Part D

Retrofit Module Design Guide

Part D: Prefabricated Metal Panel Retrofit Modules

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Research partners

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The company DST S.A. (Domingos da Silva Teixeira, S.A.) in Braga was responsible for the production of the prefabricated rehabilitation module prototypes. However, some of the materials incorporated into the module were provided by some companies who sell building materials. The aluminium composite used in the panel finishing was provided by the company INOR IBERICA, SA and the agglomerated black cork insulation was provided by the Portuguese company SOFALCA, Ltd.

The LFTC (Building Physics and Construction Technology Laboratory) of the Civil Engineering Department of Minho University was responsible for the design and for the thermal characterization of the prefabricated modules and for their optimization in terms of energy performance. Experimental tests of the prototypes were carried out in the test buildings located in the Azurém Campus of the University.

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1. Introduction

1.1. Goal

Within the scope of IEA ECBCS Annex 50 "Prefab Systems for Low Energy / High Comfort Building Renewal", a Portuguese Project was set up, funded by FCT – Fundação para a Ciência e Tecnologia (Portuguese Science and Technology Foundation Programme)– entitled "Reabilitação Energética em Edifícios" (Thermal Rehabilitation of Buildings) and with the reference FCOMP-01-0124-FEDER-007189.

The aim of this project is to develop prefabricated retrofit solutions for an efficient rehabilitation regarding energy consumption, solar energy control, thermal comfort, thermal performance and acoustics and lighting behaviour, among others issues.

The developed modules will be applied onto the existent building's façade. The prefabricated solutions can integrate all the tubes and pipes related to the HVAC, domestic hot water and high quality solar systems, as well as all the necessary domestic cables, allowing their easy assembly.

1.2. Background

The weight of energy consumption in existing buildings in the overall consumption in the building sector is becoming increasingly relevant. This is mainly due to an increasingly better quality of the new buildings envelope, achieved through the widespread use of insulation, the use of more efficient windows and better use of energy conservation techniques, resulting in buildings with significantly less heating and cooling needs, when compared with the existing ones.

According to the Census 2001 [1], there are in Portugal 2 560 911 buildings built before 1990 (year of the publication of the first Portuguese building thermal performance code). These represent 76.6% of the existing buildings [1]. Due to the lack of thermal requirements and thermal concerns at the time of their construction, these buildings appear as highly energy consumers when the purpose is to guarantee minimum comfort conditions.

On the other hand, the degradation state of a vast part of the Portuguese building stock assumes proportions that can be considered alarming. This causes a reduction on the populations quality of life and a deterioration of the built heritage, while collective memory. In the last years, Portugal has invested only 13% of the total budget in the construction sector in rehabilitation of the building stock [2]. In Europe, on average, this investment is of about 40% [3]. In general, the country is not yet sensitive to the buildings rehabilitation necessity or importance, being always the new buildings much more valued.

Therefore, the project FCOMP-01-0124-FEDER-007189 was launched in order to develop solutions that enable effective rehabilitation of existing buildings, increasing the value of retrofit and encouraging this practice.

1.3. Retrofit solutions guidelines

The developed retrofit module aims to:

- Increase multi-family and single-family buildings energy efficiency through the application of insulation materials contributing to the achievement of final energy consumptions lower than 50 kWh/(m²·y).
- Be an integrated solution with the ability of including hot water, ventilation, heating and/or cooling ducts inside the module, allowing not only to hide them but also to assure the ducts insulation;
- Apply materials with high potentiality of reuse/recycle, and incorporate materials with low embodied energy (energy needed for production, transport and application of the material), minimizing the environmental impacts of the modules production;

- Be an effective solution capable of reducing the execution/application time, reducing the inconvenience caused to the occupants and involving lower financial investment, leading to a greater acceptance of this type of solutions by users.
- Comply with the Portuguese building regulations, particularly the thermal performance of buildings regulation [4].

On the other hand there is also the possibility of inserting inlet/return grids for mechanical or natural ventilation.

2. Prefabricated façade module

2.1. General

The system under development is based on traditional discontinuous prefabricated insulating finishing (although with integrated ducts), on optimized levels of insulation and on the use of a mounting system that allows a simple application and withdrawal of the modules, based on two steel U-profiles on each side of the modules, with a system of pins and holes to be fitted into a support structure that is bolted to the existing wall (Figure 1).

The dimensions of each module are of about 1 m x 1 m and its weight is of 12 kg/m². These dimensions were selected in order to ease their transportation and on site application.

The selection of the materials was based on a balance between technical and economical aspects and on the value of the embodied energy. Therefore, the selected materials were the following:

- Agglomerated black cork insulation – selected due to an industrial production without additives, being an 100% recyclable material, with a density of 110 kg/m³, with a thermal conductivity of 0.045 W/(m·K) and also very abundant in Portugal;
- Extruded polystyrene (XPS) – selected due to the technical possibility of moulding or creating cavities to lodge ducts and also due to its competitive price, once it is one of the most applied insulation products in Portugal and also in Europe;
- Aluminium finishing - since it is a 100% recycled product, easy to manipulate with traditional working tools and available in a wide range of colours and textures.

Then, after the study and test of several design alternatives, the final prefabricated module composition (from the outside to the inside) is the following: aluminium composite exterior finishing (6 mm); agglomerated black cork insulation (60 mm); steel U-profiles (1.5 mm); extruded polystyrene insulation (XPS 120 mm) with or without moulded ducts or cavities for ducts and cables; smart vapour retardant.

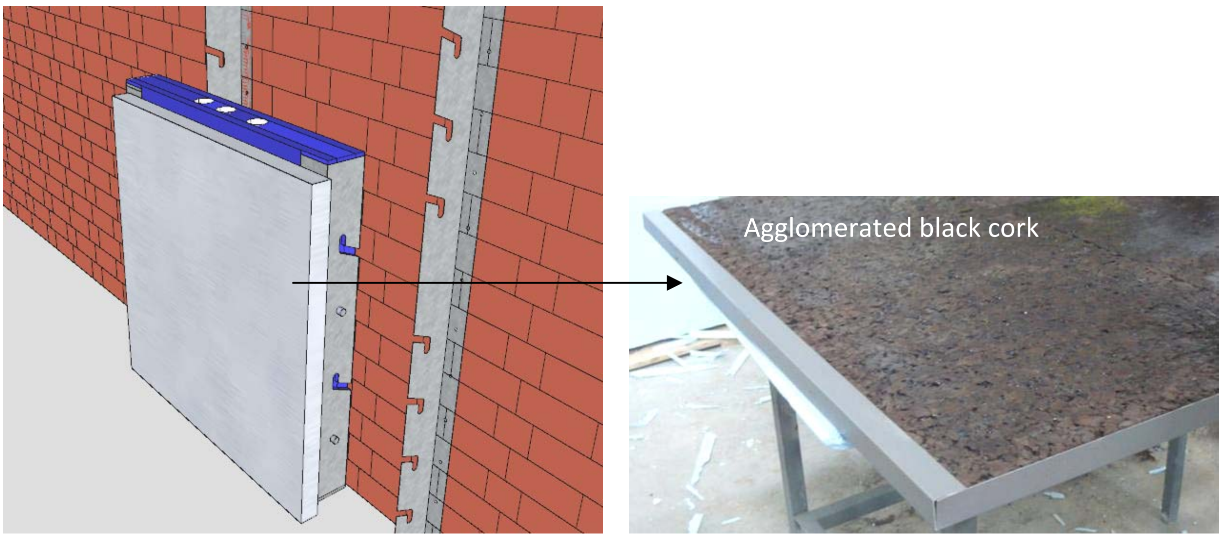


Figure 1: Prefabricated retrofit module

2.2. Views and cross sections

For a more comprehensive overlook of the retrofit module it is presented in Figure 2 the whole module in a 3D view, lateral views and middle section.

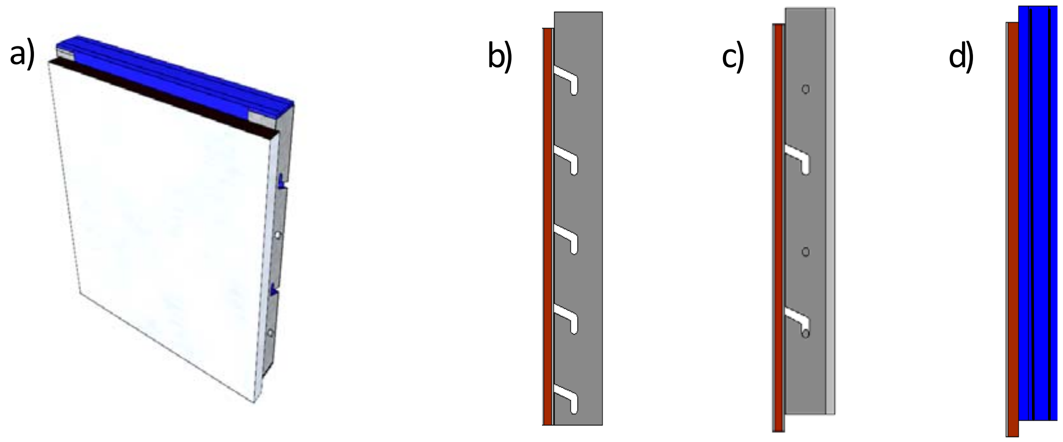


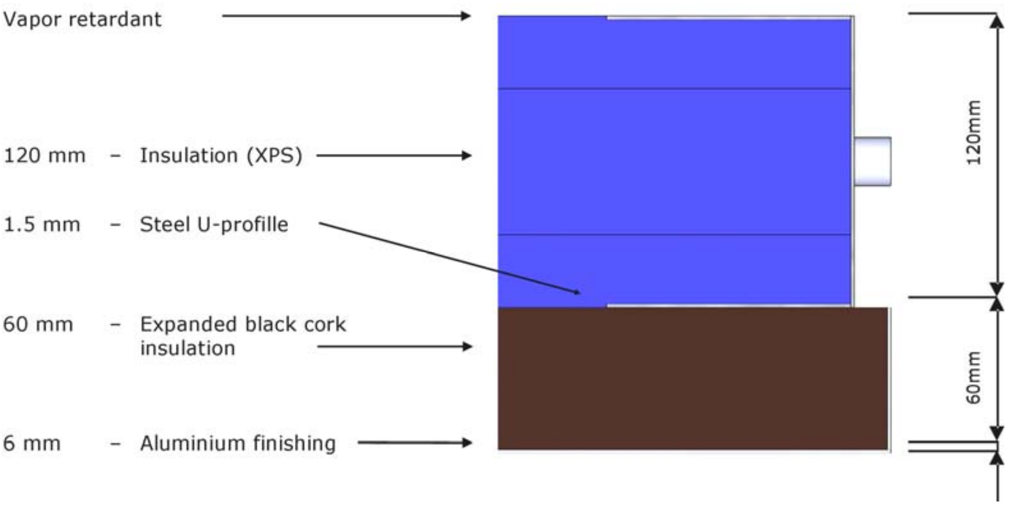
Figure 2: Module 3D view (a); lateral view with support structure (b); lateral view without support structure (c); middle section (d)

2.3. Construction details

The solution will have a total thickness of 18.8 cm and a total weight of, approximately, 12 kg/m². It is expected that with the application of this retrofit system the walls of the outer envelope will increase their thermal resistance by about 4 m²·K/W (taking into account the average value of thermal resistance resulting from the thermal resistance of the standard zone, the thermal resistance of the ducts zone and the thermal resistance of the support structure zone).

Figure 3 shows the module top view and composition.

Prefabricated module (composition):



Module structure (top view):

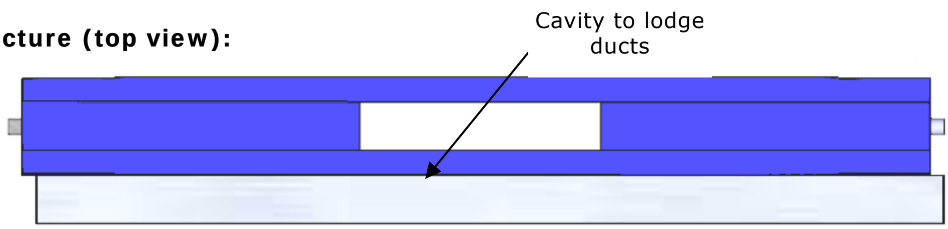


Figure 3: Module top view and module composition

2.4. Connecting technology of the façade elements

This retrofit module was designed to minimize glued and mechanical connections in its assemblage in order to improve the recycling potentialities. Thus, the XPS insulation is only fitted to the steel U-profiles and the aluminium finishing is shaped like a box in order to lodge the cork insulation (Figure 4). However, there is a glued connection between the aluminium finishing and the steel U-profile that can firmly connect these materials and also allow an easy separation of them in case of deconstruction (Figure 4).

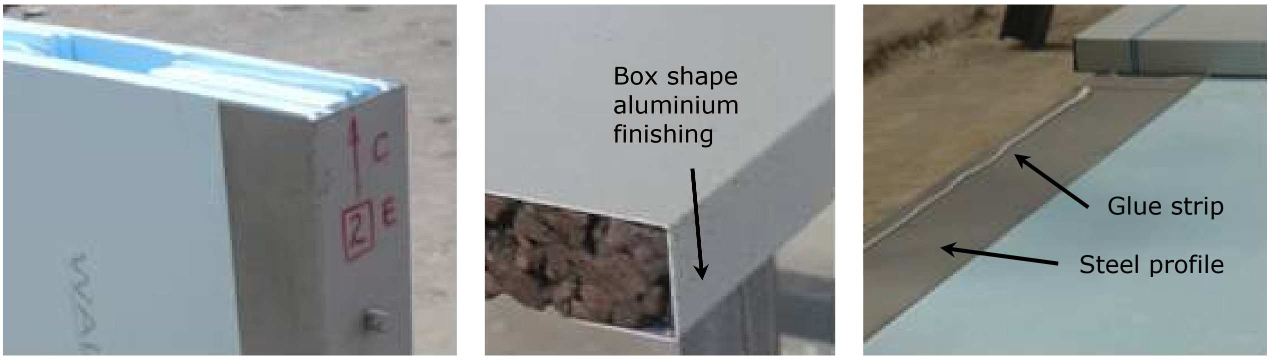


Figure 4: Retrofit Module connections: steel U-profile (left), cork insulation (centre) and aluminium finishing application (right)

With this design, the retrofit module has a high recycling potential, making possible to recycle and reuse the materials individually. This approach leads to a more sustainable solution that is based on the use of low embodied energy materials whenever possible, on the type of connections selected allowing easy deconstruction, on the improvement of the energy efficiency of the buildings and on the recycling ability of the solution in the end of the product life cycle.

2.5. Module types

Four types of modules are available for different needs. Figures 5 and 6 show these four solutions:

- standard module;
- module with a cavity to lodge cables, heating and cooling systems ducts or other installations;
- module with moulded ducts;
- modules to be applied in the buildings corners.

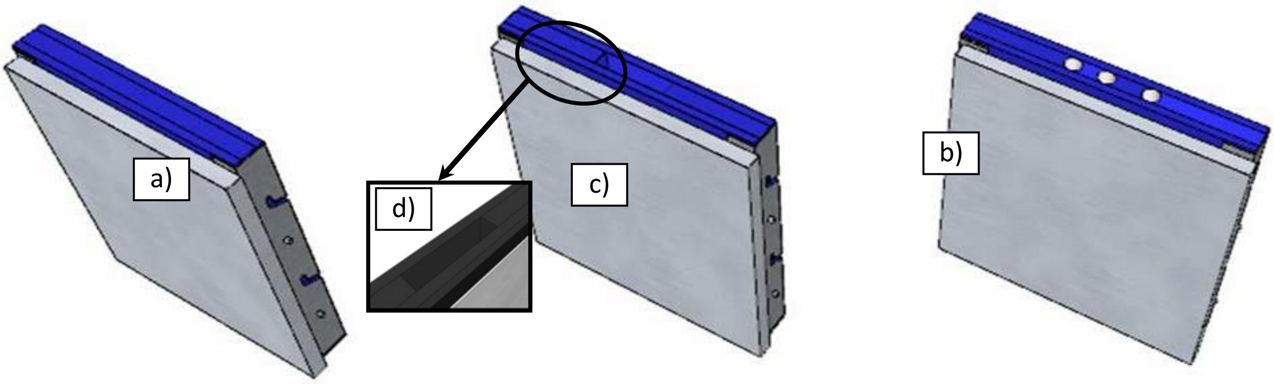


Figure 5: Original design of the prefabricated retrofit module – a) without ducts or cables; b) with moulded ducts; c) with ducts and cables cavities

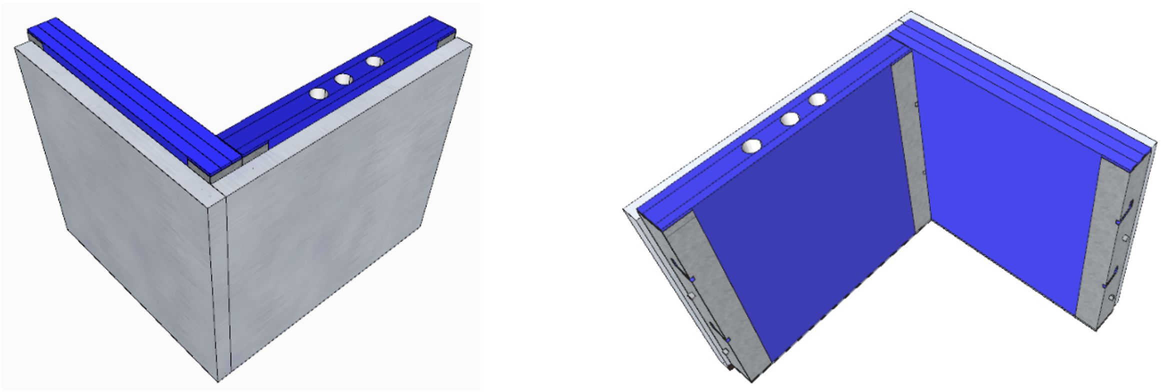


Figure 6: Prefabricated retrofit module – corner modules

2.6. Connections

The connection between the modules is done through a system of pins and holes like shown in Figure 7. This connection system will help the module fitting into the metal support structure and also to connect the modules side by side. The fitting system of the modules, placed on their sides, is a steel U-profile with a thickness of 1.5 mm.

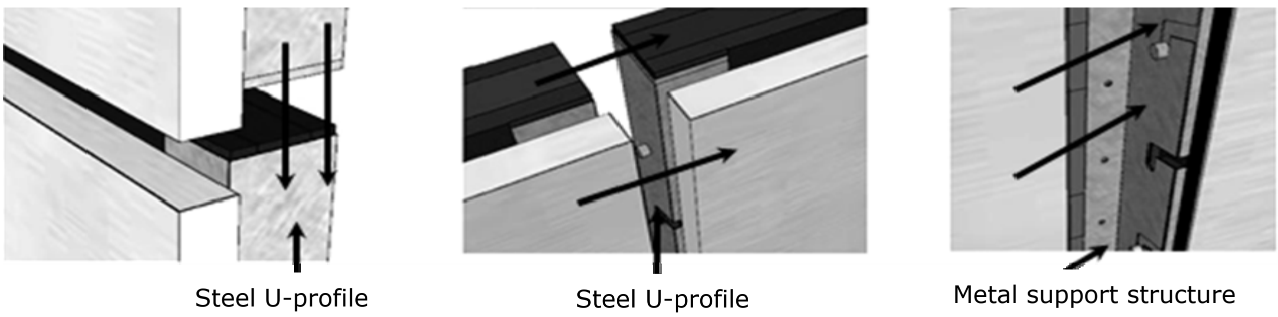


Figure 7: Retrofit module connection system and installation options

The location of the holes and pins differs from the right to the left steel U-profile of the module. This placement allows the pin to be plugged simultaneously into the left slot of the support structure and into the module slot immediately on its right (module already placed), thus ensuring a better distribution of the applied loads.

2.7. Manufacturing of the façade elements

The concept behind the module development is that it should be simple, assure a high quality and with economical viability. Its construction upholds the following steps (Figures 8 and 9):

- Production of the steel U-profiles and support structure;
- Application of the XPS insulation in the steel U-profiles;
- Production of the aluminium finishing with box shape;
- Application of the smart vapour retardant and cork insulation in the aluminium finishing;
- Connection of the aluminium finishing to steel U-profiles.

Figure 8: Support structure (left); smart vapour retardant and cork insulation application (right)

Figure 9: Application of the exterior aluminium finishing (left); retrofit module (right)

2.8. Façade module assembly process

The application of the solution to the existing wall is going to uphold two phases as shown in Figure 10:

- 1st phase - install the metallic support structure;
- 2nd phase - fit the module to the support structure using the system of indented pins (module) and gaps (support structure).

Figure 10: Steps needed to apply the retrofit module to the case study building

This mounting procedure allows a faster installation of the retrofit system and an easy replacement and reparation of the modules when needed.

2.9. Module performance

The prefabricated module performance was characterized and tested according to several issues:

- Thermal Bridges;
- Moisture control;
- Thermal transmittance coefficient (U-Value).

2.9.1. Thermal bridges

Important thermal bridges can appear in this type of highly insulated solution, especially in the connection zone. In order to minimize this problem, a mortise, like the one shown in Figure 11, was created. Thus, the connection zone is covered with a 60 mm thick layer of black cork applied in the exterior side.

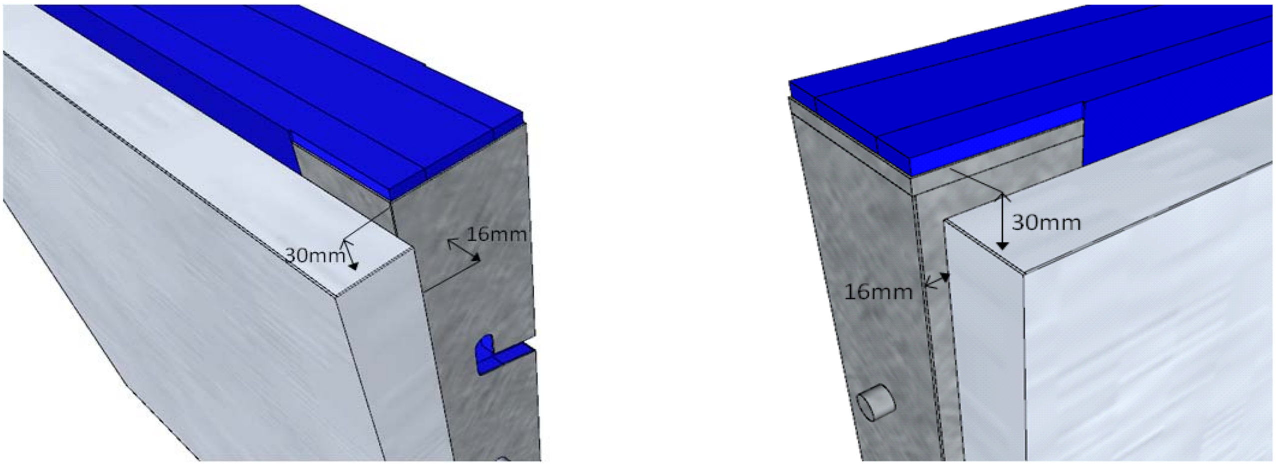


Figure 11: Retrofit module thermal bridges correction

The software THERM – 2D heat transfer model based on the finite element method [5] was used to analyze the thermal bridges in the retrofit module. The most critical sections of the prefabricated module include the connection between the module and the support structure, the steel U-profiles section and the docking area between the modules.

Figure 12 shows the module section (a) and the results obtained with this software tool, regarding the flux magnitude (b), colour infrared diagram of the temperature (c) and isotherm lines (d).

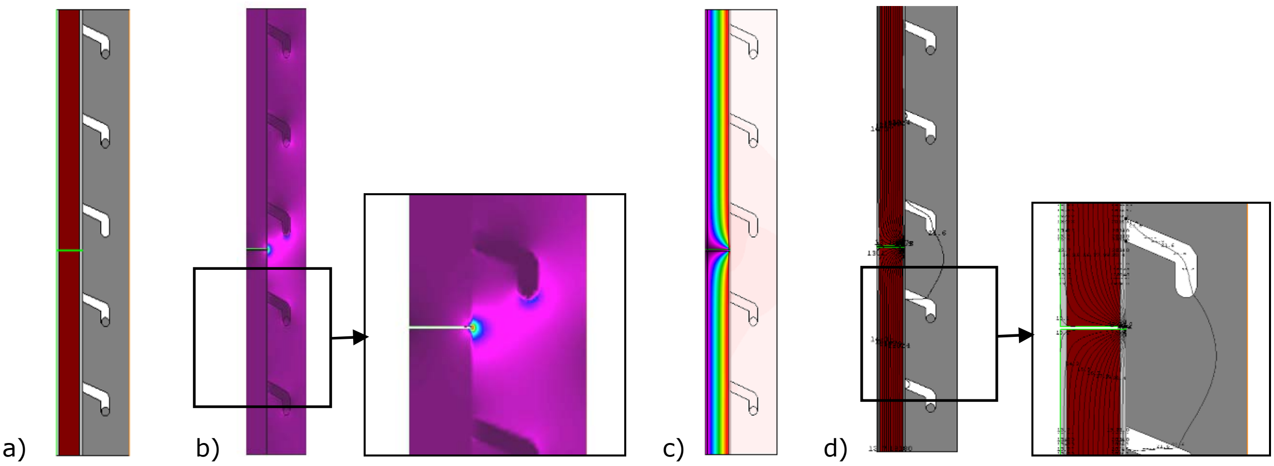


Figure 12: Prefabricated retrofit module docking area section

The colour diagrams show, as expected, that the critical heat flux occurs on the docking area between the modules. However, since the isotherms are parallel towards the end, it indicates that heat transfer is essentially 1D, which is a good performance indicator. It is also possible to observe that the only point where a slightly higher flux magnitude occurs is in the exterior part of the docking area between modules. The calculated U-Value of this section is 0.7 W/(m²·K).

This analysis was carried out for other sections of the module and the following values were obtained:

- middle section (see Figure 13a) – simulated U-Value = 0.21 W/(m²·K)
- cavity section (see Figure 13b) – simulated U-Value = 0.33 W/(m²·K)

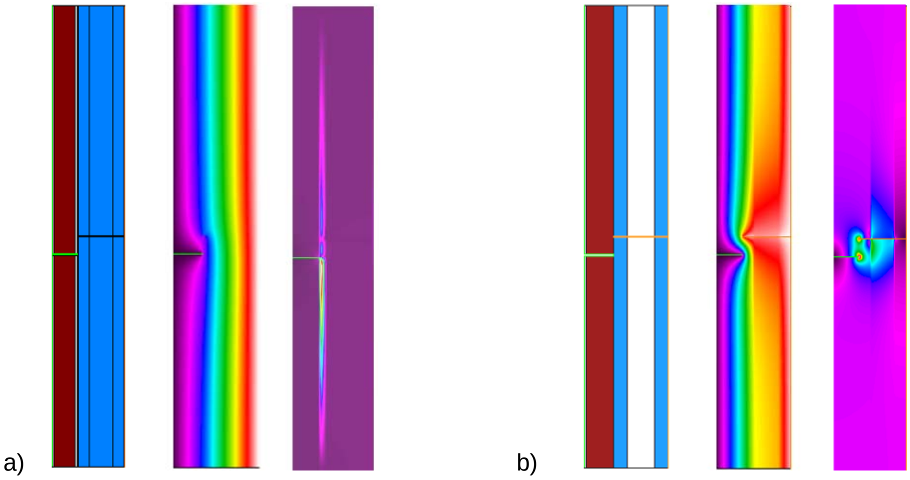


Figure 13: Prefabricated retrofit module standard (a) and cavity (b) sections

Applying the corrective solution shown in Figure 11, and according to predictions obtained with the TERM tool, it is possible to get an 80% reduction in heat flux that occurs in the docking area, thus drastically reducing the thermal bridge in this zone.

2.9.2. Moisture control

To analyse moisture problems in the module, it was used the program WUFI®, acronym for "Wärme- und Feuchtetransport instationär" ("Transient Heat and Moisture Transport"). WUFI® is designed to calculate the simultaneous heat and moisture transfer in a building component [6].

The critical zones for moisture occur between the different material connections and between the module and the existing wall (see Figure 14).

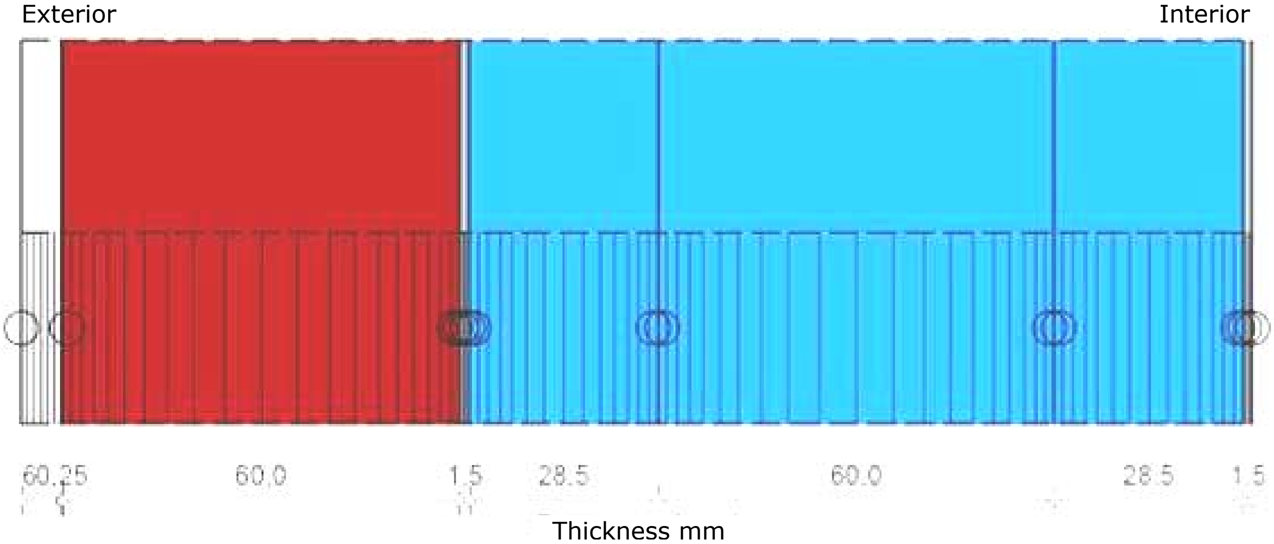


Figure 14: Prefabricated retrofit module - Transversal section

The simulated relative humidity range (20%-90%), combined with the observed temperatures, showed no risk of moisture build-up. In Figure 15 it is presented a whole year simulation results of the temperature inside the module (in red), the relative humidity (in green) and the moisture content (in blue). Therefore, no moisture content was observed inside the prefabricated module.

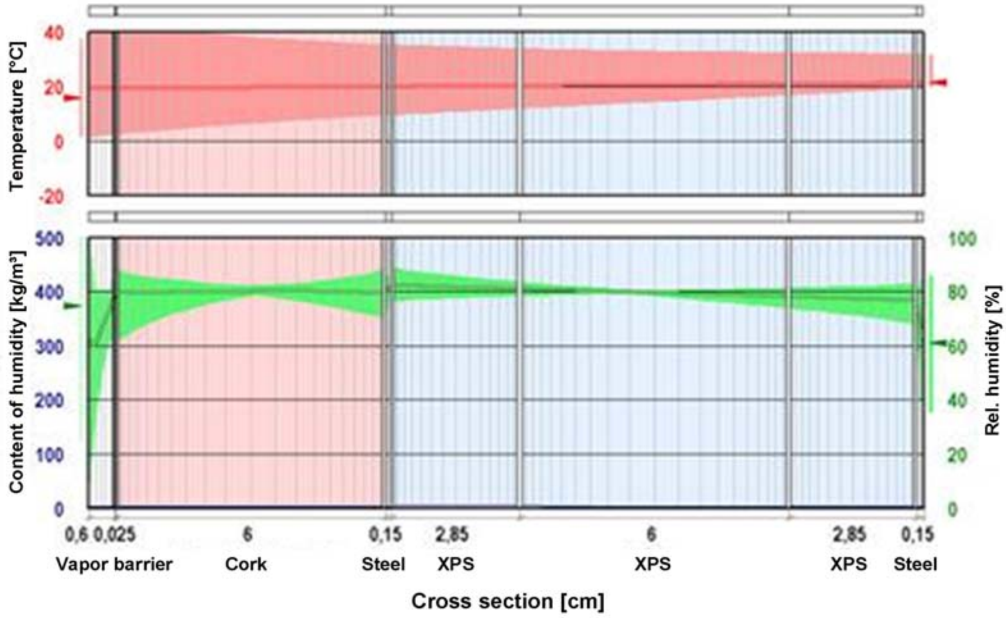


Figure 15: Prefabricated retrofit module - moisture transfer calculation

The amount of vapour passing through the wall can be controlled with the addition of a vapour retarder between the interior finishing and the existing wall, minimizing the chances for interstitial condensation if more extreme climatic conditions occur.

2.9.3. Thermal transmittance coefficient (U-value)

In order to determine the retrofit modules thermal performance, it was necessary to test them in a controlled environment. In this sense, several modules were applied onto a wall separating two controlled rooms in a controlled test building facility and instrumented with several flux meters and thermocouples connected to a monitoring system (see Figure 16).

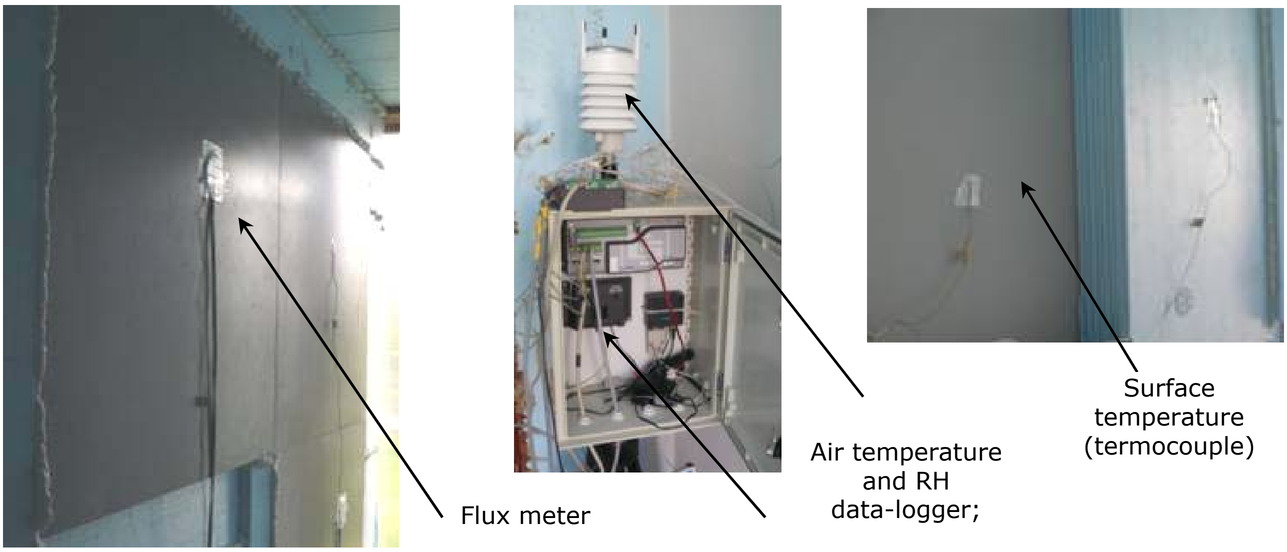
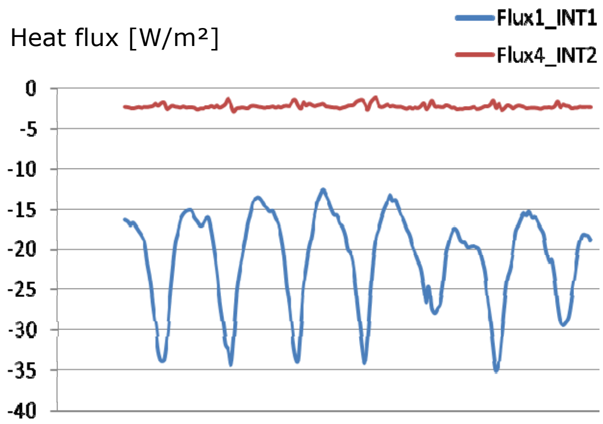


Figure 16: Prototypes with measurement system

The obtained results within the measurement campaign, presented in Figure 17, show that the application of the module to the existing wall reduced significantly the heat flux between the two compartments.



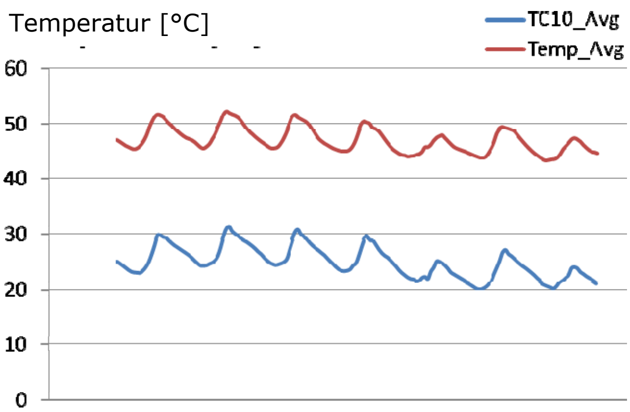


Figure 17: Heat flux in the partition wall without the module (Flux1_INT1) and heat flux in the partition wall with the retrofit module (Flux4_INT2) and air temperature in room 1 (TC10_Avg) and air temperature in room 2 (Temp_Avg).

The infrared images of the module when applied to the partition wall (Figure 18) show a significant surface temperature difference between the retrofit module and the partition wall. There is also an indication that a small thermal bridge is present in the connection between modules, as predicted by the software THERM.

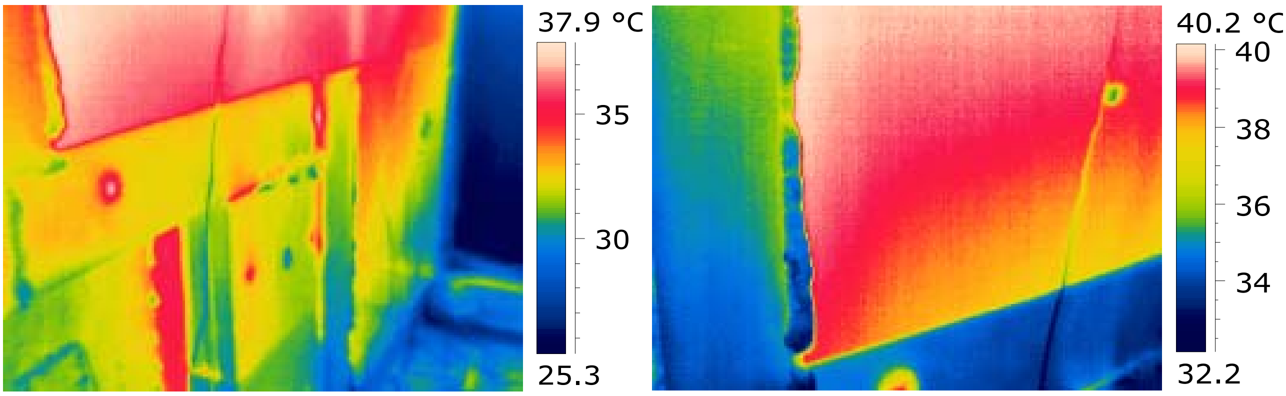


Figure 18: Retrofit modules infrared image.

One of the conclusions of the measurement campaign was that the U-Value in the retrofit module standard zone is 0.19 W/(m²·K). The U-Value in the ducts cavity zone is 0.30 W/(m²·K), which results in an overall retrofit module U-Value of 0.23 W/(m²·K).

3. Module application

To evaluate the energy performance of the retrofit modules integrated in a real building, it was modelled a single-family house from the 80's, located in Braga (north of Portugal) with an area of 55 m², a steel reinforced concrete pillars and beams structure and single pane CMU (Concrete Masonry Unit) exterior walls. The building retrofit was simulated with the dynamic simulation tool eQuest® [7] and modelled with Google SketchUp® (see Figure 19 [8].

Figure 19: Case study with retrofit needs: a) photograph; b) exterior 3D model; c) interior 3D model; d) 3D model cross-section

The overall retrofit strategy of the building consisted not only on the module application onto the external walls, but also on the general improvement of the building envelope, i.e., roof slab insulation (application of 12 cm of XPS), ground slab insulation (application of 8 cm of XPS) and replacement of the existent single glazing and aluminium frame windows (Uwdn = 4.1 W/(m²·K)) by double glazing and aluminium frame with thermal break windows (Uwdn = 2.5 W/(m²·K)).

The original building presented a U-value for the exterior walls of 1.9 W/(m²·K). With the application of the prefabricated retrofit modules it was possible to significantly reduce this U-Value to 0.2 W/(m²·K) (overall value, including thermal bridges) strongly contributing to a better energy performance of the building. The results obtained with the test building thermal simulations showed a significant reduction of its energy needs as presented in Table 1.

Energy needs kWh / (m²·y)	**Single family building in Braga**	
	Original situation	With retrofit module
Heating	334.1	18.7
Cooling	0.3	5.3
Domestic hot water	19.4	19.4
Total	353.8	43.4

Table 1: Simulated final energy needs for the case study

The use of the retrofit modules reduced significantly the U-value of the exterior walls and this allowed the reduction of the building energy needs in 69%. With the application of the remaining measures the reduction of the energy needs was of about 89%, helping to achieve the 50 kWh/(m²·y) goal defined in the project.

It is also possible to observe a slight increase in the cooling needs, since the higher insulation level of the building requires a longer time for the building to cool. This problem is aggravated when many consecutive hot days occurs. However, the cooling needs are not significant when compared with the total needs.

4. Conclusions

The Portuguese retrofit module solution, developed within the frame of the Project - FCOMP-01-0124-FEDER-007189, has a measured overall thermal resistance of 4.35 m²·K/W and a U-Value of 0.23 W/(m²·K). It presents a small thermal bridge in the docking area section, between modules, and no significant thermal bridges occur in any other sections. The module shows no risk of moisture build-up.

A major advantage of this module is the type of connection to the existing wall that can greatly reduce the installation time. Another advantage is the simplicity of the fabrication method that can guarantee the solution quality.

Just as an example, the application of this solution to a test building resulted in the reduction of the thermal transmission coefficient of the exterior opaque envelope from 1.9 to 0.2 W/(m²·K) contributing to a reduction of 69% of the total building needs.

Therefore, this is a solution with good performance indicators, showing a great potential to be used in high quality low energy building retrofit, having in mind that this solution has been developed and optimized for the Portuguese reality.

However, this solution can also be a valid option for other countries' realities using different materials but maintaining the same concept. Table 2 shows some alternative solutions with equivalent thermal performance.

Thickness (mm)	Original retrofit module materials	Alternative retrofit module materials		
6	Aluminium composite finishing	Aluminium composite finishing	Aluminium composite finishing	Aluminium composite finishing
60	Agglomerated black cork insulation	Rock wool insulation	Glass wool insulation	Rock wool insulation
1.5	Steel U-profile	Steel U-profile	Steel U-profile	Steel U-profile
120	Extruded polystyrene insulation	Rock wool insulation	Polyurethane panel insulation	Expanded polystyrene insulation
1	Vapour retardant	Vapour retardant	Vapour retardant	Vapour retardant
U-Value W / (m²·K)	**0.23**	**0.23**	**0.24**	**0.24**

Table 2: Alternative solutions in terms of materials for the retrofit module

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Civil Engineering and Geomatics, Switzerland
Swiss Federal Laboratories for Materials Science and Technology Empa,
Building Science and Technology Laboratory, Switzerland

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