ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 64(2): 49−56, 2022
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2022.64.2.05

ANALYSIS OF THE THERMAL BRIDGE OF WOOD WINDOW INSTALLATION POSITION

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ABSTRACT

The paper is focused on assessing the impact of wood window installation position in terms of wall thickness. The thermal bridge created this way is defined as a linear thermal transmittance [Ψ] of the construction. In this particular case, the thermal bridge is created by the wall and window constructions. For the purpose of this study, one wood window construction was used and compared when installed in various wall constructions. Emphasis was placed mainly on composed walls, which are used mostly in wood panel constructions.

Model walls of various compositions, however, having the same thermal performance were evaluated in the study. In order to achieve the same values of thermal resistance of walls, various theoretical materials were used. Following the performed analyses, the course of the dependence between the development of wall temperatures was evaluated. Reference values were represented by a temperature of 0°C and window positions where the system window-wall reaches the minimum value of the linear thermal transmittance of the window installation $\Psi_{i,min}$.

The hypothesis that the position of $\Psi_{i,min}$ depends on the steepness of the temperature gradient (represented by the temperature curve direction) was not confirmed. Results presented in this study can be used for estimating the window position with $\Psi_{i,min}$ at the level of 7 – 11 % of the wall thickness measured from the place in the construction with a temperature of 0°C.

Key words: thermal bridges, linear thermal transmittance, window, wood panel structures.

INTRODUCTION

Thermal bridge can be defined as a place where a decrease in the construction surface temperature occurs. It occurs in places where the thermal transmittance differs from the rest of the construction (HALAHYJA *et al.* 1985). One such place is an opening in the building envelope with installed e.g., window.

Previous studies focused on thermal performance of window installation compared the impact of installation position of a wood-aluminium window on the deformation of the thermal field in the place of installation. These analyses worked with the hypothesis that there is a dependence between the magnitude of the temperature gradient, deformation of the 2D thermal field and the best position of window installation, i.e. the place where the values of the linear thermal transmittance of window installation is the lowest $\Psi_{i,min}$ (NÔTA and DANIHELOVÁ 2021).

The development of the values of linear thermal transmittance of the window installation (Ψ_i) depending on the position of the window in the wall is parabolic (MISIOPECKI *et al*, 2017; HØYDAL 2019) and depends primarily on the thermal performance of window, wall and the installation details (MISIOPECKI *et al.* 2017; HØYDAL 2019). This is also reflected in the respective equation for calculating the linear thermal transmittance of the window installation (Ψ_i):

$$\Psi_i = L^{2D} - U_{wall}.b_{wall} - U_w.b_w \tag{1}$$

L^{2D} - two-dimensional thermal conductance [W/(m.K)];
U_{wall} - thermal transmittance of wall according to EN ISO 6946 [W/(m^2.K)];
b_{wall} - projected width of the wall element [m];
U_w - thermal transmittance of the window according to EN ISO 10077-1 [W/(m^2.K)];
b - projected width of the element analysed [m].

The position with the minimum value of Ψ_i is individual for every building, thus for every wall or window construction, as well as for carrying out the installation. Therefore, it is important to consider all of these factors prior to installation and subsequently select the most suitable position. In practice it would mean to make a series of calculations for every window, considering various window positions and corresponding installation detail, and subsequently determine the position with the minimum value Ψ_i. However, this is demanding and complicated due to time and economic reasons.

MATERIALS AND METHODS

We decided to compare the development of Ψ_i for the model wall construction with the thermal resistance of the wall construction (R_{wall}) at the level of 3.67 (m^2.K)/W corresponding to the heat transfer coefficient (U_{wall}) 0.27 W/(m^2.K), and the equivalent thermal conductivity coefficient is ca. 0.1 W/(m.K). Five experimental wall constructions with the width of 0.350 m were studied, whereas one of them was homogenous (HW) and four were inhomogeneous – composite walls (IHW).

Tab. 1. Number of layers and thermophysical properties of the experimental walls.

Marking of walls	HW	IHW1	IHW2	IHW4	IHW4
Number of layers of the walls	1	2	3	4	7
R_{wall} resp. U_{wall}	3.67 (m^2.K)/W resp. 0.272 W/(m^2.K)				
$\lambda_{eq,wall}$	0.1 W/(m.K)				

For individual wall variants, theoretical materials with the following values of the linear thermal transmittance were considered.

Tab. 2. Linear thermal transmittance for the theoretical materials and equivalent materials.

Theoretical Materials	**λ [W/(m.K)]**	**Similar to the Materials**	**λ^*[W/(m.K)]**
Material Nº. 01	0.0462	Stone Wool (85 kg/m^3)	0.046
Material Nº. 02	0.0668	Mineral Wool Boards	0.06 – 0.07
Material Nº. 03	0.0727		
Material Nº. 04	0.1000	Aerated Concrete	0.096 – 0.204
Material Nº. 05	0.2000	Plasterboard	0.220
Material Nº. 06	0.2930	Slightly Ventilated Air Cavity	0.220 – 0.320
Material Nº. 07	0.3050	Ceramsite Concrete	0.28 – 0.70
Material Nº. 08	0.4500		
Material Nº. 09	0.5000	Brick Concrete	0.52 – 0.89
Material Nº. 10	0.6000		
Material Nº. 11	0.8000	Lime Plaster	0.880
* By STN 73 05040-3/2012			

Individual wall compositions are provided in Table 3.

Tab. 3. The composition of the model walls introduced into the interior to the exterior.

Model Wall	**Materials (from interior to exterior)**	***Thickness [m]***
HW	Material Nº. 04	0.350
IHW1	Material Nº. 11	0.200
	Material Nº. 01	0.150
IHW2	Material Nº. 05	0.100
	Material Nº. 03	0.200
	Material Nº. 05	0.050
IHW3	Material Nº. 05	0.025
	Material Nº. 10	0.075
	Material Nº. 03	0.225
	Material Nº. 05	0.025
IHW4	Material Nº. 08	0.0125
	Material Nº. 06	0.050
	Material Nº. 08	0.0125
	Material Nº. 02	0.205
	Material Nº. 08	0.015
	Material Nº. 07	0.050
	Material Nº. 09	0.005

For carrying out the calculation, an insulated triple pane wood window designated for energy passive houses with construction depth of 125 mm was used. The thermal performance of the window and its parts was as follows: thermal transmittance of window frame U_f = 0.784 W/(m^2.K); thermal transmittance of glassing U_g = 0.600 W/(m^2.K); linear thermal transmittance of glassing Ψ_g = 0.033 W/(m.K) and thermal transmittance of window U_w = 0.659 W/(m^2.K).

Calculation of Ψ_i-value was carried out according to the methodology *B.C. Reference Procedure for Using THERM to Determine Window Performance Values for Use with the Passive House Planning Package*. The "BC Reference Procedure" published in September 2019 is the first methodology using LBL THERM software to be recognized by the Passive House Institute for use in certifying Passive Houses to the International Passive House Standard" (FENESTRATION ASSOCIATION OF BC, 2019).

It was conducted by modelling in computer programme THERM 7.8 (HUIZENGA *et al.* 2017). Boundary conditions for the calculation were according to the standard STN 73 0540.

Reference temperature:	internal	$\theta_i = 20.0$ °C (293.15 K),
	external	$\theta_e = -12.0$ °C (261.15 K).
Reference surface resistance:	internal	$R_{si} = 0.13$ (m^2.K)/W,
	external	$R_{se} = 0.040$ (m^2.K)/W.

Calculations were carried out using data from various positions of window installation within the window opening in the wall, and the positions were gradually moved by 5 mm. The first extreme position was in the place where the window was aligned with the exterior surface and the other extreme position was aligned with the interior surface. The first extreme position was determined by the window frame axis being in the distance of 62.75 mm from the exterior surface (Fig. 1 – A); in the other extreme position the window frame axis was 287.75 mm from the exterior surface (Fig. 1 – B).

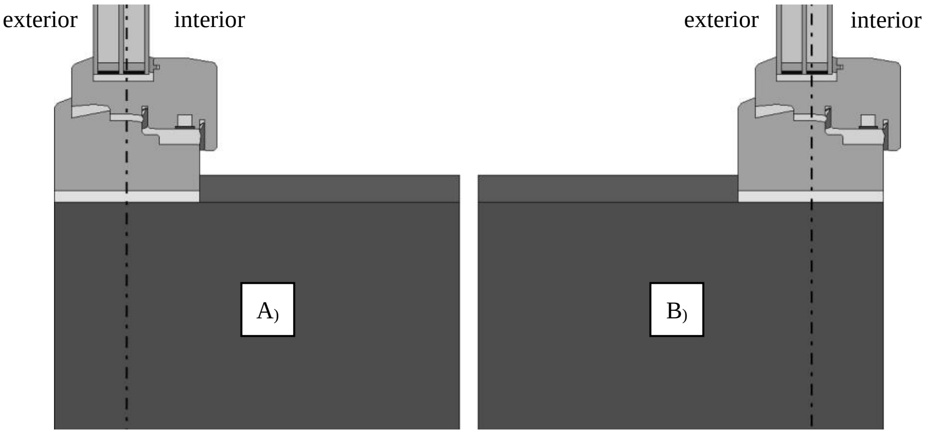

Fig. 1. Representation of the extreme positions of the window in the structure A) exterior position – 62.75 mm, B) interior position – 287.75 mm.

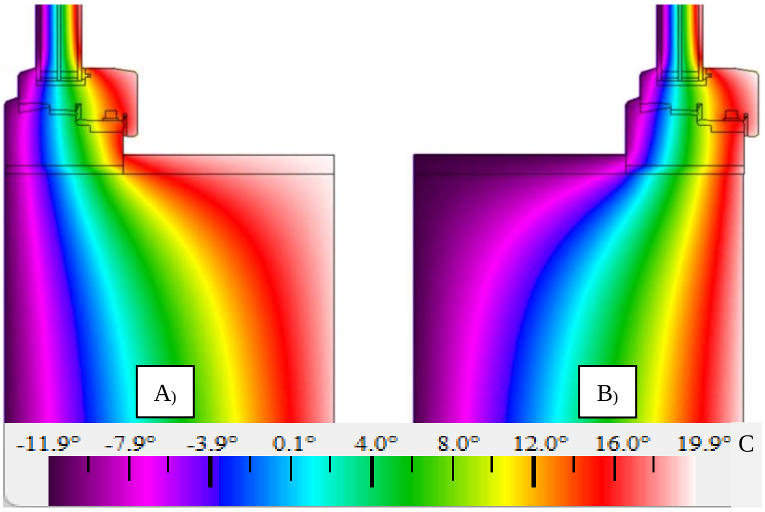

Fig. 2. Temperature field 2D model (HW)
A) exterior position – 62.75 mm, B) interior position – 287.75 mm.

RESULTS AND DISCUSSION

Individual models of window installation position in the wall construction were used to create a graphic illustration of the course of linear thermal transmittance of window installation. The graphic illustration of the Ψ_i development also includes the temperature development in the construction. This enables us to compare the window position with the minimum value $\Psi_{i,min}$ and the position with the temperature 0°C.

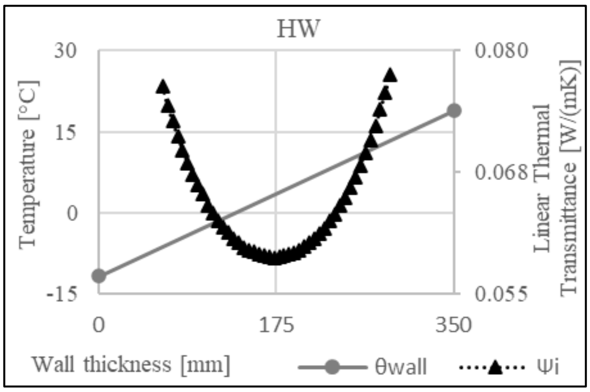

Fig. 3. Course of temperature and linear thermal transmittance for HW construction.

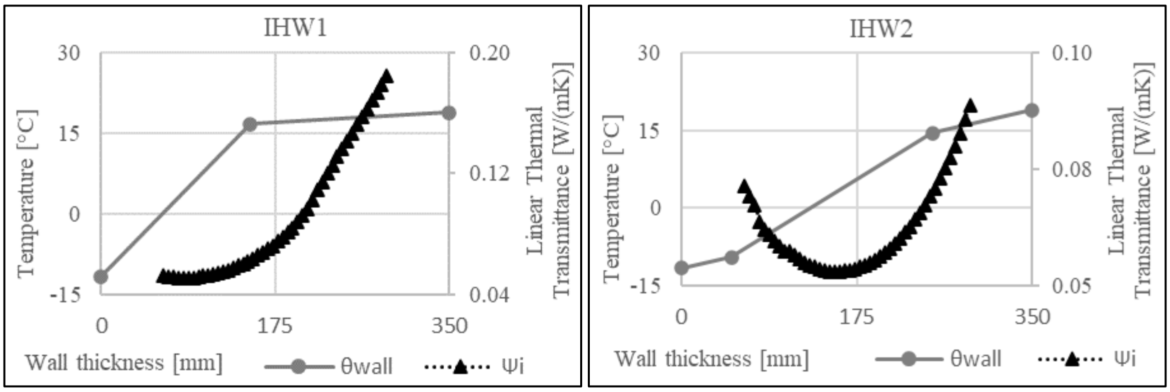

Fig. 4. Course of temperature and linear thermal transmittance for IHW1 and IHW2 constructions.

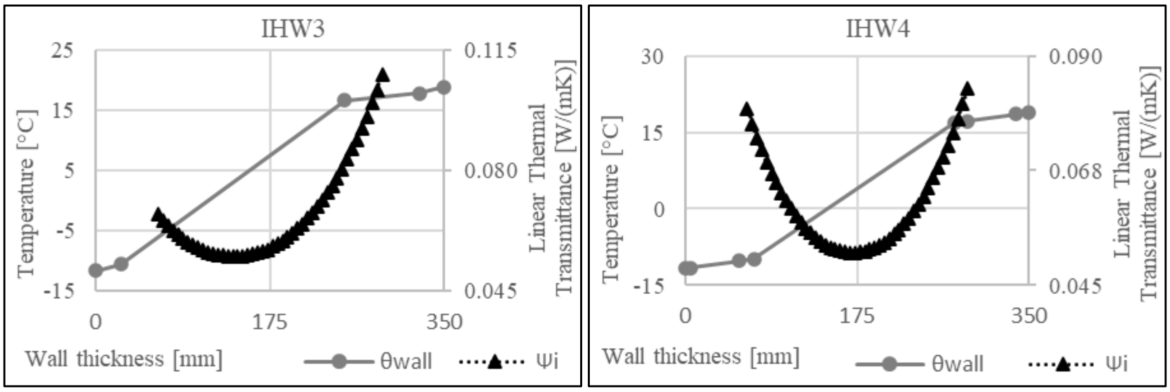

Fig. 5. Course of temperature and linear thermal transmittance for IHW1 and IHW2 constructions.

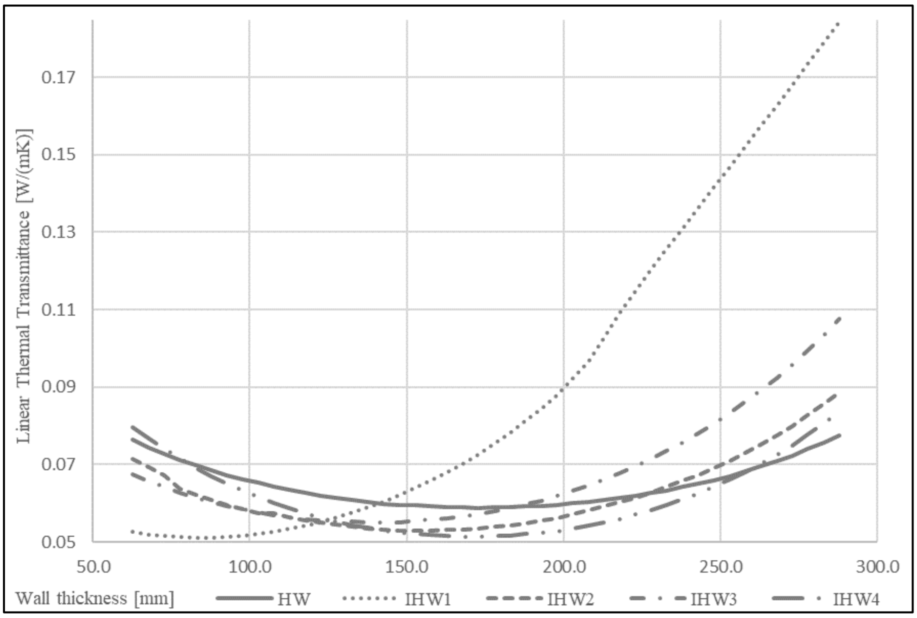

Fig. 6. Course of linear thermal transmittance for modelled constructions.

After establishing the equation for trend line of the Ψ_i values, the values of $\Psi_{i,min}$ were calculated, and the line position ($d\ \Psi_{i,min}$) in individual wall constructions was established. Subsequently, the curve direction (m) of the temperature development was calculated in these construction parts. For a precise comparison the position of 0°C isotherm ($d\ \theta_0$) was determined in the wall construction, as well as the curve direction of the temperature development at that point ($m\ \theta_0$). See Tab. 4.

Tab. 4. Values of minimal linear thermal transmittance, position of $\Psi_{i,min}$, and temperature 0°C, and curve direction (m) of temperature distribution at $\Psi_{i,min}$, and 0°C place.

Experintal wall	$\Psi_{i\text{-}min}$ [W/m.K]	$d\ (\Psi_{i,min})$ [mm] (from exterior side)	$d\ (\theta_0)$ [mm] (from exterior side)	$m\ (\Psi_{i,min})$ [-]	$m\ (\theta_0)$ [-]
HW	0.0585	173.22	133.63	87.19	87.19
IHW1	0.0507	91.90	61.67	188.92	188.92
IHW2	0.0526	155.80	129.00	119.89	119.89
IHW3	0.0543	139.68	112.21	121.10	121.10
IHW4	0.0510	171.41	145.47	130.43	130.43

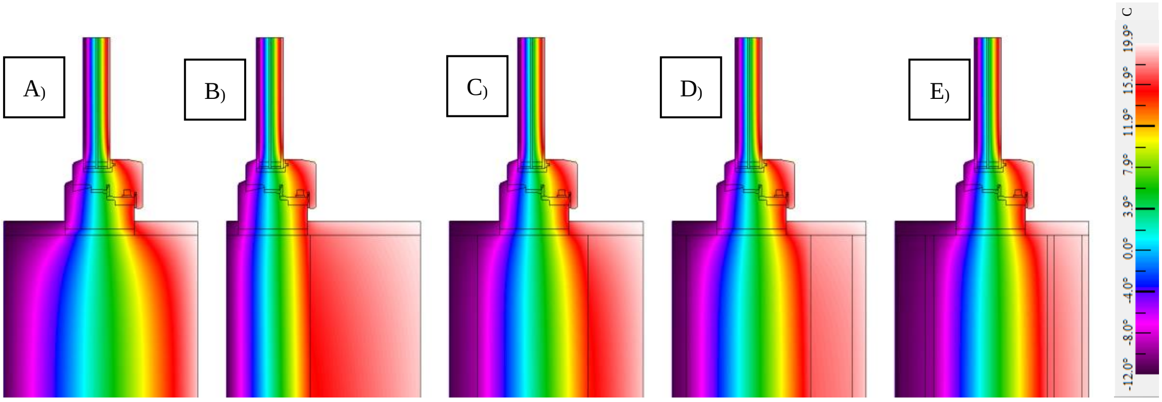

Fig. 7. Course of Temperature field 2D models, position of $\Psi_{i,min}$
A) HW, B) IHW1, C) IHW2, D) IHW3, E) IHW4.

When comparing the zero temperatures and the position of the $\Psi_{i,min}$ value, it can be seen that they are placed in the same segment of the construction temperature development. This segment can be, with all constructions, characterised by the steepest course of the temperature change. This implies that the construction parts have the biggest thermal resistance, i.e., it is the location of the main thermo-insulation component of the composition. When comparing the positions of $d\Psi_{i,min}$ and $d\theta_0$, their dependence represented by the linear correlation coefficient (r = 0.986) can be seen. This can lead to a conclusion that the position of $\Psi_{i,min}$ shows almost perfect direct proportion relative to the position of the zero temperature in the wall construction. Their positions vary in the range between of 7 – 12 % when the temperature gradient is 32°C, whereas a composite wall has slighter difference, and a homogeneous wall shows a more prominent difference. See Tab. 5.

Tab. 5. Distance between temperature 0°C and minimum linear thermal transmittance, and curve direction of temperature distribution at place 0°C.

Experintal wall	Δd (θ_0 - Ψ_{min}) [mm]	Δd (θ_0 - Ψ_{min}) [%]	m (θ_0) [-]
HW	39.60	11.31	87.19
IHW1	30.22	8.64	188.92
IHW2	26.80	7.66	119.89
IHW3	27.47	7.85	121.10
IHW4	25.93	7.41	130.43

When comparing only composite walls, the position of the minimum value $\Psi_{i,min}$ and the curve direction of the temperature development in the position of this value shows linear correlation at the level of r = 0.89. This indicates a great direct proportion of the temperature change and linear thermal transmittance. However, the higher the number of layers is the less accurate the correlation is. In addition, when adding the homogeneous wall, the linear correlation indicates a mean inverse proportion of the values (r = -4.415).

CONCLUSIONS

The hypothesis that the position of $\Psi_{i,min}$ depends on the steepness and the course of temperature development in the construction, which was set in the study of Nôta and Danihelová (2021) cannot be confirmed, based on these data. On the contrary, the direct proportion can be rejected. Nevertheless, it can be concluded that with the steady-state border conditions and overall temperature gradient of 32°C, the best place for window installation is located at 7 – 12 % of the overall wall thickness towards the interior, measured from the position of the 0°C temperature in the studied construction. The data are conditioned by the fact that the window installation detail is not modified in any way, e.g., by overlying the window frame by exterior insulation. Such modifications change the conditions and must be assessed individually.

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