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COST AND THERMAL - TECHNICAL OPTIMIZATION OF WOODEN CONSTRUCTION IN THE PASSIVE STANDARD

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ABSTRACT

The article describes the thermal - technical point of four wooden constructions in the passive standard, when one of the constructions was tested in an accredited laboratory 1007.4 thermal - technical diagnostics. The sample was made according to the laboratory´s requirement 1700 x 1700 mm and tested according to the test harmonized standard ČSN EN ISO 8990: 1994 Thermal insulation - Determination of thermal transmission properties in the steady state temperature - calibration and guarded hot box. The object of the tests was to declare heat thermal transmittance value - U value based on the measured surface temperatures (θsi) and energy consumption. Thermal resistance and thermal transmittance were empirically calculated according to the measured and standard values in accordance of the CSN 73 0540: 2011. Thermal protection of buildings. The other three structures will be structurally modified to reflect this normative value $U_{pas\ 20}$ = 0.12 - 0.18 (W.m^{-2} . K^{-1}) and ensure their cost optimization.

KEYWORDS: Wooden construction, insulation, passive standard, low - energy buildings, coefficient of heat thermal transmittance value, thermal resistance.

INTRODUCTION

In an effort to reduce greenhouse gas emissions generated in the construction industry, particularly residential construction, constructions and concepts with improving thermal insulation properties are created. They use energy more efficiently (Lombard et al. 2008). To create such functioning objects several factors must be met. One of the factors is to maintain the best possible thermal insulation properties of the building envelope, which is achieved both by the use of suitable materials and their proper combination and connection. Innovative concept of construction of the building envelope is given below. When used in practice this concept will improve the thermal insulating properties of the construction and in compliance with the other principles of the construction of low-energy buildings (i.e. air tightness, use of a heat recovery ventilation, etc.) reduces the overall energy consumption of the building.

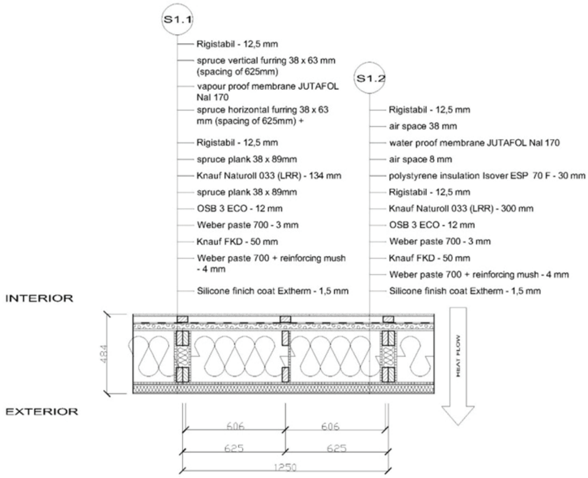
Heat-insulating properties of the construction are represented, among others, by heat using thermal transmittance coefficient U and thermal resistance R. These two values were determined in the practical part of this project. For purposes of measuring guarded hot box according to DIN EN ISO 8990: 1994 was used to determine the heat transfer coefficient U. This method is commonly used in the world for detection of insulation properties of building components and structures (Asdrúbal and Baldinelli 2011; Gao et al. 2004; Burch et al. 1990). Nussbaumer et al. (2006) used a similar method to determine thermal transmittance of structures from vacuum insulation and concrete. Measured values ranged from approximately 0.16 to 0.18 W.(m^{-2}•K^{-1}). In another study Wakili and Tanner (2003) present results of three methods to determine the value of U. One was tested in a warm cabinet according to EN ISO 8990: 1994 and the other two methods were theoretical calculations according to EN 1745: 2008 during examination of the walls made of perforated porous clay bricks. The results of this study showed the measured value of coefficient U at approximately 0.115 to 0.128 W.(m^{-2}•K^{-1}) and calculated values were by approximately 3-5 % higher. Skujans et al. (2007) used equipment similar to heat cabinet (also according to the aforementioned standards) for measurement of thermal transmittance. There has also been steady and controlled flow of heat through walls made by using plaster and polystyrene foam. The measured U-value ranged from 0.36 ± 0.10 W.(m^{-2}•K^{-1}). The lowest recommended values of coefficient U for passive buildings are reported in the range from 0.12 to 0.18 [W.(m^{-2}•K^{-1})] (CSN 73 0540-2: 2011).

MATERIAL AND METHODS

The proposed structural systems respect current trends in the construction and technical design possibilities of wood. The proposed systems meet all the requirements of technical standards in terms of stability, endurance, thermal and technical properties of the shells of buildings, fire resistance and requirements for hygienic safety of living space.

Construction 1

First designed and tested construction system is a construction system of perimeter walls and partition walls made of wood. Construction system consists of small sized panels that are



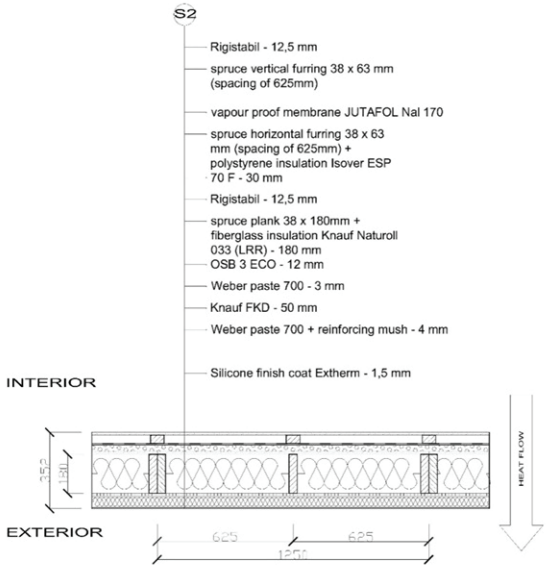
partially completed (sheathed OSB 3 to 12 mm thickness boards or prefabricated wooden frames, which will sheathed with Rigistabil 12.5 mm thickness boards on construction site).

Filling of the wall interior is made from mineral insulation Knauf Naturoll 033. The basic dimensions of panels for perimeter walls are 1250 x 89 x 2480, 1250 x 89 x 2510, 1250 x 89 x 2850 mm.

Construction 2

The second proposed construction system is a construction system of wood-based perimeter walls. Construction system consists of small sized panels that are partially completed (sheathed with OSB 3-12 mm thickness boards, which will be sheathed with Rigistabil 12.5 mm thickness boards on construction site).

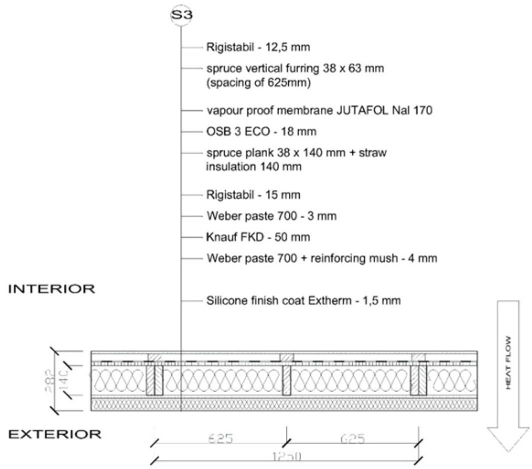
Filling of the wall interior is made from mineral insulation Knauf Naturoll 033. The basic dimensions of panels for perimeter walls are 1250 x 180 x 2480, 1250 x 180 x 2510, 1250 x 89 x 2850 mm.



Construction 3

The third construction system is construction system of perimeter walls made of wood. Construction system consists of small sized panels that are partially completed (sheathed Rigistabil 15 mm boards, which will sheathed with OSB 3-18 mm thickness boards on construction site).

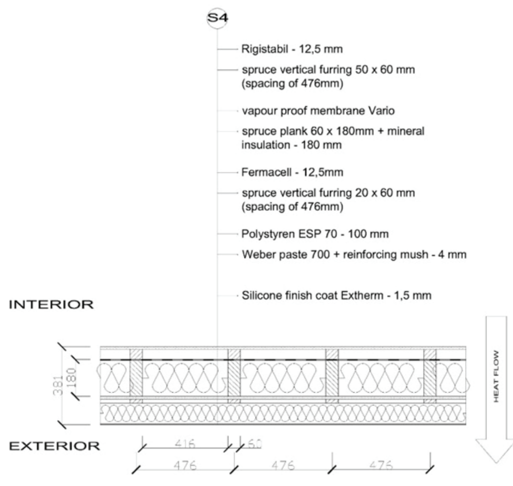
Filling of the wall interior is made from mineral insulation from compressed straw. Dimensions of basic panels for perimeter walls are 1250 x 140 x 2480, 1250 x 140 x 2510, 1250 x 140 x 2850 mm.



Construction 4

The fourth designed construction system is construction system of perimeter walls made of wood. Construction system consists of wall panels that are partially completed (sheathed only with Fermacell boards - 12.5 mm thickness, which will be complete on the site).

Filling of the wall interior is made from mineral insulation with heat transmittance 0.04 W.(m^{-2}•K^{-1}). The dimensions of the basic modules are based on the size and layout of the structure of the house. The maximum length is up to 13.000 mm.



Methods

- Draft of perimeter wall construction of a passive standard.
- Selection of suitable insulating material with adequate heat transfer into the circumferential wall.
- Measurement of heat thermal transmittance value of perimeter wall construction in the

protected heat cabinet. Test sample of perimeter wall was manufactured by Jaroslav Blažek - Joinery (Fig. 1). Wall was subsequently transferred to an accredited testing laboratory CSI a.s. where the sample wall measuring 1.700 x 1.700 mm was installed in protected hot box in accordance with standard ČSN EN ISO 8990: 1994 (Fig. 2). Upon completion of the test, part of wall cross-section subsample was tested for moisture determination according to ČSN EN ISO 12570: 2011 (Fig. 3) and the actual determination of moisture content of samples (Appendix 3).

Fig.1: Photo of tests (Blažek).

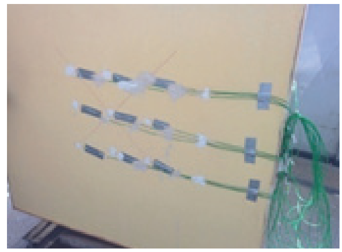


Fig. 2: Photo of tests (Školník).

- Empirical calculation of heat thermal transmittance value of perimeter wall construction.
- Proposal of three optimized constructions of perimeter walls for passive houses.
- Selection of suitable insulating materials with appropriate thermal transmittance value to the circumference walls.
- Empirical calculation heat thermal transmittance value the three proposed perimeter wall constructions.
- Calculation of the economic performance of the proposed perimeter wall constructions.
- Evaluation of the calculated results.

RESULTS AND DISCUSSION

Experimental determination of thermal resistance

The test was carried out in three weeks. Surface temperatures were measured through the heat flux density using electrodes positioned on the surface. Three measurements were carried out with a deviation of 5 %. Using the measured data thermal resistance and heat transfer coefficient was calculated (Tab. 1).

Tab. 1: Results of the determination of thermal resistance.

Measurement number	Thermal resistance R ($m^2.K.W^{-1}$)	Heat thermal transmittance value U ($Wm^{-2}K^{-1}$)
1	11.10	0.090
2	11.86	0.084
3	11.65	0.086
Average	11.54	0.087

Note: Measurement uncertainty ± 5 %.

Determination of moisture

After measurement of thermal resistance, samples for determination of moisture content were taken from the individual layers of composition of the test panel. These samples were dried in a ventilated oven at 105±2°C to constant weight.

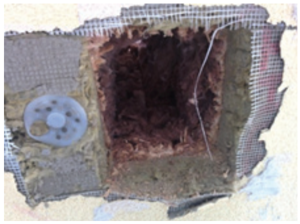


Fig. 3: Photo of tests (Školnik).

Tab. 2: Results of the determination of the moisture content.

Layer	Moisture materials u (%)
Isover EPS 70 F	0.9
Rigistabil	0.2
OSB3 board	9.1
Knauf LRR 1. layer	1.4
Knauf LRR 2. layer	0.7
Knauf FKD, glue	1.6

Note: uncertainty in determining the mass of samples is ± 0.1 g.

Determination of thermal transmittance by using empirical method

Calculation of the upper limit of the thermal resistance in heat heterogeneous constructions.

$$\frac{1}{R'_T} = \frac{f_a}{R_{Ta}} + \frac{f_b}{R_{Tb}} + \frac{f_c}{R_{Tc}} + \frac{f_d}{R_{Td}} + \frac{f_e}{R_{Te}} \qquad (1)$$

$R'_T = 10.526\ m^2 \cdot K \cdot W^{-1}$

Calculation of the lower limit of thermal resistance in heat heterogeneous constructions.

$$\frac{1}{R_j} = \frac{f_a}{R_{aj}} + \frac{f_b}{R_{bj}} + \frac{f_c}{R_{cj}} + \frac{f_d}{R_{dj}} + \frac{f_e}{R_{ej}} \qquad (2)$$

$R'_T = 10.526\ m^2 \cdot K \cdot W^{-1}$

$$R_T = \frac{R'_T + R''_T}{2}$$

$$R''_T = R_{si} + R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{se} \qquad (3)$$

$R''_T = 9.759\ m^2 \cdot K \cdot W^{-1}$

$$R_T = \frac{10.526 + 9.759}{2} = 10.143\ \mathrm{m}^2 \cdot \mathrm{K} \cdot \mathrm{W}^{-1} \qquad (4)$$

Calculation of the relative error

$$e = \frac{R'_T - R''_T}{2\ .\ R_T} \times 100\ \% \qquad (5)$$

$$e = \frac{10.526 - 9.759}{} \text{ x } 100\ \%$$

$$e = \frac{10.526 - 9.759}{20.286} \text{ x } 100\ \% = 3.78\ \%$$

$$\text{U} = \frac{1}{R_T} = \frac{1}{10.143} = 0.098\ W \cdot m^{-2} \cdot K^{-1} \qquad (6)$$

U-value measured by an accredited CSI laboratory ……….. U= 0.08 W•m^{-2}•K^{-1}
Calculated U-value according to ČSN EN ISO 6946:2008…………U = 0.098 W•m^{-2}•K^{-1}
The value measured according to a calculation is about 13 % worse than laboratory tests.

$$0.098 < 0.12\ \text{W}\cdot m^{-2}\ .\ K^{-1} < 0.18\ \text{W}\cdot m^{-2} \cdot K^{-1} \qquad (7)$$

The construction is thermally overdesigned by about 40 % compared to the declared U value. It is out of defined range for recommended values of thermal transmittance coefficient for passive buildings according to ČSN 73 0540:2011.

Empirical calculation of optimized constructions

After measuring and subsequent calculation of the heat transfer coefficient for the first proposed construction three other constructions of perimeter walls for passive standard construction were designed. These structures have been optimized at the recommended thermal transmittance value of the wooden construction from 0.18 to 0.12 W•m^{-2}•K^{-1} according to ČSN 73 0540:2011.

Construction **2**

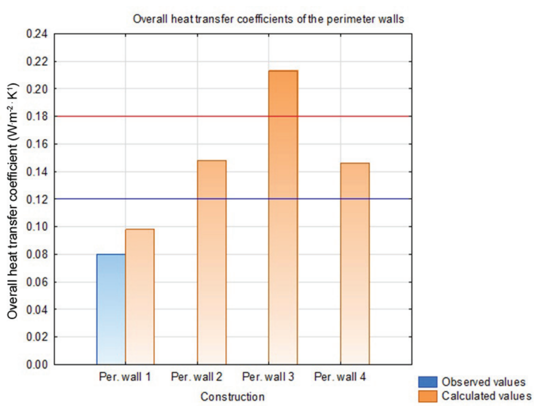
Calculated U-value	U = 0.148 W•m^{-2}K^{-1}
Value adjusted by 13 %	U = 0.129 W•m^{-2}K^{-1}

Construction **3**

Calculated U-value	U = 0.213 W•m^{-2}K^{-1}
Value adjusted by 13 %	U = 0.185 W•m^{-2}K^{-1}

Construction **4**

Calculated U-value	U = 0.146 W•m^{-2}K^{-1}
Value adjusted by 13 %	U = 0.127 W•m^{-2}K^{-1}



Cost efficiency

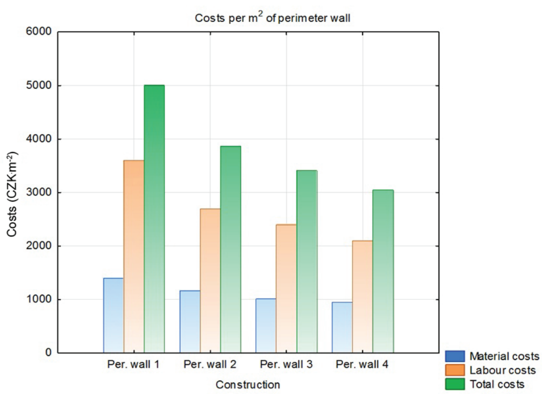
Costs of the materials were obtained from the Internet. Labor costs are determined by an expert estimate. Hourly rate was determined at 300 CZK per hour. Costs do not include VAT. When comparing the cost of square meter of construction, the most expensive was the first non-optimized construction with price 5 000 CZK·m^{-2}. It came out as the most economically intensive construction. The second construction made of small sized panels has construction costs lower by 23.8 % compared to the first. The third construction made of small sized panels has construction costs higher by 31.74 % than the first one. The fourth construction made of wall panels has about 39 % cheaper construction costs than the first one.

Perimeter construction **1**
- Material cost = 1400 CZK
- Labor costs = 12 x 300 = 3600 CZK
- Total costs = 5000 CZK

Perimeter construction **2**
- Material cost = 1161CZK
- Labor costs = 9 x 300 = 2700 CZK
- Total costs = 3861 CZK

Perimeter construction **3**
- Material cost = 1013 CZK
- Labor costs = 8 x 300 = 2400 CZK
- Total costs = 3413 CZK

Perimeter construction **4**
- Material cost = 947 CZK
- Labor costs = 7 x 300 = 2100 CZK
- Total costs = 3047 CZK



CONCLUSIONS

When comparing the proposed constructions, we came to several partial findings. Deviation of the measured and calculated values was detected for the first designed construction. After three measurements of thermal transmittance value of construction (using experimental method of thermal cabinet) measurements (0.087 $W \cdot m^{-2} \cdot K^{-1}$) were lower by 13 % than in empirical calculation (0.098 $W \cdot m^{-2} \cdot K^{-1}$). For this reason it might be assumed that measurement error is around 13 %, but this claim cannot be proved by only one test.

Because of the very low coefficient of thermal transmission which is below the recommended amount for passive houses according to ČSN 73 0540:2011 ($U_{pas\ 20}$ = 0.12 - 0.18 [$W \cdot m^{-2} \cdot K^{-1}$]) for the first construction, other three optimized constructions of the peripheral constructions were designed. Heat thermal transmittance was empirically calculated for proposed constructions. Construction number two had coefficient of (U-value) 0.148 $W \cdot m^{-2} \cdot K^{-1}$, construction number three had (U-value) 0.213 $W \cdot m^{-2} \cdot K^{-1}$ (this design has not complied with the recommended value of heat wall penetration) and construction number four had 0.146 $W \cdot m^{-2} \cdot K^{-1}$. Subsequently costs of one square meter were calculated for all four structures and the values were compared. Construction number four was evaluated as the best one with cost per m^2 lower by 39 % than the first non-optimized construction whilst meeting the recommended heat transmission.

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