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Chances in plastics and composites in building skins - case studies

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Abstract

Plastic and composites markets have good perspectives of growing up in a near future and more important in the long term [1]. Composites as a whole can offer solutions in terms of: low weight/mass, durability, corrosion resistance, design flexibility, build efficiency, insulation properties, part consolidation, toughness, high strength to weight ratio, ease in assembly and low maintenance and retrofit panels, among others. These advantages has promoted the introduction of these materials in modern life. Outstanding benefits in building sector compared to traditional materials are lightweight and better behaviour in terms of corrosion.

Some case studies that AIMPLAS has collaborated, using plastics and composites in building sector are described as follows:

- Biocomposites (natural fibers and/or bioresins) can offer solutions to building sector with lower environmental impact, reduced CO2 (natural fibres, bio resins), renewable resources, healthier construction, healthier living for an external skin. (OSIRYS PROJECT [2])
- Bio-based recyclable, reshapable and repairable (3R) fibre-reinforced EpOXY composites for windows profile. (ECOXY PROJECT [3])
- Joule effect plastics for envelopes. (HOTSHEET PROJECT).

Keywords: Biocomposites, plastics, lightweight, building, envelope, profiles, insulation, bio-based resins, construction.

1. Introduction

One of the main advantages of polymer matrix composites (formed by two or more components acting in synergy) is that they are materials offering a high mechanical resistance with regard to its density, compared to conventional materials. As a result, composites have a number of significant advantages for a wide range of applications. For instance, they allow obtaining complex shapes with high precision, they also have an excellent resistance to degradation and they are highly resistant to corrosion.

Advanced composite materials have been used in the last 50 years in several high performance applications: military vehicles, luxury yachts, large wind turbine blades, aircrafts, sports and leisure equipment such as skis, snowboards and surfboards. Currently, they are beginning to be more widely used in architecture, where they offer a significant weight saving and an ability to create complex shapes, what provides more design freedom to architects.

Designing with composite materials opens a range of possibilities in the construction sector, such as optimising the performance of the structure by means of simple changes in some of the constituents of the composite material (resin types, types and configuration of reinforcing materials, etc.)

Whereas during the last 100 years architects have just used the conventional construction materials in their designs (wood, stone, steel, concrete, etc.), composite materials are currently revolutionising architecture. Their applications in the field of construction have allowed the progressive replacement of traditional materials and many barriers that designers used to find when implementing projects with a futuristic design have disappeared.

Up until now, composites have been more commonly used in secondary structures and huge self-supporting structures, such as domes. However, some architects and engineers are currently developing more complex solutions to satisfy the creativity of some designers and their desire to challenge the established canons when designing buildings and unique works. These applications are only possible with composite materials, since we take advantage of the combination of the low weight of these materials and their ability to be moulded in such complex shapes, this is an opportunity for obtain new skins for the buildings.

2. Biocomposites

The construction industry as a whole needs an update in terms of legislations and sustainability in order to adapt itself to the new demands of the inhabitants. This can be applicable in two sectors; new buildings and restoration, taking also into consideration the need of energy-efficient buildings.

Currently, in the building envelope sector, composites are being used in the fabrication of panel sections and profiles. These impact-resistant structural elements have the advantage of quicker and safer installation and their modular design equally answers requirements of building made of other traditional materials [4]. An additional development in this area can be the use of sustainable composites. Previous studies [5] [6] [7] [8] [9] have shown that biocomposites manufactured from natural materials such as natural fibres and bio-derived polymers; offer a sustainable alternative to traditional polymers and composites, but with lower environmental impacts, reduction of CO_2 due to the use of natural fibres and bio-resins, use of materials from renewable sources, healthier construction, as well as a higher quality of living conditions for the inhabitants of houses.

Within the construction sector you can find some examples of biocomposites applications. Many of these biocomposites, among which are panels, do not contain dangerous substances such as those currently used in conventional panels. They are also lighter, which helps save fuel during transport and the construction. This reduction in weight, together with the possibility of recycling them at the end of their useful life cycle, are very important factors when defining if the products are compatible from the ecological point of view. Another important aspect is that these biocomposites can be formulated to meet the required fire resistance properties and acoustic insulation properties.

Material	Thickness (mm)	Density (kg/m^3)	Absorption coefficient[1]				NRC[2]
			250 Hz	*500 Hz*	*1000 Hz*	*2000 Hz*	
Glass wool	50	50	0.45	0.65	0.75	0.80	0.663
Rock wool	50	80	0.29	0.52	0.83	0.91	0.638
Polystyrene	50	28	0.22	0.42	0.78	0.65	0.518
Polyurethane	50	30	0.30	0.68	0.89	0.79	0.665
Mineralized wood fibers	50	470	0.25	0.65	0.60	0.55	0.513
LECA3	50	460	0.66	0.94	1.00	0.81	0.853
Rubber beads	5	1400	0.20	0.82	0.50	0.56	0.520
Polyester	45	20	0.56	0.85	0.98	0.95	0.835
Sheep wool	60	25	0.24	0.38	0.62	0.84	0.520
Hemp fibers	40	40	0.59	0.60	0.56	0.52	0.568
Kenaf Fibers	50	50	0.48	0.74	0.91	0.86	0.748
Flax	35	43	0.66	0.84	0.79	0.53	0.705
Coconut fibers	35	70	0.28	0.40	0.64	0.74	0.515
Cellulose	50	28	0.60	0.90	0.75	0.53	0.695

Table 1: Acoustic properties of traditional materials and based on natural fibers

[1] The sound absorption coefficient of a material describes its ability to absorb sound and is measured over a number of specific frequencies. The result is expressed as a number between 0 and 1, where 0 refers to a total reflection and 1 to a total absorption. If the coefficient is multiplied by 100, the value gives a percentage of the incident sound that is absorbed.

[2] The Noise Reduction Coefficient (commonly abbreviated in English as NRC) is a scalar representation of the amount of sound energy absorbed when interacting with a particular surface. An NRC of 0 indicates perfect reflection; an NRC of 1 indicates perfect absorption.

Biocomposites are those materials formed by natural fibres and/or bio-resins. The most used natural fibres are jute, hemp and kenaf. Among the bio-resins we can stress polyurethane resins, epoxy or vinylester, 100 % bio-resins such as furanic resins and bio-thermoplastics. Usually, the bio content of a resin is between 10 % and 100 %.

In this line, the project OSIRYS [2] was developed to improve energy efficiency and indoor environmental air quality through the development of forest-based biocomposites for façades and interior partitions. The project was structured around the production of four products: a curtain wall system, a multilayer façades system and interior windows and partitions. As the main finishing element of a building, with the development of these products, it is intended to achieve a great impact in the indoor air quality and the market of buildings construction reducying the volatiles. The consortium tasks include the development of new materials: a multifunctional photocatalytic cladding, light foam panels to replace plasterboards, flame-retardant cork panels for sound absorption, flame-retardant biocomposites panels, weatherproof biocomposites panels for exterior claddings, high mechanical-performance biocomposites profiles and bio-adhesives allowing to join the different components.

The combination of all these materials together with innovative designs allowed obtaining new products such as:

- Fibre foamed board
- Biocomposites panel reinforced with extruded fibre
- Thermosetting biocomposites profile
- Flame-retardant cork insulator
- Adhesives with low content of VOC (Volatile Organic Compounds)
- Biocomposites cladding panel

(a) (b) (c)

Figure 1. Prototype of foamed plates (a), Biocomposite extruded panels reinforced with fibres (b), Thermosetting biocomposites profiles (c)

The project provide two demos, one in northern Europe and another one in southern Europe:

1. The southern Europe demo building will be developed by VISESA, the public housing corporation of the Basque Government, which is on charge of most of the social housing developments in the Basque Country.
2. Tartu Demo site for the OSIRYS project is the Tartu Mart Reinik Gymnasium’s football stadium building. The stadium building is a brand new 250 m^2 building that was intended to improve conditions at the stadium. Stadium building was constructed mainly from the OSIRYS project materials: curtain wall elements, multilayer façades and indoor wall elements, to improve indoor environmental quality and energy efficiency by evolving forest-based biocoposites and products.

Figure 2. Social Housing block in San Sebastian, Spain (Osirys Demo Building)

Figure 3. View of Tartu Mart Reinik Gymnasium's football stadium building

Figure 4. View of courtain wall section

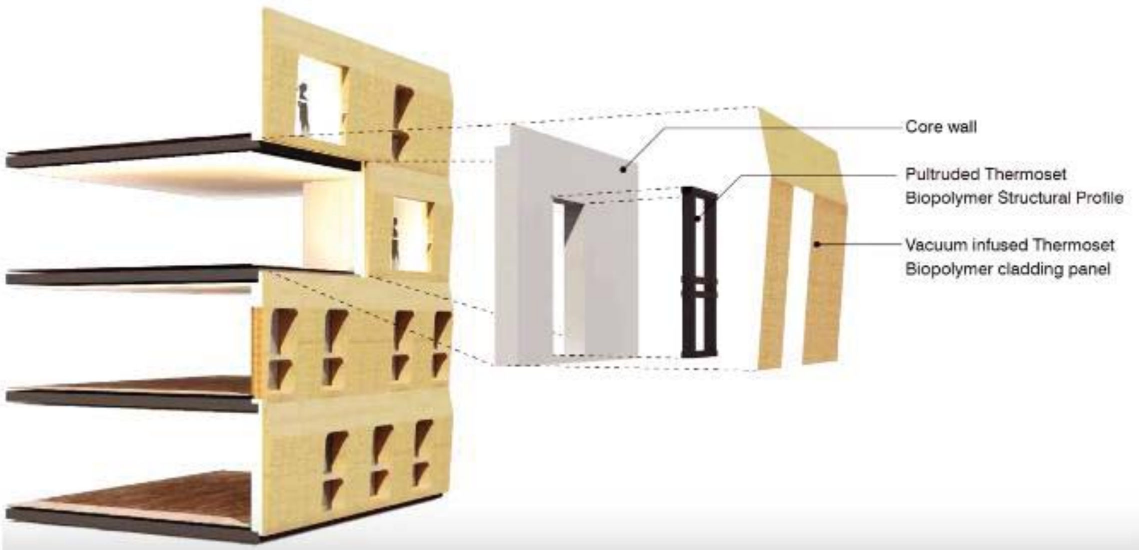

Figure 5. View of construction section

3. Bio-based recyclable, reshapable and repairable (3R) Composites

For the construction sector, where corrosion resistance is a main issue, glassfibre-reinforced polymers composite (GFRP) rebars have shown a good corrosion resistance. However, current composites cannot be easily bent, are not weldable and are difficult to recycle. For these reasons, the materials that will be developed in ECOXY [3] will be validated in the construction sector (as proof of concept) using their today's relevant standards and applicable certifications, obtaining a window profile for the construction sector as a demonstrator.

Mainly, ECOXY [3] composites will be manufactured by state of the art methods like resin transfer moulding (RTM), wet compression moulding, thermoforming or pultrusion, but in contrast to current materials, they will be:

1. Reshapable using compression-moulding technologies. This means that a cured laminate could be reprocessed to create new 3D parts, which is not possible with traditional thermoset composites.

2. Repairable by applying heat and pressure to the damaged area for both fibre/matrix delamination and matrix micro-cracks, enabling prolonged life time.

3. Recyclable by using two different approaches:

    - Grinding to get reprocessable recyclates (short-fibre-reinforced matrix) for the manufacturing of new parts.

    - Recovery of the fibre and the matrix through matrix dissolution in specific solution agent.

These new advanced functionalities will be achieved using cutting-edge chemistry. Commonly used epoxy resin systems are reacted with curing agents, known as hardeners, to obtain infusible and unreprocessable thermoset matrices. These compounds are based on reversible covalent bonds that under certain conditions (temperature and pressure) can rearrange while keeping the crosslink density. This feature gives the materials the new set of properties (3R), while keeping the mechanical properties unaltered at operational conditions. This chemistry proposed in ECOXY is based on recent developments of CIDETEC, the coordinator of the project.

Besides, ECOXY [3] will use and benefit from the advantages of using natural and/or bio-based fibres, such as the low specific weight which results in a higher specific strength and stiffness than glass, their renewable nature and the fact that they are producible with low investment at low cost. As a reference flax rovings and fabrics, specially designed to have a good interaction with the new matrix, will be developed. In addition, the innovative route of implementing bio-based polylactic acid (PLA) yarns as reinforcement for composites will be explored. The performance of these yarns will be upgraded by implementing special polymer grades and by reformulating the material; applying bio-based polymers and additives and integrating a bio-based self-healing functionality in the polymer reinforcement structures.

Finally, ECOXY [3] aims to explore case studies where reference products can be replaced with ECOXY [3] composites with the corresponding economic and environmental benefits due to the increased the End of Life (EoL) options.

4. Joule effect plastics for envelopes.

Currently the architectural envelopes are including a large number of intelligent systems, in order to improve this envelope in terms of thermal insulation, acoustic, smart materials that achieve significant improvements in the self-cleaning of the enclosure, intelligent dimming systems, etc.

With new developments in home automation, buildings are capable of self-managing electricity consumption, thus optimizing the resources of both self-generation (solar panels, wind turbines, etc.) and those supplied by the network.

Nowadays radiant floor heating is based on three technologies: air-heated, electric and hydronic. Air cannot hold large amounts of heat, so radiant air floors are not cost-effective in residential applications. Hydronic radiant floor systems pump heated water from a boiler through tubing laid in a pattern under the floor. Water pipes are buried so deep into the floor that it takes between 4 to 7 hours for it to heat up. This means that hydronic heating systems has a high energy consumption. Furthermore, the maintenance of water-based systems is difficult to repair. Electric radiant floors use electric cables or electrically conductive plastic mats installed beneath the floor covering. It is cost-effective when used with flooring of significant thermal mass as concrete. Electric systems are cheaper to install and maintain than hydronic systems. Electric heating systems are based on Joule effect by which a conductive material generated heat when current passes through it. The most typical electric floors are made from cables. Cables generate heat, but the heating area is low, making the system less effective. Wired floors consumption is around 150 – 170 W/m2. Companies such as Nuheat [11] Suntouch [12],Warmup [13] and Bekotec [14].

The newest under floor electric heating products are film systems. They consist of a conductive ink printed onto a PET laminate and printing cooper as electrodes. The drawbacks of this system are: price of the functional printing technology, difficult to recycle at the end of the product life, difficult to be cut to adapt to different geometries. These types of product are produced nowadays by companies such as Quietwarmth [15], Thermosoft [16] y Daewoo Enertech [17].

The above-mentioned heating floor systems are commercial solutions ready to be installed. Moreover, different coatings are being investigated to be used as resistive heaters. A german company FutureCarbon GmbH is developing a Carbo e-Therm heating layers, plus they are characterized by excellent resistance to water and alkalis. This coating is very efficient: one liter of Carbo e-Therm lasts for coating a surface of up to 4 sqm. It can be applied manually or automatically, either by brush, by blade, by roller or by spraying. After applying the layers, the drying time is quite short. Compared to conventional resistance heating, carbonous coatings distributes heat uniformly without any hot spots.

The ability of carbon fibres (CFs) to conduct electric current can be used in heat transfer applications in the composites manufacturing industry [18]. Using CFs as heating elements [19], ultra-light carbon fibre reinforced plastic (CFRP) sandwich-structured have been developed, in order to accelerate the resin flow via the Joule effect, curing and soldering [20]. Conductive polymers [21] are also used as conductive layer for heating purposes, for example, the PANI-JOULE [22] process is based on a technology using a thin layer of an organic aqueous-base conductive polyaniline ink. It is possible to generate heat via a Joule effect by applying voltage to the terminals of the coating. The quantity of heat is proportional, among other things, to the resistance of the coated surface and to the voltage applied. The aim is to replace conventional heating systems in the automobile industry and construction.

In this context, AIMPLAS has developed an innovative technology available for building envelope; a plastic sheet that, through the Joule effect, is capable generating enough heat to be used as a radiant floor, cieling or inner sheet in walls . This development was achieved within JOSPEL project [10] and it is protected by the patent P201830593.

The principal characteristics of this new development from AIMPLAS are:

- Uniform heating
- Recyclable
- Upper service temperature 70ºC
- Heating homogeneity
- Customizable heating performance varying plastic formulation, panel geometry and applied voltage
- Processing: validated for sheet extrusion and thermoforming. Formulation can be adapted to other processes like injection and compression moulding

For these reasons, this sheet is able to be placed in any part of an envelope, to generate a heated cabin, also serving as a vapor barrier and being able to be an active part of an intelligent system of internal control of the envelope of a building and even, its possible use in external enclosures as a system to improve the air chamber of a ventilated façade.

Several of its technical characteristics are:

a) Heating calibration curve:

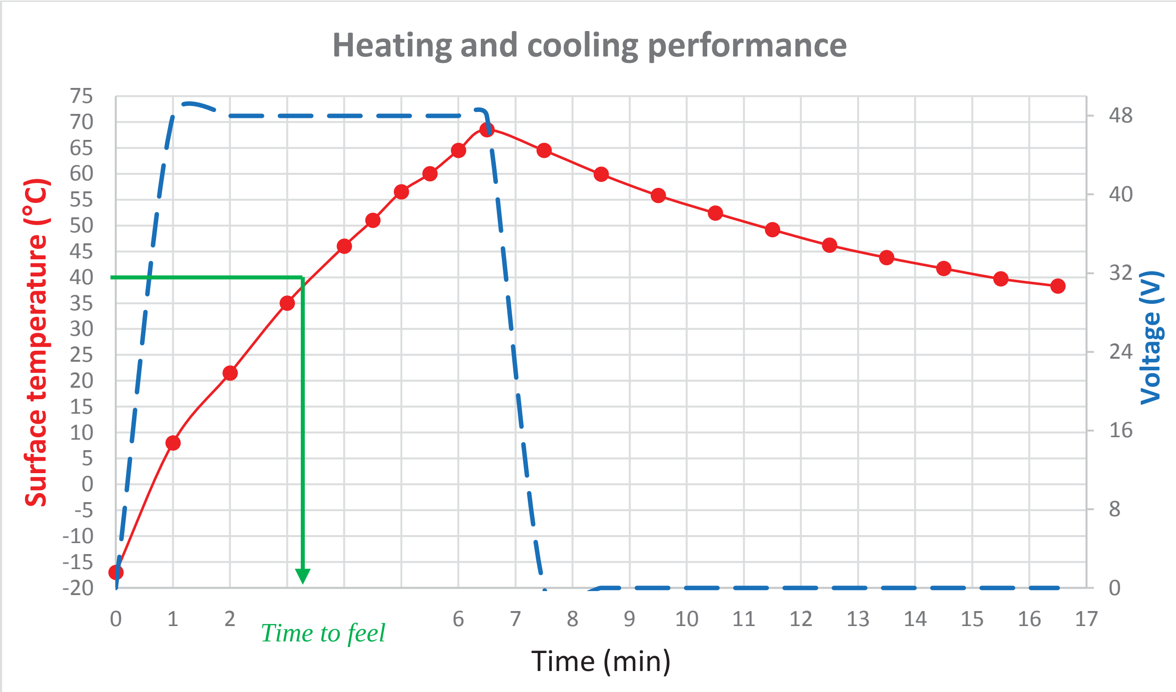

Figure 6: Heating behavior of thermoplastic heating panels

b) Energy consumption:

Table 2: Power consumption

	Panel geometry	Maximum Voltage (48V) Fast heating	Average Voltage (24V) Temperature maintenance at 50ºC
Power (W)	(350 x 250 x 2) mm	120	64
	(15 x 15 x 1) mm	20	5

c) Influence of the thickness

Higher thickness reduces the sheet resistance increasing the heating effectiveness. Figure 7 compares the heating behavior of the same formulation and the same geometry varying the sheet thickness.

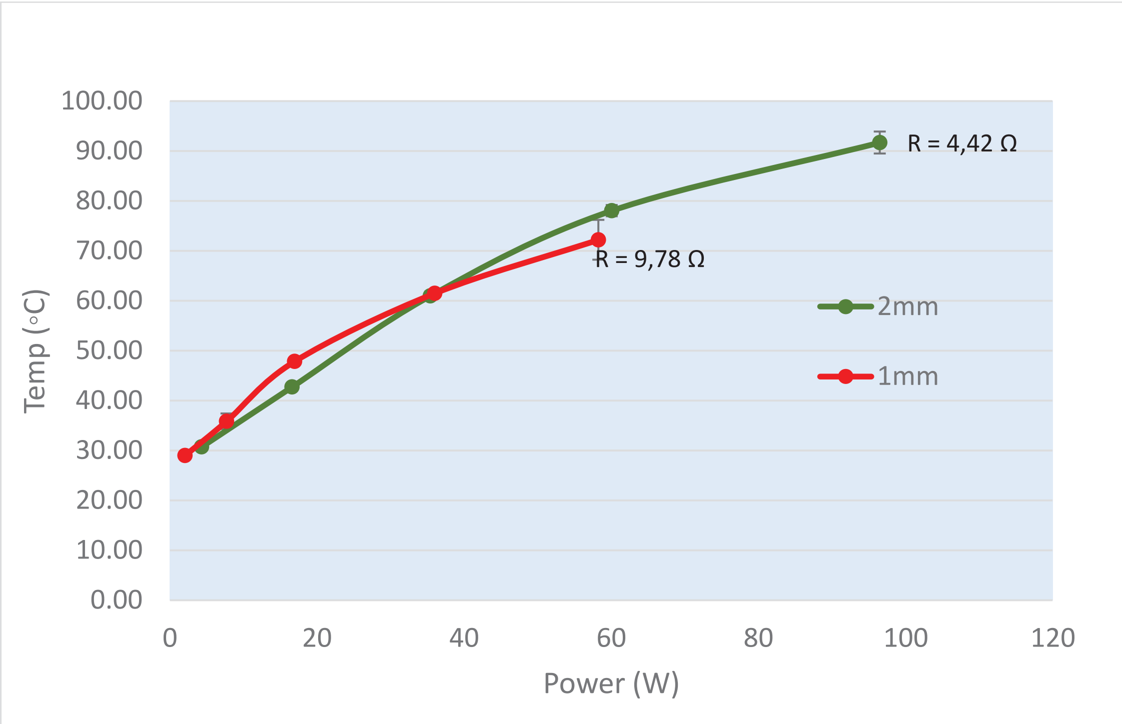

Figure 7: Influence of the sheet thickness on the heating performance

d) Continuous working test

Objective: Maintaining the heating panel at 50ºC for 100h
Panel geometry: (350 x 250 x 2) mm – 30W

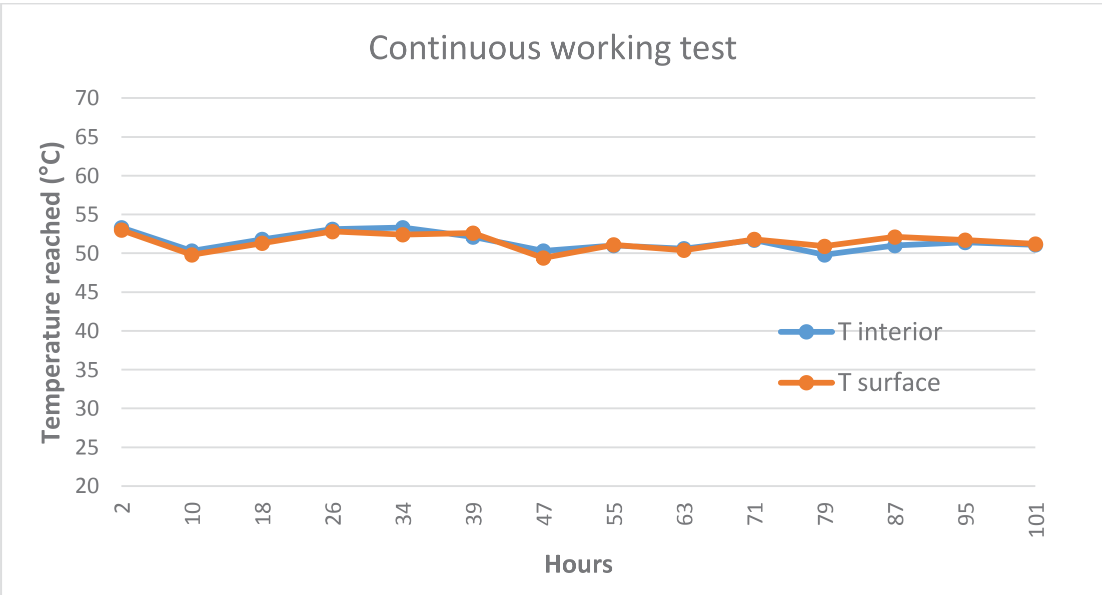

Figure 8: Continuous working test

e) Climatic ageing test

Dry heat 85ºC 504h - Cold -30ºC 504h
Electrical properties of the heating device were not affected after the ageing test.

f) Thermal properties

Table 3: Vicat and HDT of the heating panels

Test Results	
Vicat Temperature (ºC)	99,8 ± 0,2
HDT (ºC)	68,6 ± 1,1

These properties can be modified to meet different specifications or requirements.

5. Conclusions

As it is previously described in different case studies, plastics and composites are a real alternative in construction sector due their advantages related to weight, ease of assembly, maintenance and design. These materials can be applied in different applications, such as:

- Biocomposites provides a real alternative to obtain products adapted to building sector which improved sustainability.
- A Bio-based recyclable, reshapable and repairable composite for develop a window profile, with fire retardant properties.
- A new system to optimize the internal temperature of the building with a monitored system with a Joule effects sheet. Maintaining a homogeneity of heat.

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