Environmental and economical assessment of refurbishment concepts

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Short Summary

This paper summarises the results of the recent research Methods and Concepts for Sustainable Renovation (MECOREN) carried out at VTT. The project aimed at creating new understanding about

- sustainable refurbishment concepts for residential buildings.
- environmental and economical impacts of alternative refurbishment concepts
- suitable methods for the environmental assessment of refurbishment concepts.

Alternative refurbishment concepts were studied on the level of the Finnish residential building stock. Different refurbishment concepts were compared by assessing the impact in terms of energy and greenhouse gases.

When assessing the greenhouse gases (GHGs) of buildings and the effect of refurbishment on GHGs, it is important to choose a right method with the help of which the emissions of energy are calculated. This is especially important when district heat and electricity are used as sources of energy.

The paper also assesses the significance of embodied environmental impacts in sustainable refurbishment projects. The environmental impact of renovation materials was compared to the saved environmental impact due to the energy saving achieved with the help of refurbishment. The demolition and building a new building was also considered as an alternative.

The assessment of the economical potentials of refurbishment concepts was carried for cases where an extensive refurbishment is needed for an out-dated building. However, also separately done refurbishment measures such as changes of windows, refurbishment of facades etc. should lead to a reasonable improvement of energy performance. The economical life cycle impacts of refurbishment depend on the investment cost and the reduction of energy consumption. However, a successful refurbishment also affects the resale value of the building. A significant increase in the value (market value) by means of extensive refurbishment can be achieved when the building is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. Compensation can also be achieved by increasing the density of the area (with the help of extensions such as an additional storey or building).

Keywords: Sustainable renovation

1. Introduction

This paper presents the main results of the research project Methods and Concepts for sustainable Renovation (MECOREN) carried out at VTT in 2009–2012 (Häkkinen 2012). The overall research project was a Nordic collaboration. The project had the following research partners: VTT in Finland, SINTEF in Norway, SBI in Denmark and KTH in Sweden.

The paper analyses the impacts of alternative renovation scenarios on the Finnish building stock in terms of greenhouse gases (GHGs). The study focused on residential buildings. The calculations were carried out for years 2010, 2020 and 2030. In addition to the assessment of the renovation concepts of building stock, the objective of the paper is also to

- discuss and give recommendations about the use of environmental data for energy sources
- discuss and make conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use
- assess and make conclusions about the economic impacts of building renovation.

Information on total floor area of the Finnish housing stock was used as the basis for the analyses. The total floor area of the Finnish housing stock was first divided into age groups based on the available statistical information on residential housing stock.

In the next phase, the size and performance of buildings in different age groups were defined. The defined performance includes the types of structures, floor height and volume of a building, number of inhabitants, and heating energy, electricity and water consumption. These defined figures were then used as an input for creating exemplary buildings which were dealt with by the energy calculation program WinEtana.

By using the information of the exemplary buildings and the composition of the current housing stock, a theoretical maximum energy saving potential for the Finnish residential stock can be calculated. This was done by applying different energy saving measures to the exemplary buildings. The measures under study were: additional thermal insulation, replacement of windows, replacement of ventilation system and implementation of solar heating.

Based on the assessed energy savings, also savings in GHGs can be calculated. These calculations were based on energy production profiles in Finland.

The housing stock develops and changes over time. Thus the estimation of the current housing stock is not sufficient for estimating the situation in 2020 and 2030. New construction adds the floor area of the housing stock and obsolescence, deterioration and finally demolishment decreases it.

The degree of building degradation was taken into account, since energy renovations are often feasible only in the connection of other renovation. The study used an assumption that energy renovations are made only when the buildings would need renovation in any case.

2. Environmental profiles for electricity and district heat

In order to assess the environmental potential of different renovation concepts the environmental profiles for heat and electricity was calculated as an average value for 2004–2008.

The models built for the calculation of the average electricity supply and heat production include fuel extraction (heavy fuel oil, hard coal, natural gas extraction, greenhouse gas emissions from peat manufacturing), electricity and heat production both in electricity and combined heat and power (CHP) plants, net imports and transmission losses. The used allocation methods for CHP are energy allocation and benefit distribution. Due to lack of data, separate heat production is taken into account only for heavy fuel oil (78% of heat produced with oil is from separate production in 2008). Other fuels are mainly used in CHP plants (75–95% of heat produced in CHP) and the shares of separate production are smaller.

Table 1: LCA based environmental profiles for average Finnish electricity (considering net imports).

	Benefit		Energy	
	Electricity	**District heat**	**Electricity**	**District heat**
CO2 fossil, kg/MWh	309	236	222	273
CO2 biogenic, kg/MWh	121	134	67.5	160
CH4, kg/MWh	0.821	0,364	0.709	0,424
N2O, kg/MWh	0.000654	0.000397	0.000523	0.000448
GHG, kg/MWh	330	245	240	283

The GHGs of electricity produced in condensing power plant has been earlier assessed to be 966 g/kWh (Holopainen et al. 2010).

The newest prediction made by the Finnish Ministry of Employment and Economy was done in the connection of the new climate and energy strategy. On the basis of preliminary information and in accordance with the newest base scenario the predicted emissions for district heat and electricity are as follows:

Table 2: Predicted emissions for district heat and electricity

Characteristic emission, g CO2/kWh	**2010**	**2020**	**2030**
Electricity delivery	230	179	36
District heat	243	216	191

The base scenario takes into consideration the measures already decided such as feed tariff for electricity delivery, subsidies for renewable energy and nuclear power plants already received positive decisions in principle. The allocation of fuels in CHP district heat and electricity was done on the basis with energy method. The scenario also assumes that all electricity is produced in Finland in 2020 and 2030. The scenario considers the assumed decrease of energy demand for heating of buildings. This scenario takes into consideration the impact of energy performance regulations and the impact of changes in building stock (demolition of building and building of new buildings). In addition, the scenario assumes that the use of heat pumps is increased so that those contribute to 7 TWh of the use of primary energy. It also assumes that oil heated houses change the heating system and make use of ground heat pumps and the houses heated by electric air heat pumps.

3. Environmental impact of materials in building refurbishment

The objective of this part of the study was to assess the significance of building materials in building renovation in terms of GHGs. The environmental impact of renovation materials was compared to the saved environmental impact due to the energy saving achieved with the help of renovation. This study considers:

- Two refurbishment methods
- External insulation – with new additional insulation, new façade and roof
- Replacement renovation – with replaced and additional insulation and with a new façade of the same type
- Demolition level
- Partial demolition and renovation (cases M1 and M3) (see Table 4)
- Total demolition and new construction (cases M2 and M4) (see Table 4)
- Two refurbishment targets
- Low energy building structures,
- Passive energy building structures.

Environmental impact for renovation materials was based on VTT’s database. The assessed operational energy (Table 3), the renovation cases (Table 4) and the assessed GHGs for the different cases (Table 5) are presented in the following tables.

Table 3: Operational energy for the studied case (existing multi-storey building, 29 apartments), for renovation and for new construction.

	Existing building	Renovation, Low energy envelope	Renovation, Passive structure envelope	New, Passive energy building
	MWh/a (kWh/m²)	MWh/a (kWh/m²)	MWh/a (kWh/m²)	MWh (kWh/m²)
Heating energy (district heating)	241 (130)	93 (50)	70 (38)	18 (10)
Service water heating	94 (51)	94 (51)	94 (51)	94 (51)
Electricity	82 (44)	55 (30)	55 (30)	55 (30)
Total	417	242	219	166

Table 4: Refurbishment cases for concrete multi-story building

Structure	**Low energy structures**		**Passive energy structures**		
	Case M1	**Case M2**	**Case M3**	**Case M4**	**Case new**
Demolition	–	Outer concrete layer	–	Outer concrete layer	Existing building
Exterior wall	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	concrete element with tile facade
Base floor	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	(EPS + parquet)
Roof	R1 (asphalt mastics cover)	R1 (asphalt mastics cover)	R1 (asphalt mastics cover	R1 (asphalt mastics cover)	asphalt mastics cover
Window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window

These cases indicate that the increased material consumption because of refurbishment to the level of low-energy and passive-level structures causes an increase in GHGs but this is significantly lower compared to the saved GHGs because of saved operational energy.

4. Energy consumption of the current housing stock and energy saving potential

The heating energy use and electricity use were calculated for all residential buildings by using model buildings. An exemplary building was created to present each of the different age-type groups in the building stock as explained earlier (Section 1), and these model buildings were then used for calculating the energy consumption of the housing stock.

When buildings exit the housing stock, savings in heating energy and electricity consumption take place. This also results in a decrease in GHG emissions, assuming that the emissions for the different energy types remain unchanged over time. Buildings also undergo energy renovations, which decrease their energy consumption, and result in reduced GHG emissions. Finally, the heating method of buildings may be changed causing changes both in energy consumption and GHG emissions.

The results show the total energy consumption of the building stock, after all buildings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings; the year of consideration is 2030.Table 6 shows that the assessed GHG saving potential of different renovation alternatives ranges from 3% (solar heat installation) to 27% (a combination of renovations). In addition to energy renovations, buildings may also undergo renovations related to their heating systems. The study focused on detached houses, since changes in their heating systems are relatively easy to implement, and, for example conversions from electrical heating to geothermal heating has already become quite popular. Table 7 shows the assessment results for GHG emissions, if all the detached houses with electric heating and oil-heating changed their heating method by 2030.

Table 5: GHGs for a multi-storey building (operation period 50 years)

	Existing building, no renovations	Refur-bishment to low en-ergy build-ing Case M1	Low energy building new con-struction Case M2	Refur-bishment to pas-sive structure Case M3	Refur-bishment to passive structure Case M4	Passive structure building, New con-struction Case M New
Demolition			342		342	21 702
Exterior wall		13 028	59 867	18 245	65 408	152 045
Base floor		8 735	8 735	8 735	8 735	41 273
Partition wall		0	0	0	0	86 832
Roof		16 650	16 650	21 314	21 314	45 024
Partition floor						107 566
Window		9 776	9 776	9 776	9 776	9 776
TRP to site		237	857	268	889	7 066
Heating	2 533 770	979 879	979 879	736 359	736 359	185 472
Electricity	915 327	606 095	606 095	612 279	612 279	612 279
Hot water	991 475	991 475	991 475	**2,673,676**	991 475	991 116
Total	**4,440,572**	**2,625,874**		**2,398,452**	**2,446,578**	**2,260,151**
Total/m^2	**2,400**	**1,419**	**1,445**	**1,296**	**1,322**	**1,222**

Table 6: GHG-emissions of buildings, no-renovation scenario compared to scenarios where different energy renovation methods are applied.

	CO2-equ emissions from heating			CO2-equ emissions, elec-tricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy ren-ovations	9.30	0	0%	2.00	0	0%	11.30	0	0%
Passive-level envelope	7.43	1.88	20%	2.00	0	0%	9.43	1.88	17%
Ventilation renovation	8.52	0.79	8%	2.07	-0.07	-3%	10.59	0.72	6%
Solar heat in-stallation	8.96	0.35	4%	2.00	-0.01	0%	10.96	0.34	3%
Window reno-vation	8.78	0.52	6%	2.01	-0.01	0%	10.79	0.51	5%
Renovation combination	6.13	3.17	34%	2.07	-0.07	-4%	8.21	3.10	27%

Table 7: Effect of the assumed change in heating method on GHGs

	CO2-equ heating			CO2-equ electricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy renovations	5.169	-	-	1.204	-	-	6.373	-	-
2030, electric heating changed to ground heating	3.721	1.448	28%	0.852	0.352	29%	4.573	1.800	28%
2030, oil heating changed to wood heating	2.718	2.451	47%	1.198	6	1%	3.916	2.457	39%
2030, electric heating changed to ground heat-ing, and oil to wood heating	1.270	3.899	75%	0.845	0.359	30%	2.116	4.257	67%

The change in heating methods may not necessarily cause energy savings, but it may lead to significant GHG emission savings. If all the detached houses with electrical heating changed their heating method to ground heating, and all houses with oil-heating to wood heating, estimated GHG savings would equal to about 4.3 Mt, or 67%, compared to the baseline case.

5. Effect of calculation rules

As there is a rapid change in the assessed CO_2 values of electricity and district heat between the years 2010, 2020 and 2030, the possible consideration of this change in LCAs of buildings has a significant effect on final results. It is here recommended that especially when making building level and stock level life cycle assessments over 50 years' period, the assessed change in emission values should be considered. An example of the significance of the issue is given in the following.

When the GHGs because of total operational energy use during 50 were calculated (section 3) by using the emission values of 2010, the result is significantly bigger (1.99Mt CO_2e) than when the total GHGs are calculated considering the predicted change in the emission values of electricity and district heat (the assessed result falls to1.44 Mt CO_2e). Thus also the share of building materials from the total GHGs increases (in this example it increases from below 20% to roughly 25%). The share of materials in the latter case roughly equals to the combined share of heating and electricity while the heating of water is responsible for roughly 50% of the assessed GHGs.

However, when making building stock based analyses about the significance of renovation scenarios, it is also important to take into account, whether a particular decrease in the demand for delivered electricity is actually needed as a partial measure in order to make the change (decrease of GHGs) to happen. The ability of building sector to react to the challenge is an important prerequisite for Finland in order to be able to respond to the requirements of decreasing GHGs. The role of building sector is double in such a way that it is first important to decrease the GHGs of the building stock with help of improved energy performance and indirectly to enable the better power generation (in terms of GHGs) with the help of reduced demand for delivered electricity.

Section 4 shows assessment results for the final energy use and related GHG emissions of the Finnish residential building stock in 2020 and 2030. According to the results the total final energy demand in 2030 would be 29 TWh including 29 TWh for heating spaces and 9.2 TWh because of the use of electricity. This assessment takes into account the assessed outgoing share of the current stock and the share of buildings needing either light or thorough renovation during the coming years. It is also based on assumption that an effective combination of energy renovation measures would be done for those buildings that need thorough renovation. The share of electricity

from the assessed 29 TWh is 27% (7.8 TWh). However, the total use of electricity could be further decreased by roughly 4 TWh with help of ground heat pumps of detached houses. Assuming that the energy is produced with help of district heat and electricity and by using either 2010 values or predicted values for GHGs, we receive different results for the assessed impact of building stock in 2030:
The assessed GHGs of the existing building stock is 9.1 Mt by using the present values
The assessed GHG of the existing building stock s 4.7 by using the predicted values (2030)
If we further consider the assessed savings in demand for delivered electricity because of the change of attached houses from electrical heating to ground heat pumps, we receive the following results:
The assessed GHGs of the existing building stock is 8.1 Mt by using the present values
The assessed GHG of the existing building stock in 2030 is 4.5 by using the predicted values.

6. Economical assessment of renovation concepts

The potentials to remarkably and economically improve the energy performance of buildings are linked to the cases where an extensive renovation is needed for an out-dated building. However, also separately done changes of windows, refurbishment of facades etc. should lead to a reasonable improvement of energy performance. On the basis of the study, the life cycle impacts of successful renovation concepts can be summarized as follows:

- significant reduction of energy consumption and related GHGs
- reasonable increase of investment cost
- reasonable savings in life cycle costs
- increase of resale value.

The most significant increase in economic value (market value) with the help of extensive renovation can be achieved when the building or the block of buildings is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. In these cases the costs of renovation can be compensated with the help of the increase of market value. This can also be realised by increasing the density of the area. Effects on economic values of houses and buildings and departments may sometimes be significant because of improved performance and because of aesthetical improvement.

The economic and environmental impact of the renovation of certain building types and groups was also assessed. The assessment was done for detached buildings from 1940–1959, detached buildings from 1980–1989 and for residential blocks of flats from 1960–1069 and 1970–1979. These groups of building were selected because of their big share from the whole building stock. Alternative renovation concepts were as follows: Renovated with 100mm thermal insulation, Renovated with 100mm thermal insulation and ventilation renovation, Renovated with passive level envelope, Renovated with a combination of renovations. On the basis of economical assessment results the following recommendations are given:
All studied alternative energy saving methods are favourable in the case of detached houses from 1940-1959 as the effect of the improved insulation of envelope is very high. Also almost net zero energy level may be achieved in an economical way when connected to an extensive renovation and when there is a need to improve the quality of indoor climate.
In the case of relatively new detached houses (1980-1989), almost net zero energy target is the most economical when there is a need for extensive renovation and need to improve the quality of indoor climate.
In the case of detached houses the target of almost net zero energy building is recommended while in the case of residential blocks of flats passive level envelope and possible renewal of ventilations are the most economical when there is a need for extensive renovation and need to improve the quality of indoor climate.
The economic impact studies were also made regarding the whole existing building stock. In the case of required renovations it was assumed that 75% of all buildings which need thorough renovations shall be renovated with 100mm additional thermal insulation and 25% of them with 100mm thermal insulation and ventilation renovation. The total volumes, cost savings, investment costs, needed annual support and labour effects of renovation concepts in the whole residential building stock in Finland were assessed to be as follows:

Table 8: The assessed total volumes, cost savings, investment costs, needed annual support and labour effects of renovation concepts in the whole residential building stock in Finland

Whole residential building stock Total area 266 000 **mill. m^2 (2010), renovated area 140 000 m^2** by 2030.	Renovated area in year **mill. m^2/y**	Corresponding annual heating cost savings in average **mill. €/y**	**Corresponding** extra investment costs **mill. €/y**	Annual need for public support (10-15% of investment) **mill. €/y**	Labour effects Person years/y
Renovated totally with required energy savings	7.0	-45	+650	65 100	9 000
Renovated totally by new ventilation and passive level envelope	7.0	-70	+1 350	150 200	17 000
Renovated totally to almost net zero energy buildings	7.0	-140	+2 750	270 400	31 000
Renovated 50% by new ventilation and passive level envelope and 50% to almost net zero energy buildings	7.0	-105	+2 050	150 200	26 000

7. References

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