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 reference building

Figure 1. MORE-CONNECT pilot building in Odense, Denmark – before and after renovation.

The building used for the assessment of favourable concepts is a generic building representing a typical WorldWar2 apartment building block in Denmark similar to the Danish pilot project shown on fig. 1 A few characteristics are given below:

- Number of apartments: 24
- The current renovation needs: New windows, ventilation system with heat recovery
- The current heating system is a radiator-based system and the supply is district heating.

1.2 Dimensions and characteristics of the reference building

The following table summarizes the dimensions and characteristics of the reference building – per flat and building:

Parameter	Unit	Data – per flat/building	Parameter	Unit	Data
Building period		1958-1968	Typical indoor temperature	°C	20
Gross heated floor area	m^2	76,5/1836	Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation)	kWh/ ($a*m^2$)	
Wall area (excl. windows)	m^2	28,9/694	U-value wall	W/(m^2*K)	1,1
Roof area pitched	m^2		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	19,1/478	U-value attic floor	W/(m^2*K)	0,4
Area of ceiling of cellar	m^2	18/432	U-value ceiling of cellar	kWh/m^2	0,5
Area of windows to North	m^2	5/120	Energy need for cooling	W/(m^2*K)	
Area of windows to East	m^2	0,8/19,2	U-value windows	Factor	3,1
Area of windows to South	m^2	10/240	g-value windows	W/(m^2*K)	0,75
Area of windows to West	m^2	0,8/19,2	Energy need hot water	kWh/m^2	14
Average heated gross floor area per person	m^2	42,5	Airflow rate	m^3/(h*m^2)	1.15

2 The MORE-CONNECT solution

The general objective of the MORE-CONNECT building renovation concepts is to achieve primary energy reductions of 80%. This target has constituted the framework for the concept development.

The first step of the concept development focus on a generic apartment building in Denmark supplied by district heating. As district heating generally has low energy dependent costs in Denmark (it also has fixed costs, which is not influenced by energy savings) it is hard to show direct cost-efficiency of energy saving measures. For the next step it was decided to conduct the analyses (concept development calculations) for three more heating supply systems:

- Oil furnace
- Heat pump and
- Wood chip boiler

The analysis used as a reference the situation where the costs of an anyway renovation measure with no consequences for the energy consumption were added to the current total running costs of the building. This anyway renovation taken into consideration was:

- Painting of wooden windows every 7th year.

The costs of this painting includes also the need for putting up a scaffold – letting it stay for 10 days and taking it down again. Working with a 30-year time perspective the total costs of this building renovation was calculated to be 3,79 EUR/m²a. When the energy measures considered included the exchange of windows this costs is reduced to 1 EUR/m²a corresponding to the use of scaffolding once for mounting the new windows.

The following energy saving and renewable energy technologies were analysed:

- Additional roof insulation (30 cm)
- Additional façade insulation (10 cm & 20 cm)
- New 3-layer energy windows
- New heat recovery ventilation (HRV) system with good efficiency and additional airtightness of the building (comes at no cost when combined with new windows)
- Solar thermal system (2 m² per apartment)
- Solar PV (5 m² mono-crystaline per apartment)
- Solar PV – (19 m² amorphous per apartment) - one of the Danish MORE-CONNECT technologies is a PV-roofing system meant to replace an existing roof. So, an additional calculation is made with this technology.

3 Investigated renovation packages

For the identification of favourable concepts, an assessment of various possible renovation packages was carried out. The renovation packages are assessed with respect to greenhouse gas emissions, primary energy use, and costs.[1] The technologies considered for the analysis were generic energy measures. In conclusion, the two Danish MORE-CONNECT technologies were considered in particular.

For the pre-selection of favourable concepts, the investigated renovation packages are shown in the following table.

Renovation Package	Description of energy saving measures
Ref	In the reference case, the windows are repainted every 7th year. This measures do not improve the energy performance of the building.
M1	The roof is insulated with 30 cm of mineral wool.
M2	The wall is insulated with 10 cm of mineral wool.
M3	The wall is insulated with 20 cm of mineral wool.
M4	The windows are replaced by 3-layer low energy windows
M5	A balanced mechanical ventilation system with a high efficiency heat recovery is installed combined with new sealing to obtain increased airtightness of the building - HRV
M6	M1+M3+M4
M7	M6+M5
M8	Additionally to M7, 2 m^2 thermal solar collectors per apartment are installed
M9	Additionally to M8, 5 m^2 PV system per apartment is installed

[1] For a description of the assessment methodology, a separate document is available entitled: «Methodological framework and instructions for the selection of favorable concepts for the pilot projects (Task 6.1 part 1)»

4 Assessment of investigated renovation packages and selection of favourable concept

4.1 Overview graphs

For the generic building presented above, the expected impacts of the investigated renovation packages were calculated for four heating systems:

- District heating
- Oil furnace
- Heat pump
- Wood chip boiler

The results are presented below in four sub-paragraphs for each of these heating systems. A couple of calculations of the exchange of the two first of these heating systems with a heat pump system was additionally made to check the result of including this as part of the renovation package concept – see chapter 5.

4.1.1 District heating

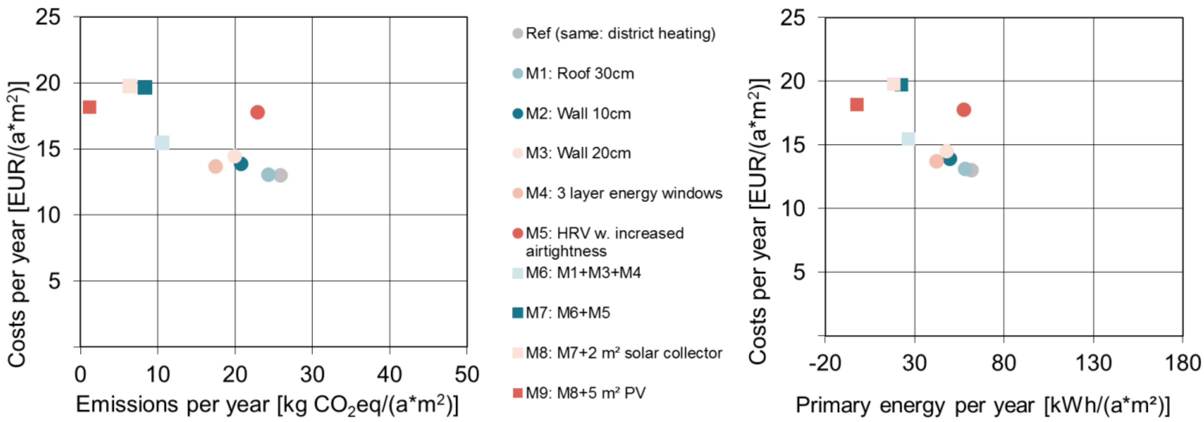

Figure 2 – Cost vs. emissions and primary energy use - district heating

As it appears from the two plots on fig. 2, each individual energy saving technology reduces the CO_2eq – emissions and primary energy consumption and they all increase total costs. Especially, the installation of the heat recovery ventilation system increases costs significantly. This could be a point for discussion as a balanced mechanical ventilation system is generally needed when renovating an existing building, because the existing ventilation systems often do not provide the necessary air-exchange rates to avoid humidity problems such as mould growth, which can cause very substantial costs to the building association. Having this viewpoint, the costs of this particular measure should not be assigned as an energy renovation costs, but as an anyway renovation costs. As this costs is quite considerable – 4,8 EUR/a/m² - this would completely change the picture and make the M9 –solution set cost-effective. Alternatively, newer and cheaper decentral mechanical ventilation system with heat recovery can be considered. This will be done in a sensitivity analysis performed on the final selection of energy renovation concept.

When adding measures it can be seen that emissions and primary energy consumptions are strongly reduced and the total cost increase to about 20 EUR/a/m² when the HRV-system is included. Finally, the PV-system brings the costs somewhat down, but not below the reference costs. The end result is an CO_2eq-emissions at app. 1,1 kgCO_2eq/(a*m²) and a primary energy just below 0.

4.1.2 Oil furnace

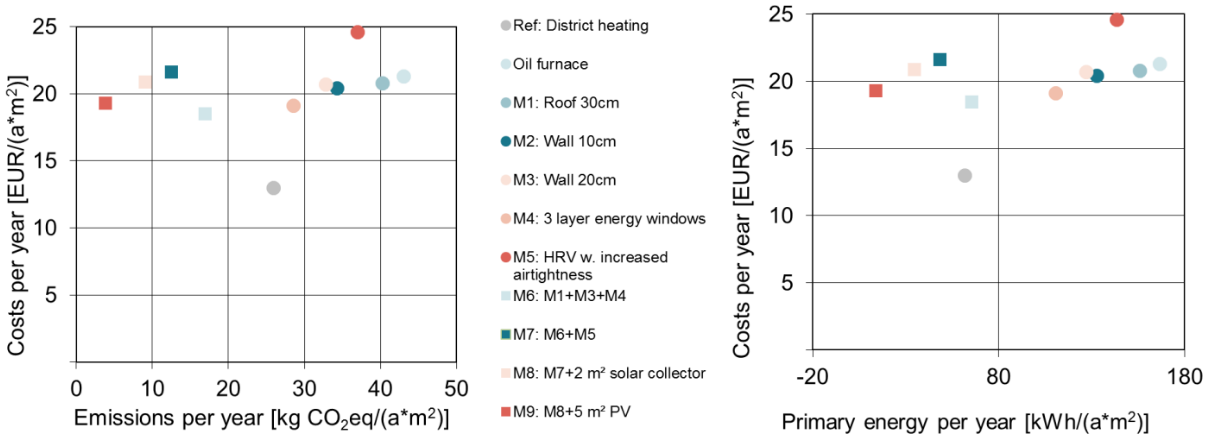

Figure 3 – Cost vs. emissions and primary energy use – oil furnace

The oil furnace case shows much higher initial costs than for district heating which improves the cost-efficiency of both the individual energy saving measures and of the total concept solution sets. Still, however, the mechanical ventilation with heat recovery as individual measure increases the total costs. The combined energy concept package reduces the energy consumption down to 14 kWh/m²a, which is below the NZEB level accepted in Denmark. The CO_2eq is correspondingly reduced down to 3,8 kg CO_2eq/m²a. Total costs is reduced from 21 EUR/m²*a to 19 EUR/m²*a making the total energy concept cost-efficient. Again – considering the HRV-system as an anyway measure or using an alternative cheaper system will reduce the total cost considerably – making this renovation very cost-efficient.

4.1.3 Heat pump

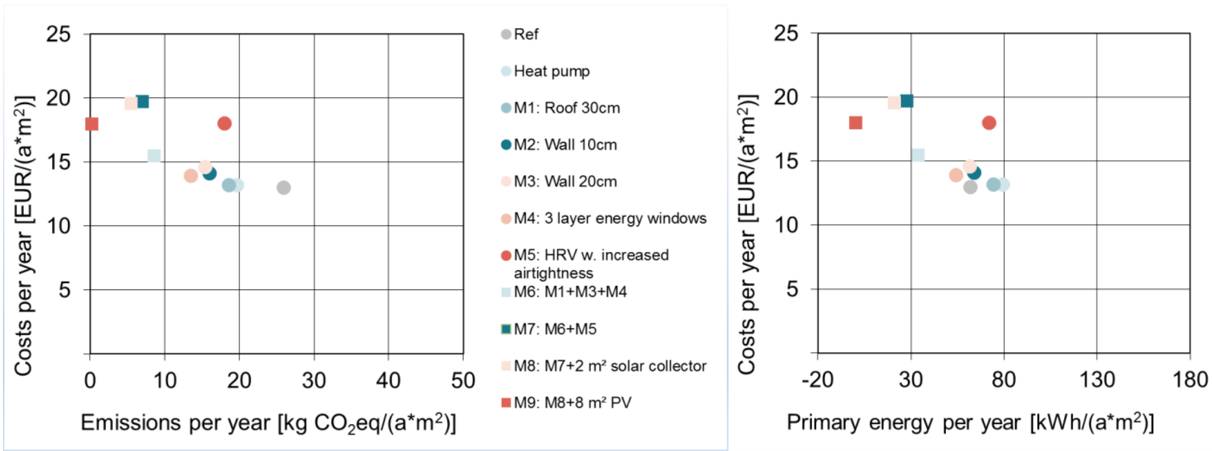

Figure 4 – Cost vs. emissions and primary energy use – heat pump

This case is comparable to the district heating case – the initial starting costs are almost the same and the pattern is much like that for district heating. It should be noted that the calculations do not account for different electricity prices between using the PV-generated electricity directly and "storing" it on the grid. In an actual energy renovation case, this would need to be accounted for – the most preferable situation is obtained when all the PV-electricity can be used directly or stored in an on-site battery. For both GWP and non-renewable primary energy consumption the concept M9 reaches approximately 0, but at higher total costs: 18,2 EUR/m²*a compared to 13,2 EUR/m²*a.

4.1.4 Wood chip boiler

As seen in figure 5 the total costs, primary energy consumptions and greenhouse gas emissions are considerably lower for the wood chip burner heating supply system than for the other three cases.

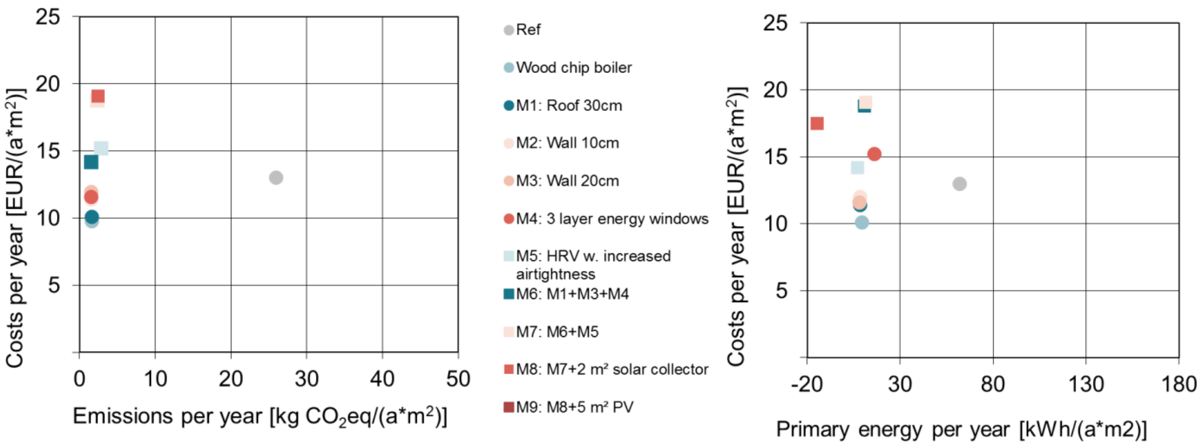

Figure 5 – Cost vs. emissions and primary energy use – wood chip boiler

This makes the analysis of energy renovation measures quite interesting, because not only the total costs increases, so do the primary energy consumption and the greenhouse gas emissions for some of the measures: The new windows and the HRV-system. When looking at the plots in figure 5 it is seen that only the PV – system brings the primary energy and the emissions down. Actually, this is the only system for which the total concept brings the CO_2-emission below 0 (-2,3 $kgCO_{2eq}$/m²*a). However, for all cases the final total costs are higher than the starting point. From a pure financial viewpoint this means that a building heated with a wood chip boiler should not be energy renovated! However, including the value of co-benefits as described in paragraph 4.3 changes this conclusion – see 4.3.

4.2 Discussion of results from assessment

The calculations presented in the previous paragraph show that the MORE-CONNECT energy saving goal of 80% can be reached for all four heating systems. The final total costs are reduced for one of the heating systems – the oil burner. Table I presents a summary of the total costs and the non-renewable primary energy consumption for the concept M9 in each of the 4 cases compared to the reference situation.

Table I – Total costs and final primary energy consumption. Summary of the results.

Heating system	Reference costs, EUR/(a*m²)	Concept M9, EUR/(a*m²)	Reference primary energy consumption, kWh/m²a	Concept M9 primary energy consumption, kWh/m²a
District heating	13	18,2	61,9	-3
Oil furnace	21,3	19,3	167	14
Heat pump	13,2	18	79	0,2
Wood chip burner	9,8	17,5	9,7	-14,8

The differences between reference total cost and total costs for the concept M9 in Table I should not be seen isolated, but in relation to the rent and the improved value of living in an apartment. The typical rent for an apartment of 76.5 m² in Denmark amounts to 126 EUR/(a*m²), so the reference energy costs is in the order of 10% of the rent. The variations in total costs due to the energy renovation are – seen in this perspective - relatively small – around 4-5% for the three first and most common cases. The general conclusion is that for a 5% increase in rent one can reach 80% reduction in non-renewable primary energy use or better.

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

Embodied energy was included in the calculations of CO_2-emissions and primary energy use.

Reuse of materials or indoor environment were not taken into account. However, an energy renovation results in other benefits for the tenants of a building than saving energy and reducing CO_2-emissions. Newer research (IEA EBC) points at so-called co-benefits, such as improved indoor air quality, improved thermal quality and improved use of space to mention a few. The financial value of these co-benefits are hard to identify precisely, but it is useful to illustrate the potential of this in a couple of examples.

If the co-benefit for the tenants of the renovated apartments due to the improved indoor climate – thermal and air quality – is estimated to 5%, this corresponds to a theoretical value for rent increase of app. 6 EUR/(a*m²), which makes even the three first of the above renovation concepts financially attractive. Due to the insulation of the external façade (wall and windows), the external surfaces become warmer and therefore people can stay and furniture can be placed near both walls and windows. This means in practice that the useful apartment area increases, which may also be taken into account – if estimated to app. 0,5 m around the perimeter – it will correspond to a housing rent value of 29 EUR/a*m². Taken this into consideration makes these measures very economically attractive for all heating systems.

4.4 Lessons learnt based on pilot project

The energy saving technologies developed in Denmark for the MORE-CONNECT project is a robot, which can work onsite on large areas for example applying external insulation to an external wall and a PV-roofing system. The external wall insulation installed by a robot has the same thermal properties as the insulation used for the analyses above, but the price has not yet been proven significantly lower than that of a conventionally applied insulation (this is expected to change in the future – see 4.6). So, the use of this development doesn't change the calculation results right now. However, the idea of the PV-roofing system, which was demonstrated at the Danish pilot project does have a cost-efficiency implication. Especially, if the whole roof is covered with the PV-cells as is the basic idea of the producer – Ennogie. This is assumed for the finally selected concept – see 4.5.

4.5 Finally selected concept

. For the finally selected favourable concept, the whole roof is covered with PV. This means that the area of PV will be app. 19 m² per apartment. This is a lot more than the 5 m² used in the analysis for the concept development above – on the other hand, the use of a complete PV roof means that there is no room for the thermal solar collectors. The plots presented in figure 6 shows the results of this change of the last concept – M9 – pointed out with the arrow on the plot to the left.

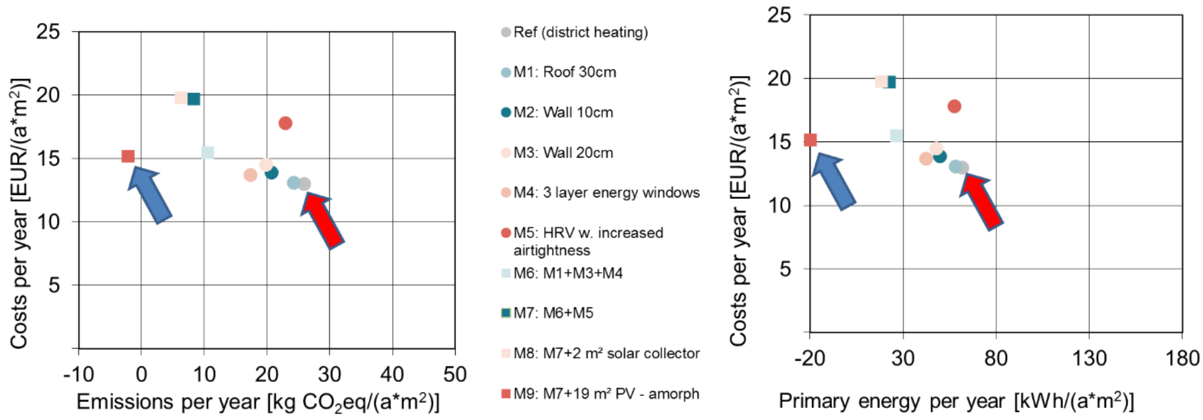

Figure 6 – Cost vs. emissions and primary energy use – district heating with PV-roof

When re-calculating the costs, greenhouse gas emissions and primary energy consumption as shown in figure 6 the result is that the total cost is reduced in comparison with the case presented in 4.1.1. In this scenario the MORE-CONNECT PV-roof replaces another roof installation, the cost of which is therefore deducted and the cost of the PV-roof is assumed to be 1075 EUR/kWp. Alternatively, the costs related to a roof replacement could be included in the reference costs, and the full costs could be indicated in the renovation package M9) – the end result would be the same for comparison with the reference case. Both the greenhouse gas emissions and primary energy consumption become negative. The installation of this new PV-system therefore has the result that the energy renovation of the buildings will go beyond_the nZEB goal - the renovated buildings become plus-energy buildings. This adapted version of concept M9 is considered to be the finally selected favourable concept.

4.6 Sensitivity analyses

The final cost of the selected favourable concept is, however, still higher than the cost for the reference case. As mentioned I 4.1.1 one of the reasons for this is the high cost for the mechanical ventilation system with heat recovery. Implementing newer, simpler systems with the same heat recovery efficiency and electricity consumptions as the conventional systems this cost can be brought considerable down. In the graphs presented in figure 7 the assumption is that the costs can be halved. As is seen from the graphs this brings the total costs per year for the final concept, M9, down to the same level as the costs for the reference case. In other words: Below zero emissions and primary energy use can be reached in a cost-efficient way.

Another relatively high cost is the cost of wall insulation. It is assumed that within a few years the use of the robot solution developed within the MORE—CONNECT project the installation costs of external wall insulation can be brought considerable down. For the sensitivity analysis made here, it is assumed that the use of the robot can bring the total costs down with 30%. The result of using this assumption is shown in figure 8.

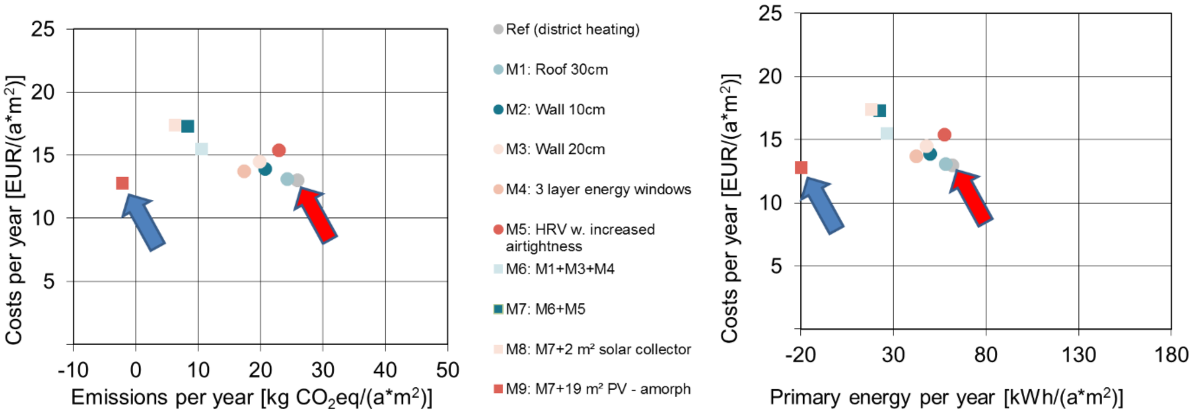

Figure 7 – Cost vs. emissions and primary energy use – district heating with PV-roof and new cheaper HRV – systems.

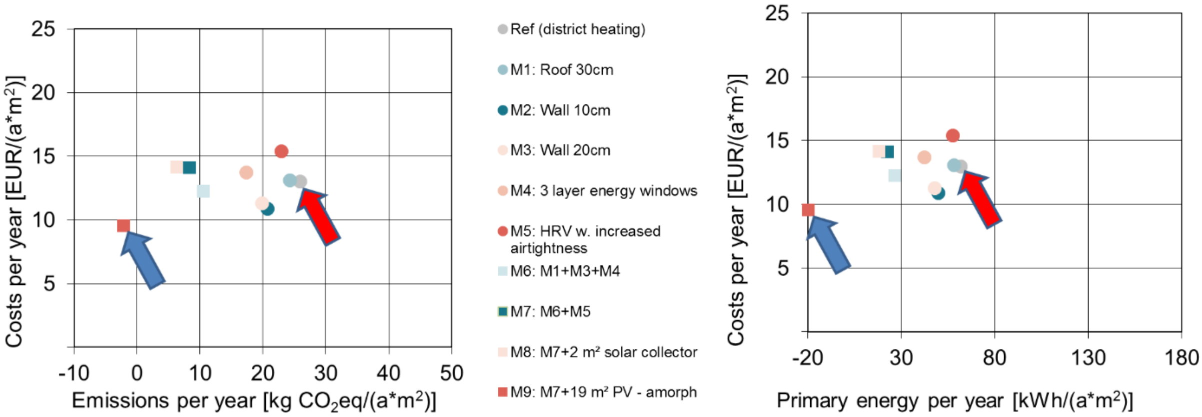

Figure 8 – Cost vs. emissions and primary energy use – district heating with PV-roof, new cheaper HRV – systems and external insulation implemented by robot at 30% reduced cost.

From figure 8 it appears that this final assumption in combination with the reduced price for the mechanical ventilation with heat recovery results in total costs that are considerable lower than for the reference case. – between 20 and 25% lower.

5 Conclusions

The energy renovation concept development calculations performed for the 4 heating systems shows that an energy renovation down to nZEB-level can be reached in all cases. For the case with an oil burner as heating supply system this can be done directly cost-effectively – that is with the same or reduced total costs compared to the reference case. However, when taking into account a **financial value of co-benefits** from the energy renovation all cases are cost-effective.

The change of heating system was generally not considered as one of the renovation technologies to be part in the concept development. The main reason for that is a large majority of apartment blocks in Denmark is heated with district heating (90%) and the replacement of that with another heating system is not likely to become cost-effective. However, two test calculations were made for the district heating system and the oil furnace system. For these a change to a heat pump system was added to the concept M9 to check the above reasoning. The result is that for both cases the total costs increase slightly – with 1 EUR/(a*m²) for the DH system and 0,5 EUR/(a*m²) for the oil system and both the CO_2-emissions and the primary energy become close to 0. <u>This means that this exchange should be considered in each individual case</u> <u>– most obviously when the existing oil furnace needs to be renovated anyway.</u>

The sensitivity analysis carried out in the end shows that with two reasonable assumptions for cost reduction of the mechanical ventilation system with heat recovery and the cost of applying 20 cm of external insulation using a robot, the total costs of the final renovation concept with below zero emissions and non-renewable primary energy consumption can brought be down significantly, with total cost being reduced by 20-25% compared to the reference case.