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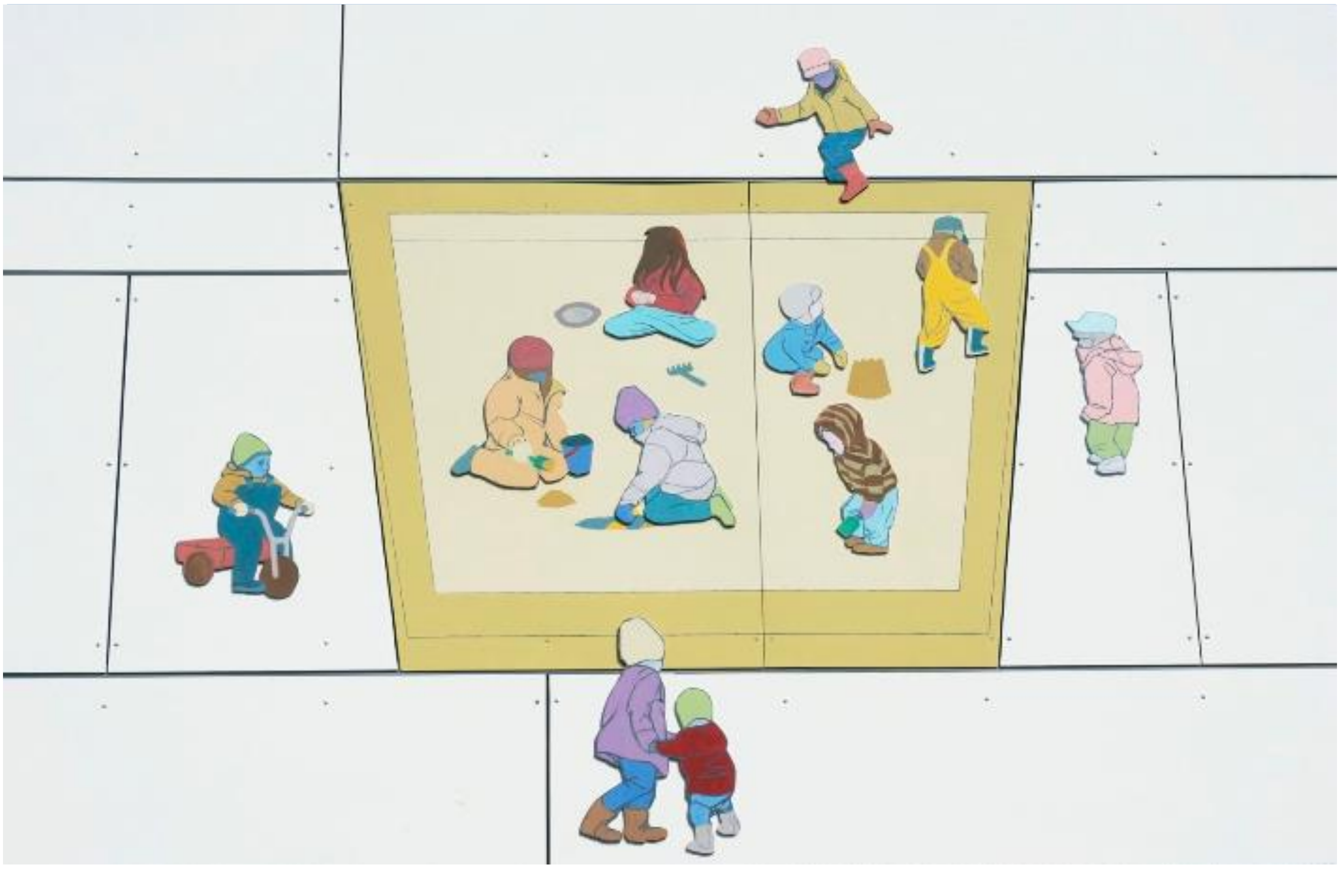

The climate impact of a preschool building in Gothenburg

Focus on the building process and the construction materials

Master's Thesis in the Master's Programme Design for Sustainable Development

EMELIE AXELSSON

Department of Civil and Environmental Engineering
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Master's Thesis BOMX02-16-122

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Cover:
The artistic design LEK I: Sandlåda of Johanna Tymark, 2014, on one of the facades at the preschool on Södra Sälöfjordgatan.
Johanna Tymark Göteborg, Sweden, 2016

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ABSTRACT

Until today, the construction sector's focus has been to reduce the environmental impact of the operation phase by building energy efficient buildings and using renewable energy solutions. This due to the operational phase is being considered, from a life cycle perspective, the stage that has the greatest climate impact. Recent studies report that the building's carbon footprint has become more equal between the construction process and the operational phase. This is given by the reduced energy usages resulting in tight and well-insulated building envelopes and has also increased the use of building materials.

The aim of this master thesis is to bring up the question about the climate impact of the construction materials in the building process, and identify building materials with large impact on the climate in a new built preschool in Gothenburg by calculating a part of an LCA analysis. The delimitation has been made to the preschool building's envelope and the analysis is based on a "cradle to gate"-LCA, meaning that the building material's climate impact caused by the manufacturing which have been analyzed.

The result of the calculation is that approximately 293 tons of carbon dioxide have been emitted during the production of the analyzed materials which are included in Södra Sälöfjordsgatans preschool. The concrete slab represents the largest climate impact by 27%, followed by 26% for intermediate floor and the framework 18%. These results provide an indication of where the major climate impact can be found in the form of building materials and how, in the future, we can work with them to get even better result. Is the desire a comprehensive picture of the environmental impact of the preschool, other environmental categories than climate change should be taken into account. To summarize we need to explore, develop and cooperate more within this subject. If the building sector is going to reduce the climate impact of our buildings, we should do it together, alone is not strong.

Key words: LCA, "cradle-to-gate", Lokalförvaltningen, preschool, climate impact, CO_2-emissions

Klimatpåverkan från en förskolebyggnad i Göteborg
Focus på byggnadsprocessen och valet av byggnadsmaterial

Examensarbete inom mastersprogrammet e Design for Sustainable Development

EMELIE AXELSSON
Avdelningen för Bygg och Miljöteknik
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SAMMANFATTNING

Fram till idag har byggsektorns fokus varit att minska miljöpåverkan från driftsfasen genom att bygga energieffektiva byggnader och använda förnybara energilösningar. Detta på grund av att driftfasen ansetts vara, ur ett livscykelperspektiv, det skede som haft störst klimatpåverkan. Nya studier rapporterar att byggnadens klimatpåverkan blivit mer jämställd mellan byggprocessen och driftfasen, med tanke på det minskade energibehovet som resulterat i täta och välisolerade klimatskal, men framförallt ökat användningen av byggmaterial.

Syftet med detta examensarbete är att ta upp frågan om klimatpåverkan från byggmaterialen i byggprocessen, och identifiera de byggmaterial med stor klimatpåverkan som finns i en nybyggd förskola i Göteborg genom att beräkna en del av en LCA-analys. Avgränsningen har gjorts till förskolans klimatskal och analysen är baserad på en "vaggan till grind"-LCA, som betyder att det är byggmaterialens klimatpåverkan utifrån produktionen som analyserats.

Resultatet från beräkningarna är att cirka 293 ton koldioxid släppts ut under tillverkningen av de analyserade material som ingår i Södra Sälöfjordsgatans förskola. Betongplattan står för den största klimatpåverkan med 27%, följt av 26% för mellanbjälklaget samt stommen 18%. Dessa resultat ger en fingervisning om var de stora klimatbovarna i form av byggnadsmaterial finns och hur vi i framtiden kan arbeta med dessa för att kunna bli ännu bättre. Är önskemålet en helhetsbild av förskolans miljöpåverkan bör även andra miljökategorier än klimatpåverkan beaktas. Sammanfattningsvis tyder allt på att vi måste undersöka, utveckla och samarbeta inom ämnet. Vill byggsektorn minska klimatpåverkan från våra byggnader bör vi göra det tillsammans, ensam är inte starkast.

Nyckelord: LCA, ”Vagga till grind”, Lokalförvaltningen, förskola, klimatpåverkan, CO_2.

Contents

Preface

This master thesis has been carried out from January 2015 to June 2016 at the department of Civil and Environmental Engineering at Chalmers University of Technology, Sweden.

I will like to express my gratitude to my supervisors Angela Sasic at Chalmers and Nina Jacobsson Stålheim at Lokalförvaltningen in Göteborg, you are highly appreciated for all your help and support.

I would also like to thank Holger Wallbaum at Chalmers and Lisa Andersson at Miljöbron[1], for your cooperation and involvement.

Thanks to the opponent at the presentation of this thesis; you provided valuable comments and insights which helped in finalizing the report.

I will also like to thank all the people I have spoken to during meetings and interviews for sharing their knowledge and thoughts, you have provided important information for this thesis.

Finally, it should be noted that this master thesis could never have been conducted without all the support from my family and friends.

Göteborg, June 2016

Emelie Axelsson

[1] Miljöbron stands for "the environmental bridge" and serves like a link between students at universities and companies in the hope of contributing to a sustainable development.

Notations

A_{temp} – Indoor area heated more than 10˚C
BBR – Boverkets byggregler
BPD, BVD – Bulding product declaration, Byggvarudeklaration EPD – Environmental product declaration
GWP_{100} – Global warming product
LCA – Life cycle assessment
LF – Lokalförvaltningen
IEA – International Energy Agency
IVA – Kungliga Ingenjörvetenskapsakademien
IVL – Svenska miljöinstitutet
PBL – Plan och bygglagen
PCR – Product category rules

1 Introduction

In Sweden, the building sector plan, build and design the environment all around us and it impacts every humans' life. The sector includes all the actors in construction, civil engineering, utilities and building industry, from the government, developers and property owners to entrepreneurs, architects and technical consultants. It is the largest industry in the country and is controlled by politics and operated by a long term development and planning processes (Sundén et al, 2015).

Until today, the building sector's focus has been to reduce the environmental impact of the operational phase through energy efficient buildings and renewable energy solutions. The sector has reduced the energy consumption dramatically by building dense and well-insulated building envelopes. The environmental impact caused by the building process, from the raw material to the completed building, has not been in focus (IVA, 2014).

All the focus on the operational phase is based on studies made in the early 21st century. Adalberth et al presented a life cycle assessment study about the climate impact and the energy usage during a building's lifecycle in 2001. The given result indicates that the operation phase has the most impact with 85% against manufacturing 15%. Based on this result the numbers have become a common assumption of the relation between the manufacturing and the operations climate impact.

Latterly new case studies indicate that these well used numbers, 15% vs. 85%, is not relevant for the buildings today. By reduced needs of energy and increased use of construction materials, the building's climate impact is shifted from the operation to the manufacturing seen in a lifecycle perspective, e.g. the two studies of Brown et al (2014) and Liljenström et al (2015). Their result indicates that the building process and the choice of the construction materials have more impact than previously thought. In the report by Liljenström et al (2015), the climate impact from the building process assess equal 50% vs. 50% for a multi-family dwelling in the operation of 50 years. The assessed multifamily dwelling is a passive house built in Stockholm with prefabricated concrete. The calculations are made with district heating and Nordic electricity.

Due to these new studies, the building sector need to find other possibilities to reduce the environmental impact from the building process and to start focus on the climate impact caused by construction materials. *"The knowledge in this field can increase and create favorable conditions for the politicians and all the different actors in the building sector to take appropriate actions"* (Liljenström et al, 2015).

1.1 Aim

The aim for this master thesis is to bring up the question about climatic impact of the construction materials in the building process; increase the knowledge and discuss measures to limit the climate impact of future preschool buildings. By calculation identify the construction materials in a new built pre-school building with the largest impact.

1.2 Lokalförvaltningen in Gothenburg

This master thesis has been made in cooperation with the department of public facilities in Gothenburg municipality: Lokalförvaltningen, LF. They both administer and build the facilities for the municipality and is one of the biggest actors in Sweden with over three thousand buildings and a total area of over two million square meters. The buildings mostly consist of pre-schools, schools, nursing homes, group homes and administrative facilities[2].

Today Lokalförvaltningen builds facilities using little energy during their operating time, called operating energy. Their standard is 45 kWh/m^2 year with possibilities to some additional energy use regarding to the large air changes a school requires[3]. It is very low in relationship to the demands of 80 kWh/m^2 year Boverket states in BBR when this study started in January 2015. From the first of March 2015 Boverket changed their demands to 65 kWh/m^2 year.

In previous studies LF has made, they have pointed out the relevance of climate impact and the relation between climate impact of materials and the operation time. In the future they also have a goal to reduce their climate impact from the production phase. In "Klimatstrategiskt program för Göteborg", Göteborg Stad (2014) state their goal: *Göteborgs stad will decrease the climate impact from purchasing goods and materials until year 2030. The level of the goal is today under investigation.* This is the goal for the whole municipality, and with this master thesis LF wanted to investigate the climate impact from their purchasing of building materials and with this information try to reduce the impact by purchasing other materials with lower impact during the lifecycle.

1.3 Delimitations

A lifecycle perspective includes all the stages of a product's life from raw material to production, manufacturing until dissembling or demolition. When working with life cycle assessments and to be able to analyze the climate impact of a building, it is necessary to define a functional unit, evaluation indicators and system boundaries.

1.3.1 The functional unit and selection of case study

The functional unit is a precondition for being able to compare different items and services (Tyréns, 2015). This master thesis has been delimited to facilities and a preschool which are administered by Lokalförvaltningen and sited in Gothenburg with a reference study period of 50 years. The reference study period means the calculation time of time-dependent aspects that has a climate impact such as operation and maintenance.

In the selection of a preschool, the demands were that it should be a preschool with a conceptual design for Lokalförvaltningen today and was built within the last few years. It should be a two storey building with 4-6 departments, since more and more preschools today are built like that. The preschool that was selected based on established criteria is Södra Sälöfjordsgatans förskola, located on Hisingen. It is an L-shaped pre-school building with two floors and with five departments.

[2] J Stålheim, Nina; Lokalförvaltningen, Supervisor for this Master Thesis 2015, Interview (18 January).
[3] J Stålheim, Nina; Lokalförvaltningen, Supervisor for this Master Thesis 2015, Interview (18 January).

The starting point was that if the preschool could be more efficient, the new variants would become much better. However, the relationship between them would be the same. Focus has not been to find the optimal design, for example to slim the construction, minimal the envelope surface or minimizing the thermal bridges etc.

1.3.2 The evaluation indicator

The evaluation indicator is a parameter used to describe the climatic impact. Focus for this master thesis has been the evaluation of the carbon dioxide emissions related to the construction materials in a new built pre-school building. According to the standard EN 15978, the climate impact in the study is described by the indicator global warming potential, $GWP_{100,}$ expressed in units of kg CO_2-equivalents. For notification, the biogenic absorption of carbon dioxide and carbonation of concrete is not included in this master thesis.

1.3.3 The system boundaries

The system boundaries identify which aspects that are included in the analysis and which are omitted. All the phases in the lifecycle of a building are considered in a life cycle assessment, LCA. The European standard EN 15978:2011 define the system boundaries and include all the processes downstream and upstream needed to establish and maintaining the building's features. The idea for this master thesis was not to make a full LCA, since previous studies suggest that the construction material has a great climate impact of the building process.

The system boundaries in this study are made to the choice of construction materials and their climate impact of the modules A1-A3 – product stage. It means that this master thesis is a cradle-to-gate assessment with relevant phases from resource extraction, cradle, to the manufacturing, gate, before the product is transported to the consumer. The use phase and disposal phase are not included in the analysis.

A building consists of a variety of subsystems, including parts and construction materials. Focus for this master thesis has been construction materials related to the buildings envelope like concrete, wood and insulation etc. The building’s envelope means that the construction parts like walls, intermediate floor, foundation, footings, framework and roof are taken into account. Previous studies have shown that these materials have large climate impact regarding to volume, type of material and its manufacturing. These materials are chosen considering those studies and that Lokalförvaltningen purchase these materials in big volumes.

The climate impact from transports and manufacturing caused by roofing materials, windows, doors, interiors, installations, equipment’s etc. are not taken in consideration in the analysis. This is due to the extensive data needed and its likely relatively low contribution to the total climate impact caused by the construction materials.

2 Method

Most of the work has been carried out at Lokalförvaltningen and the department of development, but also in cooperation with the project department and the technical department of energy, environment and safety expertise. The method can be divided in two: the collection of information and the collection of data.

2.1 The collection of information

This method is based on literature studies, interviews, workshops and seminars; all to gather information about the subject and about Lokalförvaltningen. The literature study is based on the available research materials until October 2015. The research materials have mainly been collected from IVA, Boverket, Sveriges Byggindustrier, Tyréns and IVL.

To complement the literature study a couple of workshops and seminars have been attended regarding to the climate impact from the building process. At the seminars the companies Tyréns and Riksbyggen present their work regarding to the subject. The two workshops in spring 2015 in Stockholm were arranged by a group of researchers that work with a development of a national agenda that could create a strategic innovation area.

To learn about the organisation Lokalförvaltningen and their building process, semistructured interviews have been made with the supervisor for this master thesis and project leaders. Some different project meetings have also been attended during spring 2015.

2.2 The data collection

Data from the selected conceptual pre-school building has been collected from spreadsheets, energy analysis, construction documents and design drawings provided by the digital archive of Lokalförvaltningen. The majority of data is related to the foundation, frame, middle floor and parts of walls and roofs. The technical requirements and instructions of Lokalförvaltningen have been used as a support for the thesis, along with environmental requirements, including the use of Byggvarubedömningen, BVB.

All the calculations for this master thesis has been made in a excel file. The data for specified construction materials, like density and global warming product, GWP, are collected from production sheets, Byggvarudeklarationer, Environmental Product Declarations, study reports and resellers. If the specified product hasn´t been available, a similar product has been selected or international generic data from the database Ecoinvent have been used.

3 Terms and definitions

To get a deeper understanding of life cycle assessments and climate impact, this following chapter will define some important terms and definitions.

3.1 The concept of life cycle assessment, LCA

The concept of life cycle assessment, LCA, is a methodology developed to assess the environmental impact during a product's or a service's lifecycle from "Cradle-to-grave". It is the most widespread and widely accepted analysis tool to calculate the environmental impact of construction. It gives a holistic approach with detailed studies from raw material to production, manufacturing until dissembling or demolition (Baumann & Tillman, 2004; ISO 14040:2006). A LCA consist of four steps in an iterative process including the life cycle of all the materials and more detailed analyses of greenhouse effect, ozone depletion etc. due to the industrial processes of production. Even if LCA has existed for a long time, the knowledge and applications are limited in the building sector (Liljenström et al, 2015).

Historically, life cycle assessment of buildings is not new. In the 1990s, a range of environmental assessment tools for buildings based on life cycle assessment were developed in different countries (IEA, 2001). Miljöbelastningsprofilen and the tool Ecoeffect is two examples developed in Sweden. The problem with a high number of different assessment tools with different system boundaries is to compare the results with each other. For example, Adalberth et al (2001) and Thormark (2002) have done similar calculations based on different system boundaries for their calculations of a building's climate impact.

In order to counteract the high number of different assessment tools, the International and European standardization organization, ISO and CEN, in the 2000s developed standards to perform such calculations. Today, the accepted way to perform calculations of the environmental performance of buildings is specified in the standard EN 15978. Furthermore, the standard EN 15804 gives product specific rules, PCR. In 2014, a PCR for buildings were adopted which was compatible with standards EN 15978 and EN 15804 (Liljenström et al, 2015).

In Figure 1, the standards EN 15978 and EN 15804 are illustrated. The building's life cycle is divided into different information modules (A, B, C, D) which represent the product stage, construction stage, usage, end of life and benefits and loads beyond the building lifecycle. In this master thesis, the modules A1-A3 are in focus occurring upstream in the building process. B-C are modules that occur downstream, which means the operation time and is based on scenarios. D is defined as additional information (Liljenström et al, 2015).

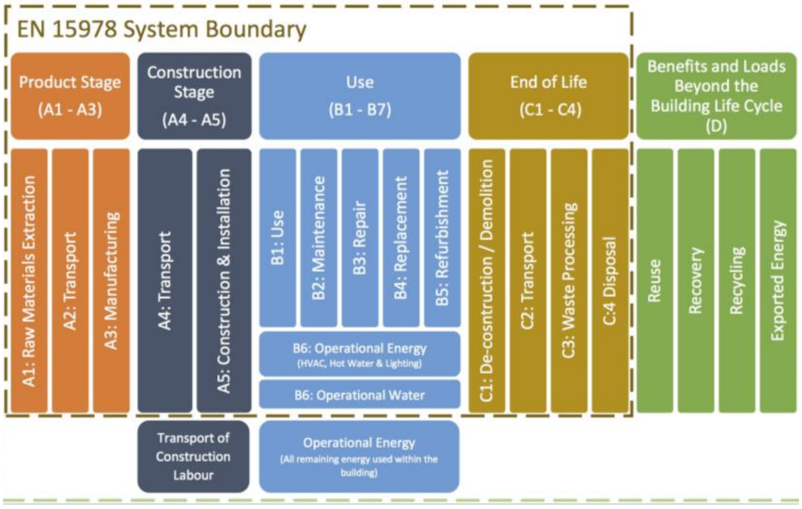


Figure 1- In the standards EN 15978 and EN 15804 the building system boundaries are divided into different information modules (A, B, C, D). These are divided into sub-modules (A1, A2 ..., B1, B2, ..., etc.)

3.1.1 Module A1-A3 Product stage

The product stage includes the information modules A1 to A3 and it is the consisting modules in a cradle to gate assessment. A1 includes everything related to the extraction of the raw material. After the extraction, the material are processed and construction materials are produced, A3. The transports between the extraction and manufacturing are included in A2 (Liljenström et al, 2015).

3.2 Environmental Product Declaration, EPD

Environmental Product Declaration, EPD, is an international system of environmental declarations based on international standard[4]. It is an independently verified document with information about the life cycle climate impact of products mostly based on cradle to gate assessments. To make the Environmental Product Declarations transparent and comparable, some specific rules are made, called Product Category Rules, PCR. PCR are standards for how the EPD should be done in detail in each product category in order to make the LCA-result relatively unambiguous (Erlandsson, 2014).

3.3 LCA-Tools, databases and data quality

To make environmental impact assessments, there is a variety of different types of LCA-tools. Anavitor and 360optimi are examples of well-established software for buildings, excel files are also used and generic LCA-tools as Gabi and SimaPro. SimaPro are the common software of LCA analysis in Sweden (Boverket, 2015). To make an LCA the global warming product, GWP, for each ingoing construction materials and processes is needed. In Sweden, there are no databases that are easily used and free of charge. The data used are often a mix of different data sources, depending on what is available. It can be data from international databases or EPD-data and specific data from suppliers. In SimaPro, the database Ecoinvent is available which contains continuously updated verified generic data. Ecoinvent is an established database of generic data according to PCR for buildings (Boverket, 2015). As mentioned before, this master thesis has used an excel file for calculations.

[4] ISO 9001, ISO 14001, ISO 14040, ISO 14044, ISO 14025

3.4 The building product declarations, BPD

The building product declarations, BPD, *(swe. Byggvarudeklarationer, BVD),* is a documentation that declares the chemical content of a specific material and other environmental performances. Because of the easy accessibility, the document is often used as a basis for prioritizing of construction materials and other assessments system, for example Byggvarubedömningen. Another perspective is that the declaration of material content indicates how the material environmental needs to be handled during the various life stages.

3.5 The assessment tool Byggvarubedömningen

Lokalförvaltningen uses Byggvarubedömningen, a web-based tool[5] that facilitates the selection of construction material. It is a system and a database collecting the most common construction materials in the building sector, which are all environmentally assessed. The environmental assessment is based on criteria that evaluate both the ingoing properties of substances and the life-cycle impacts of the product. Today, the assessment is based on Byggvarudeklarationer (BVD3), safety sheets, eventual declaration of the contents of substances etc. By the criteria and the assessment, the product finally will be graded as "recommended", "accepted" or "avoided". Lokalförvaltningen uses Byggvarubedömningen to achieve their goal with non-toxic and sustainable construction, to get a declaration of what kind of materials and substances their buildings consist of. It is a way for LF to take responsibility for what is left for the future generations. LF require the use of BVB in all projects. BVB is also highlighted in their environmental policy (Lokalförvaltningen, 2015).

3.6 Certifying tools

In the quest to make a sustainable building, a lot of different rating system and certifying tools has been developed all over the world (Boverket, 2015). Some examples are Minienergie, passivhus, LEED and BREEAM to mention some of them. This multitude of currently existing approaches to assess the environmental performance of construction materials and buildings lead to a lot of confusion in the building industry. The increasing awareness has increased the interest for LCA based information, and also the needs for a clarification and harmonization at European/regional level of various environmental assessments. LEED and BREEAM both include the assessment of the climate impact from the building process.

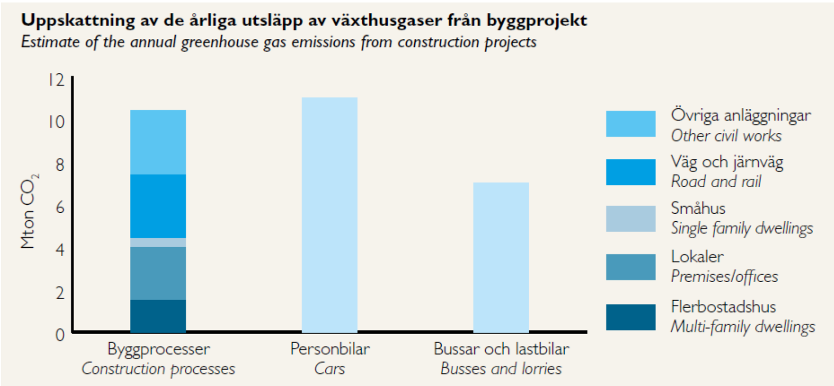
The certifying tools have also played a role in promoting the development of databases and product specific information, like EPDs, for construction materials and processes (Boverket, 2015). For example, BREEAM-nor exist in Norway and DGNB in Germany. In Sweden, the most common certifying tool is Miljöbyggnad. It is a tool to reach environmental friendly buildings with good quality which are better than the BBR standard. Miljöbyggnad does not evaluate indicators highlighting low climate impact from construction materials. This is an issue for future development.

[5] www.byggvarubedömningen.se

4 Collection of information

During Almedalsveckan in summer 2014 the Royal Swedish Academy of Engineering Sciences, IVA and Sveriges byggindustrier presented an intermediate report from an ongoing research of the climate impact from the building process. Calculations from that study indicate that the climate impact from the Swedish building sector stands for around 10 million tons of CO_2-equivalents each year, 4 million by housing projects and 6 million by construction projects. This corresponds to about 17 percent of the total Swedish emissions of greenhouse gases in the year 2012. Table 1 describe the fact that it is the same size of emission as from all the cars in Sweden and more than is generated by all the lorries and busses (IVA, 2014).

Table 1 - The table describes the relation between the construction processes and cars' total CO_2 emissions each year in Sweden (IVA, 2014)



The report, the climate impact from the building process, made by KTH and IVL (Liljenström et al, 2015) were published in January 2015. The report looks at the climate impact caused by the building process, upstream, from the raw material to the completed building. It is a case study of a new built multi-family concrete dwelling in Stockholm, called Blå Jungfrun. The building is a passive house with 55kWh/m^2A_{temp}. Results given from this study show that the materials stand for 84% of the buildings climate impact. Concrete represents 50% of the climate impact from materials, processes at the building site 13% and transports to the building site only 3%. Comparisons of the built low energy building are made with the same building with a garage and with a similar theoretical house based on demands of BBR. The results from the comparisons show that the climate impact would increase 20%, much due to the increase of concrete, and the energy efficient building has lower climate impact than a building by demands from BBR. Thus, the climate impact of the energy efficient building is lower, even if it contains more materials.

4.1 The knowledge and application in Sweden

In September 2014, the Swedish government gave Boverket, the Swedish authority for building and housing, a mission to investigate the state of research and knowledge regarding the climate impact of buildings in a lifecycle perspective (Regeringsbeslut, 2014). The assignment was made in cooperation with Naturvårdsverket, the Swedish agency of environmental protection and Statens energimyndighet, the Swedish authority of energy. Today Bygglagen, BBR and Plan och Bygglagen, PBL, only regulates what goes on downstream.

According to the analysis of Boverket presented in 2015, the research has come far within the subject of climate impact caused during the construction phase. The problem is that application is limited in Sweden. Some developers have used LCA calculations to improve the knowledge and investigate how requirements could be set. The major entrepreneurs have worked with the question and have experience of different LCA-tools. At the municipal level, there are a handful of municipalities that have tested and investigated ways to move towards reducing climate impact. For example, the city of Stockholm has recently adopted a policy to demand climate impact calculations in their own projects costing over 10 million Swedish crowns (Boverket, 2015). For the supplier of construction materials, focus is on Byggvarudeklarationer and the chemical substances in the materials. According to the development of EPD, it is the large companies in the steel, cement and insulation industry that produce EPDs for their products; Much because of the fact that climate impact caused by the production phase has been a significant environmental aspect.

4.2 The international application of LCA

In its report, Boverket (2015) has compiled a table illustrating the progress made internationally by the implementation of LCA calculations for reducing climate impact in buildings. Table 2 shows that, in many countries, there is a mix of actors who drives the development, both the authorities and industry.

Table 2 - This is an overview of the actors in the respective countries which are driving the development to enhance the application of life cycle thinking in construction.

	Industry organizations	Certification systems	Research Institute	The industry of construction materials	Authorities / Public actors	Entrepreneurs / Developers / Constructors
Australia		X				
Brazil						
Denmark		X			X	
Finland	X					X
Italy						
Japan			X	X		
Netherlands		X			X	
Switzerland					X	X
Spain			X		X	
United Kingdom			X	X		X
Sweden		X	X			X
South Korea			X		X	
Czech Republic		X	X	X		
Deutschland			X		X	
Austria	X	X			X	

For example in Austria the Austrian Institute for healthy and ecological building, IBO, has worked with the development of different tools for LCA calculations. The result is the software Ecosoft and Baubook, earlier Bauteilkatalog. It is a catalog with open data for different types of construction solutions. The Netherlands has come far with regulations, since first of July 2013 there is a requirement of LCA calculations to receive building permits for new residential and office buildings of 100 m^2 usable area. In order to fulfill the requirements, the Netherlands has its own database of construction materials, as well as a freely available calculation system.

5 Case study – Södra Sälöfjordsgatans förskolan

The pre-school Södra Sälöfjordsgatans förskola is located on the southern part of the island Hisingen, Gothenburg, very close to the soccer field Sälöfjordsvallen and few steps away from the port in Eriksberg. Figure 2 is pictures of the pre-school that was built during 2012-2014 and opened in August 2014. It is a two storied L-shaped building with five departments.

Figure 2 - Picture of the building, streetview and the yard.

The building has an area, $A_{temp,}$ of 1103 m^2 and is heated by district heating and with floor heating. The energy analysis document was issued by the external consultant Sweco Systems AB (Brändemo, 2013). The basic information from the energy analysis document is presented in Table 3. The calculations have been made by the program IDA ICE 4.5.2, more used at Lokalförvaltningen is VIP ENERGY.

Table 3 - Basic information of the building extracted from the energy analysis (Brändemo, 2013).

Type of framework	
Area A_{temp} (m^2)	1103
Average termal conductivity coefficient (W/m^2*K)	0,15
Fraction of window spacing (window area/building area)	14%
Shape factor (enclosing area/A_{temp})	1,9
Indoor temperature	20℃
Operating energy consumption (kWh/ m^2*year)	115
Total energy consumption (MWh/year)	124

5.1 The construction of the preschool building

For this study, only the parts associated with the buildings envelope is taken into account. The buildings envelope means the construction parts like walls, intermediate floor, foundations, footings, frameworks and the roof. The construction of wood and steel beams is standing on a concrete slab. The walls consist of a wind stopper, wooden studs, gypsum and insulation; both rock and mineral wool. The exterior with fibre cement boards are not included in the calculations. The intermediate floor slab consists of prefabricated concrete slabs and the roof has wooden rafters, studs and insulation of mineral wool. The sheet metal on the roof is not included in the calculation.

6 Data collection and calculations

To be able to calculate the climate impact of the preschool building in Gothenburg, both the amount of building construction materials and the global warming product, GWP_{100} for each material is required. The amount of the building materials is obtained from calculation sheets and construction drawings of the preschool building. The calculation sheet is made in the spreadsheet program Wiksell at the calculation department at Lokalförvaltningen. In the calculation sheet each construction material and its costs are specified in order to obtain a total cost for the entire building project. The construction drawings are made by the consulting firm Härlanda Byggteknik AB.

To calculate the climate impact of the preschool, the amount of construction materials from calculation sheet was transformed in to an excel-file. In the file, each building part was listed with the ingoing material components and its amounts. To get the weight in kilogram of each material, every component was calculated in to a total volume, m^3 and then multiplied with the materials density. The data of density is collected from product sheets and building material books listed in the Appendix A: Data references. Standard values are used. The result from this calculation is listed in Table 4.

To get the climate impact from each material the materials' weight is multiplied with the materials GWP. The data of global warming products can be collected from a variety of different databases. In this thesis, the data is collected from production sheets, product declarations, study reports and resellers. If the specified product has not been available, either a similar product has been selected or international generic data from the Ecoinvent database. All the references are listed in Appendix.

In the calculations some modifies are made:

- In the wall and the roof, the façade and roof layer is not included in the calculation.
- A CO_2-value for the windstopper has not been found, therefore the same way as cement due to it consisting of 80% cement.
- In the calculation of the amount of concrete in the middle floor the dimensions were changed. The building is built with floor heating and which is not standard according to Stålheim at Lokalförvaltningen (2015). Thus, the amount of concrete is reduced.
- In the calculations of the concrete slab, the elevator shaft is seen as an area related to the slab.

Table 4 - A list of construction materials with total amount extracted from the building drawings and the calculation sheet (Willman, 2012).

Walls	Timber lath	5,61	m^3
954m2	Rock wool	95,40	m^3
	Cembrit Windstopper	4,29	m^3
	Timber stud	33,06	m^3
	Mineral wool	276,66	m^3
	PE foil	0,19	m^3
	Steel stud	0,22	m^3
	Gypsum board	24,80	m^3
	Steel sheet	0,02	m^3

Intermediate floor	Concrete	12,96	m^3
648 m^2	Reinforced steel	1036,80	kg
	Prefab concrete board	174,96	m^3

Foundation	Concrete C25/30	141,85	m^3
709,25 m^2	Reinforced steel	22696,00	kg
	Extruded polystyrene G100	212,78	m^3

Footings	Concrete C25/30	59,42	m^3
	Cement	1,84	m^3
	Reinforced steel 80 kg/m3 concrete	4736,20	Kg
	Extruded polystyrene G100	46,87	m^3

Framework	Concrete	0,88	m^3
	Reinforced steel	88,00	Kg
	Steel pillar	18 960,00	Kg
	Glue laminated timber	33,3996	m^3

Roof	Tongue in groove	18,81	m^3
855 m^2	Timber lath	3,46	m^3
	Fibreboard	2,74	m^3
	Mineral wool	402,20	m^3
	Timber studs	17,03	m^3
	Gypsum board	0,64	m^3

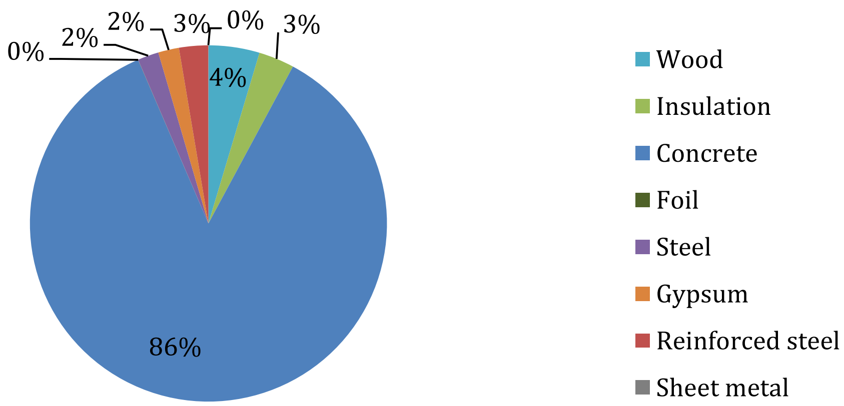
7 Result

In this chapter, results from the calculations made in chapter 6 are presented. The result is presented in three different circular diagrams; the relation between the construction materials, the climate impact of the construction materials and the climate impact of the building divided by each building part.

7.1 The relation between the construction materials

The construction of the building consists of seven defined material groups; wood, insulation, concrete, steel, reinforced steel, gypsum and plastic foil. The materials have a total weight of 1082 ton. The diagram in Table 5 illustrates the relation of each material's total weight. The amount of concrete is the largest with 86% of the constructions total weight, which is 930,5 ton of the total weight of 1082 ton.

Table 5 - The total weight of the construction materials in kilogram presented in percent.

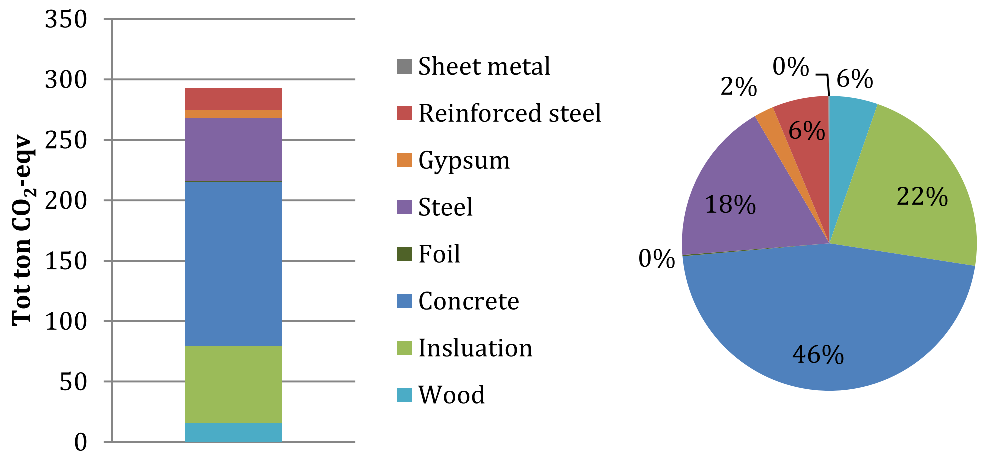


7.2 The climate impact of the preschools construction materials

The result from the calculation of climate impact per the construction materials is that the construction materials in the buildings envelope of the pre-school have a total climate impact of 293 ton CO_2-eqv. The impact from each material is presented in Table 6, and in the Appendix B: Data table Tyréns.

In the circular diagram, Table 6, each materials climate impact is presented in percent. The diagram illustrates that concrete stands for 46% of all calculated climate impact, the second is insulation with 22% and third is steel, with 18%. It means that the material with significantly largest impact in this buildings envelope is concrete.

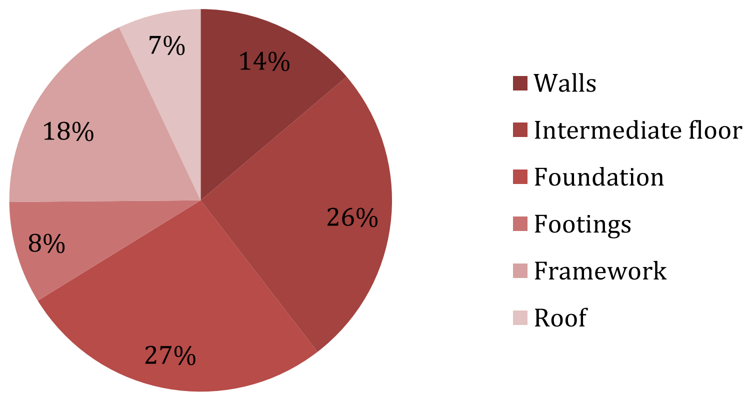
Table 6 - The climate impact of each construction material presented in total ton CO_2-eqv and in percent.



7.3 The climate impact of each building part

The result from the climate impact divided by components is presented in the circular diagram, Table 7. The diagram illustrates that the slab and the middle flooring has the largest climate impact.

Table 7 - The climate impact of each construction part presented in a circular diagram and a table.



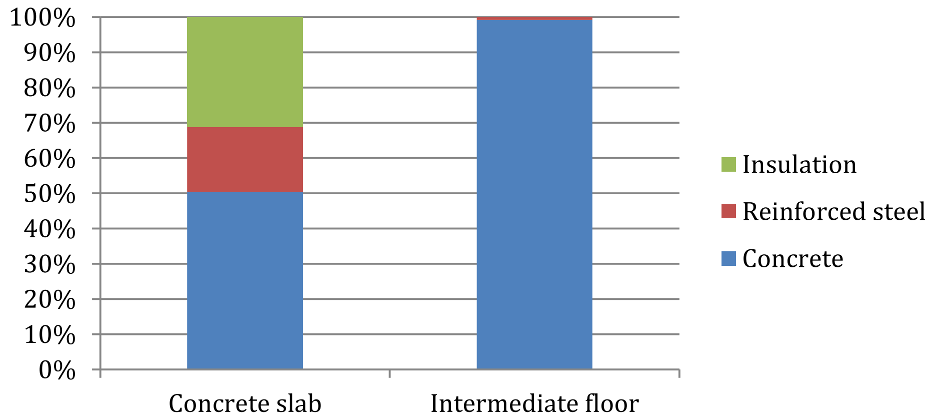
Building part	Ton CO_2-eqv
Walls	40,46
Intermediate floor	75,38
Foundation	78,10
Footings	25,36
Framework	53,11
Roof	20,51
TOTAL	293

8 Analysis

One analysis of the results given is that the concrete slab and intermediate floor has the greatest climate impact related to the construction materials. Together they represent 53% of the total climate impact. This is followed by the framework and the exterior walls; these together constitute approximately the same climate impact as just the foundation. The building part with the lowest climate impact is the roof.

In a separate analysis of the concrete slabs and the intermediate floors, constituent materials and its climate impact the following results is obtained in the Table 8. In the diagram, the concrete's contribution to the climate impact from the construction materials is illustrated, followed by the reinforcing steel and insulation. The reason to the large climate impact of the concrete depends mainly on its cement component. The manufacture of cement requires a lot of fossil-based energy and large amounts of carbon dioxide (Tyréns, 2015). The amount of cement in concrete is therefore crucial for the final result of the concrete's climate impact.

Table 8 - A separate analysis of the concrete slab and the intermediate floors constituent materials and their climate impact.



Given that climate impact is directly linked to weight, the building materials' weight is analyzed in relation to the impact. According to the results given in Table 5 and Table 6, concrete stands for 86% of the total weight of material but only 46% of the total climate impact. More noteworthy are the results of insulation and steel. Insulation consists of 3% of the total weight and 22% of the climate impact. Steel stands for 2% of the total weight and 18% of the climate impact.

To get away from the factor of size and get a number that is comparable with other results from climate impact calculations, the impact can be accounted even per square meter usable area. For the pre-school the climate impact is 0,266 ton CO_2-ekv/m^2 A_{temp}.

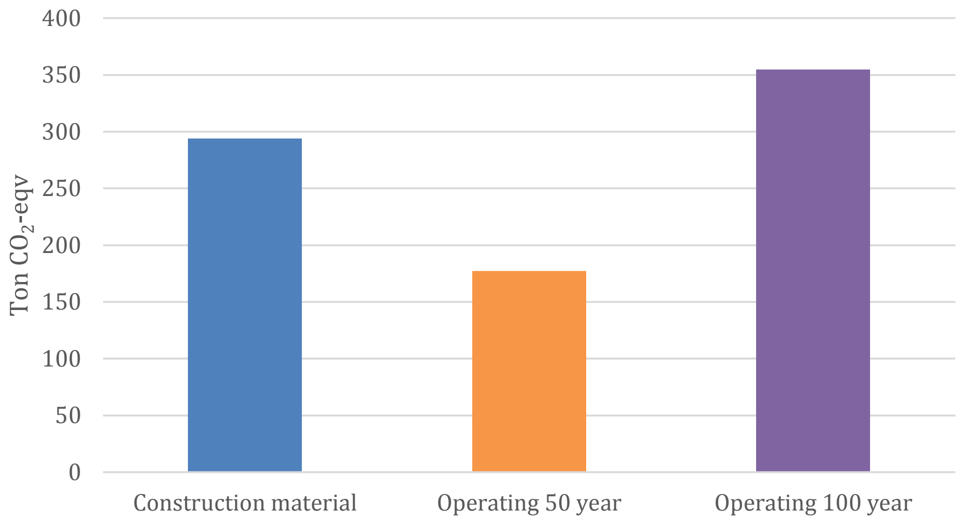
8.1 The construction phase in relation to the operation

To get a little sense of how much impact the material in the construction phase stands for in relation to the operation, the climate impact from the construction materials has been compared with the impact from district heating and Nordic electricity after 50 years and 100 years. According to the supplier, Gothenburg Energy (2014), has district heating a carbon footprint of 56 gCO_2/kWh and according to Energimyndigheten

(2015) has Nordic electricity a carbon footprint of 125,5 gCO_2/kWh. This calculated with Lokalförvaltningens demands on low energy consumption, 45 kWh/m^2year, gives the following results visualized in Table 9. In the calculation the district heating stands for 35 kWh/m^2year and 10 kWh/m^2year stands for the electricity related to the real estate.

After 50 years the impact from the operation is more than half of the construction materials included in this thesis. Which means that the operating impact is larger after a hundred years. The relation between the construction materials and the operating after 50 years become 62% versus 38%. These results prove earlier observations that the construction materials stand for a large part of the building's carbon footprint.

Table 9 - The climate impact of the construction materials in relation to the impact of the operating after 50 years and 100 years.



9 Sensitivity analysis

Based on the analysis in chapter 8 and the results presented in chapter 7, a sensitivity analysis is made were alternative data were used to see how the preschool building's total climate impact could be affected by these modifications. The possibilities to compare alternative products in a cradle-to-gate LCA are usually limited. It is more suitable for comparing the same product from different suppliers and CO_2-values (Erlandsson, 2014).

9.1 The collection of data

The collection of data is one of the critical elements having a major impact on the result. The collected data in this report is of great uncertainty and is not considered fully reliable because of the sources of the data are of varied quality. For example, it is only data provided from suppliers in form of EPDs which represent emission data with a very low margin of error. For this master thesis this concerns data for reinforced steel: Celsa EPD, steel profiles: Europrofil EPD, laminated timber: Martinsons EPD, and gypsum: Gyproc EPD. The rest of the data are mainly based on Byggvarudeklarationer, BVD, which seen from a LCA-perspective does not provide information of a satisfying quality.

Examples of these are concrete that is such a heavy construction material with high density. This has a great influence on the concrete's carbon footprint which is dependent on the weight in the definition of global warming product, GWP_{100}. This means that depending on the data source used for concrete has a large impact on the calculations, since different databases and different producers of concrete materials have different CO_2-value. This is due to various physical processes needed to produce the same material; each process may have different requirements and effects on the environment.

The used value for concrete in this master thesis is 0,118 kg CO_2-eqv/kg. It is generic data for concrete, sole plate and foundation [SE] Alloc def U taken from the report of Tyréns (2015) and the program SimaPro with the database Ecoinvent. More specific values can be obtained from the producers own calculations. The most reliable are the values presented in the materials own environmental product declaration, EPD. Continuous research is ongoing to the impact from the cement production, and there are results showing that concrete’s climate impact can be reduced (Riksbyggen, 2015). However, these materials are not on the market but information tells that the climate impact value can be improved with continued research and material developments, together with slim designs where less amounts of concrete are required.

For notation, producing reinforced steel represent a significant part of the total carbon dioxide emissions. This is due to coal-fired blast furnaces. But only 3% of the reinforced steel is assumed to come from virgin resources (Tyréns, 2015); thus the primary character, the remaining 97% is likely to come from the secondary sources, recycling. This is a factor of uncertainty because the virgin percentage can vary and is sometimes as high as 30-40%, although it is more common that 100% is recycled. Celsa is Norway´s largest recycle company and have a 100% recycled production. The EPD of their material present a GWP with 0,360 kg CO_2/kg. With a higher proportion of non-virgin resources, the reinforcement would have a major impact. For example IVL Miljödatabas has a value 0,820 kg CO_2/kg (Tahiri, 2011). In the result, the reinforced steel is calculated with a value of 0,634 kg CO_2/kg. If the reinforced steel with 100% recycled material and a value of 0,360 kg CO_2/kg would be used, the climate impact from reinforced steel would decreased from 18,11 ton CO_2 to 10,28 ton CO_2. The total impact would be 285 ton CO_2 instead of 293 ton CO_2.

9.1.1 The result with generic data resources

To visualize divergence in results, different data resources can cause, the same calculations as in chapter 7 is made but with data from IVL Miljödatabas (Tahiri, 2011). A list of the data is presented in Appendix C: Data table IVL Miljödatabas. The result from the calculations made with numbers from IVL Miljödatabas gives a total climate impact of 234 ton CO_2 instead of 293 ton CO_2. The new result, compared with the result is presented in Table 9 and Table 10. An analysis of the given result from chapter 7 is that the relation between the different materials is equal, concrete has the major impact followed by insulation and steel in the both calculations. It is the same with the relationship between the different building parts even if different data resources have been used, the foundation still has the largest impact while the intermediate floor and the framework follows.

Table 10 - The given result compared with the new result of the climate impact from each material.

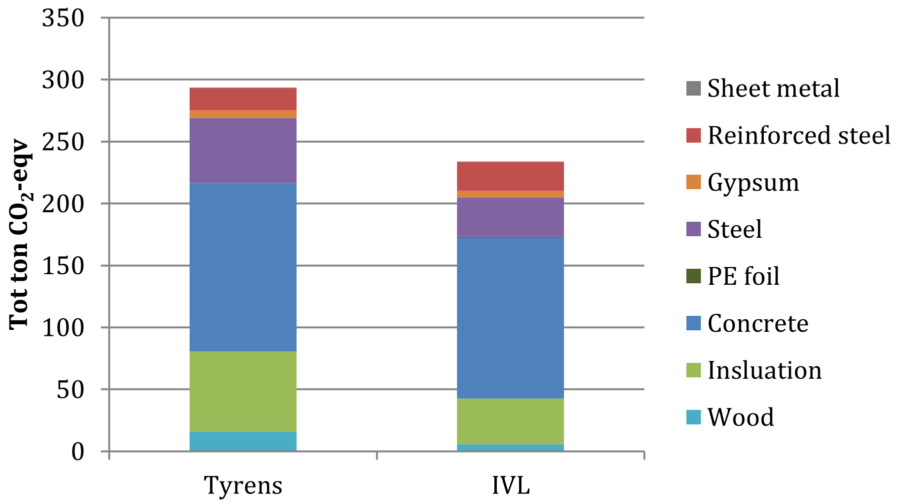
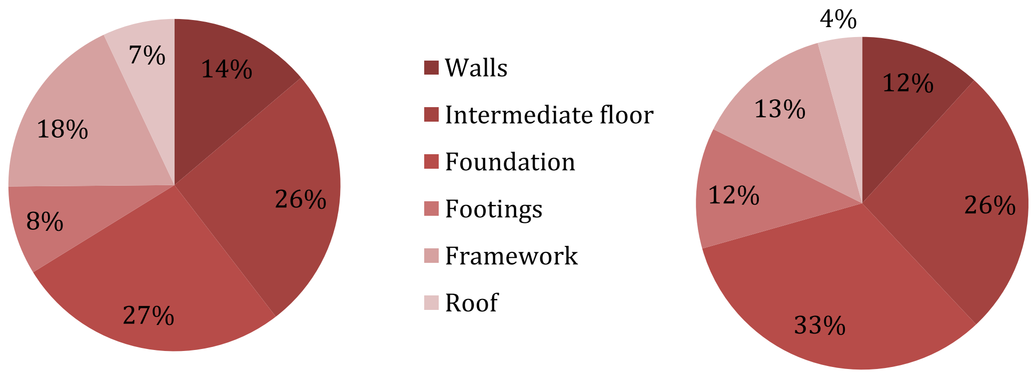


Table 11 - The given result compared with the new result of the climate impact from each building part.



9.2 The choice of construction solutions

The choice of construction can have a major impact. To give the result another dimension calculations are made with another wall construction of concrete. Just to visualize the divergence of a chosen construction with the same u-value 0,15. The modified wall construction consist of concrete sandwich with dimensions 75 concrete, 200 insulations and 150 concrete (Strängbetong, 2014). The total amount of each material is listed in Table 12.

Table 12 - A list of the total amount of each material in the modified wall construction.

Walls	Concrete	214,65	m3
954m2	Extruded polystyrene G100	190,8	m3
	Reinforced Steel	17172	kg

The result from the calculation with the modified wall construction is that the preschools envelope has a total climate impact of 345 ton CO_2-eqv instead of 293 ton CO_2-eqv. It means that the existing wall construction has a lower impact than the one with concrete walls. The given result visualized in Table 13 may not be extraordinary but it visualizes how the choice of construction affect the result.

Table 13 - The climate impact of each construction part in the existing construction compared with the impact of the modified construction.

Building part	Existing construction (Ton co2-eqv)	Modified construcion (Ton co2-eqv)
Walls	40,46	92,27
Intermediate floor	75,38	75,38
Foundation	78,10	78,10
Footings	25,36	25,36
Framework	53,11	53,11
Roof	20,51	20,51
TOTAL	293	345

10 Discussion

A good start to reduce the climate impact of today's buildings is to begin to understand what is contributing the most to the overall climate impact. Everything that is done has a climate impact, more or less; there is nothing that can be done without causing an impact on the climate (Göteborg stad, 2014). What is important is to identify the building materials with the worst impact to be able to make choices whenever it is possible.

The starting point for this master thesis was that the construction materials was identified as a major contributor to the climate impact. Calculations are made to be able to identify materials with large amounts and impact of the climate. Even before the calculations were made, it is well known that concrete has a higher impact in comparison to wooden material. But in some cases it is not possible to just replace materials without causing consequences.

In the case study of the preschool in Gothenburg, the material volumes and CO_2-values have been calculated. From the calculations, it appears that big parts of the building structure consist of concrete. Based on the given results, it is important to optimize the concrete structures as much as possible, considered to the density, the thickness and the amount of reinforced steel. Since the concrete has such a high density the climate impact of concrete structures becomes high, because of the GWP has the unit kg CO_2-eq/kg even if the construction does not only consist of concrete elements. Is not only the concrete that has a large impact on the climate, the reinforced steel is a contributing factor to the climate impact of the foundation as well the insulation.

In order to reduce the climate impact caused by the construction materials in a preschool building, is it important to optimize the construction or replace the construction materials by other materials with less impact. It seems impossible today to give advice about the selection of materials, more than to select the right materials in the right place. Someone said at a breakfast seminar: “you cannot decide to build only in one material, both concrete and wood is materials that will exist in the building sector. Focus must be on reducing the climate impact from the processes and the production, and to ensure a safe product. Reduce the content and adding another, there must be underlying material. Although more and more houses will be built in wood that will still be more concrete buildings.

10.1 Cooperated organization of the professions

The knowledge and the will to learn about the subject today is divided based on the given results and the collection of the knowledge in Sweden gained through participation in workshops, breakfast seminar and reports from IVL and Boverket. The actors who are interested in reducing the climate impact mainly work internally to increase their knowledge in the subject. This means that the actors develop their own tools for calculation that help them to compare and reduce their climate impact in their buildings. One reason for this may be that more and more companies are becoming interested in highlighting their actions through environmental certification and through that achieve a competitive advantage.

The workshops in Stockholm were contributing to the understanding of the different actors' knowledge of the subject. Different groups expressed different reasoning and the opportuning to participate at two separate occasions gave the possibility to compare the discussions between various professions. Especially the discussion in the second part was distinguishing, the focus on research areas differed completely depending on the profession the individual belonged to. Issues that were considered important at the first workshop were less important at the second. This demonstrates how complex the whole situation is, and that it is difficult to know where to start.

The availability and quality of data has a key role in life cycle assessments and it is important that this information is easy to collect. Today the collection of data is a part that is perceived time consuming and difficult and is something this thesis has proven. The process of calculation starts with collection of the amounts of materials from drawings and spreadsheets to collect CO_2 data to make prospective LCA calculations. A simplified process is requested, for example it would be easier if the amounts of construction materials in spreadsheets and BIM-models could be transformed in to a LCA calculation tool.

Another reason for the LCA-calculation being time-consuming is that the comparison of the construction materials today it is very limited. There is a desire for a national organizational system that can coordinate the efforts of common calculation systems and standards that permit the comparison of different solutions, where CO_2 is a variable. A development of a national database that can set the standard could provide good opportunities to easily get accessible data which helps to make conscious choices between different construction materials. Good examples are the databases Byggvarubedömningen and Sunda hus that helps actors in the Swedish building sector to make the selection of materials based on the chemical content. While it is important to know that there is an access to free tools in some of the member countries in Annex 57. However, they are difficult to apply and lacks in transparency (Boverket, 2015). This lack of reliable and verifiable data increases the demand for EPDs, but the use is still limited today. Because of there is no adequate amount of produced EPD which is important to consider before the supply of EPD data can be demanded.

10.2 How does Lokalförvaltningen go further with the given results?

Lokalförvaltningen, LF, as the property developer for municipal in Gothenburg and owner of the projects, has a major opportunity to reduce their buildings climate impact. They control the construction and the building process and therefore have the opportunities to control the choices regarding the location, the building standard, the construction materials and the design of technical systems that contribute to reducing climate impact. LF is also responsible for operation and service, which means that LF as a management developer is interested in an optimal balance between investment and operational costs which is contributing to energy saving.

This proves that it is important for LF to get involved in the whole picture regarding the climate changing factors, such as the design and the choice of construction materials but also the energy demands and the construction. Thus it is important that LF use their position as an actor in the municipality to be in the forefront of development and act as a role model when it comes to the energy use and climate impact of the school buildings.

Lokalförvaltningen, as a big public actor in the city of Gothenburg, have an opportunity to enhance the application of life cycle thinking in construction and the ability to contribute to more use of technical solutions that both promote sustainable techniques and use renewable energy resources when that it is possible.

Now, there is an opportunity to, let the knowledge serve as a foundation to be able to set demands on the construction process and the public procurement. In some countries, the public actors have pushed the development forward. The closest is Norway's example of Statsbygg with its LCA tools, Klimagassregnskap.no, In Germany is BNB, bnb-nachhaltigesbauen.de, a sister to the certifying system DGNB (Boverket, 2015).

Then the following questions are set, what kind of standards should LF require? How many? Then what is reasonable? Lokalförvaltningen has an advantage when it comes to energy caused by the operational phase with their goals of 45 kWh/m^2, it is lower than the demands on facilities of BBR. LF does not only work with the operation energy consumption, they have come far when it comes to demands of the chemical content in the construction materials with help of Byggvarubedömningen. It is significant that there is a will to find improvements when it comes to environmental issues. The will to learn about the climate impact from construction materials is a contribution to that.

According to several references, education is seen as an important factor for understanding. The more people who are aware, the more impact it provides on the entire sector. As someone expressed it in one of the attended workshops in Stockholm 2015, "We cannot continue as we do, we have a responsibility for future generations.” More research is needed, and for this change to happen, first and foremost a willingness to change is required, together with cooperation and a common vision and structure among, agencies, architects and builders. The subject is still quite new and the knowledge is not so widespread. This once again shows that actors need guidance and access to tools and data. An important step for the development in Sweden is Sundén et al’s work (2015) to assemble the industry to workshops that give opportunities to talk about the topic, expanding the knowledge and establish a network. For further development, an organization and financing to move forward with development of measurable indicators, monitoring and clear requirements for incentives are necessary (Sundén et al, 2015).

11 Further studies

Based on produced data and the results in this study, several areas need to be further developed. In general, by given information and today's discussions in the construction sector, it is very clear that knowledge about the climate impact from the building process is very low. All actors require more support and knowledge to be able to take action, both models and tools. Clearer requirements from legislation, policy makers and developers would make it easier to develop appropriate agreements and land allocations.

Regarding the climate impact of construction materials, it has come up during the process requests for further studies on the optimization of constructions; can some parts be slimmer? What does the designer say? It is important that further studies are made on alternative solutions. For example, is both wood and steel pillars needed in the frame of a two-story pre-school building? Is it possible to only use wood?

Today, a large climate impact caused by construction materials has been identified, but how can it be reduced? One way would be to look at the different materials in the construction, for example, only wood or only insulation. As the analysis indicates in chapter 8 the insulation stands for 3 % of the total weight but 22 % of this preschool buildings climate impact. Regarding to this would it be interesting to investigate if there is an optimization point between the amount of insulation and the energy of operation? If it is possible to minimize the amount of insulation and how will it affect the heat usage over time? What happens to the balance of the climate impact and with the LCC-balance? The question is, do we need to increase or decrease the amount of insulation to be optimally sustainable from an LCA perspective, or is the amount we use today optimal?

To get the climate impact of the whole pre-school building, Södra Sälöfjordsgatans förskola, and to complete the life cycle assessment, calculations needs to be made on the climate impact from the excluded materials like the layer of roof and exterior walls, indoor walls, windows, installations etc. The life perspective with the downstream modules B and C also needs to be taken into account in the calculations.

One idea with in this master thesis was to do an evaluation of a preschool constructed in two floors with only a wooden frame, and compare the climate impact from that construction with the steel and wooden construction at Södra sälöfjorgatans förskola. This is with the hope that a wooden frame would have a smaller climate impact. However, there wasn’t enough time for this, meaning that this is a relevant issue for further studies.

12 Concluding remarks

For the master thesis of climate impact of the construction materials in a pre-school building in Gothenburg regarding module A1-A3 material production the following conclusions are made:

Approximately 293 ton of carbon dioxide is emitted during the production of the analyzed materials that are included in Södra Sälöfjordsgatans förskola.

The concrete slab stands for the greatest climate impact with 27%, followed by 26% for the middle flooring and the framework 18%.

The construction element consisting of concrete, reinforcement and insulation has the greatest contributions to the module A1-A3 material production total impact. This is because the production of these materials needs a lot of fossil-based energy and the burning of this contributes to greenhouse emissions.

The collection of data is one of the critical elements having a major impact on the result. The collected data forming the base for this report is of great uncertainty, and is not considered fully reliable because of the data sources are of varied quality. Most of the data has been based on building product declarations, BPD 3 and generic Ecoinvent data, because there is very little supporting data available in the form of EPD.

Critical to the results given because of the collected data, and a non-relevant overall picture without a hint of where the construction materials with major climate impact are and how in the future we can work with it to get even better and how to proceed.

For notis to get a comprehensive picture of the climate impact of a preschool building it is needed other climate impact categories that are taken into account in addition to the climate impact and to this master thesis.

"The key is not to compare made calculations with each other, instead using the calculations to experiment with improvements." It is necessary to work with development of benchmarks that can provide indicators for the climate impact of buildings which indicate if the impact is high or low (Boverket, 2015).

Everything indicate that we need to research, develop and co-operate within the subject. Should the building sector reduce the climate impact, we should do it together; alone is not strong.

13 Recommendations for Lokalförvaltningen

Caused by this master thesis followed recommendations are highlight for Lokalförvaltning:

- Based on what emerged during the process would a first step for Lokalförvaltningen be to ask for all the construction materials EPDs in the procurement. That could lead in a turn to requirements of LCA calculations with the total amount of the buildings climate impact when the building sector is ready. Today would it not be relevant to have demand on how low the climate impact would be for a preschool building.
- For Lokalförvaltningen it would be interesting to immerse themselves in a construction material for example insulation to start setting specific environmental requirements based on the climate.
- Start to co-operate with other actors in Sweden to develop the Swedish work and spread the knowledge.
- Start communicating their environmental outwards for example by environmental certification but also by highlighting how far they have come with their participation in environmental awareness and theirs high requirements on low climate impact and low energy consumption.

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Appendix

Appendix A: Data references

The calculated density for each material

Material	kg/m^3	Material	kg/m^3
Timber lath	500	Extruded polystyrene	30
Rockwool	85	Cement	2350
Cembrit Windstopper	1450	Reinforced steel	80
Timber stud	420	Steel pillar	
PE foil	937	Glue laminated timber	430
Steel stud	7850	tongue in groove	420
Gypsum board	800	Timber lath	420
Steel sheet	7900	Fiberboard	900
Prefab concrete slab	2350	Mineral wool	28
Concrete C25/30	2350		

Reference: Burström, P G. (2007)

CO_2 references from Tyrens, 2015

Material	kg CO_2-ekv/kg mtrl	
Timber lath	0,289	Swanwood, softwood, kiln dried, planed SE Polypropylen
Rockwool	1,270	EPD Rock wool, SE production Alloc Def U, EPD nr 00131Erev1
Cembrit Windstopper	0,693	Fibercement coated EPD Cembrit holding FI production
Timber stud	0,289	Swanwood, softwood, kiln dried, planed SE Polypropylen
PE foil	2,196	Plastic film, polypropylene SE production Alloc Def U
Steel stud	2,536	Steel, europrofil SE production Alloc def U
Gypsum board	0,313	Gypsum plasterboard gyproc GN13 SE Alloc def
Steel sheet	2,536	Steel, europrofil SE production Alloc def U
Prefab concrete slab	0,205	Concrete UPB AS LV production Alloc def U
Concrete C25/30	0,118	Concrete, sole plate and fondation SE Alloc def U
Extruded polystyrene	3,976	Polysyrene foam slab 0% recycled SE Alloc def U
Cement	0,118	Concrete, sole plate and fondation SE Alloc def U
Reinforced steel	0,360	Reinforcing steel, EPD Celsa, EPD nr. S-P-00305
Steel pillar	2,536	Steel, europrofil SE production Alloc def U
Glue laminated timber	0,329	Glue laminated timber, Puuinfo Oy RT Env Declaration FI
Tongue in groove	0,289	Swanwood, softwood, kiln dried, planed SE Polypropylen
Timber lath	0,289	Swanwood, softwood, kiln dried, planed SE Polypropylen
Fiberboard	0,289	Swanwood, softwood, kiln dried, planed SE Polypropylen
Mineral wool	1,270	EPD Rock wool, SE production Alloc Def U, EPD nr 00131Erev1

CO_2 references from IVL Miljödatabas (Tahiri, 2011).

Material	kg CO_2-ekv/kg mtrl	**IVL miljödatabas**
Timber lath	0,107	tryckimpregnerat trävirke
Rockwool	1,186	mineralull (stenull)
Cembrit Windstopper	0,413	cementbaserad skiva
Timber stud	0,098	klassat trävirke T
PE foil	1,825	plastfolie (PE)
Steel stud	1,546	stål & metallvaror
Gypsum board	0,27	Gipsskiva
Steel sheet	2,089	plåt- & regnvattenbeslag
Prefab concrete slab	0,137	fabriksbetong k30
Concrete C25/30	0,137	fabriksbetong k30
Extruded polystyrene	1,884	Cellplast EPS
Cement	0,413	Cementbaserad skiva
Reinforced steel	0,82	Armeringstål
Steel pillar	1,546	Stål & metallvaror
Glue laminated timber	0,107	Limträ (L40)
Tongue in groove	0,108	Sågat trävirke
Timber lath	0,108	Sågat trävirke
Fiberboard	0,295	Board (träfiber skiva)
Mineral wool	0,661	Mineralull (glasull)

Appendix B: Data table Tyréns

Wall	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Timber lath	5,61	m3	500	2804,8	0,289	0,811
Rock wool	95,40	m3	85	8109,0	1,270	10,298
Cembrit Windstopper	4,29	m3	1450	6224,9	0,693	4,314
Timber stud	33,06	m3	420	13883,6	0,289	4,012
Mineral wool	276,66	m3	28	7746,5	1,270	9,838
PE foil	0,19	m3	937	178,8	2,196	0,393
Steel stud	0,22	m3	7850	1688,0	2,536	4,281
Gypsum board	24,80	m3	800	19843,2	0,313	6,211
Steel sheet	0,02	m3	7900	120,6	2,536	0,306
						40,463

Flooring	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete	12,96	m3	2350	30456,0	0,118	3,594
Reinforced steel	1036,80	kg		1036,8	0,634	0,657
Prefab concrete board	174,96	m3	2350	411156,0	0,173	71,130
						75,381

Foundation	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete C25/30	141,85	m3	2350	333347,5	0,118	39,335
Reinforced steel	22696,00	kg		22696,0	0,634	14,389
Extruded polystyrene	212,78	m3	30	6383,3	3,819	24,378
						78,102

Footings	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete C25/30	59,42	m3	2350	139637,0	0,118	16,477
Cement	1,84	m3	2350	4321,3	0,118	0,510
Reinforced steel 80 kg/m3 concrete	4736,20	kg		4736,2	0,634	3,003
Extruded polystyrene	46,87	m3	30	1406,0	3,819	5,369
						25,359

Framework	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete	0,88	m3	2350	2068,0	0,118	0,244
Reinforced steel	88,00	kg		88,0	0,634	0,056
Steel pillar	18960,00	kg		18960,0	2,536	48,083
Glue laminated timber	33,40	m3	430	14361,8	0,329	4,725
						53,107

Roof	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Tongue in groove	18,81	m3	420	7900,2	0,289	2,283
Timber lath	3,46	m3	420	1454,4	0,289	0,420
Fibreboard	2,74	m3	900	2462,4	0,519	1,278
Mineral wool	402,23	m3	28	11262,3	1,270	14,303
Timber studs	17,03	m3	420	7153,6	0,289	2,067
Gypsum board	0,64	m3	800	513,6	0,313	0,161
						20,5127

Simplified data table Tyrens

Wall		ton CO_2-ekv
954m2	Wood	4,82
	Insulation	20,14
	Windstopper (Cement)	4,31
	PE foil	0,39
	Steel	4,28
	Gypsum	6,21
	Steel sheet	0,31
		40,95

Flooring		ton CO_2-ekv
648m2	Concrete	74,72
	Reinforced steel	0,66
		75,38

Foundation		ton CO_2-ekv
709,25m2	Concrete	39,34
Concrete slab	Reinforced steel	14,39
	Insulation	24,38
		78,10

Footings		ton CO_2-ekv
Siroc	Concrete	16,48
	Cement	0,51
	Reinforced steel	3,00
	Insulation	5,37
		25,36

Framework		ton CO_2-ekv
	Concrete	0,24
	Reinforced steel	0,06
	Steel	48,08
	Wood	4,73
		53,11

Roof		ton CO_2-ekv
855m2	Wood	6,05
	Insulation	14,30
	Gypsum	0,16
		20,51

Appendix C: Data table IVL Miljödatabas

Wall	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Timber lath	5,61	m3	500	2804,8	0,107	0,300
Rock wool	95,40	m3	85	8109,0	1,186	9,617
Cembrit Windstopper	4,29	m3	1450	6224,9	0,413	2,571
Timber stud	33,06	m3	420	13883,6	0,098	1,361
Mineral wool	276,66	m3	28	7746,5	0,661	5,120
PE foil	0,19	m3	937	178,8	1,825	0,326
Steel stud	0,22	m3	7850	1688,0	1,546	2,610
Gypsum board	24,80	m3	800	19843,2	0,270	5,358
Steel sheet	0,02	m3	7900	120,6	2,089	0,252
						27,515

Flooring	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete	12,96	m3	2350	30456,0	0,137	4,172
Reinforced steel	1036,80	kg		1036,8	0,820	0,850
Prefab concrete board	174,96	m3	2350	411156,0	0,137	56,328
						61,351

Foundation	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete C25/30	141,85	m3	2350	333347,5	0,137	45,669
Reinforced steel	22696,00	kg		22696,0	0,820	18,611
Extruded polystyrene	212,78	m3	30	6383,3	1,884	12,026
						76,305

Footings	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete C25/30	59,42	m3	2350	139637,0	0,137	19,130
Cement	1,84	m3	2350	4321,3	0,413	1,785
Reinforced steel 80 kg/m3 concrete	4736,20	kg		4736,2	0,820	3,884
Extruded polystyrene	46,87	m3	30	1406,0	1,884	2,649
						27,448

Framework	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Concrete	0,88	m3	2350	2068,0	0,137	0,283
Reinforced steel	88,00	kg		88,0	0,820	0,072
Steel pillar	18960,00	kg		18960,0	1,546	29,312
Glue laminated timber	33,40	m3	430	14361,8	0,107	1,537
						31,204

Roof	Tot mtrl		Density	Tot mtrl kg	CO_2/kg	Tot CO_2
Tongue in groove	18,81	m3	420	7900,2	0,108	0,853
Timber lath	3,46	m3	420	1454,4	0,108	0,157
Fibreboard	2,74	m3	900	2462,4	0,295	0,726
Mineral wool	402,23	m3	28	11262,3	0,661	7,444
Timber studs	17,03	m3	420	7153,6	0,108	0,773
Gypsum board	0,64	m3	800	513,6	0,270	0,139
						10,092

Simplified data table IVL Miljödatabas

Wall		ton CO_2-ekv
954m2	Wood	4,82
	Insulation	20,14
	Windstopper (Cement)	4,31
	PE foil	0,39
	Steel	4,28
	Gypsum	6,21
	Steel sheet	0,31
		40,95

Flooring		ton CO_2-ekv
648m2	Concrete	74,72
	Reinforced steel	0,66
		75,38

Foundation		ton CO_2-ekv
709,25m2	Concrete	39,34
Concrete slab	Reinforced steel	14,39
	Insulation	24,38
		78,10

Footings		ton CO_2-ekv
Siroc	Concrete	16,48
	Cement	0,51
	Reinforced steel	3,00
	Insulation	5,37
		25,36

Framework		ton CO_2-ekv
	Concrete	0,24
	Reinforced steel	0,06
	Steel	48,08
	Wood	4,73
		53,11

Roof		ton CO_2-ekv
855m2	Wood	6,05
	Insulation	14,30
	Gypsum	0,16
		20,51