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Feasibility studies of energy retrofits – case studies of Nearly Zero-Energy Building renovation

Riikka Holopainen[a,]*, Adriana Milandru[b], Hannele Ahvenniemi[a], Tarja Häkkinen[a]

[a]VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, 02044 VTT, Finland
[b]ISPE Institutul de Studii si Proiectari Energetice, Bulevardul Lacul Tei 1-3, București 020371, Romania

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Abstract

This paper analyses the feasibility of Nearly Zero-Energy Building Renovation from the technical, environmental, economic and social point of view using the energy consumption calculations for country-specific reference case buildings before renovation, after a traditional renovation and after a Nearly Zero-Energy Building Renovation (NZEBR) as the starting point. Technical feasibility is analyzed by examining the proven technology level, possible technical risks in renovation or with respect to the energy performance and assessment of the overall technical feasibility for individual NZEBR measures. Social feasibility is analyzed by examining the impact on living space and other social aspects and the overall assessment of social feasibility for individual NZEBR measures. Environmental feasibility is analyzed by comparing the reduction of greenhouse gas emissions of traditional renovation and NZEBR using the Life Cycle Analysis (LCA) method. Economic feasibility is analyzed by comparing traditional renovation with NZEBR using the Life Cycle Costing (LCC) method.

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Keywords: Nearly Zero-Energy Building renovation; reference buildings; feasibility study

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1. Introduction

The building sector accounts for 40 % of the energy use within EU. There is a great potential to reduce energy use and thereby greenhouse gas emissions [1]. However, near zero energy demand in 2050 could only be reached with very ambitious renovation measures [2].

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* Corresponding author. Tel.: +358405710364.
E-mail address: Riikka.holopainen@vtt.fi

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In Finland the housing stock has 2.8 million actual dwellings with a high proportion of flats in blocks (44 %). The share of multi-family buildings of existing buildings is 46 %. A relatively large housing stock was built in the 1950s,'60s and '70s and the share these houses of the total housing stock is 43 %. This is the most interesting housing stock from the renovation business point of view not only because of volume but also because of their renovation needs [3]. The main reason for the big production volumes of blocks of flats in the '60s and '70s was internal immigration from rural areas to urban areas. These blocks of flats from the '60s and '70s are typically constructed of prefabricated concrete elements and their energy-efficiency is worse than the energy-efficiency of the older brick built buildings. Nearly all multi-family residential buildings in urban environment are connected to district heating. Concerning cost-effectiveness and resources, Heljo and Vihola [4] have identified following central reasons explaining why renovation measures have not been taken up: 1) if no refurbishment need exists, replacement of an element only because of energy saving reasons is most probably unfeasible, 2) only short-term profitability might be assessed, 3) there is contradictive information about profitability, 4) financing the project might be problematic.

According to the national statistics, the total dwelling stock in Sweden in 2010 was 4.5 million dwellings. Of these dwellings approximately 44 % were one- or two-dwelling buildings and 56 % were multi-dwelling buildings. Swedish authorities have identified a large potential for energy efficient measures within the Swedish residential sector. During 1965-1975 approximately 1 000 000 million dwellings were built in Sweden, within an ambitious housing program called the Million Program implemented by the Swedish Social Democratic Party. The aim was to provide affordable housing for all. Today approximately 830 000 multi-dwelling buildings still exists in Sweden and 600 000 of these buildings need to be renovated. Swedish Energy Agency has identified buildings constructed within the Million Program as a prioritised type of building to renovate. These buildings mainly consist of prefabricated elements in concrete and they are poorly insulated. The energy consumption in these buildings is nearly 40% higher than in new-built buildings. The dominant renovation need is mostly maintenance work on facades and roofs as well as renovation of the ventilation system.

In the Netherlands about 33% of residential building stock is owned by social housing companies, 55% by private owners and 11% by commercial rental companies. Almost all houses build before 1970 have an energy label class between D and F. Only 5% of the present housing stock has an energy label of class A or higher. Many houses built before 1990 still have a relatively poor energy performance, even if some improvements e.g. double window glazing, have been implemented. There is therefore a very large potential for energy-efficient renovation of houses built before 1990. A very substantial part of this potential is owned by social housing associations, but also private ownership is important. Most common dwelling-types in this category are single-family row houses and multi-family apartment buildings. Many houses built during the period of 1960-1990 were constructed in large volumes following a standard construction concept. Therefore the development and implementation of standard renovation concepts for such houses should be relatively straightforward. However, standard concepts for NZEBR are not offered much yet, due to reluctance among owners to go this far in an energy efficiency improvement. Some demonstration projects with near zero-energy renovation have been conducted over the past years but the number of houses in this category is still very small. A large potential for NZEBR exists in the Netherlands but it is not actively taken up by market parties and investors yet.

Romania has around 7.38 million dwellings of which 58 % are located in an urban area. The building sector is dominated by residential buildings representing about 95 % of all buildings. The most common residential building types are dwellings in collective buildings, block-of-flats, in urban area (42.5 % of total dwellings). The existing residential buildings are generally old, 70 % of them were built before 1980. These buildings have poor thermal properties, with average annual heating demand values between 180-240 kWh/m^2. However, several pilot projects have demonstrated that it is possible to reduce their heating energy consumption with at least 40-50 %. Popescu et al. [5] studied the impact of energy efficiency measures on the prices of existing buildings in Romania and found that retrofitting increased prices of apartments with 2-3% on average.

Spain had a massive construction activity between the 50's and the 80's due to the industrial development period. These were all pre-normative constructions. Therefore most of the Spanish building stock erected during this period is of poor quality and highly inefficient in terms of energy. A significant transformation of the Spanish residential building stock is the target of the recent construction policies in Spain, where energy-efficiency and building renovation are two main priorities. Regarding renovation necessity, there is a large residential building stock in Spain that need to be renovated. According to the results of the SECH SPAHOUSEC project the Spanish building stock is mainly composed of block of flats (70 %) which are usually located in high density urban areas. Previous works undertaken by TECNALIA have classified the buildings typologies in Spain. Among all, three typologies are the most interesting regarding energy efficiency renovation opportunity: Buildings from the beginning of the XIX century, Social Housing (1940 – 1964) and City expansion buildings (1970). The different constructive scheme of these three building typologies and the socio-economic condition of the tenants cover a broad spectrum of conditions, resulting in the need to define different intervention strategies that could later on be implemented massively. Spanish Social Houses are characterized by groups of identical free standing buildings located near the suburbs of industrial cities. They are commonly very poor quality dwellings, built with easy-to-obtain and cheap construction materials and systems. Some characteristics are: ground floor + three or four floors, pitched roof with ceramic tiles, double brick façade without insulation, mortar based envelope painted without decoration, no balconies and no viewers, basic windows with simple glass and without air tightness, without heating and insulation, without elevator, habitability problems (small dwellings) and very high socio-economic vulnerability as there live families with high income problems and low knowledge and education levels.

In our study we analysed the feasibility of Nearly Zero-Energy Building Renovation (NZEBR) over traditional renovation. First, we defined reference buildings. Secondly a technical and social feasibility study was made to evaluate and analyse the potential to achieve NZEBR for the identified residential typologies. Thirdly the environmental feasibility was studied using Life Cycle Assessment /LCA) and finally the economic feasibility was studied using Life Cycle cost (LCC) calculations. The target countries were Finland, Sweden, Romania, Netherlands and Spain, partner countries in the IEE NeZeR-project, where the calculations were made.

2. Methods and data

This paper analyses the feasibility of Nearly Zero-Energy Building Renovation from the technical, environmental, economic and social point of view using the energy consumption calculations for country-specific reference case buildings before renovation, after a traditional renovation and after a Nearly Zero-Energy Building Renovation (NZEBR) as the starting point.

Technical feasibility is analysed by examining the proven technology level, possible technical risks in renovation or with respect to the energy performance and assessment of the overall technical feasibility for individual NZEBR measures. Social feasibility is analysed by examining the impact on living space and other social aspects and the overall assessment of social feasibility for individual NZEBR measures. Environmental feasibility is analysed by comparing the reduction of greenhouse gas emissions of traditional renovation and NZEBR using the Life Cycle Analysis (LCA) method. Economic feasibility is analysed by comparing traditional renovation with NZEBR using the Life Cycle Costing (LCC) method.

The case studies were made for different reference buildings in each target country. These reference buildings were selected by research partners from each target country to represent the building types identified as most in need of an ambitious renovation. The Finnish reference building was a five-floor multi-family building from the 1970s. The Swedish reference building was a four-floor multi-family building from the beginning of 1960s. The Dutch reference building was a multi-family building built between 1965-1974. The Romanian reference building was a ten-floor multi-family building constructed in 1977. The Spanish reference building was a five-floor multi-family building constructed in 1967. The main characteristics of the reference buildings are presented in Table 1. For more details please see the respective project report [6].

Table 1. Basic information about the reference buildings

Country	**Finland**	**Netherlands**	**Romania**	**Spain**	**Sweden**
Space heating source	District heating	Local gas stoves	District heating	Electric radiators	District heating
DHW heating source	District heating	Gas-fired flow heater	District heating	Electric water heaters	District heating
Electricity source	Power grid	Power grid	Power grid	Power grid	Power grid
Heated floor area, m^2	1,850	270	3,135	1,368	4,553
Specific space heating consumption, kWh/m^2,a	130	107	177	81	103
Specific DHW heating consumption, kWh/m^2,a	51	16	15	33	29
Specific electricity consumption, kWh/m^2,a	44	4	21	9	10
Structure typology	Reinforced concrete	Brick walls + wooden floors	Reinforced concrete	Reinforced concrete	Reinforced concrete
Wall typology	Concrete with heat insulation	Single leaf brick façade without insulation	Monolithic concrete with insulation	Double leaf brick without insulation	Aerated concrete
Wall U-value, W/m^2K	0.6	2.8	1.83	0.81	0.54
Roof typology	Flat or sloping roof with insulation	Inclined roof covered with tiles	Flat roof without insulation	sloping roof without insulation	Low sloped roof with mineral wool insulation
Roof U-value, W/m^2K	0.39	2.6	0.91	1.56	0.24
Floor U-value, W/m^2K	0.48	2.9	2.41	1.3	0.54
Window typology	Wooden frame + double glass	Wooden frame + single glass (sliding windows)	Double wood frame + single glass	Aluminium frame + single glass	Wooden frame + double glazing (coupled)
Window U-value, W/m^2K	2.79	5.2	2.56	5.7	2.7

3. Results

3.1 Technical and social feasibility study

First the traditional renovation and Nearly Zero-Energy Building Renovation (NZEBR) measures were defined for each reference building of a target country [7]. Then the energy saving potentials with a traditional renovation and NZEBR were calculated. The properties and consumptions of the country-specific reference buildings after a traditional renovation are presented in Table 2 and after a NZEBR in Table 3.

Table 2. Reference buildings after the traditional renovation

Country	**Finland**	**Netherlands**	**Romania**	**Spain**	**Sweden**
Space heating source	District heating	Individual gas condensing boiler	District heating	Individual natural gas boilers and water radiators	District heating
DHW heating source	District heating	Individual gas condensing boiler	District heating	Individual natural gas boilers and solar panels	District heating
Electricity source	Power grid	Power grid	Power grid	Power grid	Power grid
Specific space heating consumption, kWh/m^2,a	50	26	100	28	79
Specific DHW heating consumption, kWh/m^2,a	51	11	15	34	25
Specific electricity consumption, kWh/m^2,a	30	7	8	9	9
Wall U-value, W/m^{2}K	0.14	0.37	0.56	0.21	0.54
Roof U-value, W/m^{2}K	0.10	0.27	0.20	0.2	0.13
Floor U-value, W/m^{2}K	0.15	0.3	0.35	1.3	0.54
Window U-value, W/m^{2}K	0.7	1.65	1.35	frame 2.2 glass 3.3	1.13

The energy saving potential with traditional renovation was calculated to be between 20% - 45% and with a NZEBR between 60% - 90%. Figure 1 presents the energy consumption saving potentials with both alternative renovation types.

Table 3. Reference buildings after NZEBR

Country	**Finland**	**Netherlands**	**Romania**	**Spain**	**Sweden**
Space heating source	District heating, exhaust air heat pump	Individual gas condensing boiler	District heating	Biomass thermal plant + water radiators	District heating + exhaust air heat pump
DHW heating source	District heating, exhaust air heat pump	Individual gas condensing boiler + solar water heater	District heating + Solar thermal system	Biomass thermal plant	District heating
Onsite RES measures	Heat pump, solar thermal panels, PV panels	Solar thermal panels	Solar thermal panels PV panels	Biomass PV panels	PV panels
Specific space heating consumption, kWh/m^2,a	19	5	63	20	33
Specific DHW heating consumption, kWh/m^2,a	10	6	15	35	22
Specific electricity consumption, kWh/m^2,a	35	7	8	9	8
Wall U-value, W/m^{2}K	0.09	0.27	0.40	0.15	0.17
Roof U-value, W/m^{2}K	0.08	0.19	0.20	0.13	0.08
Floor U-value, W/m^{2}K	0.15	0.27	0.35	1.30	0.54
Window U-value, W/m^{2}K	0.70	1.00	0.83	frame 1.58 glass 1.48	0.90

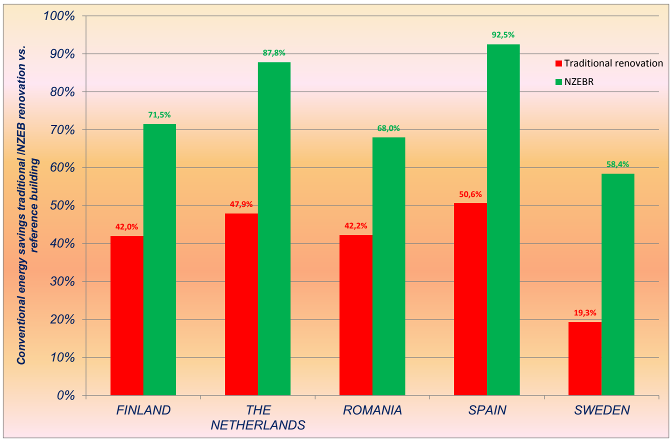

Figure 1. Energy saving potential on traditional and Nearly Zero-Energy Building Renovation calculated for reference buildings in target countries

Technical feasibility was analyzed by country-specific experts by examining the proven technology level, possible technical risks in renovation or with respect to the energy performance and assessment of the overall technical feasibility for individual NZEBR measures in target countries. Social feasibility was analyzed by examining the impact on living space and other social aspects and the overall assessment of social feasibility for individual NZEBR measures.

Insulation of exterior opaque building elements - walls, roof, and floor - is an already proven technology and the technical and social risks are minimums in all countries for exterior insulation systems (Figure 2). However, a small increase of risks (2 instead 1) in the case of internal insulation is noticed in Finland and Spain. The identified technical and social risks are also very small for energy-efficient double/triple glass windows in all target countries (Figure 3). This is an already proven technology in Finland and Sweden, but in the other countries this technology is not usually used in renovation of residential buildings. Triple glass windows are used as a NZEBR measure in other countries except Spain, where double glass windows are used due to the milder climate.

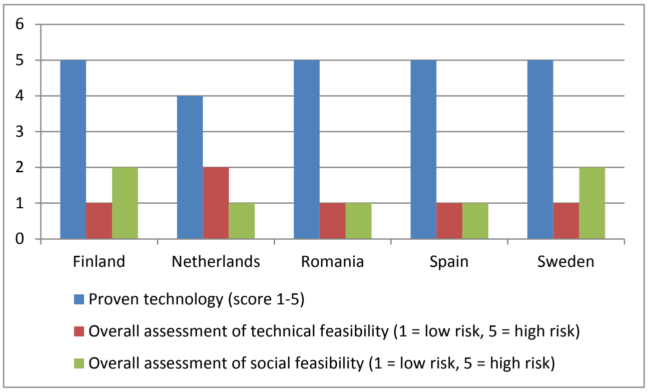

Figure 2. Technical and social feasibility of insulation of exterior opaque building elements

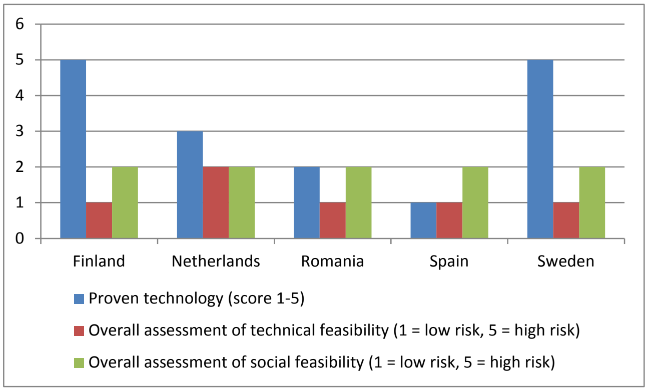

Figure 3. Technical and social feasibility of energy-efficient windows

Mechanical ventilation system is an already proven technology in Finland and Sweden, countries with large experiences to implement this ventilation system for residential buildings, but in the other target countries this system is found difficult to be implemented for existing multi-family buildings. Taking into consideration the important size of this intervention work, the implementation of this measure could induce medium risks from technical and social point of view in all of the target countries.

Based on the climatic conditions and geographic position of each country, the measures of renewable energy source (RES) implementation contain PV panels, solar thermal collectors, biomass sources or heat pumps (Figure 5). Due to the EU programs and financial supports for promotion of utilizing RES, this is an already proven technology in all target countries. These measures induce medium risks in NZEBR feasibility. As a common example for all countries, the measure for implementation the PV panels induce minimum social risks due to the financial advantages of residents and minimum or medium technological risks resulted from choosing the electricity distribution system (on-grid or with electricity storage elements).

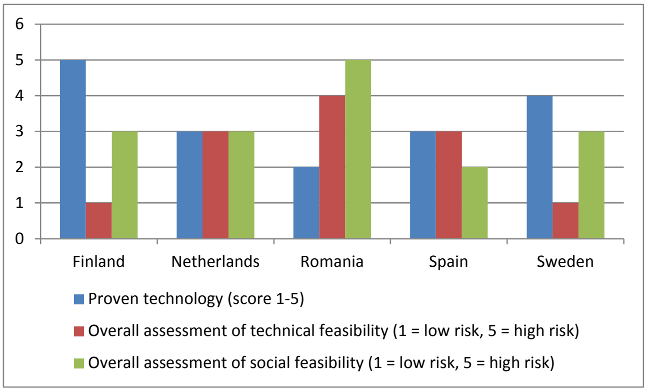

Figure 4. Technical and social feasibility of mechanical ventilation system

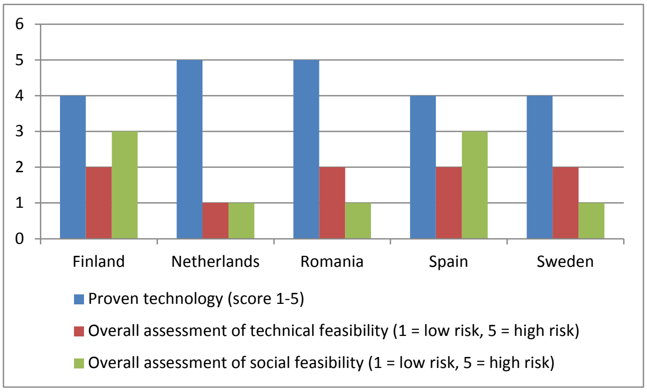

Figure 5. Technical and social feasibility of the utilization of renewable energy sources

3.2 Environmental feasibility study

Environmental feasibility was analyzed by comparing the reduction of greenhouse gas emissions of traditional renovation and NZEBR using the Life Cycle Analysis (LCA) method. LCA is traditionally used for calculation and evaluation of the potential environmental impacts of a product, process or service, taking into account of the environmentally relevant inputs and outputs of the system over the life cycle (ISO 14044:2006). Here LCA was used to quantify the environment impacts and benefits obtained through implementation of the NZEBR measures for a reference building in comparison with a traditional renovation [8]. The reference time in the LCA was 30 years. The calculation took into account the production of renovation building materials and the energy use of the usage stage (without household electricity). Transportations of the materials were not considered. Only major building materials in the renovation were taken into account including e.g. floor slab, external walls, roof, windows, ventilation and RES. Detailed information about the LCA calculations is found in [8].

According to the LCA results, the reduction of greenhouse gas emissions was between 20% and 80% with a traditional renovation and between 50% and 90% with Nearly Zero-Energy Building Renovation. Total greenhouse gas emissions (for energy and material) during 30 years of operation were lower after a Nearly Zero-Energy Building Renovation than after a traditional renovation alternative in all target countries (Figure 6).

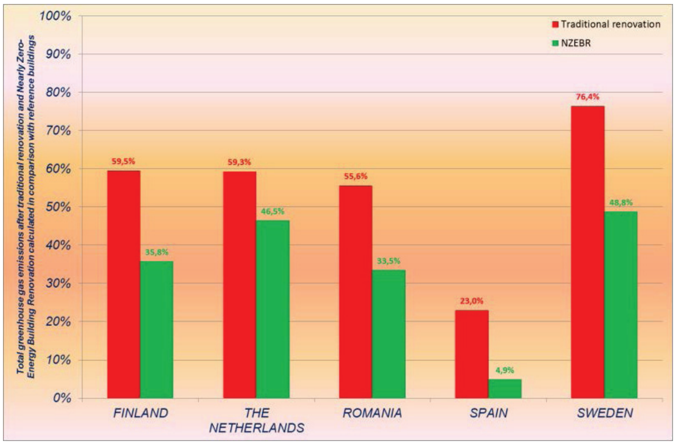

Figure 6. Total greenhouse gas emissions after traditional renovation and Nearly Zero-Energy Building Renovation calculated in comparison with reference buildings in target countries

3.3 *Economic feasibility study*

Economic feasibility was analysed by comparing traditional renovation with NZEBR using the Life Cycle Costing (LCC) method. Figures 7 to 11 present the country-specific total costs of the reference building without renovation, with a traditional renovation and with NZEBR.

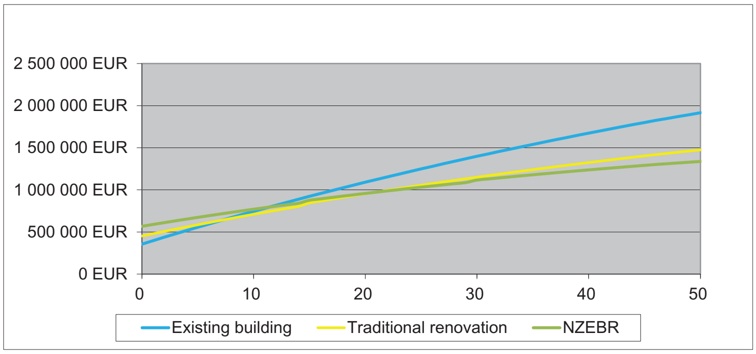

Figure 7. LCC results for Finland (inevitable refurbishment measures assumed also for the reference building)

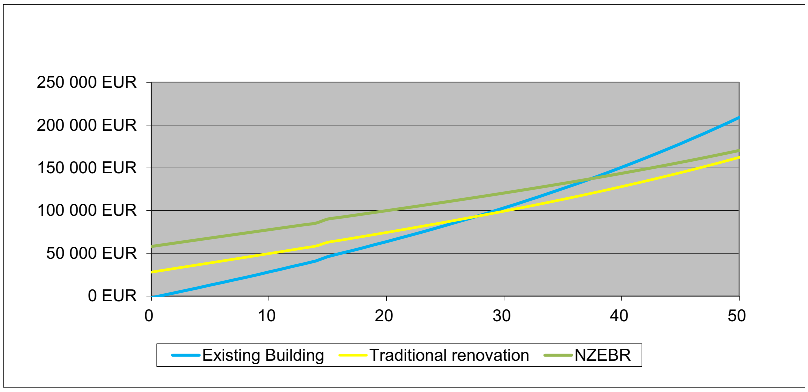

Figure 8. LCC results for Netherlands

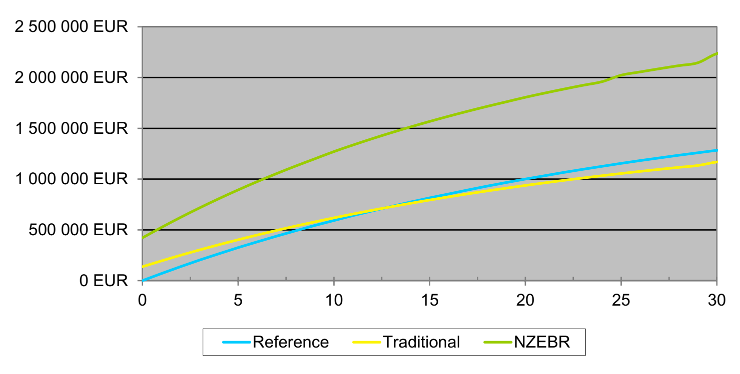

Figure 9. LCC results for Romania

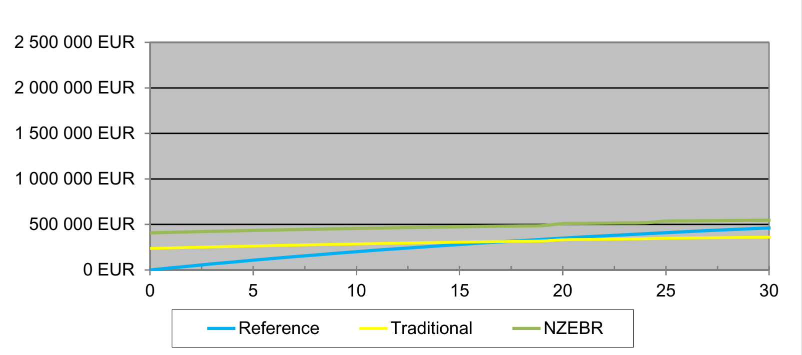

Figure 10. LCC results for Spain

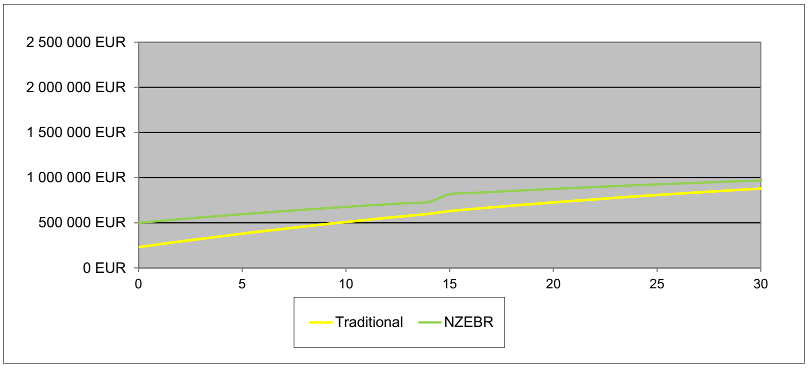

Figure 11. LCC results for Sweden

4. Discussion and conclusions

The results of the economic feasibility study show how with present price levels for building renovation and household energy consumption the Nearly Zero-Energy Building Renovation (NZEBR) is often not economically feasible from the owners' perspective. However, there is good potential for cost reductions in NZEBR by technological and process improvements and when a higher market volume is reached. The revaluation of the building also increases economic profitability.

When assessing the feasibility of energy retrofits of buildings, the focus is normally on future energy savings and the payback time of the investment. However, energy retrofits of buildings can have a great number of other benefits – in addition to lower energy costs – including increased aesthetic value of the building and improved indoor comfort, among others. Although these benefits are normally not considered in the economic analyses, they might however have a significant effect on the economic feasibility of retrofits because of the increased property value; for example improved aesthetics and indoor comfort indeed increase the property price. Also, residents might be increasingly willing to pay a price premium for ecological housing. Well insulated and airtight construction, minimized thermal bridges and low u-value windows reduce the feeling of draft and temperature variation during the day and year, and external noise from surroundings. An effective mechanical ventilation system ensures clean and plentiful fresh air, removes dust and odour, reduces the risk of allergies, controls the air humidity and gives a possibility to adjust ventilation rates according to the needs. These improved comfort levels and wider societal and health benefits increase the profitability of NZEBR from a societal perspective.

The results of the environmental feasibility study demonstrate the advantages of NZEBR over the traditional renovation alternative in the target countries and sustain the implementation of NZEBR measures by showing a significant increase of fossil energy savings and reduction of greenhouse gas emissions when comparing implementation of technical NZEBR measures in comparison with traditional building renovation.

The EU policies and strategies acknowledge the importance of building renovation as a key element in reaching the long-term energy and climate goals, as well as having a positive economic impact. Key actors to make the change happen towards NZEBR penetration are big owners of residential building stock such as social housing organizations and local authorities who are able to support and encourage house owners for energy efficient retrofitting. The starting point for NZEBR is the willingness of house owners and portfolio owners to start energy efficient renovation and their understanding in the economic, environmental and other benefits. Key actors also include designers, consultants and contractors who do own design. In addition to the owners - who state requirements – the sector needs skilled designers who are able to plan and design right solutions for NZEBR. Financing institutes and ESCOs are also key actors, as their financing support is essential in NZEBR.

NZEBR has good potential to increase the property, resale and user values through lower energy costs, better indoor climate and higher energy class. NZEBR can also increase the life time of the building and ensure the long-term affordability of the living costs. For further studies we propose examining how the various benefits of building refurbishment could be integrated into the economic assessment by considering e.g. the increased property value and in this way motivate building owners to take up energy retrofit measures.

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