A COMPARATIVE GREENHOUSE GAS ANALYSIS OF ENERGY EFFICIENCY RENOVATION AND NEW CONSTRUCTION IN A RESIDENTIAL AREA – A PRELIMINARY STUDY

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ABSTRACT

Buildings are accountable for nearly half of the global greenhouse gas (GHG) emissions. Building sector is also considered to have the most economical potential for climate change mitigation. Several cities in Finland consider construction of new energy efficient residential areas as one strategy to reach even the short- and mid-term climate change mitigation goals of the future. Replacing existing residential areas that are in poor shape with new buildings is often considered as an economically more feasible option than renovating these areas. However, new construction projects cause significant GHG emissions in a short time period and the benefits of the improved energy efficiency realize only after several decades. Furthermore, energy efficiency improvements may also be implemented in the old buildings during the renovation process in an economically sustainable manner. Thus, legislation and regulation officials may have too little knowledge at their disposal in decision-making.

The study evaluates the GHG emissions of the renovation process of an existing suburban building and compares it to a recent construction project of a residential area with similar attributes. The research method of the study is life cycle assessment that takes the indirect emissions of the supply chains into account besides the direct emissions. The case study screens whether renovating existing suburban areas is a better way to promote climate change mitigation than constructing new ones. The results of the study indicate that renovating the current building stock may be ecologically more sustainable than replacing it with new buildings. The results and conclusions of the study have value in evaluating the current climate change mitigation strategies as well as in preparing new ones.

Keywords: Carbon spike, LCA, climate change mitigation, renovation, construction, real estate business (REB)

INTRODUCTION

Climate change is considered a major threat for the future of the mankind (IPCC, 2007). Climate change phenomenon is largely due to changes in the atmospheric concentration of greenhouse gases (GHGs) carbon dioxide (CO_2) being the most significant of them. Increase in the global GHG level is primarily due to the use of fossil fuels, land-use change worsening the situation with a smaller contribution. In the most pessimistic scenario presented by the IPCC, the global CO_2 emissions increase by 90% to 140% in the next 38 years resulting in an increase of global average temperature by 4.9 to 6.1 degrees Celsius and an average sea level rise of 1.0 to 3.7 meters. In the most optimistic scenario the CO_2 emissions decrease by 50% to 85%. As a result the global average temperature would increase by 2.0 to 2.4 degrees and the sea level would rise by 0.4 to 1.4 meters. Thus, even the most optimistic scenario results in considerable consequences to the environment, and more importantly, to mitigate the consequences to this level, significant changes in current emissions would be rapidly needed.

In Europe for example, the European Union has set short and mid-term GHG reduction goals for the years 2020 and 2050 in order to achieve the optimistic prediction; 20% to 30% reduction by 2020 and 85% to 90% reduction by 2050 compared to the 1990 level (European Commission, 2012). While the action programs include a variety of means, buildings are in a central role due to them being significant contributors to the climate change with a share of one third of the global energy consumption and the same share of GHG emissions (Huovila et al., 2007). In addition, buildings are considered to have the most economic potential for climate change mitigation of all sectors around the world (IPCC, 2007).

The life cycle emissions of buildings have been widely studied in the past (e.g. Junnila et al., 2006; Sharrard et al., 2008). According to these studies use phase seems to dominate the buildings' life cycle emissions with a share of 90%. Thus, the use phase has been a primary strategic target for carbon emissions reductions in Europe (García-Casals, 2006). However, as a consequence of the recent increases in the building energy efficiency requirements in many countries (e.g. Finnish National Building Code), the construction phase emissions have been increased and together with the reduced need for operating energy i.e. heating and cooling, actually radically changed or even inverted the

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situation. According to recent studies in the case of a new passive house, the construction phase accounts for as much as 90% of the total life cycle emissions (Gustavsson et al., 2010).

Most developed countries have a massive number of buildings that are at the end of their technical operating life and which need to be either renovated or replaced. For example almost half of the multi-storey buildings in Finland were built in 1960s and 1970s (Official Statistics of Finland, 2011). Furthermore, although the buildings were only designed to operate for 30 years (Hankonen, 1994), at the moment they have been occupied for 40 to 50 years. The number of buildings in need of an immediate renovation in Finland is approximately half a million (Köliö, 2011). Renovating or redeveloping this type of building mass is a global issue in both economic and ecological point of view (Power, 2008). Furthermore, the energy efficiency of these buildings is currently poor; in fact, they represent the weakest energy efficiency buildings in overall (Environmental Centre of Helsinki, 2008).

Improving the energy efficiency of the building stock has been considered as one of the primary strategies in reaching the climate change mitigation goals in the future in Finland (Finland's Environmental Administration, 2008; City of Helsinki; City of Turku). This can take the form of energy efficiency renovations or construction of new more energy efficient buildings. While construction of energy efficient buildings might seem a prominent way to reduce the energy requirements of the building stock in the long run, the fact often neglected is that new construction projects cause a high amount of GHGs in a short time period (i.e. carbon spike) because of large embodied energy in the construction materials and large amount of energy used in the construction process (Junnila et al., 2006; Säynäjoki et al., 2011). This carbon spike has been studied earlier by the authors (Heinonen et al., 2011; Säynäjoki et al., 2012) with a result that the spike seems to be such significant that it may hinder the plausibility of GHG savings by the reduced energy consumption for several decades. So there seems to be a genuine demand for additional ways of reducing the energy consumption of the current building stock with smaller construction phase carbon spike.

Renovations of the existing building stock are a less studied subject compared to new construction projects because of smaller perceived potential to the climate change mitigation. Renovations of current buildings have also been thought as a less attractive way of renewing the building stock due to significant energy improvements being often regarded as not economically feasible. Previous studies that have evaluated the economic and ecological possibilities of renovative actions compared to demolition have also found that one of the reasons for favouring new constructions instead of renovations is that the current building stock does not always fill the current requirements of size and differentiation (Itard et al., 2007). Furthermore, the efficiency improvement potential of renovations is often regarded low compared to new (low energy) buildings. However, improving energy efficiency while executing other major refurbishments, can be an economically feasible way of decreasing the energy consumption to the level of new low energy buildings (Power, 2008).

Timing of the carbon emissions is another significant factor in the climate change mitigation. According to previous studies, releasing GHG emission now may be more harmful to the environment than releasing them in the future (Dutil, 2011; Schwietzke, 2011), especially as major GHG reductions are needed within a very short timeframe. Thus, large construction phase carbon emissions are especially harmful as they occur in the near future. Additionally, there are numerous uncertainties related to the emissions occurring in the distant future. For example, the carbon intensity of the energy production is likely to decrease in the future (Finnish Energy Industries, 2010), which further encourages avoiding short-term GHG emissions.

The purpose of this study is to compare the life cycle GHG emissions from a residential renovation project with those from construction of a new building using two case samples. For this, the study evaluates the carbon emissions of a residential renovation process of an old Helsinki suburban residential building from the 1970s, which also includes energy efficiency improvements. Additionally, the study presents an assessment of the life cycle GHG's of a new construction project of a concrete element based multi-storey residential building. The construction phase carbon spikes of the two are then compared in order to analyse the activities' implications to the climate. The case study finds that the emissions are clearly lower in the renovation project, indicating that according to the preliminary screening, a higher priority should be given for energy improvements in the existing building stock in order to achieve even mid-term overall energy requirement gains. The life cycle assessment (LCA) method of the study is described in the second section of the paper. The results are presented in the section three. The fourth section consists of conclusions and discussion of the study.

RESEARCH DESIGN

Method

The method used in analysing the emissions is life cycle assessment (LCA). The purpose of the approach is to take the indirect emissions of the supply chains into account besides the direct emissions of the manufacturing process. Both the two main LCA methods have been used in analysing construction activities' GHG emissions: the most popular approaches are process LCA and input-output LCA (IO LCA). The third entity is hybrid LCA's that combine the features of the two before mentioned methods. In this study the primary method employed is IO LCA, supplemented with a hybrid LCA application in the analyses of new construction.

IO LCA is a method developed by a Nobel Prize winner Wassily Leonthief in the 1930s. The method converts monetary inputs into GHG emissions using input-output matrixes that are built for specific economies. The method uses national sector-by-sector economic interaction data in combination with sector level environmental effects of resource use data (Bilec et al., 2006). The perspective of the IO LCA is top down so all the indirect emissions of the supply chains are taken into account. Most LCA methods require a boundary definition of the analysis, as the chain of different processes of the product life cycle is almost indefinite. The subjective decision might lead into a situation where also relevant processes are left outside the analysis with the irrelevant ones. The top down approach eliminates the issue of subjective boundary definition as the input-output matrixes include all sectors of an economy by default (Suh et al., 2004). Carrying out IO LCA analyses is rapid as the method converts costs directly into emissions according to the sector selection. IO LCA analyses neither require many resources, as besides the rapid analyses some IO LCA tools are freely available on the Internet (Hendrickson et al., 2006). One of these applications is economic input-output LCA (EIO-LCA) of Carnegie Mellon University, which was used in the majority of the analyses in the study (Carnegie Mellon University Green Design Institute, 2008).

However, the IO LCA suffers also from a few disadvantages. IO LCA matrixes consist of aggregated sectors that appear as "a black box" for the users of the IO LCA applications (Treloar et al., 2000). Thus, the emissions of a single process inside the IO LCA sector are impossible to distil from the other processes. Additionally, IO LCA is not capable of distinguishing two different products within one sector and thus is not suitable for comparing similar products within one industry (Hendrickson et al., 2006). Finally, IO LCA models often treat imports as domestic production, as does EIO-LCA, and thus do not take into account the possibility of different production technologies abroad.

Another method of carrying out life cycle assessments is the process LCA. When carrying out process LCAs the emissions of the manufacturing processes are analysed one by one. The purpose is to include all relevant processes into the modelling. Process data uses quantities of materials as primary data and specific process data i.e. amounts of GHGs emitted per material quantity as secondary data. Process LCA is capable of very accurate LCAs since each process is analysed using case specific primary and secondary data (Suh et al., 2004). Process LCA is also suitable for carrying out comparisons of similar products as manufacturing processes are analysed separately using specific data (Hendrickson et al., 2006).

The perspective of process LCA is bottom up so it is vulnerable to truncation error that is a consequence of the cut-offs in the analyses (Bilec, 2007). As each process is analysed separately, the chain of the analysis has to be cut at some point (Suh et al., 2004). Thus, there is no guarantee that only the irrelevant processes are left outside the modelling chain. The process LCAs are also resource intensive as modelling is time consuming and the modelling tool software is usually expensive.

Hybrid LCA is a combination of IO LCA and process LCA methods. The purpose of the hybrid LCA is to combine the fore mentioned strengths of the two LCA methods (Suh et al., 2004; Bilec, 2007). The IO LCA's share of the hybrid model reduces the significance of boundary definition issue. IO LCA also decreases the time and data intensiveness of the modelling process. The process LCA's share of the model enhances the overall accuracy of the model as well as the capabilities of the model to distinguish similar modelling objects within one industry. The decision of relative shares of IO LCA and process LCA in the final hybrid model are based on the object modelled, availability of the primary and secondary data and available resources.

The model used in this study is an application of hybrid LCA that consists mostly of EIO-LCA method for the construction materials and construction work. Production of electricity and heat in the new construction process is modelled using the process LCA while EIO-LCA is used to model the indirect emissions of the process. The hybrid LCA model of the study is referred as tiered hybrid LCA in the literature (Bullard et al., 1978; Bilec, 2007).

Research process

The study analyses the renovation GHG emissions of a multi-storey apartment building that was built in the 1970s and is located in Southern Finland. The net area of the building is approximately 1722 square meters (m^2). The renovation process also includes improving the energy efficiency of the building with various construction components. The study then analyses the GHG emissions in the scenario that consists of replacement of the existing 1970s building with a new building. The carbon footprints of these two alternatives are then compared in order to reveal the environmental efficiencies of potential ways to extend the operational lifetime of residential areas that are at the end of their technical operation time.

The GHG emissions of renovation process of a multi-storey building built in 1970s were analysed using the EIO-LCA method that uses construction costs as primary data. The costs of various renovation activities were extracted from the literature (Lantto, 2011). The activities include traditional renovation activities that raise the technical level of premises into the current adequate level. The renovation activities also include improving the energy efficiency of the building to the reference 2010 level. Total costs of the renovation project were approximately 2.3 million euros. The activities were categorized into eight general tasks that are then divided into a few subcategories. The categories and shares of the total costs were:

- Exterior wall renovation (8%)
- Replacement of windows (16%)
- Renewal of roof (3%)
- Renovation and restoration of air conditioning (9%)
- Plumbing reconstruction (23%)
- Renovation of balconies (8%)
- Renewal of electricity, communications and antenna system (4%)
- Retrofitting of an elevator (30%)

The costs of the subcategories were matched with respective EIO-LCA sectors in order to reveal the GHG emissions of the activities. Construction management, planning and site activities that were present in almost every subcategory were modelled by using the EIO-LCA sector "Services to buildings and dwellings". The majority of the activities of the subcategories include combined material and construction work costs and thus were modelled with "Residential maintenance and repair" sector. Only a few subcategories include construction materials and were thus modelled with matching EIO-LCA construction material sector. The purchasing power parity (PPP) correction was used to negate the purchasing power differences related to different currencies i.e. US dollar and euro used in primary data and assessment model (The World Bank, 2011).

Another scenario analysed in the study was construction of a new building instead of refurbishing the existing building. The primary data i.e. costs of the construction project were retrieved from data provided by a large Finnish developer company of a current residential construction case in southern Finland. The building represents the current construction technology in Finland and thus is a realistic option when replacing the old existing buildings with new ones. The demolition of an existing building located on the site was excluded from the study. The primary construction material of the building is concrete elements. The net area of a one building of the construction project is approximately 2082 m^2. The total costs of the building's construction are approximately 3.6 million euros. The new construction process scaled to the extent of existing building's net area i.e. 1722 m^2 would cost approximately 3.0 million euros. That's approximately one third more compared to the costs of the renovation process. The costs of the construction project include five main materials and work categories and infrastructure, which is excluded from the study as the area being reconstructed is assumed to have an appropriate infrastructure. Each main category consists of varying amount of subcategories that were used in matching the data with the sectors of the EIO-LCA model, but are aggregated for presentation purposes to five main categories. Construction work consists of one subcategory only. Energy consists of five, concrete elements consist of one, other materials consist of 28 and other costs consist of two subcategories.

The main categories and shares of the total costs were:

- Construction work (22%)
- Energy (1%)
- Concrete elements (23%)
- Other materials (40%)
- Other costs (14%)

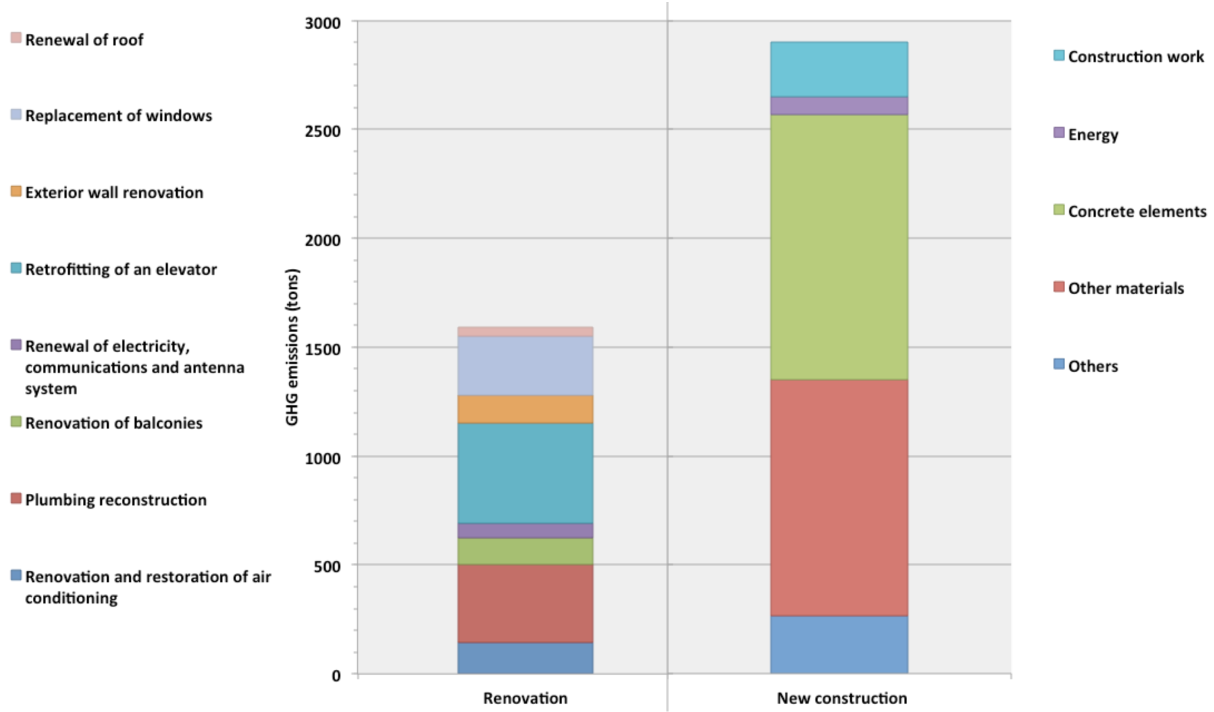
The emissions of electricity and heat used in the construction process were modelled by using local secondary data, that is, the emissions calculated with energy method from the data published by Finnish Energy Industries on the fuels and production volumes of the power plants in Finland, for the direct emissions and the EIO-LCA for the indirect emissions of the energy generation process. The emissions of electricity and heat are modelled by using the local power plant's carbon intensities. Use of local data in modelling the emissions of electricity and heat production increases the accuracy of the model. Rest of the subcategories' costs were matched with appropriate EIO-LCA sectors to reveal the GHG emissions related to the activities. Again, purchasing power parity (PPP) was used in US dollar - euro conversions to reduce uncertainties in the model (The World Bank, 2011). The uncertainties related to the method and modelling process are discussed in Conclusions and discussion section.

RESULTS

According to the EIO-LCA based assessment, the renovation process of an existing building results in approximately 1,600 tons of GHG emissions that account for approximately 0.9 tons per m^2. The retrofitting of an elevator is the most significant source of emissions with a share of 29%. Share of plumbing reconstruction is 22% and the share of window renewal is 17%. Mediocre sources of emissions are renovation of air conditioning 9%, renewal of balconies 8% and exterior wall restoration 8%. Renewal of electricity, communications and antenna system 4% and renewal of roof 3% are minor sources of emissions.

The option of constructing a new building results in GHG emissions of approximately 2,900 tons that account for roughly 1.7 tons per m^2. The materials of the new building dominate the results with concrete elements' share of 42% and other materials' share of 37% of the total GHG emissions. Construction work's share of emissions is 9% and energy's share 3%. Others account for 9% of the total GHG emissions. Thus, according to the assessments, the new construction option of a residential building results in almost twice as much GHG emissions as the renovation option. The results for both scenarios divided into a few categories are presented in figure 1.

Figure 1 The GHG emissions of renovation and new construction projects



DISCUSSION AND CONCLUSIONS

The purpose of the study was to examine two possible ways of extending the operational lifetime of a residential area. The two options in the study are renovating and improving the energy efficiency of an existing building and constructing a building that is quite similar to the renovated building. The case study was conducted by using the LCA method to find out the GHG emissions of renovation and new construction processes.

The results of the study indicate that new construction option causes almost twice as much GHG emissions as renovating an existing building. The buildings' use phase energy efficiency is approximately the same in both options. Thus in this case the use phase energy consumption may be excluded when analysing the GHG emissions of a building life cycle. Accordingly, renovating existing buildings seem to lead into fewer GHG emissions during the buildings' life cycle even though GHG emissions caused by the demolition of the existing building were excluded from the analysis.

Manufacturing of construction materials causes the most emissions of a new construction project. In the case of the new residential construction project of the study, the concrete elements are by far the most significant single source of GHG emissions. Thus, new materials and construction techniques have a significant potential of reducing the GHG emissions of the construction phase emissions. Reduced emissions of construction activities would also increase construction industry's potential in reaching mid-term carbon mitigation goals due to reduced payback times of construction phase

GHG investments. One possible solution might be replacing the concrete structure of the building with wood materials. According to Pasanen et al., (2011), the construction phase of a wood framed multi-storey building with passive house energy efficiency causes 29% less carbon emissions than a similar concrete framed building.

There are some uncertainties related to the study. First, the comparison was conducted using only two case samples and thus inferences are mainly drawn from a preliminary screening, rather than from a thorough multi case analysis. Second one is the share of the local secondary data used in the modellings. The primary data, i.e. costs and amounts of electricity and heat, used in the modellings are entirely local. However, the share of the local secondary data, i.e. process data of the energy generation process, is small compared to the share of EIO-LCA that is based on the US economy. Thus using US economy model in a Finnish context causes some uncertainties in the results of the study. However, previous studies indicate that using the method is suitable in Finnish context as well (Junnila, 2006; Heinonen et al., 2011). Additionally, the results of EIO-LCA modellings are very similar with the results of ENVIMAT modellings with corresponding sector selections. ENVIMAT is an IO LCA method that is based on the Finnish economy (Seppälä, 2009). Using the local secondary emission data for the emissions of electricity and heat in the new construction case only slightly hinders the capabilities of comparing the two construction options. However, the accuracy of the modelling increases along with the implementation of the local secondary data. According to previous literature the GHG intensity per euro of the energy production decreases when using the local secondary data instead of EIO-LCA (Säynäjoki et al., 2011). Finally, the share of the emissions caused by production of electricity and heat in the results is only minor.

The results of the study are in line with the earlier results of the authors (Säynäjoki et al., 2012). Renovation process in which the energy efficiency of the building is improved leads to roughly half of the GHG emissions compared to the construction of a new building. The use phase energy consumption causes roughly 100 tons of GHG emissions per year in a building of similar energy efficiency as the case buildings of the study (approximately 100 kWh/m^2 for heating and cooling) using the same local energy (Säynäjoki et al., 2012). As the yearly energy consumption of heating and cooling accounts for roughly 4% of the overall emissions of new construction, the carbon payback time of new construction is far too long for it to appear as a proper way of climate change mitigation. The carbon spike is significant in renovation as well, but still according to the case study, extending the lifetime of the existing building stock appears as a favorable option compared to new construction. As García-Casals (2006) suggests legislation and policies should be aimed not only to use phase but also towards construction phase emissions of the construction projects. Significantly reduced carbon spike of the construction activities combined with further improvements in use phase energy efficiency of the buildings should enhance real estate and construction industries' possibilities for climate change mitigation.

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