MORE—CONNECT

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MORE-CONNECT

# Pre-selection of the favourable concept to be tested in the pilot

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For more information about the MORE-CONNECT project see the project website:

http://www.more-connect.eu

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# 1 The pilot building

## 1.1 Description of the pilot building

The Portuguese pilot building (Figure 1) is a real building located in Vila Nova de Gaia, Porto Metropolitan Area, in the North region of Portugal. It is a social housing neighbourhood, built in 1997, and owned by Gaiurb (a municipal company). It is a multi-family building with three separate blocks, each with three floors, corresponding to six apartments (a two-bedroom and a three-bedroom per floor). In total, the building is constituted by eighteen apartments. The building is not equipped with a central heating system. Some of the apartments have portable electrical heaters (η=100%) although the majority does not have any heating system installed.

*Figure 1. MORE-CONNECT pilot building in Vila Nova de Gaia, Portugal*

The building under study is representative of about 40% of the Portuguese multifamily buildings. Building envelope (and surrounding space) presents some signs of deterioration, although in small scale. The common parts of the building (stairs, halls and walls) show signs of humidity and are in a higher state of deterioration. Inside the apartments, thermal discomfort is common and mould is clearly visible in the corners of the walls and near the windows. Extensive mould areas can also be found in some of the rooms and bathrooms ceilings. In general, current renovation needs can be related with correction of thermal bridges, increase of the insulation level and installation of a heating system.

## 1.2 Dimensions and characteristics of the pilot building

Table 1 summarizes the dimensions and characteristics of the pilot building.

*Table 1. Dimensions and characteristics of the MORE-CONNECT pilot building in Vila Nova de Gaia, Portugal*

| Parameter | Unit | Data | Parameter | Unit | Data |
|---|---|---|---|---|---|
| Building period | | 1991-2012 (1997) | Typical indoor temperature | °C | - |
| Gross heated floor area | $m^2$ | 1265 | Average electricity consumption per year and $m^2$ (excluding heating, cooling, ventilation) | kWh/ ($a*m^2$) | - |
| Wall area (excl. windows) | $m^2$ | 2712.2 | U-value wall | $W/(m^2*K)$ | 0.96 |
| Roof area (pitched) | $m^2$ | 622.12 | U-value roof pitched | $W/(m^2*K)$ | _ |
| Roof area (flat) | $m^2$ | - | U-value roof flat | $W/(m^2*K)$ | - |
| Attic floor (if attic is unheated) | $m^2$ | 514 | U-value attic floor | $W/(m^2*K)$ | 0.91 |
| Area of ceiling of cellar | $m^2$ | 514 | U-value ceiling of cellar | $W/(m^2*K)$ | 0.78 |
| Area of windows to North | $m^2$ | 0 | U-value windows | $W/(m^2*K)$ | 3.60 |
| Area of windows to East | $m^2$ | 21.5 | g-value windows | Factor | 0.78 |
| Area of windows to South | $m^2$ | 0 | Energy need for cooling | $kWh/m^2$ | 2.20 |
| Area of windows to West | $m^2$ | 10.6 | Energy need for hot water | $kWh/m^2$ | 29.60 |
| Average heated gross floor area per person | $m^2$ | 20 | Airflow rate | $h^{-1}$ | 0.4-0.6 |

## 2 The MORE-CONNECT solution

The developed MORE-CONNECT solution comprises a wood frame, an internal/external cladding made of Coretech® sheets and a filling material of polyurethane foam (Figure 2).

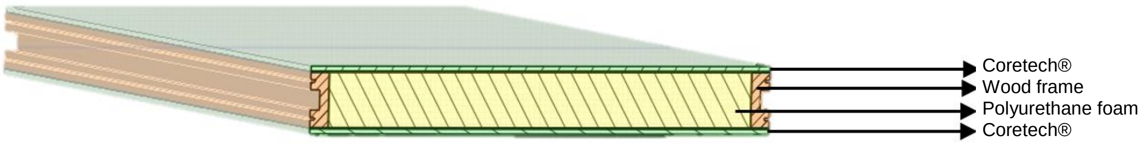



*Figure. 1 MORE-CONNECT prefabricated element for façade renovation*

During the development process, both aluminium and wood were considered for the module structure (frame). The initial structure was considered to be in aluminium because it is a widely used material in Portugal in this type of prefabricated structures and in the construction sector in general. Nevertheless, wood presents a higher thermal performance than aluminium, allowing reducing thermal bridges, particularly in the connection between modules.

Coretech® is a recycled material made from waste components of the car industry such as, kraft and cellulosic paper, polyurethane foam, fabrics and fiberglass. It presents attractive characteristics such as high durability, water and fire resistance and a very good thermal performance [1]. Although it is not widely applied in the Portuguese construction sector, there are already several applications of Coretech®, both in building envelope insulation and external cladding of buildings. Other advantage of this material is the possibility of applying any material as external coating/cladding (paint, ceramic, plaster, etc.).

Polyurethane foam was considered as filling material of the prefabricated elements given its high thermal performance and high durability.

The Coretech® panel is 8 mm thick, the wood frame 100 mm and polyurethane foam 100 mm. In total, the prefabricated module has a thickness of 120 mm. The connection between the modules is a male-female connection in the wood frame.

In order to be tested in laboratory facilities, the prefabricated elements were produced with 2.55 m of height by 1.00 m width. Nevertheless, the solution can be applied in different sizes, depending on the characteristics of the building. In the Portuguese pilot building the dimensions of the panel are 10.0 m high and 2.4 m width.

Due to the stiffness of the prefabricated element, there was the need to create an interface between the existing building wall and the prefabricated element, capable of absorbing the irregularities of the surface, guaranteeing a continuous insulation. This interface would efficiently avoid the occurrence of thermal bridges and improve the energy performance of the solution. The chosen material to act as interface was mineral wool (MW) with density of 25 kg/m$^3$. Different thicknesses of mineral wool were evaluated to analyse the total thermal performance of the prefabricated modules (panel together with the MW layer).

# 3 Investigated renovation packages

For the identification of the most favourable renovation concept, an assessment of various possible renovation packages was carried out. These renovation packages include the MORE-CONNECT solution. The renovation packages were assessed with respect to greenhouse gas emissions, primary energy use, and costs.[1] The first calculations do not include the embodied energy and embodied carbon emissions of the materials used.

For the pre-selection of favourable concepts, the investigated renovation packages are shown in Table 2. These renovation packages were then combined with different combinations of systems. The combination of systems taken into account is presented in Table 3.

[1] For a description of the assessment methodology, a separate report has been prepared in the MORE-CONNECT project [2]

*Table 2. Renovation packages for the Portuguese MORE-CONNECT pilot building*

| Renovation Package | Description |
|---|---|
| **Ref** | In the reference case, the walls are repaired and painted and the pitched roof is refurbished (with new tiles). These measures do not improve the energy performance of the building. |
| **M1** | The walls are insulated with External Thermal Insulation Composite Systems (ETICS) with 8 cm of expanded polystyrene. |
| **M2** | The walls are insulated with a MORE-CONNECT prefabricated element (12 cm) and 6 cm of mineral wool. |
| **M3** | The walls are insulated with a MORE-CONNECT prefabricated element (12 cm) and 10 cm of mineral wool. |
| **M4** | Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 12 cm of mineral wool insulation. |
| **M5** | Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 14 cm of mineral wool insulation. |
| **M6** | Additionally to M5, the cellar ceiling is insulated with 6 cm of mineral wool. |
| **M7** | Additionally to M6, the windows are replaced with new windows with an aluminium frame and an U-value for the entire window of 2.7 W/m$^{2o}$C. |
| **M8** | Additionally to M6, the windows are replaced with new windows with an aluminium frame and an U-value for the entire window of 2.4 W/m$^{2o}$C. |
| **M9** | Additionally to M8, a solar thermal system is installed. |
| **M10 (Chosen envelope solution)** | The wall is insulated with a MORE-CONNECT prefabricated element (12 cm) with a 10 cm of mineral wool and the roof is refurbished with 6 cm of polyurethane, including membrane, roof battens, shuttering, and gutter. The cellar ceiling is refurbished with a total of 6cm of Extruded polystyrene. |
| **M11** | M10 with optimized costs for the MORE-CONNECT prefabricated module. |

Table 3 Combination of systems *for the Portuguese MORE-CONNECT pilot building*

| System solution | Heating | Cooling | DHW | RES |
|---|---|---|---|---|
| **Conventional** | Electric heater η=1 | Multisplit EER=3 | Gas heater η=0.71 | |
| **A** | Multisplit COP=4.1 | Multisplit EER=3.5 | Gas heater η=0.71 | |
| **B** | Gas boiler η=0.93 | Multisplit EER=3.5 | Gas boiler η=0.93 | |
| **C** | Biomass boiler η=0.92 | Multisplit EER=3.5 | Biomass boiler η=0.92 | |
| **D** | Heat Pump COP=3.33 | Heat pump EER=2.68 | Heat Pump COP=3.33 | PV (7.5 kWp) |
| **E** | Heat Pump COP=3.33 | Heat pump EER=2.68 | Heat Pump COP=3.33 | |
| **F** | Heat Pump COP=3.33 | Heat pump EER=2.68 | Heat Pump COP=3.33 | PV (Zero) |

In system solution D, photovoltaic contribution consists of an installation with a peak power capacity of 7.5 kWp, which, together with a solar thermal system can successfully offset low energy needs for heating and DHW.

Besides the renovation solutions that result from the combination of the packages of envelope measures presented in table 2 with the systems presented in table 3, the chosen solution (M10) was also simulated together with the systems that will be implemented in the building in a later stage (biomass boiler), due to budget constraints. This package was named "Applied" solution and it consists of the components presented in table 4.

*Table 4 Components of the applied renovation solution*

| **Renovation package - Applied** | | | |
|---|---|---|---|
| **Envelope** | **System solution** | | |
| M10 | **Heating** | **Cooling** | **DHW** |
| | Biomass boiler η=0.92 | _ | Biomass boiler η=0.92 |

As observed in table 4, for the envelope, the "Applied" renovation solution has the same components as M10 and M11. This renovation solution does not have a system to deal with the cooling energy needs, because the Portuguese thermal regulation has an expeditious method to evaluate the risks of overheating by calculating a heat gains utilization factor that depends on the thermal mass and on the balance between heat gains and heat losses throughout the envelope. When this factor is higher than the reference value, the overheating risks are considered inexistent and the cooling needs are not accounted for the energy performance of the building. This is what happened in the Portuguese pilot building allowing excluding the cooling needs. To notice that this is a very common situation in existing Portuguese buildings, due to significant heat losses and medium to high thermal mass that characterize this type of buildings.

## 3.1 Overview graphs

For the pilot building, the results of the cost-optimal analysis performed for the selected renovation packages are shown in figure 2. The costs presented in figure 2 result from the application of the Net Present Value method.

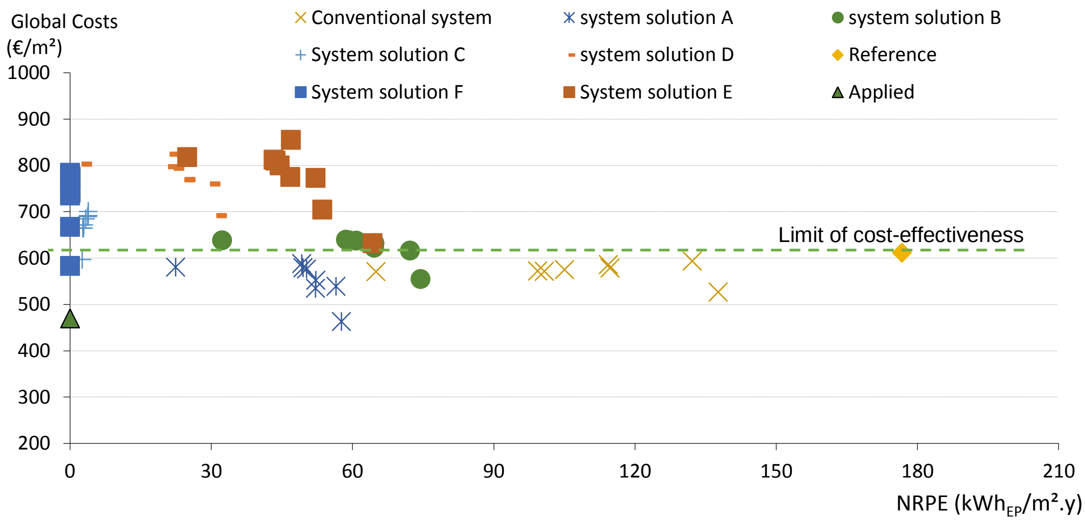
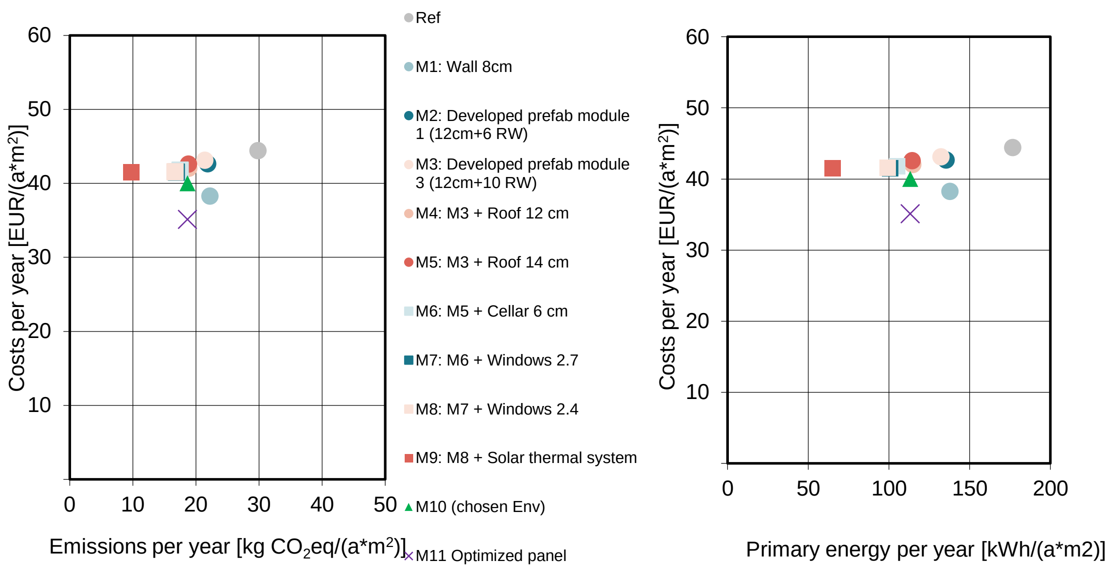


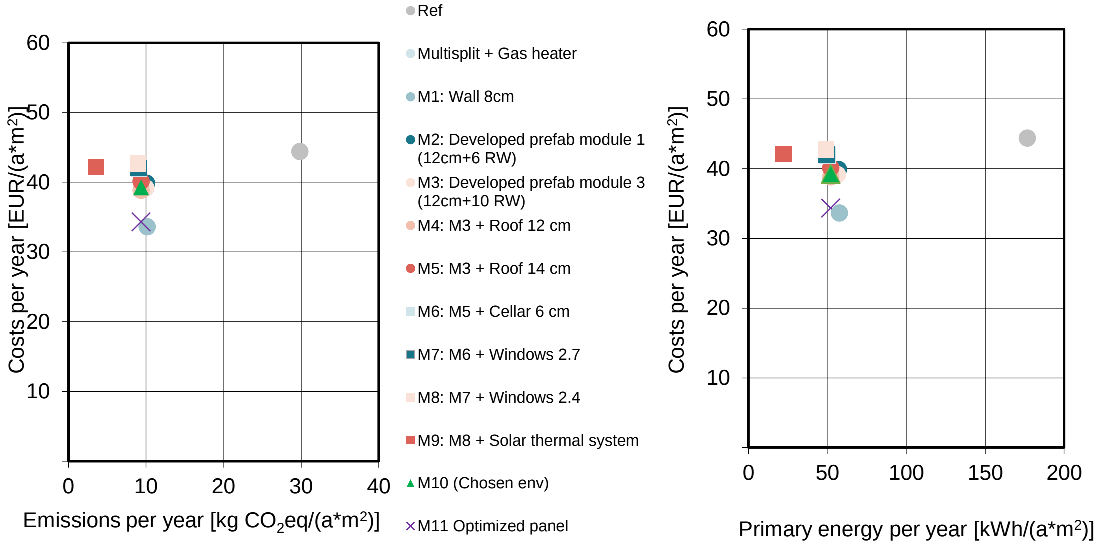

*Figure. 2 Cost-optimal results for the analysed renovation packages*

The assessment methodology applied by project partners in the MORE-CONNECT project proposes to use the annuity method for the calculation of costs. Thus, in the next figures, which show the results for each system solution, combined with each one of the 11 renovation packages for the envelope, take into consideration annualized global costs.

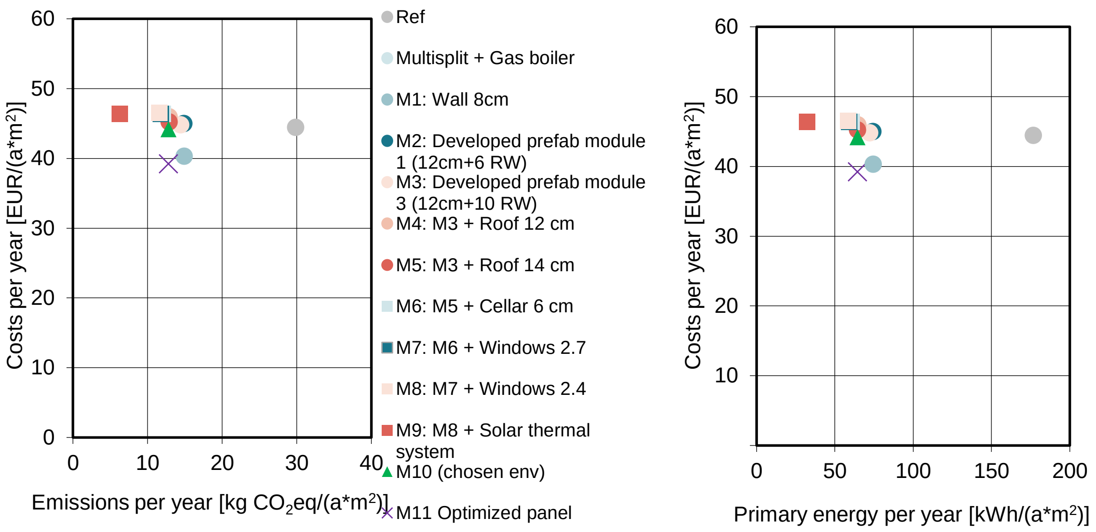
### Conventional system



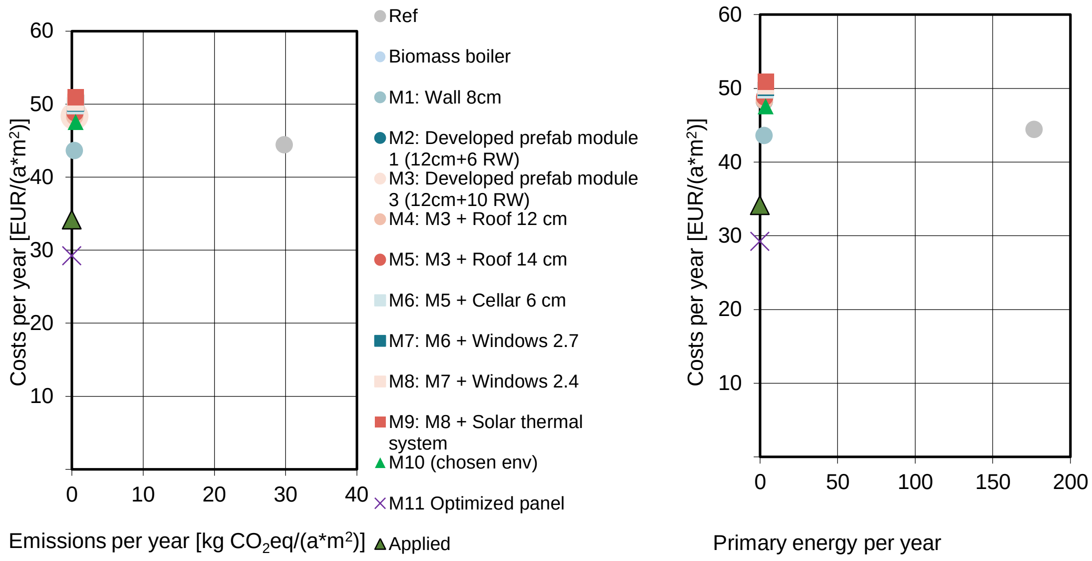
## System solution A: multisplit (heating/cooling) + Gas heater (DHW)



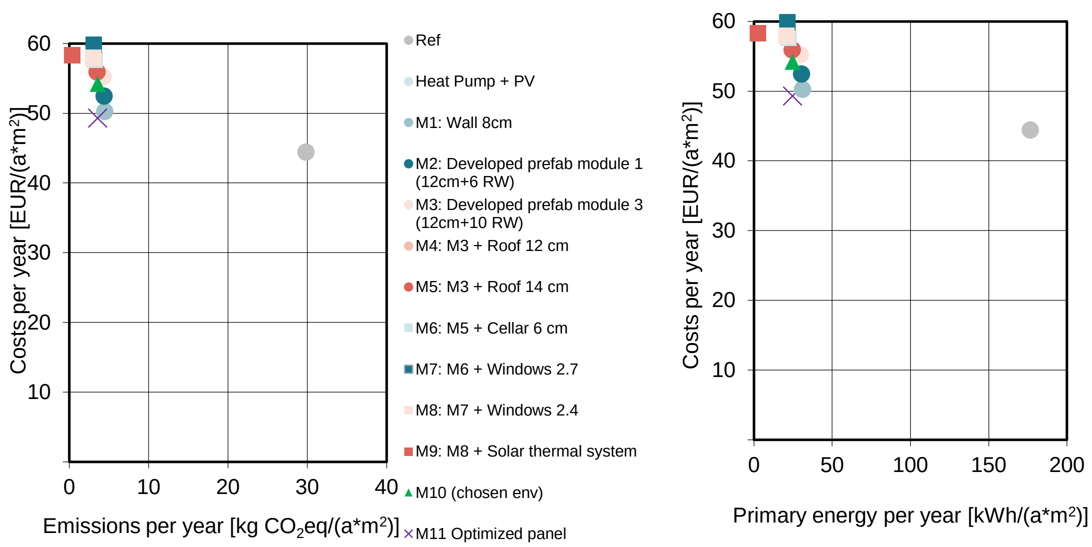

## System solution B: multisplit (cooling) + Gas boiler (heating/DHW)



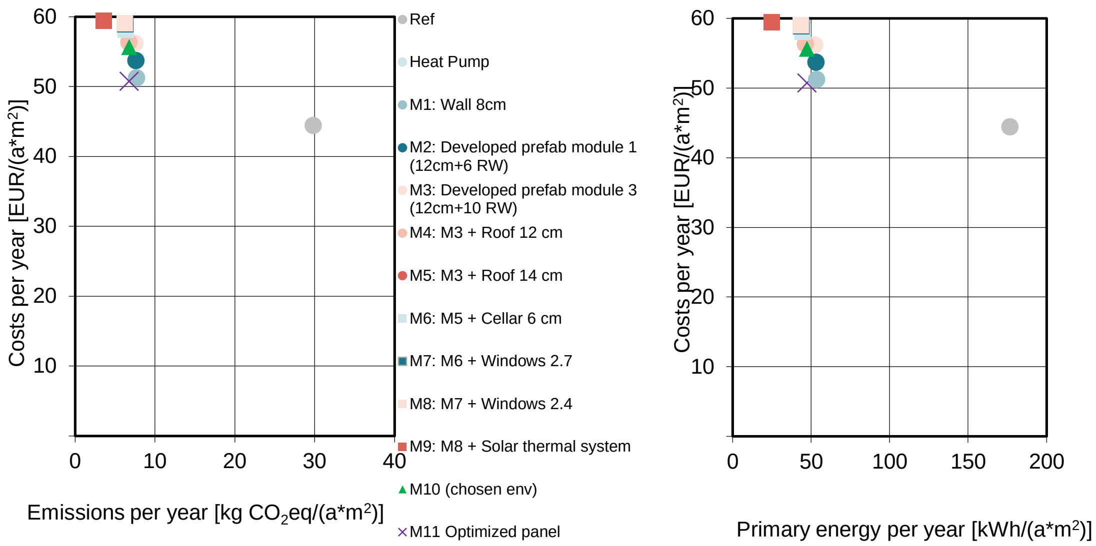
**System solution C: multisplit (cooling) + Biomass boiler (heating/DHW)**



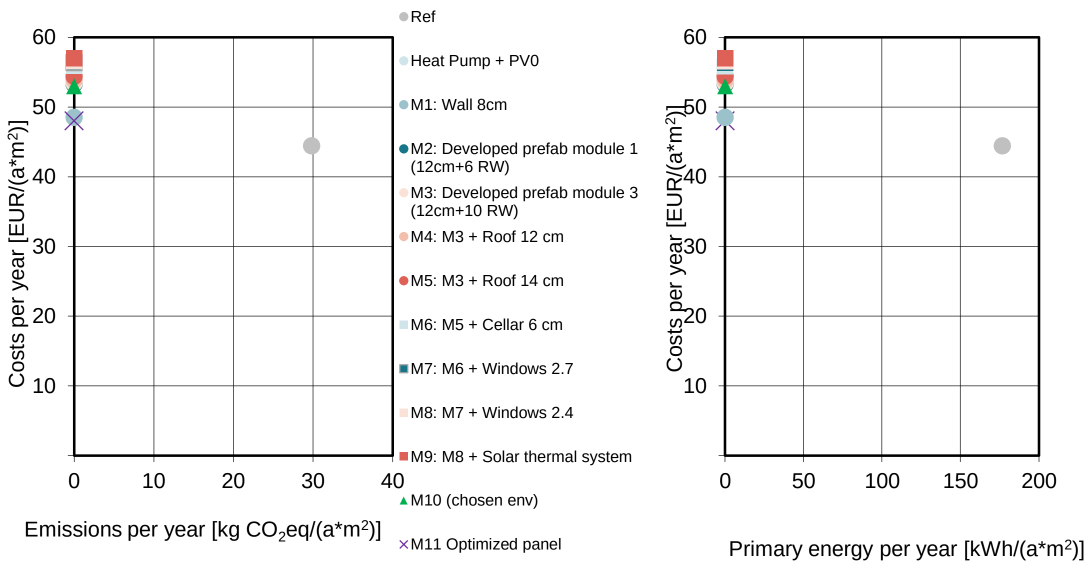

**System solution D: heat pump + PV system**



**System solution E: heat pump**




**System solution F: heat pump + PV system towards zero**



## Summary

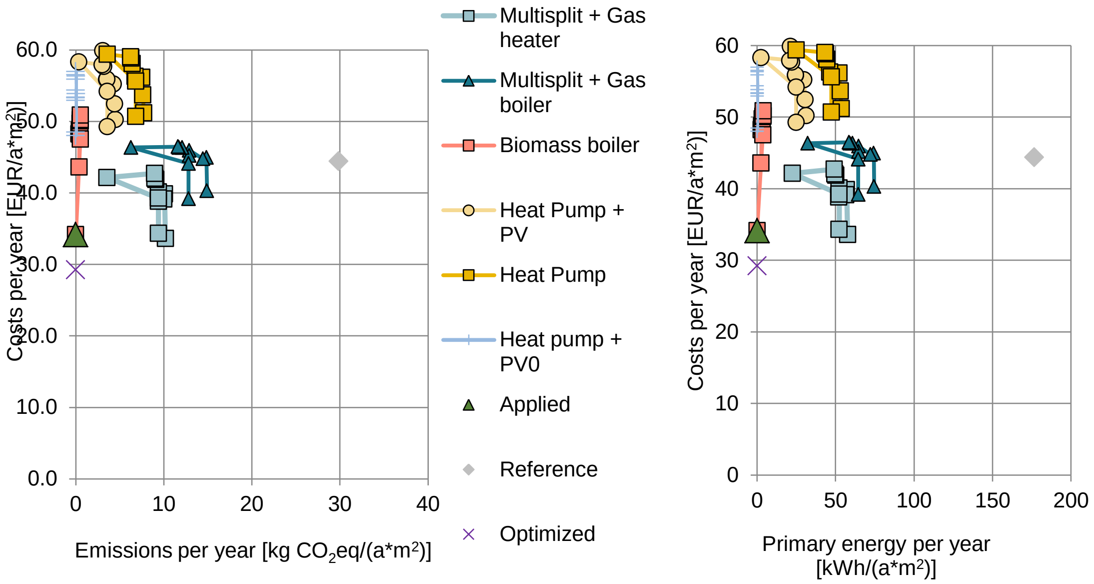



*Figure. 3 Average annualized costs of renovation measures per system solution*

Here, it is important to emphasize that the applied renovation solution is represented in the system solution C, because it also uses a biomass boiler for heating and DHW, but it does not take into account the cooling energy needs, unlike the other renovation packages.

### 3.1.1 Discussion of results from assessment without considering the embodied energy and embodied carbon emissions of the materials

In general, the most significant measures to improve the energy performance of the building are the replacement of the systems and adding insulation to the exterior walls. Adding insulation on the roof, on the cellar, as well as improving the energy performance of the windows are not so cost-effective, i.e., they are measures that allow achieving lower energy consumptions, but with an increase in global costs.

Renovation package M9 is the solution that allows reducing primary energy more significantly (this solution involves the application of the prefabricated panel on the walls, insulation of the roof, floor and also replacement of the windows), but presents a noteworthy increase in the global costs. The cost-optimal solution is the “Optimized” solution, which is equal to the “Applied” renovation package, but considering optimized costs for the prefabricated panel. This solution presents a value of primary energy of 0.00 kWh/m².a, producing 0.00 $kgCO2_{eq}$ / (m².a), because both heating and DHW non-renewable energy needs and related emissions are totally suppressed by the biomass boiler. Furthermore, it does not take into account the cooling energy needs, as explained before.

Concerning just the envelope solutions, the “Optimized” renovation package includes the prefabricated module for the walls associated with a 10 cm layer of mineral wool applied between the module and the building, 6 cm of polyurethane on the roof, and a 6 cm layer of extruded polystyrene in the cellar ceiling. This renovation package does not include the replacement of the windows.

Currently, the developed prefabricated panel presents very high investment costs because it does not have yet an optimized assembly line developed for mass production (as the other solutions have). This fact does not favour the cost-effectiveness of most of the renovation measures that include this panel. However, according to the manufacturer, whenever the prefabrication system is optimized (which will occur after the renovation of the pilot building), the costs of the panels will become much more attractive (a reduction of 73% compared to the actual costs can be achieved).

To elucidate the impact that an optimized production line may have in the global costs, the cost-optimal calculations were performed considering a much more attractive cost for the prefabricated panel (73% of the current cost). The global costs were calculated using the NPV method, as shown in figure 2.

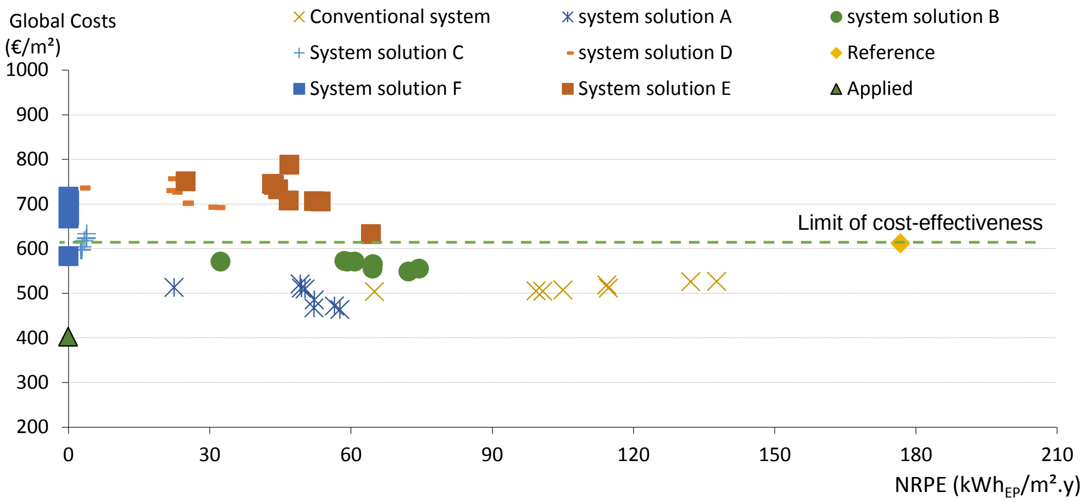



*Figure 4 Cost-optimal calculation considering the optimization of the prefabrication process of the panel*

Observing figure 4, it is possible to see that there are more cost-effective solutions, when compared to figure 2 (that shows the results with the current manufacturing costs), even with the system solution F, which had all the points above the limit of cost-effectiveness. In this figure, the cost of the prefabricated panel was reduced in accordance with the indication of the manufacturer, which resulted in an average reduction of global costs of 68€/m².

With respect to the pre-selection of the favourable concept, the following aspects are also taken into account: The main purpose of the project is to significantly reduce energy consumption and carbon emissions. Being so, the cost-optimality has a lower priority when compared with this objective. Besides, the project also has requirements concerning the timing for the execution of the renovation works and this prefabricated solution is faster to apply than the traditional solutions. As demonstrated in figure 4, the future optimization of the production line of the More-Connect panel will reduce its cost and make it much more attractive.

As explained before, the prefabricated module is associated with a layer of mineral wool to be applied between the panel and the existing façade. In this sense, when comparing solution M3 (panel with a 10cm layer of mineral wool) with solution M2 (panel with a 6cm layer of mineral wool), it was observed that the difference between both is very small in terms of energy performance.

Concerning the systems, system solution C (biomass boiler) allows reaching higher reductions regarding both carbon emissions and primary energy, allowing reductions of 98%. In cases when the cooling energy needs are not considered, the reductions on the primary energy needs may reach 100%. All renovation packages considering system solution A are cost effective. In comparison, when system solution B is taken into account, only M1 is clearly cost effective. However, with the optimization of the prefabricated panel, which has a significant impact on the cost of this façade renovation solution, all renovation packages for this system solution are below the cost effectiveness threshold.

When comparing system solutions D, E and F (solutions using heat-pumps with PV (D and F) and heat-pumps without PV (E)), all renovation packages present higher global costs, which is not very appealing. However, these three system solutions also allow significant reductions of the primary energy use and carbon emissions, sometimes above 80%. Results concerning system solutions D and F (both considering PV systems) are more beneficial than system solution E, not only in terms of reduction of primary energy use and greenhouse emissions, but also in terms of saving costs. Results also stress that a zero energy building or a zero emission building might also be possible to achieve with a larger PV installation, as in system solution F.Globally, the “Optimized” renovation package is the best solution concerning the costs among the investigated renovation packages and has the advantage of reaching zero carbon emissions and zero primary energy consumption, when the cooling energy needs are not considered. Besides, it is in accordance with the goals of the timing set for the renovation works.

## 3.2 Aspects related to reuse of materials, embodied energy and indoor environment

Aspects such as reuse and recycling of materials were considered during the development of the prefabricated panel.

For the module frame, wood was chosen over aluminium because it is a natural material and presents a better thermal behaviour. Also, at the end of the service life, wood can be easily reused for secondary materials (e.g. fibers) or used in processes of energy recovery.

Regarding the polyurethane foam, it presents the disadvantage of not being mechanically recyclable. Also for this particular panel, it would be difficult to separate and reuse the foam.

The external/internal cladding of the façade modules is Coretech®, which is a composite material made from waste components of the car industry. Hence, it helps reducing the exploitation of raw materials and the amount of waste.

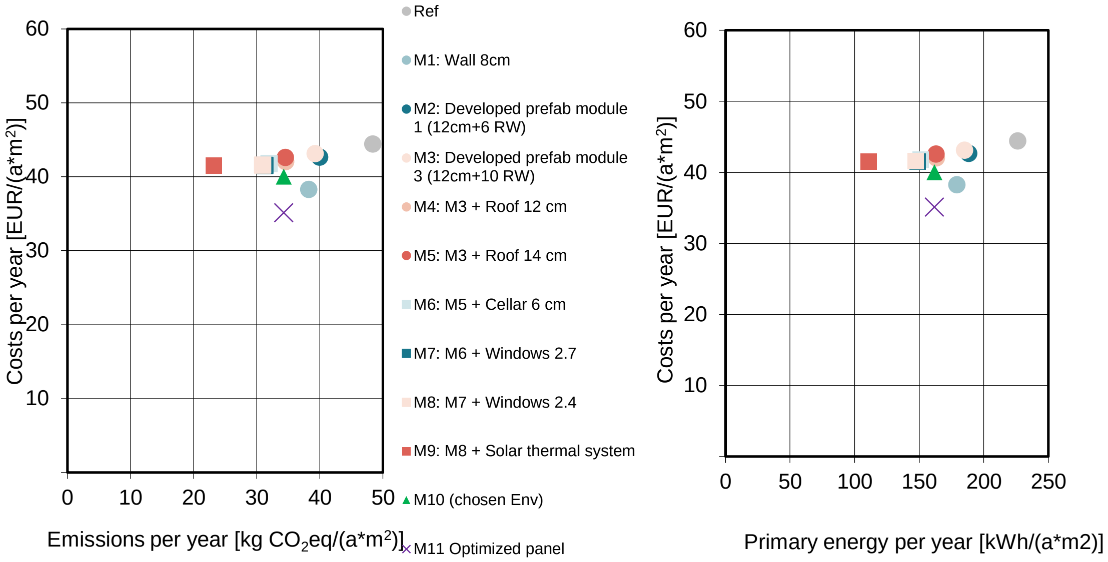
In addition to these factors, most of the chosen materials are non-toxic and inert.

To verify the impact of these environmental aspects, the embodied energy and embodied carbon emissions have also been included in the calculations of the analysed renovation solutions.

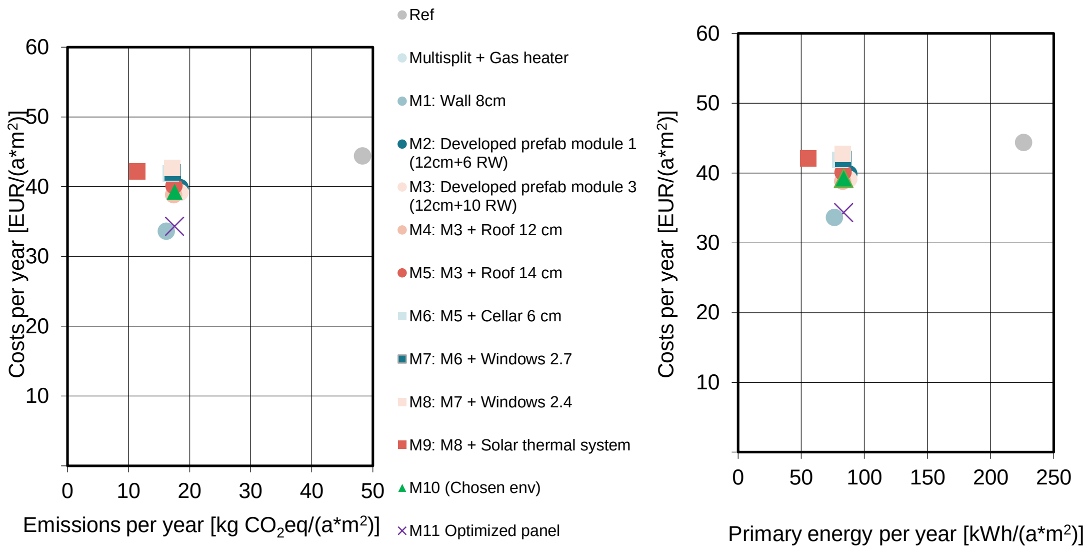
### 3.2.1 Results including the embodied energy and embodied carbon emissions of the materials used

The next figures show the results for the renovation packages combined with different system solutions, including the embodied carbon emissions and the embodied energy, calculated according to the methodological framework for the selection of favourable concepts for the pilot projects [2].

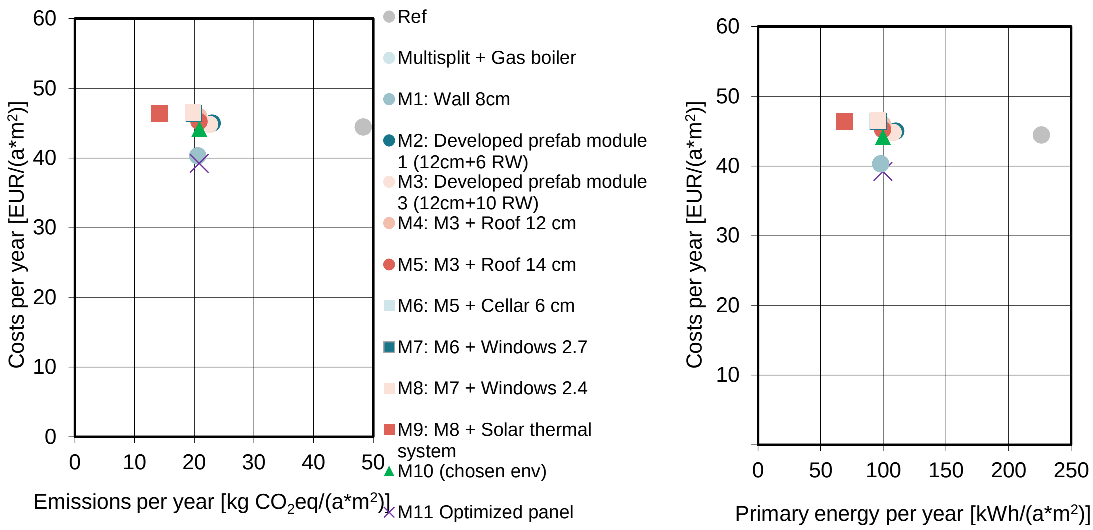
**Conventional system**



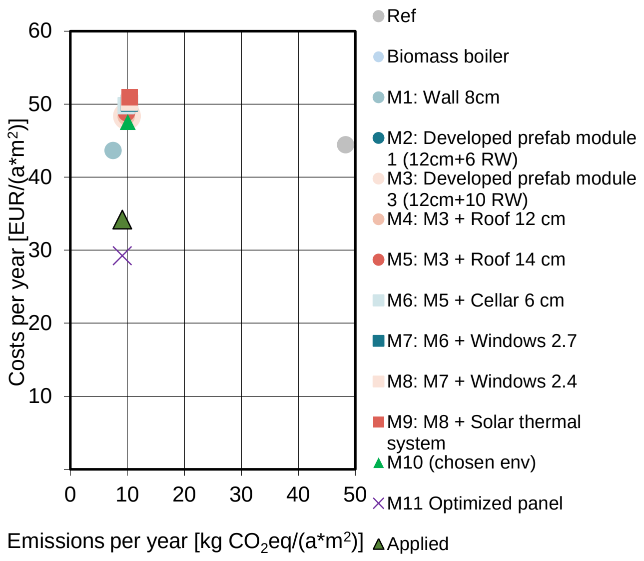
## System solution A: multisplit (heating/cooling) + Gas heater (DHW)

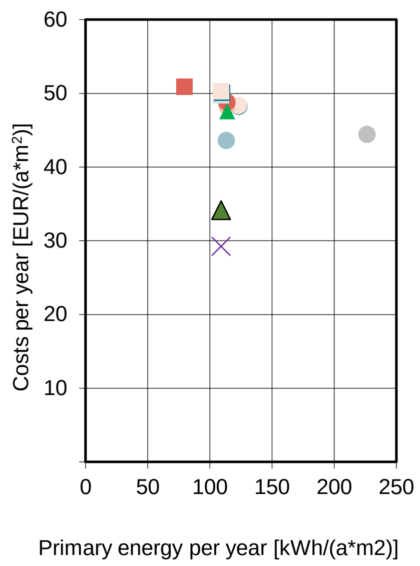



## System solution B: multisplit (cooling) + Gas boiler (heating/DHW)

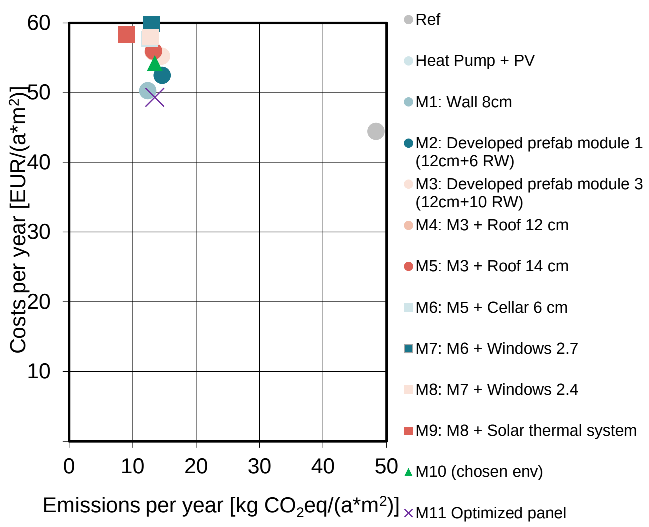


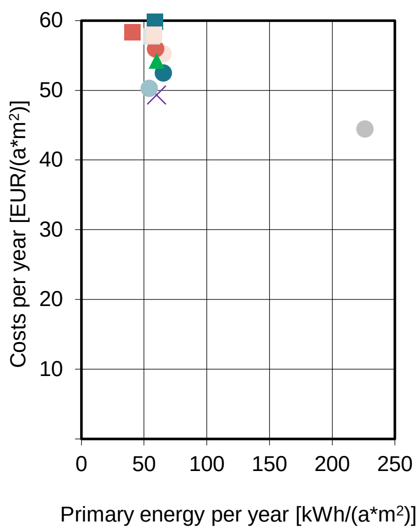
**System solution C: multisplit (cooling) + Biomass boiler (heating/DHW)**



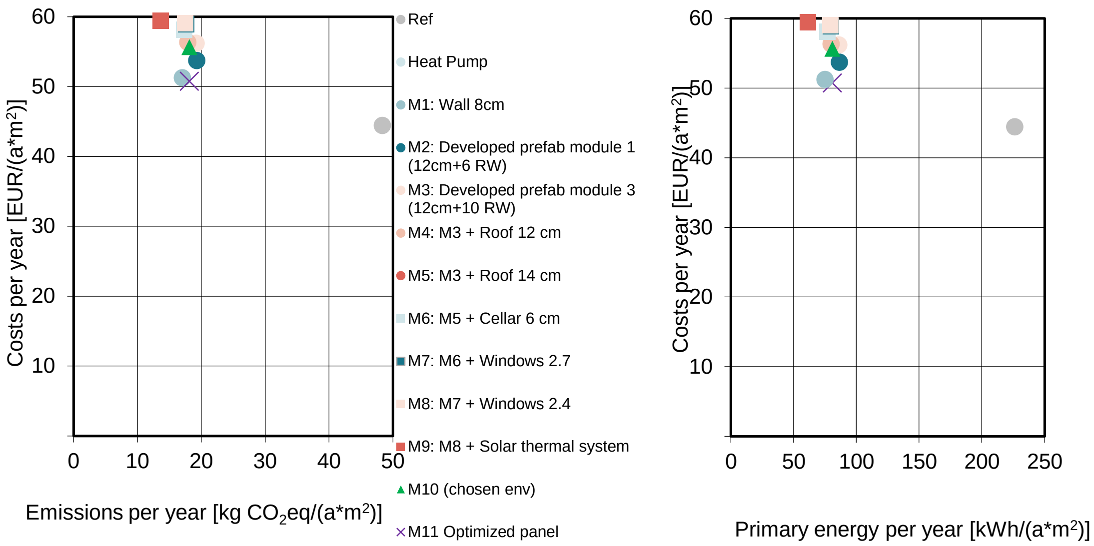




**System solution D: heat pump + PV system**

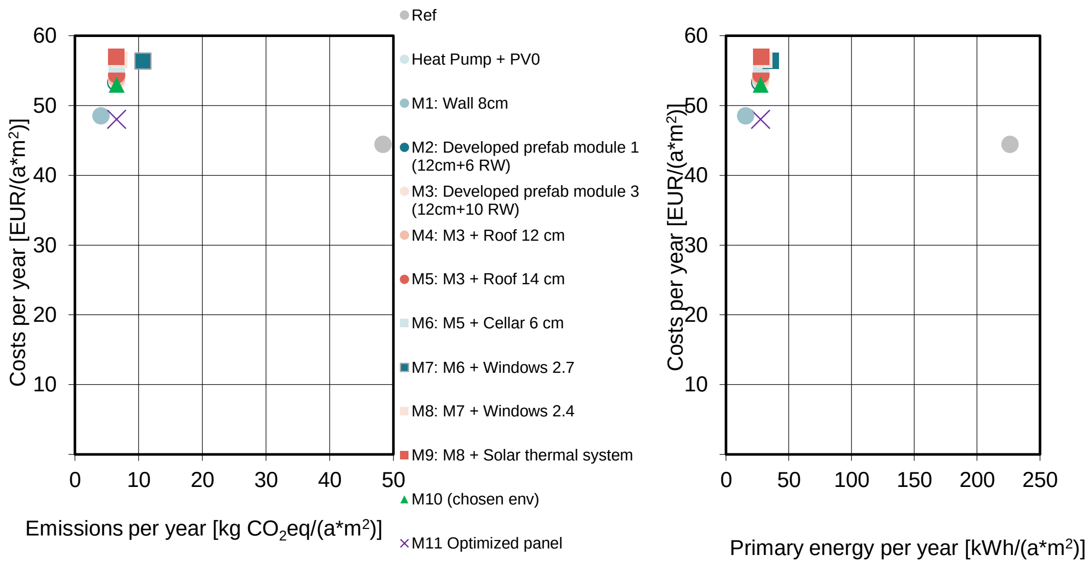


**System solution E: heat pump**




**System solution F: heat pump + PV system towards zero**



**Summary**

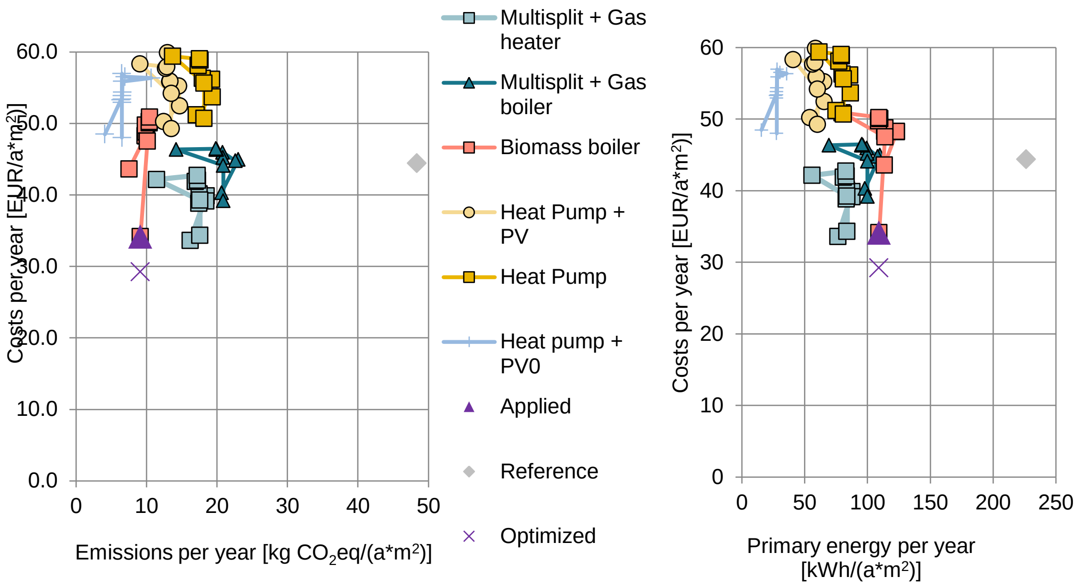



*Figure. 5 Average annualized costs of renovation measures per system solution (considering embodied energy and carbon emissions)*

### 3.2.2 Discussion of results from assessment with the embodied energy and embodied carbon emissions

The inclusion of the embodied carbon emissions and embodied energy increases the energy and carbon emissions of each renovation package. For the carbon emissions, the increase ranges from 10 to 20 kgCO2eq/(a.m²) and from 30 to 50 kWhPE/m².a. for the total primary energy.

System solution C (biomass boiler) presents a higher unitary impact concerning the total primary energy, which is reflected by a bigger dislocation of the points from zero that ranges from 80 to 150 kWhPE/m².a. Concerning the carbon emissions, the impact follows the trend of other systems. Systems F (heat pump + PV) also moves away from zero, but not as much as system C and this dislocation is mainly related to the size of the photovoltaic systems.

Despite the increase of the carbon emissions and of the total primary energy, generally, the hierarchy of the renovation packages for the envelope is kept.

The inclusion of the embodied energy and the embodied emissions does not change the cost-effectiveness. Accordingly, the cost optimal solution remains the “Optimized” renovation package combined with system solution C (biomass boiler for heating and DHW, without the cooling energy needs).

The “Applied” renovation package is among the solutions with lower global costs and lower carbon emissions. Concerning the total primary energy, the value increases significantly because of the use of a biomass boiler, which is a system with high unitary impact in terms of embodied energy.

In these conditions and concerning the project requisites, the system solution that allows reducing the primary energy above 80% is system F (heat pump + PV). However, the costs are less attractive. This is an aspect that is common to all system solutions that use the heat pump. The rest of the systems allow reductions of primary energy between 21% and 71%.

Thus, as the optimization of the production lines will not happen shortly and taking into account the objectives of the project, the most favourable concept in terms of global costs is the “Applied” renovation package, combined with system solution F.

## 3.3 Conclusions

Based on the assessment carried out, the cost-optimal solution for the envelope of the building does not suffer major changes when considering the embodied energy and embodied carbon emissions of the materials used, despite the increase observed in the values.

Without considering the embodied energy and for the envelope, the renovation package that allows the highest reduction of the energy needs is M9. It includes the prefabricated module together with a layer of mineral wool with 10 cm. In addition, for the roof there is a 14 cm layer of mineral wool and 6 cm of extruded polystyrene for the cellar ceiling. For the windows, the solution includes replacement of the windows by PVC frame and double-glazing windows. This solution leads to more significant reduction of the energy needs and $CO_2$ emissions reductions, but in terms of costs, it is not very attractive.

Thus, due to some budget constraints, renovation package M9 for the envelope was not the chosen solution to apply on the building. The chosen renovation solution for the envelope is the “Applied” which consist of the prefabricated module, with a 10cm layer of mineral wool (applied between the existing wall and the module) and for the roof, it includes a 6cm layer of polyurethane. For the cellar ceiling, the insulation has a total of 6 cm of extruded polystyrene. It does not include the improvement of the windows.

The most attractive solution in terms of costs is the Optimized (M11). This solution is equal to the renovation solution “Applied”, but with optimized costs for the panel.

Regarding the systems and without considering the embodied energy, the most favourable system in order to achieve the goals of the project (at least 80% energy reduction) is system solution C, which uses a biomass boiler and when the cooling energy needs are not considered, it allows reducing 100% of the carbon emissions and the primary energy consumption. Based on the investigated concepts, this type of heating system is pre-selected for the favourable concept.

Another system that allows reducing the primary energy and carbon emissions above 80% is system solution F (heat pump + PV panels).

Accordingly, the favourable concept comprises the following elements:

- Installation of the prefabricated module together with a 10 cm layer of mineral wool to be applied between the pre-existent exterior walls and the prefab module;
- Biomass boiler for heating and DWH.

In this sense and considering the actual costs of the panels, the "Applied" solution (M10 + biomass boiler without considering the cooling energy needs) is the most attractive concerning the global costs. This renovation package may become even more attractive with the optimization of the production process that is represented by the "Optimized" solution.

Considering the embodied energy and embodied carbon emissions, the results for the envelope packages do not suffer significant changes. Generically, renovation package "Optimized" (M11) is the cost-optimal solution for the envelope.

For the systems, the inclusion of the embodied energy and embodied carbon emissions led to some changes. System solution F is the one that allows reaching reductions of the primary energy above 80%. However, it presents higher global costs.

System solution D allows reducing the total primary energy between 71% and 81%, according to the solution for the envelope. The rest of the systems allow reductions between 21% and 71%.

Considering the embodied energy and to serve the goals of the project, the most favourable concept is comprised of the "Optimized" (M11 renovation package) for the envelope combined with system solution F (heat pump + PV 0).

**References**

[1] coretech. 2017. Coretech Portugal. Available at: http://www.coretech.com.pt/cms.php?id_cms=2

[2] Bolliger R, Ott W (2016), 'Methodological framework and instructions for the selection of favourable concepts for the pilot projects (Task 6.1 part 1)', developed within the MORE-CONNECT project, 2016