IMPACT OF POINT THERMAL BRIDGES ON THERMAL PROPERTIES OF BUILDING ENVELOPES

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During the design of energy-efficient buildings with a ventilated facade systems, the evaluation of point thermal transmittance is complicated. It requires additional theoretical knowledge, special software and skills to use it. Because of that, point thermal transmittance is often ignored in practice. The dependence of point thermal transmittance, which is appearing because of aluminum fixing elements used in the insulated wall with ventilated facade system, from the thermal and geometrical properties of construction layers are analyzed in this paper. Research has shown, that thermal properties of the supporting wall, where fixing element is located, had the biggest influence on the point thermal transmittance. When thermal conductivity of the supporting wall was increasing, as well as a thickness of the insulation layer, a value of thermal bridge was increasing in a non-linear way. For this reason, the thermal transmittance coefficient of all construction could increase up to 35%. When the thickness of the supporting wall and thermal conductivity of the insulation layer was increased, the value of point thermal bridge was decreasing. The tests revealed strong dependency of the point thermal bridge on the thermal conductivity of bearing layer material and the thickness of the bearing layer of wall. For this reason, thermal bridges should receive greater consideration. It is not enough to use the diagrams of typical fasteners that very often do not take into account the exact thickness and thermal characteristics of materials

Key words*: thermal bridge, point thermal transmittance, energy efficiency, ventilated facade systems*

1. Introduction

In the design of energy-efficient buildings according to the requirements of Directive 2010/31/ES (EPBD) [1], it is necessary to identify and to evaluate the factors that increase the energy loses of the building. One of such factors are thermal bridges where thermal resistance of the building envelope 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, such as occur at wall/floor/ceiling junctions [2]. According to references, the total impact of thermal bridges on the heating energy need is considerable and can vary from 5% to 42% [3-6]. This influence depends on weather conditions, level of insulation, the thermal bridges constructive solution, type of building (use and geometry) and of the method used to implement its effect within the calculation of the building energy demand [7-12].

Usually, in the calculations of the building energy demand, the liner thermal bridges are evaluated, which occur at the junction between two or more elements of the building envelope. Several scientific studies have been carried out, where liner thermal bridges have been investigated by different calculation and simulation methodologies, such as static/dynamic and one-dimension, where is showing only linear information; two-dimension, where is showing two dimensions, such as width and height; three-dimension, where is showing three dimensions, such as width, height and thickness (1D/2D/3D) [13-21].

But in terms of point thermal bridges, the effect of the point thermal bridges is often neglected in the analyses aimed at defining the building energy performance. Regardless, it's an important factor in the design of energy-efficient buildings. This is very important during the design of buildings with ventilated facade systems, where profiles of thermal insulation panels are fixed directly to the supporting wall or brackets are used in order to reduce the influence of thermal bridge to the properties of thermal insulation layer.

Studies show, that if solid metal profiles (which are crossing thermal insulation layer) are used for the fixing of thermal insulation, thermal resistance might be reduced twice [22-27]. If these additional heat losses, because of point thermal transmittance, are not evaluated or evaluated incorrectly, building's energy efficiency might be determined improperly and there might be problems with selection of power of heating systems, when required indoor temperature conditions will not be ensured because of extreme temperature differences between the outdoors and indoors.

In practice, in order to know the true value of a point thermal bridge one has to perform numerical simulations or experimental measurements with a specific construction. However, during the design of buildings the assessment of point thermal transmittance is difficult without special software.

The aim of this work was to evaluate the point thermal transmittance (χ-value) of aluminum fixing element (which is crossing thermal insulation layer); obtain empirical dependence which would help to predict the point thermal transmittance (χ-value) according to the following factors: thickness of the thermal insulation material, value of thermal conductivity coefficient of thermal insulation layer and type of the supporting construction material.

2. Assessment of the point thermal bridges

The point thermal transmittance of the thermal bridges (χ) is calculated according to the requirements of EN ISO 10211 [2]. The Equation (1) is given below:

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \cdot A_i - \sum_{j-1}^{N_j} \Psi_j \cdot l_j; \tag{1}$$

To determine the point thermal transmittance χ-value of a fastener by 3-D methodology, specific heat losses through repeated surface area with a fastener H and without a fastener H_S are calculated. The difference between these specific heat losses is the point thermal transmittance χ-value (Eq. (2)):

$$\chi = H - H_S \tag{2}$$

Since fasteners penetrate the insulation layer in local areas, their influence on heat transfer is evaluated by point thermal transmittance. If this point thermal transmittance is repetitive in the envelope, they can be evaluated using the transmittance correction factor ΔU (Eq. (3)), taking into account their number in 1 m^2 of the envelope or fasteners density per certain surface area of the envelope:

$$\Delta U = \chi \cdot n \tag{3}$$

Then the thermal transmittance *U*-value of the envelope can be determined from EN ISO 6946 [28] (Eq. (4)):

$$U = U_i + \Delta U \tag{4}$$

Calculations of U_i-values follow national requirements [29].

Three-dimensional temperature field calculation program HEAT3 was used for the determination of the point thermal transmittance (χ-value).

Ventilated facade system with aluminum fixing elemetns was chosen for the calculations (Fig. 1). Fixing brackets of 3 mm wall thickness and 40 mm width were used. The plastic gaskets of 5 mm thickness were inserted between the fixing bracket and the wall. The distance between the axes of aluminum framework elements was 600 mm in horizontal and vertical planes. A typical element of the framework according to the axes of symmetry was 600 × 600 mm with fixing brackets in the middle (Fig. 2). The surface area of such framework element was 0.36 m^2, and the number of fixing brackets per 1 m^2 of the wall area was: n = 2.778 pcs./m^2. The thermal conductivity coefficient of aluminum fixing elements was 160 [Wm–1K–1)].

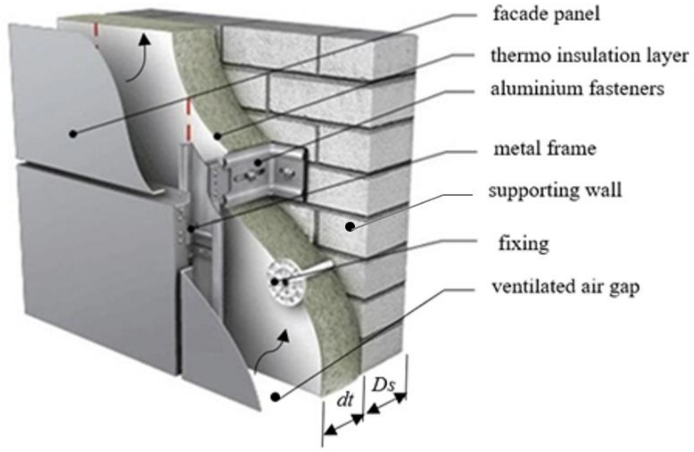

Figure 1. The principal scheme of the ventilated facades with aluminum fixing element

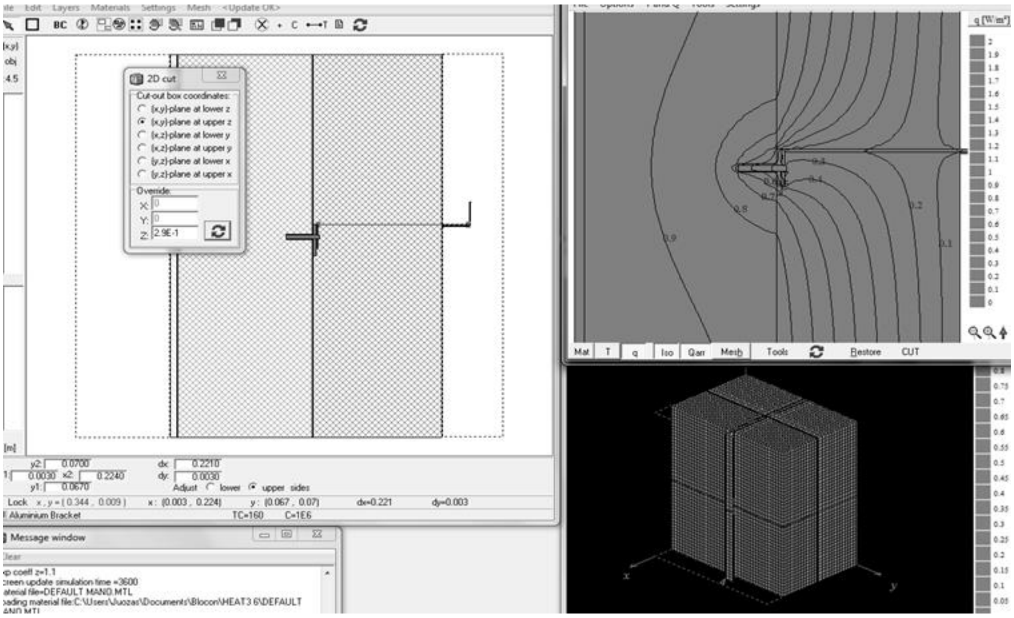

Figure 2. Calculation scheme of the thermal bridge of fixing element

The point thermal transmittance χ-value of aluminum fastener and the relationship between this value and the properties of other materials included in the structure was calculated for different variants of the structure by changing the thermal conductivity and thickness of the supporting and insulation layers (Tab. 1).

Table 1. Variations of calculated parameters

Properties	*Ds*	λs	*dt*	λt
Variants	mm	[Wm–1K–1]	mm	[Wm–1K–1]
0 (Basic data)	200	0.5	150	0.034
1	200	0.1 ÷ 1	150	0.034
2	50 ÷ 500	0.5	150	0.034
3	200	0.5	150	0.030 ÷ 0.040
4	200	0.5	100 ÷ 200	0.034

For the analyses of point thermal bridges basic construction variant was selected: thickness of the supporting wall *Ds* = 200 mm, thermal conductivity of the supporting wall λs = 0.5 [Wm–1K–1], thickness of the insulation layer *dt* = 150 mm, thermal conductivity of the insulation layer λt = 0.034 [Wm–1K–1].

3. Results

3.1. Evaluation of the dependence of point thermal bridge

After determining the trend of heat flow behaviour through fastener was calculated the thermal transmittance χ-values, while has been changed values of: thermal conductivity of supporting layer; the supporting layer thickness; thermal conductivity of thermal insulation layer; the thermal insulation layer thickness.

Figure 3 illustrates the relationship between the fastener's thermal transmittance χ-value and thermal conductivity of the supporting layer material (Var. 1, Tab.1). If the thermal conductivity λs of the supporting layer material is increased, the influence of the χ-value to total wall's thermal transmittance is increased. The chart shows that when λs-value of the supporting layer' material increases from 0.1 to 1.0 [Wm–1K–1], the χ-value increases from 0.008 to 0.039 [WK–1]., i.e. almost 5 times. That means, the influence of the fasteners on the *U*-value of the entire wall will increase from 13% to 35%.

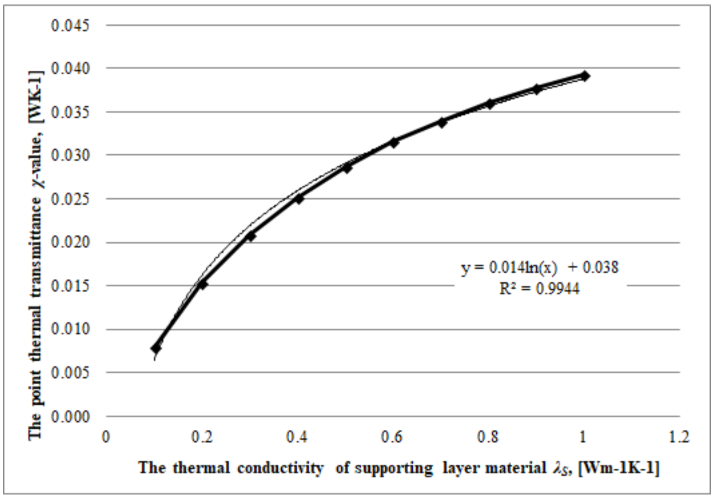

Figure 3. Relationship between the calculated χ-value of the fastener and the λ_S-value of the supporting layer material

Figure 4 shows the change in the point thermal transmittance with the change of the supporting layer thickness from 50 mm to 500 mm (Var. 2, Tab.1). It was determined that with the increase in the thickness of the supporting layer of the wall the χ-value reduces from 0.034 to 0.022 [WK–1]. The influence of the fasteners on the *U*-value of the entire wall will drop from 31% to 25%. In this case, the increase in the thickness of the supporting layer of the wall by 100 mm reduces χ-value by approximately 10%.

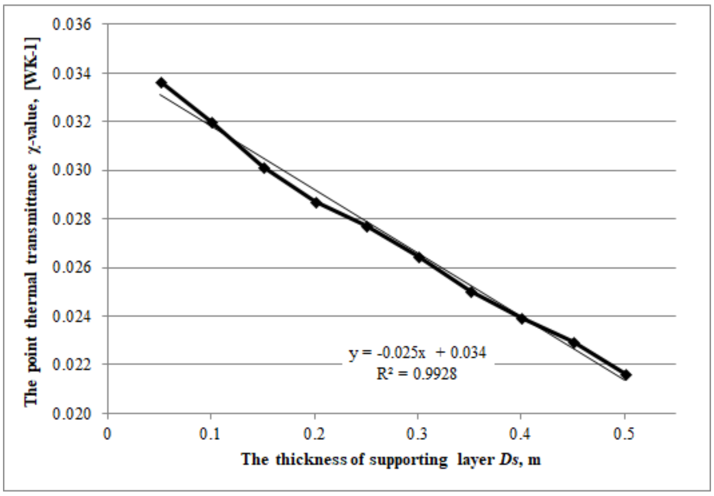

Figure 4. Relationship between the calculated χ-value and the *Ds*-value of the supporting layer of wall

Figure 5 illustrates the change in the point thermal transmittance with the change of thermal insulation material thermal conductivity λt from 0.030 to 0.040 [Wm–1K–1] (Var. 3, Tab.1.). It was determined that with the increase of the thermal conductivity coefficient of thermal insulation material, the χ-value drops from 0.029 to 0.028 [WK–1] and the influence of the fasteners on the *U*-value of the entire wall will drop from 31% to 26%. In this case, the increase in the value of thermal insulation material thermal conductivity coefficient by 0.01 [Wm–1K–1] reduces the point thermal transmittance by approximately 4%.

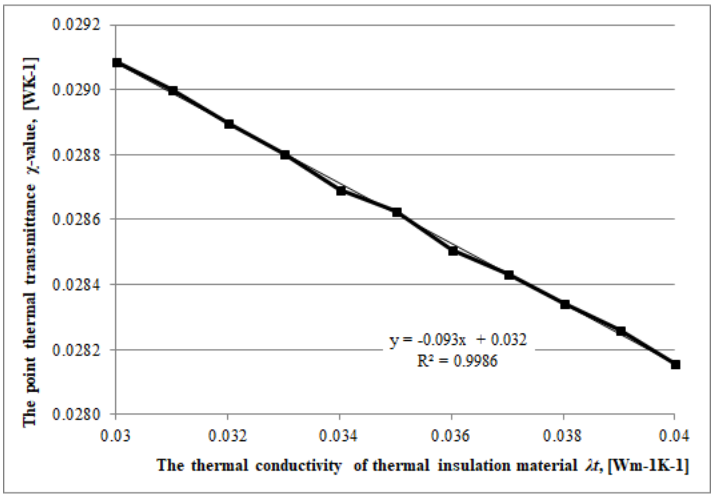

Figure 5. Relationship between the calculated χ-value and λt-value of thermal insulation material

Figure 6 illustrates the change in the point thermal transmittance with the change in the thickness of thermal insulation material *dt* from 100 mm to 200 mm (Var. 4, Tab.1.). It was determined that with the increase in dt the χ-value increases from 0.027 to 0.029 [WK-1] and the influence of the fasteners on the *U*-value of the entire wall will increase from 21% to 35%. In this case, the increase in the thickness of thermal insulation material from 100 mm to 200 mm increases χ-value by approximately 7%.

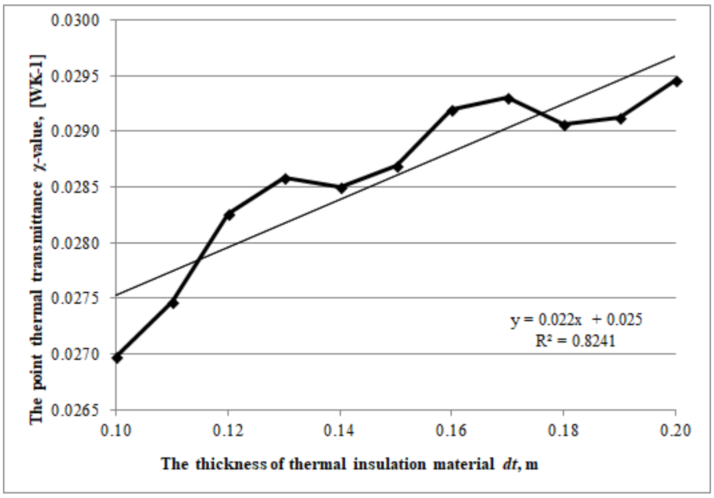

Figure 6. Relationship between the calculated χ-value and *dt*-value of thickness of thermal insulation layer

3.2. Functional dependency of point thermal bridge

The previous chapter described the dependency of thermal bridges created by the fasteners of walls with ventilated facades system on thermal conductivity coefficient and thickness of the bearing layer material as well as on thermal conductivity coefficient) and thickness of thermal insulation material. If the left-side values of Equations (which are presented on Fig. 3-6) are the same, the general functional dependency may be expressed as follows (Eq. (5)):

$$\chi = \begin{cases} 0.038 + 0.014\, ln(\lambda_S); \\ 0.034 - 0.025 D_S; \\ 0.032 - 0.093 \lambda_t; \\ 0.025 + 0.022 d_t. \end{cases} \quad (5)$$

The solution of this equations system gives a mathematical expression (Eq. (6)):

$$\chi = 0.041 + 0.4(\lambda_S) - 0.025(D_S) - 0.016(\lambda_t) + 0.022(d_t); \quad (6)$$

This Equations (Eq. (6)) allows for prediction the value of point thermal bridges, which depend on different parameters of the external wall (thickness of the layers and thermal properties of the materials).

The reliability of the formula was verified by separate calculations. The results of the comparison of the point thermal transmittance values calculated by two methods (of HEAT3 simulation and calculation according to Equation (6)) are given in Figure 9. The result shows the Equation (6) is suitable to forecast the values of thermal bridges according to thermal and geometrical properties of the structure using the aluminum fixsing element with defined dimensions.

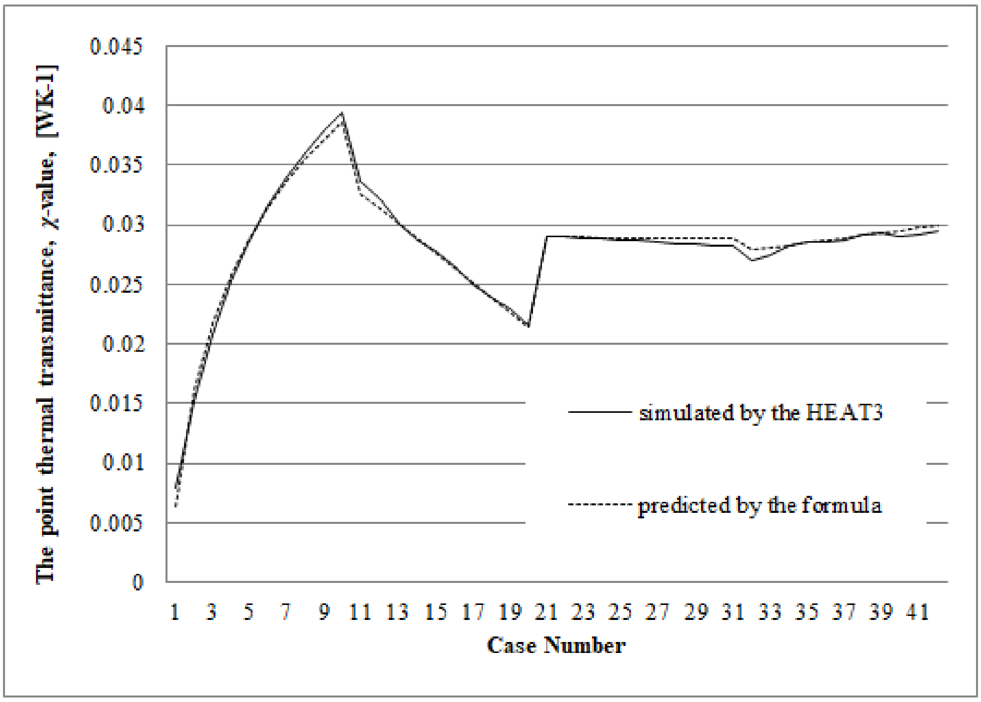

Figure 9. The values of point thermal transmittance determined by means of HEAT3 simulation and by means of Equation (6)

Conclusions

The results of investigation show that the influence of the point thermal bridges to the *U*-value of the entire wall may achieve average to 30% regarding thermal properties of materials, which are used in external walls layers and dimension of layers. This conclusion is important for the design of energy-efficient buildings.

The tests have shown that increase of thermal conductivity of the material of the supporting layer and the thickness of thermal insulation layer may increase *U*-value of the entire wall up to 35% as a result of the effect of point thermal bridge.

The point thermal bridge may decrease *U*-value of the entire wall up to 28% regarding the increase of supporting layer thickness and using insulation materials with higher thermal conductivity.

Knowing the functional dependency of point thermal transmittance values on the thermal properties of fastener materials and fastener dimensions it is possible to calculate the specific point thermal bridge by means of simplified calculation by using the empirical relationship (Eq. (6)).

Acknowledgment

This work has been supported by Basic Science Research Programme through the Kaunas Technology University (KTU) and funded by the Ministry of Environment of the Republic of Lithuania.

Nomenclature

A	area of element i of the building envelope, [m^2]
U	thermal transmittance of the building envelope, [Wm^2–1K–1)]
ΔU	transmittance correction factor, [Wm2–1K–1)]
U_i	thermal transmittance of element *i* of the building envelope, [Wm2–1K–1)]
l	length within the 2-D geometrical model over which the value of U applies, [m]
N	number of components, [-]
χ	point thermal transmittance of the point thermal bridge, [WK–1]
L	thermal coupling coefficient obtained from a 3-D calculation of the component separating the two environments being considered, [-]
H	specific heat losses through repeated surface area with a fastener, [WK–1]
H_S	specific heat losses through repeated surface area without a fastener, [WK–1]
n	number of fasteners per surface area, [pcs.m^2–1]
d	thickness of the thermal insulation layer, [m]
D	thickness of the supporting layer, [m]
Greek letters	
λ	thermal conductivity coefficient, [Wm–1K–1)]
Ψ	linear thermal transmittances of linear thermal bridge, [Wm–1K–1)]
Subscripts	
i	1-D component
j	2-D component

3D	3-D calculation of the component
t	thermal insulation materials
s	supporting layer of wall

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Submitted: 19.07.2018.
Revised: 15.07.2019.
Accepted: 24.07.2019.