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ScienceDirect

Energy Procedia 140 (2017) 240–251

Energy Procedia

www.elsevier.com/locate/procedia

AiCARR 50th International Congress; Beyond NZEB Buildings, 10-11 May 2017, Matera, Italy

Energy saving concept development for the MORE-CONNECT pilot energy renovation of apartment blocks in Denmark

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Abstract

The European Horizon2020 project MORE-CONNECT on prefabricated deep energy renovation of residential dwellings also covers pilot demonstration projects, which are to be carried out in six of the participating countries. For each country a unique, climate specific concept development analysis is carried out. The concept development follows the MORE-CONNECT methodology and thus aims towards a Zero Energy Building (ZEB) level or if cost limitations require nearly Zero Energy Building (nZEB). For the Danish situation, this means that the energy requirement for heating purpose is to be brought down from around 100 kWh/m² to below 20 kWh/m². As the pilot project has not yet been identified, concept development calculations has been conducted for a generic building. The technologies to be considered for this energy renovation are: Insulation of the façade, insulation of the roof, low-energy windows, heat-recovery ventilation, solar domestic hot water and a PV-system. Within the MORE-CONNECT two technologies are under development in Denmark. The first is a new PV-roof solution in which the PV-cells are fully integrated in the roofing elements. This PV-roof can be fitted into any roof surface shape. It can also be constructed as a PVT-roof connected to a heat pump for heating purposes. The second technology under development is 3-D finishing of a new layer of façade insulation by an industry robot. When an insulation layer has been placed on any given façade a finishing layer of plaster can be added and finished with any desired patterns or painting.

The paper presents the present stage of the concept development work and is a continuation of the first concept development analysis presented at the SBE conference in Tallinn in 2016.

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings.

Keywords: building energy renovation; concept development; nZEB; primary energy; CO2-emission; total costs

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Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings
10.1016/j.egypro.2017.11.139

1. Introduction

With 25% of the EU´s energy consumption, energy savings in the residential building sector have been identified a key to achieve the EU's ambitious 2030 climate protection targets. A significant reduction of the carbon footprint requires the immediate implementation of a coherent nearly zero energy building (short: nZEB) strategy in the residential building stock.

Since the introduction of the EPBD numerous EU research projects have been creating a solid basis of innovative technology solutions for deep energy renovation of multi-family buildings by focusing on technology development, life-cycle cost assessment and demonstrations.

However, the rate of nearly zero energy renovation in the building sector is far beyond the necessary level to reach the overall CO2-emission reduction goals. In-stead of a required refurbishment rate of at least 2% only approximately 1% of the building floor space is currently undergoing energy renovation; unfortunately, in many cases building owners restrict their ambitions to the implementation of mini-mum energy requirements.

A deep energy renovation can also be referred to as a renovation leading to a near Zero Energy Building, which is the term used in the context of the EU MORE-CONNECT project [2]. This project includes demonstration of the developed technologies with six pilot projects in the different geo-clusters represented within the project. The goals and objectives of the MORE-CONCEPT project and the concept development methodology for the pilot projects are described in the following paragraphs.

1.1. Goals and quantitative objectives of the MORE-CONNECT project

The overall qualitative technological goals of the MORE-CONNECT project are:

1. The development of cost optimal deep renovation solutions towards nZEB concepts with the possibility of extra customize (cost-effective) features
2. The development and demonstration of prefabricated multifunctional modular renovation elements - in series of 1 - concepts, in a mass production process
3. The development and demonstration of new fully automated production lines for multifunctional modular renovation elements

The related quantitative objectives of MORE-CONNECT are:

4. Deep renovation toward NZEB, with a basic reduction of the primary energy consumption by at least 80 % compared to the original consumption.
5. New fully automated production lines with a cost/output optimization leading to >35% improvement compared to the traditional construction realization process.
6. Construction site workload reduced to less than 10% of the total workload of a retrofit compared to traditionally more than 50%.
7. Total installing time on site of with a maximum of 5 days with a final goal of 2 days.
8. Return of investment of less than 8 years for the end-user.
9. Construction failure costs reduced to less than 5% compared to the traditional 15 to 20%.

The work described in this paper relates to the first qualitative and the first quantitative objectives and aims at answering the question: How should a cost optimal deep energy renovation concept that reduces the primary energy consumption by 80% be put together out of the possible relevant energy saving and renewable energy technologies for the pilot buildings in question? The present paper accounts for a follow-up analysis to the first analysis carried out in the spring of 2016 and presented at the SBE conference in Tallinn [4].

1.2. Methodology

A methodological framework for the selection of favorable concepts has been developed for the MORE-CONNECT project. This methodology uses total energy costs, primary energy and CO_2-emissions as main parameters for the analysis of different concepts.

The total costs include the following elements:

- Initial investment costs
- Replacement costs for the replacement of building elements within the evaluation period
- Energy costs, including existing energy taxes and CO_2-taxes
- Maintenance and operational costs

The life-cycle cost and cost effectiveness calculations have to be carried out either with the annuity method or the net present value (NPV – discounted cash flow) method. When total costs of an energy renovation technology or a complete concept has been found, it is presented in graphical plots against the corresponding greenhouse gas emission (GWP) and primary energy consumption. From these plots it is possible to identify the cost optimum and cost efficient concepts, which satisfy the overall MORE-CONNECT goal.

This methodology accepted for the MORE-CONNECT project is based on a methodology developed for an international cooperation project under the IEA EBC programme [3] and [5].

1.3. Anyway renovation

Buildings usually undergo major renovation for reasons other than energy use reduction. In the process of maintaining buildings, necessary renovation comes up. This may be because of necessary repairs or building updates to keep them fully functional or in line with the needs and expectations of the people who use them. It may also be because of excessive energy use, but this is then often combined with poor indoor climate and thermal and/or air quality issues. The most common rea-sons include:

- Extension of the useful building life requiring overhaul of its structure, internals partitions and systems.
- Repurposing of the building, e.g. renovation of old warehouses into luxury apartments
- Bringing the building into compliance with new or updated codes.
- Remediation of environmental problems (mold and mildew) and improvement of the visual and thermal comfort and indoor air quality,
- Adding value to increase investment (increasing useful space and/or space attractiveness/quality) resulting in a higher sell or lease price.

Energy related reasons do sometimes come into play. In this case, high energy-costs are often related to poor indoor climate (thermal and/or air quality issues).

When a necessary (anyway) renovation is due it is very important to analyze the possible energy saving measures that can be implemented along with this renovation and select the measures based on a thorough evaluation.

Any building owner must evaluate the revenue of the total investment in the renovation and generally, it is required that the energy saving measures return the investment. When making this analysis the costs of the necessary (for other reasons than energy savings) renovation – sometimes referred to as anyway renovation – should be deducted first.

2. Analysis tool – ASCOT

The ASCOT tool is a monthly calculation tools that in one step produces:

- Life-cycle cost (LCC) results: investment cost, Euro, total costs, Euro/a/m² and

- Life-cycle environment impact assessment (LCA or LCIA) results: global warming potential (GWP): kg $CO_2eq/a/m^2$ and
- Primary energy savings, $KWh/a/m^2$.

The tool has been described in [1] and in [4].

3. Basic assumptions for the analyses

3.1. Analyzed building type

When the first analyses were made, it was planned that the Danish MORE-CONNECT pilot project should be a renovation of three specific apartment blocks owned by a building association in Roskilde. These buildings are very representative for Danish social housing – recent statistic show that the average age of social housing in Denmark is 44 years and the average size of apartments 75 m². It turned out that the planned renovation could not be carried out, so the Danish MORE-CONNECT team is currently looking for another demonstration building. Until this has been identified, the concept development analysis is done for a generic apartment block representative for Danish social housing as described above. We have decided for a four-story post World War 2 (WW2) apartment block with 24 apartments. A photo of a typical representative apartment block of this type is shown on figure 1. The general specifications of this building is presented in table 1.

Figure 1 – Typical post WW2 social housing apartment block in Denmark.

Table 1 – Characteristics of the generic Danish pilot project.

Specifications of reference building	Data values
Number of apartments	24
Average size of apartments	76,5 m²
Floor height	2,6 m
Roof slope and angle	40° slope – 0° from South
Insulation level	Low (U-roof:0.4 W/m²K)
Windows	2 layer clear glass
Ventilation	natural
Heating system	radiators
Heating energy consumption, kWh/m²y	96
Climate	Copenhagen

3.2. Parameters for the financial analysis

When performing a life-cycle cost analysis a few more parameters need to be fixed. As the analysis typically is done for an economic lifetime of 30 years the choice of financial parameters for a period that long has a high degree of uncertainty. For this work it has been chosen to use a set of parameters generally recommended for this type of analysis in Denmark. The chosen parameters are presented in Table 2.

Table 2 – Financial parameters

Discount rate	3,0%
Tax of interest income	0,0%
Inflation of energy	4,0%
Inflation of maintenance	2,0%
Expected economic lifetime	30

4. Concept development for different heating supply systems

4.1. Different heating systems and anyway measures

The overall goals of the MORE-CONNECT project request a primary energy reduction of 80% as mentioned above. This requirement has constituted a general condition for the concept development.

The first step of the concept development focused 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. In the first analysis it was therefore decided to only look at a situation where some anyway measures – explained in paragraph 1.3 – were part of the energy renovation scheme. Therefore, for the next steps – presented in this paper - it was decided to conduct the analyses (concept development calculations) for three more heating supply systems:

- Oil furnace
- Heat pump and
- Wood chip boiler

and complete the analysis by considering both situations – energy renovation with anyway measures and energy renovation with no anyway measures.

The anyway measures considered were:

- External façade renovation because of deterioration of envelope og load bearing construction and
- Exchange of windows to new 2-layer low-energy windows

This reduces the cost for insulating the façade externally and for exchanging the windows. For the calculations with anyway measures it was decided to use 200 mm mineral wool insulation in the external facades – at the price of adding the insulting layer in a new building – saving costs for finishing and scaffold and to include 3-layer low-energy windows at the cost of the difference between those and the 2-layer low-energy windows.

For the situation with anyway measures the following energy saving and renewable energy technologies were analyzed:

- Additional roof insulation (20 cm & 30 cm)
- Additional façade insulation (20 cm)
- New 3-layer energy windows

- New heat recovery ventilation (HRV) system
- Solar thermal system (2 m² per apartment)
- Solar PV (~4 m² per apartment)

For the situation where no anyway measures were required, the external wall insulation and the 3-layer low-energy windows were not cost-effective. Therefore, it was decided not to include the external wall insulation in these solution sets and only look at 2-layer low-energy windows, which are more cost-effective than 3-layer low-energy windows. To reach the 80% primary energy reduction goal it was necessary to add 1 m² additional PV for three of the cases and 4 additional m² in the case where the heating supply was a heat pump.

In all cases the energy savings, emission reductions and total costs were first calculated for the energy saving technologies individually. Secondly, they were added one by one and thirdly, the renewable energy technologies were added – again one by one. The results of these calculations are shown in figure 2- figure 9.

4.2. District heating

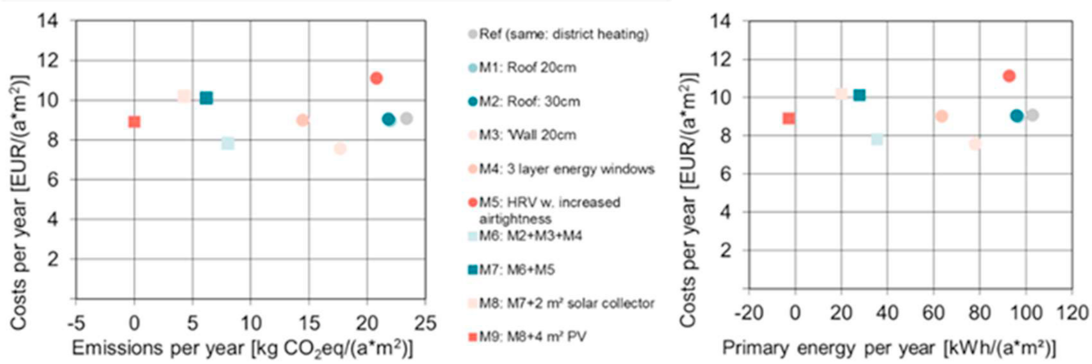

Figure 2 – Cost vs. emissions and primary energy use with anyway measures - district heating

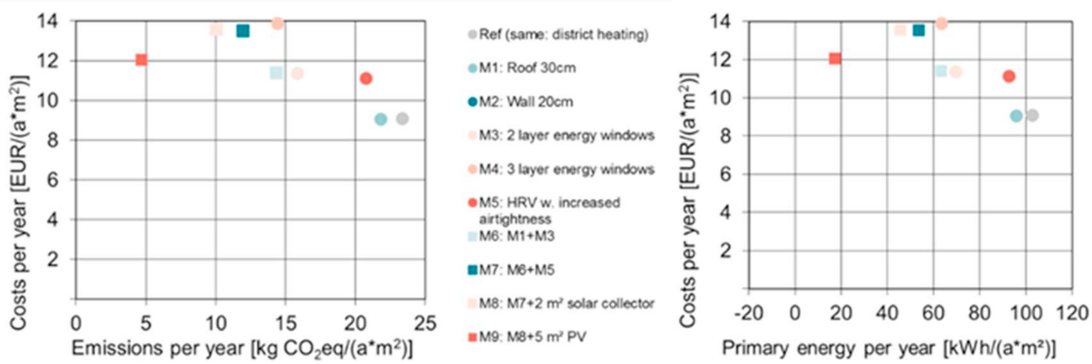

Figure 3 – Cost vs. emissions and primary energy use with no anyway measures - district heating

As it appears from the two plots on fig. 2 each individual energy saving technology reduces the CO2eq – emissions and primary energy consumption and three of them reduce total costs. Only the installation of the HRV-system increases costs. This is due to the fact that there is no anyway measure involved with respect to the ventilation of the buildings. This could be a point of discussion as balance mechanical ventilation is generally needed when renovating an existing building, because the existing ventilation systems often do not provide the necessary air-exchange rates.

When adding measures it can be seen that emissions and primary energy consumptions are strongly reduced and the total cost increase to about 10 when the HRV-system is included. Finally, the PV-system brings the costs down below the reference costs and result in CO2eq-emissions around 0 kgCO2eq/a/m² and a primary energy consumption a bit below 0.

For the case with no anyway measures only the roof insulation can be added without increasing total costs and adding up measures to reach the overall 80% reduction goal results in an increase in total costs from around 9 to around 12 EUR/a*m²

4.3. Oil furnace

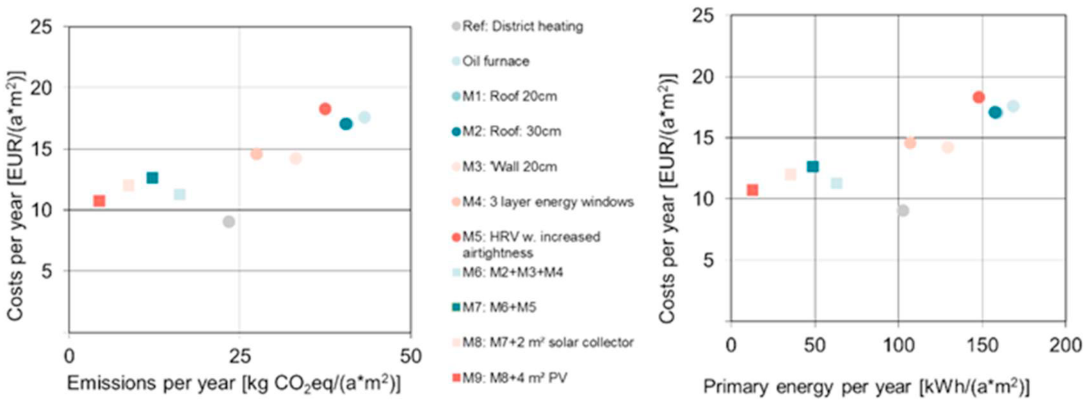

Figure 4 – Cost vs. emissions and primary energy use with anyway measures – oil furnace

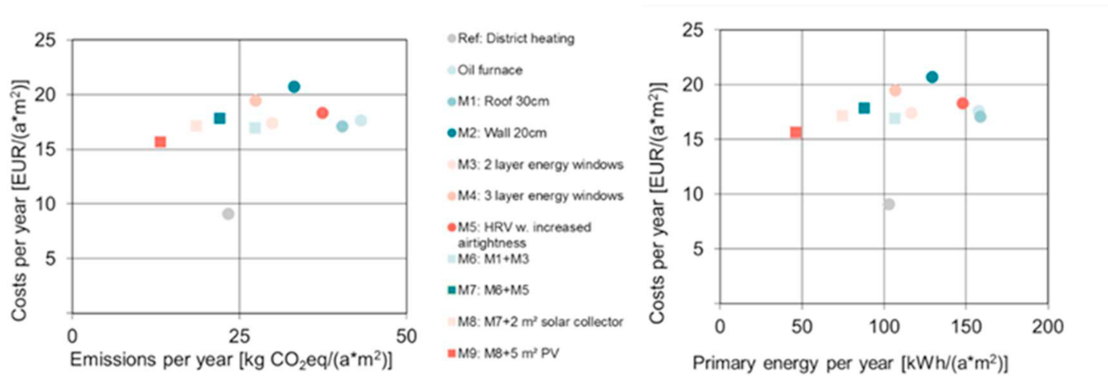

Figure 5 – Cost vs. emissions and primary energy use with no anyway measures – oil furnace.

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. In the anyway renovation case the energy concept package reduces the energy consumption down to nZEB level – the CO2eq is correspondingly reduced. For the no anyway renovation case the 80% reduction is barely met by adding 1 m² of PV. Total costs are in both situations reduced making the total energy concepts cost efficient.

4.4. Heat pump

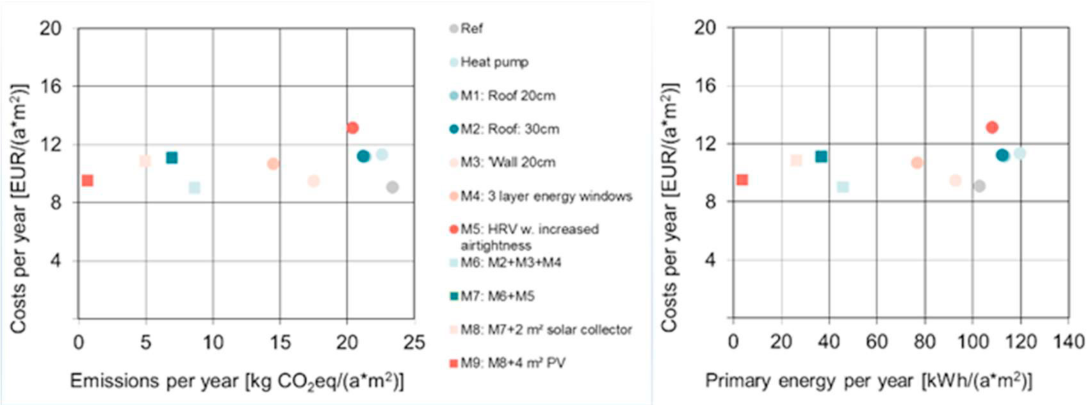

Figure 6 – Cost vs. emissions and primary energy use with anyway measures – heat pump

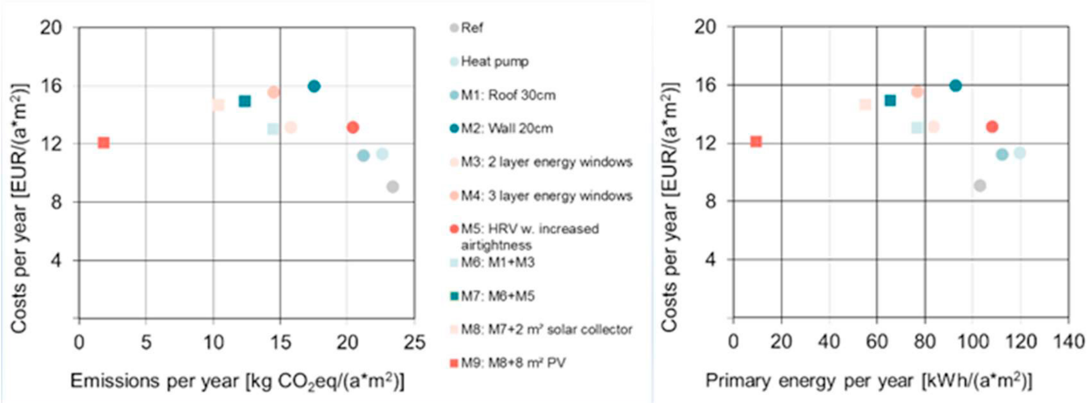

Figure 7 – Cost vs. emissions and primary energy use with no anyway measures – heat pump

These cases are comparable to the district heating cases – the initial starting costs are somewhat higher, but the pattern is much like that for district heating. Be-cause of the heat pump heating it makes good sense to increase the PV area to 8 m² in the no anyway measure case. It should be noted that the calculations do not ac-count for different electricity prices between using the PV-generated electricity directly, or "storing" it on the grid. In an actual energy renovation case, this would need to be accounted for.

4.5. Wood chip boiler

As seen in figures 8 and 9 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. 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.

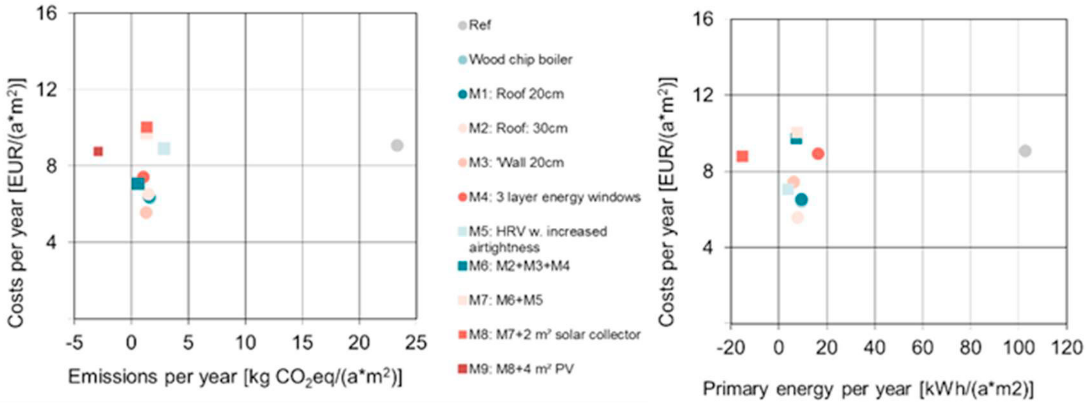

Figure 8 – Cost vs. emissions and primary energy use with anyway measures – wood chip boiler

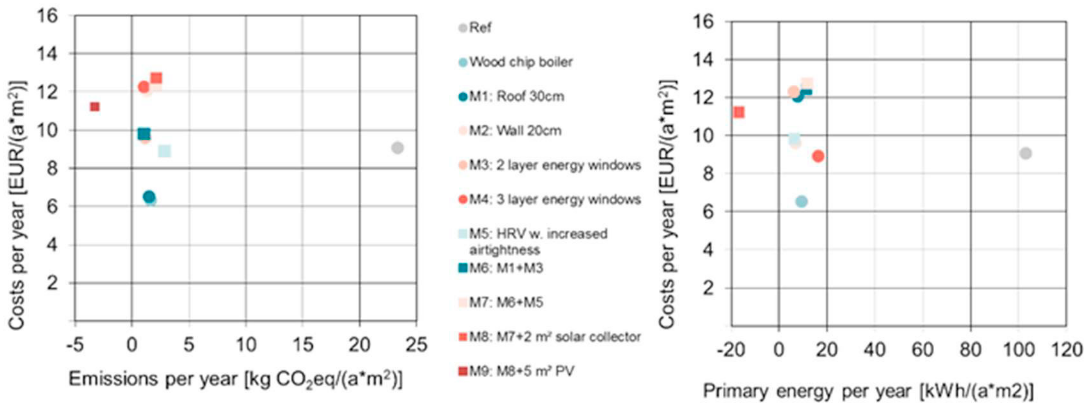

Figure 9 – Cost vs. emissions and primary energy use with no anyway measures – wood chip boiler

When looking at the plots in figures 8 – 9 it is seen that only the PV – system brings the primary energy and the emissions down. However, for all cases the final total costs is 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! Including the value of co-benefits as illustrated in paragraph 4.7, however, changes this conclusion – see below.

4.6. The results – summed up

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 and in both the case of anyway renovating and no anyway renovation measures. The final total costs are reduced for three of the heating systems in the case of anyway renovation and in one case (oil burner) for the no anyway renovation cases. Table 3 presents a summary of the total costs for the final concepts in each of the 8 cases.

Table 3 – Total costs. Summary of the results.

Heating system	Reference costs, EUR/a*m²	Final concept - with anyway measures, EUR/a*m²	Final concept - without anyway measures, EUR/a*m²
District heating	9,1	8,9	12,1
Oil furnace	17,6	10,8	15,7
Heat pump	11,3	9,5	12,1
Wood chip burner	6,3	8,8	11,2

The differences between reference total cost and total costs for the final concepts in Table 3 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.

4.7. Financial values of co-benefits

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 worst of the above renovation concepts financially attractive. It can further be argued for the case where no anyway measures were called for that the increased useful floor space that comes as a results of the insulation of the external wall – if estimated to app. 0,5 m around the perimeter – it will correspond to a housing rent value of 29 EUR/a*m². This makes also this measure economically attractive, as the additional total costs for insulating the external wall with what corresponds to 200 mm of mineral wool is 4.6 EUR/a*m².

5. Technology development in Denmark

A primary objective of the MORE-CONNECT project is to develop and demonstrate prefabricated multifunctional modular energy renovation elements. In Denmark two technologies are being developed: A new PV-roof solution in which the PV-cells are fully integrated in the roofing elements. This PV-roof can be fitted into any roof surface shape and if justified by the cost-optimization it can be constructed as a PVT-roof connected to a heat-pump for heating purposes. The PV-roof is illustrated on fig. 10. Currently, demo installations are in progress for both PV- and PVT solutions. It is expected that the developer of this technology, Innogie, are ready to deliver finalized products in the spring of 2017.

Figure 10 – PV – roof developed in the MORE-CONNECT project under construction at a demosite.

The second technology development aims at 3-D finishing of a new, insulation façade by an industry robot. At the end of this development a robot is to be able to finish any insulation layer – mineral wool, multiport, etc. and on different plaster types. The finishing can be any desired milling pattern or painting. Figure 11 shows a robot in the process of milling a plastered wall. The end goal of this solution is that it will be faster, more precise and more cost effective than present solutions.

Figure 11 – industry robot mills a plastered wall in 3d-Cad drawn patterns

6. Conclusions

The energy renovation concept development calculations performed for the 4 heating systems and the anyway measure respectively no anyway measure cases shows that nZEB can be reached in all cases. For three of the anyway measure cases this can be done cost-effective – that is with the same or reduced total costs compared to the reference case. For the no anyway measure situation this is true only for the oil furnace heated buildings. However, when considering a financial value of co-benefits from the energy renovation all cases are cost-effective – even when external wall insulation is carried out for the no anyway measure situations.

The idea of the PV-system developed in Denmark as part of the MORE-CONNECT is that the whole roof is to be covered with the PV-cells. For the generic pilot project in Denmark this means that the area of PV will be app. 19 m² per apartment. This is a lot more than the 4-8 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. When re-calculating the costs, GWP and primary energy consumption the result is that the total cost is further reduced (the PV-roof replaces another roof installation, the cost of which is therefore deducted) and both GWP and primary energy consumption becomes negative. The installation of this new PV-system therefore has the final result that the energy renovation of the buildings will go beyond the nZEB goal as the renovated buildings become plus-energy buildings at reduced total costs.

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Acknowledgements

The analysis reported in this paper has been supported by the EU Horizon 2020 programme as part of the work of the MORE-CONNECT project – www.more-connect.eu.