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## Numerical Investigation of the impact of longitudinal thermal bridging on energy efficient buildings under humid continental climate conditions: The Case of Lithuania

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# Numerical Investigation of the impact of longitudinal thermal bridging on energy efficient buildings under humid continental climate conditions: The Case of Lithuania

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**Abstract.** Thermal bridges play a major role in the thermal losses of the building shell and should be avoided, especially under winter dominant conditions and for high cooling degree days regions in Europe and worldwide. Since 2016 the requirement for all new buildings to achieve energy-efficiency class “A” came into force in Lithuania. One of the requirements to meet this class are detailed calculations of the thermal transmittance values of the longitudinal thermal bridges. The same requirement is also requested for higher energy-efficiency buildings that are qualified as “A+” (obligatory since 2018) and “A++” (obligatory from 2021 onwards) class buildings.

The purpose of this study is the numerical investigation of the impact of thermal bridges on energy efficient buildings under humid continental climate conditions. For the purpose of the study, the energy performance of the thermal bridges of a class A building, situated in Lithuania, were analyzed, using the tool Therm of LBNL a two-dimensional conduction heat-transfer analysis, based on the finite-element method. The calculations of the thermal transmittance values of the longitudinal thermal bridges were implemented in accordance with the requirements of EN ISO 10211:2008 standard. Alternative construction designs, with the aim to minimize the thermal losses of the building shell are also presented and discussed in this study. This study showed that detailed calculation of the losses through thermal bridges may have a significant importance to avoid dew points and mold in sensitive parts of the building shell, but they have a minor influence for the energy certification criteria. The findings of this study are anticipated to provide useful feedback for the future development of the construction regulations in the Baltic countries, as well as in countries with humid continental climate conditions.



## 1. Introduction

A thermal bridge is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer [1]. As the requirements for better insulation of buildings are becoming stricter, the importance of avoiding thermal bridges in energy efficient buildings is increasing [2]. In well insulated buildings, the impact of thermal bridging on the overall energy performance can be substantial. Thermal bridges in buildings are classified in point thermal bridges and linear thermal bridges. Linear thermal bridges are thermal bridges with a uniform cross section along one of the three orthogonal axes; point thermal bridges are localized thermal bridges whose influence can be represented by a point thermal transmittance [3].

Thermal bridges are observed at numerous positions of a building envelope, most commonly at junctions between two or more building elements. Common positions include [4]:

- at junctions between external elements (corners of walls, wall to roof, wall to floor);
- at junctions of internal walls with external walls and roofs;
- at junctions of intermediate floors with external walls;
- at columns in external walls;
- around windows and doors.

Thermal bridging results in augmented energy requirements for buildings heating or cooling. Recent research undertaken has shown that thermal bridging can be responsible for up to 30% of a building's heat loss [5]. Moreover, in the case of significant temperature difference between indoor and outdoor space, there is a risk of condensation in the building's envelope, which may ultimately result in mold growth with consequent poor indoor air quality and insulation degradation [6]. The energy losses through a thermal bridge are influenced by the architectural design, the materials and construction elements selected for construction works and the principal solution of main building facing systems. Some of the above mentioned components usually stay constant during the constructions works, but some are fluctuating depending on situation in the market and the contractors usually want to evaluate what limits of freedom they have to choose different solutions without making significant negative effect on the future energy demand for building exploitation and building energy efficiency class. The evaluation of partitions thermal transmittance coefficient is habitual and fast, while the exact evaluation of longitudinal thermal requires higher qualification of the designer and takes more time.

## 2. Recent advancements in the investigation of the thermal performance of thermal bridges in buildings

Recently two major trends are observed in the literature concerning the investigation of the thermal performance of thermal bridges in buildings:

- the use of advanced numerical tools, including finite elements methods
- the application of experimental methods, and specifically of IR Thermography.

Theodosiou et al. [7] conducted a numerical analysis using finite element tools to examine the impact of thermal bridges of double skin facades in view of the requirement for installation of BIPVs for achieving nearly zero energy consumption on site. The study concluded that over 25% of the thermal losses due to thermal bridges can be attributed to point thermal bridges, due to the large number of connection points between the cladding structure and the main building envelope. Other interesting conclusions delivered by this study concern the use of external insulation for existing buildings, which is fixed with brackets. The results of the study showed that despite the substantial thickness of the thermal insulation, the significant number of brackets and thus of point thermal bridges, result to noteworthy thermal losses, which exceed the

losses of the building element per se. Quinten and Feldheim [8] used finite element methods (Comsol Multiphysics) to develop a mixed equivalent wall method for the dynamic modelling of thermal bridges. Particularly in this study the steady and unsteady thermal phenomena in the 2-D and 3-D areas of building envelopes were replaced with a 1-D three-layer equivalent wall. Their method was applied for three 2-D thermal bridges and for three different outdoor conditions, delivering a good agreement with measured data. The indoor temperature in this study was considered to be a sinusoidal function of time. In the study of Lorenzati et al. [9] an experimental and numerical investigation of thermal bridging effects of jointed Vacuum Insulation Panels (VIPs) was conducted. A numerical model introduced in this study, resulted to be sufficiently reliable for the analysis of the thermal losses in VIPs due to thermal bridges created by structural joints. O'Grady et al. [10] applied IR thermography for the thermal assessment of multiple thermal bridges and windows. In this study A new window thermal transmittance or M-value is introduced, which is defined as the thermal bridging heat flow rate per unit temperature difference between the indoor and outdoor environments. Another novel element of this study concerns the application of two different numerical approaches (finite element and finite volume – CFD) to multiple thermal bridges assessment, validated against hot box measurements. The study revealed that time-consuming CFD modeling, where the convective air movements along the specimen were modelled explicitly, did not improve the results accuracy.

Garrido et al. [11] implemented a thermal-based analysis for the automatic detection and characterization of thermal bridges in buildings by employing IR thermography. The authors used the image rectification procedure with the aim to improve the geometric analysis of the examined IR thermographs. The methodology proposed in this study introduces a hierarchy for the criteria related to the automatic definition of thermal bridges in IR thermographs, according to which the thermal transmittance value is the leading criterion, followed by the temperature difference and a geometric criterion. Asdrubali et al. [12] delivered a study concerning the detection of thermal bridges from thermographic images by means of image processing approximation algorithms. Particularly the authors elaborate a segmentation method, applied in order to detect the shape of thermal bridges of the building envelope from thermographs. Sfarra et al. [13] presented an application of a new multiscale data analysis method, the Iterative Filtering (IF), which concerns IR signal analysis in the long-wave infrared (LWIR) region. According to the authors, this method allows the optimization of the detection of thermal bridges via the sparse principal component thermography (SPCT) technique. This method was demonstrated on two case studies with no internal heat input, on damaged buildings under restoration in L'Aquila city (Italy). In the study of Baldinelli et al [14] the quantification of the heat flux through a thermal bridge has been proposed, with the use of an index defined as incidence factor of the thermal bridge. The authors proposed that the heat losses of thermal bridge can be allocated to building elements, from surface temperature measurements, retrieved by the pixels with a correctly framed infrared image. Their method has been applied on three types of thermal bridges, a pillar, a pillar-beam joint and a wall-wall joint, built in a hot box apparatus, performing detailed and accurate thermographs.

From the literature review it is obvious that although in the recent years, some quite remarkable studies have been published concerning the computational and experimental assessment of thermal bridges have been published, there is still space for numerical studies, especially for the case of the calculation of the performance of thermal bridges in nearly zero energy buildings, where only few studies have been documented in the literature [7]. To this end this study aspires to deliver some useful insight and to cover the gap in the scientific literature concerning the numerical assessment of the significance of thermal bridges in nearly zero energy buildings.

### 3. Methodology

The purpose of this study was the assessment of the energy performance of the thermal bridges of a class A building in the city of Kaunas, in Lithuania, with the use of a two-dimensional conduction heat-transfer analysis finite element tool, Therm of LBNL [15][16]. The calculations of the thermal transmittance values of the longitudinal thermal bridges were implemented in accordance with the EN ISO 10211:2008 standard [3]. The energy performance of the whole building was evaluated in accordance to the national requirements of Lithuania, using the tool NRGpro5, of the Certification center of the construction products (SPSC). Thermal bridge evaluation has the impact on the value of coefficient  $C_l$  (describes primary non-renewable energy usage efficiency for heating, ventilation, cooling and lighting), energy consumption for the building heating  $Q_H$ , kWh/(m<sup>2</sup>.year), and calculated specific heat losses through the building envelope  $H_{env}$ , W/K.

#### 3.1 Numerical Tool - THERM

THERM is developed at Lawrence Berkeley National Laboratory (LBNL). THERM can model two-dimensional heat-transfer effects in building components including windows, walls, foundations, roofs, doors, appliances and other elements where thermal bridges are of concern. THERM's heat-transfer analysis allows the evaluation of a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity. THERM's two-dimensional conduction heat-transfer analysis is based on the finite-element method, which can model the complicated geometries of building products.

#### 3.2 Case Study

The case study of this report is a 3 story building with attic, consisting of 12 apartments and offices, located in Kaunas, Lithuania. As the building is situated in the old town with highly limited plot area, open car parking is made under the first floor (approx. 75 % of the built-up area) installing the first floor on the column-outer overlay construction. The first floor of the building is for commercial use, whereas there are four apartments on the second and on the third floor of the building, as well as four flats in the attic. Table 1 provides general information concerning the case study building. In Table 2 the description of the building elements of the case study building are presented. In Table 3 construction details of the thermal bridges observed in the case study building are depicted. Table 4 includes the design thermal conductivity of the building materials used, in accordance with the EN 10456:2007 standard [17].

Table 1: Case Study Building: General information


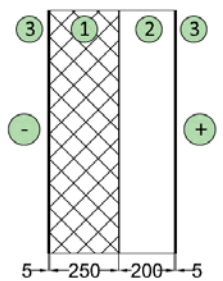
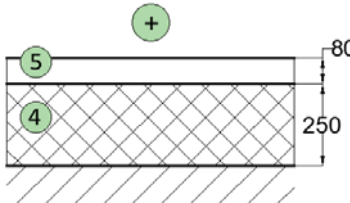
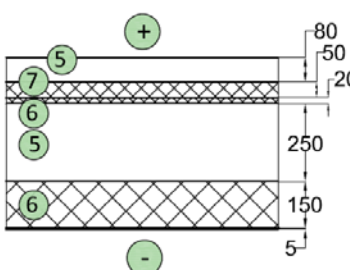
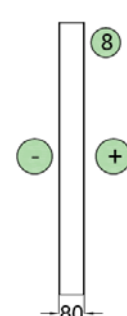
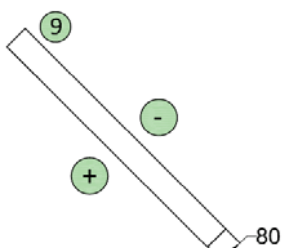
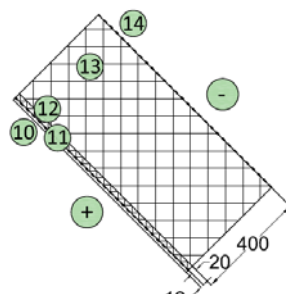
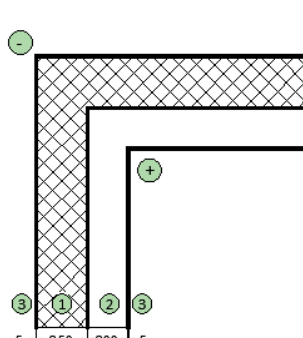
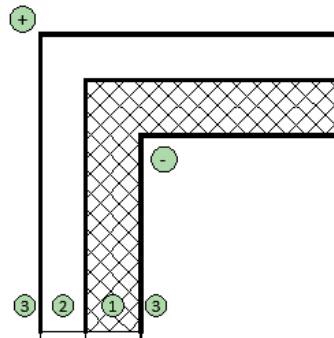
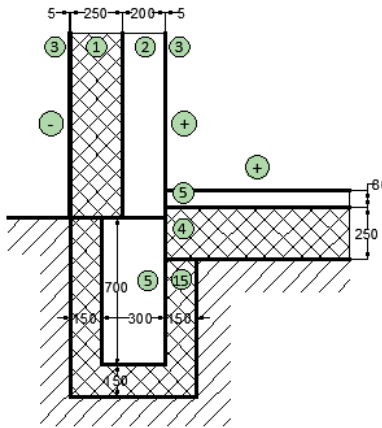
<b>Heated area</b>	1.078 m <sup>2</sup>	
<b>Heated volume</b>	2.602,54 m <sup>3</sup>	
<b>Built-up area</b>	437.43 m <sup>2</sup>	
<b>Purpose of building</b>	Residential	
<b>Tightness criteria n<sub>50</sub></b>	1 h <sup>-1</sup>	
<b>Energy performance class</b>	A (evaluation date – 2018 09 24)	

Table 2: Case Study Building: Construction of partitions

Wall	Floor	Outer overlay
 <p>1 – polystyrene foam 2 – porous concrete blocks 3 – stucco</p>	 <p>4 – polystyrene foam 5 – reinforced concrete</p>	 <p>5 – reinforced concrete 6 – mineral wool 7 – polystyrene foam</p>
Windows/Doors	Skylight	Roof
		 <p>10 – gypsum board 11 – mineral wool 12 – steam insulation 13 – mineral wool 14 – hydroisolation</p>
Wall: outer corner	Wall: inner corner	Foundation-wall
		

Foundation-window/door	Skylight-roof	Wall-window/door	Wall-window/door: to the lintel

Table 3: Case Study Building: Construction of thermal bridges

<b>Outer overlay-wall: outer corner</b>	<b>Outer overlay-wall: inner corner</b>	<b>Balcony-wall</b>
<b>Balcony-window</b>	<b>Wall-roof: steep angle</b>	<b>Wall-roof: blunt angle</b>

Table 4: Case Study Building: Design thermal conductivity of materials used [17]

Material, construction layer	Design thermal conductivity, W/(m·K)
1. Polystyrene foam (in the non-ventilated construction, plastic joints)	0.034
2. Porous concrete blocks (in the non-ventilated construction)	0.120
3. Stucco (cement-sand)	1.000
4. Polystyrene foam (in the ground floor construction)	0.052
5. Reinforced concrete	2.500
6. Mineral wool (in the non-ventilated construction, plastic joints)	0.037
7. Polystyrene foam (in the non-ventilated construction)	0.040
8. Windows/doors (plastic frame, double-chamber glass unit, construction thickness 80 mm)	0.860
9. Skylight (wooden frame, single-chamber glass unit, one size: 0,94x1,18, construction thickness 80 mm)	0.140
10. Gypsum board	0.250
11. Mineral wool (in the ventilated construction, between 1 mm thickness steel profile, profile installation density – 600 mm)	0.0717
12. Steam insulation	0.020
13. Mineral wool (between double T-profile wooden beam, beam installation density – 600 mm)	0.042
14. Hydroisolation	0.020
15. Polystyrene foam (in the contact with the soil)	0.052
16. XPS foam (installation frame for windows, additional insulation for balconies)	0.037
17. Wood	0.180
18. Mineral wool (between double T-profile wooden timber, timber installation density – 600 mm)	0.0467
19. Concrete	1.600

Table 5: Case Study Building: Areas of partitions

Construction (orientation)	Area, m <sup>2</sup>		Share in the total envelope area, %	
<b>Non-transparent partitions</b>				
Wall (S)	191.32	903.25	9.3	43.7
Wall (N)	151.94		7.4	
Wall (E)	258.86		12.5	
Wall (W)	301.13		14.6	
Roof (S)	70.62	479.67	3.4	23.2
Roof (N)	180.89		8.8	
Roof (E)	172.34		8.3	
Roof (SW)	55.82		2.7	
Floor (horizontal)	75.43		3.7	
Outer overlay (horizontal)	343.55		16.6	
Door (N)	2.58	5.16	0.1	0.2
Door (E)	2.58		0.1	
<b>Transparent partitions</b>				
Windows (S)	100.14	255.30	4.8	12.4
Windows (N)	66.74		3.2	
Windows (E)	41.08		2.0	
Windows (W)	47.34		2.3	
Skylight (S)	2.10	3.15	0.1	0.2
Skylight (N)	1.05		0.1	



The areas and lengths of building envelope parameters were determined using external dimensioning, except the partitions in contact with the ground – internal dimensioning for these partitions was used. External dimensioning caused that some thermal bridges are evaluated with a negative linear thermal bridge transmittance parameter  $\Psi$  value, W/(m·K). Total energy performance of the building is tightly dependent on architectural solution – Table 5 includes areas, orientation and proportions of separate building constructions and Table 6 represents total amount and distribution of longitudinal thermal bridges length in the case.

Table 6: Case Study Building: Lengths of thermal bridges

Thermal bridge description	Length, m	Share in the total thermal bridge length, %
Foundation-wall	34.1	3.88 (3.35+0.53)
Foundation-window/door	5.35	
Wall-roof: blunt angle	84.70	12.43 (8.33+4.10)
Wall-roof: step angle	41.64	
Wall-window	440.72	54.77 (43.35+11.34)
Wall-window: to the lintel	115.35	
Wall-window/door	8.92	1.15 (0.88+0.27)
Wall-window/door: to the lintel	2.71	
Skylight-roof	13.20	1.30
Balcony-window	32.01	5.37 (3.15+2.22)
Balcony-wall	22.56	
Outer overlay-wall: inner corner	17.66	11.07 (1.74+9.33)
Outer overlay-wall: outer corner	94.82	
Wall: inner corner	30.00	10.13 (2.95+7.18)
Wall: outer corner	73.02	

Heat transfer coefficients  $U$ , (m<sup>2</sup>·K)/W, of the constructions were calculated using design thermal conductivity (Table 4) values that were determined combining declared and standard thermal conductivity coefficients of the materials used for the construction and taking into account metal or wooden fixing constructions. Area and length characteristics were determined combining documented and field measurements with accuracy of 1,0 cm. Heat transfer coefficient of the floor was determined also taking into account vertical insulation of the foundation beam.

#### 4. Results and Discussion

The results of partition heat transfer coefficient  $U$  calculation are given in Table 7.

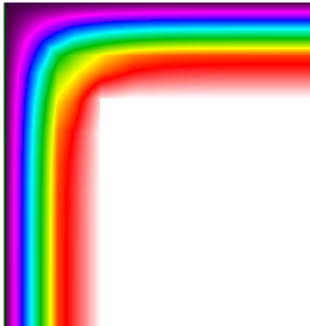
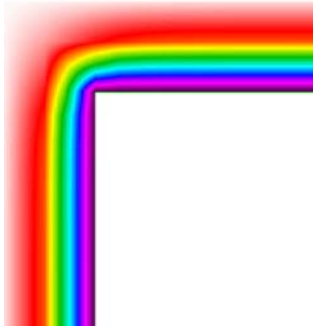
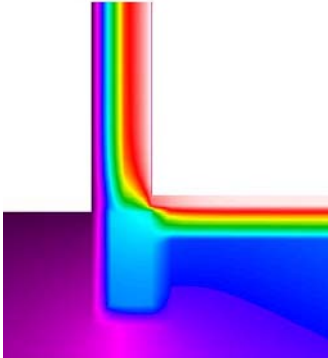
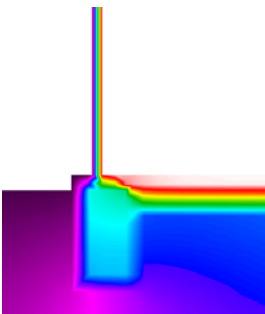
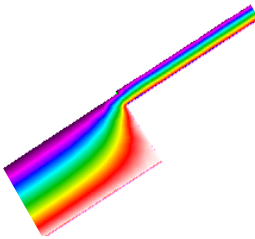


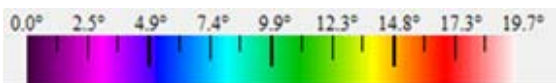
Table 7: Case Study Building: Heat transfer coefficient of partitions

Construction	Heat transfer coefficient $U$ , (m <sup>2</sup> ·K)/W
Wall	0.109
Floor	0.130
Outer overlay	0.162
Windows	0.77÷0.88 (declared values depending on the geometry of the window)
Skylight	1.400 (declared value)
Roof	0.099

The results of thermal bridge transmittance coefficient  $\Psi$  calculations are given in Table 8 together with THERM generated thermography views. Boundary conditions used for finite element analysis are 0°C outside and +20°C inside. This study focuses on the analysis of thermal losses through longitudinal thermal

bridges and dew point control on the inner surfaces of the building envelope was not analyzed so the temperature conditions selected for outside do not need to be adapted according country climate conditions.

Table 8: Case Study Building: Thermal bridge transmittance coefficient (with thermography views)

Wall: outer corner, $\Psi = -0,0599$	Wall: inner corner, $\Psi = 0,01887$	Foundation-wall, $\Psi = 0,0643$	
			
Foundation-window/door, $\Psi = 0,429$	Skylight-roof, $\Psi = 0,0494$	Wall-window/door, $\Psi = 0,001734$	Wall-window/door: to the lintel, $\Psi = 0,01281$
			
			

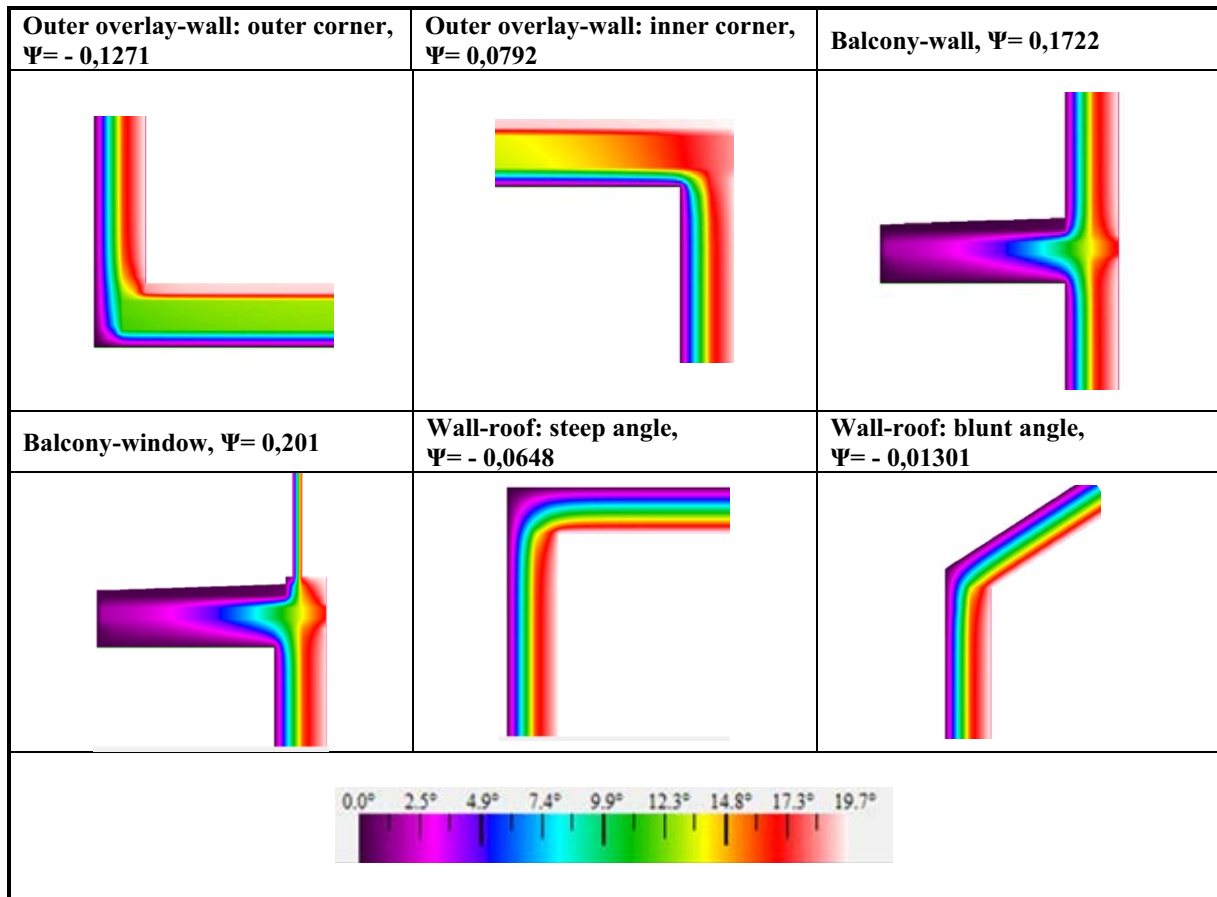


Table 9: Case Study Building: Energy performance characteristics

Parameter	Value	Share in the total values, %
Coefficient $C_I$	<b>0.2183</b>	-
Energy consumption for the building heating $Q_H$	<b>15.995</b> kWh/(m <sup>2</sup> ·year)	-
Specific heat losses through the building envelope $H_{env}$ , consisting:	<b>426.94 W/K</b>	<b>100</b>
• losses through partitions	<b>428.56 W/K</b>	<b>100.38</b>
• losses through thermal bridges, consisting:	<b>-1.620 W/K</b>	<b>-0.38</b>
1. Foundation-wall and foundation-window/door	4.35 W/K	1.02
2. Wall-roof: blunt angle and wall-roof: step angle	-3.35 W/K	-0.78
3. Wall-window and wall-window: to the lintel	1.15 W/K	0.27
4. Wall-window/door and wall-window/door: to the lintel	0.03 W/K	0.01
5. Skylight-roof	0.66 W/K	0.15
6. Balcony-window and balcony-wall	10.24 W/K	2.39
7. Outer overlay-wall: inner corner and outer overlay-wall: outer corner	-10.91 W/K	-2.55
8. Wall: inner corner and wall: outer corner	-3.78 W/K	-0.88

Partitions areas, thermal bridges lengths, thermal characteristics and data concerning engineering systems used for the case study building were used for determining energy performance parameters and building energy performance class. District heating with automatic regulation from the heat supply side and

individual automatic regulation for all the premises was chosen. The calculation showed that building is qualified as “A” energy performance class building. Energy characteristics calculation data is shown in the Table 9.

After the certification of the building in 2018 09 24 the case study building was analysed according renewed requirements of “A+” and “A++” energy efficiency class criteria and the analysis showed that the value of coefficient  $C_1$ , energy consumption for the building heating  $Q_H$  and calculated specific heat losses through the building envelope  $H_{env}$  satisfy the requirements for “A+” and “A++” classes. The barrier to reach higher efficiency class of the building is the insufficient tightness of the building, that usually shows the quality of the construction works, and the necessity to apply renewable energy sources for building energy needs. The construction sector is quite inertial in accepting new solutions and this analysis shows that further development will be forced to accelerate in engineering systems and renewable energy application fields. Also standard thermal bridge transmittance coefficients according legislation library were used to evaluate what errors would be given to the final result because of faster design procedures. This calculation showed that instead of 15.995 kWh/(m<sup>2</sup>·year) energy consumption for the building heating with detailed thermal bridge evaluation for the case study building the result is 25.421 kWh/(m<sup>2</sup>·year) and it's 58.9 % higher consumption that can cause inadequate construction solutions.

## 5. Conclusions

The numerical investigation of the impact of longitudinal thermal bridging on energy efficient of residential building in Lithuania showed that impact on the specific heat losses through the thermal bridges comparing with the specific heat losses through the whole building envelope has -0.38 % and can be called as insignificant for nearly zero energy building. Small impact to the final result does not mean that separate thermal bridges do not have impact just some thermal bridges have positive and some negative effect when building envelope area dimensioning is performed using external measuring. The biggest negative impact on specific heat losses in the case study came from outer overlay thermal bridge, -2.55 %, and the biggest positive impact came from balcony thermal bridge, 2.39 %. Thermal bridges near the windows take 54.77 % of the total thermal bridge length, but the impact for the specific heat losses is 0.27 %. The result presented in the study shows that detailed numerical analysis of the thermal bridges is necessary for exact construction solution evaluation.

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