UMEÅ UNIVERSITY

Life cycle assessment of a new and renovated building

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Master thesis, 30 hp

Master of science in energy technology, 300 hp

Department of applied physics and electronics. Autumn 2021

Abstract

Ever since the Swedish government declared their long-term goal of net zero greenhouse gas emissions by 2045, the importance of life-cycle assessments (LCA) in the building sector has increased. In 2018 the building sector in Sweden was responsible for 21% of all emissions. The first step of reducing carbon emissions is done by declaring its origins, which is where LCAs are helpful. An LCA include all CO_2 emissions emitted within a products lifespan, all the way from raw material acquisition to the end of life. It is divided into different phases according to the European standard EN 15978 and the purpose of an LCA is to determine how much emissions each individual phase accounts for and then determine where the biggest improvements can be made. In this thesis an LCA of a new building is compared to an LCA of a renovated building in order to determine whether or not it is more environmentally friendly to renovate a building. The LCAs in this thesis was done using the web-based software One Click LCA and the life-cycle phases A-B were analysed. A case study was made on the multifamily buildings in Umeå, Sweden with the help of detailed drawings. The major interests of this report has been to get more knowledge in how to perform LCAs and to see whether a renovation of a building results in lower emissions as compared to a new building. The results showed that the new building had about 23% more CO_2e emissions per m^2 than the renovated building for a lifespan of 60 years when using a Swedish energy mix, where the renovated building's emissions was 345kg CO_2e/m^2 and the new building's emissions was 425.4kg CO_2e/m^2. The embodied carbon was about 2.5 times higher for the new building compared to the renovated building and the energy use B6 for the new building accounted for 33.2% of the total CO_2 emissions while it was 72.3% of the renovated building's total emissions. When the lifespan was increased the new building became a more and more attractive alternative and it would've surpassed the renovated building soon after 100 years as the more environmental friendly choice.

Acknowledgements

This project was done in form of a master thesis corresponding to 30hp in the Master of science in energy technology program at Umeå University. I would like to thank my supervisor Gireesh Nair at Umeå University for his help and support throughout this project and for providing me with the software and building information. I would also like to acknowledge the project "Interreg Nord project Enhanced Sustainability of Built Environment by Collaboration and Digitalization" where some of the information used in this thesis comes from.

GLOSSARY

LCA - Life-cycle assessment

Embodied energy - the total energy required for all building materials

ISO 14040 - standardisation for how to structure an LCA

CO_2 - Carbon dioxide

BBR - Boverkets building regulations

Miljöbyggnad - The most common building certification in Sweden

BREEAM - Building Research Establishment Environmental Assessment Method. The most common building certification in Europe

LEED - Leadership in Energy and Environmental Design. One of the most common building certifications in the world

EN-15978 - A European LCA standard with guidelines for how to perform an LCA

EPD - Environmental Product Declaration. The environmental impact from a product or service

GHG - Greenhouse gases

GWP - Global warming potential. A unit to measure different greenhouse gases environmental impact

Contents

1 Introduction

In the last couple of years the climate has been a very hot topic, there's plenty of signs indicating that a drastic change in our way of living is needed. The Swedish government has therefore set up a long-term goal to have net-zero emissions by 2045. In order to fulfil this goal, a number of measures has to be considered. One of them is reducing the environmental impact that comes from the building sector, in 2018 the building sector in Sweden was responsible for 21% of all emissions, which is excluding all emissions from import goods [1]. Until recently, the main focus during a buildings lifespan has been to reduce its energy consumption in the user phase, since it was believed that the embodied energy only counted for a very small percentage compared to operational energy. Therefore newer buildings are designed with increasingly more effective insulation materials and carbon-intensive materials which increases the energy use in previous stages of the life-cycle [2]. In reality however, the proportions between operational and embodied energy varies a lot and in some extreme cases the embodied energy can account for as much as up to 38% of total energy use [3]. For this reason the embodied energy has gotten a lot of attention in the last couple of years from the research community. The main goal of a life-cycle assessment is to address the environmental impact of all inputs and outputs within a products lifespan, all the way from raw material acquisition to the end of life [4].

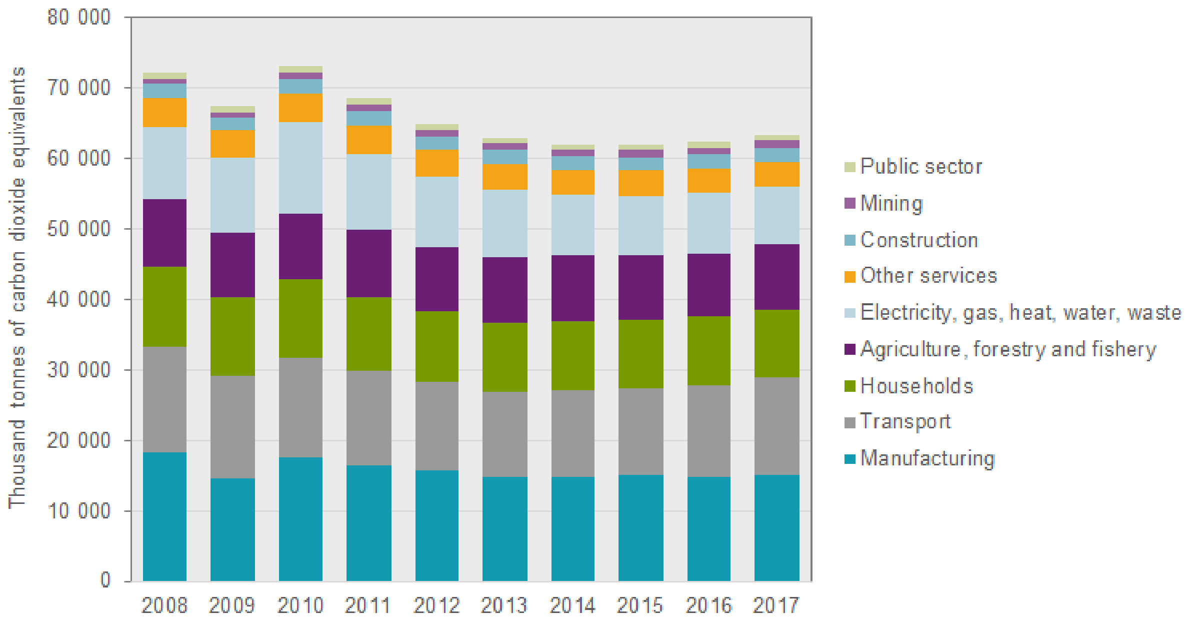

Figure 1 – Greenhouse gas emissions by the Swedish economy 2008-2017 (Statistiska centralbyrån 2019-03-28).

Life-cycle assessments have been widely used in the building sector since 1990 and it has since been broadly recognized as an important tool to obtain environmental-related product information. However, it is still less developed than life-cycle assessments in other industries [5]. LCAs within the building sector has become a distinct working area for LCA practitioners mostly due to the complexity of buildings. The environmental impact from a buildings life cycle can be separated into different phases according to the European standard EN 15978. The purpose of a life cycle assessment is to determine how much emission each individual phase accounts for and then evaluate where the biggest improvements can be made. Life cycle assessments are also commonly used to compare different types of building materials such as concrete versus wood. This life cycle assessment will be done on two different buildings, one renovated and one completely new, the results from the different buildings will then be compared to one another. A study done in Denmark by Lejla Delalic showed that renovating a building is better for both the environment and the economy as opposed to constructing new buildings [6]. This study was done to investigate whether a renovation of a building results in lower emissions from a life-cycle perspective as compared to a new building and to see if the results varies with an increased lifespan or different energy mix. In this study all phases except C1-C4 of a two-case study building will be analyzed.

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage			
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4

Figure 2 – The European standard EN 15978 for different phases in a buildings life-cycle (OneClick 2021).

2 Literature review

2.1 History of Life-cycle Assessment

The idea of life-cycle thinking has its origins in the US defense industry and the usage of LCA as an environmental management tool started in the 1960s in different ways and with multiple different names. Coca-Cola was the first company to perform an LCA in its current modern environmental understanding which was done to quantify the environmental effects of their packaging from cradle to grave. Although the emphasis at that time was primarily on solid waste reduction and not on environmental emissions or energy use [5].

2.2 Different stages of life-cycle assessment in buildings

According to ISO14040 an LCA study consists of four stages, i.e, goal and scope definition; inventory analysis; impact assessment; and life-cycle interpretation, each stage affecting the other stages in some way .(Figure 3)

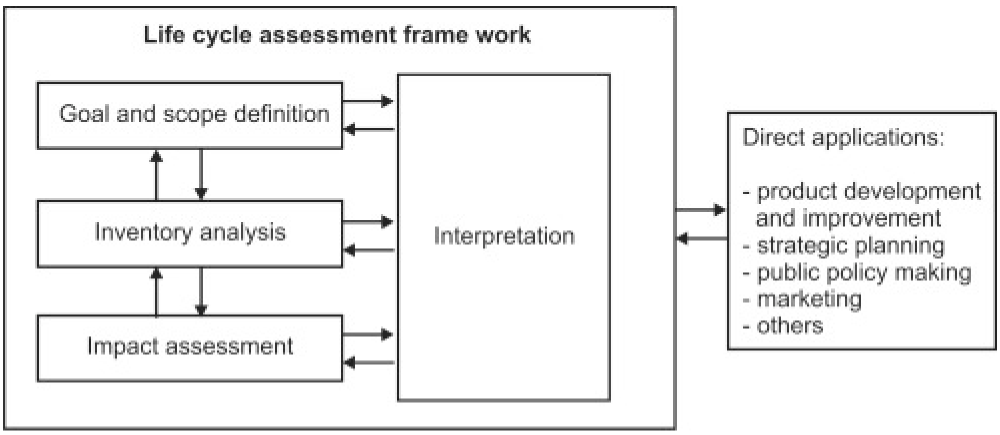

Figure 3 – Stages of an LCA according to ISO14040 [8].

These stages can according to [7] and [8] be described as below.

Stage 1: The goal and scope definition establishes the system boundaries, quality criteria for inventory data and the functional unit.

Stage 2: Inventory analysis describes the material and energy flows within the product system and its interaction with the environment.

Stage 3: In the life-cycle impact assessment the environmental impacts from Stage 2 are assigned to different environmental impact categories such as GHG emissions, ozone layer depletion etc.

Stage 4: The final stage is the interpretation of the life-cycle, it involves critical review, determination of data sensitivity and result presentation.

2.3 Increasing demand

The construction sector is the largest polluter in the world, as it is responsible for 23% of the CO_2 emissions worldwide. The sector is also a dominant resource consumer, globally it is responsible for using 60% of raw materials, by mass. This puts a lot of strain on the worlds landfill and increases material depletion since a lot of the materials used are concrete, steel and timber [9] [10]. Meanwhile, the population just keeps growing and so does the demand for new buildings, during the first quarter of 2021 there were 16 000 new apartments that began construction in Sweden, an increase of 24% to the year prior [11]. These factors combined has made people interested in finding improvements. In an attempt to reduce the impact the construction sector has on the environment a new law in Sweden will take place next year, requiring new buildings to have a climate declaration.

2.4 Climate declaration

The interests for life cycle assessment has increased a lot in the recent years as people have gotten more aware of the environment. At the beginning of next year, the Swedish government is planning to introduce a new law that requires a climate declaration for new buildings. This means that builders who intend to erect a new building and are applying for a building permit have to make a climate declaration and submit it to Boverket. The purpose of this is to reduce the emissions and motivate constructors to become more environment-friendly in their process [12]. In order to make this a possible task for constructors Boverket has developed tools as well as provided guidelines and a database with generic data for resources in the construction phase. A brief summary of the new legislation can be seen below [13].

- A new law on climate declarations for buildings in construction is proposed to enter into force on 1 January 2022.
- The requirement for a climate declaration will apply for those seeking building permits on or after 1 January 2022.
- Certain buildings will be exempt from the climate declaration requirement.
- The developer is responsible for registering a climate declaration with Boverket and for presenting proof of this to the Building Committee before final clearance may be issued.
- The legislative proposal is based on the European SS-EN 15978 standard for the assessment of environmental performance of buildings.
- Climate impacts are to be calculated in kg of CO2 equivalents per m2 gross floor area.

- The developer must save the supporting documentation for the climate declaration for 5 years.
- Supervisory responsibility will be shared between the relevant municipality and Boverket.

Together with this new law Boverket are planning on introducing limit values for climate emissions during the construction stage (A1-A5), starting from 2027 and then be lowered in two phases ending in 2043. Implementing this new law will affect everyone in the building industry, ranging from the government to product manufacturers and building owners. The consequences the government will have to face is the costs arising in connection with evaluating the system, developing IT support for the climate declaration register as well as information measures, to mention a few. Boverket has hopes to impose requirements in 2027 that climate declaration must be based on specific climate data for the chosen product, which in turn means that EPDs would be necessary. The cost of drafting a new EPD can be substantial, especially for smaller companies which means it would impact product manufacturers. Building owners could potentially also be impacted if there's too much focus on reducing the climate impact that it compromises the important functions of the building. One important thing to note is that there's currently no requirement on climate declaration for refurbishments. The motivation for this is that it could be seen as an increased administrative cost, which could slow down the progress of improving the energy efficiency of the already existing building stock [13].

With the introduction of this new law, the interest for LCA will increase as they are a good first step to lowering emissions. Since buildings are generally designed to withstand for multiple decades, it is important to have a clear idea to begin with, an LCA is the most effective when done in the planning phase. The further into the building process it gets, the less effective will an LCA become [14]. One significant problem that comes from this is that constructors usually don't have detailed product information until the construction process has begun, which means that generic data has to be used instead. Seeing that a building consists of a couple hundred different products, using generic data for all of them could lead to a big variance. It is also hard to predict the whole life-cycle for a building from the cradle to the grave as they often have a lifetime of more than 50 years. During simulations the most commonly used lifespan is 50 years even though most buildings have a longer lifetime. Studies also show that the higher the lifespan of a building the lower environmental impact it will have [15]. During their lifetime they may undergo significant changes which could make the initial LCA very inaccurate since it could alter the energy use in the maintenance phase a lot. [5].

Another problem that having LCA as a standard would bring is that it is hard to have a benchmark to compare with, since every building is unique in its surroundings, function and time. If such benchmark would exist, it could still be problematic to meet since several LCA-softwares exists that may use different databases for their products [16].

Since LCA for buildings has gained a lot of attraction in the last couple of years, many real-estate concerns have a hard time adapting. In interviews that Frida Lindberg from

Luleå Universitet held with multiple companies regarding using LCA, most of them had the same reasoning as to why they didn't use it yet, which was lack of knowledge/experience and because of economic reasons [17]. From a study done earlier this year they examined managers and industry executives impressions of the recently introduced climate declaration act. Their results showed that although the experts had a generally positive attitude towards the act, they thought that due to its lack of restrictive requirements and conditions there's no guarantee that the desired outcome will be achieved. However, they also acknowledge that the impact from this climate declaration act will only appear in the long run [18].

2.5 Policy instruments

In order to achieve the long-term goal that the Swedish government has set out, a net zero of greenhouse gas emissions by 2045, there exists a number of management control measures such as carbon tax, subventions and building regulations in Sweden [19]. Sweden's building regulations (BBR) consists of energy requirements for different types of buildings and in order for a contractor to be allowed to construct a building, they need to prove that the building will be energy efficient and must therefore provide the expected energy use beforehand, as of now the requirement for multifamily buildings is 75kWh/m^2 [20]. Buildings in Sweden can also receive a couple of environmental certificates depending on how they perform in terms of energy use etc. The most common certificate for buildings in Sweden is "Miljöbyggnad", which can be handed out after they've measured 16 different parameters such as energy use and air quality. Miljöbyggnad is divided into 3 different certificates (Bronze, Silver, Gold) depending on how the building performs where following the existing laws and recommendations is enough to reach a Bronze certificate [21]. The most common certification for buildings in Europe is however BREEAM, which has started to gain some traction in Sweden as well since in 2013 a new certification BREEAM-SE was made specifically for buildings in Sweden. BREEAM-certified buildings can range from "Unclassified<30%" to "Outstanding>=85%" depending on their total score after measuring several parameters [22]. Another certification for buildings which is known globally and used in USA is LEED, which is not only made for buildings. City areas and even a whole city can be LEED-certified. The LEED-certification is handed out in 4 different levels (Certified, Silver, Gold and Platinum) [23].

Figure 4 – LEED-certificates ranging from Certified to Platinum (Sweden Green Building Council 2022).

One Click LCA has together with Green Building Council and Statsbygg created a carbon heroes benchmark program in order to get a better understanding of what impact the materials used has on the life cycle as well as understanding how the building stock varies across building types and geographics. The program implements the standards EN15978 and ISO21930 and includes life-cycle stages A1-A4, B4-B5 and C1-C4. The benchmark is divided into 7 equally distributed ranges from A-G, an example of this can be seen in figure 5. It is updated and generated approximately every six months [24].

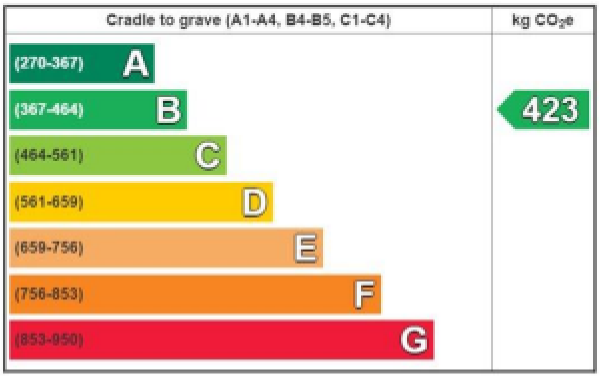

Figure 5 – Example of performance metric carbon heroes benchmark (One Click LCA 2019).

2.6 Global warming potential

Greenhouse gases (GHG) warm the earth by absorbing gases and reduces the rate at which the energy can escape the atmosphere. All gases differ in their ability to absorb energy and they therefore differ in their environmental impact [25]. In order to do a fair comparison in gases global warming impacts, the global warming potential (GWP) was developed. GWP is measured in kg CO_2e/m^2 and it is a measure of how much energy the emissions 1 ton of a gas will absorb over a given time period compared to the emissions of 1 ton of CO_2 [26]. Figure 6 shows the GWP for the major greenhouse gases, for example does 1kg of Methane have the same GWP as 25kg of CO_2.

Greenhouse gas	Chemical formula	Global Warming Potential, 100-year time horizon	Atmospheric Lifetime (years)
Carbon Dioxide	CO2	1	100*
Methane	CH4	25	12
Nitrous Oxide	N2O	265	121
Chlorofluorocarbon-12 (CFC-12)	CCl2F2	10,200	100
Hydrofluorocarbon-23 (HFC-23)	CHF3	12,400	222
Sulfur Hexafluoride	SF6	23,500	3,200
Nitrogen Trifluoride	NF3	16,100	500

Figure 6 – Global warming potential and atmospheric lifetime for major greenhouse gases [27].

2.7 European LCA standard EN-15978

In order to have a uniform and transparent way of both performing an LCA on a building and analysing its result, certain standards has been implemented. The European LCA standard EN-15978 is one of those standards. It contains guidelines for the system boundaries and how to collect and analyse the data, amongst several other things [28]. According to this standard, a buildings lifetime should be divided into four main parts, the product phase(A1-A3), construction phase(A4-A5), use phase(B1-B7) and end of life phase(C1-C4). For a new building the system boundary should include all these phases while for an already existing building the system boundary shall only include the stages that's included in the buildings remaining service life. A description for all of the phases can be found below, except for the end of life phase since it won't be included in this study. For comparative results and benchmarking, the same reference study period (RSP) shall be applied. The default RSP for a building is the same as the required service life of the building which will be set to 60 years for this thesis [29].

2.7.1 Product Phase A1-A3

Raw material supply (A1) includes emissions generated from raw material extraction, the transportation to industrial units and the emissions from when the materials are being processed. The energy and material waste are also taken into account. Transport impacts (A2) includes the impacts of the fuel production as well as the exhaust emissions from the transport of all raw materials from suppliers to the manufacturer's production plant. Production impacts (A3) cover the manufacturing of the production materials and fuels used by machines, as well as handling of waste formed in the production processes until end-of-waste state.

2.7.2 Construction Phase A4-A5

The construction phase includes the exhaust emissions from transportation of building products to the building site (A4) from the manufacturer's production plant as well as the environmental impact from producing the used fuel. A5 covers the construction of the building, i.e. installation of the materials and products, exhaust emissions resulting from using energy during the site operations and the environmental impacts of production processes of fuel, energy and water. The impacts and aspects related to any losses during the construction process is also included.

2.7.3 Maintenance and replacement B1-B5

When the building is completed the user phase begins, which includes all events in the buildings lifetime. The emissions cover impacts from raw material supply, transportation, production and manufacturing of the replacing material as well as the handling of waste. B1 covers any emissions to the environment during the normal use of the building such as emissions from coated surfaces, floor finishes, building facade etc. Maintenance of the building (B2) includes any activities carried out to maintain the required technical and functional performance of the building and covers both preventative and regular maintenance. Any work that is being done to repair a building component and therefore return it to its initial state is covered by B3, and it covers both corrective, responsive and reactive repairs. B4 includes replacement of damaged components that can no longer be repaired or which has come to their manufacturer-specified end of life date. Any major work that's done in order to either renew or repurpose the building or its components is considered refurbishment and is covered by B5.

2.7.4 Energy use B6

The use phase energy consumption includes impacts from the production processes of fuel and externally produced energy. Any energy used in normal operations of the building during its life-time is also covered such as lighting and safety/security installations, energy transmission losses are also considered.

2.7.5 Water use B7

The water consumption during use phase includes the impacts from water consuming processes such as drinking and hot water, it also includes the production processes of fresh water [30] [31].

2.8 Environmental product declaration

Performing an LCA on a building involves plenty of different individual products. Every product has gone through an LCA of its own and the environmental impact from that product in a life-cycle perspective can be collected from an environmental product declaration (EPD) [32]. While EN15978 is the standard that's being used for LCAs of complete buildings, there's another standard when it comes to building products, EN15804. The EN15804 building product LCA standard stands as a foundation for EPDs and is making the information transparent and comparable [33]. An EPD is compliant with the ISO 14025 standard and they're all registered and accessible in a public and free EPD library. Since EPDs follow the ISO 14025 standard it means that products that are within the same product category rules (PCR) are easily compared with one another [34].

There are currently more than 28 European EPD programs that are all based on ISO 14025 and EN15804 which helps manufacturers create or locate EPDs. While it is usually good to have standardizations, it doesn't only come with positives. The EN15804 standard comes with the same core rules for all construction products, services and processes regardless of their functional and technical performance. This limits the viability of comparing the environmental impact between products, for example can two types of thermal insulations that's being used in a roof only be compared to one another if they have a similar heat transfer resistance over a similar life time. Another example is that the standard simplifies calculations by providing several alternative calculation methods for one decision point (e.g. data sources and system boundaries) which creates a bigger variety of methodological choices and can reduce the reproducibility and consistency [35].

2.9 Challenges of LCA

While the concept of life cycle assessments for buildings has existed for a long time, it has still a far from flawless procedure. Analyzing buildings using LCA is one of the most complex applications of LCA due to the sheer amount of variables that has to be calculated. This becomes highlighted when one is trying to compare LCA results from different studies and parameters such as use of primary versus delivered energy, age, source, location and technology of the manufacturing processes etc. vary between the studies. A design or technology that is deemed sustainable for one location may not show the same result in a different location. As of 2017 there were no guidelines on how to appropriately compare LCA results or even a way of performing an LCA that was internationally acceptable. There's also been multiple attempts in trying to standardize functional units, so far without success. The usage of different functional units today are part of the reason why it can be challenging to compare LCA results [36]. To fill in some of these gaps and extend the LCA system some researchers have started developing a new system called dynamic life cycle assessment (DLCA). Since the life cycle of a building is generally quite long, there will be variation in occupancy behavior and other factors that the traditional LCA method doesn't take in consideration. In order to account for these changes a dynamic system is needed such as DLCA [37].

The key difference between a traditional LCA and DLCA is the consideration of time-varying factors, where things such as the energy mix evolution over time and recycling rates over time are considered in the DLCA [38].A traditional process-based LCA method where the user itemizes the inputs and outputs works great for a simple product like a paper mug. However when it comes to really complex constructions that can consist of a couple hundred individual products it can quickly spiral out of control and feel overwhelming. Therefore defining the boundary becomes necessary which can be hard to do without compromising the result [39]. In an attempt to ease these problems a new method of performing LCAs has gained some traction called hybrid LCA, which combines the advantages of the detailed process from a traditional LCA with the extended system boundary of an LCA called input-output (I-O) [40]. The hybrid LCA helps reduce the truncation errors (errors from a bad approximation or round-off) from the process-based LCA while it increases the resolution of the I-O LCA and has thus been considered appropriate for evaluating complex products such as a building [41].
Hybrid LCA is argued to achieve both specificity and system completeness and is therefore often considered to be a more complex method than IO- or process-based LCAs. Due to the complexity there are cases where a simple process-based LCA performs better than a hybrid, therefore one shouldn't always default to hybrid LCAs. A critical evaluation of whether the effort of hybridization would lead to improved estimates needs to be done for each individual case [42].
Throughout the years as the awareness of the importance of LCAs has increased, more LCA softwares has been developed and there's currently more than 15 different tools that's been recognised by BREEAM [43]. Several studies has been done comparing LCA tools to one another and a study from 2017 that compared three different LCA tools (Athena Impact Estimator for Buildings, Kieran Timberlake's Tally, Pre SimaPro) concluded that the results given had a 10% variation in global warming [44]. Another study done in 2018 that compared SimaPro to GaBi confimed that the choice of tool significantly affects the outcome as it had a 15% discrepancy in results for the whole building [45]. Guiyuan Han showed in his study that even though two tools (BEES, EcoCalculator) are built on the same database, they emphasized different materials and would therefore give similar but not exactly the same results [46]. This reveals the importance of bringing all softwares to a common platform that does not have so many differences in their results. In the spring of 2021 Boverket released a generic database with climate data for construction products and energy, with regards of the conditions in Sweden. The database is adapted to the needs of the industry and contains the necessary generic climate data to make a climate declaration [13].

Although the research around building LCA has increased a lot in the past decade, there's still very limited research on the stakeholder's perspectives on the value of LCA. Even though this has been overlooked it is an important aspect since the stakeholder's play an important role in promoting LCA in the building industry. In a recent study that was carried out in New Zealand, results showed that stakeholder's had an overall positive view on the value of LCA on buildings, around 72% of the stakeholders participating in the study agreed that LCA can improve the environmental analysis process, however this wasn't reflected in their use of LCAs as less than 15% reported that they had any previous experience with LCA at all [47].

In a study that the NORNET LCA network did in 2016 where they studied the challenges and needs for the Nordic building industry in the development for building LCAs, they found that there were plenty of knowledge gaps in building LCA. A survey was handed out to 57 participants with various degrees of experiences within LCA, they described the main challenge of building LCAs as "lack of estimated default values on building parts or components for use in screening LCA". A screening LCA can be used for a quick initial overview of the environmental impacts of a building and is valuable in the early design phases of a building when the details of the life cycle inventory are not known [48]. It is a known problem that it is difficult to apply an LCA in early design phases due to the level of detailed data required, the interviewees suggested solution to this was to focus on the most important building parts instead of the details. They also mentioned the need for predefined default values on building elements. While this was described as the main challenge, the study showed that there were still 6 other topics labeled as important challenges such as "environmental impact of maintenance and repair" and "scenarios and building context".

Regarding the practical application of LCA, the study showed that there were two major concerns people had. One being that it was difficult to find and collect data, where they specified that data on transportation, energy carriers and waste treatment was the most lacking part. The second concern was that it was time consuming and expensive, where they specifically mentioned the data collection as being too time consuming. One respondent voiced his concern about that the attention to details in terms of quantifying the whole building and its life-cycle can impact the resources available to identify and address the "big-hitters". [49].

2.10 New vs renovated

Life-cycle assessments of buildings show that the energy used to operate a building usually accounts for the majority of the environmental impact from the building during its life-time. Improving the energy efficiency as well as using renewable energy sources will therefore significantly reduce the operational energy use impacts. Since a lot of improvements already has been done in this area, some scientists has shifted their focus to embodied impacts instead. One frequent suggestion for reducing the embodied impacts is to focus on renovation of existing buildings [50]. Another way of improving the environmental impact from a building throughout its life-time would be to extend its life-time. According to a study done by Rob Marsh in 2016, a building with a lifespan of 80 years reduces the environmental impact by 29% and 100 years by 38% in comparison to a lifespan of 50 years [51]. One major problem, that should be considered non-sustainable human behaviour is that only 17% of building demolitions is because of deterioration, whereas 44% is due to subjective perception and 26% is due to change in use [52]. One way to extend a buildings life-time is to renovate it, however something to consider is that a new building can have a lifespan more than six times longer than a refurbished one [15]. In figure 5 the boundary extension that's needed for a renovated building is shown.

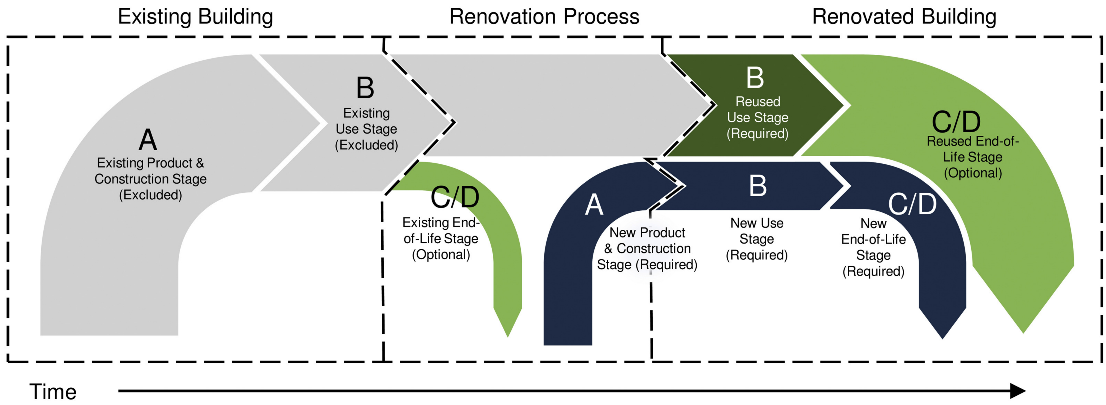

Figure 7 – Renovation LCA stage and boundary diagram [50].

A large portion of buildings in Europe today are very old and does not meet todays standards and building codes, many of these will have to be refurbished or demolished in the near future. LCAs may play an important role in determining the outcome for these buildings. Studies on building refurbishments using an LCA approach are lacking and the ones that do exist rely on a new building LCA to find the improvements that could reduce their environmental impacts. More in-depth research in this field is therefore recommended [53].

2.11 Similar LCAs performed

While there has been many life-cycle assessments performed on buildings throughout the years, there's only been a handful to the best of my knowledge where they compared a new building to a renovated building and most of them includes or excludes different parts of the phases in Figure 7. In a study done in Norway in 2009 where they wanted to understand the burdens or benefits of renovating a building they excluded phases C1-C4 for both buildings, however they included the existing building's demolition. It is the only known comparative LCA study where they included stage B in the renovation scenario in Figure 7. Their study showed that it was significantly more environmental friendly to build a new construction rather than renovating an existing one, which can be seen in Figure 8 below. The refurbished construction was considered to have low adaptability and its energy demand could therefore not be lowered as much as initially planned [54].

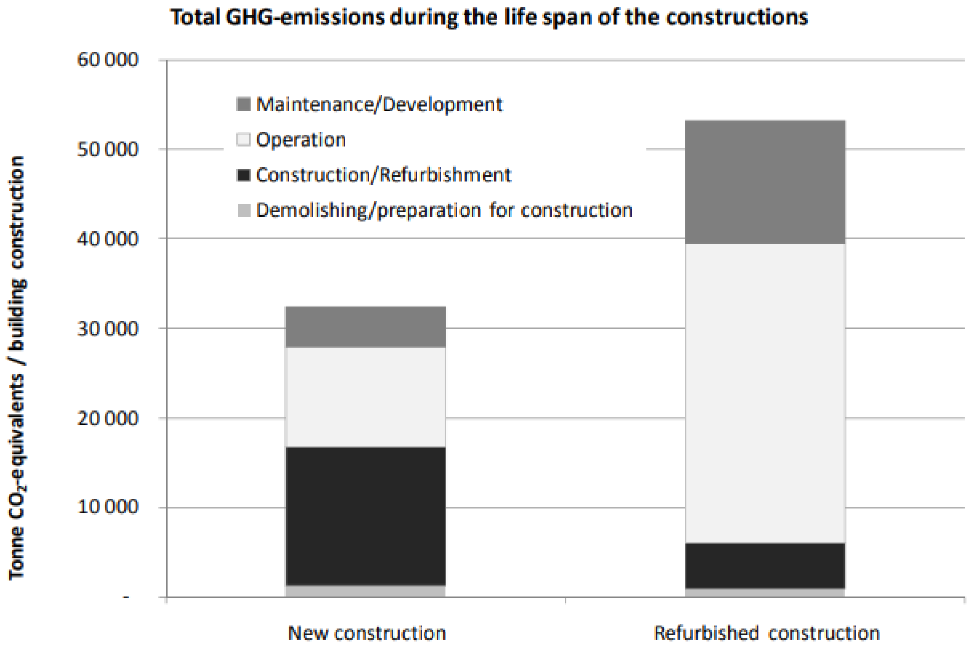

Figure 8 – Total emissions of greenhouse gases for a new and refurbished construction during 60 years from a similar LCA study [54].

Another study that was done in 2019 by Hasik et.al compared the full life cycle of a new building to a renovated building suggested that a renovation would help avoid between 53% to 75% of the impacts from the new construction scenario [50]. In Anne-Françoise Marique and Barbara Rossis study from 2018 it was concluded that the use phase was the most harmful phase for both a new and renovated office building. Their results also indicated that the retrofitting of the building was significantly less harmful compared to a complete demolition/reconstruction which can be seen in Figure 9 below. Worth noting is that they didn't include the use phase in their simulation which may explain the difference from the study shown in Figure 8. They also pointed out that aside from the environmental impact, other concerns such as the cultural/historical value of the building, the cost and the social problems that comes with a demolition of a building should be evaluated for each specific case [55].

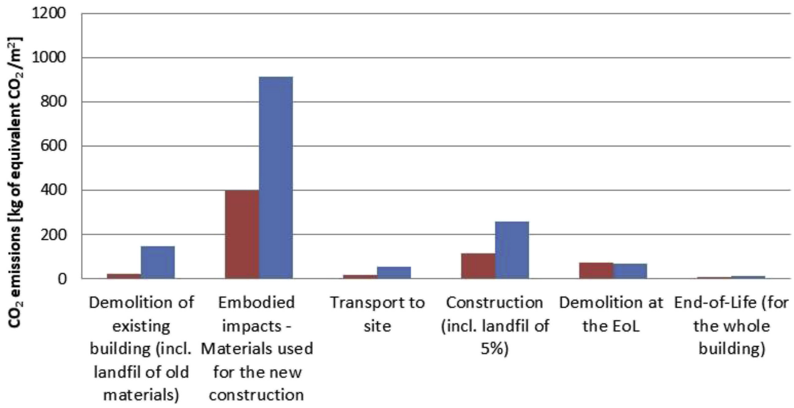

Figure 9 – CO_2 emissions per phase for the renovated (red bars) and new (blue bars) building where the use phase is excluded [55]

The number of LCAs performed on renovated buildings are far from that of a new building, it could therefore be hard to find relevant information on this topic. A study from 2017 tried summarising all the recent contributions related to the environmental impact of building renovations where they used the LCA methodology. They found that the main issue for building refurbishments was the interpretation of the system boundaries in EN15978:2012 and that most studies was made using a process-based LCA. From the studies that they analysed different interpretations of the standard had been made and different system boundaries had been used. All studies included stages A1-A3 and B6, but stages such as C1-C4 and the construction process varied a lot. The biggest difference between the studies was the interpretation of the boundaries and the results are therefore hard to compare. According to the authors the studies are barely comparable to each other due to their choice of LCA method, that usually is affected by truncation errors [53].

3 Method

The environmental impact of a buildings lifetime can be determined through a life cycle assessment(LCA). To be able to compare the environmental impact from the two buildings to one another, detailed drawings was handed out of both buildings. The amount of materials needed was then calculated and used in the simulations under certain system boundaries and European standards. The energy consumed over the span of a year in regards of both district heating and electricity in both buildings had already been declared and was therefore handed out as well.

3.1 System boundaries

In order to perform an LCA certain system boundaries has to be defined. The study period was set to be 60 years because it can be assumed that after 60 years the building will have been renovated to the point where only a few of the original building components remain, this even though most buildings will have a longer service life, up to 100 years [56]. Another simulation was also done using a lifespan of 100 years to see how the results would change with an increased lifespan.

The LCAs in this thesis was done using the web-based software One Click LCA and followed the European LCA standard EN-15978. The life cycle phases A-B were analysed.

3.2 Case Study

The core of this project is to compare the life cycle environmental impact from a newly built multifamily building to a renovated multifamily building in Umeå.

Figure 10 – Drawing of the North side of the new building.

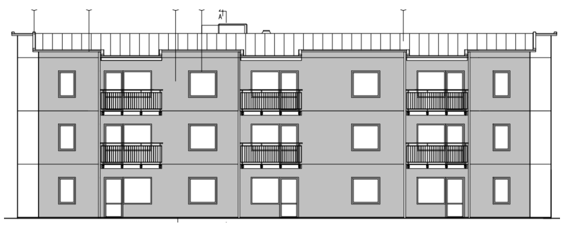

Figure 11 – Drawing of the west side of the new building.

The buildings are owned by Bostaden and the construction started in April 2014 and was finished by the end of 2015, the whole project was estimated to cover 3400m^2 [57]. The new building has a pre-constructed sandwichwall with a brick-facade and consists of 24 apartments. The renovated building has regular external walls and kept its brick-facade throughout the renovation and consists of 23 apartments. The heated area of the buildings, A_{temp}, are 990m^2 for the renovated building and 430m^2 for the new building. According to Statistiska Centralbyrån (SCB) there's an average of 1,9 residents per apartment in multifamily buildings [58], and according to Sveby the average water usage per person and year is 18m^3 [59]. The yearly water consumption for both of the buildings was then estimated to 821m^3 for the renovated building with 46 residents and 787m^3 for the new building with 44 residents.

For the renovated building the yearly heating and electricity used ended up as 78kWh/m^2 and 16kWh/m^2 respectively. The yearly energy consumption for the new building was 45kWh/m^2 for the heating and 8kWh/m^2 for the operational electricity. A generic Swedish energy mix was used where the GWP was 0.0519kg CO_2e/kWh for the electricity and 0.042kg CO_2e/kWh for the district heating. Simulations were also done using a generic European Union energy mix instead of the previous generic Swedish energy mix. That energy mix had a GWP of 0.43kg CO_2e/kWh for the electricity and 0.13kg CO_2e/kWh for the district heating [60].

3.3 Material use

To be able to perform an LCA on a building there are a bunch of material data that's needed. In order to obtain these data, detailed drawings of the building and its components was studied. An example of one of these drawings can be seen in Figure 12 below.

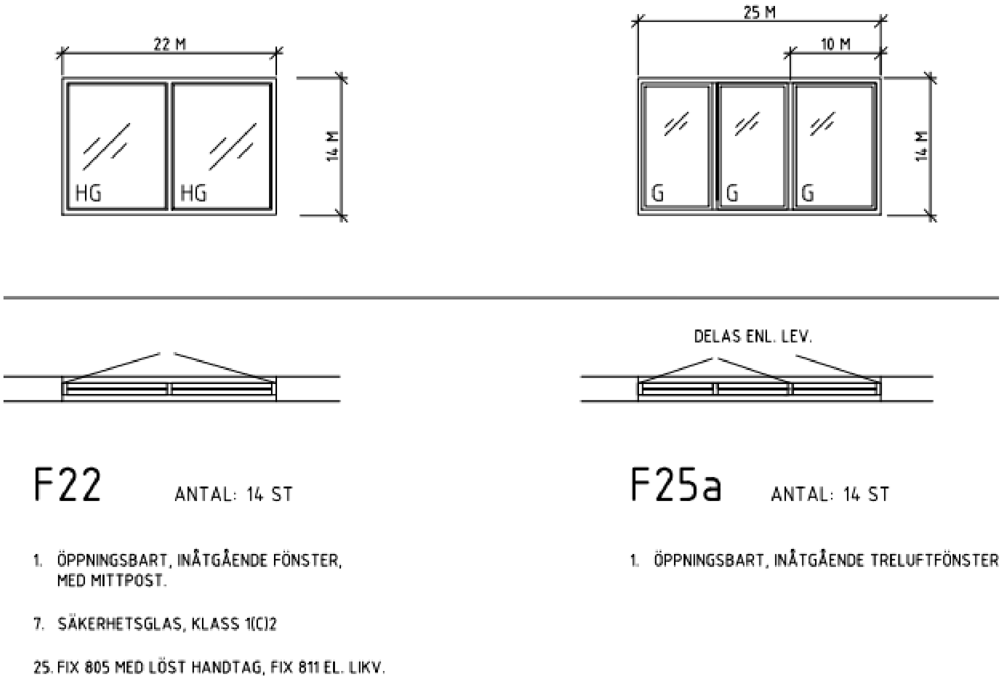

Figure 12 – An example of one of the drawings that was handed out in order to calculate the material use.

With the help of these drawings, a good estimate of how much of each material was needed for each component of the building could be obtained, these values were then inserted into the software. Since the exact type of material wasn't specified, generic values were used for everything. The transportation of the materials to the construction site and back was given an estimated distance and vehicle. Data for major input parameters for both buildings can be seen in the table below. This data was achieved by making a couple of assumptions, the major ones being the relation of the construction area between the buildings since only the total area was given, and also that the same type of materials was used in both buildings.

3.4 LCA software

In this study the chosen software was One Click LCA with a student-license. One Click LCA is a web-based software that was founded in Finland in 2001. It requires a license to use it and it is one of the most common life-cycle assessment softwares that's made specifically for buildings. One Click LCA is compatible with more than 40 certifications such as LEED, BREEAM and ISO standards. In order to perform an simulation with the software one can start with inserting the individual materials manually as in Figure 13 and 14, where it is possible to chose from different EPDs or generic products.

Table 1 – Major input parameters for both the new and renovated building.

Parameters	New building	Renovated building
Calculation Period	60 years	60 years
Gross floor area	430m^2	990m^2
Electricity /year	3440kWh	15840kWh
District heating /year	19350kWh	77220kWh
Water consumption /year	787m^3	821m^3
Construction site	2200m^2	1200m^2
Foundation concrete	50m^3	0
Asphalt roofing	140m^2	285m^2
External wall insulation	28m^3	64m^3
Triple-pane glazing	128m^2	118m^2

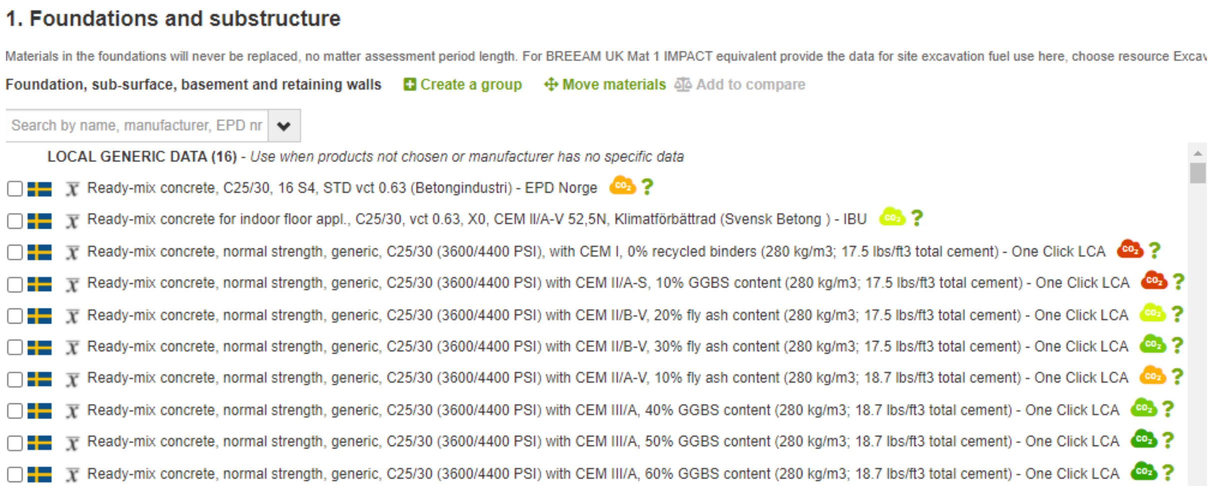

Figure 13 – A screenshot from One Click LCA where a drop-down menu with different local generic products can be chosen as the foundation for the building.

Figure 14 – A screenshot from One Click LCA where a drop-down menu with different regional EPDs can be chosen as the foundation for the building.

It is also possible to insert the drawings of the building from Revit or similar software in order to get all the material details. The transport distance and vehicle for every single material can also be manually inserted and if nothing is inserted generic values will be used instead. Both the energy use and water use is registered by the user and it is possible to choose from different energy sources and water sources. The impact from the construction site can either be generalised by only registering the area of the construction site, or it can be more detailed where the energy, fuel and water use during the construction has to be inserted.

4 Results

4.1 Renovated building

The LCA performed on the renovated building was done over a period of 60 years and a 100 years. During the 60 year time period a total of 341 tons of CO_2e was emitted, which translates to 345kg CO_2e/m^2. During the 100 year time period a total of 545 tons of CO_2e was emitted, which translates to 551kg CO_2e/m^2. The embodied carbon made up 61 kg CO_2e/m^2 of this, according to benchmarks this would result in the best possible classification A, which can be seen in figure 15 below. The emissions from each different phase in the buildings life cycle for the 60 year period can be seen in figure 16. We can see that the energy usage is by far the biggest contributor to the emissions and it's responsible for 72.3% of the buildings total CO_2e emissions. Second biggest contributor is maintenance and replacement (B1-B5) followed by materials (A1-A3). The emissions from each different phase in the buildings life cycle for the 100 year period can be seen in figure 17, while the order of impact is still the same, the energy phase B6 has increased to 75.1%.

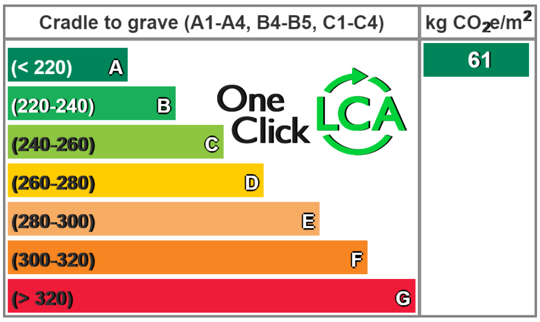

Figure 15 – Benchmarks for the embodied carbon (kg CO_2e/m^2) in a building from cradle to the grave (A1-A4, B4-B5, C1-C4).

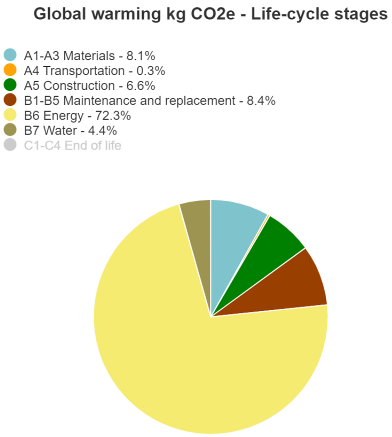

Figure 16 – The total CO_2e emissions from the different LCA phases for a 60 year period.

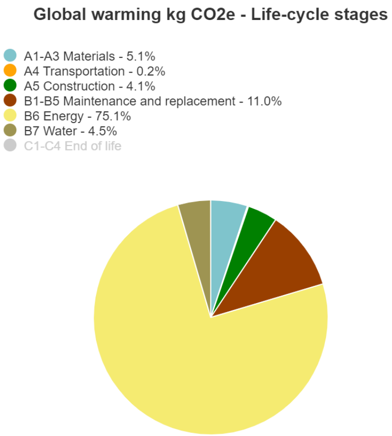

Figure 17 – The total CO_2e emissions from the different LCA phases for a 100 year period.

The different materials environmental impact from the production phase A1-A3 can be seen in figure 18. The doors and windows has the biggest impact, around 41% followed by the floor and ceiling 39.7%. The external wall had the least impact out of all the material classifications and is only responsible for 8.5% of all materials environmental impact.

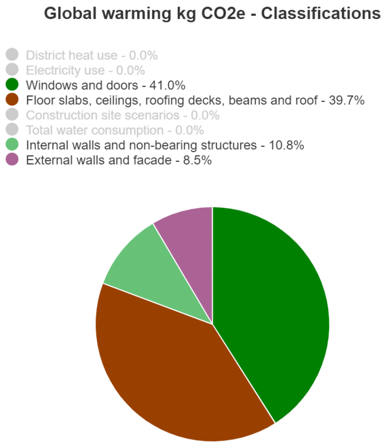

Figure 18 – The construction products with largest CO2 emissions in the renovated building.

4.2 New building

The LCA performed on the new building was done over a period of 60 years and a 100 years. During the 60 year time period a total of 183 tons of CO_2e was emitted, which translates to 425.4kg CO_2e/m^2. During the 100 year time period a total of 245 tons of CO_2e was emitted, which translates to 570kg CO_2e/m^2 The embodied carbon made up 159 kg CO_2e/m^2 of this, according to benchmarks this would result in the best possible classification A, which can be seen in figure 19. The emissions from each different phase in the buildings life cycle for the 60 year period can be seen in figure 20. We can see that the energy B6 is the biggest contributor to the emissions and it's responsible for 33.2% of the buildings total CO_2e emissions. Second biggest contributor is the materials (A1-A3) which made up 28.1% of the CO_2e emissions, this is followed by the construction A5. The emissions from each different phase in the buildings life cycle for the 100 year time period can be seen in figure 21, while the order of impact is still the same, the energy phase B6 has increased to 41%.

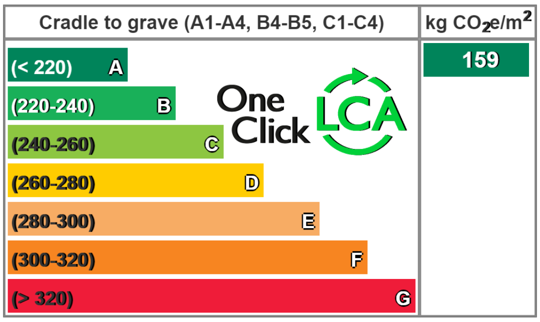

Figure 19 – Benchmarks for the embodied carbon (kg CO_2e/m^2) in a building from cradle to the grave (A1-A4, B4-B5, C1-C4).

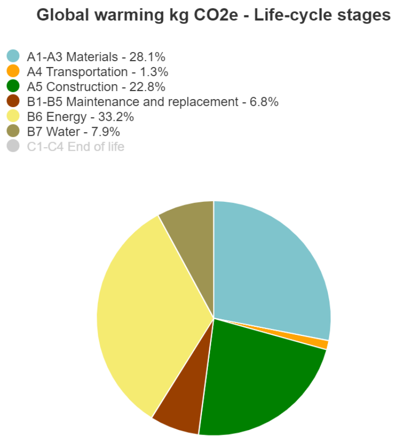

Figure 20 – The total CO_2e emissions from the different LCA phases for a 60 year time period.

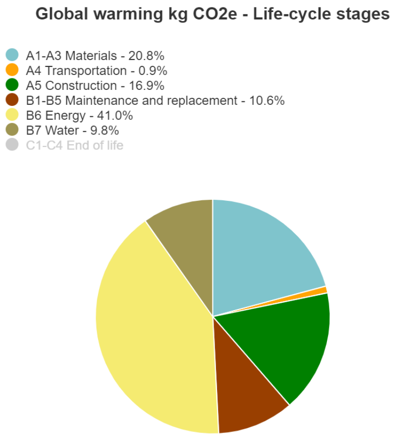

Figure 21 – The total CO_2e emissions from the different LCA phases for a 100 year time period.

The different materials environmental impact from the production phase A1-A3 can be seen in figure 22. The external walls and facade was the classification with the biggest impact, around 40% followed by the windows and doors at around 20%. The internal walls and non-bearing structures had the least impact and was only responsible for 10.8% of the total environmental impact from the materials.

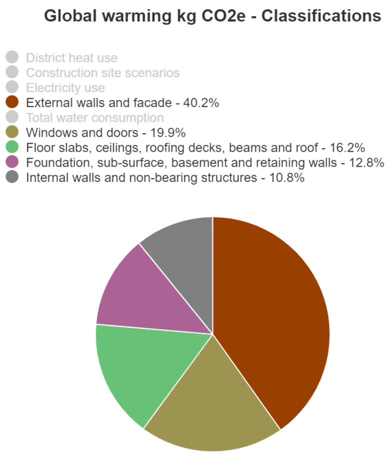

Figure 22 – The construction products with largest CO_2e emissions in the new building.

4.3 European Union energy mix

LCAs were performed on both buildings with a generic European Union energy mix instead of the previous generic Swedish energy mix. Over the span of 60 years a total of 1090 tons of CO_2e was emitted from the renovated building which corresponded to 1101kg CO_2e/m^2. During the same time-frame the new building emitted 358 tons of CO_2e which translated to 833.4kg CO_2e/m^2. The energy stage B6 ended up representing 91.4% of the total emission for the renovated building which can be seen in figure 23 below. For the new building the energy stage B6 represented 66.2% of the total emissions which can be seen in figure 24.

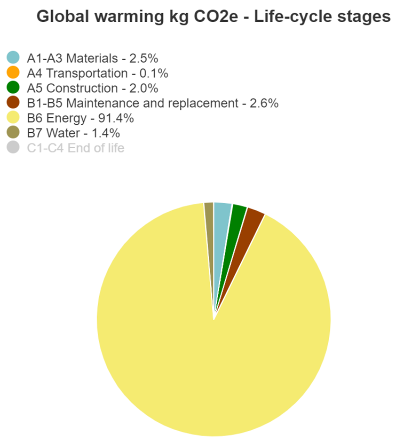

Figure 23 – The total CO_2e emission from the different LCA phases for the renovated building using a generic European Union energy mix.

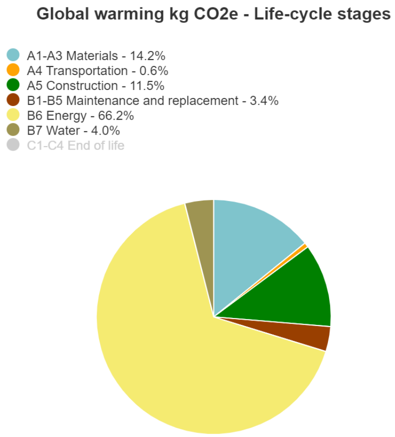

Figure 24 – The total CO_2e emission from the different LCA phases for the new building using a generic European Union energy mix.

4.4 Comparison

The LCA performed on the renovated building resulted in emissions of 345kg CO_2e/m^2, while the LCA performed on the new building resulted in 425.4kg CO_2e/m^2, which is around 23% more emission per m^2 for the new building. Both buildings would have the best possible classification A, when it comes to embodied carbon. Although the embodied carbon in the new building was roughly 2.5 times higher compared to the renovated building. The order of impact each phase in the LCA had was different for the two buildings, even though the energy B6 had the biggest impact in both buildings, the rest of it looked quite different. The biggest difference between the two was the materials (A1-A3) which represented 28.1% of the CO_2e emissions for the new building and only 8.1% for the renovated building. The material with the biggest environmental impact was different for the buildings, where windows and doors had the most emissions in the renovated building and the external walls and facade was the largest contributor in the new building.
When using the generic European Union energy mix which had a GWP almost 10 times as high as compared to the Swedish mix for the electricity, the new building had 24.3% less emissions per square meter than the renovated building over a span of 60 years. The energy use B6 in the renovated building went from representing 72.3% of the total emissions with the Swedish energy mix to 91.4% with the European Union energy mix while the new building saw an increase from 33.2% to 66.2%.

Simulations were also done using a calculation period of 100 years instead of 60. This increased the portion that the use stage B1-B7 made up in the renovated building from 85.1% to 90.6% while it reduced the emissions from 5.75kg CO_2e/m^2/year to 5.51kg

CO_2e/m^2/year which is an reduction of 4.2% of the yearly emissions. For the new building the portion from the use stage B1-B7 was increased from 47.9% to 61.4% while the emissions was reduced from 7.09kg CO_2e/m^2/year to 5.7kg CO_2e/m^2/year, which is an reduction of 19.6%. After 100 years the new building still has more emissions per year, 5.7kg CO_2e/m^2/year compared to 5.51kg CO_2e/m^2/year for the renovated building.

5 Discussion

5.1 Renovated building

That the embodied carbon for the renovated building shown in figure 15 was going to be low was expected since the concrete foundation never was replaced and they also kept the brick-facade throughout the renovation. Considering that concrete is the material with the highest environmental impact and that it was negligible for this simulation it is no surprise to see low numbers for the embodied carbon. However, seeing that it passes the A benchmark several times over there was most likely other factors playing a part as well. Knowing that the production of windows is generally quite energy-consuming it therefore has a substantial impact on the environment, it came as no surprise to see that it had similar emissions to that of the floor and roof. Since they didn't have to replace the facade it was expected that the external walls would have a low impact, it is however surprisingly close to the impact of the internal walls which is most likely due to the insulation. The energy use is usually the major contributor to the CO_2 emissions for buildings with a lifespan like this and it was expected that it would be as dominant of a factor that it was in the renovated building which can be seen in figure 16. The total emission from the renovated building that ended up at 345kg CO_2e/m^2 seems a bit on the low side, at least if compared to Anne-Françoise Marique and Barbara Rossis study shown in Figure 9 where they excluded the use phase and still had emissions of about 500kg CO_2e/m^2. However their embodied carbon was significantly higher and it wouldn't even pass grade F in One Clicks benchmark shown in figure 15, which for a renovated building can be argued that it is not reasonable. The reason for this is possibly because they put in a lot of effort to ensure that the architectural aspects of the building was maintained. All phases in this study excluding B6 only accounted for barely 100kg CO_2e/m^2 which is also on the lower side. Worth to mention though is that these phases, especially materials (A1-A3) are prone to truncation errors in a process-based LCA like this, and like mentioned before it can be hard comparing process-based LCAs.

5.2 New building

From figure 20 one can see that the energy B6 was the stage responsible for the most CO_2e emissions, followed by materials (A1-A3) and construction (A5). This seems to be a very normal distribution of emissions for new buildings. That the embodied carbon made up 159kg CO_2e/m^2 of the emissions and made the cut for the A-classification in figure 19 by quite a lot was a bit surprising, however it is not unreasonable since the classification was made for new buildings. The total emissions in this study ended up at 425.4kg CO_2e/m^2, while only the embodied carbon in Anne-Françoise Marique and Barbara Rossis study accounted for more than 800kg CO_2e/m^2. Although it is worth questioning the reliability of this source since according to the benchmarks in figure 19, the worst classification G is reached already at 320kg CO_2e/m^2 which means that the study from figure 9 more than doubles that amount.

5.3 Comparison

The composition of the CO_2 emissions from the different LCA phases for the new building looks somewhat similar to that of the renovated building, the biggest difference being that for the new building the materials A1-A3 and construction A5 makes up for a significantly bigger portion of the total emissions, while the energy B6 is much more prevalent in the renovated building. Since the whole purpose of a renovation is to use less materials and less construction time this was to be expected. That the embodied carbon for the new building was roughly 2.5 times higher than that of the renovated building shows how much of a difference not having to create a new foundation makes since that was probably the biggest different in terms of material between the two. Rob Marsh mentioned in his study that a significant reduction of emissions per year could be achieved if the lifespan was increased from 50 to 100 years, therefore another simulation was done using the calculation period of 100 years instead of 60 years. The longer the lifespan is of a building the more impact the use stage B1-B7 will have on the overall emissions, since the use phase already made up for 85.1% of the emissions in the renovated building in a span of 60 years, the emissions per year wasn't reduced by a lot when the lifespan was increased, only a mere 4.2% reduction per year. For the new building where the use phase wasn't quite as impactful as in the renovated building and it only made up for 47.9% of the total emissions, the emissions per year were reduced by a lot more when the lifespan was increased. However the 19.6% reduction is still far from the 30-40% that Rob was claiming, the only way to obtain such a high reduction would be if the construction phase and materials made up for an even larger portion of the overall than in the new building, and the energy use has to be a lot lower.

Overall when looking at the GWP for the two buildings, one can see that the new building ends up emitting around 23% more CO_2e/m^2 during a 60 year lifespan. Since the energy usage during the use phase and especially the district heating differed so much between the buildings this made up for the majority of the discrepancy in emissions per m^2. The reason that the renovated building is in need of so much more heating is largely because of the difference in heated area between the two, where the renovated building is more than twice as big. However this doesn't explain the fact that the emissions per m^2 differ to that extent, this is likely due to that the insulation and U-value in the renovated building isn't as effective as in the new building, especially in the parts that were not touched at all, the foundation and facade.

When using an energy mix that was significantly worse in terms of GWP it was no surprise to see the energy stage B6 increase the way it did, it was however a bit surprising to see that the new building ended up being more environmental friendly with this new energy mix, even for a lifespan of 60 years. The new building went from having 23% more emissions than the renovated building to having 24.3% less emissions just from changing the energy mix, this goes to show how much of a difference the energy mix can make and how important it actually is. Although this study didn't quite achieve the numbers that Hasik et.al study achieved [50] where they claimed a renovation would help avoid 53-75% of the impacts from a new construction, it still showed that it is in fact more environmentally friendly to renovate a building, assuming it has a lifespan of less than

100 years. After 100 years the new building only had 3.4% more emissions and since the use phase was significantly larger in the renovated building, it is safe to assume that the new building will end up having less emissions than the renovated building soon after 100 years. According to Beatriz Palacios-Munoz study new buildings have significantly longer lifespans than renovated ones [15]. It is therefore not unlikely that a new building would last for over a 100 years, however most LCAs today are done using a 50-60 year lifespan and for a 60 year scenario the renovated building proved to be about 23% more efficient in terms of emissions.

6 Conclusions

It was shown that for the renovated building the largest polluter by far was the use phase even when the building had a lifespan of 60 years, and it becomes even more dominant with a lifespan of 100 years. However for the new building the product phase and construction phase had the largest impact when the lifespan was 60 years, but when the lifespan was increased to 100 years the use phase ended up being the largest emitter for the new building as well. This is even though the energy production in Sweden is considered to be one of the most environmental friendly in the world, which goes to show that this is where the focus should be if one wants to reduce the total emissions in the life-cycle. The choice of energy source has a big effect on the results. The foundation which is the material that made up the majority of the difference in (A1-A3) between the buildings should not be overlooked and when one is looking to improve their material choice, a lot could be saved just from using the most environmental-friendly concrete. In terms of GWP and emissions per m^2 the new building ended up being the largest emitter by about 23% more for a 60 year lifespan, however the new building became a more and more attractive alternative the longer lifespan the building had and it would have surpassed the renovated building soon after 100 years. This study further strengthens the claims mentioned in the introduction that a renovation of a building results in lower emissions from a life-cycle perspective as compared to a new one, at least for lifespans lower than 100 years.. While it is good that the Swedish government tries to incentivize constructors to build more environmental-friendly, LCAs in its current state feels too unreliable to have as a base for such a law. As it is right now there's too many factors that can affect the outcome, all from the choice of software and LCA method to the product database. However as mentioned before we will only see the effect of the climate declaration in the long run.

7 Future Work

Since the results could have a variation of 15% depending on what type of software the simulations was done in, it would be interesting to see the same study being done using a different software to see how reliable these results are. It would also be interesting to see the same study being done with a much more detailed list of materials where electronics, VVS and smaller products are included to see what impact they would have had. The construction phase in this study was simplified to where only the area of the construction-site was given, but there was an option to use more detailed information in the simulation which leaves some room for improvement for a future study. For future studies when it comes to LCAs in general I think it is in need of a lot more standardisation's and guidelines such as choice of software and database.

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