Thermal performance characterization of a modular system for facade

CARDOSO, C.[, a], JALALI, S.[,b]

Department of Civil Engineering
University of Minho
Campus de Azurém, Guimarães, Portugal

[a]cesar_cardoso@civil.uminho.pt, [b]said@civil.uminho.pt,

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Abstract. The developed system corresponds to multifunctional prefabricated modular elements that combine an insulation layer with a cast coating material for exterior that can imitate stone or concrete. These systems need auxiliary elements of fixing to connect them mechanically to the structural wall of the building, in order to ensure its stability, using anchorage, profiles, rails, among others. The use of these systems connected to the coating interrupts the continuity of thermal insulation, causing additional heat losses through linear and point thermal bridges, having an detrimental effect on thermal performance of the system. The development of fixing of present multifunctional panels was based on the evaluation and adoption of appropriate solutions in order to minimize thermal bridges and reinforce the stability of the panel. For evaluation purposes some models are evaluated, with different connecting systems, configurations and different materials such as aluminium, stainless steel, galvanized steel and Glass Fibre Reinforced Polymer (GFRP) profiles. The quantification of thermal bridges, for evaluation of thermal performance, has been made using computing programs, HEAT2 and HEAT3. The evaluation of a system developed in this research work, i.e. incorporating profiles in thermal insulation, shows a good thermal resistance contributing significantly to the thermal insulation and energy conservation in building.

Introduction

The modular prefabricated elements for thermal insulation are facade systems that combine an insulating layer with a coating material, generally moulded and pigmented on the external surface [1].

These panels are increasingly used in construction, specifically for thermal insulation or reinforcement in facades rehabilitation. Similarly, they are used because of the high labour costs and short execution deadlines required leading to larger industrialization of constructive systems.

In these systems there is no air chamber between support surface and insulating layer. The coating may be bond to the insulation layer with approximately the same length and height of the insulation [1]. Such panels need auxiliary pieces of fixing, i.e. anchorage, profiles, rails, among others, to connect them mechanically to external walls and ensure their stability.

For mechanical design purposes, these panels are differentiated according to the methods of fixing. The fixing to the support surface can be made through the insulation or coating layer, with H or I shape profile that serve as panel support, the form and type changes depending on the range of products. Figure 1 shows two fixing systems available on the market with connection profiles to insulation material, and with connection to the coating. Both systems have the European Technical Approval with the classification of Veture Kit - prefabricated unit for external wall insulation, according to the ETAG Guideline 17[2,3,19].

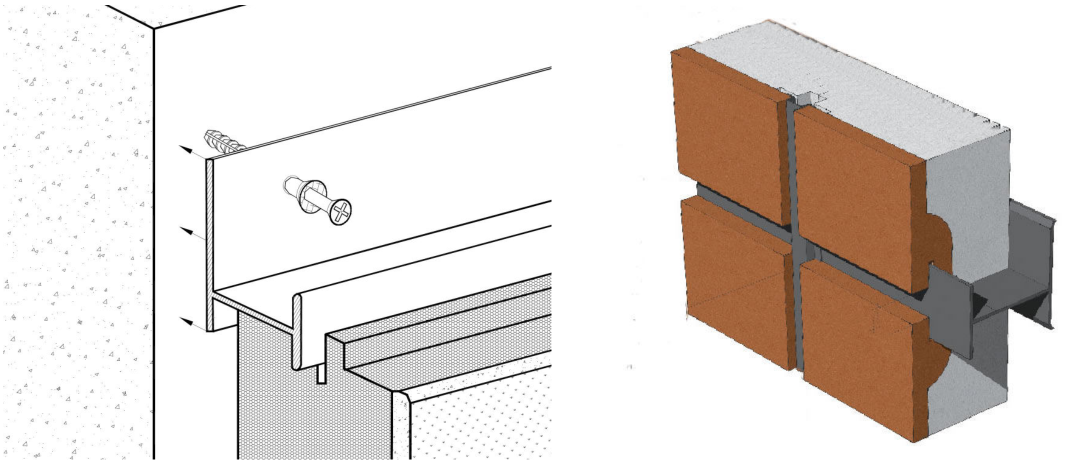

a) b)

Figure 1 – Veture Kit available in the market: a) connected to insulation, b) connected to coating [2,4]

The profiles are made with anodised aluminium and fixed to the wall with plastic anchors. The panel dimensions may vary according to the project specifications, with standard length of 450 mm or 600 mm and height from 300 to 1400 mm [2, 3].

The use of these systems connected to the coating interrupts the continuity of thermal insulation, causing additional heat transmission losses through linear and point thermal bridges having an adverse effect on the thermal performance of the system.

The final report developed by Assessment and Improvement of the EPBD Impact (ASIEPI) mentions that for "near zero energy buildings" for both new and existing buildings, the elimination or reduction of all types of thermal bridges will become crucial [5]. In Europe, in countries such as the Czech Republic, the thermal bridge can increase from 7% to 28% with higher quality of building envelope, without additional concerns with thermals bridges; in Netherlands, this increase can affect 11% of the energy performance of the building [5]. A study on the impact of thermal bridges for mild climate of Mediterranean countries states that the correction of thermal bridge turns out to be an effective measure to minimize the primary energy consumption of heating (25% for attached houses and 17.5% for detached houses), but only slightly improves(around 3.5%) the cooling performance of the building, the average annual global energy conservation would be around 8.5% [8]. In Portugal, a research work developed in this area notes that thermal bridge may achieve some 20% of total thermal loss [6]. This shows that the thermal bridges play an important role in the thermal performance of buildings, therefore, require a more careful attention in order to reduce heat losses.

Thermal bridging is specific to design and can be complex and time consuming to calculate. For this reason, some countries in Europe allow a default thermal bridging value to be used, as a percentage of the overall heat loss calculation (typically 15%) [18]. According to the Portuguese Regulations for the Characteristics of the Thermal Behaviour of Buildings (RCCTE), the linear thermal bridges allow a default thermal bridging value to be used and do not take into account the geometry, detail and material properties. The RCCTE indicates minimum requirements for thermal transmittance coefficient (U) for building envelope. The maximum admissible value ($U_{máx}$) and recommend reference value (U_{ref}) are given. Table 1 presents these requirements according to the element of the vertical building envelope and winter climate zone.

Table 1 – Maximum and reference thermal transmission coefficients ($U_{máx}$) and (U_{ref}) for vertical building envelope [9]

Vertical building envelope	Winter I_1	Winter I_2	Winter I_3
$U_{máx.}$ [W/m^2.ºC]	1.80	1.60	1.45
$U_{ref.}$ [W/m^2.ºC]	0.70	0.60	0.50

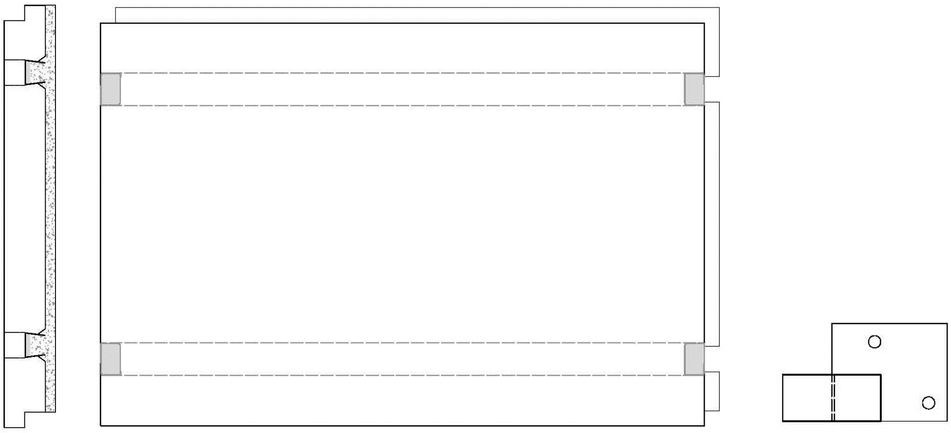
Although Portugal does not limit the maximum values of thermal bridges, there are some criteria that can be used for analysing the relative importance of linear thermal bridges (see Table 2).

Table 2 – Classification of thermal bridge effect by class [7]

Class	Class C1	Class C2	Class C3	Class C4
Ψ-value [W/m.ºC]	$\Psi < 0.1$	$0.1 \leq \Psi < 0.25$	$0.25 \leq \Psi < 0.5$	$\Psi \geq 0.5$
Effect	Negligible	Poor	Important	Very important

Prototype of the panel

The prototype of the panel results from the combination of an insulating layer with a coating of casted material, based on hydraulic binders and aggregates, which serves as surface finish. Each panel consists of one or three U-shaped embedded profiles. These profiles are embedded in the insulation layer, at the interface with the coating layer, and oriented in such a way as to allow the filling of the open cavity of the profile with material of the coating layer (Fig. 2a). These profiles are distributed along the length of the coating layer, ensuring the mechanical and dimensional stability of the panel, by reinforcement, and also the connection to the support. To assure the connection of profile to support, the system includes an attachment device with a regular basis, a terminal "T" shaped and tabs (Fig. 2b). The fixing of the panel is ensured by a simple fitting of the accessory of fixing to profile, therefore this not needs auxiliary means of fixation. The prototype has the standard dimensions of 600 mm length / 400 mm of height for ease of handling and adequacy of the productive process.



a) b)

Figure 2 – Panel system: a) prototype of the panel, b) auxiliary of fixing [1]

The placement and shape of the profiles were designed to improve the adhesion of the coating to the thermal insulation and prevent the fall of coating in case of fire. Their placement can also reduce the loss of thermal transmission, when compared with the traditional auxiliary of fixing that interrupts the continuity of thermal insulation, improving this way the thermal performance of the system. Figure 3 shows a scheme of how the panels can be mounted.

The selected material for thermal insulation, was extruded polystyrene (XPS), according to EN 13164. The auxiliary connection and the embedded profile are constituted by galvanized steel, presenting a thickness of 1.5 mm and 1.2 mm, respectively. The properties of these materials are presented in Table 3.

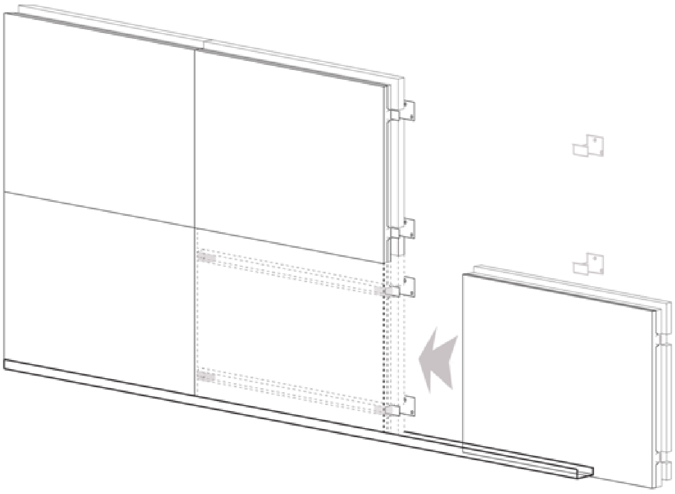
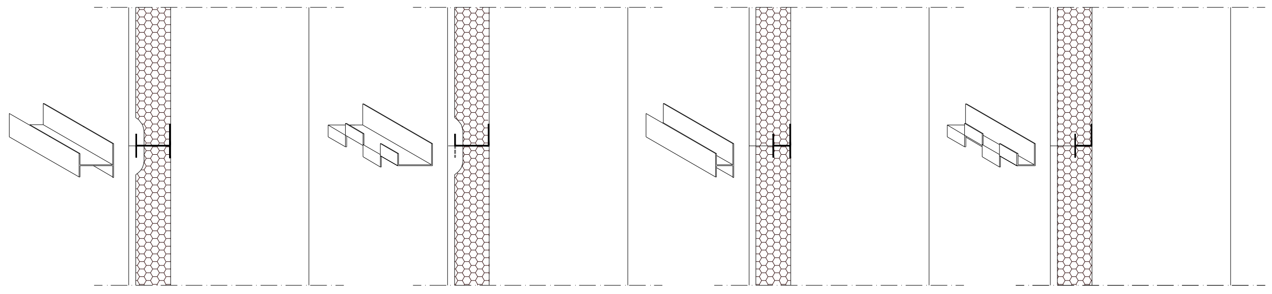


Figure 3 – Arrangement drawing of the panel [1]

Methodology, simulation model and materials

The sensitivity analysis in this research work began with an extensive study conducted to evaluate the linear thermal transmittance (Ψ) of different systems of fixing in facade panels. The subsequent study to minimize thermal bridges of the profiles led to the development of the embedded\profile in panel and consequent development of auxiliary fixing to the support, leading the final design of the panel. For the characterization of repeated thermal bridges selected for the sensitivity study two shapes of profile, in "H" or "I" and "L" were selected, connected to the coating layer or the thermal insulation layer, which schemes are presented in Figure 4.



Model 1 – profile "H" with connection to the coating | Model 2 – profile "L" with connection to the coating | Model 3 – profile "H" with connection to the insulation | Model 4 – profile "L" with connection to the insulation

Figure 4 – Simple wall with profile in "H" and "L" shape connected to the coating layer or the thermal insulation layer

The quantification of linear thermal transmittance (Ψ) was carried out on the basis of computational program HEAT2, with a two-dimensional geometric model, under steady state conditions, according to the European standard EN ISO 10211 [10, 11]. The procedure starts with the calculation of thermal coupling coefficient matrix (L_{2D}), expressed in W/(m.ºC), obtained from the two-dimensional coefficient heat transfer. The two-dimensional geometric model used to characterize linear thermal bridges of the prototype and a system Venture kit are presented in Figure 5.

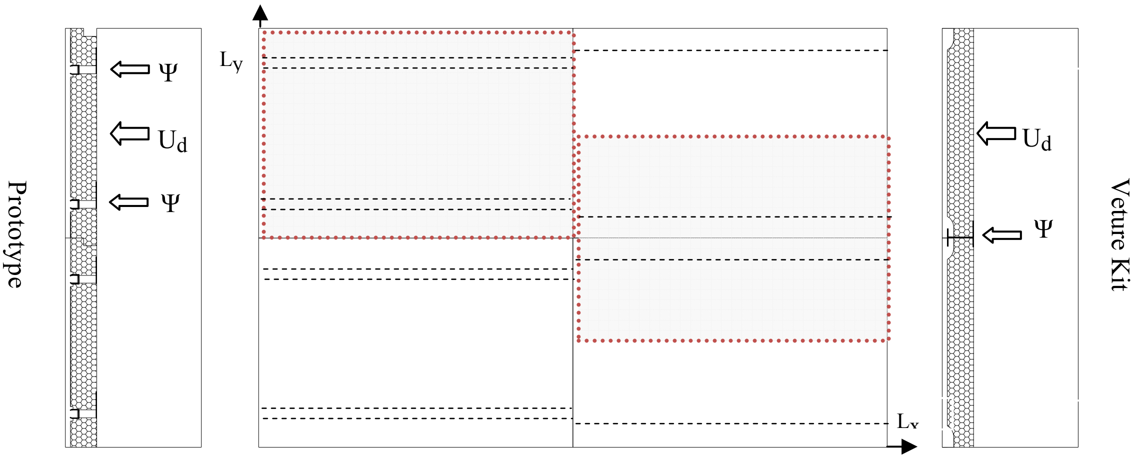


Figure 5 – Two-dimensional geometric model of the panel and a system Veture kit

The panel dimensions considered for the study were the standard, with 600 mm length / 400 mm in height. In case of profile type “H”, this interrupts the thermal insulation with a distance of 400 mm (L_y) and in case of embedded profile this distance, for the purpose of calculating, is considered equal to 200 mm (L_y).

The quantification of point thermal transmittance (χ) current in the panel, by the introduction of the auxiliary accessory of fixing, has been carried out in computational program HEAT3, with a three- dimensional geometric model (Fig. 5), according to EN ISO 10211 [10, 11].

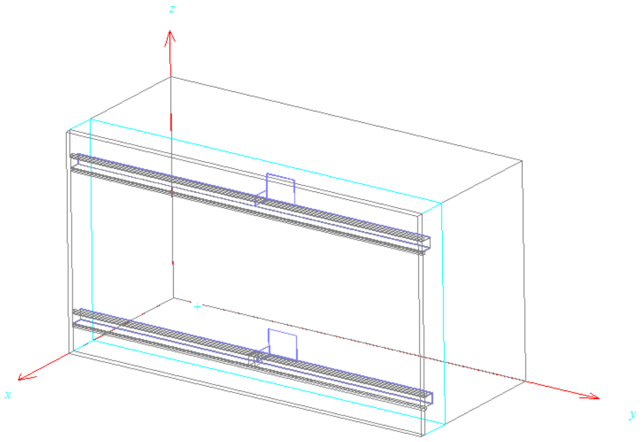


Figure 5 – Three-dimensional geometric model of the prototype obtained by the HEAT3

In both geometric models, the point thermal bridges caused by mechanical anchors will not be calculated, considering its negligible value. For the purposes of dynamic simulation a boundary temperature conditions of 20ºC to the surrounding interior and exterior envelope to 0 ºC, representative of the heating season were used. For defining of temperature boundary conditions are considered 20ºC for interior envelope and 0ºC for exterior envelope were considered, representative of the heating season.

The support solutions considered for the study were a simple wall, in ceramic brick with 220 mm of thickness. The insulating material used was extruded polystyrene (XPS) with thicknesses of 40 mm, 50 mm, 60 mm, 80 mm and 100 mm. Different materials were selected for the profile: aluminium; galvanized steel; stainless steel and Glass Fibre Reinforced Polymer (GFRP). Because of good thermal and mechanical properties of cork, this has been used as thermal break material between the profile and the support wall, with thicknesses of 2 mm, 4 mm and 6 mm. The main thermal parameters of all the materials used in simulations are shown in Table 3.

Table 3 – Main thermal properties of the materials used in simulations [13, 14, 15, 16].

Material	Thermal conductivity (λ) [W/m.ºC]	Density (ρ) [kg/m^3]	Specific heat capacity (c) [MJ/m^3.ºC]
Ceramic brick of 220 mm	0.412	683	0.628
Plaster	0.940	2000	2.000
Extruded polystyrene (XPS)	0.029	30	0.042
Aluminium	200	2700	2.425
Galvanized steel	50	7800	3.596
Stainless steel	16	7850	3.690
Glass Fibre Reinforced Polymer (GFRP)	1.40	1650	1.568
Cork	0.060	320	0.800

Calculation of thermal bridges

The calculation of the thermal transmittance coefficient (U_d) of the wall covered by the system, without thermal bridges, is given by the equation (1), according to EN ISO 6946 [17].

$$U_d = \frac{1}{R_{si} + R_{structure} + R_{insulation} + R_{coating} + R_{se}} \tag{1}$$

Where: R_{si}, R_{se} is the inside and outside film resistance [m^2.ºC/W]; $R_{structure}$ is the thermal resistance of the wall the panel is fixed on [m^2.ºC/W]; $R_{insulation}$ is the thermal resistance of the panel insulation layer [m^2.ºC/W]; and $R_{coating}$ is the thermal resistance of the panel external coating layer [m^2.ºC/W].

As previously mentioned there are several types of thermal bridges; in the case of the panels of facade fixed with profiles may be designated for linear thermal transmittance (Ψ) and in case of auxiliary fixing and anchorages are designed by point thermal transmittance (χ). The calculation of the thermal transmittance coefficient (U_d) of the structure wall and system, considering the thermal bridges, is given by the equation (2).

$$U_p = U_d + \frac{\Psi_{profiles}}{l_{profiles}} + \eta_{fixation} \cdot \chi_{fixation} \tag{2}$$

Where: $\Psi_{profiles}$ is the ψ-value for the thermal bridges due to horizontal or vertical profiles [W/m.ºC]; $l_{profiles}$ is the length of the vertical or horizontal profiles [m]; $\eta_{fixation}$ is the density of fixation [m^{-2}]; and $\chi_{fixation}$ is the χ -value for the point thermal bridges due to rail fixing [W/ºC].

The quantification of linear thermal transmittance (Ψ) through the computer program is given by the equation (3), according to EN 10211 [10].

$$\Psi = L_{2D} - \sum_{j=1}^{Nj} U_j . l_j . \tag{3}$$

Where: L_{2D} is the thermal coupling coefficient through the calculation at two dimensional[W/m. ºC]; U_j thermal transmittance coefficient of the envelope, component j, [W/m^2.ºC]; and l_j is the length within the two-dimensional model which the U_j does apply [m].

The thermal coupling coefficient (L_{2D}) has been determined through the equation (4), according to EN 12011 [10].

$$L_{2D} = \frac{\phi_l}{\Delta\theta} \tag{4}$$

Where: $\varnothing_l$ is the heat flow obtained by differential temperatures verified [W/m] and Δ_θ is the differential temperature between the two environments [ºC].

Results and discussion of the sensitivity study of thermal bridging

The results relative to the sensitivity analysis, obtained from the computer simulation HEAT2, are presented in this section. Linear thermal bridge (Ψ) and thermal transmittance coefficient (U_p) have been evaluated for each type of model (Fig. 4), using different material for the profile and a thermal break solution, as a function of the insulation thickness.

The results obtained for the Ψ and Up, by varying the type of profile in aluminium, are given in Figure 7.

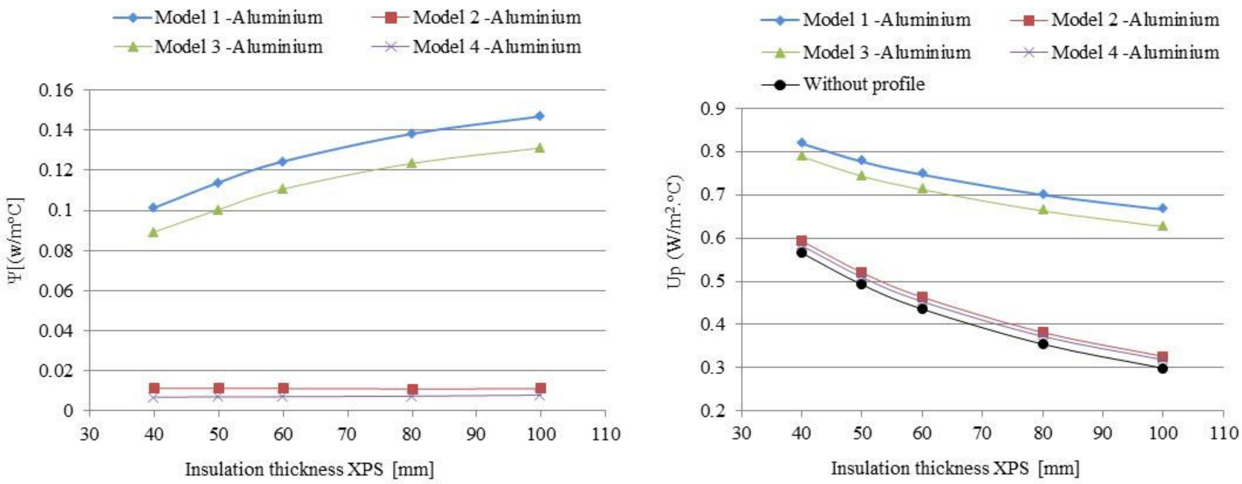


Figure 7 – Linear thermal bridge and thermal transmittance coefficient as a function of the insulation thickness and type of the profile

The results presented in Figure 7 show that heat loss by linear thermal bridge is significant in profile "H" or "L" connect to the coating layer that interrupts the continuity of the thermal insulation. In the case profile "H", connect to the coating layer with 400 mm spacing, the increase in Up range from 0.25 W/m^2.ºC (45%) to 0.37 W/m^2.ºC (123%) depending on the insulation thickness. An increase of isolation thickness of 40 mm to 100 mm contributes to increase about 45% the Ψ.

The results obtained for the Ψ and U_p with the model 1, by varying the material of profile "H", are given in Figure 8.

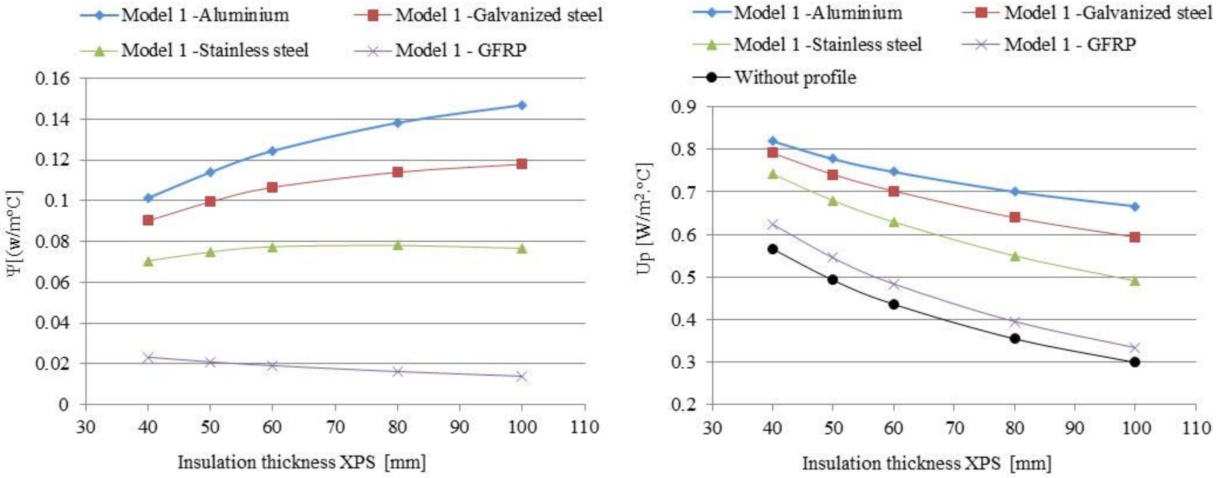


Figure 8 – Linear thermal bridge and thermal transmittance coefficient as a function of the insulation thickness and material of the profile

The results obtained in Figure 8 show that the use of GFRP contributes significantly to the reduction of the Ψ in case that the profile is connected to the coating layer and, therefore the Up. In comparison with the aluminum, the increase in U_p reduces from 0.25 W/m^{2}.ºC (45%) to 0.06 W/m^{2}.ºC (10%) to 40 mm of insulation.

The results obtained for the Ψ and U_p with the profile in aluminium, by varying the thickness of thermal break, are given in Figure 9.

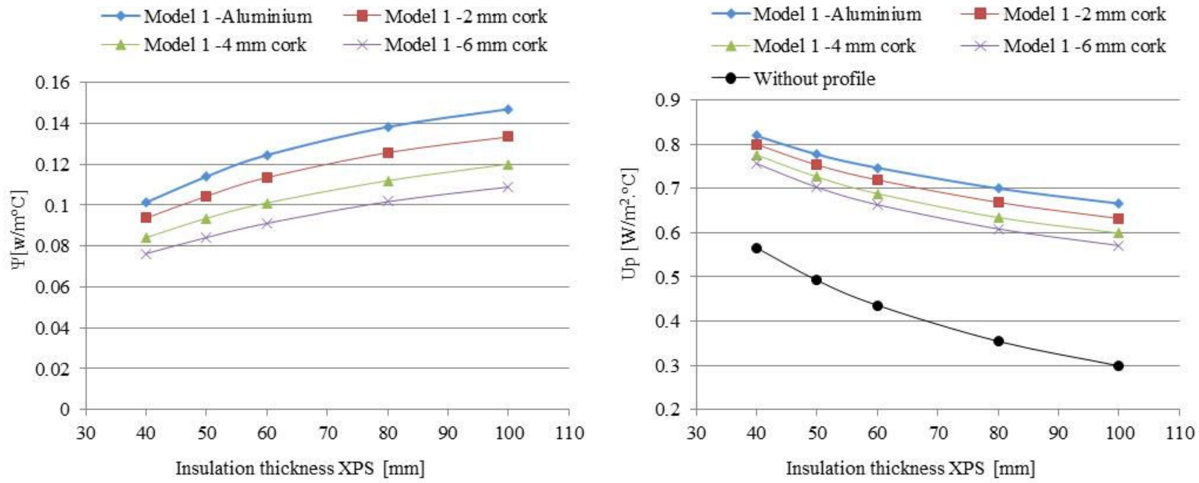


Figure 9 – Linear thermal bridge and thermal transmittance coefficient as a function of the insulation thickness and thickness of thermal break

The results obtained in Figure 9 show that the use of thermal break positioned between the "H" shape profile and the support reduces the Ψ but has a negligible effect in U_p.

Evaluation and analysis of prototype thermal performance

The evaluation of thermal performance of the prototype panel was made by the determination of linear thermal bridge, through the computer program HEAT2, and the determination of coefficient of heat transmission U_p, through the computational program HEAT3 [11, 12]. The point thermal transmittance value of the thermal bridge, created by the introduction of the fixing device, was determined by the equation (2). Table 4 presents the results obtained.

Table 4 – Linear and point thermal bridge, thermal transmittance coefficient as a function of the insulation thickness

Insulation thickness [mm]	Ψ [W/ mºC]	χ [W/ºC]	Up [W/m2.ºC]
40	0.0081	0.0210	0.65
50	0.0056	0.0230	0.57
60	0.0043	0.0233	0.50
80	0.0027	0.0239	0.42
100	0.0019	0.0229	0.35

Figure 10 presents the effect of point and linear thermal bridges, in the form of isothermals of temperature, for one panel with 40 mm of insulation thickness.

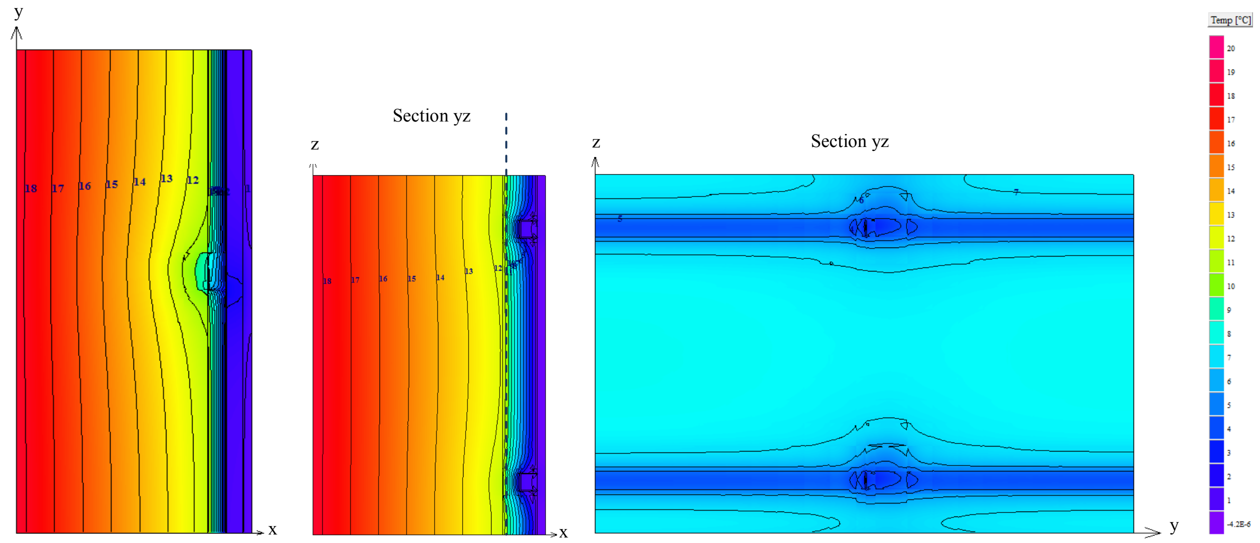


Figure 10 – Isothermals of temperature

Figure 10 presents the value of U_p for the “H” shape profile and for the prototype panel as a function of the insulation thickness.

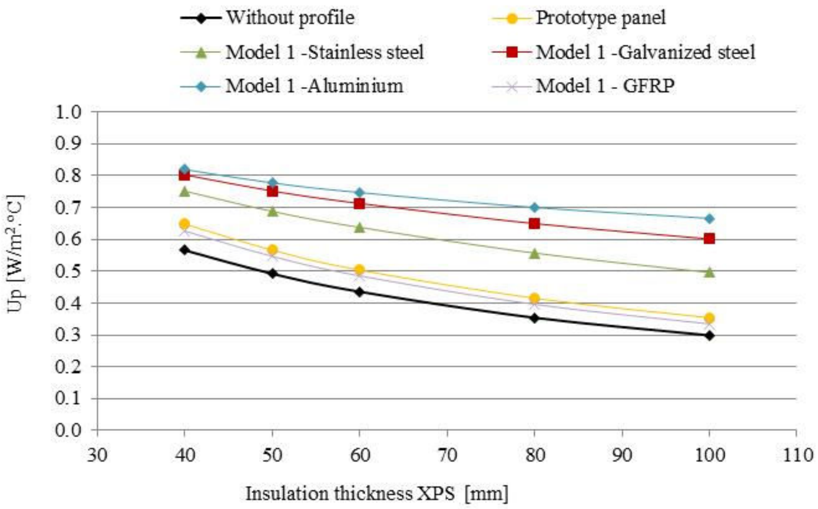


Figure 11 – Thermal transmittance coefficient (U_p) as a function of the insulation thickness

The results obtained in Figure 11 show that the prototype had a good thermal performance, only comparable to the GFRP profile. For the fixing system of the prototype, the U_p value increase 0.08 W/m^2.ºC (15%) a 0.06 W/m^2.ºC (19%), for 40 mm and 100 mm, respectively.

Conclusion

This paper presents a sensitivity study to evaluate the influence of thermal bridges resulting from the presence of fixing profiles, connected to the insulating or coating layer, in the building envelope. Furthermore, it presents the evaluation of thermal performance of a prototype developed and proposed here. The research was performed using Heat2 and Heat3 tools for 2D and 3D modeling.

According to results obtained in the sensitivity study using program Heat 2, the U_p value increases substantially by the thermal bridges created when metal profiles linked to the coating layer are used. For a support wall in ceramic brick of 220 mm and a fixing element in aluminium (model 1), that has the highest value of thermal conductivity among the materials studied, the contribution of linear thermal bridges on the U_p value increases from 0.25 to 0.37 W/m^2.ºC, i.e. from 45% to 123%, when thermal insulation thickness increases from 40 mm to 100 mm. The use of less conductive material for fixing element (the profiles) such as GFRP, reduces significantly the effect of thermal bridges on U_p compared to aluminium, decreasing 0.25 (45%) to 0.06 W/m^2.ºC (10%) for 40 mm insulation thickness. The analysis also showed that using cork as a thermal break did not have the expected impact in reducing U_p. According to Table 2 the linear thermal bridges is classified as class C2, i.e. having a poor effect, but because these thermal bridges repeat at a constant interval of 400 mm they have an important effect on the overall thermal performace of the building facade.

The prototype of the developed panel shows a good thermal resistance for common thickness of thermal insulation, contributing significantly to the thermal insulation and energy conservation in building. Due to the arrangement and location of the embedded profiles, thermal bridge of the proposed system was reduced significantly when compared to that of metallic profiles linked to coating layer. The thermal bridge created by the introduction of this fixing system in galvanized steel, resulted in a small increase in U_p, of 0.083 (9%) and 0.06 W/m^2.ºC (19%) for 40 mm and 100 mm of insulation thickness. The application of insulation thickness less than 40 mm was not considered for support system in ceramic brick of 220 mm, as it results in a U_p less than the maximum U value required. Furthermore, an insulation thickness of 60 mm is necessary to achieve the reference value (U_{ref}) for the most unfavorable winter climate zone I_3.

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