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THERMAL DESIGN OF EXTERIOR WALLS MADE OF WOODEN BEAMS

PROJEKTOWANIE CIEPLNE PRZEGRÓD ZEWNĘTRZNYCH Z BALI DREWNIANYCH

Abstract

In the paper were shown the calculation results of thermal parameters of exterior walls made of wooden beams and their joints. The selected joints of wooden beam walls were analysed numerically. On the basis of the calculation and analyses, an evaluation was made according to the requirements formulated in the Regulation [1] and the directives of the National Centre for Environment Protection and Water Management [2] concerning buildings of NF15 and NF40 standards.

Keywords: *beam*, *hydro-thermal analysis*

Streszczenie

W artykule przedstawiono wyniki obliczeń parametrów cieplnych ścian zewnętrznych z bali drewnianych i ich złączy. Przeprowadzono analizę numeryczną wybranych złączy ścian z bali drewnianych. Na podstawie obliczeń i analiz dokonano oceny wg wymagań sformułowanych w Rozporządzeniu [1] oraz wytycznych Narodowego Funduszu Ochrony Środowiska i Gospodarki Wodnej [2] w zakresie budynków w standardzie NF15 i NF40.

Słowa kluczowe: *bale drewniane*, *analiza cieplno-wilgotnościowa*

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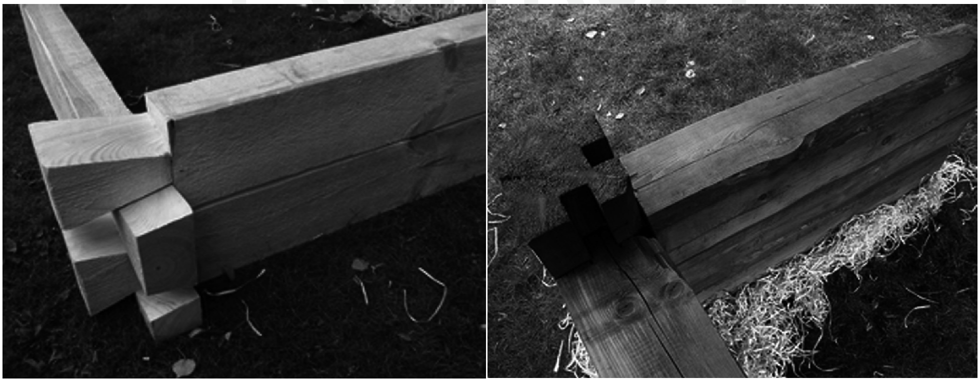
1. Introduction

A building and especially its casing, in an essential manner, take part in providing thermal comfort for the needs of humans, separating the unfavourable and constantly changing external environment from the interior. It is the wall construction that shapes the physical parameters of a particular building, and this cannot be accidental. Undoubtedly, the most popular in Poland is masonry technology. We can distinguish single and multi-layer walls in which some layers fulfil a construction function and others for insulation. However, it can be noticed that on the Polish market, there is a growing offer of housing utilising wooden technology. The material used for the main construction of such houses is spruce or pine wood. Depending on the applied wood type, humidity and thermal insulation, the insulation properties can vary. Every year, specialised companies erect about four thousand single-family houses using wooden frame technology. Additionally, there are approximately one thousand more built from solid and insulated beams. Thus, in a period of one year, five thousand houses of wooden construction are built. Development of this kind of construction is a result of investor belief in its energy-saving and ecological properties. Most often, two basic construction systems are used for erecting outer walls made from solid beams:
– Quoin construction,
– Vertical-post beam construction [3].

a) b)



quoin construction — vertical-post beam construction

Fig. 1. Example of construction system of wooden beam walls [4]

Often, because of thermal protection requirements, buildings are made of insulated solid beams. In a subsequent part of the article, calculations of the thermal parameters of solid wooden beam and insulated beam walls will be shown.

In the following of the paper presents the calculation of the thermal parameters of the external walls of solid and isolated beams.

2. Own tests and calculations

At the first stage of calculations of thermal transmittance U_c [W/(m²·K)], two variants of outer walls of wooden beams were selected (Fig. 2):
- variant I (outer wall of solid beams),
- variant II (outer wall of insulated beams).

Calculations were done according to procedure PN-EN ISO 6946:2008 [5].

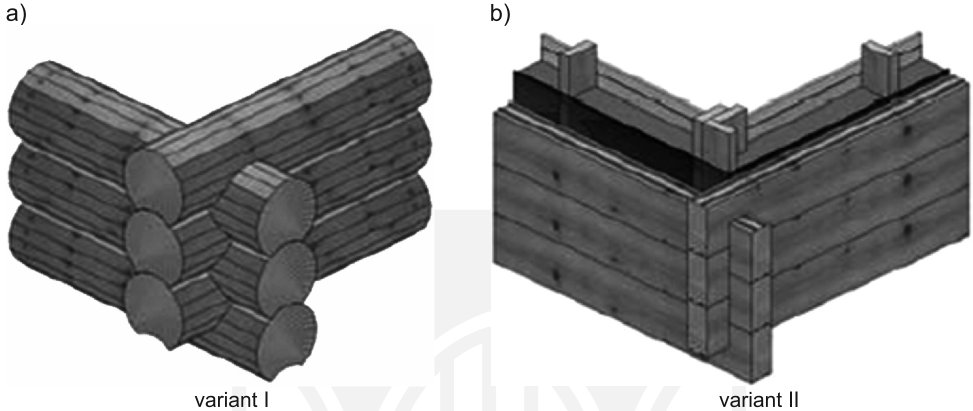


Fig. 2. Example of material solutions of walls from wooden beams [3]

For the second stage of calculations, 6 joints of the outer walls of the wooden beams analysed in the two variants were chosen (Fig. 2):
- connection of outer walls in the corner (M1),
- connection of the outer wall with a window in a cross section of a window frame (M2),
- connection of the outer wall with a window in a cross section of the breast of a window (M3),
- connection of the outer wall with window in a cross section of a wall rim (M4),
- connection of the outer wall with window in a cross section of a wall plate (M5),
- connection of the outer wall with roof in a cross section of a wall rim and lintel (M6).

Calculations of the basic parameters of thermal bridges were done:
- linear thermal transmittance Ψ [W/(m·K)] according to inside measurements (Ψ_i) and outside measurements (Ψ_e); in the case of bridge M4, M5 and M6, branch thermal transmittance concerning heat loss by corresponding parts of the connection was also defined,
- minimal temperature on an inside partition surface at the thermal bridge $t_{min.}$ [ºC],
- temperature factor f_{Rsi} [–] on the base of minimal temperature t_{min} [ºC].

The following assumption were made for calculation:
- the building was localised in zone III – temperature of outside air t_e = –20ºC, temperature of inside air t_i = + 20ºC,
- values of the thermal conductivity coefficients of building materials λ [W/(m·K)] were assumed based on tables in [6, 9],

– thermal transmittance U_c [W/(m^2·K)] was calculated according to PN-EN ISO standard No 6946:2008 [5],
– conditions of heat reception on the inside and outside surface of a partition were assumed according to PN-EN ISO 6946:2008 [5] for calculation of heat flux and according to PN-EN ISO 13788:2003 [7] for calculation of temperatures and temperature factor f_{Rsi},
– modelling of the analysed connections was done according to principles formulated in PN-EN ISO 10211:2008 [8].

The procedures of calculation of the construction connection require setting principles of modelling, which means setting the geometric criteria, an instruction for setting the heat conductance of materials, margin conditions, manner and method of calculations and the methodology of the setting of temperature distribution [9].

Calculation by use of the TRISCO computer program is possible after definition of geometrical models. They can be obtained by dividing the building into many parts using the so-called cutting planes. The section should be created in such way that the results gained by the assumed models do not differ substantially from the results that are obtained when treating the building as a whole. Each geometric model of a connection consists of a central part or parts, side parts and, if necessary, a base. A single model is always limited by section planes and can contain more than one heat bridge. Below is shown the detailed procedure of setting the parameters of an outer wall connection with the roof in a cross section of a wall rim and lintel with a window (Fig. 3).

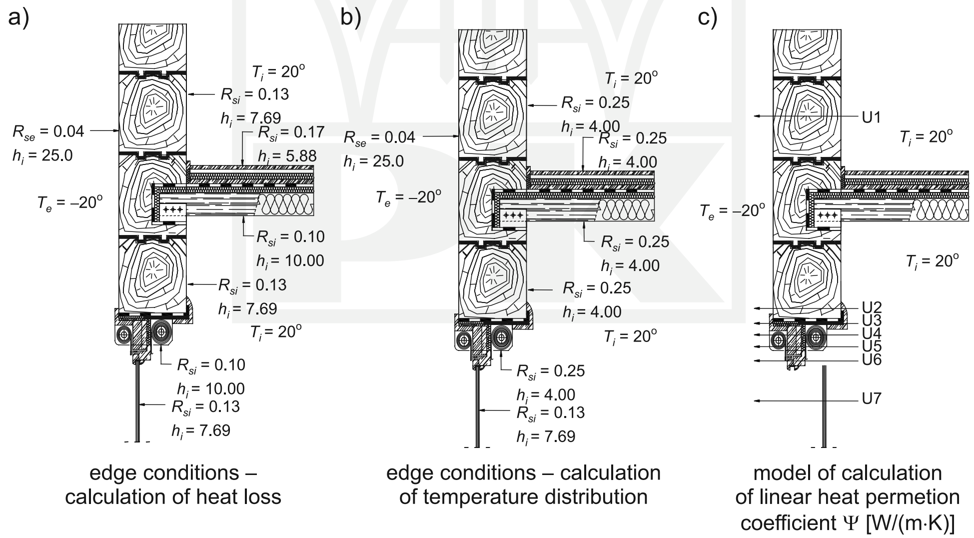


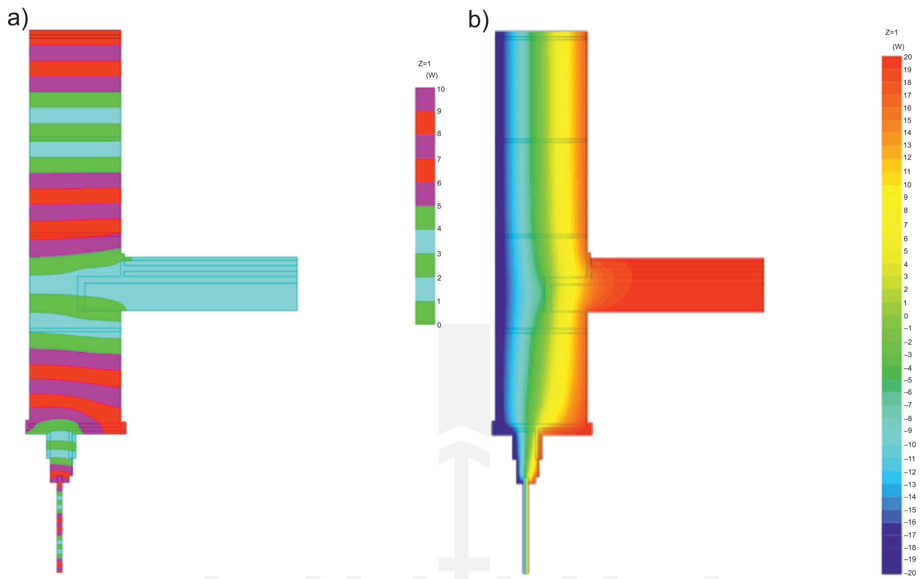
Fig. 3. Connection of an outer wall of wooden beams with a roof in a cross section of a wall rim and lintel with a window [3]

Based on the performed calculations using the TRISCO program, the values of inflow heat flux were defined as:

– window wood surface $\Phi_O = 27.83$ W, $L_O^{2D} = 0.695$ W/(m·K),

– lower part of a connection (below roof surface) $\Phi_d = 9.05$ W, $L_d^{2D} = 0.226$ W/(m·K),

– upper part of a connection (above roof surface) $\Phi_g = 16.05$ W, $L_g^{2D} = 0.266$ W/(m·K).



Lines of heat flux (adiabates)

Temperature distribution in a connection – isotherms

Fig. 4. Results of the numeric analysis of the connection [3]

Next were defined the values of linear heat permeation coefficient Ψ_i [W/(m·K)] (according to outer measurements), defined according to the procedures described in [6, 9], for a particular parts of a connection:

– branch thermal transmittance through a window: $\Psi_{iO} = 0.056$ [W/(m·K)],
– branch thermal transmittance through a lower part of the connection: $\Psi_{id} = 0.076$ [W/(m·K)],
– branch thermal transmittance through an upper part of the connection: $\Psi_{ig} = 0.022$ [W/(m·K)],
– linear thermal transmittance for the whole connection: $\Psi_i = 0.154$ [W/(m·K)].

In the range of humidity parameters, the minimal temperature $t_{min.}$ [ºC] in the connection and temperature factor f_{Rsi} [–] were set:

– minimal temperature in the connection was set based on calculations using the TRISCO computer program – $t_{min.}$ 15.95ºC,
– the value of the temperature factor is $f_{Rsi} = 0.898$.

Based on the calculations of a particular connection, it is possible to work out catalogue cards of sections made of wooden beams necessary for calculations and heat and humidity analyses. The detailed results of the calculations of selected connections are presented in Table 1.

Table 1

Results of the physical parameters of selected connections of walls made of wooden beams

Heat bridge	**variant I** (U_c = 0.287 [W/(m²·K)])				**variant II** (U_c = 0.195 [W/(m²·K)])			
	Solid pine beam 53 cm thick				Solid pine beam 27 cm thick Mineral wool 15 cm thick GKF board 2.2 cm thick			
	Ψ_i [W/(m·K)]	Ψ_e [W/(m·K)]	t_{min} [ºC]	f_{Rsi} [–]	Ψ_i [W/(m·K)]	Ψ_e [W/(m·K)]	$t_{min.}$ [ºC]	f_{Rsi} [–]
M1	0.06	–0.27	13.32	0.83	0.04	–0.15	15.25	0.88
M2	0.07	0.07	13.19	0.83	0.07	0.07	14.91	0.87
M3	0.07	0.07	13.32	0.83	0.06	0.06	14.57	0.86
M4	Ψ_i = 0.04 Ψ_{id} = 0.01 Ψ_{ig} = 0.03	Ψ_e = –0.05 Ψ_{ed} = –0.01 Ψ_{eg} = –0.04	16.84	0.92	Ψ_i = 0.05 Ψ_{id} = 0.06 Ψ_{ig} = -0.01	Ψ_e = –0.06 Ψ_{ed} = –0.03 Ψ_{eg} = –0.03	16.99	0.92
M5	Ψ_i = 0.07 Ψ_{iD} = 0.02 $\Psi_{iŚ}$ = 0.05	Ψ_e = –0.15 Ψ_{eD} = –0.03 $\Psi_{eŚ}$ = –0.12	14.79	0.87	Ψ_i = 0.09 Ψ_{iD} = 0.05 $\Psi_{iŚ}$ = 0.04	Ψ_e = -0.09 Ψ_{eD} = –0.07 $\Psi_{eŚ}$ = –0.02	14.62	0.87
M6	Ψ_i = 0.15 Ψ_{iO} = 0.06 Ψ_{id} = 0.08 Ψ_{ig} = 0.02	Ψ_e = 0.05 Ψ_{eO} = 0.04 Ψ_{ed} = –0.05 Ψ_{eg} = 0.06	13.89	0.85	Ψ_i = 0.12 Ψ_{iO} = 0.06 Ψ_{id} = 0.04 Ψ_{ig} = 0.02	Ψ_e = 0.06 Ψ_{eO} = 0.06 Ψ_{ed} = 0.03 Ψ_{eg} = –0.03	13.38	0.83

Denotation concerning branch coefficients of heat permeation coefficient:
Ψ_{id} – linear thermal transmittance of lower connection part [W/(m·K)],
Ψ_{ig} – linear thermal transmittance of lower connection part [W/(m·K)],
Ψ_{iD} – linear thermal transmittance of the roof [W/(m·K)],
$\Psi_{iŚ}$ – linear thermal transmittance of lower connection part and outer wall [W/(m·K)],
Ψ_{iO} – linear thermal transmittance of the window [W/(m·K)].

3. Calculation results analysis

The basic characteristic parameters of outer walls of wooden beams and their connections are:

– thermal transmittance U_c [W/(m²·K)], defining the heat loss through a flat (solid) outer wall,
– linear thermal transmittance Ψ_i [W/(m·K)], defining additional heat loss resulting from the existence of heat bridges,
– temperature factor f_{Rsi} [–], serving the evaluation of condensation on the inside surface of a partition (risk of fungi and mildew development) in the location of a heat bridge.

Based on the performed calculations and analyses, the following conclusions can be formulated:

– outer walls of housing made of wooden beams must fulfil the same requirements of thermal protection that are set for all outer partitions. According to regulations binding until the end of 2013 ($U_{c(\max)}$ = 0.30 [W/(m^2·K)]), walls made of homogenous wooden beams should have an average thickness of 53 cm. However, according to more strict requirements from 2014 ($U_{c(\max)}$ = 0.25 – 0.20 [W/(m^2·K)]), their thickness should be a minimum of 78 cm. In accordance with the above, an alternative construction of a wall of pine beam 27 cm thick with a 15 cm thick layer of mineral wool insulation from the inside was proposed. Accordingly, was suggested an alternative construction of a pine beam wall of thickness 27 cm with a layer of 15 cm insulation of mineral wool inside. tools (professional computer programs) let us establish correct heat loss and temperature distribution in the analysed connections (Table 1).
– the values of the linear heat permeation coefficient (Ψ_i) according to PN-EN ISO 14683:2008 [10] are approximate values (without taking into account the thickness of an outer partition and thermal insulation); in the table are gathered the results of the (Ψ_i) parameter for the selected connections obtained according to own calculations and based on PN-EN ISO 14683:2008 [10].
– Based on a value of thermal factor f_{Rsi}, it can be stated that in the analysed connections (Table 1), there is no risk of development of mildew and fungi. In all analysed connections, there is a condition observed for avoiding condensation on the inner partition surface (risk for mildew and fungi development) ($f_{Rsi} \geq f_{Rsi(\text{kryt.})}$). The edge (critical) value of the temperature factor, concerning the parameters of internal and external air, of the analysed calculation variants are $f_{Rsi(\text{kryt})}$ = 0.778.
– The analysed connections of walls of wooden beams (except the M6 connection) fulfilled the requirements of the guidelines from the National Centre for Environment Protection and Water Management [2] in the range of buildings of the NF40 standard, as they are characterise with values of Ψ [W/(m·K)] smaller than $\Psi_{\max.}$ = 0.10 [W/(m·K)] (in the case of balcony boards $\Psi_{\max.}$ = 0.20 [W/(m·K)]). The connections do not fulfil the requirement within the range of buildings of the NF15 standard ($\Psi_{\max.}$ = 0.01 [W/(m·K)]).

Table 2

Results of physical parameters of selected connections of walls made of wooden beams

Analysed connections of outer walls	Values of linear thermal transmittance Ψ_i [W/(m·K)]			
	Own calculations		Catalogue cards PN-EN ISO 14683:2008 [10]	
	variant I	variant II		
M1	0.06	0.04	(C4)	0.10
M2	0.07	0.07	(W10)	0.10
M3	0.07	0.06	(W10)	0.10
M4	0.04	0.05	(IF4)	0.80

*) for analyses, catalogue cards for framing wooden walls were taken according to PN-EN ISO 14683:2008 [10]
*) for analyses, only the M1, M2, M3, M4 connections were chosen (in the PN-EN ISO 14683:2008 [10] standard, there is lack of equivalents for M5, M6 connections)

4. Conclusions

The design of exterior walls of buildings made of wooden beams is a complex issue. Comprehensive evaluation of a building casing (outer partitions) should concern the partitions as well as their connections. The selection of construction and insulating materials should not be accidental, but should be based on detailed calculations and analyses. What is particularly significant is the correct design of the outer partition connection when it comes to minimising heat loss and eliminating heat loss and condensation on the inner partition surface.

Besides of heat and humidity issues of outer partitions of wooden beams and their connections there is a need to work out particular detailed design and executive guidelines within the range of acoustic insulation and fire protection.

References

[1] Regulation of the Ministry of Transport, Building and Marine Economy amending the regulation on the technical conditions that buildings and their location should fulfil.

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