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From 2016 "A" energy efficiency class buildings should be designed and built in Lithuania, as their energy consumptions are considerably less comparing with the ones that were built before. In order to meet high requirements of "A" energy efficiency class buildings should be used new energy efficient structural and insulating solutions should be made. In order to evaluate overall heat losses in these joints more exactly it is required to calculate values of heat transmission coefficients of linear thermal bridges in "A" energy class buildings.

The project of semi-detached building was chosen in order to analyse influence of linear thermal bridges for building's energy consumption as there are all kinds of linear thermal bridges which values must be calculated. Buildings energy efficiency designing program, which based on EN ISO 13790, was used to calculate building's heat losses. Heat transmission coefficients of linear thermal bridges were calculated using program THERM. Two variations were analysed: building's energy consumptions are close to the lowest point of A class requirements when building's envelopes and joints of units in joint places are the same as they are in currently built houses; and effective energy solutions of building's joints.

The results of analysis showed that requirements of "A" class can be reached using ordinary solutions for building's envelopes and joint units but if linear thermal bridges are designed like that, it makes 16 % heat losses through envelopes, and it is similar to heat losses through building's walls (17 %), furthermore, it is about 1.5 times bigger than heat losses through roof (10 %) or floors (10 %). Specific heat losses of thermal bridges make 7.80 kWh/m^2 per year. The biggest overall heat losses are through walls and windows joint thermal bridges (specific heat losses make 13.55W/K). Another significant part of heat losses comes from walls and floor joints (specific heat losses make 11.88W/K).

After solutions of buildings with energy effective building's envelopes and units joints were analysed it can be stated that overall heat losses decreased about 10 kWh/m^2 per year, it is 20 %. Heat losses through

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thermal bridges make only 3 % of overall heat losses through envelopes, it is **122** kWh/m^2 per year.
According to results of the analyse general specifications were made for designing building envelopes of “A” energy efficient class:

- The building of “A” class can be designed using ordinary solutions of linear thermal bridges, bigger heat losses through thermal bridges can be covered by increasing thickness of thermal insulating layers and using windows of better thermal behaviour but as a result the costs of building house increase too.
- When effective solutions of linear thermal bridges are used, the same energy efficiency of the building can be reached using less thermal insulating layers, windows and doors of less thermal behaviour if the building of better energy characteristics is designed.

KEYWORDS: Energy efficiency class, linear thermal bridges, overall heat losses, thermal insulation.

Introduction

A significant part of heat losses in a building can be due to thermal bridges. A thermal bridge is a part of the building envelope where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity and/or a change in thickness of the fabric and/or a difference between internal and external areas (EN ISO 10211:2008). Constructional nodes, in which most cases create linear thermal bridges, are these:

- external and internal wall corners (**Fig. 1 a, b**)
- different thickness of external wall (**Fig. 1 c**);
- the junction of outer wall and floor slab (**Fig. 2 a**);
- the junction of outer wall and window/door (**Fig. 2 b**);
- the junction of outer wall and balcony slab (**Fig. 2 c**)

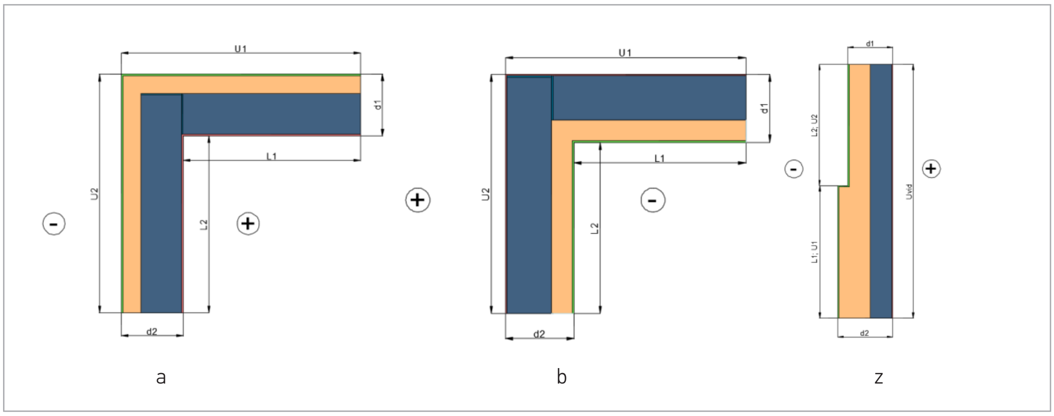


Fig. 1

Constructional nodes of linear thermal bridges: a) external wall corner; b) internal wall corner; c) different thickness of external wall

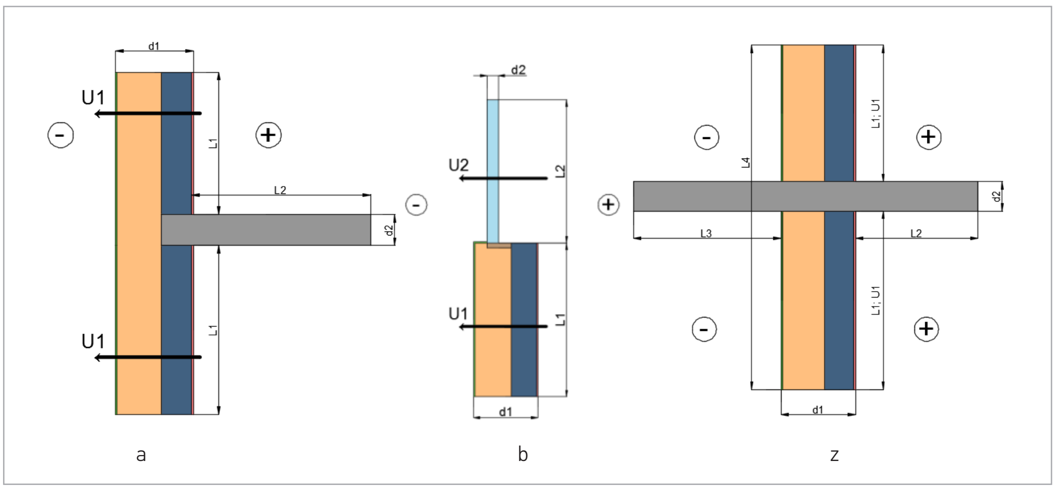


Fig. 2

Constructional nodes of linear thermal bridges: a) the junction of outer wall and floor slab; b) the junction of outer wall and window; c) the junction of outer wall and balcony slab

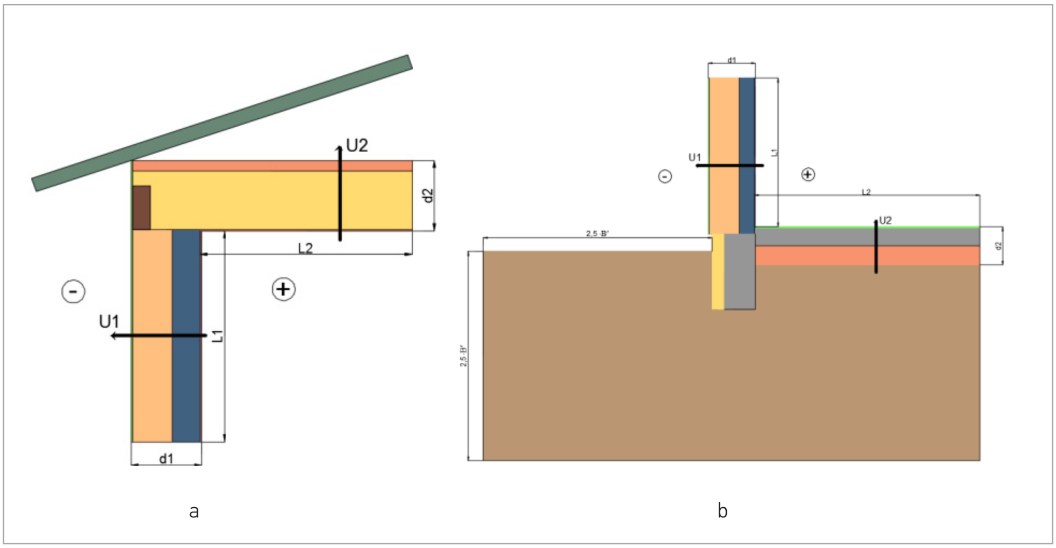


Fig. 3

Constructional nodes of linear thermal bridges: a) junction of outer wall and roof; b) the junction of outer wall and floor on the ground

_ the junction of outer wall and roof (Fig. 3 a);

_ the junction of outer wall and floor on the ground (Fig. 3 b).

According to different sources, the actual weight of thermal bridges in the energy demand of dwellings can vary from 5 to 39% (Quinten, Feldheim , 2016). Therefore, influence of linear thermal bridges for total building heat losses is significant and especially in designing "A" energy efficiency class buildings. Heat losses of building through linear thermal bridges can be significantly reduced if correct decisions in designing junctions of envelopes are chosen. Sometimes the right solution of problem nodes can determine energy efficiency class of the building.

In order to avoid large heat loss through thermal bridges their structural nodes must be responsibly resolved. Most often it becomes problematic nodes in buildings windows, balconies and foundations junction with the outer walls (Cappelletti et al. 2011, Gea et al. 2011).

Gea H. et al. (2011) were analysing impact of balcony thermal bridges. Their study showed that reducing the heat transfer through balcony slabs could benefit in terms of reducing the peak heating load by 6–16% and peak cooling load by 1–3% for scenarios simulated. The overall reduction on annual space heating energy consumption is 5–11% and less than 1% reduction for the annual space cooling energy consumption (Gea et al. 2011).

According to Ibrahim M. et al. (2014) the study in France has been found that windows offset thermal bridges energy load constitutes around 2-8% of the total house load. Applying the new coating, which thermal conductivity is 0.03-0.04 (W/m·K), reduces the windows offset thermal bridge load by about 24% to 50% (Ibrahim et al. 2014). Fig. 4 shows the windows offset thermal bridges energy load percentage of the total load of the house for 3 different cases: no coating on the thermal bridges, 1 cm coating is added, and 2 cm coating is added (Ibrahim et al. 2014).

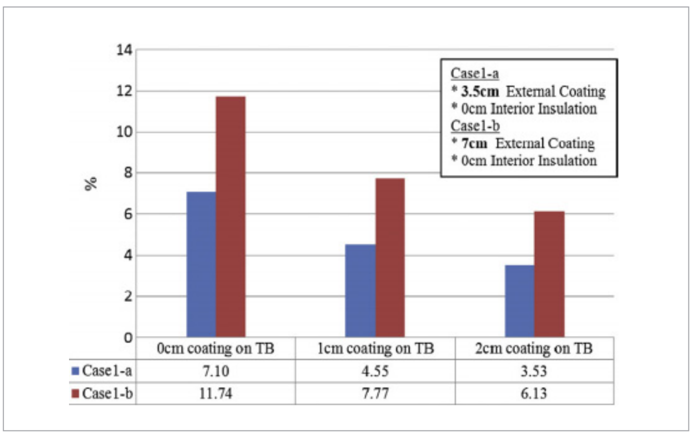


Fig. 4

Windows offset thermal bridge load percentage of the total cooling/heating (Ibrahim et al. 2014)

Calculation of thermal bridges

In Lithuania in project of energy performance classes A, A+ and A++ of buildings (their parts) must be submitted to linear thermal bridges design solutions and these bridges design heat transfer coefficients should be based on calculations (STR 2.05.01:2013).

Thermal bridges may be defined as a part of the building envelope penetrated by materials with different thermal conductivity and/or with changed thickness/amount of materials used and/or with difference between internal and external areas, according to EN ISO 10211 (Berggren and Wall 2013).

Most of Building Energy Simulation tools (BES) handle 1D heat transfer computation. The method consists in adding a term to take into account the 2D thermal bridge impact on the heat balance. Integration of thermal bridges in BES depends on the simulation tools: variation of both the surface transmission coefficient of the wall, variation of the surface or specific transmission coefficient. They can be classified in two categories:

- point thermal bridges characterized by a punctual coefficient of transmission in W/K. They are caused by a singular point in the envelope (eg. in a local fixing system);
- linear thermal bridges characterized by a linear transmission coefficient Ψ, W/m·K. They are associated to a length (intersection between two walls) (Viot et al. 2015).

The linear thermal transmittance of the thermal bridges () is calculated as in Eq. (1):

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j, \quad (5)$$

where
L_{2D} – the thermal coupling coefficient obtained from a 2-D calculation,
U_j – the thermal transmittance of the 1-D element *j*
l_j – the length of the 1-D element *j* (EN ISO 10211:2008).

Measuring of lengths and areas may be done according to three different ways: internal, overall internal or external dimensions. The differences are shown in Fig. 5 (Berggren and Wall 2013).

Are done many of studies examining thermal bridges calculation methods and modelling (Quinten et al. 2016, Berggren and Wall 2013, Martina et al. 2012, Hoffman and Schwartz 1980, Asdrubali et al. 2012, Ge and Baba 2015). In this study linear thermal bridges were calculated with program „THERM". This program is designed to calculate two-dimensional temperature fields. Ascione at al. (2013) were analysing finite element and finite volume methods of calculation and the accuracy of methods. Their study showed that these methods of calculation are reliable.

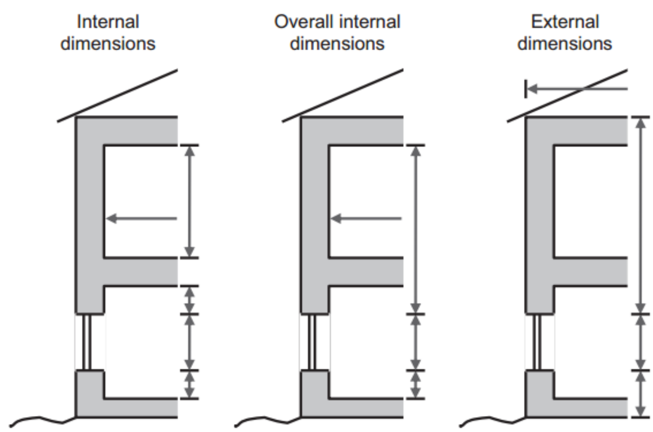


Fig. 5
Three different methods of measurement according to EN ISO 13789 (Berggren and Wall 2013).

Research object

The project of semi-detached building (**Fig. 6**.), with 310,2 m^2 of heating area was chosen to find out linear thermal bridges influence for building's energy consumption. The selected building's envelope material, heating, ventilating and hot water systems meets „A" energy efficiency class requirements.

As it is shown in **table 1**, biggest part of heat losses are through windows (20.43 kWh/(m^2·K)) and the lowest part are through doors/gates (3.46 kWh/(m^2·K)). It can be explained by analyzing the area's and thermal transmittance coefficient relation. Windows consist 99.02 m^2 area and has 1 W/(m^2·K) of thermal transmittance coefficient. While doors/gates with similar thermal transmittance coefficient but has only 22.75 m2 of area. Walls and roof consist of bigger part of area, but has 10 times lower thermal transmittance coefficient.

Fig. 6
Semi-detached building

Table 1
Building envelope area, heat transfer coefficients and heat loss through building envelope

Partition name	Area, m²	Thermal transmittance coefficient, W/(m²·K)	Heat losses of building's area, kWh/(m²·K)
Wall	346.3	0.12	8.29
Roof	237.3	0,1	4.90
Windows	99.02	1	20.43
Doors / gates	22.75	1.00 / 1.32	3.46
Floor	196.78	0.19	5.00

Results

The thermal transmittance coefficient of linear thermal bridges can be effected by making different materials installing solutions. As it is shown in **Fig. 7**, two external walls with different materials but with similar thermal transmittance coefficient were selected for calculations. The wall's thermal transmittance coefficient of linear thermal bridge which consist of -0.05 W/(m·K) was made of gypsum plaster, cavity concrete blocks and neopor EPS 70N. Other wall was made of tiles, neopor EPS 70N, silicate blocks and gypsum. The thermal transmittance coefficient of linear thermal bridge of this type of wall was -0.07 W/(m·K).

As it is shown in **Fig. 8**, two different foundation insulation types were analyzed. First example was insulated only with vertical insulation, second example was insulated with vertical and horizontal insulation. Result of heat transfer coefficient is changing from 0.17 W/(m·K) to 0.03 W/(m·K).

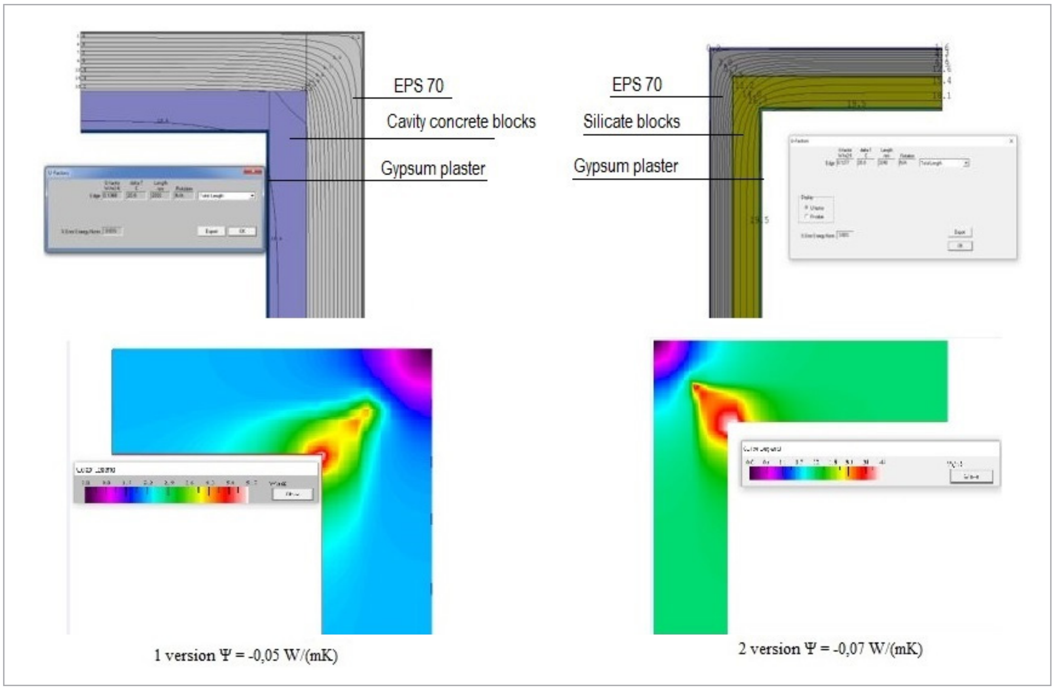


Fig. 7
Calculation results of walls external corner different insulation cases

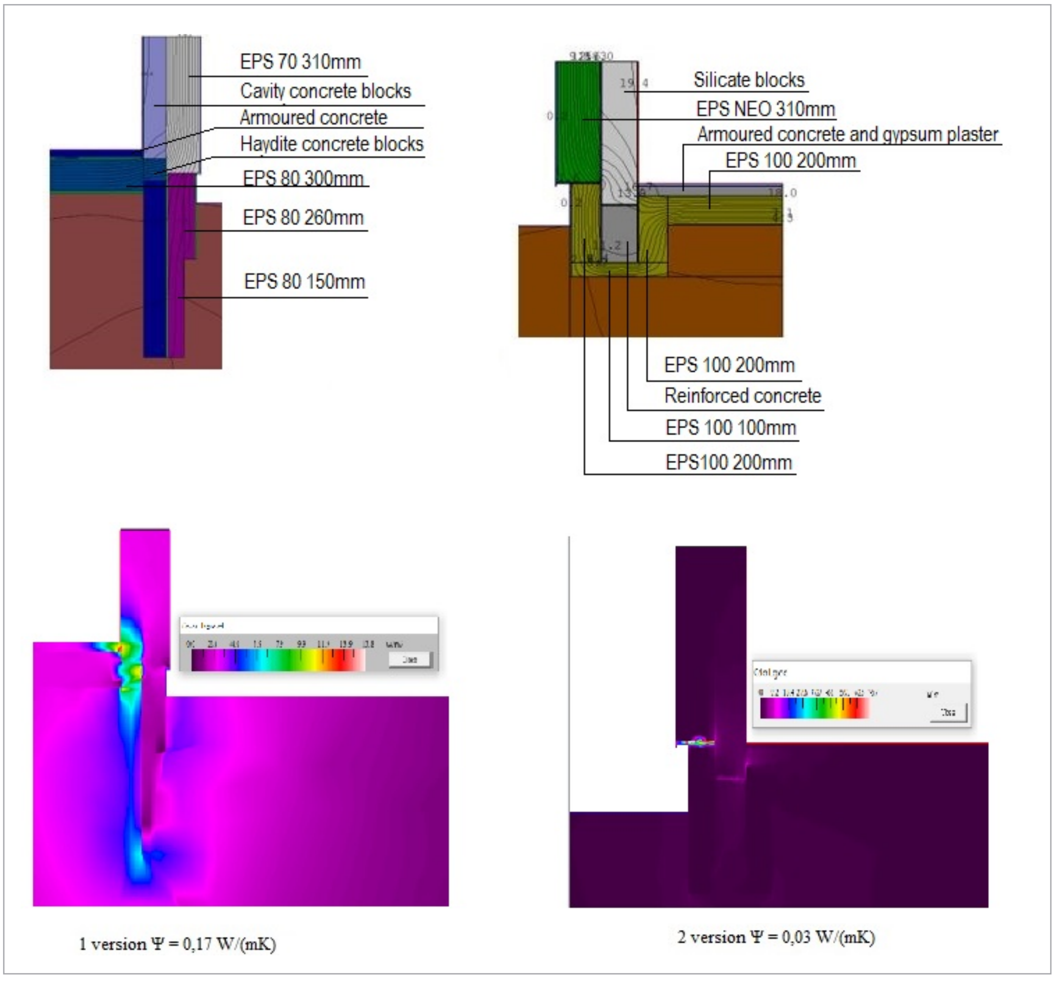


Fig. 8
Calculation results of foundation different insulation cases

The difference between window position is shown in **fig. 9**. First example shows window installation directly into lintel, while second example shows window installation in insulating material. Result of heat transfer coefficient is changing more than three times - from 0.10 W/(m·K) to 0.03 W/(m·K).

The difference between window position is shown in **Fig. 10**. First example shows window installation directly into wall, while second example shows window installation in insulating material. Result of heat transfer coefficient is changing more than four times - from 0.09 W/(m·K) to 0.02 W/(m·K).

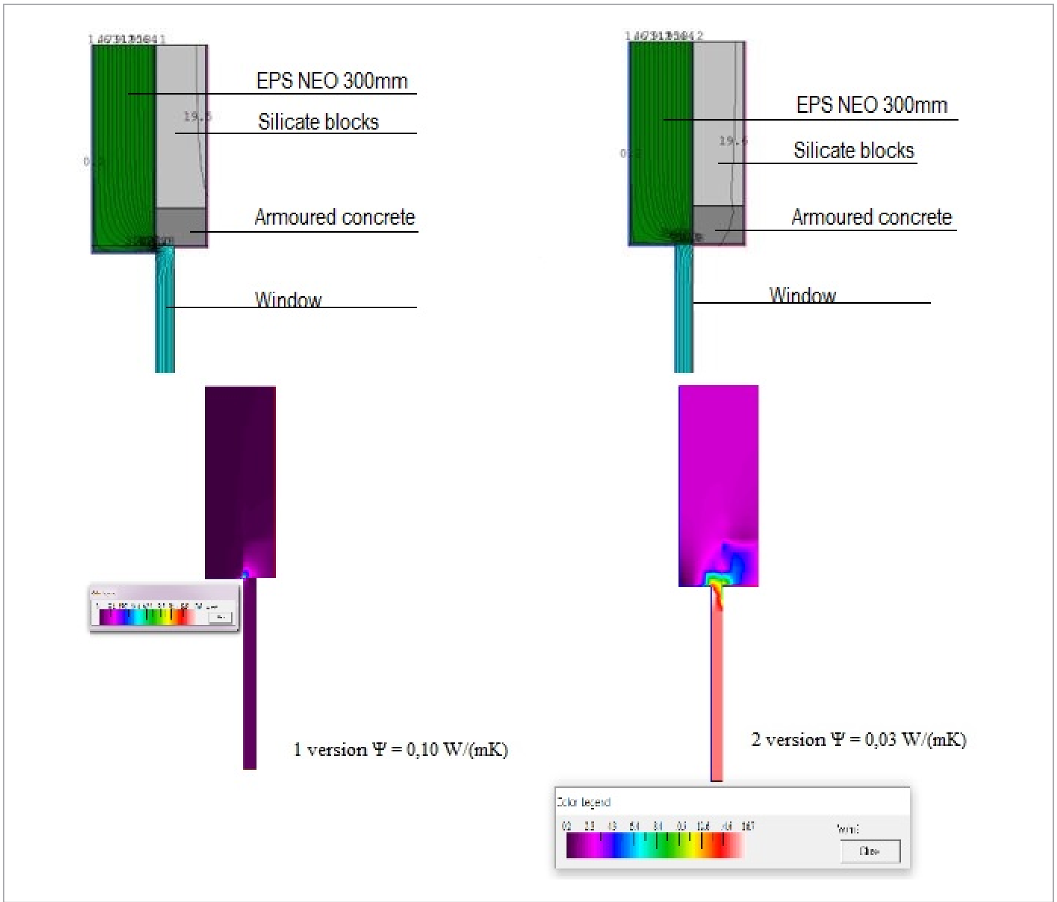


Fig. 9

Calculation results of window and lintel different connection types

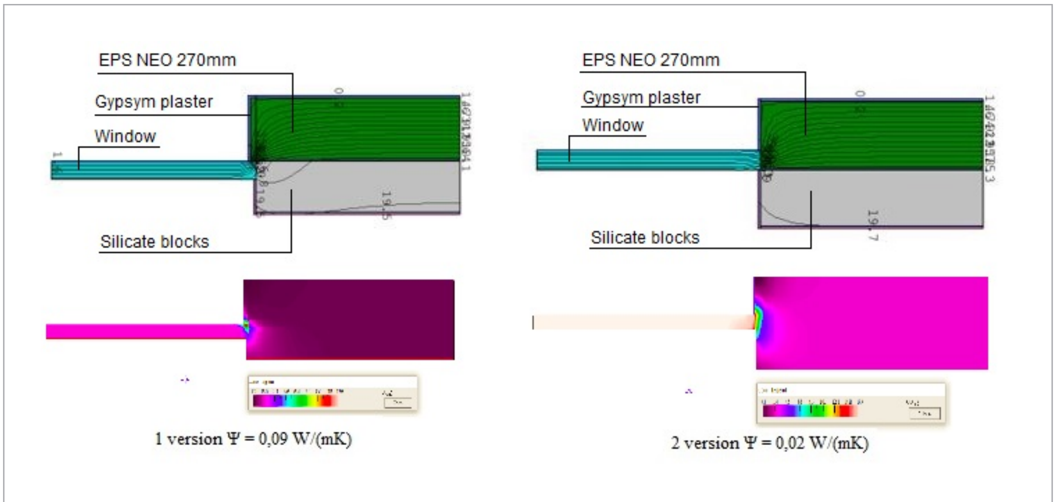


Fig. 10

Calculation results of window and wall different connection types

The difference between window position is shown in **Fig. 11**. First example shows window installation directly on foundation, while second example shows window installation in insulating layer. Result of thermal transmittance coefficient is changing from 0.22 W/(m·K) to 0.02 W/(m·K).

The difference between balcony installation is shown in **Fig. 12**. First example shows balcony connection to ceiling, while second example shows balcony connection directly to the wall. Result of thermal transmittance coefficient of linear thermal bridge is changing from 0.13 W/(m·K) to 0.01 W/(m·K).

Fig. 11

Calculation results of window and foundation different connection types

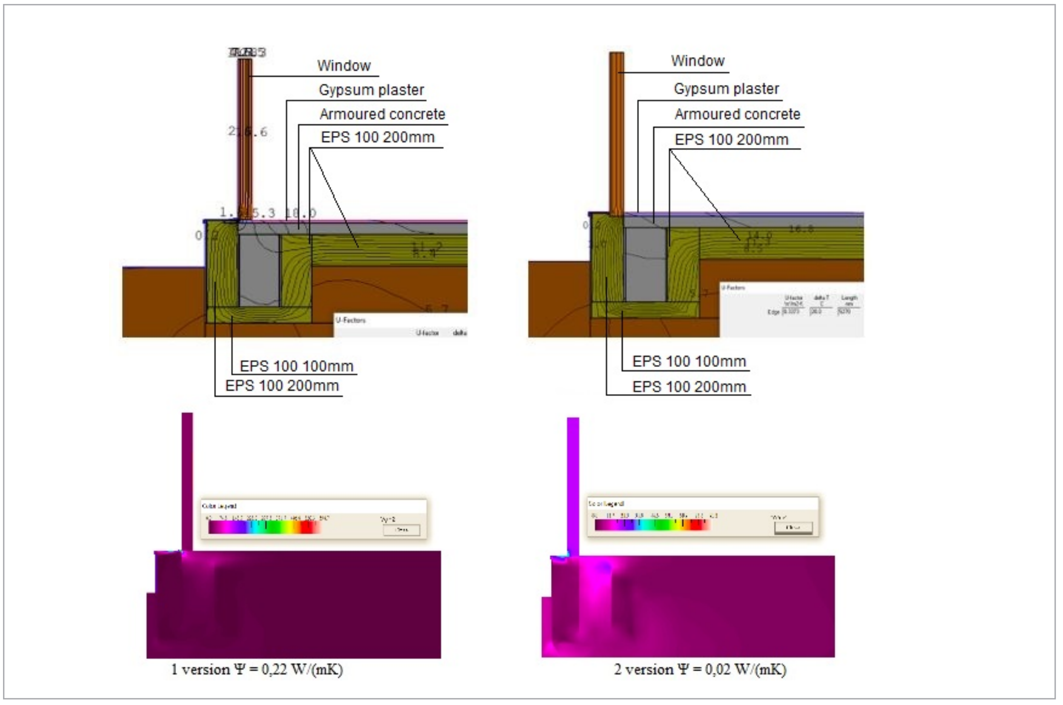
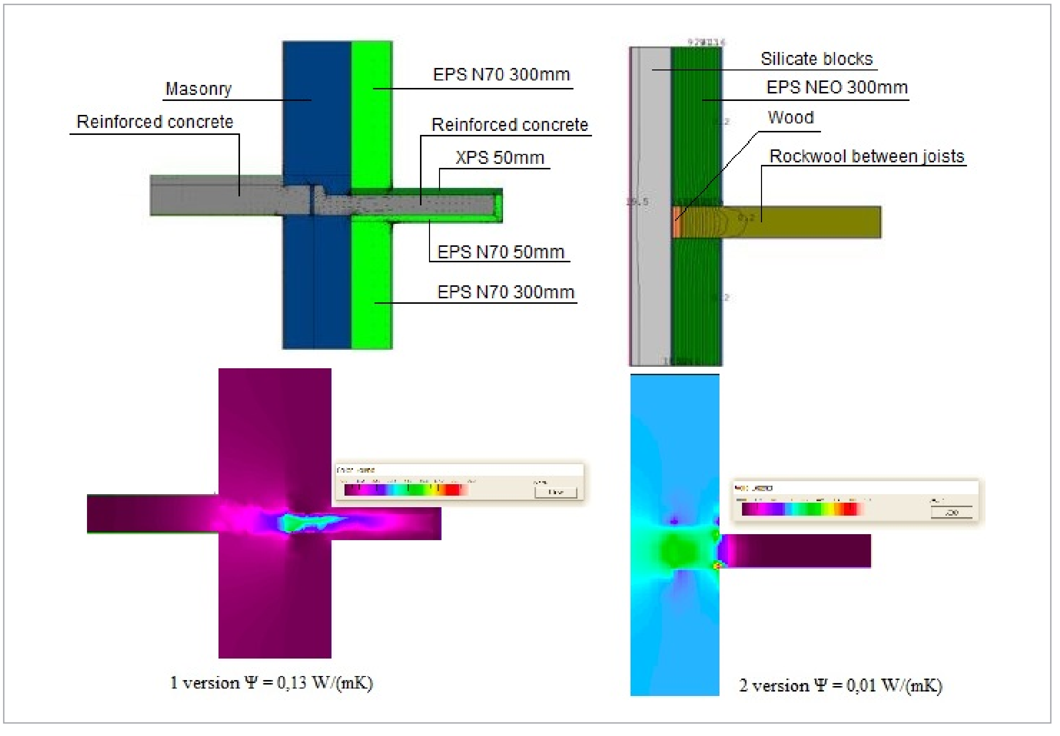


Fig. 12

Calculation results of balcony different installation types



Firstly, building's energy consumption calculations were made including heat losses through first version of linear thermal bridges. As it is shown in **table 2**, energy consumption of linear thermal bridges consist 8.6 % of total building's energy consumption.

The minus and plus sign in thermal transmittance coefficient of linear thermal bridges helps to evaluate overlaps and shortages of thermal bridges length. As it is shown in **table 3**, the total balance is 38.79 W/K, which is 7.80 kWh/(m^2·K).

Table 2

Composition of building's energy consumption

Name of energy consumption	Energy consumption, kWh/(m^2·K)	%
Heat losses through building's walls	8.29	9.2
Heat losses through building's roof	4.90	5.4
Heat losses through building's floor	5.00	5.5
Heat losses through building's windows	20.43	22.5
Heat losses through building's doors	3.46	3.8
Heat losses through building's linear thermal bridges	7.80	8.6
Heat losses through building's ventilation system	5.35	5.9
Total energy consumption of building's electricity systems	3.21	3.5
Electricity consumption for building's lighting	0.90	1.0
Heat energy consumption for the use of hot water	10.37	11.4
Heat energy consumption of the building's heating systems	13.42	14.8
Heat energy consumption of the building's cooling systems	7.47	8.2
Total:	90.60	100

Table 3

Linear thermal bridges length, heat transfer coefficients and heat losses

Name of thermal bridge	Length, m	Thermal transmittance coefficient of liner thermal bridges Ψ, W/(m·K)	Heat losses, W/K
External corner of the wall	50.52	-0.05	-2.53
Internal corner of the wall	23.12	0.02	0.46
Wall / roof junction with parapet (external)	30.26	-0.02	-0.61
Wall / roof junction with ridge (external)	22.8	-0.03	-0.68
Wall / roof junction with ridge and parapet (external)	24.2	-0.03	-0.73
Wall / garage roof junction (internal)	20.72	0.02	0.41
Wall / garage roof junction (external)	12.98	-0.04	-0.52
Wall and floor junction	69.9	0.17	11.88
Wall and windows junction (insulated lintel)	53.86	0.1	5.39
Wall and windows junction (insulated masonry)	150.5	0.09	13.55
Windows and foundation junction(insulated foundation)	22.02	0.22	4.84
Windows and garage roof junction(insulated slab)	1.5	0.17	0.26
Wall and gate junction (insulated lintel)	5.36	0.1	0.54
Wall and gate junction (insulated masonry)	9.48	0.09	0.85
Garage floor and gates junction	5.36	0.47	2.52
Wall and balcony junction	24.24	0.13	3.15
Total:			38.78

Secondly, building's energy consumption calculations were made including heat losses through second version linear thermal bridges. As it is shown in **table 4**, energy consumption of linear thermal bridges consist 1.5 % of total building's energy consumption.

After evaluating second version linear thermal bridges, thermal transmittance coefficients of linear thermal bridges is shown in **table 5**, the total balance is 21.99 W/K, which is 1.22 kWh/(m²·K).

Table 4

Composition of building's energy consumption

Name of energy consumption	Energy consumption, kWh/(m²·K)	Heat losses part of whole energy consumption
Heat losses through building's walls	7.70	9.6%
Heat losses through building's roof	4.55	5.7%
Heat losses through building's floor	4.64	5.8%
Heat losses through building's windows	18.98	23.6%
Heat losses through building's doors	3.21	4.0%
Heat losses through building's linear thermal bridges	1.22	1.5%
Heat losses through building's ventilation system	4.97	6.2%
Total energy consumption of building's electricity systems	3.21	4.0%
Electricity consumption for building's lighting	0.90	1.1%
Heat energy consumption for the use of hot water	10.37	12.9%
Heat energy consumption of the building's heating systems	11.00	13.7%
Heat energy consumption of the building's cooling systems	9.52	11.9%
Total:	80.27	100%

Table 5

Linear thermal bridges length, heat transfer coefficients and heat losses

Name of thermal bridge	Length	Thermal transmittance coefficient of liner thermal bridges Ψ, W/(m·K)	Heat losses, W/K
External corner of the wall	50.52	-0.07	-3.54
Internal corner of the wall	23.12	0.02	0.46
Wall / roof junction with parapet (external)	30.26	-0.02	-0.61
Wall / roof junction with ridge (external)	22.8	-0.03	-0.68
Wall / roof junction with ridge and parapet (external)	24.2	-0.03	-0.73
Wall / garage roof junction (internal)	20.72	0.02	0.41
Wall / garage roof junction (external)	12.98	-0.04	-0.52
Wall and floor junction	69.9	0.03	2.10
Wall and windows junction (insulated lintel)	53.86	0.03	1.62
Wall and windows junction (insulated masonry)	150.5	0.02	3.01
Windows and foundation junction(insulated foundation)	22.02	0.02	0.44
Windows and garage roof junction(insulated slab)	1.5	0.17	0.26
Wall and gate junction (insulated lintel)	5.36	0.1	0.54
Wall and gate junction (insulated masonry)	9.48	0.09	0.85
Garage floor and gates junction	5.36	0.47	2.52
Wall and balcony junction	24.24	0.01	0.24
Total:			21.99

Conclusions

After literature analysis was done how linear thermal bridges affect building energy consumption it was found that inadequate building structures and combinations of materials selection can create preconditions to have greater heat loss than the envelopes with same thermal properties but different design solutions. Foreign researchers found that certain solutions can reduce up to 11 percent thermal energy of the building.

The analysis of the building in this paper showed that constructional solutions of a balcony, the foundation and the foundation with the showcase window had the greatest influence for the value of linear thermal bridges. Replacement of balcony design solution passing through the slab through the outer wall into the design solution of the wooden frame attachment to an exterior wall reduced the value of linear thermal bridge 13 times (from 0.13 W/(m·K) up to 0.01 W/(m·K). Belt foundation with a one-sided insulation up to 1.8 m deep change to 0.3 m recessed foundation insulation with a two-side reduced thermal bridges value of almost 6 times (from 0.17 W/(m·K) to 0.03 W/(m·K). Showcase windows installation in the foundation thermal insulation layer reduces thermal bridges value almost 11 times (from 0.22 W/(m·K) to 0.02 W/(m·K)) compared with the installation of the floor structure.

According to the requirements of EU directives from 2021, all new buildings will be built that do not consume energy (Zero Energy). According to the Lithuanian construction requirements of technical regulations from the end of 2016, all newly built buildings will have to have at least "A" class energy performance of buildings. However, in order to design and build building of a high-energy performance class it is not enough to choose only regulatory requirements of the thermal properties or engineering system. The test of the buildings thermal performance, examined in the paper, showed that the correct solutions of linear thermal bridges reduced the building annual energy consumption of the building for heating 2.42 kWh/(m·K) and cooling to 2.05 kWh /(m·K), that is around 751 kWh/K and 636 kWh/K per year.

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