

Dependencies of heat transmittance through the ventilated wall system on thermal conductivity of connectors crossing thermal insulation layer

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Abstract. The ventilated facade systems are widely used for improvement of energy efficiency and reducing of heat losses of newly built buildings and for existing buildings. To reduce the influence of point thermal bridges on heat transfer through the ventilated facades, previous often used aluminium alloy connectors as a change to stainless steel and reinforced plastic connectors. Different thermal characteristics of connectors using in ventilated facade systems, significantly influence the heat transfer coefficient of building's walls. Previous empirical calculations of the heat transfer through ventilated facade walls with different connectors according to standard methodology and numerical modelling showed significant differences in results, therefore experimental research with the fragments of the ventilated facade systems were carried out using a guarded hotbox method.

The aim of this experimental research was to analyse the heat flows through the ventilated wall system with different kind of heat-conductive connectors. Expanded polystyrene foam ($\lambda - 0,031 \text{ W/(m}\cdot\text{K)}$) was used as thermal insulation material, thickness 300 mm, and three types of heat-conductive connections were installed: aluminum alloy ($\lambda - 160 \text{ W/(m}\cdot\text{K)}$), stainless steel ($\lambda - 17 \text{ W/(m}\cdot\text{K)}$) and glass fiber reinforced plastic ($\lambda - 0,23 \text{ W/(m}\cdot\text{K)}$).

The measurements in the guarded hotbox were useful for analysis of differences in results according to the standard and numerical calculations methods. The experimental studies showed that the results are very close to the numerical simulation results. The empirical calculation method gave similar results to the other two methods, except in the case of highly heat-conductive connectors.

1 Introduction

According to the Energy Performance of Buildings Directive of European Commission, Member States have to set up minimum energy performance requirements for new buildings and for existing ones that undergo major renovation [1]. Consequently today newly built and renovated buildings must meet high energy efficiency requirements. The

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ventilated facade systems are used for both the newly built buildings as well as for the renovated buildings.

In cold climate zones, it is very important to evaluate correctly the influence of point thermal bridges on the heat transfer through ventilated facade systems. The heat-conductive connectors, which cross the thermal insulation layers, have a thermal conductivity that can sometimes be over 4000 times higher than the thermal conductivity of thermal insulation material. A lot of research was carried out to investigate the reduction in heat transmittance of wall constructions due to the influence of linear and point thermal bridges [3-7]. Theodosiou et al. found that the disregard of point thermal bridges in cladding systems of facades could lead to significant underestimation of actual heat flows what can account for 5 % to almost 20 % of the total heat flows through the building envelope [4].

Composite connectors, which combine metal and less heat-conductive materials, are used in the external ventilated wall to reduce heat loss through the walls envelopes instead of metal connectors. Song et al. investigated a few of composite connectors. His study showed that the composite connectors could reduce overall heat losses through the envelope of wall up to 68 % comparing with the conventional metal connectors [8].

There are three options for evaluating the impact of heat conductive connectors on heat transfer. The most commonly used standard methodology is EN ISO 6946:2017 [10], according to which calculates the change in heat transfer coefficient of the structure due to impact of connectors. The influence of thermal bridges can also be assessed using numerical methods [9]. Ji et al. [11] calculated the effective thermal conductivity λ_e of the insulation system with different anchors by using a numerical simulation method. Authors chose different materials of anchors (nylon, steel, stainless steel and aluminium alloy) and different sizes of the anchors (16 mm², 36 mm², 64 mm², 100 mm² and 144 mm²). The results showed that the use of the anchors has great negative influences on the effective thermal conductivity λ_e of the insulation system. The effective thermal conductivity λ_e increases with the increase of anchor properties, such as its density, size, thermal properties and length [11]. For example, the use of aluminium alloy anchors in mineral wool insulation system increases λ_e from 0.04 W/(m·K) to 0.1007 W/(m·K), which results in the increase of building energy consumption of 7.4% [11]. The most realistic method of estimating the influence of heat conductive connectors on total thermal transmittance of wall is the measurement of real-size construction fragments by the hotbox method described in standard EN ISO 8990:1999 [12].

The results of previous studies showed that the results of standard and numerical calculations differ significantly, especially when using highly heat conductive aluminium alloy connectors. Therefore, the aim of this study was to compare the results of calculation and measurement and to clarify the reasons for the differences in calculation result.

2 Methodologies

2.1 The empirical calculation method

Calculating the heat transfer coefficient U of walls fragment, according to the empirical calculation method, the total resistance R_T of all fragment layers is calculated, from which the thermal transmittance U_0 without mechanical fasteners is found and the correction of the thermal transmittance due influence of heat-conductive connectors according to Eq.2 is added:

$$U = U_0 + \Delta U_f \quad (1)$$

According to the standard EN ISO 6946:2017 [10] the correction to the thermal transmittance is given by:

$$\Delta U_f = \alpha \cdot \frac{\lambda_f \cdot A_f \cdot n_f}{d_1} \cdot \left(\frac{R_1}{R_{tot}} \right)^2 \quad (2)$$

Where: $\alpha = 0.8$ if fastener fully penetrates the insulation layer; $\alpha = 0.8 \times \frac{d_1}{d_0}$ in the case of recessed fastener; λ_f – thermal conductivity of the fastener (W/(m·K)); n_f – the number of fasteners per m²; A_f – the cross-sectional area of one fastener (m²); d_0 – the thickness of the insulation layer containing the fastener (m); d_1 – the length of the fastener that penetrates the insulation layer (m); R_1 – the thermal resistance of the insulation layer penetrated by the fasteners (m²·K/W); R_{tot} – the total thermal resistance of the component ignoring any thermal bridging.

2.2 Numerical calculation method

A more precise calculation of the impact of mechanical fasteners can be obtained by the numerical calculation method validated by standard EN ISO 10211:2017 [9]. Using 3-D finite-difference numerical simulation software HEAT3 (version 6.1.0.0) two models of wall fragment with the same dimensions are designed: with heat-conductive connections and without them. The heat flow through each model is calculated by HEAT3 program and the difference between them indicates the amount of heat flow due to the influence of the connectors. This procedure represents the equality of the standard EN ISO 10211:2017 [9]:

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

where L_{3D} – the thermal coupling coefficient obtained from 3-D calculation of the 3-D component separating the two environments being considered; U_i – the thermal transmittance of the 1-D component i separating the two environments being considered; A_i – the area over which the value U_i applies; Ψ_j – linear thermal transmittance; l_j – the length over which the value Ψ_j applies; N_j – the number of 2-D components; N_i – the number of 1-D components.

Then the correction to the thermal transmittance is given by:

$$\Delta U_f = n_f \cdot \chi \quad (4)$$

Where: n_f – the number of fasteners per m².

2.3 Experimental “Hotbox” method

Experimental measurements were carried out using the guarded hotbox method. The guarded hotbox consisted of a cold chamber, a hot chamber and a metering box. A test specimen is installed between the cold chamber and the hot chamber. The procedure of measurements is validated against the standard EN ISO 8990:1999 [12]. The air temperature of the cold chamber was set to 0° C, and the temperature of the hot chamber was set to 20° C.

2.4 Parameters of wall fragments for theoretical and experimental research

Experimental and theoretical researches were carried out with thickness 300 mm of thermal insulation layer from expanded polystyrene foam ($\lambda = 0.031 \text{ W}/(\text{m}\cdot\text{K})$). The thermal insulation material is crossed by “L” shape connectors made from aluminium alloy ($\lambda =160 \text{ W}/(\text{m}\cdot\text{K})$), stainless steel ($\lambda =17 \text{ W}/(\text{m}\cdot\text{K})$) and glass fiber reinforced plastic ($\lambda =0.23 \text{ W}/(\text{m}\cdot\text{K})$). The thickness and height of all heat-conductive connectors are the same – 3 mm and 100 mm respectively. The length of connectors depends on thickness of thermal insulation layer. The structure and dimensions of the fragment are shown in the Fig. 1.

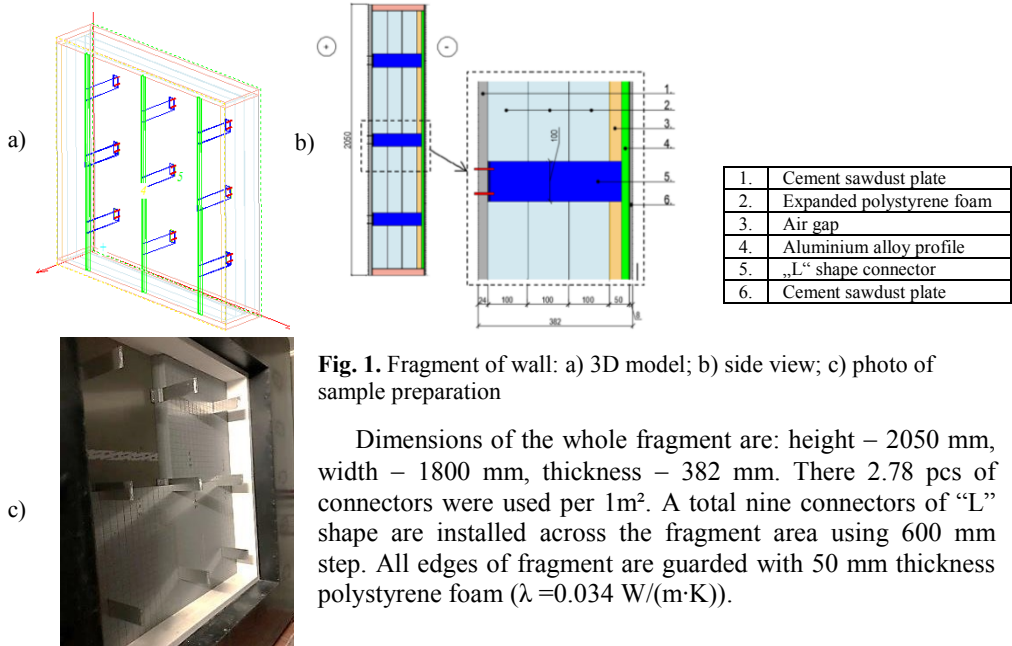


Fig. 1. Fragment of wall: a) 3D model; b) side view; c) photo of sample preparation

Dimensions of the whole fragment are: height – 2050 mm, width – 1800 mm, thickness – 382 mm. There 2.78 pcs of connectors were used per 1m². A total nine connectors of “L” shape are installed across the fragment area using 600 mm step. All edges of fragment are guarded with 50 mm thickness polystyrene foam ($\lambda =0.034 \text{ W}/(\text{m}\cdot\text{K})$).

3 Results

Calculations and measurements results by three methods are shown in Table 1. The research showed that, using connectors with lower heat conductivity, the difference between values of heat transmittance of wall is not significant. However, the biggest difference of heat transmittance is noticeable in the calculations by the empirical method with aluminium alloy connectors, which have the highest thermal conductivity. In this case, the value of heat transmittance by the empirical method is almost two times higher than by hotbox and numerical methods. The calculated correction to the thermal transmittance of wall fragment with aluminium alloy connectors also indicated the highest difference comparing with other two methods.

Table 1. Calculations and measurements results of heat transmittance by three different methods

Material of connectors	Hotbox method			Numerical method			Empirical method	
	U_c W/(m ² ·K)	χ_c W/K	ΔU_c W/(m ² ·K)	U_c W/(m ² ·K)	χ_c W/K	ΔU_c W/(m ² ·K)	U_c W/(m ² ·K)	ΔU_c W/(m ² ·K)
Without connectors	0.105	-	-	0.098	-	-	0.100	-
Glass fiber reinforced plastic	0.103	-0.0006	-0.0016	0.099	0.0002	0.0005	0.101	0.0004
Stainless steel	0.123	0.0074	0.0205	0.125	0.0109	0.0302	0.136	0.035
Aluminium alloy	0.201	0.0401	0.1114	0.200	0.0417	0.1159	0.432	0.331

Fig.2. shows temperature distribution and intensity of heat flow through the models with aluminium alloy (a, b) and stainless steel (c, d) connectors. Analysing the fields of temperature it was observed that using aluminium alloy connector much lower temperature reached the inner surface of wall than using the stainless steel connector. The intensity of heat flow through the aluminium alloy connector was almost four times higher than through the stainless steel connector.

The heat flows through the specimen and through the one connector are shown in Table 2. Comparing the values of heat flow through the specimen by the experimental hotbox method and numerical 3-D calculation method, the difference is up to 5 % between them. It means that simulation models of wall fragments were created with very close conditions to the real fragments used in experimental measurements. In order to analyse the reasons of very significant differences in results, the values of the heat flow through the one connector were calculated for each case. These results clearly showed tendency that the more conductive connectors are used, the higher amount of heat flow dissipates to the boundary layers. It means that heat flow does not go only through the connector, how the empirical method evaluates. The tendency is also visible in the Fig. 2. (a, c). For that reason, the heat transfer from heat-conductive connector to thermal insulation material should be analysed additionally.

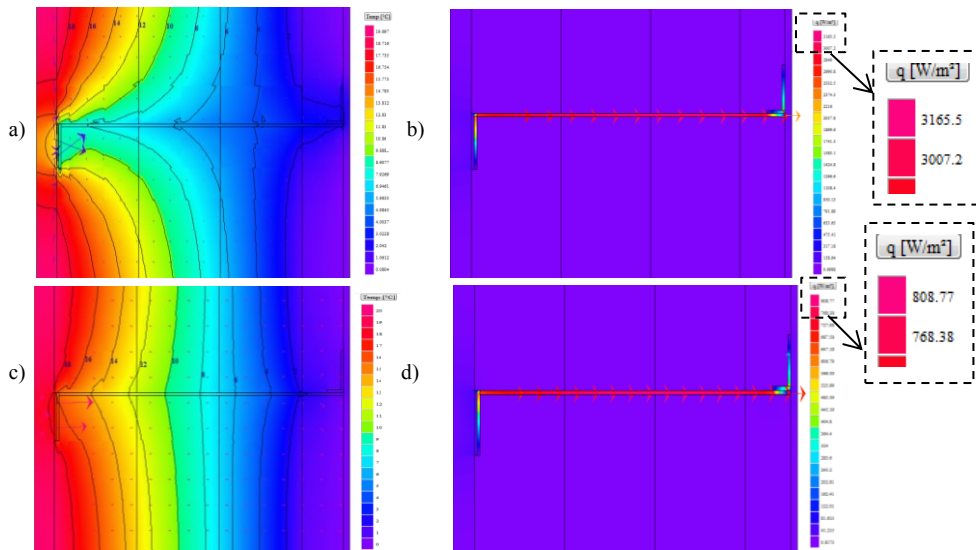


Fig. 2. Temperature distribution (left) and intensity of heat flow (right) with aluminium alloy connector (a; b) and stainless steel connector (c; d)

Table 2. Calculations and measurements results of heat flow by different methods

Material of connectors	Hotbox method		Numerical method		Empirical method
	Heat flow through the specimen Φ , W	Heat flow through the one connector Φ , W/K	Heat flow through the specimen Φ , W	Heat flow through the one connector Φ , W/K	Heat flow through the one connector Φ , W/K
Without connectors	7.624	-	7.262	-	-
Glass fiber reinforced plastic	7.521	0.001	7.296	0.0002	0.0007
Stainless steel	8.953	0.007	9.218	0.011	0.051
Aluminium alloy	14.835	0.040	14.765	0.042	0.480

4 Conclusions

The results of this study confirmed that numerical calculation method is more accurate than empirical calculation method, calculating heat transmittance through the ventilated wall with heat-conductive connectors. According to the empirical calculation method the difference in results of heat transmittance of wall system with two types of connectors and without connectors were obtained up to 10 % comparing with the results of experiments. That could mean that the simple empirical method is appropriate and sufficiently precise for calculations, but the results with the connectors made of aluminium alloy refuted this assumption, whereas the difference of more than twice was obtained. The distribution of field of temperature is also diverse around the connectors made from different materials. It can be assumed that the empirical method should be corrected for calculations with extremely heat-conductive connectors such as aluminium alloy. For this reason, there is a need to carry out more comparative calculations and experimental measurements with various materials and thickness of thermal insulation and different kind of connectors to analyse heat transfer from the connector to thermal insulation material.

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