MORE—CONNECT

European Commission, Horizon 2020 Programme

MORE-CONNECT

Final selection of favourable concept based on LCA

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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 reference building

1.1 Description of the reference building

The Portuguese reference building (Figure 1) is located in Vila Nova de Gaia, Porto Metropolitan Area, in the North region of Portugal. It is part of 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 reference building in Vila Nova de Gaia, Portugal

The reference building is representative of about 40% of the Portuguese multifamily buildings. The building envelope (and surrounding space) presents some signs of deterioration, although in small scale. The common areas of the building (stairs, halls and walls) show signs of humidity and are in a high 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 to the correction of thermal bridges, an increase of the insulation level and the installation of a heating system.

1.2 Dimensions and characteristics of the reference building

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

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

Parameter	Unit	Data	Parameter	Unit	Data
Building period		1991-2012 (1997)	Typical indoor temperature (Heating/Cooling Season)	°C	15/25*
Gross heated floor area	m^2	1265	Average electricity consumption per year and m^2	kWh/ $(a*m^2)$	48.4-**
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 needs for cooling	kWh/m^2	2.20 ***
Area of windows to West	m^2	10.6	Energy needs for heating		53.36***
Average heated gross floor area per person	m^2	20	Energy needs for hot water	kWh/m^2	29.60***
			Airflow rate	h^{-1}	0.4-0.6

*Average values from monitoring data from one year measurement campaign (2017)

**Data extracted from INE [1] (including lighting and electrical appliances and excluding heating, cooling and DHW. Considering DHW, the average electricity consumption is 69.4 $Kwh/a*m^2$).

***Simulated values

2 The MORE-CONNECT solution

In the context of the MORE-CONNECT research project, a prefabricated modular panel to improve insulation of the exterior walls was developed. The MORE-CONNECT solution comprises a wood frame, an internal/external cladding made of Coretech® sheets and a filling material of polyurethane foam (Figure 2).

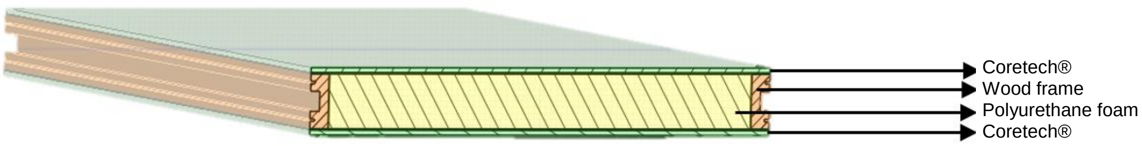

Figure 2 - MORE-CONNECT prefabricated element for façade renovation

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 [2]. 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 10 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 the laboratory facilities, the prefabricated elements were produced with 2.55 m height and 1.00 m width. Nevertheless, the solution can be produced and applied in different sizes, depending on the characteristics of the building. In the Portuguese reference 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 a low density mineral wool (MW) (density of 25 kg/m^3). Different thicknesses of mineral wool were evaluated in order to analyse the thermal performance of the global solution for 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 building energy renovation alternatives was carried out. In a first stage, combinations of renovation packages with system solutions were assessed with respect to greenhouse gas emissions, primary energy use, and costs.[1] In a second stage, calculations included the embodied energy and the embodied carbon emissions of the materials used in the combinations. The investigated renovation packages are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. These renovation packages were then combined with different system solutions, which are detailed in Table 3.

In terms of building envelope, the analysis was focused on the MORE-CONNECT solution. The first renovation package (Ref) comprises the reference situation from which the cost-effectiveness is going to be evaluated. The implementation of 8 cm ETICS was already

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1 For a description of the assessment methodology, a separate report has been prepared in the MORE-CONNECT project [3]

identified in other study [4] as being the cost optimal solution for the envelope of this kind of buildings. Being so, in order to serve as comparison, there is one renovation package (M1) considering this type of wall insulation. The subsequent renovation packages (from M2 to M11) explore different insulation thicknesses and progressively test new layers of intervention for the building renovation. Finally, the last renovation package (M12) intends to explore the effect of the production cost optimization on the prefabricated panel. Due to technical, social and financial issues, the building owner selected the renovation package M11 (Selected Renovation Package) as the solution to be implemented in the building.

Table 2. Renovation packages for the Portuguese MORE-CONNECT reference 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 in the interface with the existing wall.
M3	The walls are insulated with a MORE-CONNECT prefabricated element (12 cm) and 10 cm of mineral wool in the interface with the existing wall.
M4	Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 6 cm of mineral wool insulation.
M5	Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 12 cm of mineral wool insulation.
M6	Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 14 cm of mineral wool insulation.
M7	Additionally to M6, the cellar ceiling is insulated with 6 cm of mineral wool.
M8	Additionally to M7, the windows are replaced with new windows with an aluminium frame and an U-value of 2.7 W/m^{2o}C.
M9	Additionally to M7, the windows are replaced with new windows with an aluminium frame and an U-value of 2.4 W/m^{2o}C.
M10	Additionally to M9, a solar thermal system is installed.
M11 Selected Renovation Package)	Additionally to M3, the roof is refurbished with 6 cm of polyurethane, including membrane, roof battens, shuttering, and gutter. The cellar ceiling is refurbished with a 6cm layer of extruded polystyrene.
M12	M11 with optimized costs for the production of the MORE-CONNECT prefabricated module.

The systems in Table 3 were chosen in accordance with the multitude of implemented options found in the national context, as well as innovative solutions including renewable energy sources, which present the highest potential for energy and emissions reduction. The conventional system (electric heater for heating, a multisplit system for cooling and a gas heater for domestic water heating) is what is considered to be implemented in the existing building before the intervention.

In this context, it is worth to highlight that, in system solution D, the photovoltaic contribution consists of an installation with a peak power capacity of 7.5 kWp, which, together with a solar thermal system, can successfully compensate the low energy needs for heating and DHW (Domestic Hot Water). In system solution F, the photovoltaic contribution consists of an installation with the necessary capacity to fully compensate the energy needs. Similarly, in system solution G, the size of the photovoltaic system is adequate to compensate for the heating and cooling needs, whereas DHW is supported by a solar thermal installation, sized according to the minimum requirements of the Portuguese legislation.

Table 3 Combination of systems *for the Portuguese MORE-CONNECT reference 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)
G	Multisplit COP=4.1	Multisplit EER=3.5	Electric Boiler COP 1.5	PV (Zero) ST for DHW

In terms of systems, and due to budget constraints and material availability, the building owner decided to implement a biomass boiler as a centralized heating system in the building. In order to accommodate this option, the selected renovation package (M11), along with the cost optimized version of the panel (M12), were tested in conjunction with this system in a new combination designated as “Selected System Combination”, as detailed in Table 4. The system solution in this combination is identical to system solution C without the system to deal with the cooling energy needs. 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 reference building allowing excluding the cooling needs. It is relevant 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. In addition, and following what is considered in national thermal regulations, it should be clarified that, in this analysis, only non-renewable energy is considered in terms of primary energy and emissions calculations.

Table 4 Renovation Packages and System solution for the Selected System Combination.

Selected System Combination (Renovation Packages +System Solution)			
Renovation Package	**System solution**		
M11 (M12)*	**Heating**	**Cooling**	**DHW**
	Biomass boiler η=0.92	_	Biomass boiler η=0.92

*M12 corresponds to M11 with optimized production costs of the prefabricated panel.

4 Assessment of investigated renovation packages and selection of favourable concept

4.1 Overview graphs

For the reference building, the results of the cost-optimal analysis performed for the selected renovation packages are shown in Figure 3. The costs presented in Figure 3 result from the application of the Net Present Value method.

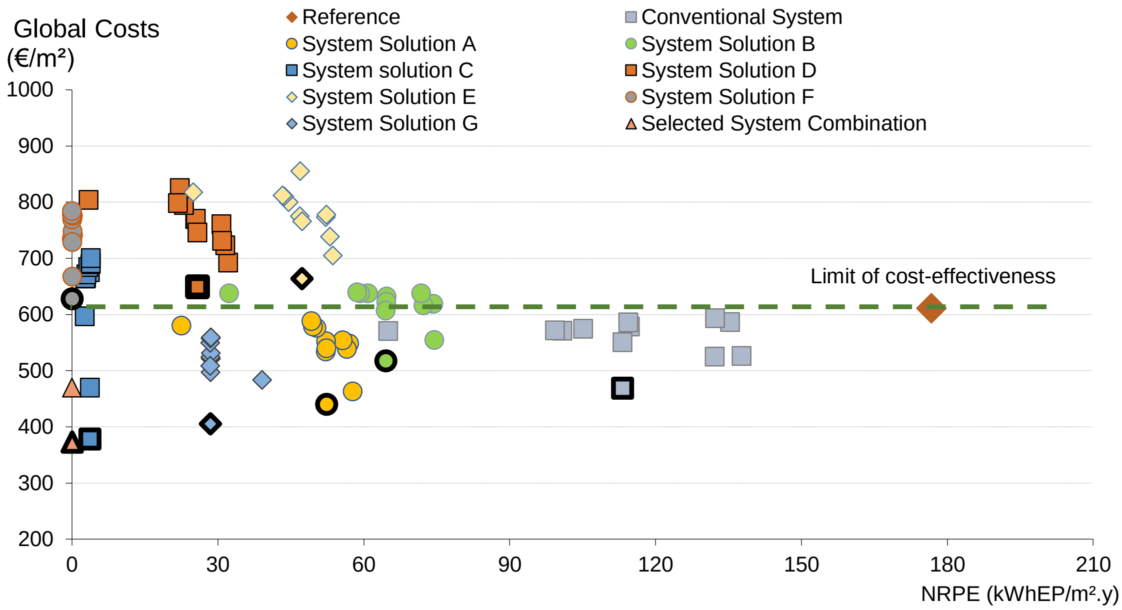
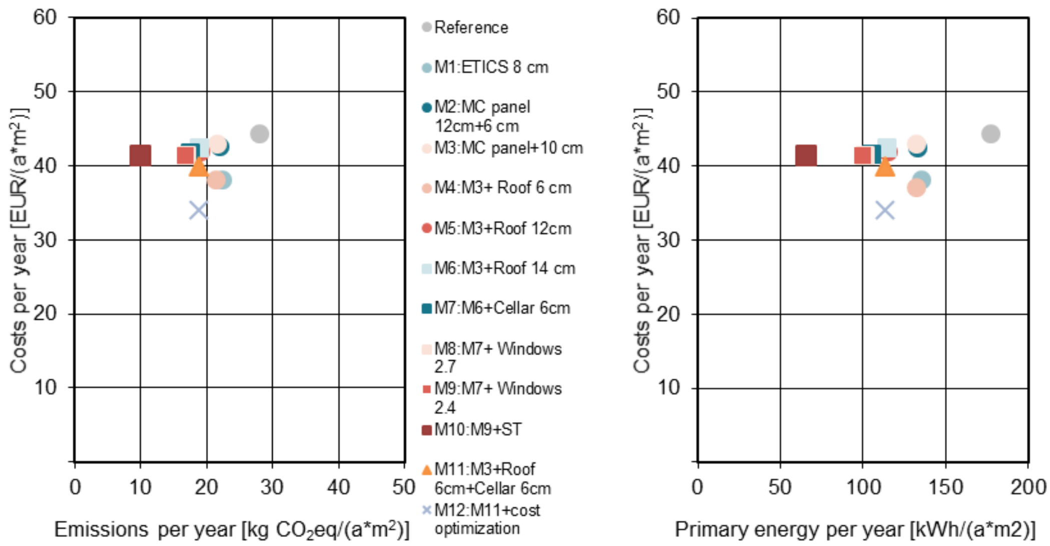


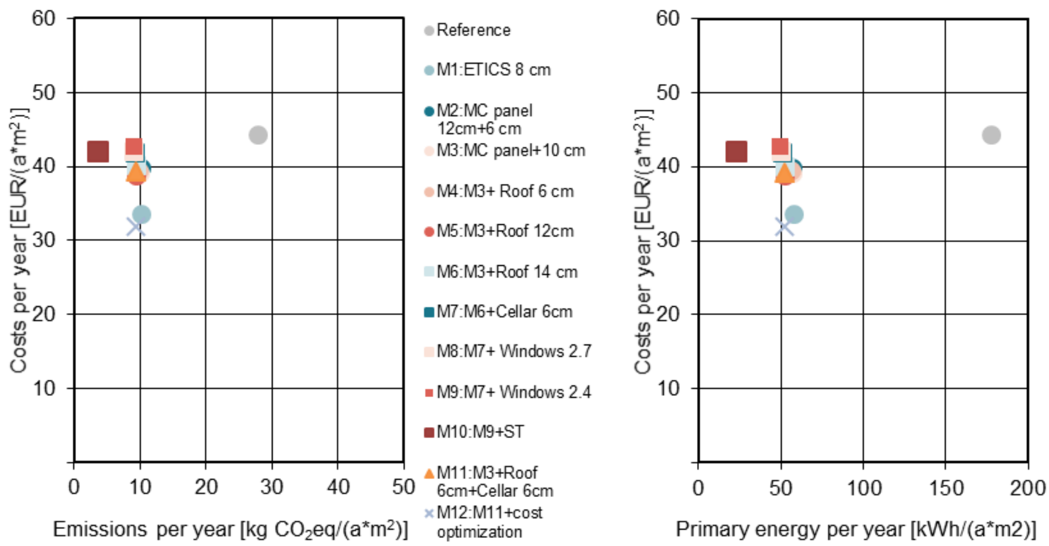
Figure 3 - Cost-optimal results for the analysed renovation packages (the solutions that include the cost optimized panel (M12) are highlighted with a black outline)

The assessment methodology applied by project partners in the MORE-CONNECT project proposes to use the annuity method for the calculation of costs. Thus, Figure 4 shows a group of graphs with the results for each system solution, combined with each one of the 12 renovation packages for the envelope, taking into consideration annualized global costs.

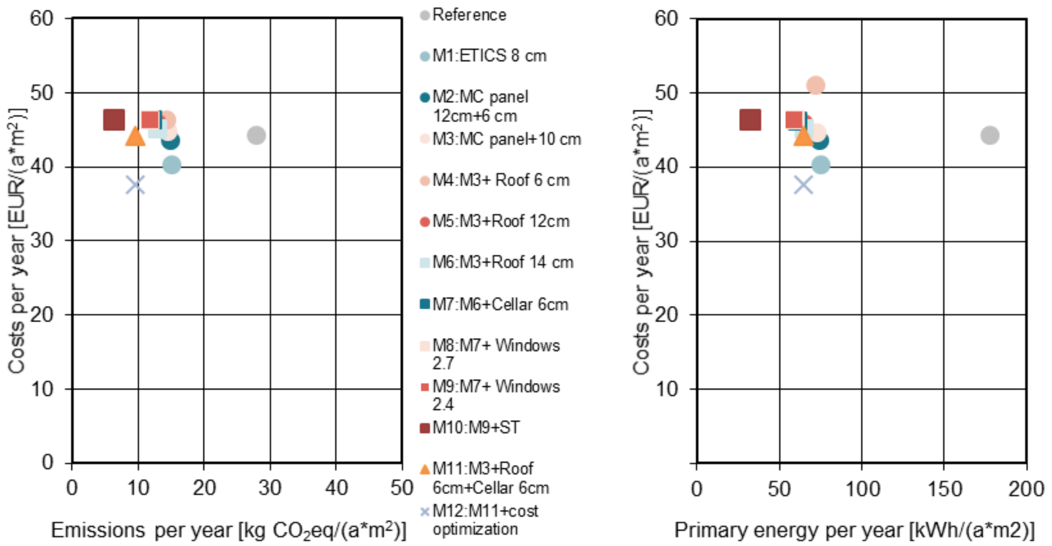
Conventional system



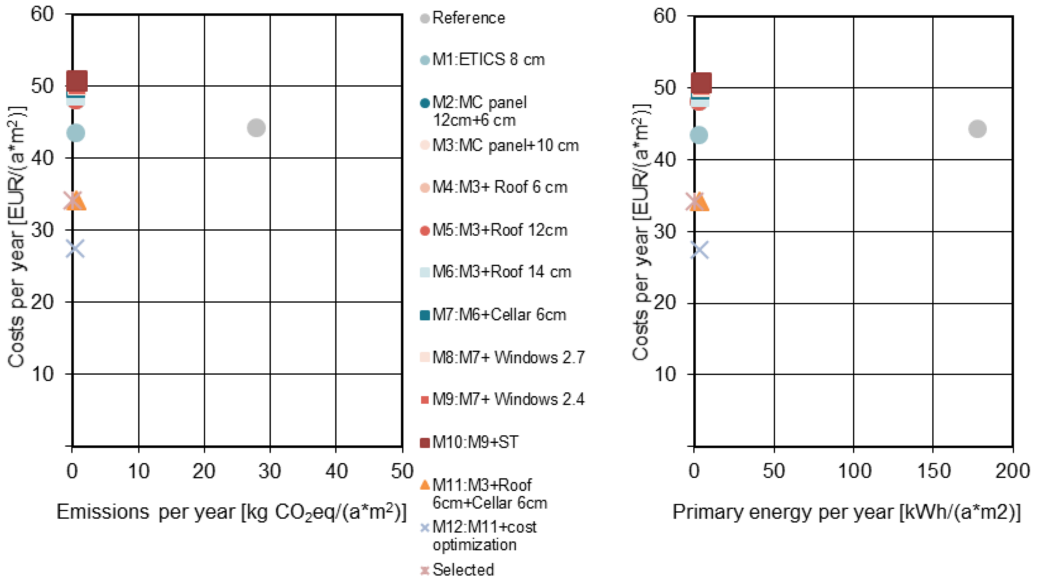
System solution A: Multisplit (heating/cooling) + Gas heater (DHW)



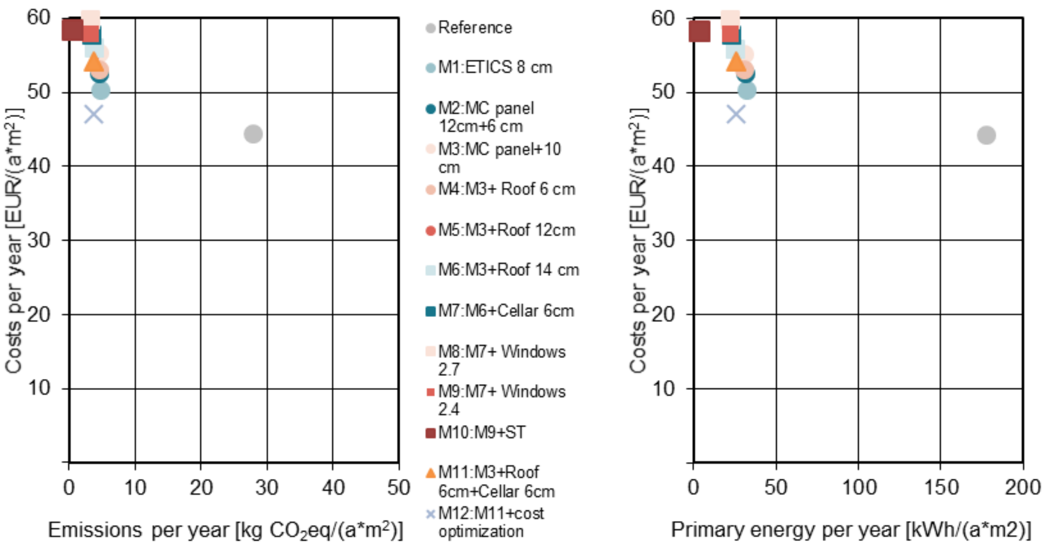
System solution B: Multisplit (cooling) + Gas boiler (heating/DHW)



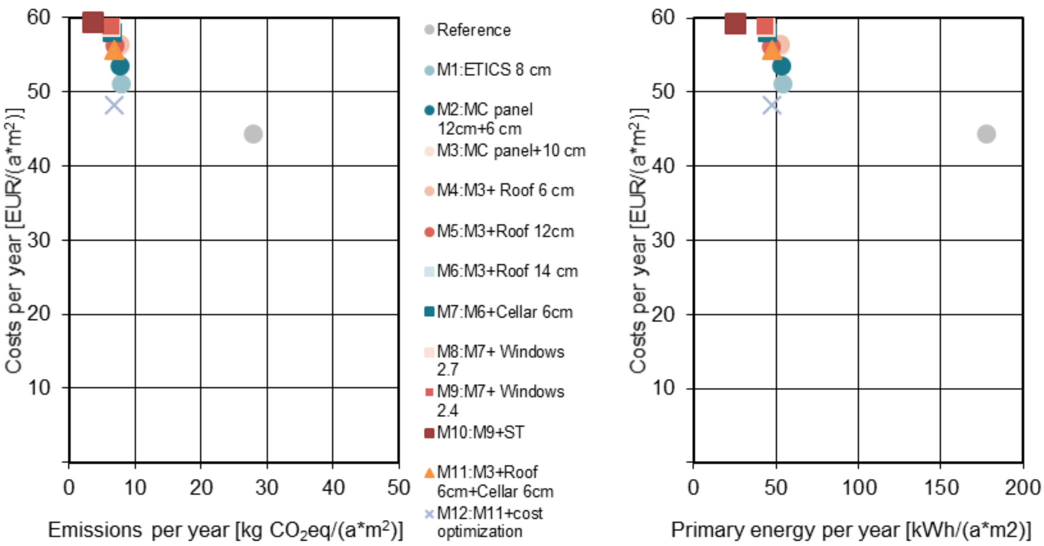
System solution C: Multisplit (cooling) + Biomass boiler (heating/DHW)



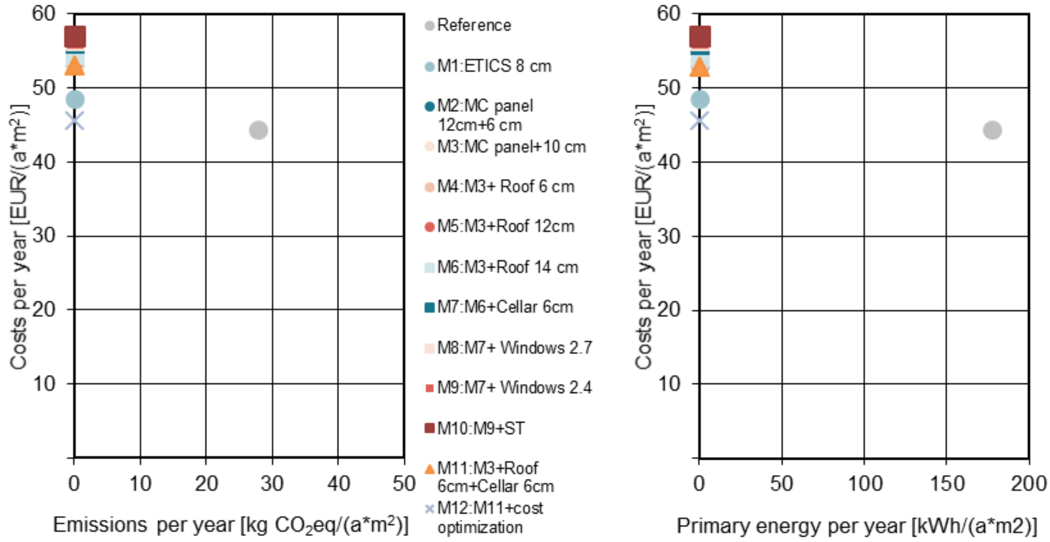
System solution D: Heat Pump + PV system



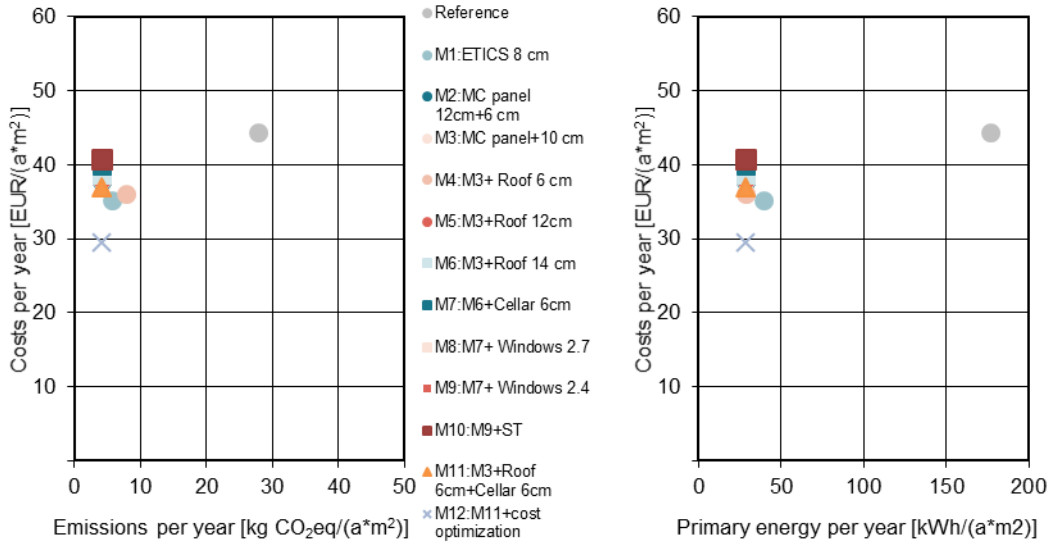
System solution E: Heat Pump



System solution F: heat pump + PV system towards zero



System solution G: Multisplit + Electric Boiler (DHW)+PV system towards zero+ ST



Summary

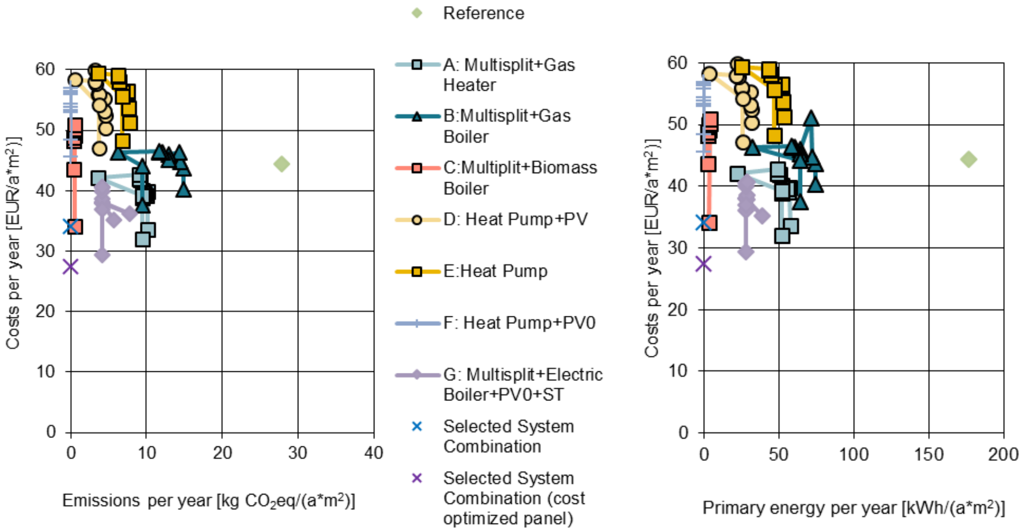


Figure 4 - Average annualized costs of renovation measures per system solution

4.2 Discussion of the assessment results without considering the embodied energy and embodied carbon emissions of the materials

In general, the most significant measures that improve the energy performance of the building are the replacement of the systems and the addition of insulation to the exterior walls. As additional measures in the renovation packages, adding insulation to the roof, to the cellar, as well as improving the energy performance of the windows, do not contribute to the cost effectiveness of the package, i.e., they are measures that allow achieving lower energy consumptions, but with an increase in the global costs. Currently, the developed prefabricated panel also 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 packages that include this panel. However, according to the manufacturer, whenever the prefabrication system is optimized (which will occur after the renovation of the reference building), the costs of the panels will become much more attractive (a reduction of about 70% compared to the actual costs can be achieved). To elucidate the impact that an optimized production line may have in the global costs, calculations for a renovation package considering cost optimization (M12) were also performed considering a 73% reduction in terms of costs for the prefabricated panel, as shown in Figure 3 (where every M12 renovation package is marked with a bold black outline).

The position of these renovation packages in relation to the cost effectiveness threshold in Figure 3 is demonstrative of the positive effect of the optimization in costs concerning the production line of MORE-CONNECT prefabricated panel. Furthermore, with respect to the 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. 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. In addition to a potential production cost optimization, these characteristics make the prefabricated model an attractive solution to renovate the building.

When analysed individually, renovation package M10 (M9+ Solar Thermal) is the renovation package that consistently allows reducing primary energy more significantly (this package involves the application of the MORE-CONNECT prefabricated panel on the walls, insulation of the roof and of the cellar floor and also replacement of the windows), but presents a noteworthy increase in the global costs. The cost-optimal solution is the renovation package M12, which is the same as M11 (Selected Renovation Package), but considering optimized costs for the production of the prefabricated panel. This solution leads to a primary energy value of 0.00 kWh/m².a, and to an emissions production of 0.00 $kgCO2_{eq}$ / (m².a), because both heating and DHW energy needs and related emissions are totally suppressed by the biomass boiler. The renovation package M12 includes the prefabricated module for the walls associated with a 10 cm layer of mineral wool applied between the module and the existing wall. M12 also includes a 6 cm layer of polyurethane on the roof, and a 6 cm layer of extruded polystyrene in the cellar ceiling. As explained before, the prefabricated module is associated with a layer of mineral wool to be applied between the panel and the existing façade. Two different thickness regarding this layer of mineral wool were tested. In this sense, when comparing renovation package M3 (prefabricated panel with 10cm layer of mineral wool) with renovation package M2 (prefabricated panel with 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 (multisplit + biomass boiler) and F (heat pump and PV0) allow reaching higher reductions regarding both carbon emissions and primary energy, allowing a 98% reduction. In relation to the group of graphs shown in figure 4, it is important to clarify that the Selected System Combination (Selected Renovation Package + biomass boiler) is represented by System Solution C (multisplit + biomass boiler) in order to compare the effect of the cooling energy needs in calculations. If the cooling energy needs are not considered, the reductions on the primary energy needs may reach 100%. All renovation packages considering the conventional system (electric heater + multisplit + gas heater), system solution A (multisplit + gas heater) and system solution G (multisplit + electric boiler + PV0 + ST) are cost effective. In comparison, when system solution B (multisplit + gas boiler) is taken into account, only M1 (ETICS 8cm) and M12 (M11 with cost optimization) are clearly cost effective.

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. However, these three system solutions also allow significant reductions of the primary energy use and of the carbon emissions, sometimes reaching values 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 (heat pump + PV0). Globally, the Selected System Combination (M12 (M11 with panel production cost optimization) + biomass boiler) is the best renovation solution concerning the costs among the investigated renovation packages and has the advantage of reaching zero carbon emissions and zero primary energy consumption, taking in account that cooling energy needs are not considered.

4.3 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. fibbers) 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.

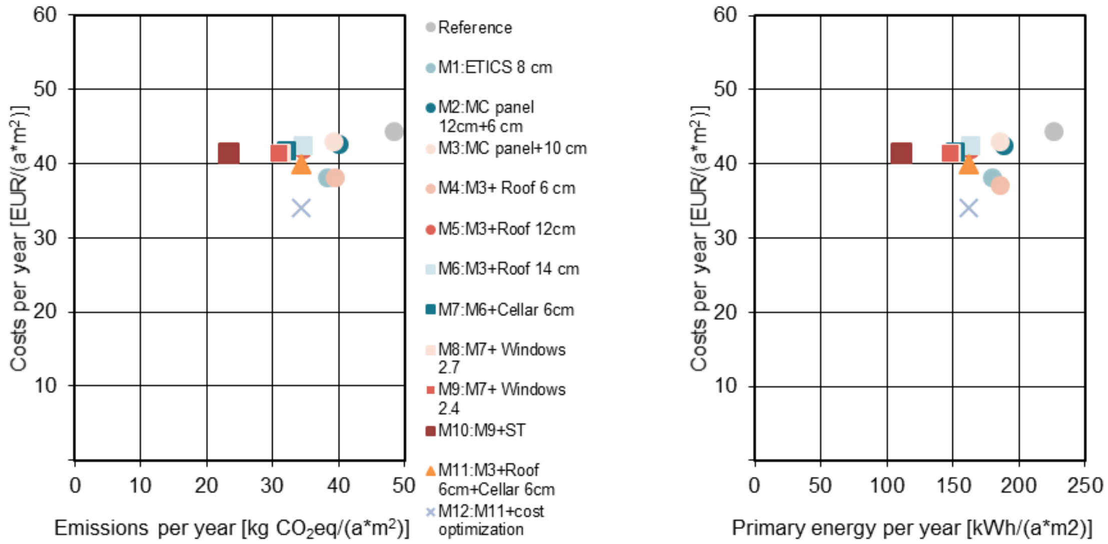
In addition to these factors, most of the chosen materials are non-toxic and inert.

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 combinations of renovation packages and system solutions.

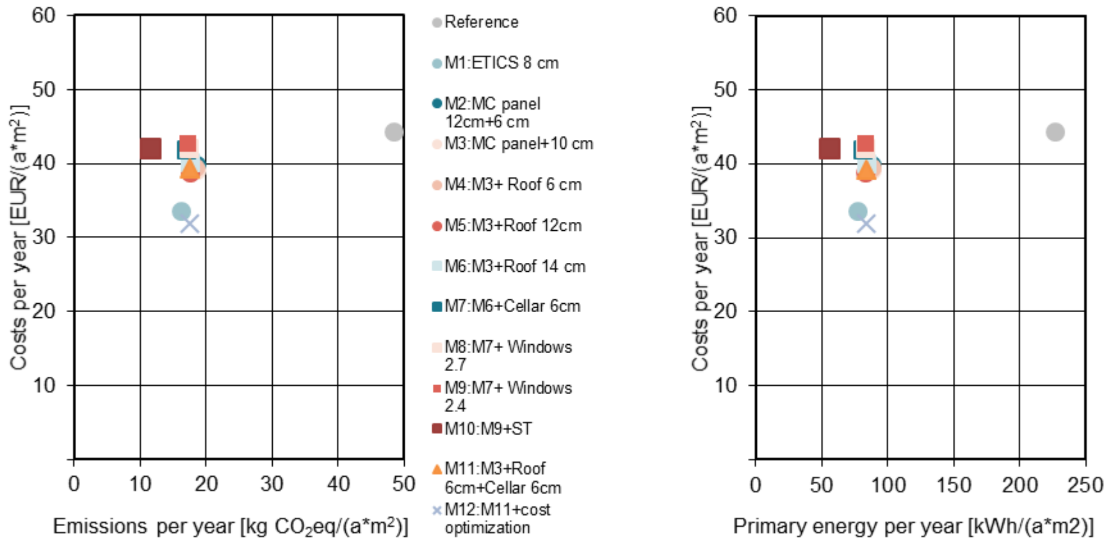
4.4 Results including the embodied energy and embodied carbon emissions of the materials used

Figure 5 shows a group of graphs presenting the results for the renovation packages combined with different system solutions, including the embodied carbon emissions and the embodied energy of the materials used, calculated according to the methodological framework for the selection of favourable concepts for the reference building [2].

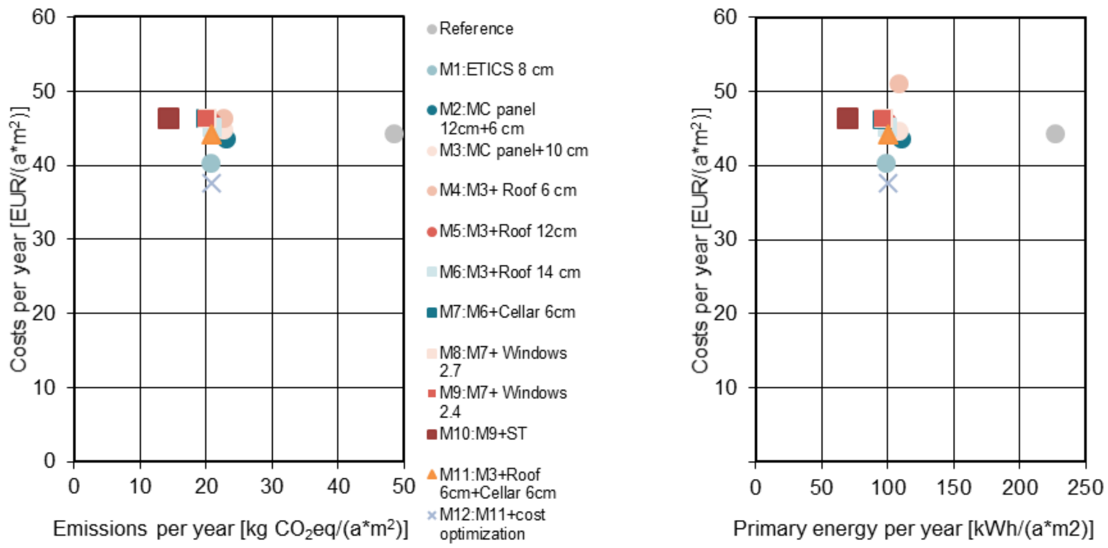
Conventional system



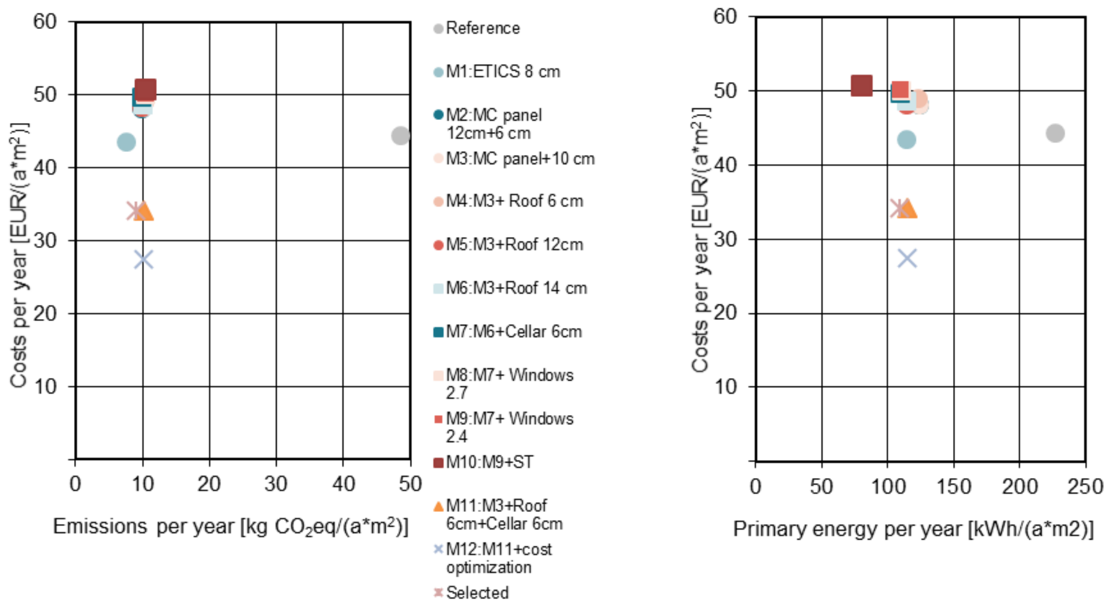
System solution A: Multisplit (heating/cooling) + Gas heater (DHW)



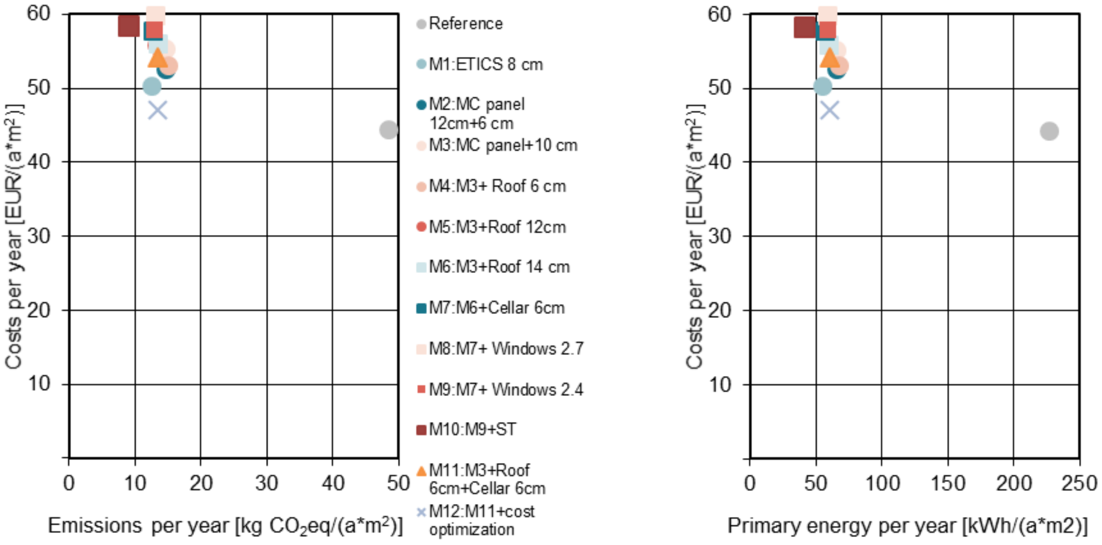
System solution B: Multisplit (cooling) + Gas boiler (heating/DHW)



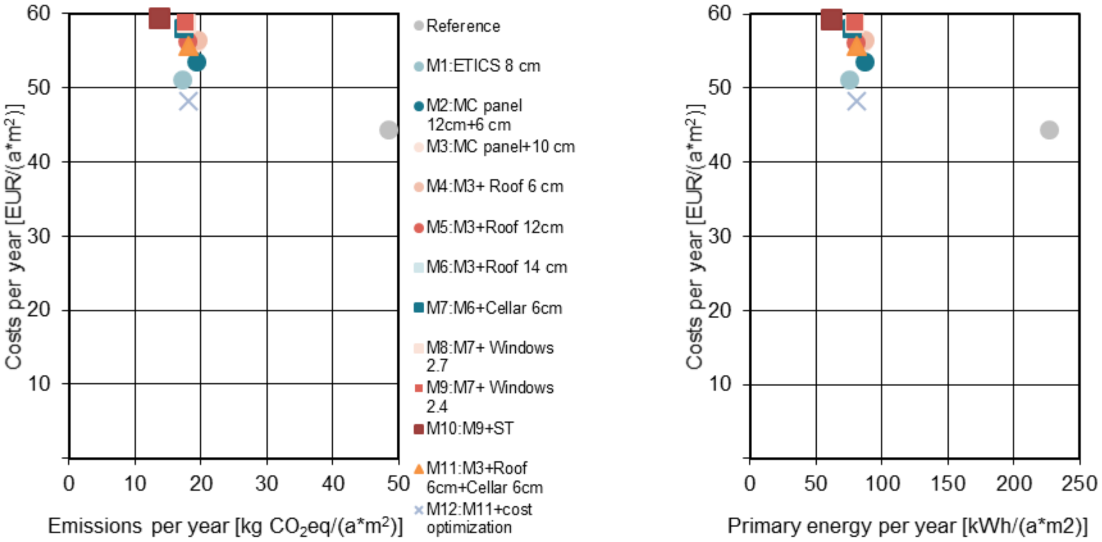
System solution C: Multisplit (cooling) + Biomass boiler (heating/DHW



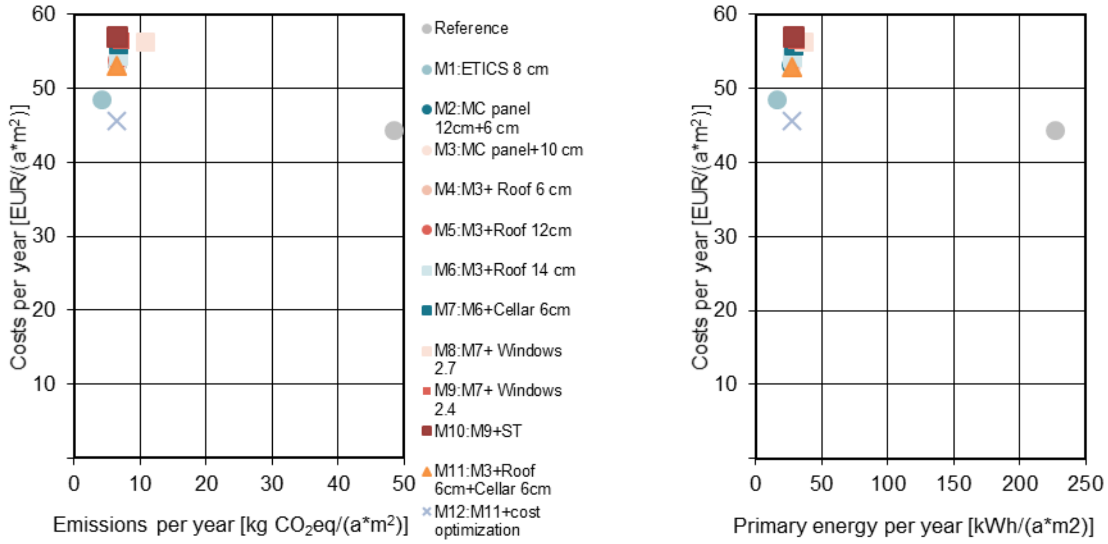
System solution D: Heat pump + PV system



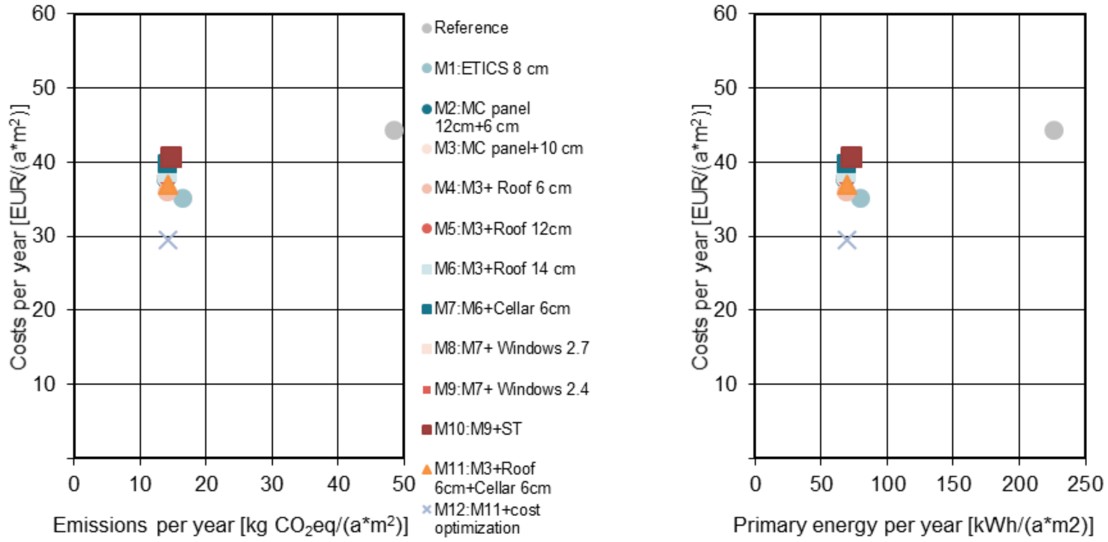
System solution E: Heat pump



System solution F: Heat Pump + PV system towards zero



System solution G: Multisplit + Electric Boiler (DHW)+PV system towards zero+ ST



Summary

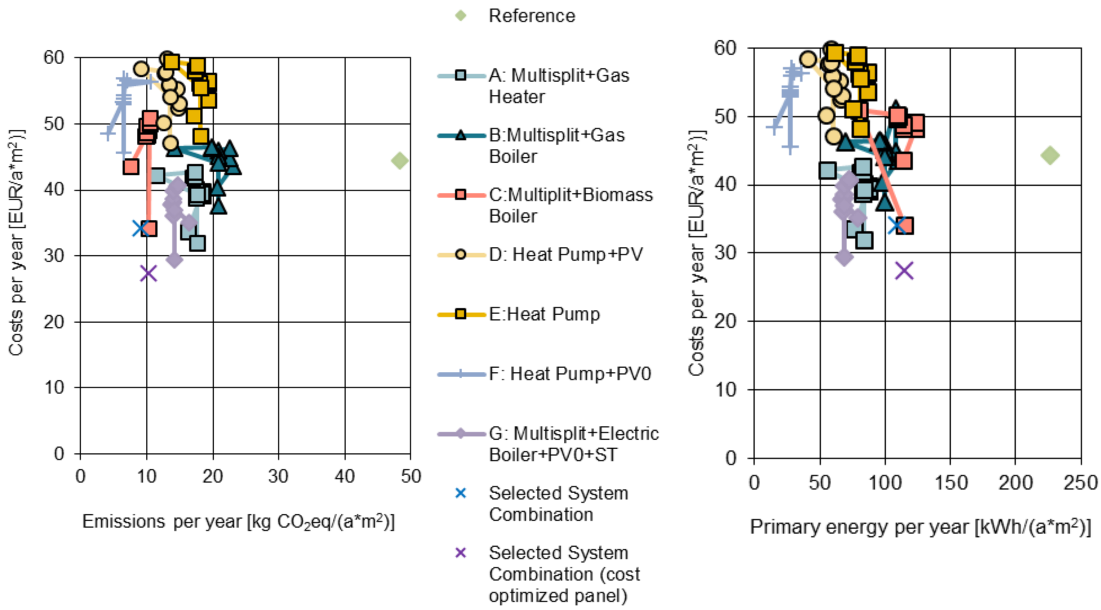


Figure 5 - Average annualized costs of renovation measures per system solution, considering embodied energy and carbon emissions

4.5 Discussion of the assessment results considering the embodied energy and the embodied carbon emissions of the materials

The consideration of the embodied carbon emissions and embodied energy of the materials used in the calculations increases the energy and carbon emissions of each renovation package. The most notable increases were observed in the combination of system solution C (Multisplit + Biomass Boiler) with the different renovation packages. For this system solution, and regarding carbon emissions, the values increase significantly. As an example, calculations for the renovation package M8 (M7 + Windows 2.7), which originally led to a value of 0.5 kgCO2eq/(a.m²), now show a value of 10.4 kgCO2eq/(a.m²). Similarly, in terms of embodied primary energy, the increase is also relevant. For example, the renovation package M3 (prefabricated panel + 10cm mineral wool) led to a value of 123.2 kWh$_{PE}$/m².a when the embodied energy is considered, and originally showed a value of 2.9 kWh$_{PE}$/m².

System F (heat pump + PV) also leads to significantly higher values of energy and carbon emissions when compared with the previous calculations (no embodied energy and emissions considered) and this increase can be associated to the size of the photovoltaic system. The amount and size of the system and its components are the major causes of the increase observed in system G, which considers a significant number of PV and solar thermal panels, in addition to a multisplit system and an electric boiler.

Despite the observed increase of the values concerning carbon emissions and total primary energy, in general terms, the relation between combinations of system solutions and renovation packages remain identical, as well as the comparative position of the renovation packages in relation to the reference situation. In other words, a renovation package combined with a specific system solution that was considered cost-effective in the first calculations will also be cost-effective when the embodied energy and emissions are considered in these calculations. Accordingly, the cost optimal combination of the renovation package with the system solution remains the Selected System Combination (M12 (M11 with cost optimization) + biomass boiler).

5 Conclusions

Based on the assessment carried out, the favourable concept for the renovation of the envelope of the building does not change when considering the embodied energy and embodied carbon emissions of the materials used, despite the increase observed in values of primary energy and carbon emissions

Without considering the embodied energy and for the envelope, the renovation package that consistently allows the highest reduction (86% in average) of the energy needs in all the analysed systems is M10 (M9 +ST). It includes the prefabricated module together with a 10 cm layer of mineral wool applied in the interface between the panel and the existing wall. In addition to this, there is also a 14 cm layer of mineral wool on the roof and a 6 cm layer of extruded polystyrene in the cellar ceiling. For the windows, the solution includes the replacement of the windows by others with a PVC frame and double-glazing with and U-value of 2.4 W/m^{2o}C. This solution leads to a significant reduction of the energy needs and CO_2 emissions but it is not very attractive in terms of costs.

In the same situation, the cost-optimal renovation package is the M12 package, which includes the prefabricated MORE-CONNECT module, associated with a 10 cm layer of mineral wool applied in the interface between the panel and the existing wall. It also includes a 6 cm layer of polyurethane on the roof and a 6 cm layer of extruded polystyrene in the cellar ceiling. Renovation package M12 assumes that the production costs of the panel are already optimized and that a production costs reduction of 70% was achieved.

Regarding the systems, and without considering the embodied energy of the materials used, the most favourable system that allows achieving the goals of the project (at least an 80% energy reduction), is the Selected System Combination that considers a biomass boiler. Renovation packages calculated considering the System Solution C, which also uses a biomass boiler combined with a multisplit, also show relevant results in terms of primary energy and carbon emission reduction. Based on the investigated concepts, this type of heating system is 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), but at a very high cost. However, it is worth highlighting that system solution G also allows significantly reducing primary energy (in average 84%) while still maintaining the cost effectiveness.

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;
- 6 cm added insulation to the roof and cellar;
- Biomass boiler for heating and DWH.

Considering the embodied energy and embodied carbon emissions of the materials, the results for the envelope renovation packages do not suffer significant changes. Generically, renovation package M12 (M11 with cost production optimization) is the cost-optimal solution for the envelope.

For the systems, the inclusion in the calculations of the embodied energy and embodied carbon emissions of the materials led to some changes and a significant increase in the values of primary energy and carbon emissions associated to the renovation solutions, particularly in solutions that include renewable energy sources, as in system solutions C, F and G. The analysis was important in terms of determining the impact of these renovation solutions on the global performance.

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