Chapter 13
The Best Solution for Renovation in Terms of Climate and Economy

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Abstract EU aims to reach carbon neutrality by 2050. Besides energy consumption reduction, also greenhouse gas emissions have to be cut starting from the production of materials and construction work through the use phase to the end of the use of the building. Existing buildings are estimated to provide a high potential for reducing global warming. This paper focuses on research question, how reasonable are energy efficiency improvements of existing buildings, as the materials used in the process produce CO_2 emissions and increase costs compared with conventional maintenance. This issue is a part of the Sustainable Development Goal 13 Climate Action, which integrates climate change measures into national policies, strategies, and planning and a part of Goal 11 Sustainable cities and communities, which tries to increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion resource efficiency mitigation and adaption to climate change. The carbon footprint of an existing renovated building constitutes mainly from energy consumption emissions. In life cycle costs, the deciding factor is investment. If the building was heated by zero-emission ground source heat, structural renovations would not be worth doing. On the other hand, structural improvement of energy efficiency is recommendable if a building is connected to district heating (DH). Strong reasons, either endogenous or exogenous, must exist for replacing an existing building with a new one. They cannot be justified with the carbon footprint or life cycle costs. These results apply to countries, where the energy efficiency of existing buildings is reasonably good.

Keywords Deep renovation · Rebuilding · Carbon footprint · Life cycle cost · Energy efficiency

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13.1 Introduction

EU aims to reach carbon neutrality by 2050 (EU, 2019). In practice, this means that the greenhouse gas emissions of a Member State may not exceed the carbon sinks of the country. The EU has made a determined effort to reduce energy consumption in buildings. In the future, low emissions or even the carbon neutrality requirement will be extended to cover the entire life cycle of a building, starting from the manufacture of materials and construction work through the use phase to the demolition of the building. Carbon dioxide emissions from the life cycle phases are referred to as the carbon footprint of a building. The carbon footprint is therefore a narrower concept than life the cycle assessment (LCA) or environmental product declaration (EPD), which also takes into account other greenhouse gases and their impact on the environment.

Economic decision-making has traditionally been strongly based on the comparison of alternative investment costs or the cost-benefit analysis, which takes into account not only the costs but also the achievable benefits. In order to promote energy efficiency, developers have been recommended to use life cycle costs (LCC) as a decision-making tool (EU, 2012). If energy prices increase significantly, it will be worth investing in energy efficiency. Therefore, in addition to investment costs, developers have been encouraged to assess the operating costs of various alternatives. The outcome of the Swedish study came also to this conclusion in economic comparison between a zero alternative (no energy efficiency improvement), renovation to a passive house today, renovation to a passive house in ten years, and rebuilding. The most economically viable alternatives were the ones that contain renovation. Although these alternatives lead to higher investment costs compared with the zero alternatives, relatively soon they were covered by earnings (Dahlöf & Malmros, 2011). Almost a decade later, the Swedish study had the same conclusion. Renovation is more affordable in terms of life cycle costs. The moderate level, as a rule, is more cost-optimal than an ambitious repair. The LCC of the energy renovation is highly dependent on the building type and thermal performance prior to energy renovation (La Fleur et al., 2019). However, renovation is not an option in all cases. The building may simply be of such poor quality that it is not worth making an expensive energy-related investment (Verbeeck & Cornelis, 2011).

The existing building stock is seen as a highly potential target for improving energy efficiency and reducing climate emissions (Bpie, 2011). Besides positive planetary impacts, a Swedish study found the positive social impacts of renovation in terms of the social cost of carbon in the study where renovation and new construction are compared with keeping buildings in their original state (Nydahl et al., 2022). However, developers have a half-hearted approach to energy efficiency on account of the fact that, with the current energy prices, repayment times for measures may amount to dozens of years. For this reason, energy and renovation grants and benefits linked to energy efficiency agreements have been introduced in order to promote improvements in energy efficiency (Bertoldi et al., 2020). The question has also been raised whether low-profit projects should be supported (Dubois & Alleker, 2015).

The assessment of the carbon footprint of the life cycle has thus brought new perspectives to public debate. Can energy efficiency improvements in old buildings be seen as reasonable as the materials used in the process produce CO_2 emissions? How long will it take to compensate for such extra emissions with a more energy-efficient building or low-emission heating? Is it even worth renovating buildings when the energy industry is in the process of giving up fossil fuels in energy production? The energy produced in a purely centralized manner reduces emissions from buildings with poor energy efficiency.

A systematic review of case studies that compared the life cycle carbon footprint of refurbished and new buildings showed that most refurbishments had a lower footprint and some new buildings performed better than refurbished ones. This study also shows that on the basis of current evidence, it is still not possible to conclusively determine which of the alternatives is preferred (Schwartz et al., 2018). Another similar literature study focused on buildings located in northern latitudes and found 15 comparisons between renovation and rebuilding (Huuhka et al., 2021). A summary of the comparisons was that renovation is less carbon over a short time span, but often also over a longer time span. Rebuilding may become more low-emission in the long term if a highly energy-efficient new building and a weak existing building have been paired. Long carbon investment compensation time is problematic from the perspective of combating climate change and mitigating its effects. This is the case also in the Swedish million program era buildings. The study of them came to the conclusion that the renovation of the current building clearly had the least climate impact compared to demolishing and building a new building, assuming 50 years life span (Eskilsson, 2015).

The question is now topical for apartment buildings built in the 1960s and 1970s from precast concrete units. With the society urbanizing at the time, a great number of such buildings were built. Construction techniques that made use of industrial precast concrete units were developed to satisfy high demand, but their quality and, in particular, architecture have proved inferior to those of buildings dating back to the previous periods. Many buildings absolutely need the renewal of their facade and potable water pipelines (Nippala & Vainio, 2017). At the same time, due to energy and climate targets, the energy efficiency of buildings should also be improved. Additional measures will increase repair costs to the extent that demolition and rebuilding will become viable alternatives to renovation.

Upgrading the existing stock to reduce CO_2 emissions cheaply, quickly, and easily would be invaluable in shaping future housing policy. All referred researchers reminded that further analysis is needed for example carbon footprint and building embodied energy content. Instead, centralized energy production, decentralized energy supply, and micro-combined heat and power production (CHP) can change the outcome of energy analyses on what is the best option in terms of costs and climate impacts (Power, 2008).

13.2 Research Question and Method

What is the best development scenario for the economy and the environment regarding apartment buildings dating back to the 1970s: to carry out only the necessary technical repairs or a large-scale renovation which, in addition to technical repairs, would improve energy efficiency, or the demolition and replacement by a new building?

The method of research is a case study. The case is a typical 1970s concrete panel building. Four development options are being tested for it. For alternatives, carbon footprint and life cycle costs are calculated by standardized methods.

Option A: Maintenance. The exterior walls of the building will be subjected to surface finishing, with the water and sewer systems being renewed. Old windows are replaced by new windows. With regard to the heating system, measures are taken to maintain its operation, which include the renewal of the heat exchanger and automation system, as well as the balancing of heat distribution. After these measures are taken, the energy class of the building will be C.

Option B: Deep Renovation. Building exterior walls will be further insulated, with the windows and water and drainage systems being renewed. The energy efficiency of the heating system will be improved with a new heat exchanger and heat recovery for the ventilation system. The building will remain connected to the district heating system because it is the predominant heating method for apartment buildings in urban areas. Renovation meets the energy efficiency requirements and the share of renewable energy. After renovation, the energy class of the building will be B.

Option C: Concrete Rebuilding. The old building will be demolished and a new building of the same size made of precast concrete units will be built. As the new building meets the current energy efficiency requirements set for new A-class construction, it will also be equipped with a heat recovery system and solar panels. The new building will also be connected to the district heating system. Its energy class will be A.

Option D: Wooden Rebuilding. The old building will be demolished, with a new wooden block of flats being built in its place. In terms of energy efficiency, it will be equal to option C, that is, its energy class will be A.

For all four options, the carbon footprint is calculated in accordance with the calculation guidelines issued by the Finnish Ministry of the Environment (Kuittinen, 2017) by using national emission coefficients (CO_2-data, 2021). As emissions are calculated for 30 years, there is no need for the replacement of building parts. The sensitivity of energy production's global warming potential has been tested in four scenarios. Scenario 1 emission coefficients are the same as set in the Finnish long-term Renovation Strategy for 2020 (Ministry of Environment, 2020; Energy year, 2021) and will not change in 30 years. Scenario 2 takes into account in emission coefficients the cleaning of energy production when fossil fuels are replaced by renewals in order to make Finland carbon neutral by 2035 a reality (Koljonen et al., 2019). Scenario 3 is an accelerated scenario 2 to allow district heating production to get out of fossil fuels imported from Russia. In scenario 4, district heating (DH) is replaced by ground source heat (GSHP) in all options. The default coefficient of GSHP performance is 2.9.

Life cycle costs are calculated for 30 years by using EU rules (EU, 2012). Renovation costs and new building costs (investment cost) are typical for this building type (The Housing Finance and Development Centre of Finland (ARA), 2022). The residual cost has been calculated based on the technical life of the buildings (Rakennustieto, 2008). The level of maintenance costs of the property is based on statistics (Finance of housing companies, 2021). The sensitivity of costs is examined using two different energy prices which indicates the price level 2021–2022 (Nordpool, 2022), and three different assumptions of energy price development and alternative discount rates as well. Interest rate options have been set at a level suitable for public investment and private low-risk investments (Streicher et al., 2020). The 30 years chosen for the review period is an EU recommendation for cost-optimality reviews in residential buildings (EU, 2012). The baseline situation of the case under consideration and the significant variables of alternative development strategies are summarized in Table 13.1. The calculation assumptions and variables are summarized in Table 13.2.

This analysis uses constant euro. Prices do not contain the effect of inflation but represent a standard price level, that is, the purchasing power of the selected base year. To discount them, a real interest rate will be used.

Table 13.1 Description of scenarios

	Unit	A. Maintenance	B. Deep renovation	C. Concrete rebuilding	D. Wooden rebuilding
Total floor area	m^2	3000	3000	3000	3000
U-value of windows	W/m^2K	2.5	1.0	1.0	1.0
U-value of walls	W/m^2K	0.4	0.29	0.17	0.17
U-value of roof	W/m^2K	0.4	0.4	0.09	0.09
U-value of basement	W/m^2K	0.4	0.4	0.16	0.16
Heat recovery	%	–	65	65	65
Heating	–	DH/GSHP	DH/GSHP	DH/GSHP	DH/GSHP
Heat consumption	kWh/m^2	200/70	70/25	55/20	55/20
Auxiliary electricity	kWh/m^2	5	5	5	5
Other electricity (exl. from LCC)	kWh/m^2	30	30	30	30
Energy class DH	–	C	B	A	A
Investment cost	€/m^2	600/700	1000/1100	3000/3100	3300/3400
Residual value	€/m^2	275	425	2350	2350

Table 13.2 Calculation assumptions

Variable	Unit	Value
Lifespan of building/calculation period		
Scenario A, B	a/a	50/30
Scenario C, D	a/a	100/30
Interest rates		
Basic	%/a	3
Sensitivity	%/a	0 and 6
Energy price incl. taxes		
Electricity	cent/kWh	10/20
District heating	cent/kWh	10/20
Energy price development		
Basic	%/a	2
Sensitivity	%/a	0 and 4
CO_2 emissions year 2020/year 2050		
Electricity	g/kWh	65/12
District heating	g/kWh	160/45
Maintenance cost	€/m^2, a	6
Maintenance cost development	%/a	2

Swiss research (Streicher et al., 2020) uses 3% as a discount rate. This rate was considered too low for companies awaiting returns. On the other hand, the study showed that a discount rate of more than 8% caused energy investments to be no longer profitable. The study used 30 years as a time span, justifying it to be typical. Similarly, the same 30 years is the recommendation of the European Commission for the period considered (EU, 2012).

The price of electricity in Finland has been at a level of 30–40 €/MWh for a long time. Electricity transmission and taxes raise the unit price by 10 snt/kWh (Energy, 2022). At the beginning of the year 2022, price level has been stable at 10 €/MWh. In the year 2021, NordPool's price has ranged from zero to 60 €/MWh. At the beginning of the year 2022, the Russian invasion and economic sanctions have not pushed prices as high as did dry summer in the Nordic countries. The price of district heating has changed since 1996 to about 30€/MWh for 2022 approx. 85€/MWh (Energy, 2022). Used district heating price 10 snt/kWh is at the same level as 2022–2023 becoming heating prices. Giving up fossil fuels pressures to raise prices.

13.3 Results

13.3.1 Carbon Footprint

In options A and B, emissions from materials and construction work are low (Table 13.3). Typically, renovation measures can be done without heavy, high-emission materials. Compared with options A and B, in options C and D emissions

Table 13.3 Carbon footprint of *o*ptions A, B, C, and D over 30 years by *e*nergy *s*cenarios 1, 2, 3, and 4

	Unit	Option A	Option B	Option C	Option D
Building materials and construction	$kgCO_2/m^2$	25	40	340	240
Energy scenario 1	$kgCO_2/m^2$	1000	355	285	285
Energy scenario 2	$kgCO_2/m^2$	510	180	145	145
Energy scenario 3	$kgCO_2/m^2$	435	155	125	125
Energy scenario 4	$kgCO_2/m^2$	70	30	25	25
Carbon footprint 1, total	$kgCO_2/m^2$	1025	**395**	625	525
Carbon footprint 2, total	$kgCO_2/m^2$	535	**220**	485	385
Carbon footprint 3, total	$kgCO_2/m^2$	460	**195**	465	365
Carbon footprint 4, total	$kgCO_2/m^2$	100	**75**	370	370

are caused by the demolition of the old building and the construction of new buildings. With the emission coefficients of the current energy generation, described by energy scenario 1, the emissions of materials would be almost irrelevant in renovation options (A, B), and about half the emissions of rebuilding options (C, D). As energy production abandons fossil fuels, either in a planned (energy scenario 2), or accelerated (energy scenario 3) time frame, the materials' proportion of emissions will increase.

Apartment buildings are typically located in cities, and connected to the district heating network (DH). District heating could be replaced by a property-specific ground source heat system (GSHP, energy scenario 4). Heat harvested from the ground is emission-free, and the operation of heat pumps uses electricity. The maximum cumulative emissions have Option A Maintenance, which heating energy consumption is nearly twice as much as other options. In terms of emissions, the order of alternatives from the lowest carbon footprint to the largest would change to B, A, C, and D. In DH energy scenarios 1–3, option A owned the largest global warming potential in a 30-year period.

In DH scenarios 1–3 rebuilding options C and D need 10 years or more to compensate for emissions of demolition and materials of new buildings (Fig. 13.1). GSHP scenario 4 emission savings of A-energy class new buildings are not sufficiently compensated material emissions in a selected 30-year period.

13.3.2 Life Cycle Costs

The case building is either connected to district heating (Table 13.4) or heated by ground source heat (Table 13.5).

If there is no return expectation for investment, zero may be used as a discount rate for life cycle calculation. The zero interest rate, but a brisk rise in energy prices makes option A: maintenance the most affordable. Of course, low energy prices or even free energy (GSHP) support option A.

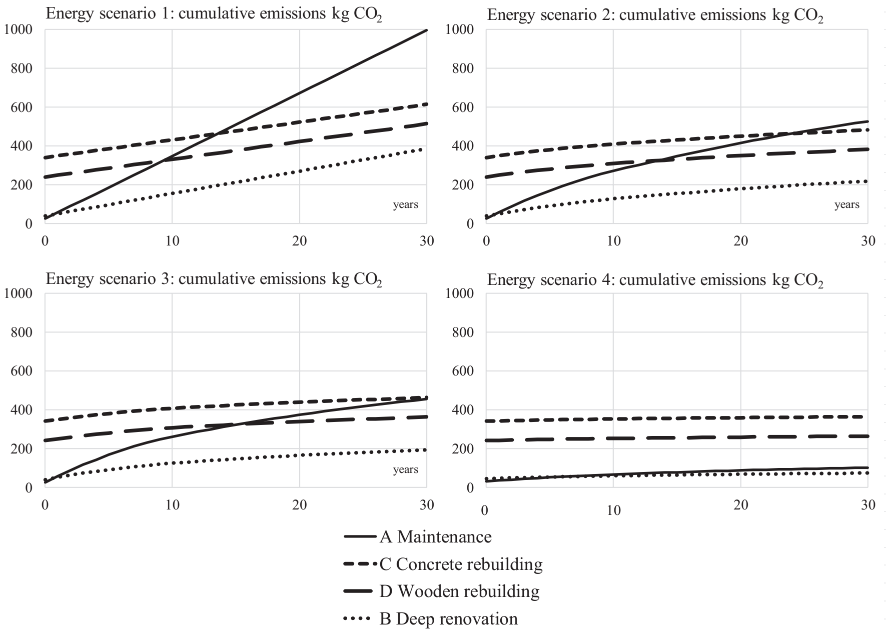

Fig. 13.1 Cumulative emissions of options A, B, C, and D by energy scenarios 1, 2, 3, and 4

Table 13.4 Net present value (€) of *o*ptions over 30 years if building is connected to DH network

		Energy price 10 snt/kWh			Energy price 20 snt/kWh		
Option	Interest rate	+0%	+3%	+6%	+0%	+3%	+6%
A	0%	1215	**1070**	**966**	**1850**	1493	1268
B		**1062**	1141	1147	1294	**1295**	**1258**
C		1090	2317	2790	1276	2440	2879
D		1390	2617	3090	1576	2740	3179
A	2%	1448	1199	**1041**	2317	1750	1420
B		**1147**	**1188**	1175	1465	1389	1314
C		1159	2354	2812	**1413**	2516	2923
D		1459	2654	3112	1713	2816	3223
A	4%	1796	1385	**1147**	3012	2123	1632
B		1274	**1256**	1214	1719	**1526**	**1391**
C		**1260**	2409	2843	**1616**	2625	2985
D		1560	2709	3143	1916	2925	3285

Higher discount rates are used if there is a return expectation for the investment or a loan has been used for financing, the interest of which should be paid. If the interest rate is higher than zero and the energy price is either 10 snt/kWh 20 snt/kWh or free (GSHP), option B: deep renovation improves its competitiveness. The advantage of renovation options A and B arises from investment costs. Although

Table 13.5 Net present (€) value of options over 30 years if the building is heated by GSHP

		Energy price 10 snt/kWh			Energy price 20 snt/kWh		
Option	Interest rate	+0%	+3%	+6%	+0%	+3%	+6%
A	0%	**912**	**902**	**874**	1144	**1057**	**984**
B		1022	1148	1181	**1115**	1210	1225
C		1082	2345	2839	1159	2396	2875
D		1382	2645	3139	1459	2696	3175
A	2%	**997**	**950**	**901**	1315	**1151**	**1040**
B		1056	1167	1192	**1184**	1247	1247
C		1110	2360	2848	1216	2428	2894
D		1410	2660	3148	1516	2728	3194
A	4%	1124	**1018**	**940**	1569	**1288**	**1117**
B		**1107**	1194	1208	**1285**	1302	1279
C		1153	2383	2861	1301	2473	2920
D		1453	2683	3161	1601	2773	3220

new buildings consume less energy, it is not enough to repay higher investment costs over a period of 30 years. It is the higher investment costs that are the reason why option D: wooden rebuilding remains in last place in comparison to life cycle costs.

13.4 Discussion

For the first time, the Energy Performance of Buildings Directive adopted a position on improving the energy efficiency of old buildings in 2010. Due to this and climate concerns, the environmental perspective has also been strongly involved in the official steering of construction and property management. In the first phase, the focus was on energy consumption and greenhouse gas emissions created during use. For these, the steering emphasized technical feasibility, economy, and functionality. Another guiding principle was combining improvements in energy efficiency improvements with other repairs that would otherwise be made. For example, an intact facade need not to be touched, but if it needs repairs due to damage, at least improving heat insulation should be considered.

The most recent perspective included in the steering is the carbon footprint of the building's life cycle. Based on this study, the carbon footprint and life cycle costs can, but not always, coexist in harmony. Timber construction provides an exception; it has a small carbon footprint but is somewhat more expensive than concrete construction. The cost-effectiveness of concrete in apartment building construction stems from determined development work which began in the 1960s. Regarding the construction of wooden apartment buildings, technological development is lagging behind in industrial-scale construction.

This study has sought to provide an answer to the question of what should be done with apartment buildings dating back to the 1970s, which need renovation. The options examined were A: maintenance, B: deep renovation, C: concrete rebuilding, and D: wooden rebuilding. For these scenarios, carbon footprints and life cycle costs were calculated. Compared with the current new buildings, the energy consumption of a building of this age is three times higher.

Based on the carbon footprint and life cycle costs, option A: maintenance is rather competitive. This option is often excluded in studies if the focus is on the reduction of energy consumption and emissions. In Finland, however, the alternative is relevant because energy efficiency has been taken seriously since the 1970s oil crisis. If the expected life of the building is limited, it is the recommended choice in all respects. However, in terms of the carbon footprint, district heating should be replaced with a ground-source heat pump. Heat pumps are also recommended by other studies (Niemelä et al., 2017; Hirvonen et al., 2021). If the building has an expected long life span, the recommended scenario is B (deep renovation). This option is particularly favored from an environmental point of view, as has been found in other studies (Huuhka et al., 2021; Hasika et al., 2019).

Scenario C (Concrete Rebuilding) has a large carbon footprint. Scenario D (Wooden Rebuilding) has high life cycle costs. The adoption of these solutions requires strong arguments. The change from embodied and operational energy consumption to global warming potential has not changed the outcome of comparisons in 10 years (Nippala & Heljo, 2010; Dahlöf & Malmros, 2011). These naturally include serious damage or interior health hazards. The decision of demolishing a building and build a new, larger one may also be based on the fact that the location has untapped potential. For example, a new building multiplies the amount of floor area in an attractive location. In addition, when taking into account the difference in sales prices or rent levels between old and new apartments, replacing the old building with a new one may be a clearly profitable choice.

Even, if buildings may look similar to each other, they are also individuals. There is a great number of endogenous and exogenous factors. Their combination determines the choice between conservation, renovation, or rebuilding (Verbeeck & Cornelis, 2011; Schwartz et al., 2018; Vainio & Nippala, 2019).

In the spring of 2022, one major exogenous factor is the EU's goal of getting rid of fossil fuels imported from Russia. Fossil fuels are used in combined heat and power production (CHP). District heat is an excellent form of heating but only if the energy source is renewable. The foundation of the Kyoto pyramid is structural improvements before changing the heat source. These good principles may be worth bargaining and betting on the electrification of heating, since it is easier to find zero-emission propulsion for heat pumps than enough renewable energy sources for large-scale district heating. This potential development has been seen many years ago (Power, 2008).

13.5 Conclusion

The main conclusion from the comparisons of carbon footprints and life cycle costs is that the lower energy consumption will not be able to pay back their higher carbon or financial investment compared with the renovation of existing buildings. European Energy Crisis 2022 may not change the mutual competitive situation of alternatives. The increase in energy prices will also increase construction costs as well as the economic and social risks that hold back investment in new construction.

Most of the carbon footprint in the options comes from the emissions of operational energy. The crucial factor in life cycle costs is renovation or construction costs. From both perspectives, option B: deep renovation proved the most advantageous option. Environmentally, it loses its affordability for option A: maintenance if the selected heating means is GSHP. As a result of option B: deep renovation, the building will remain a building from the 1970s. With regard to the housing market, this means that housing sale prices and rents will remain at a significantly lower level compared with renovated or completely new buildings. Strong reasons, either endogenous or exogenous, must exist for demolishing an old building, that is, implementing option C: concrete rebuilding or option D: wooden rebuilding. They cannot be justified with the carbon footprint or life cycle costs.

The study has been carried out in the climate conditions of northern Europe, where energy is consumed for heating buildings. However, this has been taken into account in building technology, because, as a rule, old buildings are heat-insulated and equipped with three glass windows, for example. Such endogenous properties of buildings and, exogenous properties accountable to location, limit the general applicability of the results. As they are, they are best applied to the Baltic Sea countries. One finding that is more broadly applicable to Europe indicates that, in the terms of carbon footprint, renovation is the most profitable option. Strong arguments must exist for demolishing a building and replacing it with a new one.

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