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Analysis of the Thermal Bridging Effect on Ventilated Facades

T.Theodosiou[a,*], K.Tsikaloudaki[a], D.Bikas[a]

[a] *Laboratory of Building Construction and Building Department of Civil Engineering,*
Aristotle University of Thessaloniki, P.O. Box: 429, Gr-54124 Thessaloniki, Greece

Abstract

Resent developments on the requirements regarding the thermal efficiency of buildings and building envelopes, have increased the need for energy retrofit of building envelopes. Cladding systems and ventilated facades are among the most attractive solutions to these problems due to a variety of reasons, including aesthetics, moisture control, serviceability and resistance to environmental factors. Despite all the benefits of these structures, their actual thermal efficiency has not been studied extensively yet. In many countries, the thermal performance of these structures is treated in the same way as more simple structures like ETICS. Within the framework of the European project E2VENT, an thorough study of the nature of thermal bridges has been performed – among others- in order to reveal the nature and the magnitude of thermal bridge effects in such structures, to investigate the design parameters that can assist in minimising their contribution in overall heat flows and to improve the overall thermal efficiency of the building envelope. Results shows that thermal bridges in metal cladding systems can be a significantly weak point in thermal insulation protection if no special care is given during the design and the construction process. By simply neglecting point thermal bridges due the lack of specific requirements, to the insufficient knowledge or by considering that only the use of thermal-break products can efficiently treat it, can significantly decrease the thermal insulation quality of the façade, leading to undesirable results.

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Keywords: Thermal bridges; aluminum cladding; building façade; thermal insulation

1. Introduction

Ventilated building facades are an external envelope technique with significant benefits over traditional, single skin facades. These benefits cover almost all building physics topics, from moisture to thermal efficiency, noise, fire

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[*] Corresponding author. Tel.: +30-2310-995818; fax: +30-2310-995603
E-mail address: tgt@civil.auth.gr

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resistance and structural efficiency. Aluminium cladding systems, are a special case of ventilated facades, presenting some additional benefits that have highly promoted their penetration, especially into the building retrofit marker. These lightweight structure is considered to be a sustainable construction system since it is almost fully recyclable, it promotes external thermal insulation using more environmental friendly thermal insulation materials and it minimizes linear thermal bridges that can account for a large portion of thermal losses through the building envelope [1,2]. Recent developments in European building requirements regarding the energy efficiency of buildings, are promoting the use of such system in numerus building energy retrofit projects. In this context, improving the efficiency of this technique can lead to more efficient buildings. This is one of the main goals of the E.U. funded project E2VENT: Energy Efficient Ventilated Façades [3]. Within the framework of E2VENT, a Smart modular heat recovery unit (SMHRU) and a latent heat system for thermal storage (LHTES) are integrated within the cladding system in order to provide a holistic, and yet, simple and sustainable solution for the energy upgrade of existing buildings. The cladding system is optimized by means of thermal, and structural efficiency, in order to develop characteristics specially for the retrofit of existing buildings.

In most EU member states, the thermal efficiency of metal cladding systems is treated similarly to traditional single skin envelopes. Thermal bridge effects are taken into account, but only those that have the form of linear thermal bridges. Point, or 3-dimensional thermal bridges, are usually neglected since, their effect on heat flows through the building envelope is considered to be very small, and extremely difficult to estimate, since such calculations are based on analytical finite-element analysis tools, not suitable for studies in the construction industry. In the absence of special legislations and requirements regarding the treatment of these constructions, it is quite common to overlook the existence of this effect, not only during the design stage but also during the construction phase.

While in traditional building envelopes, the magnitude of point thermal bridges is of minor importance, this is not the case in double-skin facades. These constructions require a relatively large number of points where the external envelope has to be secured on the internal-substrate envelope. At these areas, steel or aluminium brackets, penetrate the insulation layer. Although the volume of the brackets is extremely small compared to the one of the insulation layer, its thermal transmissivity can be more than 2000 times higher, leading to intense thermal bridge heat flow between the warm interior wall behind the thermal insulation and the cold structural metal frame in winter and via-versa in summer. Recent studies show that overlooking point thermal bridges is such constructions can lead to more than 20% underestimation of the actual heat flow magnitude, depending on a variety of factors [4].

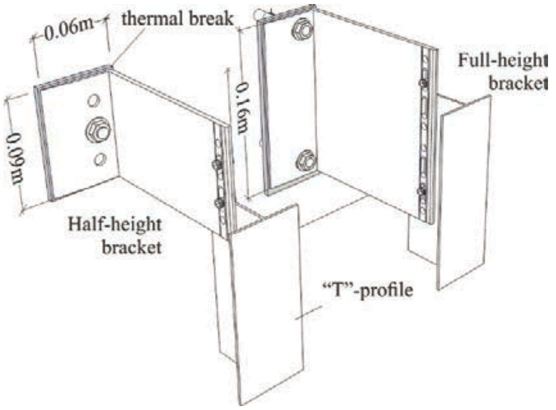

Figure 1. Sketch of the brackets used in E2VENT system. Half-height bracket is used in positions between floors and full height brackets in positions at floor level

Within the framework of the E2VENT project, a lot of effort was invested on studying in detail the point thermal bridge problem of the system under development. The main goal is to investigate the nature of thermal bridge effects, by analysing the contribution of each factor. The analysis includes the effect not only of the elements of the E2VENT system, but also the effect of the parameters related to substrate wall, where the system is expected to be installed. This effort has two main goals. The first is to optimise the design of the system, since the coupling of the structural and the thermal analysis can lead to an efficient design that will respect both requirements. The second is to develop a tool for accurate calculation of the thermal bridge magnitude on a variety of substrate envelopes (existing buildings), under different structural element configurations. This will enrich the design process and will allow building professionals to support the thermal efficiency of the building by accurately incorporating the thermal bridge effect without a need for time and money consuming, complicated, finite element analyses.

2. Methodology

In order to develop a tool aimed at assisting the design process of cladding systems, the work performed in the framework of the E2VENT project had to comply with established standards, as those currently in use in building construction studies. Although existing standards does not cover the case of such complex thermal bridges, they provide recommendations and requirements. According to ISO 10211, the required accuracy of such complex geometries can be achieved only through a finite element analysis [5]. In order to accurately analyse the thermal bridge effect, a detailed computational model was developed within the ANSYS Workbench finite element analysis environment. The three dimensional nature of the point thermal bridge effect on cladding systems required a detailed calculation approach in order to take into account the complex geometry and the great differences in Thermophysical properties of adjacent materials. Since the actual cladding assembly (figure 2) presents symmetry in the horizontal plane, the calculation makes use of this symmetry to reduce the size of the modelled element and increase the calculation speed. It is noted that with the exception of the bracket characteristics and the area of the element, all other characteristics presented in the figure are variable and part of the multi-parametric study. Mesh optimization resulted in a calculation mesh consisting on average on 150000 tetrahedral elements. The actual number of calculation elements can vary depending on the examined parameters in every study.

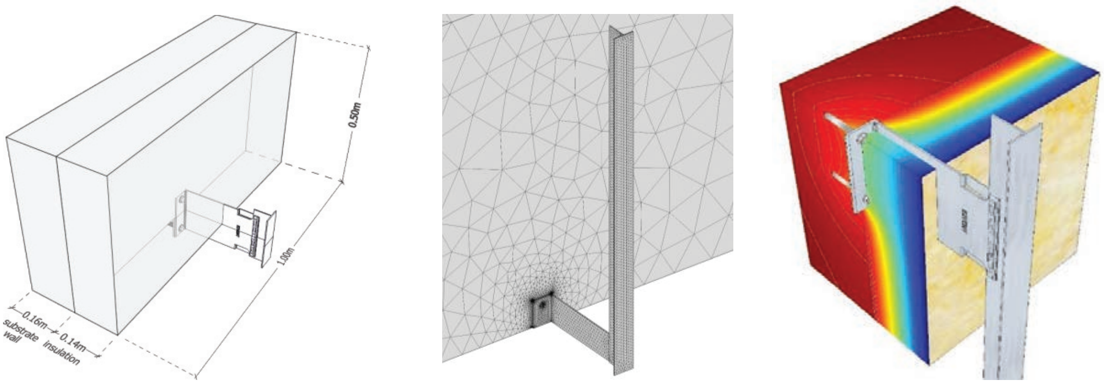

Figure 2. Sketch of a simulation element using symmetry (left), of calculation mesh at the area of the full length bracket (middle) and of calculated isothermal contour around the anchorage area (right).

The problem of point thermal bridges is a multi-parametric problem, highly affected by the geometry under study and the thermophysical properties of all materials involved within the geometry. Any change in one of the parameters of the effect can lead to changes of the thermal bridge magnitude that do not follow a linear relation and, most important, it is not always clear if the change in thermal bridge magnitude would be analogous or reverse analogous. Since the E2VENT system has been designed in order to be modular and to easily adopt to a wide range of requirements, all these parameters have to be taken into account in order to provide the required level of accuracy, detail and confidence on the value of the results. Most of these parameters are presented in table 1.

Table 1. Parameters under investigation.

Parameter	Range	Comments
Bracket type	Half / Full Height	*Each bracket has different thermal behavior due to the different geometry*
Wall thickness [m]	0.10 m to 0.45 m with a step of 0.05 m	*A wide range ensures representation of most common external wall thicknesses.*
Wall material thermal conductivity, λ [W/(m·K)]	0.2, 0.3, 0.50, 0.75, 1.0, 1.5, 2.0, 2.5 W/(m·K)]	*Most common materials used in wall elements are represented within the examined range*
Thermal insulation thickness [m]	0m to 0.30 m with a step of 0.025m	*Covers existing wall structures and all highly insulated one, even by nZeb or Passive House standards*
Anchor type	Synthetic, Steel or Chemical anchor	*All anchor types are examined*

3. Results and discussion

3.1. Thermal break

The use of a thermal break pad is an efficient measure in order to decrease the thermal bridge effect. The insertion of a low-thermal conductance layer between the back of the bracket and the wall, is supposed to drastically minimise thermal bridge phenomena. While thermal analysis verifies that the thermal break significantly alters heat flow at the bracket area (figure 3), the magnitude of the effect is highly related to the thermal conductivity of the thermal break material and its thickness. Nevertheless, mechanical strength requirements significantly limit the use of materials of low thermal conductance and of sufficient thickness. Materials that have good thermal insulation behaviour do not have the required strength level and vice versa. In most cases, a thermal break having thermal conductivity close to 1 W/(m·K) with no more than 6mm of thickness is the best permitted choice. In addition, the thermal break layer can only decrease heat flow by direct contact of the bracket to the wall and does not affect the anchor that penetrates the wall.

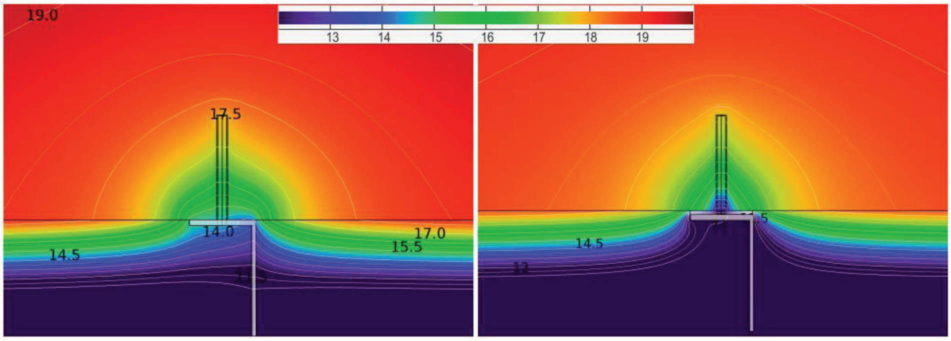

Figure 3. Isothermal surfaces showing temperature distribution on a plane vertical to the anchor for the scenario without thermal break (left) and with thermal break pad (right)

By interrupting the direct contact of the aluminium bracket and the substrate wall, heat flow is significantly decreased as figure 4 clearly shows. However, the effectiveness of this measure is not in accordance with what its name implies. The effect is minimum in the case where the substrate wall material has small thermal conductivity, since thermal resistance is also provided by the substrate wall, and the contribution of the thermal break is minimised.

In the case of a hollow-clay brick wall, with material thermal conductivity of around 0.5-0.6 W/(m·K), the increase of heat flow due to the absence of the thermal break pad is close to 10% in the case of a full height bracket and 15% for a single height one, while a concrete element faces increase of almost 20% and 23% for the examined bracket types.

The effect is more intense in the case of half-height brackets, since after the insertion of the thermal break pad, heat flow is channelled through the single steel anchor, while in the case of full height bracket, the area of the conductive steel material is doubled, decreasing the additional protection offered by the thermal break pad.

This is clearly presented in figure 3, where heat flow is mainly concentrated around the anchor in the case of a bracket with thermal break (right picture), while the absence of the thermal break pad results in smoother and more widely distributed material temperatures. Although, anchoring the façade mainly on materials of low thermal conductivity may sound like an effective measure to minimise thermal bridges, other strength restrictions, suggest that facade anchoring on such materials of low mechanical strength can have only secondary role and the façade should be anchored on materials of higher strength, and unavoidably, higher conductivity.

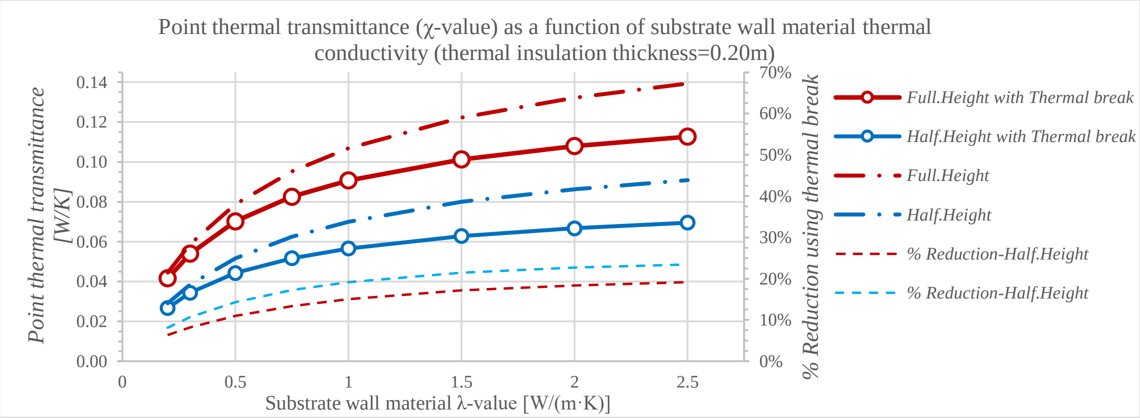

Figure 4. The effect of the thermal break, on the point thermal transmittance for various thermal conductivities of the substrate wall (steel anchor)

3.2. Material of the substrate wall

Existing walls on buildings where the E2VENT system may be applied, can consist on a variety of materials, from lightweight materials with thermal insulation capabilities to heavy materials, like reinforced concrete, that are relatively good heat conductors. The investigation performed in the analysis, covered a thermal conductance range that includes almost all materials found in European buildings. As it can be seen on figure 3.9, the thermal conductivity of the wall material ranges from 0.2 W/(m·K), representing lightweight insulation bricks, clay bricks having a thermal conductivity around 0.60 W/(m·K) up to very conductive materials like reinforced concrete found in columns, beams and concrete plates.

The analysis clearly shows that the importance of the examined factor is significant for the extend of the thermal bridge effect. In materials having some thermal insulation capabilities, the type of the bracket, the number of anchors penetrating the insulation layer or the thickness of the insulation layer play a less important role, since the wall can provide some thermal insulation between the cold bracket and the warm interior.

On the contrary, more common materials like clay bricks or concrete cannot provide such protection and point thermal transmittance can reach relatively high values. As it can be easily seen, the full height brackets can reach much higher heat flow values in comparison to the single-anchor, half height brackets.

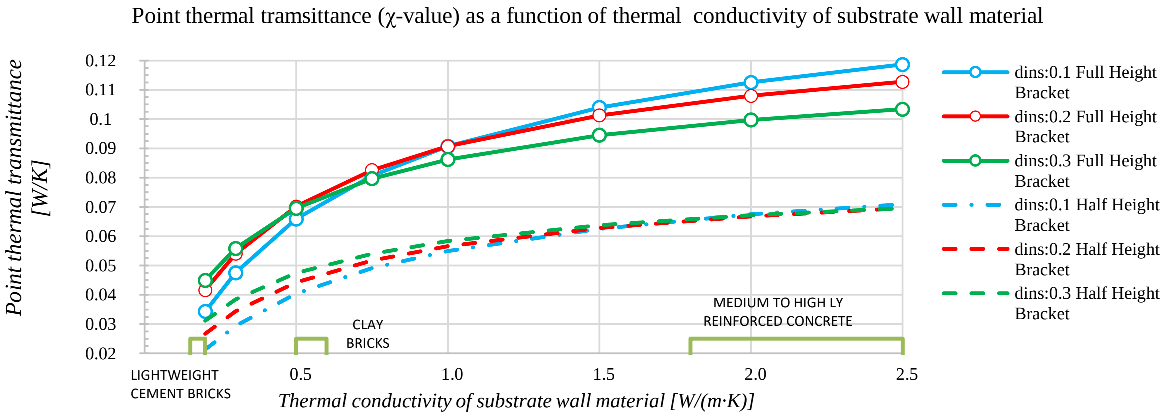

Figure 5. The effect of the thermal conductivity of the substrate wall material, on the point thermal transmittance

3.3. Thickness of thermal insulation layer

The thermal insulation layer, placed at the external side of the substrate wall, is part of the E2VENT system. In competitive refurbishment renovation measures like ETICS, this parameter is the most important one since the effectiveness of such systems are almost entirely depend on it. This might not be the case for the E2VENT system but, obviously, it remains a target parameter. In most cases, the minimum thickness is imposed by local regulations and requirements in order to ensure a maximum allowable thermal transmittance of the wall element (U-value). In the framework of this analysis the material used for thermal insulation was considered to be rock wool with thermal conductance of 0.035 W/(m·K). Results are presented in figure 6 for both brackets.

The thermal conductivity of the substrate wall plays an important role as is can be seen in figure 6. In cases where the wall has some thermal insulation capabilities (low thermal conductivity), the thicker is the thermal insulation layer, the higher is the point thermal transmittance. On the contrary, on more thermally conductive materials, the increase in thermal insulation thickness leads to a reduction of the point thermal bridge magnitude. This behaviour represents the complexity of the subject under investigation, since the portion of the phenomenon attributed to geometric factors and the part attributed to heat flow factors are highly depended of the examined parameters.

In every case, since existing wall materials are expected to have thermal conductance more than 0.5 W/(m·K), one can conclude that the increase in thermal insulation thickness can contribute to a small decrease of point thermal transmittance in the case of full-height brackets, most probably because the thickness of the insulation layer is analogous to the length that heat has to travel through the highly conductive bracket.

In the case of half-height brackets, differences between various wall materials are smaller. This is obviously attributed to the higher thermal resistance of this this type of bracket since the anchors penetrating the insulation are reduced by 50% compared to the previous case. Consequently, the thermal conductivity of the wall is less important, since the higher thermal resistance of the single bracket has already decreased thermal bridge heat flows.

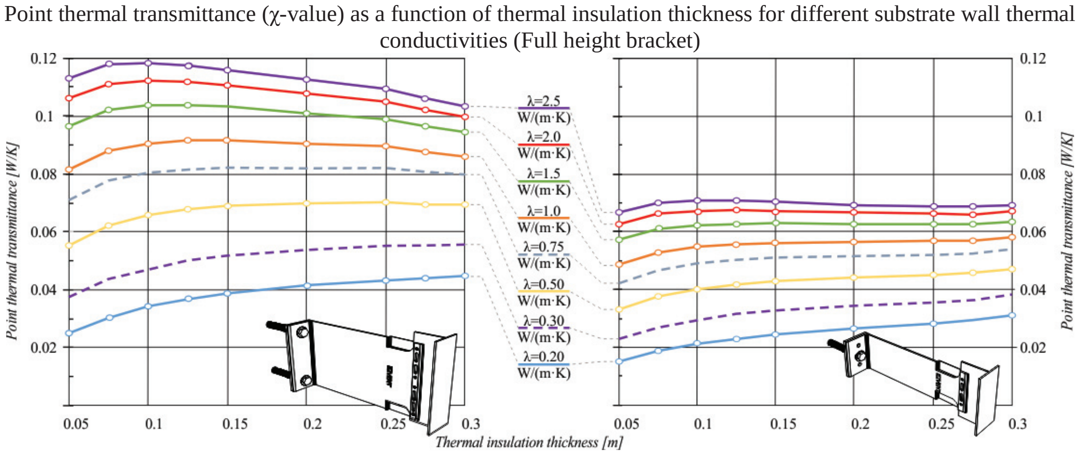
Point thermal transmittance (χ-value) as a function of thermal insulation thickness for different substrate wall thermal conductivities (Full height bracket)

Figure 6. The effect of the thickness of the thermal insulation on the point thermal transmittance for the case of the Full-height brackets, for a variety of substrate wall thermal conductance.
The results refer to rockwool insulation material (λ=0.035 W/(m·K))

3.4. Anchor type

Depending on the substrate material, a possible choice of anchors includes steel or plastic. Relatively recent advantages in anchoring technology have led to chemical anchors that present many advantages. In the case of the E2VENT system, where the quality, conditions and aging of the substrate material may be of unknown quality, chemical anchors is an attractive alternative, mainly for their mechanical properties. In addition, their influence on the thermal bridge effect is currently unknown. The thin continuous medium that separates the steel fastener from the substrate material is expected to act as a thermal insulator, decreasing the thermal contact between the wall and the fastener, which is the weakest part of the anchoring system with regards to the thermal bridges.

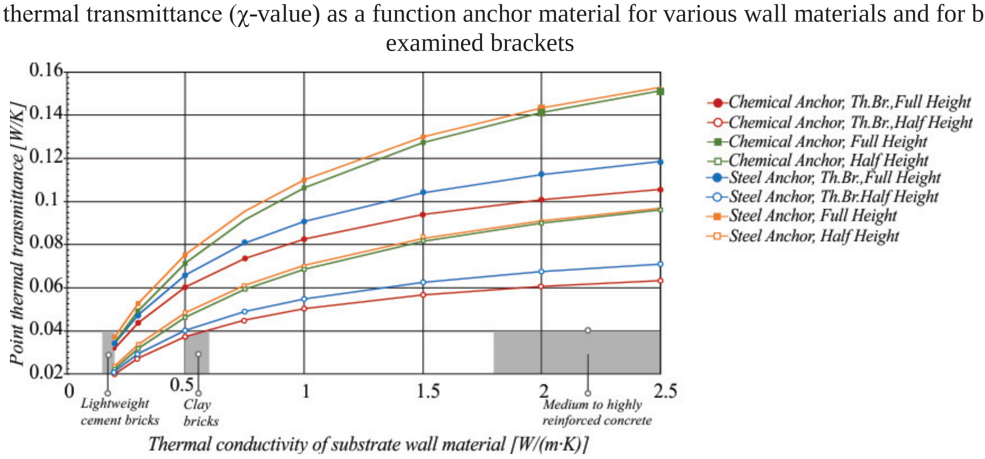
Point thermal transmittance (χ-value) as a function anchor material for various wall materials and for both examined brackets

Figure 7. The effect of the thickness of the thermal insulation on the point thermal transmittance for the case of the Full-height brackets, for a variety of substrate wall thermal conductance.

The thermal conductivity of the examined materials is indicative of their effect on the thermal bridge effect. Steel anchors have a λ-value of 65 W/(m·K) compared to 0.20 W/(m·K) and 0.09 W/(m·K) for plastic and chemical ones respectively. On the other hand, the very thin layer (2-3 mm) covering the steel fastener may be an indication of the significance of this factor.

Since literature regarding true characteristics of chemical anchors is very limited, this study does not consider the diffusion of the injected liquid material in the wall material and the possible alteration of thermophysical properties of the wall material around the anchor. As it can be seen from figure 7, the effect of the contribution of the chemical anchor is increased in the cases of the full height bracket and the high thermal conductivity of the wall material. This shows that the chemical anchor can decrease thermal bridge heat flows, especially in cases where other parameters of the support system does not lead to an optimum behaviour regarding the thermal bridge effect. The contribution in these cases is close to 10% heat flow reduction. Although such a contribution is not a highly effective measure, when all other chemical anchor benefits are considered, it becomes obvious that the anchor type for the E2VENT system cannot be other than the chemical one.

4. Conclusion

The study of point thermal bridges found in the examined aluminium cladding system configuration has analysed the design factors related to the magnitude of point thermal bridges. As it is common for such constructions, point thermal bridges are an important problem is these facades, but proper design can significantly contribute to an optimum results. Taking also into account the elimination of linear thermal bridges, due to the position of the thermal insulation layer, the study has optimized the supporting structure of the E2VENT system.

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