Demolish, recycle, build new or renovate – energy use throughout the life cycle.

Abstract. The building industry has a major impact on the global carbon emissions, the use of natural resources and generation of waste. A drastic change is needed for this industry to be a part of a sustainable future. Within this research, a case study is performed to investigate how cultural values of a building can be preserved when energy efficiency measures are taken, with a low global warming potential (GWP). Keeping the cultural values of the red brick façade, the original window shape and the natural stone in the plinth, there is still an energy saving potential of halve the energy use for space heating. The GWP of the measures taken is strongly dependent on the energy mix in the district heating system.

1. Introduction

The building industry has a major impact on the global carbon emissions, the use of natural resources and generation of waste. A drastic change is needed for this industry to be a part of a sustainable future. From a European perspective, the construction industry accounts for half of all raw materials extracted, half of the total energy use, one third of all water use and one third of all waste generated [1]. The Swedish construction industry accounts for more than 20% of Sweden's total climate emissions, where the main climate impact is related to the building materials used. In addition, a large fraction of the material purchased by the construction industry becomes waste; more than 30% of all waste generated in Sweden is generated from this sector, and only half of the waste is recycled. The latest energy statistics for the Swedish building industry unfortunately shows an increase of energy use, carbon emissions and generation of waste from construction activities in Sweden [2].

Life-cycle energy use in buildings is strongly associated with energy use during the operational phase. The operational energy use in buildings stands for 33 % of Sweden’s total energy use and energy efficiency measures are still very important. However, the environmental impact from the building industry needs to take into account other aspects for a more complete picture, such as carbon impact through the buildings full life cycle and use of natural resources. It is important that the strive for environment impact reduction also is carried out in accordance with the objective Good built environment and the bill regarding Configured living environment, which includes demands on the preservation of cultural historical values.

Within this study, a broader scope of the energy use is analysed and presented both as kWh and GWP (Co2-eq), using LCA including all scopes of a building’s life cycle. With a demonstration project as a base, it is studied how to combine these three focus areas, weighing equal aspects on energy use, climate impact and cultural-historical values.

2. Method

The demonstration project used in this study is situated in the center of Lund, Sweden. It consists of five apartment buildings, designed and built in the late 1940s and early 1950s, as accommodation for nurses, working at the nearby hospital. The five buildings have three or four stories with a concrete load bearing structure and a red brick façade. The buildings and the character of the site are well-preserved, no additional buildings such as environmental houses or changes in the exterior appearance, for example new entrance doors.

One of the buildings was studied in detail within this study, regarding possible renovation measures. This building consists of three stories with a basement and 15 one-room apartments. The building has a central hydronic radiator heating system, connected to the district heating system. An exhaust fan has been added to the original natural ventilation system, with exhaust air devices placed in bathrooms and kitchens in every apartment.

The overall method for this study is to evaluate the choice of renovation measures with multiple objectives, reducing energy use, minimizing environmental impact and preserving the cultural values associated with the building. The impact on energy use is evaluated using the simulation software IDA ICE, [3], [4], [5] and the LCA is performed using Open LCA with data from different databases. The impact on cultural value is taken into account by a qualitative assessment. A schematic of the process is shown in Figure 1, which also show that renovation measures will be evaluated separately and in combination.

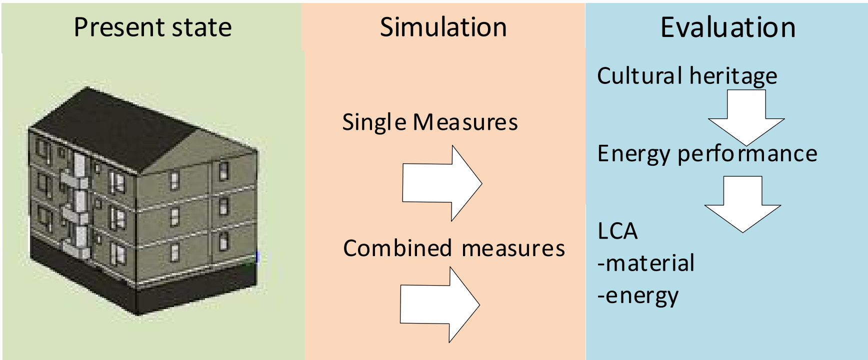

Figure 1. Schematic description if evaluation procedure

The indoor environment was examined in two apartments, by measuring indoor temperature, carbon dioxide concentration and air exchange rate. The measured exhaust air flow rate in the apartments was high, between 0,8 – 1,0 l/s,m^2. The legislative ventilation demand in apartments in Sweden is 0,35 l/s,m^2, making the measured results exceed the demands by far. The indoor temperature did not vary much during the test period of 14 days, and was approximately 22°C. The measured indoor carbon dioxide concentration was approximately 550 ppm and relative humidity approximately 45%. The apartments used in the study had no tenants at the time for measurements.
The results of the measured values of indoor environment shows that both ventilation rates and indoor temperatures in the existing building are in line with current Swedish legislation and not required to be remedy in the renovation measures evaluated in the study.

The inventory of cultural values was made by interviewing former residents, previous workers in the area and by visual inspections on site supplemented with a literature study.

2.1. Energy simulation

The building is located and modelled in Lund, Sweden, (longitude 13°E, latitude 55°N) using a climate file representing a typical year. This typical year is constructed from climate data for the period 1981-2010 by the Swedish Meteorological Institute on behalf of the building industry standard for energy calculations, [6]. The building has a heated floor area of 800 m^2, constituting of both apartments, stairwell and basement, each floor was modelled the same way and simplified to four apartments (one in each corner) together with the stairwell. The basement and stairwell is modelled to be heated to 15°C and the apartments to 21° , the latter according to the Swedish building regulations, [7]. Each floor is approximately 200 m^2, where 17% were stairwell.

Heated floor area is in Sweden defined as area within the exterior walls heated to more than 10°C. The internal heat load, from occupants and household electricity, was also modelled according to the Swedish building regulations. The heat from appliances was modelled as a flat load in the apartments summing up to a total of 30 kWh/·m^2·a of which 70% was allowed to be used during the heating season corresponding to about 3.5 W/m^2. The occupancy was on average 0.04-0.05 persons/m^2, with activity of 1 MET. The ventilation rate was modelled according to the measurements and averaged to 0.6 l/s, m^2, used both before and after renovation. This value is higher than the value of 0.35 l/s, m^2 fresh air supply stated by the Swedish building regulations, however, it is necessary to have a higher airflow in smaller apartments in order to have a sufficient rate of removal of air. The building envelope properties are listed in Table 1, both for the present state and for the renovation measures.

Table 1. Building properties for the present state and for renovation measures

Present state	Properties	Single measures	New properties
$U_{Exterior\ wall}$	0.77 W/(m²K)	Wall insulation	0.4 W/(m²K)
$U_{attic\ floor}$	0.65 W/(m²K)	Attic floor	0.25 W/(m²K)
U_{Window}	2.8 W/(m²K)	New window	2 W/(m²K)
$U_{basement\ wall}$	3.6 W/(m²K)	Added window pane	1.8 W/(m²K)
$U_{basement\ floor}$	4.4 W/(m²K)	Added glass cassette	1.3 W/(m²K)
Air leakage	1.6 l/(s m²) ext. area at 50 Pa	Air leakage	0.4-1.6 l/(s m²) ext. area 50 Pa
Thermal bridges	15 % of U_{tot}·A_{tot}	Mech. Vent. Heat Recovery	Heat recovery efficiency70 %
		Thermal bridges	15 % of U_{tot}·A_{tot}

2.2. Global Warming Potential

Global warming potential (GWP) has been assessed by using the life cycle assessment (LCA) method. The LCA included the life cycle stages production (A1-A3) and end of life (C1-C4) for the materials needed for the energy renovation measures and the operational energy use (B6) for the building. The base case of the building only includes the global warming potential of the current energy use of the building. The base case is compared to the global warming potential of the energy use and the added material related to each renovation measure.

The global warming potential, due to the energy use in the building, was assessed in the software OpenLCA (version 1.10.3). Within the software OpenLCA, the ILCD 2011 midpoint v.1.0 method was chosen for the calculations [8]. The used environmental impact category within this method is called "Climate change - ILCD 2011 Midpoint". The free database European reference Life Cycle Database of the Joint Research Center version 3.2 (ELCD) is used for the life cycle inventory (LCI) data for energy sources.

The functional unit of the study was 1 m^2 heated floor area of a renovated building that fulfils the building regulations in Sweden. The calculation period of 50 years was used in this study. Since this is the expected lifespan of a new building.

The global warming potential have been assessed for five energy mix scenarios, see Table 2. The energy mix scenarios are developed from four parameters that impact the global warming potential of the energy mix. The four parameters are; 1) the share of different energy sources in the district heating mix, 2) the assumed change of sources of energy in the district heating mix over the calculation period of 50 years, 3) the source for LCI data, and 4) the electricity mix in the district heating system. For each scenario, one of the parameters have been changed from the base case scenario (Scenario III) that has the district heating mix of the location of the building. It is assumed that the energy mix in the district heating system is not changed during the calculation period, the LCI is taken from the ELCD database, and the district heating system has the Swedish electricity mix.

The building is located in Lund and the mix of energy sources in the district heating system in Lund is according to [9]. In Scenario V the sources of energy are based on the average mix of sources from all district heating systems in Sweden 2019 [10]. Energiföretagen have LCI data for the energy mix that is used in Lund district heating, this source for LCI data is assessed in Scenario I [9].

In Scenario II the sources of energy are assumed to change over the 50 years of calculation. The changes of energy sources are based on a scenario that was developed by the Swedish Energy Agency [11]. It is assumed that there will be no fossil fuels in the energy mix for heating. In the scenario the energy provided by electricity and biofuels has increased since the energy from natural gas and oil has been excluded. In scenarios IV, the average electricity mix for Sweden has been changed to the average electricity mix for Europe. This scenario has been included since the electricity mix in Sweden is connected with the rest of Europe.

Table 2: Energy mix scenarios.

Energy mix scenario	District heating system	Assumed change over 50 years	Source for the LCI data	Electricity mix
Scenario I	Lund	No change	Energiföretagen [9]	Swedish
Scenario II	Lund	No natural gas or oil	ELCD database	Swedish
Scenario III (base)	Lund	No change	ELCD database	Swedish
Scenario IV	Lund	No change	ELCD database	European
Scenario V	Sweden	No change	ELCD database	Swedish

The global warming potential for the added materials, the LCI input, has also been collected from EPDs. The EPDs were collected from three different databases for EPDs [12]- [14]. For each renovation measure, a maximum and a minimum GWP impact from the materials has been assessed. Several different EPDs for each included material has been compiled and compared. The EPDs for materials that were found with the largest GWP were added together and forms the maximum material case and the EPDs for materials with the lowest GWP were added together and forms the minimum case.

The expected lifespan of the included components in this study are assessed according to the methodology in ISO 15686-2:2012 and ISO 15686-8:2008. For added materials in the building envelope measures the component have an expected lifespan of 30 years in this study, in according to EN 15459:2007. For the ventilation measure, the expected lifespan of the new air handling unit (AHU) is 20 years [15], 30 years of the new duct system [16], 25 years for the supply air devices [17].

3. Results

3.1. Cultural values

Some of the cultural values associated with this site are not connected to the buildings or the materials, but of a more abstract nature, where the most frequent value mentioned is Venue. This place has been used both as a workplace and a place for staying, highly associated by meetings and interactions. This cultural value needs to be taken into consideration in the future development of the area.

The buildings have a factual architecture characterized with the ideas of functionalism. The courtyards are sunny to let in a lot of air and light, and the real estate has a high green area factor. The architect Ingeborg Hammarskjöld-Reiz is part of the ideas of emerging functionalism, but also creates human living environments. The architect is characterized by a sense of care. Cultural values in the exterior and interior expression of the building are many, where the most important are exterior materials visible for passers-by. The red brick facades are characteristic for the area and was manufactured at a nearby brickyard.

Three building materials are seen to be significant according to cultural values: the brick façade, the original shape of the windows and the natural stone in the plinth. The renovation measures evaluated in this study are chosen to preserve these cultural values; New windows replacing the old ones, an insulating glass cassette added instead of the inner pane of the existing windows, an added pane in the existing windows, interior wall insulation (CaSi), mechanical ventilation with heat recovery or added insulation on the attic floor.

3.2. Energy simulations

Figure 3 a) and 3 b) show the modelled energy use for heating of the building. In figure 3 a) the energy use for the base case (present state) together with each single measure are shown. The energy use is presented as annual use, normalized using the functional unit of heated floor area shown on the y-axis. The renovation measures are represented by acronyms on the x-axis explained in the textbox to the right. Figure 3 b) show the impact on the energy use for heating when combining different renovation measures. For both 3 a) and 3 b) the impact of the renovation measures can be compared to that of the base case and it is clear that the energy use is reduced for all measures.

The best single measure is the installation of mechanical ventilation with heat recovery (MVHR), that reduces the energy use for heating from 143 to 95 $kWh/m^2 \cdot a$. In figure 3 b) that best combination of measures in terms of reducing energy use is new window, wall insulation, attic floor insulation and MVHR, that reduces energy use from 143 to 54 $kWh/m^2 \cdot a$. This best-case combination is used for simulation of different global warming potential with different energy mixes as presented in Figure 5.

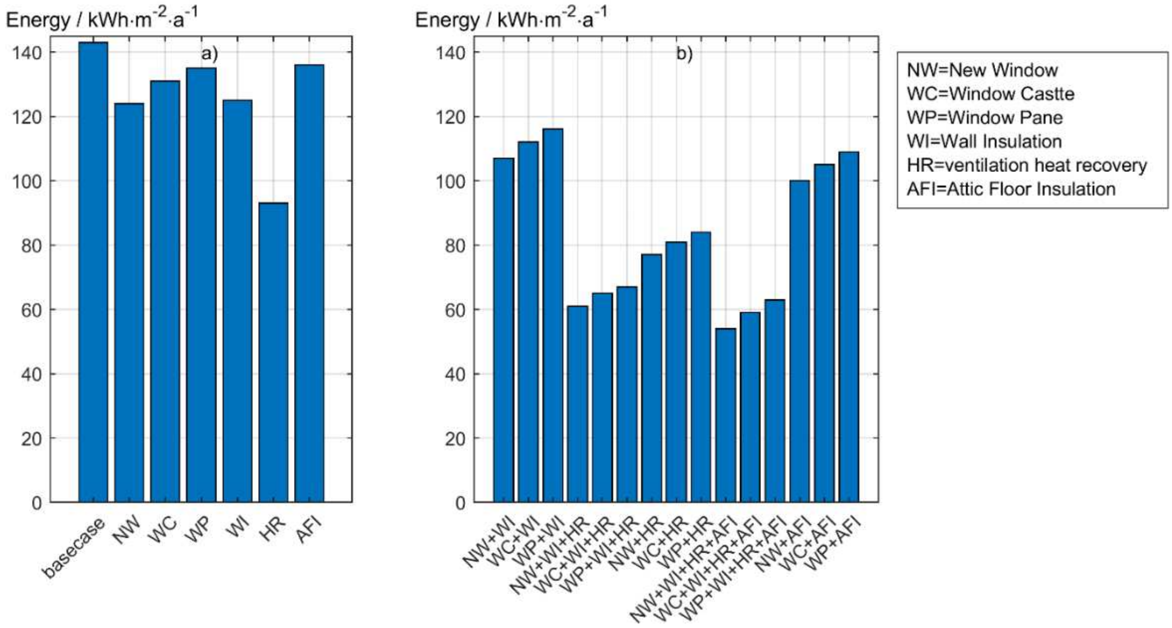

Figure 2. In a) the simulated energy use for heating for the base case and each single renovation measure. In b) the simulated energy use for heating for combinations of renovation measures.

3.3. Global warming potential

Figure 4 shows the global warming potential (GWP) for the five individual renovation measures and the base case, where no renovation is made. For each renovation measure, the GWP for the buildings' energy use and the added material due to renovation is presented. For each simulated renovation case, three stacks of GWP are simulated. The left stack shows the GWP of both the material used and GWP from operational energy use, the middle stack is GWP only from operational energy use and the right stack shows of the GWP from the material used for the renovation measure taken.

The highest value of the stack uses material with high GWP, and the lowest values uses material with low GWP, as described in the method. The two dotted lines in Figure 4 indicates the GWP for the operational energy use using the best and worse energy mix for the base case. This means that if the energy and material with high GWP is used, the renovation measures decrease the GWP if the top of the stack is below the dotted line at the top. On the other hand, if energy and material with low GWP is used, the renovation measure decreases the GWP if the bottom of the stack is below the bottom dotted line. The simulated operational energy use is also included in Figure 4 to show how the yearly energy demand varies depending on different renovation measures.

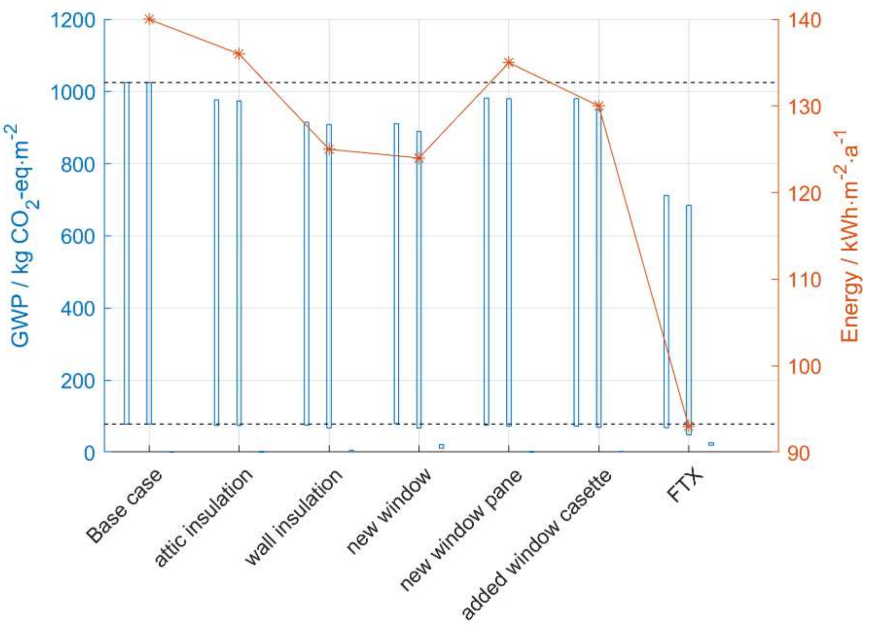

Figure 4. Simulation of the global warming potential (GWP) and energy demand for the five individual renovation measures and the base case, where no renovation is made.

The GWP for the best-case renovation according to energy measures, varies much between different energy scenarios as presented in Figure 5. The base case, where no renovation measures are taken, are compared with the best-case using materials with low GWP (min) and with materials with high GWP (max). Using scenario I, only renovation measures using materials with low GWP decreases the total GWP compared to when no renovation is made. With all other scenarios, from II to V, all renovation measures decrease the total GWP of the building.

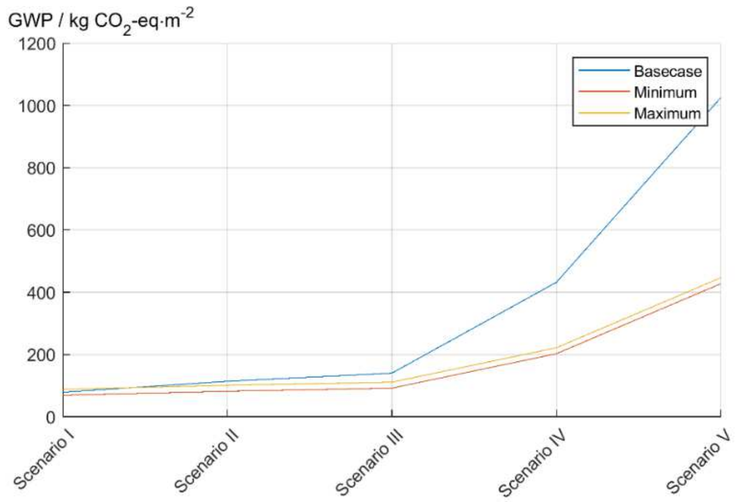

Figure 5. Simulation of the global warming potential (GWP) for the best-case renovation for the different energy scenarios.

4. Analysis and discussion

For this case study, it is shown to be possible to perform an energy renovation of the building, keeping the important cultural values in the building materials, with the potential of halve the energy use for space heating. However, the GWP of the measures taken varies much depending on energy mix in the district heating system.

Both Figure 4 show, with stacks very close to the bottom line, and Figure 5 show with scenarios I, II and III that energy with low GWP hardly promotes any measures at all. The GWP is lower for the combination of measures but only marginally. With an energy scenario with the lowest GWP, installation of a ventilation system with a heat exchanger is the only renovation measure where the GWP decreases compared to the base case, where no renovation is made.

First when using energy with higher GWP, the measures can seem to have a higher impact. This could be summarized as if your building is in an energy system with low GWP, do next to nothing, or in a system with high GWP, do everything. However, the problem is not that easily described. The global energy use needs to decrease drastically, making energy efficient measures important perhaps even in an energy system that we today model as having low GWP for the coming 50 years.

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