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Composite polymeric materials as an alternative to aluminium for improved energy performance of ventilated façade systems

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Abstract. Ventilated façade systems have become an interesting solution in the field of energy efficiency for buildings thanks to their associated improvement in thermal insulation properties. However, differences exist between real and theoretical thermal performance, resulting in an increase of actual energy consumption above predicted values. Part of this mismatch can be attributed to thermal bridges both at support elements and at construction junctions, which are usually overlooked by simplified calculations. The present study assesses the potential for substituting metallic elements with polymeric composite materials for two key elements of ventilated façades: the support subframe of the external cladding and the external window reveals. Thermal, structural and durability properties are specifically assessed. Results show that overall heating energy savings between 7 and 13% can be obtained through the use of pultruded composite profiles at support brackets and window reveals instead of aluminium components. Such solutions are feasible from a mechanical and durability point of view, and the extra costs are offset in a short period through the reduction in heating expenses.

1. Introduction

The improvement of the thermal insulation properties of building envelopes is widely recognised as one of the most efficient interventions for improving the energy efficiency of buildings, becoming a key measure on the road towards Nearly Zero Energy Buildings (NZEB) [1]. Given the urgency of energy efficiency targets and the relatively slow replacement rate of buildings, the incorporation of insulation to existing façades is of special interest. Ventilated façades (VF) and external thermal insulation composite systems (ETICS) are among the most widely adopted renovation solutions for external walls.

However, the relation among insulation thickness and energy savings is not linear or straightforward and the full potential of the insulation assembly can be partially unexploited if the specific design is not balanced in terms of compatibility between materials. While a range of commercial solutions is already available for ETICS systems, this issue remains a problem in VF assemblies due to their more stringent structural requirements [2].

In ventilated façade systems, the outer cladding is generally supported by a subframe anchored to the structural wall using aluminium brackets. Junctions and construction details around the cladding, such as window reveals, are also often solved using aluminium elements. Given the extremely high thermal conductivity of aluminium, the effect of the insulation is compromised not only at the anchoring points of the subframe (point thermal bridges) but also at the entire contour of the window reveals (linear thermal bridges), thus reducing the insulating properties of the façade.

The development of innovative systems that mitigate or eliminate these thermal bridges is of special interest to optimise VF solutions. This paper investigates the incorporation of polymeric composite



materials as a substitute to aluminium to reduce thermal bridges both at the support framing and the window reveal junctions.

2. Ventilated façade with polymeric composites

An innovative ventilated façade is proposed, delivering improved performance through the inclusion of polymeric composite materials as a substitute for metallic components. This improvement is twofold as it aims for both increased energy savings and a better durability of the components, with a mechanical performance equivalent to current aluminium-based systems.

The proposed development primarily addresses the façade renovation market and hence it is conceived as a retrofit solution for existing building envelopes. Ventilated façades incorporate a new external cladding with a rear-ventilated air cavity, as well as a thermal insulation layer placed against the external surface of the existing wall substrate. In the façade assessed in this study, the cladding is supported by a subframe made of T-shaped vertical profiles, which are anchored to the existing wall substrate by means of L-shaped brackets (figure 1b).

The potential impact of substituting metallic elements of ventilated façades by pultruded composite materials is assessed in this paper. Two key components of the system have been identified: the subframe and the external window reveals. The main objective is the reduction of thermal bridge heat loss, by locally replacing a material with very high thermal conductivity ($\lambda = 160\text{--}230$ W/mK) by polymeric composite materials with much lower conductivity ($\lambda = 0.1\text{--}0.7$ W/mK). This replacement would result in a reduction of the overall heat flow across the façade (and thus an improvement in overall energy efficiency), but mechanical response and durability also need to be considered. In addition, the cost effectiveness of the incorporation of these new components is also a subject of interest.

3. Thermal performance assessment

An assessment has been carried out to calculate the reduction in heat flux across a ventilated façade obtained by replacing aluminium elements with polymeric composite materials. An uninsulated two-leaf brick wall without thermal insulation has been adopted as a case study, renovated by means of a ventilated façade with 120 mm thick mineral wool insulation ($\lambda = 0.035$ W/mK). The thermal transmittance resulting from the renovation has been calculated at $U = 0.223$ W/m²K through one-dimensional calculation [3], which does not consider the impact of thermal bridges such as anchoring elements or construction junctions with slabs and reveals. With the aim of quantifying the multi-dimensional heat flow through such junctions, numerical modelling has been performed using finite element analysis [4].

3.1. Impact of subframe brackets

In order to model the additional heat flow through the anchoring elements of the subframe, TRISCO v13.0 software has been used to compute the heat flow over the three-dimensional model of a support bracket (figure 1). L-shaped brackets and T-shaped vertical profiles have been modelled both in aluminium ($\lambda = 230$ W/mK) and polymeric composite ($\lambda = 0.055$ W/mK) to calculate the impact on heat flow. Overall dimensions considered for L-shaped brackets are 75 mm in height, 45 mm width (surface in contact with existing wall) and 160 mm length (protruding from external surface of original wall). The section of T-shaped vertical profiles measures 80 mm (flange) by 70 mm (web). The thickness adopted for both elements is 4 mm for aluminium and 6.4 mm for pultruded composites.

Table 1 presents the point thermal transmittance χ calculated for each anchor detail, and the resulting increment over the U -value of the wall (considering a density of 1.25 anchors per m²). Results show that the calculation of one-dimensional thermal transmittance (U) underestimates thermal losses in all cases. The pultruded composite elements result in a better thermal performance than aluminium in all cases. The improvement is highest for the L-shaped support brackets: if these elements are made of pultruded composite, the additional heat flow can be considered negligible (< 3%) and the material choice for the T-shaped vertical profiles becomes almost irrelevant regarding heat transfer.

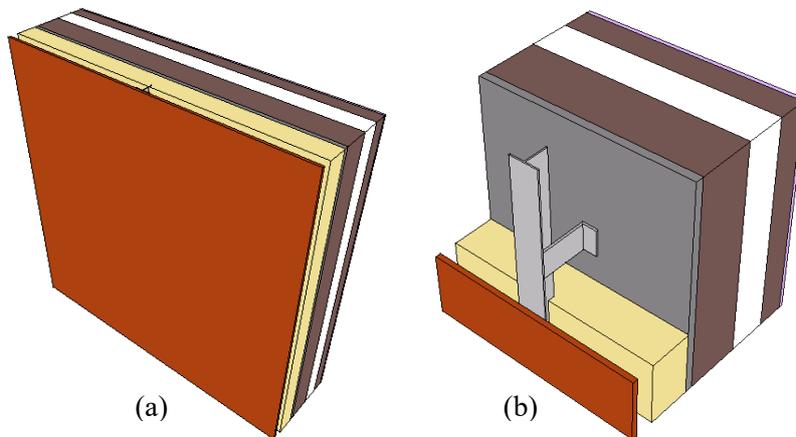


Figure 1. Three-dimensional thermal model of a support bracket of the new ventilated façade: (a) complete model with all materials, (b) partial view of model with cladding and insulation cut showing L-shaped support bracket and T-shaped vertical profile

Table 1. Additional heat flux through subframe elements of the ventilated façade for different material choices (aluminium and composite)

	Aluminium L Aluminium T	Aluminium L Composite T	Composite L Aluminium T	Composite L Composite T
Point thermal transmittance, χ [W/K]	0.051	0.030	0.004	0.003
Increment over U -value [W/m ² K] (percentage increment)	0.063 (28.3%)	0.037 (16.5%)	0.006 (2.5%)	0.004 (1.7%)

3.2. Impact of reveal material

An additional numerical modelling assessment has been carried out in order to quantify the impact of the external window reveals on heat transfer. As such thermal bridges are of linear nature, heat flow over two-dimensional models has been computed using the software THERM v6.3. Sill, jamb and head junctions (figure 2) have been modelled without and with thermal insulation (20 mm thick) behind the reveal finish. Two material choices have been modelled for external reveals: bent panels composed of a plastic core ($\lambda = 1$ W/mK) with 0.5 mm aluminium facings ($\lambda = 230$ W/mK), and pultruded composite panels ($\lambda = 0.055$ W/mK). The overall thickness of the panels is 3 mm in both cases. It has been considered that sill and lintel pieces are made of reinforced concrete, and the existing window (aligned with the interior surface) will remain in the same position after the renovation. The surface of the wall in contact with window frames has been considered adiabatic for the purpose of calculations.

The additional heat flux (over the one-dimensional measurement U) calculated for each of these models is expressed as a linear thermal transmittance Ψ in table 2. Polymeric composites reduce the heat flow in all cases, but the extent of this reduction depends on the type of junction and the presence or absence of thermal insulation behind the reveal finish. If insulation is omitted, the use of polymeric composite panels provides a 5% reduction of the additional heat flow in head, jamb and sill details. By placing 20 mm of thermal insulation behind the reveal finish, a significant reduction is achieved on the additional heat flow. The benefit of polymeric composites is marginal when the insulation covers the window frame at head and jamb, (figure 2d and f) but substantial (34% reduction) when the continuity of insulation and window frame is not feasible, such as at the sill junction (figure 2b). While the impact of these reveal junctions over the overall heat flow will depend on the specific ratio and geometry of the windows, results indicate that this impact appears higher than for the anchoring system assessed above.

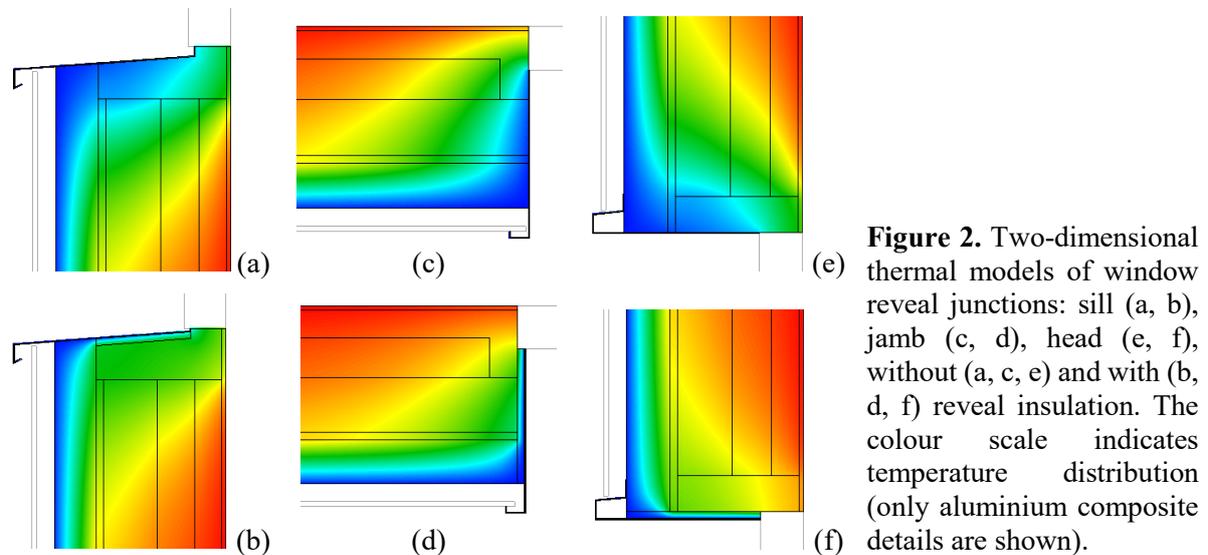


Figure 2. Two-dimensional thermal models of window reveal junctions: sill (a, b), jamb (c, d), head (e, f), without (a, c, e) and with (b, d, f) reveal insulation. The colour scale indicates temperature distribution (only aluminium composite details are shown).

Table 2. Additional heat flux through external window reveal junctions of the ventilated façade for different material choices (aluminium-faced panel and polymeric composite material)

		No reveal insl.		20 mm reveal insl.	
		Aluminium	Composite	Aluminium	Composite
Linear thermal transmittance, Ψ [W/mK]	Head	0.756	0.713	0.257	0.255
	Jamb	0.412	0.390	0.180	0.179
	Sill	0.975	0.923	0.635	0.418

4. Impact on the energy consumption of buildings

In the previous section, an assessment has been made for the reduction in heat flux obtained through the use of polymeric composite materials replacing aluminium components in ventilated façades. The aim of the present section is to estimate the resulting reduction in the overall energy consumption of buildings. Simulations have been carried out at whole-building level using an energy balance method [5]. Two variants have been considered for the type and dimensions of the building:

- A multi-family housing block with 6 dwellings (3 floors), with external dimensions of 20 m in length and 10 m in depth, with 86 m² floor area per dwelling
- A semi-detached house with two adjacent duplex dwellings, with a floor area of 110 m² per dwelling, and external dimensions of 15 m in length and 10 m in depth

The chosen building shapes and dimensions correspond to common house geometries in Europe [6]. Longitudinal façades have been oriented to north and south, and it has been considered that windows are uniformly distributed and cover 25% of the façade area. Windows with thermal transmittance of $U = 1.4$ W/m²K and solar factor $g = 0.58$ have been considered. Four representative climates, broadly covering the European continent, have been assessed: Madrid, Paris, Warsaw and Stockholm. Different material choices have been compared for the L-shaped brackets of the subframe (figure 1b) and the external window reveals (figure 2), as assessed in the previous section. It has been considered that thermal insulation (with thickness of 20 mm) is placed behind the window reveals.

The results of the simulations at building scale are detailed in table 3. If energy demand per floor area is used as a metric, both dwelling types (collective and semi-detached) result in broadly similar figures for overall consumption and energy savings achieved by the proposed systems. Heating energy savings achieved by using polymeric composite brackets range between 2.3% and 6.6%. The savings resulting from polymeric composite window reveals range between 3.8% and 6.6%. If both solutions

are combined, overall savings achieved for heating energy consumption are in the range between 6.9% and 13.0%. While the relative savings (%) are highest in warmest climates, the coldest climates yield higher absolute savings (kWh).

Table 3. Calculations of annual heating energy demand for a collective and semi-detached building, in four different locations, for different material choices (aluminium/composite) at brackets and reveals.

	Material choices		Annual heating energy demand [kWh/m ²]			
	Subframe brackets	Window reveals	Stockholm	Warsaw	Paris	Madrid
Collective dwelling	Aluminium	Aluminium	131.5	112.3	70.7	37.6
	Aluminium	Composite	125.8	107.3	67.2	35.0
	Composite	Aluminium	126.2	107.6	67.4	35.1
	Composite	Composite	120.5	102.8	63.9	32.7
Semi-detached dwelling	Aluminium	Aluminium	130.8	111.8	69.7	36.0
	Aluminium	Composite	127.8	109.2	67.9	34.7
	Composite	Aluminium	125.8	107.4	66.6	33.8
	Composite	Composite	121.8	104.0	64.2	32.1

5. Mechanical, durability and cost considerations

In addition to the impact in energy terms, aspects associated with mechanical analysis, durability and cost effectiveness of the system have also been considered.

A preliminary mechanical analysis has been carried out to estimate the section size required for the polymeric composite bracket. In the case of the window reveal the mechanical behaviour is not a critical aspect, thus this analysis has not been performed on this element. Therefore, a comparative mechanical analysis has been carried out between a composite bracket (using Italian guideline CNR-DT 205/2007) and an aluminium bracket (using Eurocode 9), based on the case study of the collective dwelling in an urban environment, from which the design loads (according to Spanish regulation CTE) have been obtained. Required section sizes are L100×45×4 (h75) for aluminium brackets and 2L100×45×4 (h75) for pultruded composite ones, doubling the required quantity of material. Nevertheless, as the pultruded composite profiles have an orthotropic behaviour and there is no applicable regulation, the final mechanical validation will be achieved by certified mechanical testing.

Given the characteristics of the resin and fibre of the pultruded polymeric composite profiles [6], two main requirements have been identified to guarantee the durability of these elements: UVA resistance and surface scratch resistance. These requirements need to be fulfilled by window reveals especially, due to their continued environmental exposure. The exposure to UVA combined with rain cycles causes the premature ageing of the resin and the deterioration of the surface of the pultruded composite profiles, in the absence of a specific treatment. These problems can be solved with two possible treatments: paints based on polyurethane or epoxy, or by applying a reformulated resin with additives. On the other hand, window reveals can be manufactured with colored resins reducing the visual impact of possible surface scratching.

Finally, the payback for replacing metallic support brackets and external window reveals with polymeric composite materials has been calculated for the case study of the collective dwelling in Madrid (Spain). For calculating heating expenses, annual energy demand values from table 3 have been considered. Such calculations are presented in table 4. The cost increase for substituting metallic components with pultruded composites has been calculated at 2.7% using price estimations provided by

manufacturers. The resulting payback period is calculated at 1.85 years, which indicates a good economic viability for the solution.

Table 4. Calculation of energy cost savings obtained by substituting metallic support brackets and external window reveals with polymeric composite materials in a collective dwelling block in Madrid

Annual heating energy saving [kWh/m ²]	Dwelling area [m ²]	Annual energy saving per dwelling [kWh]	Gas price [€/kWh]	Annual cost savings per dwelling [€]
5.39	86	463.54	0.07	32.45

6. Conclusions

The desktop study described in this paper has demonstrated that the partial replacement of metal elements with polymeric composite materials brings a significant improvement of the thermal performance of ventilated façade solutions. In order to optimize the whole system this concept has been applied to two key elements: the support brackets of the cladding subframe and the external window reveals. The use of pultruded composite profiles for each of these elements has a broadly similar impact on energy consumption. When both solutions are combined, overall savings in heating energy consumption up to 13% have been calculated for the case studies assessed. While the scenarios analysed in this paper are based on typical building shapes and construction details, the specific improvements achieved are dependent on external climate, building geometry (number and shape of openings) and the position of the window within the façade.

A mechanical assessment has concluded that the substitution of support brackets with polymeric composites is feasible, though it requires an increased amount of material. Affections on durability have been discussed and available solutions presented. As a final conclusion, the cost analysis indicates that while there is a slight extra cost for the use of polymeric composites instead of aluminium, this is offset in a short period of time thanks to the energy savings achieved.

Acknowledgments

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