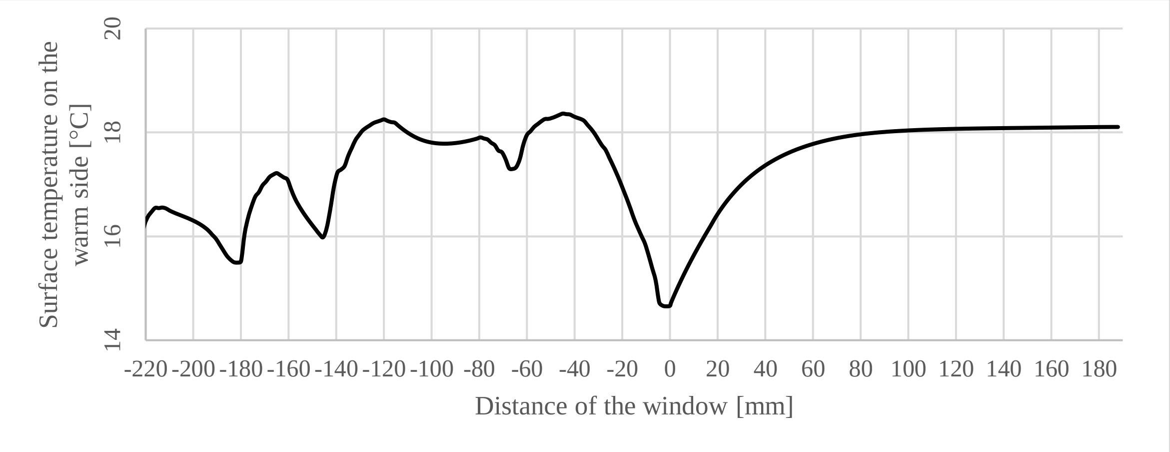

Fig. 2 Interior surface temperature of the wooden window frame and IGU whit Chromatech ultra F spacers - detailed model. $\Theta_{\mathrm{si\ min}} = 14.65$ °C.

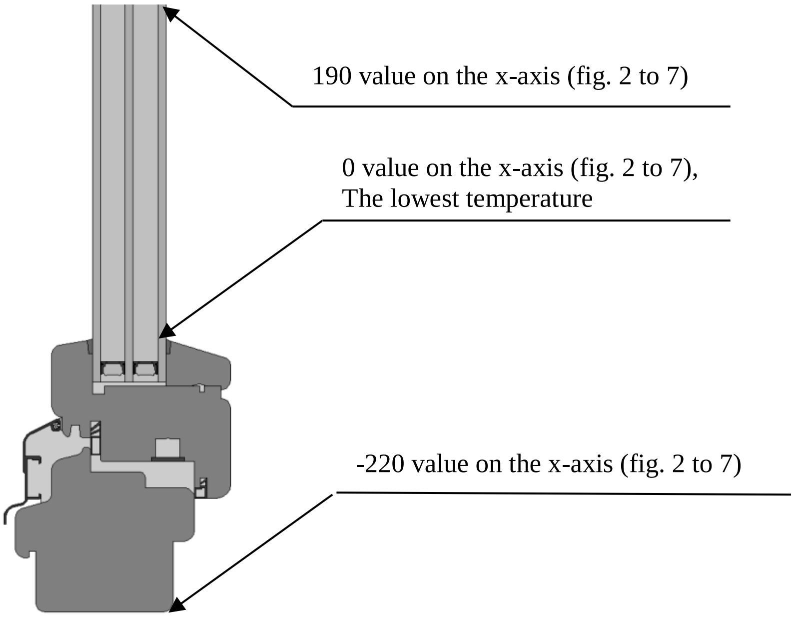

Fig. 3 Distance of the windows – value on the x-axis in Fig. 2.

The biggest difference between surface temperatures was recorded in the glazing detail reaching the value of 0.09 °C, representing 0.64%.

Tab. 3 Interior surface temperature of the edge of glass.

spacer		$\Theta_{si\ min}$ [°C]	$\Delta\Theta_{si\ min}$ [°C] DM vs. 2B	$f_{Rsi\Theta}$ [-]	$\Theta_{e\ pd\text{-}min}$ [°C]
Chromatech ultra F	detailed model	14.65	0.48	0.733	−20.17
	2B model	14.17	**3.30%**	0.709	−16.84
Chromatech ultra S	detailed model	14.61	0.58	0.730	−19.84
	2B model	14.03	**3.97%**	0.701	−15.97
Thermix TX pro	detailed model	14.60	0.49	0.730	−19.80
	2B model	14.11	**3.36%**	0.706	−16.48
Thermix TX.N plus	detailed model	14.56	0.45	0.728	−19.48
	2B model	14.11	**3.11%**	0.705	−16.45
TGI Spacer	detailed model	14.61	0.48	0.731	−19.88
	2B model	14.13	**3.30%**	0.707	−16.61
TGI Spacer M	detailed model	14.60	0.49	0.730	−19.80
	2B model	14.11	**3.37%**	0.706	−16.47

More significant difference for the wooden window was recorded in comparing the detailed model of the spacer with the Two Box model. This represented approx. 0.5°C being 3.40%. From this aspect the difference is not significant. However, if the thermal coefficient is used to determine the minimum exterior temperature for condensation ($\theta_{e,\ pd\text{-}min}$), the temperature difference between the detailed and Two Box model is $\Delta\ \theta_{e,\ pd\text{-}min}$ 3.36°C, representing 16.94%.

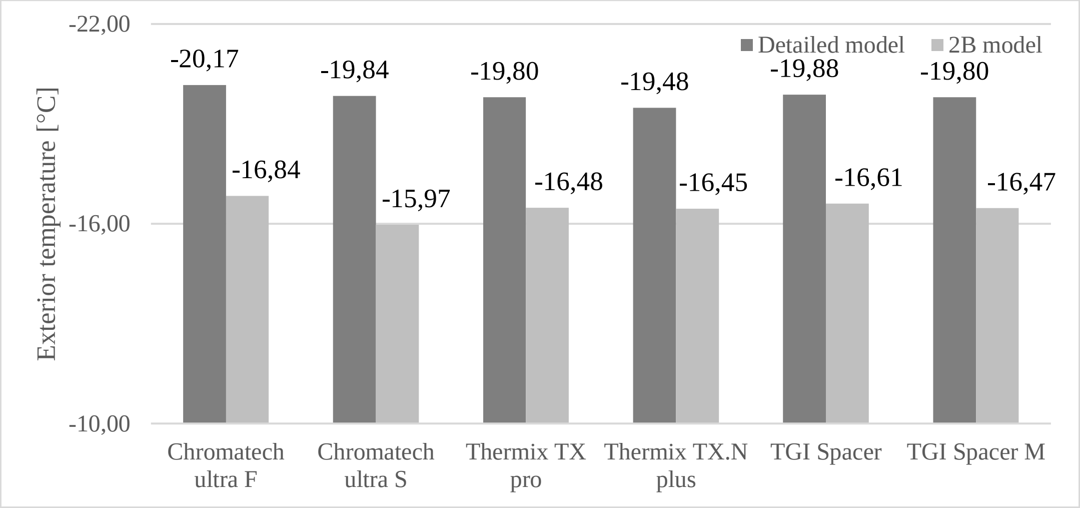

Fig. 4 Calculated exterior air temperature at which the condensation start to occur.

Following these values, we determined values of linear thermal transmittance for glazing Ψ_g for the detailed model and Two Box model for individual model situations and compared them with data from the *Data sheet Psi values for windows* (Table 4).

The difference between the detailed and Two Box model was probably caused by the used values of coefficient of thermal conductivity of individual materials used for calculations. For instance, with secondary seal representing approx. 30.29% of the insulation glazing spacer area, the value used for the detailed model is 0.26 W/mK (Dow Corning Corporation 2013) and for Two Box model 0.40 W/mK (Bundesverband Flachglas e.V.) representing performance better by 35%. The properties of the spacers were discussed in the studies of Van der Bergh *et al*. (2013), Svensen (2005) and Elmahdy (2003). Their calculation and the transfer of the detailed models to the Two Box models are described in the Guideline ift Rosenheim (WA-08/3 and WA-17/1).

Tab. 4 Comparison of psi value, Bundesverband Flachglas e.V. vs. calculated value.

spacer		Ψg BF	Ψg cal.(LBNL)	ΔΨg BF vs. cal.		ΔΨg 2B vs. detailed	
Chromatech ultra F	detailed model	–	0.026			0.012	**67.86%**
	2B model	0.038	0.035	0.003	**6.71 %**		
Chromatech ultra S	detailed model	–	0.027			0.014	**64.95%**
	2B model	0.041	0.038	0.003	**7.01 %**		
Thermix TX pro	detailed model	–	0.027			0.012	**68.63%**
	2B model	0.039	0.037	0.002	**6.34 %**		
Thermix TX.N plus	detailed model	–	0.028			0.012	**68.81%**
	2B model	0.040	0.037	0.003	**6.74 %**		
TGI Spacer	detailed model	–	0.027			0.012	**68.30%**
	2B model	0.039	0.036	0.003	**7.28 %**		
TGI Spacer M	detailed model	–	0.026			0.013	**67.16%**
	2B model	0.039	0.037	0.002	**6.22 %**		

Table 5 illustrates the U_w values calculated according to the STN EN ISO 10077 for the variants of linear thermal transmittance coefficient according to the Bundesverband Flachglas (BF) (U_wΨgBF), calculated with the Two Box model (U_wΨg2B) and with the detailed model (U_wΨgDM), as well as comparisons of the differences between the calculated values and values provided by the Data sheet Psi values for windows (Bundesverband Flachglas e.V.).

Tab. 5 Comparison of U-value of wooden windows with different psi-value.

spacer	U_w ΨgBF [W/m^{2}K]	U_w Ψg2B [W/m^{2}K]	U_w ΨgDM [W/m^{2}K]	ΔU_w Ψg2B vs. DM. [W/m^{2}K]		ΔU_w Ψg BF vs. DM. [W/m^{2}K]		U_w Ψg BF,2B,DM by EN ISO
Chromatech ultra F	1.729	1.694	1.671	0.023	**1.36%**	0,059	**3.41%**	**1,7**
Chromatech ultra S	1.736	1.700	1.673	0.027	**1.62%**	0,064	**3.68%**	**1,7**
Thermix TX pro	1.732	1.696	1.673	0.023	**1.38%**	0.059	**3.42%**	**1,7**
Thermix TX.N plus	1.734	1.698	1.675	0.023	**1.38%**	0.060	**3.43%**	**1,7**
TGI Spacer	1.731	1.695	1.673	0.023	**1.34%**	0.058	**3.38%**	**1,7**
TGI Spacer M	1.732	1.696	1.672	0.025	**1.46%**	0.061	**3.50%**	**1,7**

According to the calculations, the heat transfer coefficient for various spacers varied in thousandths of W/m^{2}K and did not exceed 0.40%.When comparing individual models and thus also the Psi factor values, the difference was in the range of hundredths of W/m^{2}K and did not exceed 3.68%. When rounding according to the paragraph 7.2.3 of STN EN ISO 10077-1, the U_w values do not vary.

CONCLUSIONS AND FUTURE WORK

According to the calculations carried out using six detailed models of insulation glazing spacers and Two Box models of the corresponding spacers, the impact on the minimum surface temperature is insignificant for individual spacer types, on average 0.64%. Nevertheless, the most significant difference occurred when comparing the detailed models with Two Box models – 16.94%. Eventually, such differences do not affect the value of heat transfer coefficient of window.

It can be supposed that this difference occurred due to the impact of thermal performance of the materials used in the production of individual spacers mentioned in the CCFAT documents. Since the study dealt with the theoretical calculation of the surface temperatures, confirming such assumption will be discussed in subsequent studies. Laboratory measurements will be required in order to confirm the temperature causing condensation in various types of spacers.

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