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Life Cycle Assessment of a BREEAM certified building

With a focus on greenhouse gas emissions

Master's thesis within the Industrial Ecology programme

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Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Report number 2014:8

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Cover:
The office buildings Koggen 1 and 2, situated in Västra Hamnen in Malmö, Sweden.

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ABSTRACT

The objective with this study is to evaluate how efficient the environmental certification system BREEAM is for newly constructed buildings, concerning reduction of greenhouse gas (GHG) emissions. This is done by a comparison between a BREEAM certified building and a non-certified, fictive building. A Life Cycle Assessment is done in the software tool GaBi. The method starts with a goal and scope, where a functional unit of $1\ m^2$ office floor area $\cdot$ year is chosen. The GaBi integrated databases Professional and Construction are used together with external data sets to perform an Inventory Analysis. After that the Impact Assessment is done, including the results of the impact characterisation in the form of charts showing the total GHG emissions from the two buildings.

The results show that 22.0 kg $CO_{2,eq}/m^2 \cdot$year are generated from the investigated processes of the certified building Koggen 2 and 33.8 kg $CO_{2,eq}/m^2 \cdot$year are generated from the non-certified, fictive building. 61 % of the total emissions are generated from the fictive building, which indicates that the BREEAM certification is efficient when evaluating reduction of GHG emissions for the certified building in this study. The use phase generates most emissions, 20.4 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 32.7 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building. This stands for 93 and 97 % of the total emissions, which can be compared to other studies where around 80 % of the GHG emissions can be allocated to the use phase. Commuting is not included in all building related LCA studies, but in this study it is and stands for 19.5 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 19.1 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building, which makes it the biggest source of emissions during the use phase. Heating also generates emissions (1 % of the total emissions from the use phase for Koggen 2 and 26 % for the fictive building) followed by operational electricity (1 % and 10 %). During the production phase, the external walls and the roof constructions contribute to the most emissions (0.80 and 0.58 kg $CO_{2,eq}/m^2 \cdot$year respectively for Koggen 2 and 0.94 and 0.07 kg $CO_{2,eq}/m^2 \cdot$year respectively for the fictive building). The building material that contributes to most emissions is concrete, with 0.96 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2, which stands for 60 % of the emissions from the production phase of this building. The heat pumps are shown to be an efficient tool to reduce emissions from heating and cooling. Heating generates 0.253 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 8.4 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building. Cooling contributes to 0.074 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 1.79 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building. The production of the heat pumps generates 0.119 kg $CO_{2,eq}/m^2 \cdot$year. Similar studies have shown that commuting, operational electricity, heating and concrete production are the main emitters of GHGs, which also the results of this study shows.

Keywords: BREEAM, carbon dioxide emissions, climate change, environmental certification, global warming, Koggen 2, Life Cycle Assessment (LCA)

Livscykelanalys av en BREEAM-certifierad byggnad
Med ett fokus på utsläpp av växthusgaser
Examensarbete inom masterprogrammet Industrial Ecology
Institutionen för Energi och Miljö
Avdelningen för Miljösystemanalys
Chalmers tekniska högskola

SAMMANFATTNING

Syftet med denna studie är att utvärdera hur effektivt miljöcertifieringssystemet BREEAM är vid nybyggnation, med avseende på minskade utsläpp av växthusgaser. Detta sker genom en jämförelse mellan en BREEAM-certifierad byggnad och en icke certifierad, fiktiv byggnad. En livscykelanalytisk undersökning görs med hjälp av programvaran GaBi. Till att börja med beskrivs mål och omfattning av studien, där en funktionell enhet av $1\ m^2$ golvarea · år väljs. De GaBi-integrerade databaserna Professional och Construction används tillsammans med externa dataset för att utföra en inventeringsanalys. Därefter sker en konsekvensbedömning, vilken inkluderar resultaten av studien i form av diagram som visar de totala utsläppen av växthusgaser från de båda byggnaderna.

Resultaten visar att 22.0 kg $CO_{2,eq}/m^2 \cdot$år uppstår från den BREEAM-certifierade byggnaden Koggen 2 och 33.8 kg $CO_{2,eq}/m^2 \cdot$år från den icke certifierade, fiktiva byggnaden. 61 % av de totala utsläppen genereras från den fiktiva byggnaden, vilket tyder på att en BREEAM-certifiering är effektiv med avseende på minskade utsläpp av växthusgaser för byggnaden i denna studie. Användarfasen genererar mest utsläpp, 20.4 kg $CO_{2,eq}/m^2 \cdot$år för Koggen 2 och 32.7 kg $CO_{2,eq}/m^2 \cdot$år för den fiktiva byggnaden. Detta står för 93 och 97 % av de totala utsläppen, vilket kan jämföras med andra studier där runt 80 % av växthusgaserna kunnat allokeras till användarfasen. Pendling är inte inkluderat i alla byggnadsrelaterade LCA-studier, men i denna står den för 19.5 samt 19.1 kg $CO_{2,eq}/m^2 \cdot$år för de båda byggnaderna, vilket gör det till den största utsläppsprocessen under användarfasen. Uppvärmning bidrar också till utsläpp (1 % för Koggen 2 och 26 % för den fiktiva byggnaden) följt av driftel (1 % och 10 %). Under produktionsfasen bidrar ytterväggarna och takkonstruktionerna till de största utsläppen (0.80 och 0.58 kg $CO_{2,eq}/m^2 \cdot$year respektive för Koggen 2 samt 0.94 och 0.07 kg $CO_{2,eq}/m^2 \cdot$year respektive för den fiktiva byggnaden). Det byggnadsmaterial som bidrar till mest utsläpp är betong, med 0.96 kg $CO_{2,eq}/m^2 \cdot$år för Koggen 2, vilket står för 60 % av utsläppen från produktionsfasen för denna byggnad. Värmepumparna har visat sig vara ett effektivt verktyg för att minska utsläppen från uppvärmning och kylning. Uppvärmning genererar 0.253 kg $CO_{2,eq}/m^2 \cdot$år för Koggen 2 och 8.4 kg $CO_{2,eq}/m^2 \cdot$år för den fiktiva byggnaden. Kylning bidrar till 0.074 kg $CO_{2,eq}/m^2 \cdot$år för Koggen 2 och 1.79 kg $CO_{2,eq}/m^2 \cdot$år för den fiktiva byggnaden. Produktionen av värmepumparna genererar 0.119 kg $CO_{2,eq}/m^2 \cdot$år. Liknande studier har visat att arbetspendling, driftel, uppvärmning och betongproduktion är de främsta källorna till utsläpp av växthusgaser, vilket även resultaten från denna studie visar.

Nyckelord: BREEAM, GWP, klimatförändringar, Koggen 2, koldioxidutsläpp (CO_2-utsläpp), livscykelanalys (LCA), miljöcertifiering

Contents

Preface

In this study, a life cycle analytic comparison between two buildings has been done to investigate the efficiency of the environmental certification system BREEAM concerning reduction of greenhouse gas emissions. The report has been carried out from January to June 2014 and is a master's thesis written as a part of the master programme Industrial Ecology. The project is carried out at the Department of Energy and Environment, Division of Environmental Systems Analysis at Chalmers University of Technology, Sweden. The project is performed in cooperation with the consulting group COWI and the construction and property development company NCC.

This project has been carried out with assistant professor Birgit Brunklaus as examiner and assistant professor Jutta Hildenbrand as supervisor. BREEAM Assessor Maria Hedqvist and Environmental Engineer Johanna Millander have supervised at COWI. I would like to thank my supervisors and examiner for all the help and inspiration they have given during the writing of my thesis. I also would like to thank Veronica Koutny Sochman, Larissa Strömberg and Pär Friis at NCC for helping me find information about the investigated buildings and for the contribution of the LCA software tool.

Finally, I would like to thank Anna Sarbring for being my opponent and a good friend during the writing process. I would also like to thank my classmate Lauren Fong for the help she have given me with the software tool GaBi.

Göteborg June 2014

Anna Augustsson

Notations

A	The total office floor area
A_{temp}	The total area of all temperature controlled areas inside the building envelope intended to be heated to more than 10 degrees Celsius
BBR	Boverkets Byggregler (National building regulations for Sweden, from the Swedish national board of housing, building and planning)
BREEAM	Building Research Establishment Environmental Assessment Method
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
$CO_{2,eq}$	Carbon dioxide equivalent
FU	Functional unit
GWP	Global warming potential
HCFCs	Hydrochlorofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
N_2O	Nitrous oxide
Ppb	Parts per billion
Ppm	Parts per million
Specific energy consumption	The energy use of the building distributed over A_{temp}, expressed in kWh/m$^2 \cdot year$

1 Introduction

Climate change is today widely accepted as a threat to mankind and the concept of sustainable development together with large amounts of emitted carbon dioxide (CO_2) are some of the reasons. The atmospheric CO_2 concentration has increased from 280 to 379 parts per million (ppm) during the last 250 years, which mainly is a result of land use change and the use of fossil fuels (IPCC, 2007).

The Brundtland Report defined sustainable development as

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987).

The population of the world is growing and to be able to meet the needs of the present and future generations, changes need to be done considering resource use and emissions. Several sectors in society are responsible for greenhouse gas (GHG) emissions and the building sector is one of them. When only looking at energy, the building sector stands for 30 to 40 percent of the global energy use (United Nations Environment Programme, 2007). In Sweden, the building sector stands for approximately 20 percent of the GHG emissions (Wallhagen, Glaumann & Malmqvist, 2011). Previous research indicates that the building sector has high potential to reduce its emissions for a relatively low cost (Ürge-Vorsatz et al., 2011).

To be able to reduce emissions from buildings, knowledge about causes and documentation is important. One way to document emissions is to use an environmental certification system. These systems can be used as an incentive to reduce the environmental load of a building, but there are several other benefits such as ensuring a good indoor environment, getting a better building quality and increased financial value of the building (Heincke & Olsson, 2012, pp. 12-13). There are several certification systems from different countries on the market today, such as BREEAM (Building Research Establishment Environmental Assessment Method, Great Britain), LEED (Leadership in Energy and Environmental Design, United States), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen, Germany), Green Star (Australia), Miljöbyggnad (Sweden) and HQE (Haute Qualité Environmentale, France) (Heincke & Olsson, 2012, pp. 16-68). In this study BREEAM is chosen due to the fact that it is the most widely used certification system globally, and because it considers most aspects of the building process, such as the production phase and the use phase of the building (Heincke & Olsson, 2012, pp. 104-105).

The objective with this study is to evaluate how efficient the BREEAM certification system is for newly constructed buildings, concerning reduction of GHG emissions. This is done by a comparison between a BREEAM certified building and a non-certified building at the same geographical location. The emissions from the certified building are compared with the emissions that would have been emitted if the building would not have been certified. The non-certified building is represented by a fictive building for which the national building regulations in Boverkets byggregler (BBR) are used together with a reference building, Kaggen.

To be able to investigate and calculate the GHG emissions a systematic approach needs to be used. Buildings have a relatively long lifetime with GHG emissions not only focused to the production phase. Therefore Life Cycle Assessment (LCA) is a suitable approach and the LCA software tool GaBi is used to be able to structure and interpret the data. An LCA considers the complete resource use and all emissions from a product, from cradle to grave. This means that all the emissions related to production, maintenance and deposition of the product will be included, from the production of building materials to deposition of building materials when the product has reached its end of life (Baumann & Tillman, 2004, p. 19). In this study an LCA of two buildings is performed. One of the buildings is the BREEAM certified building Koggen 2 in Malmö and the other is a non-certified, fictive building.

An LCA can investigate several different environmental aspects, but in this study there is a focus on global warming potential (GWP). BREEAM investigates ten different categories in which a building can achieve credits for a certification. Six of these categories are related to generation of GHG emissions and are therefore investigated in this study (BRE Global, 2009). The investigated system categories are limited to the ones concerned in the certification system, which results in a comparison of differences in emissions from the two buildings rather than the actual amount of GHGs emitted. The emissions included in this study are from the lifetime of a building, which is assumed to be 50 years.

The purpose of this study is to understand how efficient the BREEAM certification system is when it comes to reducing GHG emissions and what difference it makes to certify a building or not. To fulfil the purpose this method is a suitable choice.

1.1 Background

One of the goals with environmental certification systems is to reduce the environmental load from buildings, but the question is how big the effect of the certification systems is. This study aims at investigating the difference in GHG emissions from a building certified with BREEAM compared to a non-certified building.

The study is conducted in collaboration with the consulting group COWI. They work with Industry, Infrastructure, Buildings and the Environment and have been using BREEAM in several projects (COWI, 2013a). A BREEAM certification can result in one of the six grades; *Unclassified*, *Pass*, *Good*, *Very Good*, *Excellent* or *Outstanding* (BRE Global, 2009, p. 37). COWI are the first company in Sweden to reach the grade *Excellent* for one of their projects, Koggen 2 in Malmö (COWI, 2013a).

NCC is a construction and property development company that works with property development, construction, infrastructure, materials and service. NCC Construction Sverige AB is the developer and contractor of Koggen 2 and of the non-certified, reference building Kaggen in Malmö, which will be investigated in this study (NCC, 2014). NCC will contribute with the LCA software tool GaBi and additional data, such as construction site specific data, about Koggen 2 and Kaggen.

1.2 Aim

The aim with this study is to understand how efficient the environmental certification system BREEAM is for newly constructed buildings concerning reduction of GHG emissions. This is done by performing an LCA on two buildings, one certified with BREEAM and one non-certified, fictive building, with the same size and the same geographical location.

1.3 Method

Literature studies about LCA and BREEAM have been done, which have resulted in Chapter 2.

Data that is used have been collected both with assistance of COWI and NCC to get specific data for the buildings and also from the databases Professional and Construction integrated in the software tool GaBi, version 6. The LCA has been conducted according to the principles of the ISO standard 14040, even though it is not a full ISO study. For example, no peer review was performed. Calculations have been made with GaBi.

To start with, a goal and scope definition was conducted with specifications about the study and how it was performed. After that the data was collected and an inventory analysis was conducted where a system model was constructed. This part included the construction of a flowchart, data collection for the specific activities that are included and finally calculations in relation to the chosen functional unit.

After the inventory analysis, an impact assessment was made with a focus on GWP, where the collected data was translated to carbon dioxide equivalents ($CO_{2,eq}$). After that an analysis of the results was made and finally a sensitivity analysis, where alternative choices were investigated to see how this would affect the results.

2 Theory

A literature study is done, which has resulted in this chapter. Basic concepts of LCA and the environmental certification system BREEAM are described, so that the reader easier can understand the following chapters.

2.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is a method that presents environmental impacts of products and services. By using this method the impacts of the product's entire life cycle are taken into consideration. This is called 'from cradle to grave' and means that every process of the product's lifetime is included: raw material acquisition, transportation, production, use phase, end-of-life treatment, recycling and disposal (International Organization for Standardization, 2006).

2.1.1 Methodology of LCA

An LCA study contains four phases: Goal and Scope definition, Inventory Analysis, Impact Assessment and Interpretation (International Organization for Standardization, 2006). For a better understanding of the connections between the LCA phases, see Figure 1.

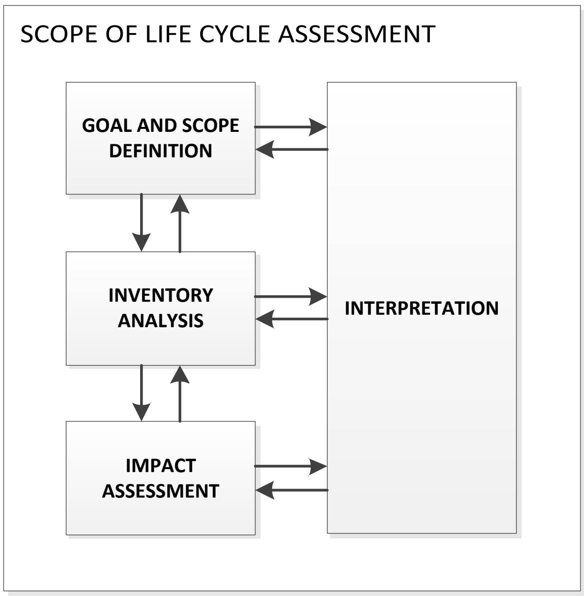


Figure 1: The phases of an LCA (International Organization for Standardization, 2006).

The Goal and Scope of the study includes descriptions and specifications of certain parameters such as intended application, intended audience, product system, functional unit, system boundaries, allocation, impact categories, data requirements and quality, assumptions, limitations, critical review and format of the report (International Organization for Standardization, 2006, p. 11).

After the Goal and Scope have been decided on, an Inventory Analysis is done. This part of the LCA includes data collection and calculation of input and output flows, which generates Life Cycle Inventory (LCI) results. The collected data mainly consists of information about amounts and weight of energy, raw materials, products, co-products, waste and emissions. The calculations mainly consist of validation of data, relating to unit processes and relating to the functional unit (International Organization for Standardization, 2006, p. 13).

The third and final phase before interpretation of the results is Impact Assessment. The mandatory parts of the Impact Assessment are the selection of impact categories, classification and characterization (International Organization for Standardization, 2006, p. 15). Classification means that the data is sorted according to environmental impact. Characterisation means that the contribution, in the form of equivalent emissions, to the different environmental impacts is calculated (Baumann & Tillman, 2004, p. 29).

The optional parts of the Impact Assessment are Normalization, Grouping and Weighting (International Organization for Standardization, 2006, p. 15). Normalization means that the results from the characterisation are related to a reference value. Grouping means that the results from the characterisation are sorted into different groups such as global, regional and local impacts. Weighting means that the importance of an environmental impact is weighted against the importance of other environmental impacts. There are different approaches used when performing weighting, which can be based on different values such as economic values, target values for emissions or expert judgements.

Finally, as a part of the interpretation, specific analyses, such as sensitivity analysis, can be made on the data quality to be able to investigate uncertainties in the results and the effect of methodological choices (Baumann & Tillman, 2004, pp. 134-144).

2.1.2 ISO standards

The International Organization for Standardization (ISO) has produced standards for environmental management. For LCA studies the 14 000 series is used, more specifically ISO 14 040 and ISO 14 044. To use the term *LCA study according to ISO* the requirements in these standards need to be followed (König et al., 2010, p. 39).

ISO 14 040 is an overarching standard describing the different components of an LCA. ISO 14 044 describes the requirements of the LCA in further detail (International Organization for Standardization, 2006).

2.1.3 Impact categories, global warming potential and greenhouse gases

There are several different impact categories that can be investigated in an LCA. The most common ones are Depletion of abiotic resources, Land use, Global warming potential, Ozone depletion potential, Human toxicity potential, Eco toxicity potential, Photochemical ozone creation potential, Acidification potential and Eutrophication potential (Baumann & Tillman, 2004, pp. 145-157).

GWP is the impact category that calculates carbon dioxide equivalents ($CO_{2,eq}$) and enables an insight in the negative progress of global warming. Greenhouse gases (GHGs) are compared with CO_2 and converted to $CO_{2,eq}$. Due to their different capacities to absorb infrared radiation, different GHGs have different ability to heat the atmosphere. Based on these differences a characterization factor is constructed, which is multiplied with the LCI results and $CO_{2,eq}$ are obtained (Baumann & Tillman, 2004, p. 149).

Different GHGs remain in the atmosphere for different amount of time. Therefore GWP can be calculated for different time horizons, 20, 100 or 500 years, where GWP100 looks at radiative forcing over 100 years (IPCC, 2007, pp. 31-33). In Table 1 a summary of the most common GHGs and their characterization factors for GWP for 100 years (GWP100) relative to CO_2 are shown. A comprehensive list of all characterization factors for GWP100 can be found in Appendix A.

Table 1: A summary of the most common GHGs and their characterization factors for GWP for 100 years relative to CO_2 (IPCC, 2007, p. 33-34). A comprehensive list of GHGs and their characterization factors can be found in Appendix A.

Trace gas	Chemical formula	Characterization factors for GWP 100 years
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
CFC-11	CCl_3F	4 750
CFC-12	CCl_2F_2	10 900
CFC-13	$CClF_3$	14 400
CFC-113	CCl_2FCClF_2	6 130
CFC-114	$CClF_2CClF_2$	10 000
Carbon tetrachloride	CCl_4	1 400
HCFC-22	$CHClF_2$	1 810
HCFC-123	$CHCl_2CF_3$	77
HCFC-124	$CHClFCF_3$	609
Sulphur hexafluoride	SF_6	22 800
PFC-14	CF_4	7 390

2.1.3.1 Carbon dioxide

CO_2 naturally occurs in the atmosphere, but during the last century the concentration has increased drastically, from approximately 280 to 379 ppm. The main reasons for this increase are fossil fuel combustion together with cement production, which together stand for 75 percent of the emissions. The rest have resulted from land use changes, mainly from deforestation (IPCC, 2007, pp. 3, 512).

2.1.3.2 Methane

Methane (CH_4) naturally occurs in wetlands, oceans and vegetation. During the last century the concentration has increased drastically though, from 715 to 1774 parts per billion (ppb). The main reasons for this increase are coal and natural gas as energy sources, waste disposal at landfills, the use of biomass, the ruminant animal industry and the rice agriculture. CH_4 stays in the atmosphere for 8.4 years before it is degraded.

A development has been shown during the last 20 years, with emissions nearly stabilised (IPCC, 2007, pp. 3, 513).

2.1.3.3 Nitrous oxide

Nitrous oxide (N_2O) naturally occurs in the ocean, the atmosphere and in soils and the anthropogenic sources are about the same size as the natural sources. The concentration of N_2O in the atmosphere has increased from approximately 270 to 319 ppb during the last century and the main reason for the increase is agriculture. During the last 30 years the level of N_2O in the atmosphere has been constant. N_2O stays in the atmosphere for 114 years before it is degraded (IPCC, 2007, pp. 3, 513).

2.1.3.4 Chlorofluorocarbons and Hydrochlorofluorocarbons

Chlorofluorocarbons (CFCs) consist of carbon, fluorine and chlorine atoms. They are nontoxic chemicals that were first produced as a replacement of toxic chemicals used for refrigerators. CFCs are for instance used as refrigerants and solvents.

Hydrochlorofluorocarbons (HCFCs) consist of hydrogen, carbon, fluorine and chlorine atoms. HCFCs have been used as refrigerants and in low-demand air-conditioning since 1975 (Alexander & Fairbridge, 1999, pp. 78-79).

The CFCs have an atmospheric lifetime of 45 to 100 years, whereas the HCFCs have an atmospheric lifetime of 1 to 18 years (IPCC, 2007, p. 512). The chlorine contained in CFCs and HCFCs is destroying ozone, which during the last century have resulted in ozone depletion (Alexander & Fairbridge, 1999, pp. 78-79).

Since this is a huge environmental problem, measures have been taken to decrease and eventually stop the production of CFCs and HCFCs in the world. The Montreal Protocol has resulted in a stabilisation of CFCs. The HCFCs are still increasing in the atmosphere, but a target of phasing out the production till 2030 is set (IPCC, 2007, p. 512).

2.1.4 GaBi

GaBi is one of the leading LCA software tools, which is designed to perform analyses on the environmental aspects but also on the technical, economic and socio-economic aspects of products and services. There are two main databases connected to GaBi, Professional and Lean, but 17 additional databases are also accessible. The data in the databases is collected through research by PE International and the University of Stuttgart.

In GaBi a model is constructed consisting of plans, processes and flows. By connecting the processes to one another a flowchart is created. Several plans can be constructed and subsequently connected to one another (PE International, 2012p).

The databases that are used together with GaBi are a result of collaboration with industry, which according to the developers have resulted in more accurate inventory data. 10 expert teams are working with their individual area to develop inventory data. The areas of the expert teams are *Chemistry*, *Coating and textiles*, *Construction*, *Electronics*, *End-of-life*, *Energy*, *Metals*, *Plastics*, *Renewables* and *Transport*. When European or global data is documented in the databases, an average of the data for Europe or the world is used (PE International, 2011).

2.2 BREEAM

Environmental certifications of buildings normally investigate several different areas and consider the environmental impact of a building. Several different reasons might contribute to the willingness to certify a building. Some examples are the ability to reduce the environmental load of a building, ensuring a good indoor environment, getting a better building quality and increased financial value of the building (Heincke & Olsson, 2012). BREEAM is one out of several different environmental certification systems for buildings on the market today.

2.2.1 BREEAM background and structure

BREEAM, which stands for Building Research Establishment Environmental Assessment Method, is a British environmental certification system for buildings. Today, BREEAM is the most used certification system for buildings in the world, with 200 000 certified buildings since the start in 1990 (Heincke & Olsson, 2012). It addresses ten different categories; *1.Management*, *2.Health and Wellbeing*, *3.Energy*, *4.Transport*, *5.Water*, *6.Materials*, *7.Waste*, *8.Land use and Ecology*, *9.Pollution* and *10.Innovation*. Credits are given in each category if certain objectives are reached. These credits are summarised to one of the grades: *Unclassified*, *Pass*, *Good*, *Very Good*, *Excellent* or *Outstanding*. To reach the grade *Pass*, 30 percent of the credits need to be taken, for *Good* 45 percent, for *Very good* 55 percent, for *Excellent* 70 percent and for *Outstanding* 85 percent (BRE Global, 2009).

There are two BREEAM manuals for international use; *BREEAM Gulf* and *BREEAM Europe Commercial*. *BREEAM Gulf* can be used for any building type, whereas *BREEAM Europe Commercial* only can be used for offices, retail and industry (BRE Global, 2009, p. 13). In 2013 a new manual for Europe was released, *BREEAM International New Construction 2013*, which should be used for new construction projects (BRE, 2013).

2.2.2 BREEAM categories

The BREEAM categories in *BREEAM Europe Commercial* and a summary of the main subcategories can be found in Table 2. For further definition and description of each category and subcategory together with available credits and achieved credits for the BREEAM certified building Koggen 2, see Appendix B.

Table 2: BREEAM categories and summary of main issues (BRE Global, 2009, p. 14).

1. Management: Commissioning Construction site impact Building user guide	**6. Materials:** Embodied life cycle impact of materials Materials re-use Responsible sourcing Robustness
2. Health and Wellbeing: Daylight Occupant thermal comfort Acoustics Indoor air and water quality Lighting	**7. Waste:** Construction waste Recycled aggregates Recycling facilities
3. Energy: CO_2 emissions Low or zero carbon technologies Energy sub metering Energy efficient building systems	**8. Land use and Ecology** Site selection Protection of ecological features Mitigation/enhancement ecological value
4. Transport: Public transport network connectivity Pedestrian and Cyclist facilities Access to amenities Travel plans and information	**9. Pollution:** Refrigerant use and leakage Flood risk NO_x emissions Watercourse pollution External light and noise pollution
5. Water: Water consumption Leak detection Water re-use and recycling	**10. Innovation:** Exemplary performance levels Use of BREEAM accredited professionals

For a better view of the categories and the weighting between them, together with the weighted percentage for each category in the grade calculation, see Figure 2.

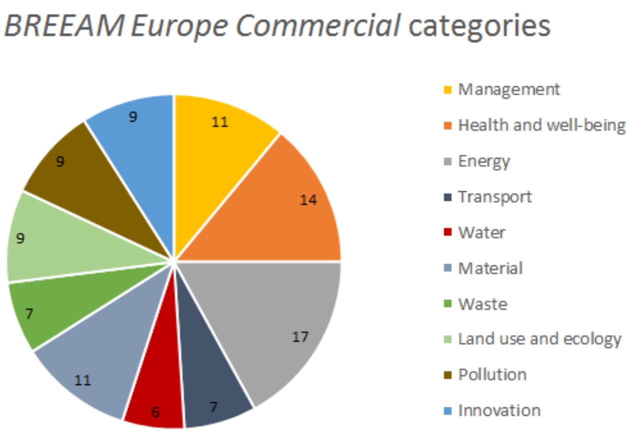


Figure 2: The categories in *BREEAM Europe Commercial* and the weighting between them with the percentage of each category defined (Heincke & Olsson, 2012, p. 23).

2.2.3 The Green Guide

The Green Guide is an LCA based tool used in BREEAM for deciding the environmental impact of building materials. It was first developed in 1996 after a need emerged for a simple tool to help with the decision of which building materials to use. The guide contains over 1 500 building materials of different kinds, such as external and internal walls, roof constructions, ground and upper floors, windows, insulation, landscaping and floor finishes. The building materials are rated with one of the six grades A+, A, B, C, D or E, where A+ gives the lowest environmental impact and E gives the highest. The ratings are based on LCA studies done by LCA experts (BRE, 2014). The electricity used in the LCA studies is based on data from 2010 and weighting is performed where climate change stands for 21.6 percent of the total environmental issues. The service life of the materials in the guide is set to 60 years (BRE Global, 2008).

3 Method - Goal and scope

In this chapter the goal and scope of the study is defined, which constitute the method of the study.

3.1 Goal

The goal with this study is to be able to understand the difference in GHG emissions between two buildings, one certified with BREEAM and one non-certified. This is done to learn how efficient the BREEAM certification system for newly constructed buildings is regarding reduction of GHG emissions and to answer the question: Does environmental certifications of buildings contribute to a reduction in GHG emissions? The intention is to compare the results from the two buildings to reach conclusions of the efficiency in reducing GHG emissions. The final comparison is available for the public.

3.1.1 Intended audience

One target audience of this study are the companies that own or rent buildings, so that they can understand the reasons for investing in environmental certifications for their buildings. Another target audience are the companies working with certification systems. If the difference that a certification system contributes to regarding reduction of GHG emissions can be shown, the companies can use this study for marketing purposes.

3.2 Scope

The scope defines the context of the study and specific information necessary for the modelling (Baumann & Tillman, 2004, p. 24). It includes definition of the product systems, functional unit, system boundaries, initial flowchart, use of BREEAM categories, impact categories, data requirements, assumptions, limitations and cut-offs, critical review and type of LCA.

3.2.1 Product systems

Two different product systems are investigated in this study. The first one is an office building named Koggen 2 which is situated in Malmö, Sweden. The building has a floor area of 8000 square meters divided between six floors. The construction started in 2011 and was completed in 2013. Koggen 2 is certified with the environmental certification system BREEAM and gained the grade *Excellent*.

The second product system is a fictive office building. This building is constructed as similar as possible to Koggen 2, except from the parts constructed differently due to the certification system BREEAM. BBR, which is a regulation for Swedish buildings from the Swedish national board of housing, building and planning, is used for energy calculations for the fictive building. An office building called Kaggen, which is situated at the same geographical location as Koggen 2 but has a different floor area, is used as a reference building for the fictive building concerning energy calculations and also for the electricity and waste needed at the construction site.

To enable a comparison of the two buildings, the fictive building is also situated in Malmö, Sweden, at the same geographical location as Koggen 2. The equal location results in the same conditions concerning climate, land preparations and area specific issues such as public transport. The function of both product systems is office floor area.

3.2.2 Functional unit

The buildings are used as office space and the function of them is to have floor area to work on. The functional unit needs to be valid for both buildings and should be easy to compare for the target audience. Therefore the functional unit is set to

$1\ m^2$ office floor area $\cdot$ year

3.2.3 System boundaries

The system boundary of the study is described as natural boundary, geographical boundary, time boundary and technical boundary. For a clarification of the natural and technical boundary, see Figure 3.

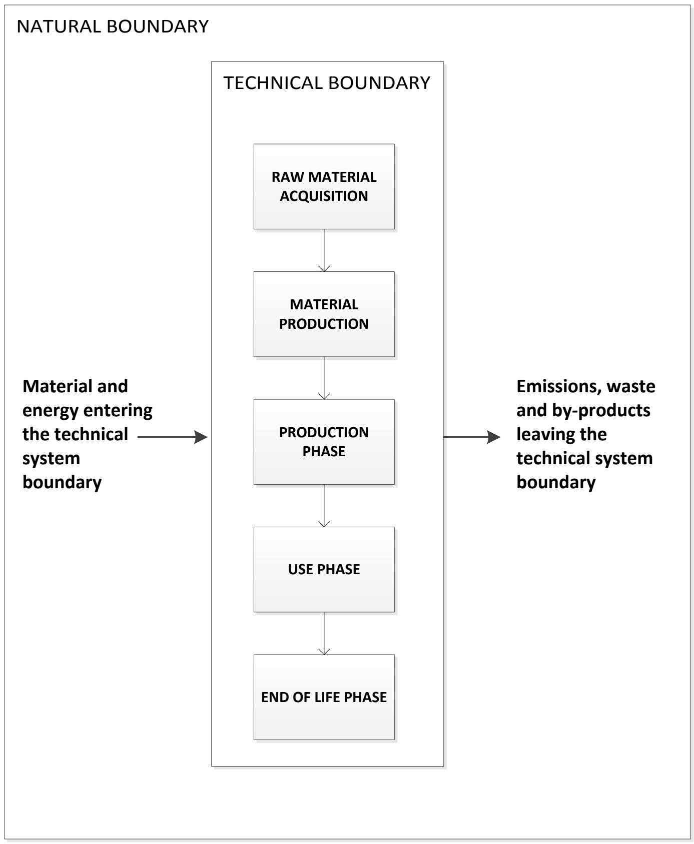


Figure 3: Natural and Technical system boundary of the buildings.

3.2.3.1 Natural boundary

The natural boundary for the buildings is set to cradle to grave, but excludes the end of life phase. A more detailed explanation follows with the description of technical boundaries.

3.2.3.2 Geographical boundary

Because of the location of the buildings the geographical boundary for the buildings, including transportation to and from the site, is set to Malmö, Sweden. The geographical boundary for energy use is set to Sweden. Materials might come from all over the world, which is why the geographical boundary for building materials is set to the world.

3.2.3.3 Time boundary

Since this study looks at existing buildings and investigating the environmental impact of them the time perspective is retrospective – looking back in time. On the other hand the LCA is conducted to be able to make comparisons to have the possibility to make changes in the future, which indicates that the time perspective is prospective – looking into the future.

The BREEAM certified building, Koggen 2, was constructed between 2011 and 2013 and the reference building, Kaggen, was constructed between 2006 and 2007. Some of the data is older and the time boundary therefore needs to be set earlier than the start of the construction. The results are assumed to be valid for ten years. A longer validation of the results is not suitable due to possible changes in energy use, transportation methods and material usage. The time boundary is therefore set to 1994 to 2024.

3.2.3.4 Technical boundary

The technical boundary is set to the categories included in the BREEAM certification system, which are further described in Section 3.2.5 and in Appendix B. The end of life phase is a cut-off from the technical boundary. The main reason is that disposal of materials from the building after its end of life is not addressed in BREEAM. Disposal of materials during the production phase is on the contrary addressed and therefore included. Another reason for excluding the end of life phase is that this phase will occur too remote in time to have the knowledge about the consequences on the environment. The lifetime of the buildings is assumed to be 50 years for both cases, which is a commonly used lifetime for buildings (Wallhagen, Glaumann & Malmqvist, 2011, p. 1870).

3.2.4 Initial flowchart

A simplified flowchart is shown in Figure 4. This is shown to understand the basic processes during the buildings' lifetimes. Energy entering the processes and emissions exiting them are not shown in the initial flowchart.

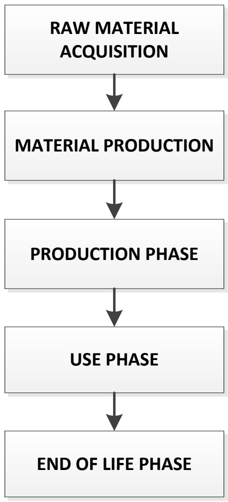


Figure 4: Initial and general flowchart of the buildings.

3.2.5 Use of BREEAM categories and manuals

In this study the *BREEAM Europe Commercial 2009* manual is used, which deals with offices, retail and industry. Table 3 shows which BREEAM categories and subcategories are included in the study. Only the subcategories for which Koggen 2 achieved credits are evaluated to be included in the study. The BREEAM categories are structured regarding which LCA process they are linked to. The actor choices that are made differently for Koggen 2 than for the fictive building are also described in Table 3 and a more detailed description can be found in Appendix G. For a more detailed description of the two buildings, see Section 4.1.

Table 3: Links between LCA processes, BREEAM categories and BREEAM subcategories together with actor choices.

LCA PROCESS	ACTOR CHOICES	SUB-CATEGORY BREEAM	CATEGORY BREEAM
Production phase (including raw material extraction and production of building materials)	Energy use at construction site	Man 3 - Construction site impacts	1.Management
	Choice of building materials	Mat 1 - Materials specification (major building elements) Mat 5 - Responsible sourcing of materials Mat 6 - Insulation Mat 7 - Designing for robustness	6.Materials

	Choice of landscape materials	Mat 2 - Hard landscaping and boundary protection	6.Materials
	Disposal of building materials at construction site	Wst 1 - Construction site waste management	7.Waste
	Re-use of building materials at construction site	Wst 1 - Construction site waste management	7.Waste
Use phase	Use of energy (including heating, cooling, ventilation, operation of installations (elevators, fans and pumps), domestic hot water use, ground heat and other kinds of electricity for the building such as external lighting).	Ene 1 - Energy efficiency Ene 5 - Low or zero carbon technologies Ene 8 - Lifts	3.Energy
	Transportation necessary to commute between home and office.	Tra 3 - Alternative modes of transport Tra 6 - Maximum car parking capacity	4.Transport
	Water consumption during the use phase.	Wat 1 - Water consumption	5.Water
End of life phase			

3.2.5.1 Excluded categories

The category *2.Health and Wellbeing* is not included in the study. All of the subcategories in this category aim at providing a comfortable and healthy indoor environment. This is important but is not directly contributing to a changed amount of emissions, which is why it is excluded from the study.

The category *8.Land use and Ecology* is not included in the study. All of the subcategories in this category investigate the impact on land and ecology in the area. The two investigated buildings are assumed to be located at the same location, which indicates that there will be no difference in GHG emissions for land use and ecology.

The category *9.Pollution* is not included in the study. All of the subcategories in this category look at different kinds of emissions, but none of them, except for the subcategory *Refrigerant use and leakage*, investigates or quantifies emissions that would contribute to global warming. The subcategory *Refrigerant use and leakage* is not relevant in Sweden, since there are regulations prohibiting use of refrigerants that contribute to global warming and depletion of the ozone layer (Miljödepartementet, 2007).

The category *10.Innovation* is not included in the study. The subcategories in this category do not contribute to a changed amount of emissions. More information about the excluded categories can be found in Appendix B.

3.2.6 Impact categories

Several different environmental impact categories can be investigated in an LCA. One of the big issues of the world today is global warming, and mitigation measures are requested in several areas of society. Burning of fossil fuels is the major cause of GHG emissions in the world (Bokalders & Block, 2009, p. 8). The building sector stands for about 30 to 40 percent of the energy used globally, which is a good reason for investigating the GHG emissions from the building sector (United Nations Environment Programme, 2007). For these reasons GWP is the impact category investigated in this study.

GWP100 is the most often used time horizon when discussing GWP, mainly because of the relatively long period of time that CO_2 stays in the atmosphere. Therefore GWP100 is used in this study.

3.2.7 Data requirements

Specific data for the BREEAM certified building, Koggen 2, is collected from COWI and NCC. Data for the fictive building is collected from the national building regulations in Boverkets Byggregler (BBR) and also from NCC which is the property developer of the reference building, Kaggen. Other necessary data for the LCA is taken from the databases Professional and Construction, which are integrated in the software tool GaBi. The used data is as up-to-date as possible, preferably from the time period 2006 – 2014, but older data will occasionally occur.

3.2.8 Assumptions

The following assumptions are made for the modelling:

- The lifetime of the buildings is assumed to be 50 years for both cases.
- The fictive building is assumed to contain 8 000 m² office floor area, the same as Koggen 2.
- The fictive building is assumed to be situated at the same location as Koggen 2, at Östra Varvsgatan in Västra Hamnen, Malmö. This assumption is made to enable an accurate comparison, without any differences in climate conditions.
- Since the hard landscaping around Koggen 2 more or less consists of standard choices, the fictive building is assumed to have equal landscaping as Koggen 2.
- The electricity used in the fictive building is assumed to come from the Swedish electricity grid mix, which is further described in Appendix I.
- The fictive building is assumed to be heated by district heating, based on the reference building Kaggen. The cooling is distributed by district cooling.
- Transportation of prefabricated materials is based on the distance between the fabric and the building. The production of the materials needed is assumed to be located near the fabric and therefore excluded from the calculations.

- Cars that are used for commuting are assumed to be of the category Euro 4 and to have an engine size of 1.4 - 2 liters.
- Employees who commute with car or electric car are assumed to travel alone in the car. Therefore vehicle kilometre and person kilometre is equal for car transportation. For bus transportation the vehicle kilometres needs to be recalculated to person kilometres.
- Most of the bus trips occur during rush hours, which results in the assumption of 60 people traveling per bus.
- One year is assumed to have 225 working days.
- The average distance traveled to and from work during one day is assumed to be 26 kilometers (Trafikanalys, 2013).
- The parking space for cars, electric cars and bicycles connected to Koggen 2 is assumed to be fully used. The rest of the employees are assumed to use public transportation in the form of busses to commute to and from work.
- The number of commuters to and from the fictive building is assumed to be 128 by car, 256 by bike and 256 by bus (Malmö stadsbyggnadskontor, 2010).
- The elevators used in Koggen 2 are standard choises and the elevators in the fictive building are therefore assumed to be of the same kind.
- Since the water consumption is small in an office building and since water-saving solutions for toilets more or less are a standard choice today, the water consumption of the fictive building is assumed to be equal to the water consumption of Koggen 2.

3.2.9 Limitations and cut-offs

The following limitations and cut-offs are made for the modelling:

- Information that is equal for both product systems is excluded from the study. BREEAM subcategories that are included in the study but for this reason will be excluded from the calculations are *Ene 8 – Lifts*, *Mat 2 – Hard landscaping and boundary protection* and *Wat 1 – Water consumption*. Other subcategories that are excluded from the calculations are *Mat 5 – Responsible sourcing of materials* and *Mat 7 – Design for robustness*. These subcategories do not contribute to direct emissions that can be quantified.
- The production of the ventilation system is excluded from the study since it is assumed to be equal for both buildings.
- The study includes environmental aspects, but excludes social and economic aspects of the product system. This is done in accordance with the ISO standard 14040 (International Organization for Standardization, 2006, p. 7).
- The end of life-phase is excluded from the study since it is not addressed in BREEAM. In addition it is difficult to know how the waste will be handled 50 years from now.
- Since the study is performed based on site specific data such as commuting and district heating in Malmö, the results are valid only for Malmö, Sweden.

- Packaging materials for construction materials are not included in the study.
- Only the building envelope, consisting of the climate separating building elements, is considered when looking at building materials.
- Tar paper for roofing is excluded since it is used for all sorts of roofing in the study.
- The external walls of Koggen 2 mainly consist of concrete sandwich elements, but also partly of natural stone, plating and wood. In this study only the areas covered with concrete sandwich elements are considered. The same surface area is used for the external wall of the fictive building.
- Koggen 2 has a roof terrace, which the fictive building also is assumed to have, and it is therefore excluded from the study.
- Maintenance of the buildings and of building materials is assumed to be similar and therefore not included in the study.
- Re-entering of recycled materials into the resource cycle is not considered in this study and therefore the emissions from the recycling process are also not included.

3.2.10 Critical review and type of LCA

A critical review can be conducted by an external or internal expert, whose task is to control if the LCA has met certain requirements. In this study two different choices are compared. Therefore a comparative LCA is conducted, where the two options is compared to each other. When performing a comparative LCA, a requirement from the standard ISO 14040 arises to perform critical review if the results are published (International Organization for Standardization, 2006, p. 17). In the case of this study a critical review cannot be done in the way the standard requires. Critical feedback and discussions are provided by supervisors and examiner and this is the replacement of a critical review. The lack of a critical review is one reason why this study is not a full ISO study.

4 Inventory Analysis

In this chapter the technical system is further described, both in words and in the form of flowcharts. Inventory data is collected and calculations of mass and energy flows are performed.

4.1 System description

The origin of building materials and the distances from the production site to Malmö can be found in Appendix D. Definitions of the systems are presented in the following chapter. Actor choices for Koggen 2 and for the fictive building, such as choice of building materials, heating and cooling system and energy sources, can be found in Appendix G.

4.1.1 Work days and employees

There were 225 work days during the year of 2013, which include the number of days in a year minus weekends, public holidays and 25 days of vacation. The calculations in this report are based on this value. 640 people are assumed to be working in the office building.

4.1.2 Commuting

For Koggen 2, the number of employees commuting by car, electric car, bicycle and bus is based on the amount of parking spaces connected to the building. The result of this is 131 persons commuting by car, 155 persons by bicycle, 5 persons by electric car and the rest of the employees, 349 persons, by bus.

For the fictive building the number of commuters is based on recommendations for parking spaces from the city of Malmö. The result of this is 128 persons commuting by car, 256 persons by bicycle and the rest of the employees, 256 persons, by bus (Malmö stadsbyggnadskontor, 2010). 0.20 kWh/km of electricity is necessary to drive an electric car. Efficiency losses due to charging of the battery, distribution losses and electrical transmission is included (Graham, 2001).

The production of the car is not included in the emissions from transportation by car or electric car (PE International, 2012a). The production of the bus is not included in the emissions from transportation by bus (CPM database, 2000). The production of bicycles is not included in transportation by bicycle and therefore this process (transportation by bicycle) is free from emissions. All of these processes are considered to be infrastructure processes. They will also be used for several other reasons, including leisure and transport to other places then the office building.

4.1.3 Waste

The unsorted waste produced at the construction site is divided equally between landfilling and incineration. The sorted waste is going to landfill. Concrete, gypsum and metals are recycled. Wood is incinerated and used for energy recovery (Wst1b, 2013), (Wst1a, 2011), (SITA, 2014). The amount of waste produced at the construction site can be found in Appendix D.

4.1.4 Building materials

The external walls which are included in the calculations for Koggen 2 consist of prefabricated concrete elements with a surface area of 2 903 m². The roof constructions consist of prefabricated concrete elements with paperboard with an area of 488 m², prefabricated lightweight Masonite elements with an area of 684 m² and a green roof with an area of 208 m². For drawings, see Appendix J. Since most of the construction parts for Koggen 2 are prefabricated, no material losses are included in the calculations.

The external walls that are included in the calculations for the fictive building have a surface area of 2 903 m² and are constructed of an external panel wall together with a load bearing steel frame, see detail drawings in Appendix J. Material losses of ten percent are included in the materials for the external wall (Josephson & Saukkoriipi, 2005, p. 29). The roof construction consists of prefabricated lightweight Masonite elements with an area of 1 380 m². For drawings, see Appendix J. No material losses are included in the lightweight Masonite roof, since it is prefabricated.

Calculations on the load bearing structure have not been made for the fictive building. It can be assumed that additional building materials are necessary due to the light weight Masonite roof, such as additional steel beams. These potential additional building materials are not included in the calculations due to uncertainties of the design of the structure.

4.1.5 Heating and cooling

Koggen 2 is heated and cooled by 16 heat pumps placed on the roof. The energy required for operation of the heat pumps is not included in the process *Electrical heat pump*, but instead included in the process *Operational electricity* in the use phase. The heat pumps are of the model *Mitsubishi Electric Mr Slim Zubadan R410A* and the specific energy requirements are 34 kWh/m² A_{temp} · year (39 kWh per functional unit).

The specific energy requirements for the fictive building are defined according to the maximum limit in BBR of 100 kWh/m² A_{temp} · year (112 kWh per functional unit), while the distribution between operational electricity, heating and cooling is based on the reference building Kaggen. The building is heated by district heating specific for Malmö, Sweden and cooled by district cooling specific for Lund, Sweden. The electricity grid mix for the Nordic region is used to maintain the heat pumps necessary for district cooling (E.ON, 2013a), (Kraftringen, 2011). The Swedish electricity grid mix is used for operational electricity in the fictive building. The distribution between energy sources for the Swedish electricity grid mix can be seen in Appendix I.

4.2 Calculation methods

In GaBi the input flows and emissions are documented for a specific output flow. These values are multiplied with the project specific values to get the correct amount of input and output flows. The external inventory data sets that have been collected from other sources than the GaBi databases can be found in Appendix C.

To reach the results for one functional unit the processes in the production phase are divided with 50 years and also with 8 000 m² where necessary. The project specific calculations for the inventory data and the results of the inventory analysis can be found in Appendix D.

In the following step, the Impact Assessment, the emissions are multiplied with the characterization factors for GWP, see Appendix A. These equations result in $CO_{2,eq}$.

4.3 Analysis and inventory results

Inventory data is collected for each individual process. The collected data is then normalized to the process and finally adjusted to the functional unit. Since an LCA software tool together with connected databases is used to collect data and perform calculations, a large number of emissions are documented. This makes it difficult to list all the emissions in the report. The external inventory data sets that are used can be found in Appendix C.

Simplified flowcharts are shown in Figure 5 to Figure 8, which explain the processes included in the production phase and the use phase. For the flowcharts produced in the software tool GaBi, see Appendix E.

The calculations together with tables of the results from the mass and energy calculation can be found in Appendix D.

In Figure 5 the production phase for Koggen 2 is shown. Processes included in this flowchart are *Electricity at construction site* which has a connection from *Electricity from the Swedish grid mix*, *Production of heat pumps*, *Production of prefabricated concrete sandwich wall*, *Production of light weight Masonite roof*, *Production of prefabricated concrete roof with paperboard*, *Production of green roof* and *Waste at construction site*. All processes except *Electricity at the construction site* and *Waste at the construction site* include *Transportation of materials*.

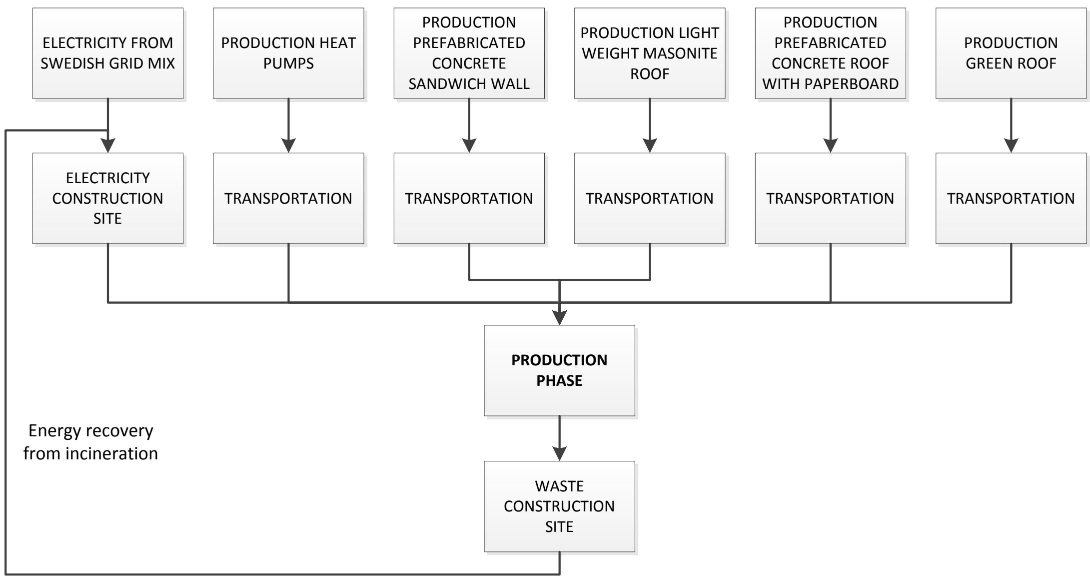


Figure 5: Simplified flowchart of the production phase for Koggen 2.

In Figure 6 the production phase for the fictive building is shown. Processes included in this flowchart are *Electricity at construction site* which has a connection from *Electricity from the Swedish grid mix*, *Production of load bearing external wall*, *Production of light weight Masonite roof* and *Waste at construction site*. All processes except *Electricity at the construction site* and *Waste at the construction site* include *Transportation of materials*.

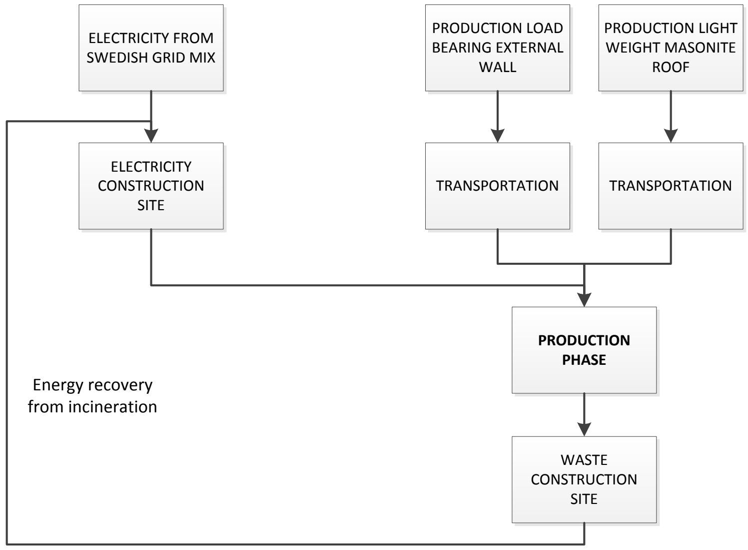


Figure 6: Simplified flowchart of the production phase for the fictive building.

In Figure 7 the use phase for Koggen 2 is shown. Processes included in this flowchart are *Operational electricity*, *Heating*, *Cooling*, *Commuting by bus*, *Commuting by car* and *Commuting by electric car*. *Electricity from wind power*, *hydro power* and *biomass* is connected to *Operational electricity*, *Heating* and *Cooling*.

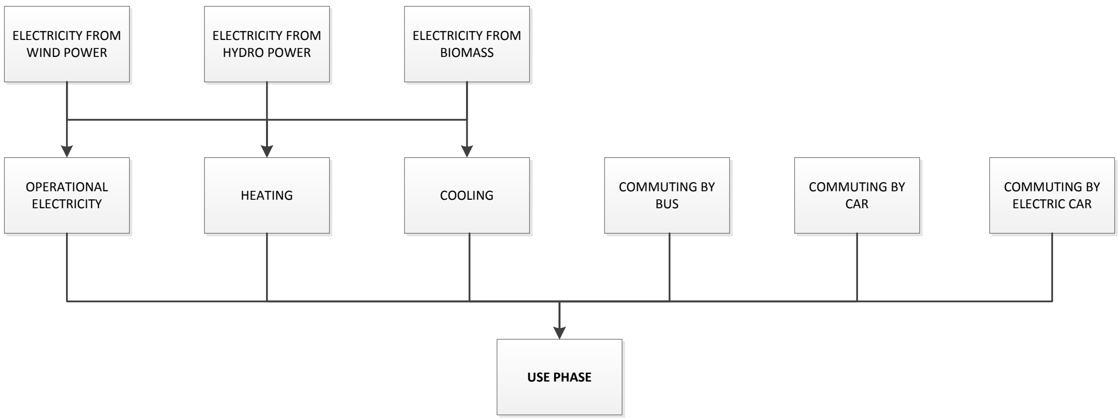


Figure 7: Simplified flowchart of the use phase for Koggen 2.

In Figure 8 the use phase for the fictive building is shown. Processes included in this flowchart are *Operational electricity*, *Heating*, *Cooling*, *Commuting by bus* and *Commuting by car*. *Electricity from the Swedish grid mix* is connected to *Operational electricity*, *District heating* is connected to *Heating* and *District cooling* is connected to *Cooling*.

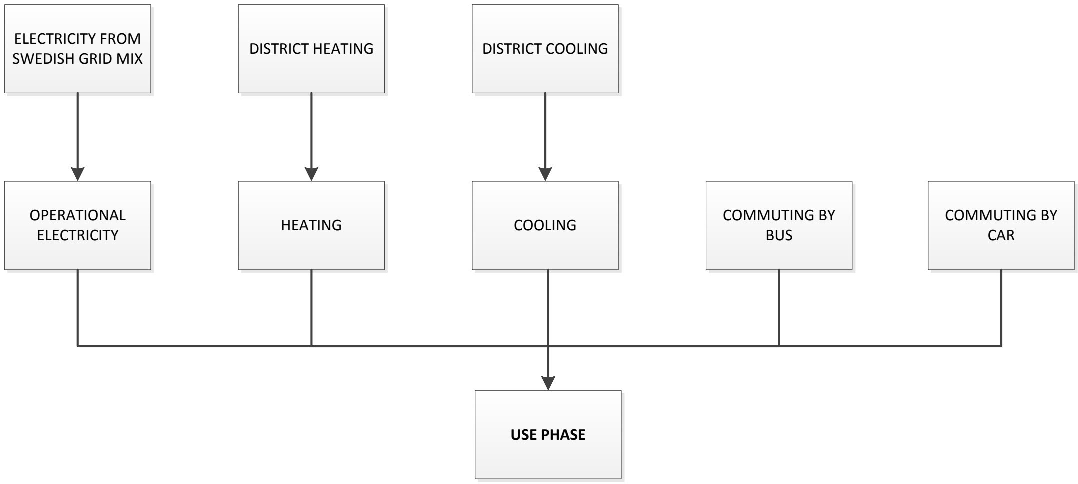


Figure 8: Simplified flowchart of the use phase for the fictive building.

5 Impact Assessment

One of the reasons for performing a Life Cycle Impact Assessment is to turn the results of the inventory analysis into more understandable data from an environmental perspective. The emissions have been defined, but they are in this step also calculated into impacts (Baumann & Tillman, 2004).

5.1 Impact definition

The impact category investigated in this study is global warming, which contributes to consequences on the health of both humans and the ecosystem. This investigation is done by documenting and calculating $CO_{2,eq}$ and by using the characterization model GWP.

5.2 Impact classification

In this step the results of the inventory analysis are classified and divided between the selected impact categories. The emissions that are connected to GWP are mainly CO_2, CH_4 and N_2O. The comprehensive list of GHGs can be found in Appendix A.

5.3 Impact characterisation - Results

This step includes calculations of the final results for the different impact categories, in this case GWP. Characterization factors are used and multiplied with the compiled inventory results (Baumann & Tillman, 2004). Table 1 in Section 2.1.3 shows a summary of the GHGs including the characterization factors for GWP for 100 years. The entire table can be found in Appendix A. With these characterization factors a total impact can be calculated. A table with the results of the Impact Assessment can be found in Appendix H. The results are also illustrated in Figure 9 to Figure 21.

As can be seen in Figure 9, the total amounts of GHGs are considerably higher for the fictive building than for the BREEAM certified building, Koggen 2. Koggen 2 contributes to 22.0 kg $CO_{2,eq}/m^2 \cdot year$, whereas the fictive building contributes to 33.8 kg $CO_{2,eq}/m^2 \cdot year$.

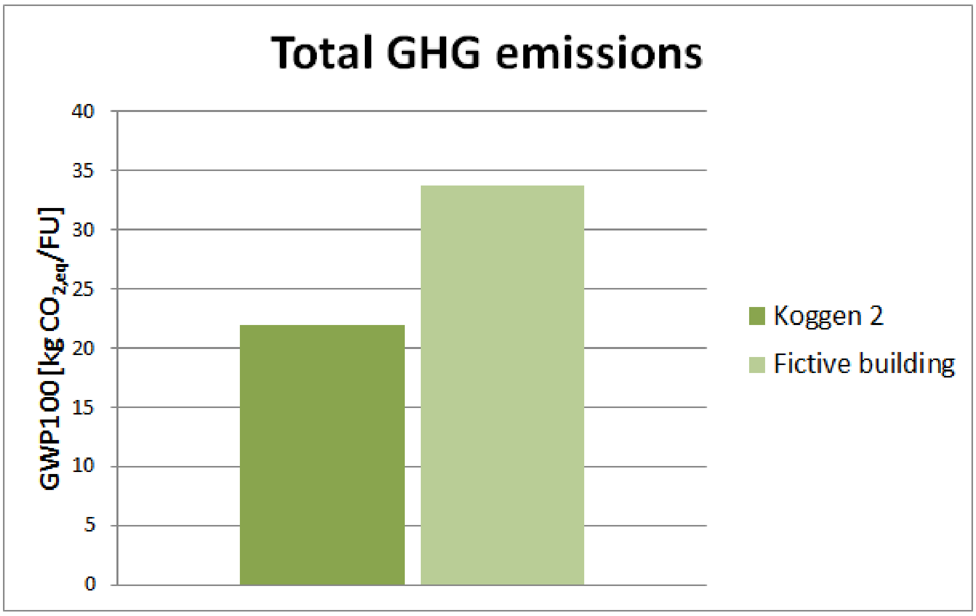


Figure 9: Total GHG emissions from Koggen 2 and the fictive building.

From Figure 10 it can be stated that the absolute majority of the emissions come from the use phase. In Section 5.3.1 and Section 5.3.2 the results are separated between the use phase and the production phase and also further separated between processes.

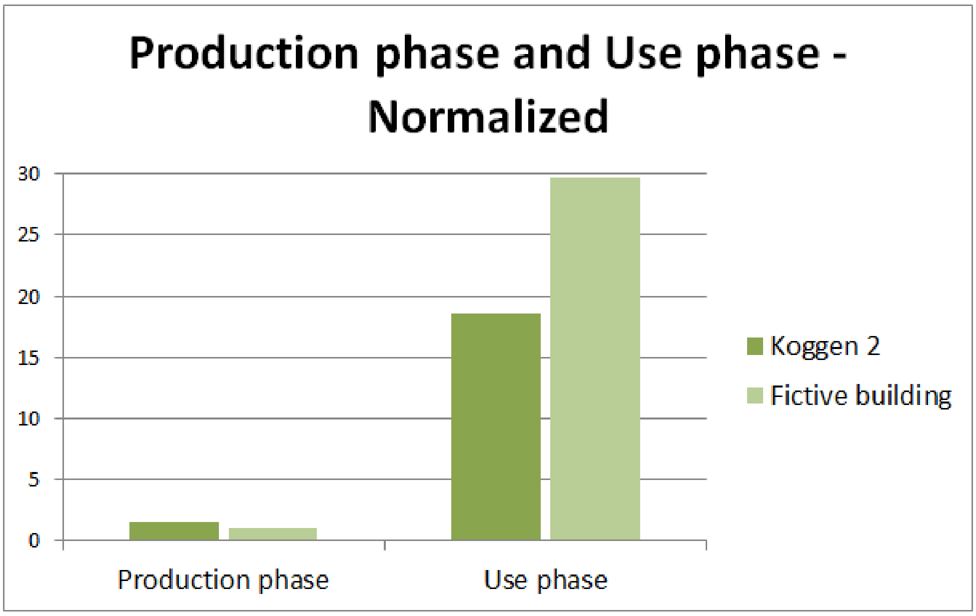


Figure 10: Total GHG emissions from the production phase and the use phase. The values are normalized, which means that the production phase for the fictive building is set to one and the other phases are put in relation to this one.

5.3.1 Production phase

The majority of the emissions are produced during the use phase, but the production phase is still important to investigate. In Figure 11 the total GHG emissions from the production phase can be seen for Koggen 2 and for the fictive building. The biggest amount of emissions is produced from Koggen 2.

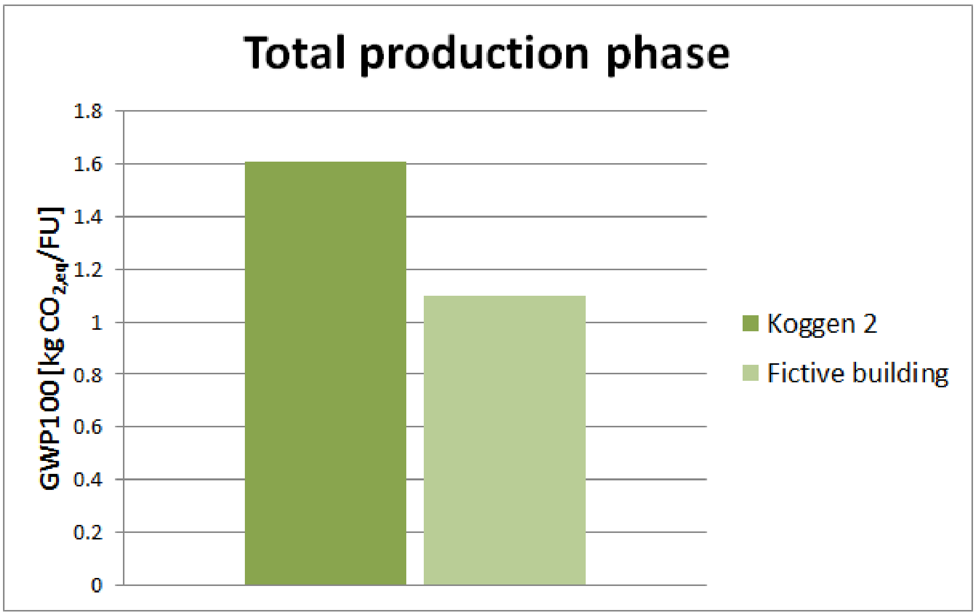


Figure 11: Total GHG emissions from the production phase.

To be able to understand which process during the production phase contributes to the emissions and to be able to compare them to each other, the processes are separated and categorised, see Figure 12 and Figure 13. It is obvious that the external walls of the two buildings are the major sources of emissions of GHGs. The roof constructions also generate relativley high emissions, with the exception of the prefabricated light weight Masonite roof. This roof construction is the only one of the compared roof constructions that does not contain concrete. Concrete is in this report shown to be a big source of GHGs, which is not present in the lightweight Masonite roof, hence the lower emissions. This roof construction on the other hand might need a more comprehensive construction, containing more steel, which would lead to higher emissions. Transportation of the building materials from production to the construction site is included in the different categories.

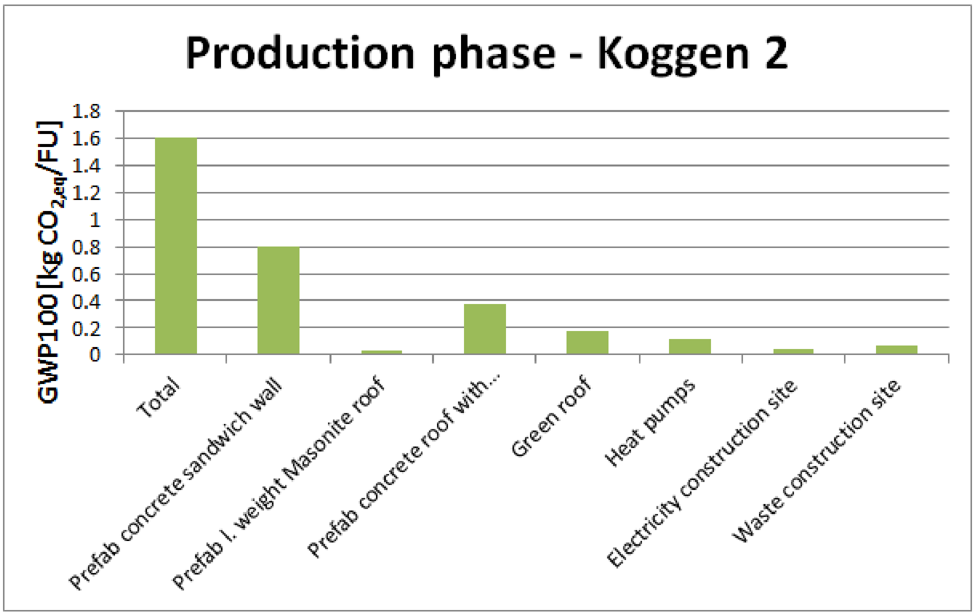


Figure 12: GHG emissions for the production phase of Koggen 2, distributed between the different categories of processes.

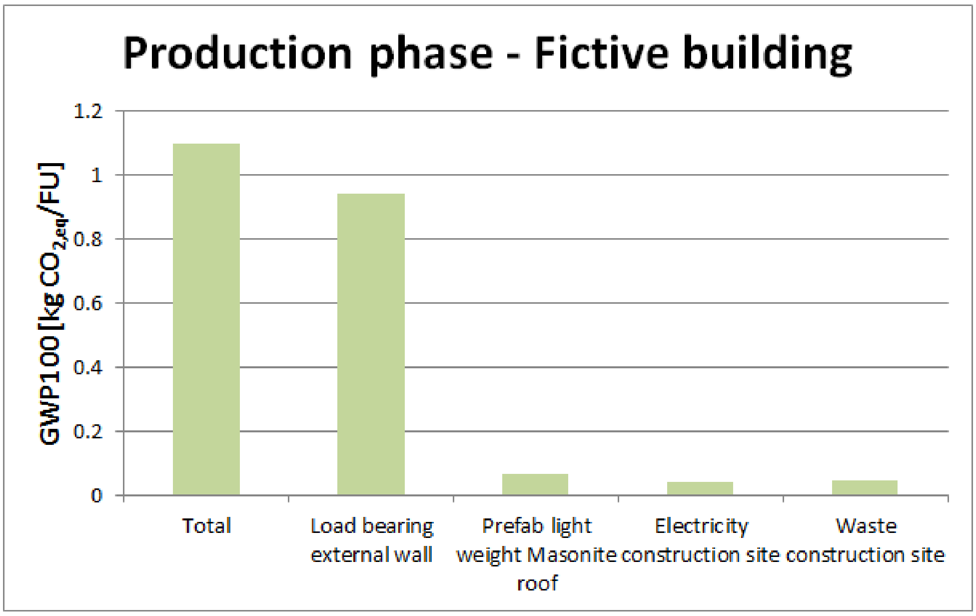


Figure 13: GHG emissions for the production phase of the fictive building, distributed between the different categories of processes.

To facilate a comparison between the categories of processes for the two buildings, each category in the production phase is shown separately in Figure 14. The values are normalized around the external wall of the fictive building. This means that the external wall of the fictive building is set to one and the other categories of processes are related to that reference point. By doing this the difference in amounts of emissions between Koggen 2 and the fictive building is better visualized. The resulting chart in Figure 14 shows that the roof constructions, the electricity at the construction site and the waste at the construction site all generate more emissions for Koggen 2 than for the fictive building. The external wall on the other hand generates more emissions for the fictive building than for Koggen 2.

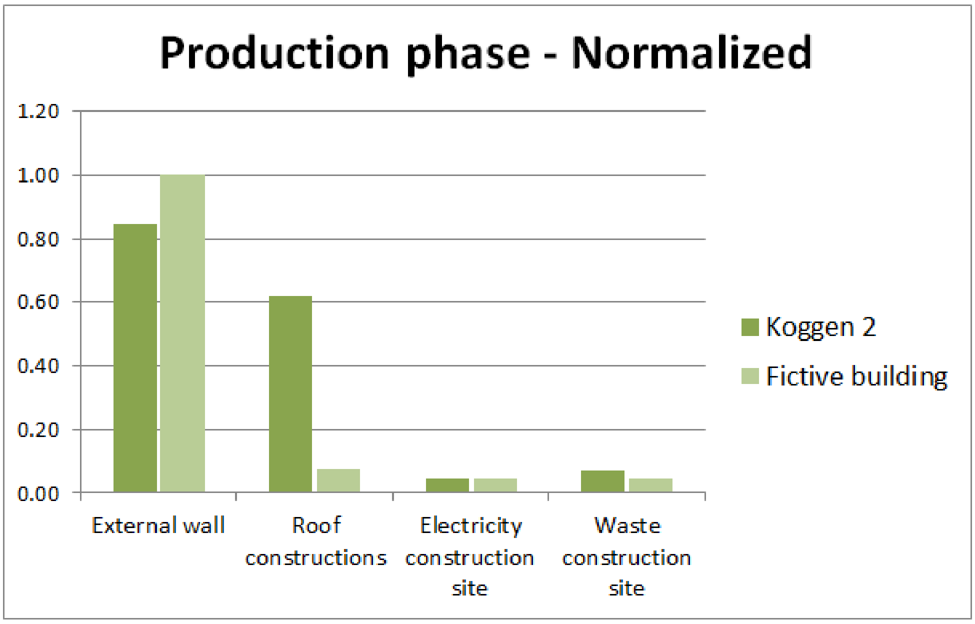


Figure 14: GHG emissions from the production phase of Koggen 2 and the fictive building, divided between categories of processes. The values are normalized to the external wall of the fictive building, which means that the external wall for the fictive building is set to one and the others are put in relation to that one.

5.3.1.1 Transportation of building materials

Some of the building materials are transported over long distances and it can be assumed that transportation of materials might represent a part of the emissions from the production phase. In Figure 15 the external walls of Koggen 2 and the fictive building are compared, where the process for transportation of building materials is separated from the production process. This is done to be able to compare the processes and to understand how big the contribution from transportation of materials is compared to the actual production.

From the resulting chart in Figure 15 it can be seen that transportation contributes to a relatively small part of the GHG emissions from the total production and transportation of the external walls. The walls used for Koggen 2 are prefabricated and transported with truck and ship from Riga, Latvia. This is the reason for a higher value for Koggen 2 than for the fictive building. Even though concrete is transported from Latvia, the production of the wall generates significantly more GHG emissions than the transportation. For details about distances and modes of transport, see Appendix D.

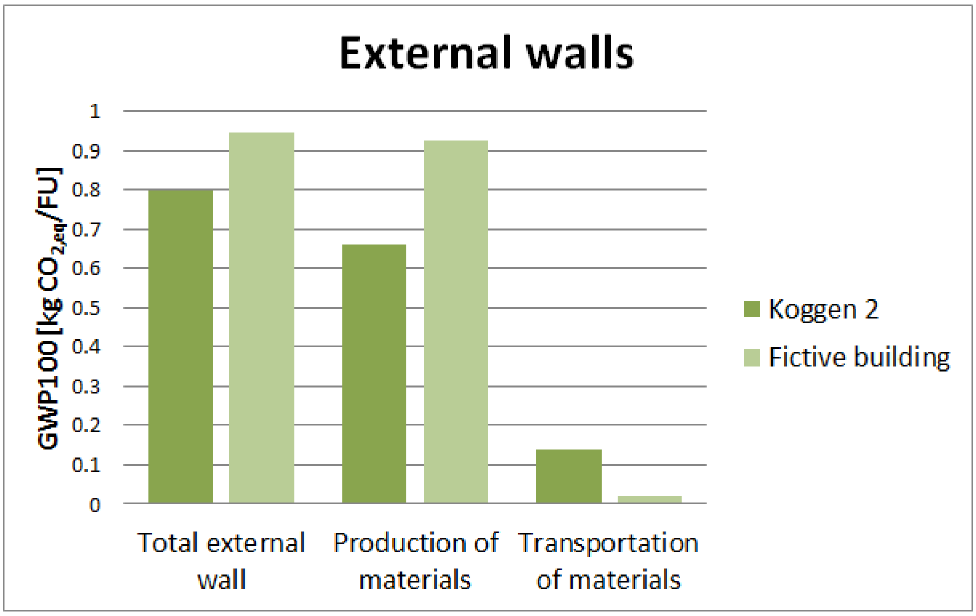


Figure 15: GHG emissions from the external walls of Koggen 2 and the fictive building. Production of the building materials and transportation of them are separated.

5.3.2 Use phase

As earlier shown, the majority of the emissions are produced during the use phase. In Figure 16 the total GHG emissions from the use phase can be seen for Koggen 2 and for the fictive building. A higher amount of emissions is released from the fictive building.

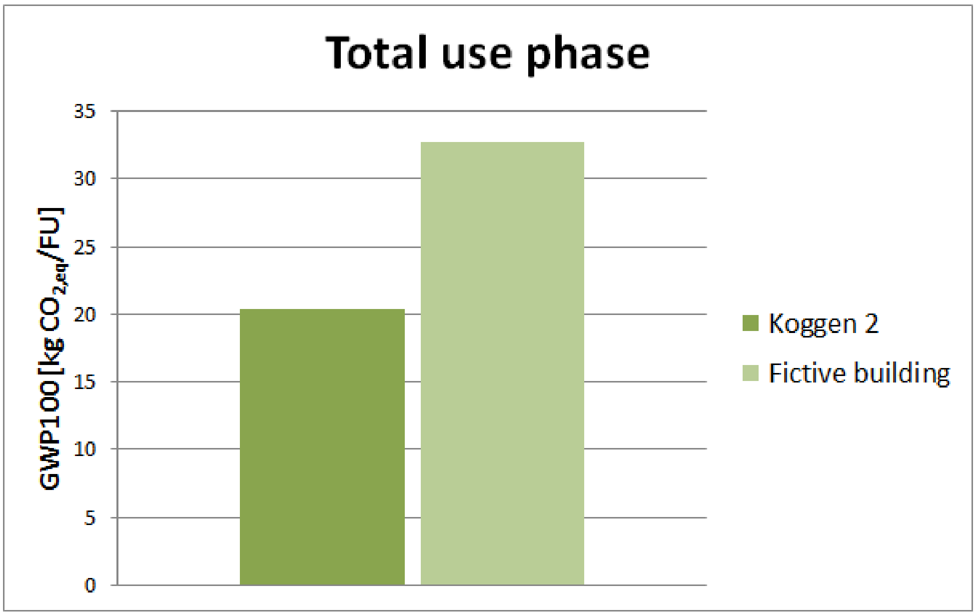


Figure 16: Total GHG emissions from the use phase.

To be able to understand which process during the use phase contributes to the emissions and to be able to compare them to each other, the processes are separated and categorised, see Figure 17. It is clear that commuting by car is the process that emits the most GHGs and for Koggen 2 this is the only big source. For the fictive building there are also appreciable emissions from district heating, district cooling and from operational electricity. Since the production of the heat pumps occurs during the production phase this is not included in the results of the use phase. To better understand the total emissions from heating and cooling, see Figure 19.

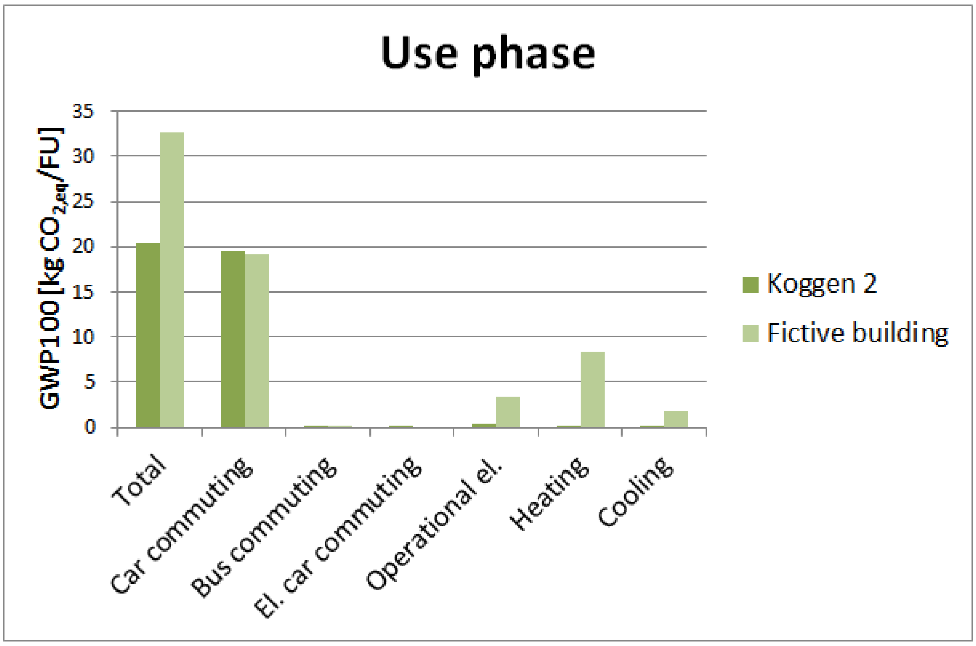


Figure 17: GHG emissions for the use phase of Koggen 2 and the fictive building, distributed between the different categories of processes.

To enable a comparison between the categories of processes, each category in the use phase is shown separately in Figure 18. The values are normalized around commuting for the fictive building. This means that commuting for the fictive building is set to one and the other categories of processes are related to that reference value. By doing this the different amounts of emissions between Koggen 2 and the fictive building are better visualized. The resulting chart in Figure 18 shows that the GHG emissions from operational electricity, cooling and heating is smaller for Koggen 2 than for the fictive building, but bigger from the process category commuting.

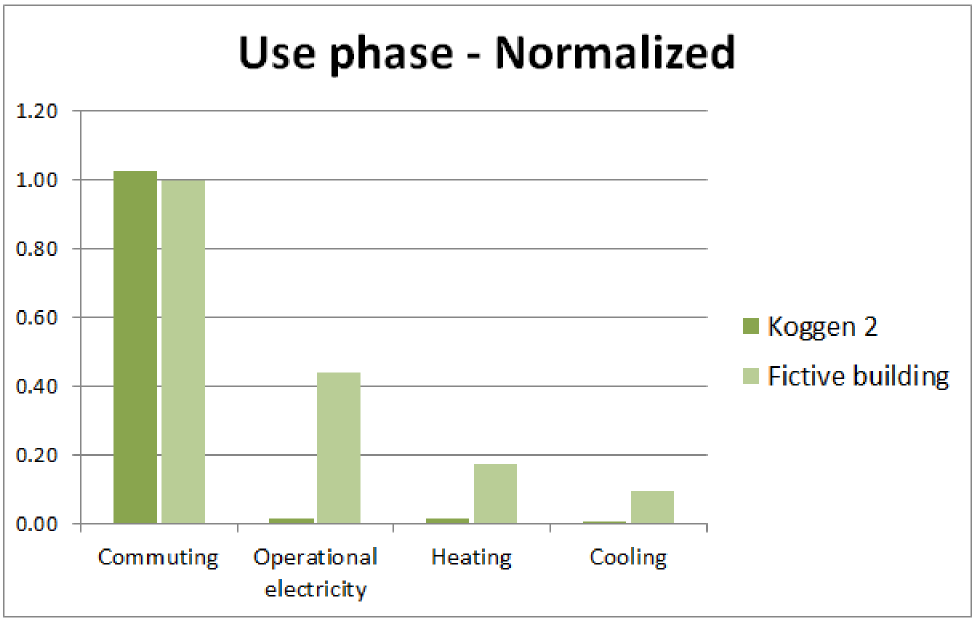
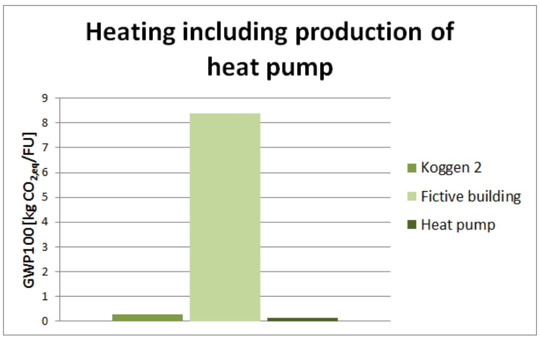


Figure 18: GHG emissions from the use phase of Koggen 2 and the fictive building. The values are normalized around commuting for the fictive building, which means commuting for the fictive building is set to one and the others are put in relation to that reference value.

The charts showing heating and cooling, see Figure 17 and Figure 18, do not include the production of the heat pumps. To reach the total amount of emissions for heating and cooling of Koggen 2, parts of the emissions from the production of the heat pumps need to be accounted for in each of the processes. To get a better understanding of the emissions from the total process of heating and cooling, they are visualised together with the production of the heat pumps, see Figure 19. It should be mentioned that the total emissions from production of the heat pumps are included in both charts in Figure 19. An allocation is problematic and the charts only aim at giving an understanding of the small proportion of emissions that the production of the heat pumps contributes compared to the heating and cooling itself. It shows that the trade-off is larger than the effort to produce the heat pumps. It should also be mentioned that Koggen 2 and the fictive building use different systems for heating and cooling. For details about the different product systems, see Section 4.1 and Appendix G.



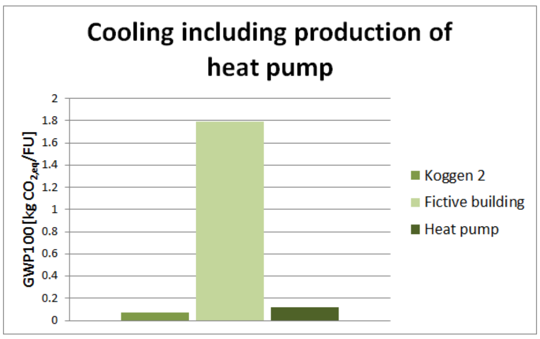


Figure 19: GHG emissions from heating and cooling, including the production of the heat pumps.

5.3.2.1 Use phase without commuting

As earlier shown, commuting contributes to a big proportion of the GHG emissions released during the use phase and during the total lifecycle of the buildings. Commuting is included in the study since it is addressed in the BREEAM certification. To get a better understanding of the building itself, the results in this section are shown without commuting.

In Figure 20 the total GHG emissions from the use phase, but without commuting, can be seen. Comparing Figure 20 with the earlier results for the use phase, see Figure 16, a big difference in emissions between Koggen 2 and the fictive building can still be seen. This can be explained by the small difference in emissions from commuting between the two buildings.

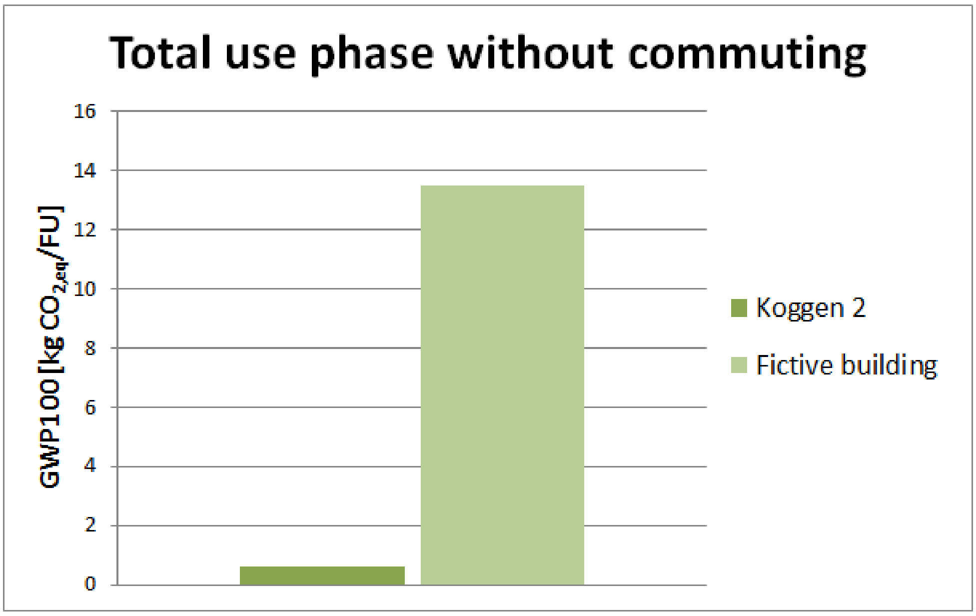


Figure 20: Total GHG emissions for the use phase, where commuting is excluded.

For a chart with separated processes but without commuting, see Figure 21. This chart gives better understanding for the importance of electricity, heating and cooling and for the choices that can be made in these areas.

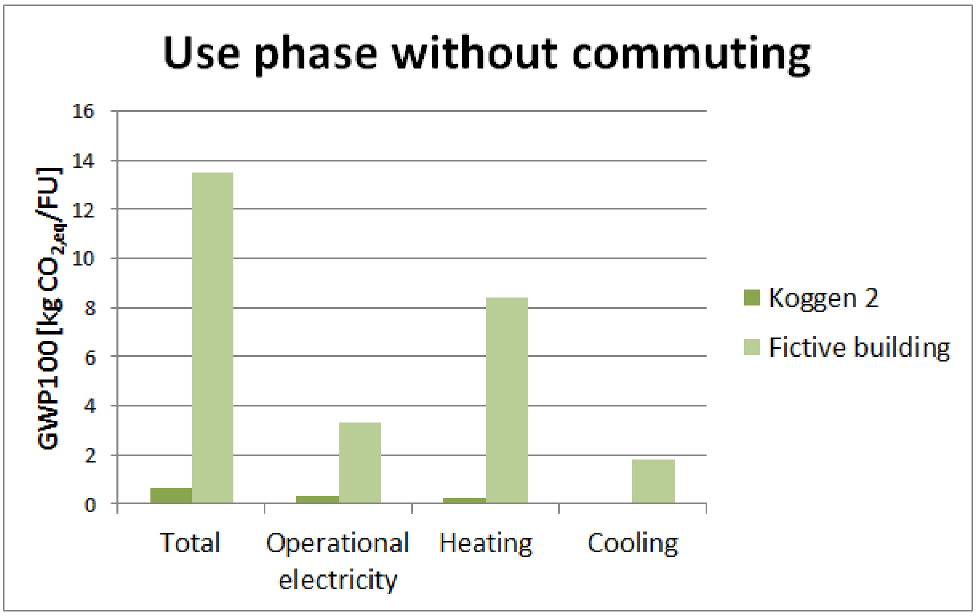


Figure 21: GHG emissions for the use phase where commuting is excluded, separated between the categories of processes.

6 Discussion

This chapter discusses the assumptions and choices that are made and how they affect the results. The results are also compared with existing research to acknowledge the reliability of the results.

6.1 Verification of results

A similar study to this one has been done by Humbert et al. (2007) for a LEED certified building. LEED is an US based environmental certification system for buildings that assesses seven key areas. These are *Sustainable sites*, *Water efficiency*, *Energy and atmosphere*, *Materials and resources*, *Indoor environmental quality*, *Innovation in design* and *Regional priority* (Heincke & Olsson, 2012, p. 34).

The impact categories investigated in this study are human health, ecosystems quality, climate change and resource consumption. The areas of importance considering environmental impact from the study by Humbert et al. (2007) are mainly commuting and electricity. Water consumption and waste generation have small impacts on the environment. These conclusions cannot be directly compared with this study, since the impact categories are different, but the conclusions indicate a consistency with the conclusions of this study. The LEED study indicates total emissions of approximately 15 500 pers-yr/building · 50 years for a standard (non-LEED) building, which means the emissions caused by one person during one year. By changing the amounts of office workers from 500 to 640 and by multiplying the emissions with amount of office workers and dividing them with 50 years and 8 000 m^2, the amounts of emissions can be translated to the functional unit for this study, which gives 19.4 kg $CO_{2,eq}/m^2 \cdot$year. The emissions from the LEED certified building are reported per LEED credit and are therefore difficult to summarise in this way. Differences of total emissions from this study depend on different choices of investigated processes and the fact that this study only investigates processes affected by the BREEAM certification.

A report by Wallhagen, Glaumann & Malmqvist (2011) performs life cycle calculations on an office building in Gävle, Sweden. The study shows that the two most important measures to reduce the environmental impact from buildings are to use other building materials than concrete and to use renewable energy. Since the report by Wallhagen, Glaumann & Malmqvist investigates the impact category GWP the results can be compared with this study, where similar conclusions are drawn.

Twelve measures were implemented in the design phase for the office building in Gävle, such as choice of energy sources and choice of building materials. This resulted in a reduction of GHG emissions by 48 percent, from 5.9 kg $CO_{2,eq}/m^2 \cdot$year to 3.1 kg $CO_{2,eq}/m^2 \cdot$year. To compare, the study of Koggen 2 and the fictive building resulted in a difference of GHG emissions by 65 percent between the two buildings. The total emissions vary between the studies because of differences in included processes, such as commuting, waste and electricity at the construction site and transport of building materials. The energy consumption of the office building in Gävle was 100 kWh/$m^2 \cdot$year, and the implemented measures reduced the energy consumption with 20 percent. This can be compared with the energy consumption for Koggen 2 of 39 kWh/$m^2 \cdot$year and for the fictive building of 112 kWh/$m^2 \cdot$year.

A report by Brunklaus, Thormark & Baumann (2010) describes a life cycle analytic study where passive houses and conventional houses are compared. By doing an actor analysis the importance of electricity is shown, both concerning electricity for the use phase and for the material production. The importance of the electricity during the use phase is also shown in this study, depending on the choice of energy used. The buildings investigated in the study by Brunklaus, Thormark & Baumann have an energy consumption of 70 to 150 kWh/m²·year. These buildings are estimated to generate 600 to 900 kg $CO_{2,eq}$/m²·year. 80 percent of the emissions are estimated to be generated during the use phase and 20 percent during the production phase. This can be compared with Koggen 2 and the fictive building which have a distribution of 93 to 97 percent from the use phase and three to seven percent from the production phase. The GHG emissions are more difficult to compare since the total emissions of 22 to 34 kg $CO_{2,eq}$/m²·year for Koggen 2 and the fictive building do not include all materials and processes from the buildings.

The end of life phase is for reasons that are further explained in Section 3.2.3.4 excluded from the study. It can be discussed if it is reasonable to exclude this phase. A report by Junnila (2004), which investigates the environmental impacts of three office buildings in Finland, shows that the demolition phase only contributes to a small part of the GHG emissions (1 percent) from the life cycle of a building. This indicates that the exclusion of the end of life phase does not affect the results of this study much. The study by Junnila also shows that the operation of the building, mainly electricity and heating, generates the most GHGs. The office buildings in that study have a relatively high energy consumption of 160 to 250 kWh/m²·year. This affects the resulting amount of GHG emissions, which was estimated to 3 000 to 4 800 kg $CO_{2,eq}$/m²·year. This study allocates about 85 percent of the GHG emissions to the use phase, 10 percent to the production phase and less than 5 percent to maintenance and demolition.

6.2 Connections between LCA results and BREEAM

The BREEAM certified building Koggen 2 represents new office buildings in Sweden, certified according to the manual *BREEAM Europe Commercial 2009*. Guidance is given of what difference in GHG emissions a BREEAM certification contributes to, but the results of the study are only specifically valid for the investigated buildings.

Table 4 describes which BREEAM categories and subcategories are investigated in the study and their connection to the LCA processes. The BREEAM category that contributes to the biggest reduction of GHG emissions in this study is *3.Energy*. By using energy efficient equipment, such as heat pumps, and by using local energy generation from renewable sources, the energy demand is decreased compared to the fictive building from 112 to 39 kWh/m²·year. The different actor choices that are made for Koggen 2 have resulted in a reduction of GHG emissions compared to the fictive building. Koggen 2 stands for 4 percent of the total GHG emissions from the energy category and the fictive building stands for 96 percent.

Alternative choices for the energy category could for instance be to use other energy sources. If coal would have been used as a source of energy, it would have resulted in 0.5 kg $CO_{2,eq}$/kWh (Wallhagen, Glaumann, & Malmqvist, 2011). The German electricity grid mix would have resulted in 0.675 kg $CO_{2,eq}$/kWh (PE International, 2010a). This can be compared to the Swedish electricity grid mix which generates 0.104 kg $CO_{2,eq}$/kWh (PE International, 2010j). Another alternative choice for the energy category is to use other technologies, such as district heating, heat boiler or photovoltaic (PV) cells. The emissions from district heating are further described in Appendix I. If

PV cells are used, the resulting emissions of GHGs is around 0.06 kg $CO_{2,eq}$/kWh (Wallhagen, Glaumann, & Malmqvist, 2011).

The absolute biggest amounts of emissions are generated from the category *4.Transport* (96 percent of the total emissions for Koggen 2 and 59 percent for the fictive building). The BREEAM certification specifies requirements of numbers of parking spaces for cars and bicycles. Commuting by car has shown to contribute to large amounts of emissions. If every car used for commuting would be used by two people instead of one, this would dramatically change the amounts of emissions from commuting. Therefore the location of the building and the possibility of public transportation and other schemes such as car sharing are of high importance concerning reduction of GHG emissions. On the other hand, the difference in GHG emissions between the investigated buildings is very small. This indicates that the BREEAM certification itself does not lead to fewer emissions, but that the transport category is important to consider and to include in the certification system.

The methodology of the BREEAM certification system allows the person performing the certification to choose which credits to achieve for the building. The categories all have different amounts of credits available, but of course the categories also are linked to different amounts of emissions. Depending on the choices that are made, different amounts of GHG emissions are generated, which means that a certification in itself do not necessarily reduce the emissions.

Table 4: Links between LCA processes and BREEAM categories together with the amounts of emissions connected to each category and the allocation of emissions between Koggen 2 and the fictive building.

LIFE CYCLE ASSESSMENT PROCESS	**SUB-CATEGORY BREEAM**	**CATEGORY BREEAM**	**AMOUNTS OF EMISSIONS [*kg $CO_{2,eq}/m_2 \cdot$ year*]**
Production phase	Man 3 - Construction site impacts	1.Management	Koggen 2: 0.0416 (50%) Fictive: 0.0413 (50%)
	Mat 1 - Materials specification (major building elements) Mat 5 - Responsible sourcing of materials Mat 6 - Insulation Mat 7 - Designing for robustness	6.Materials	Koggen 2: 1.50 (60%) Fictive: 1.01 (40%)
	Mat 2 - Hard landscaping and boundary protection	6.Materials	*N/A*
	Wst 1 - Construction site waste management	7.Waste	Koggen 2: 0.0643 (59%) Fictive: 0.0445 (41%)
	Wst 1 - Construction site waste management	7.Waste	*N/A*

Use phase	Ene 1 - Energy efficiency Ene 4 - External lighting Ene 5 - Low or zero carbon technologies Ene 8 - Lifts	3.Energy	Koggen 2: 0.617 (4%) Fictive: 13.52 (96%)
	Tra 3 - Alternative modes of transport Tra 6 - Maximum car parking capacity	4.Transport	Koggen 2: 19.68 (51%) Fictive: 19.17 (49%)
	Wat 1 - Water consumption	5.Water	*N/A*
End of life phase			*N/A*

6.3 Lifetime and maintenance

The functional unit is set to $1\ m^2$ office floor area $\cdot$ year. For the production phase this means that the emissions from material production and from the waste and electricity at the construction site are divided between 50 years. Therefore a different lifetime of the buildings would change the amount of emissions per functional unit.

Since the lifetime of the building is set to 50 years, no changes are assumed during the 50 first years of the use phase. It can be discussed if this is reasonable. The energy system will probably look differently 30 years from now. Even though this is an issue, the difference would not be that big since the energy in Sweden does not contain much fossil fuel today. A bigger issue is the transportation system. According to this study commuting definitely generates the biggest part of the emissions from the buildings. 30 years from now fossil fuels might not be used for transportation and the means of transportation might look differently. In a report by Shell (2013) predictions are made that petroleum will be phased out as a fuel for passenger transportation and replaced by electricity and hydrogen by 2070. This means that the entire energy system needs to be changed and commuting will be responsible for fewer emissions.

Maintenance is not included in the study since it is assumed to be the same for the two buildings. To get a more accurate picture of the total emissions of the buildings the maintenance should be further investigated. Different types of constructions generally have different needs of maintenance. Concrete is highlighted in this report for contributing to large amounts of GHG emissions. The production of cement, which is one of the components of concrete, is an energy demanding process, which results in big amounts of GHG emissions when fossil fuels are used. The cement production contributes to five percent of the global anthropogenic CO_2 emissions (Kruse, 2004). A lot of improvements have been done in the cement production industry during the last years though, which indicate a decrease of emissions and energy demand (Bokalders & Block, 2009, p. 45). On the other hand concrete is nearly free from the need for maintenance and is a resistant material that can stand high temperatures, moisture and mould (Engström, 2007, p. 1.10).

A report by Junnila (2004) states that maintenance generates a relatively small part of the GHG emissions from a building, in a life cycle perspective. It should be stated though that this study investigates office buildings in Finland, where a different electricity grid mix is used with a higher share of fossil fuels, resulting in high emissions from the use of electricity. The Finish electricity grid mix generates 0.36 kg $CO_{2,eq}$/kWh (PE international, 2010d), which can be compared with the Swedish electricity grid mix which generates 0.104 kg $CO_{2,eq}$/kWh (PE International, 2010j). Still, the minor importance of maintenance compared to other parts of the life cycle of a building is acknowledged.

For the BREEAM certification to be able to contribute to a reduced impact on the environment it is necessary that the tenants of the building understand how to maintain it. The study *Energy-efficient behaviour in office buildings – EBOB* shows that office buildings often do not perform as energy-efficiently as they were planned to. Some of the reasons for that is lack of information to the users of the building and lack of interest in using the building as it was planned, for instance by not switching of computers and the light by the end of the day (United Nations Environment Programme, 2007, p. 24).

To encourage this, one of the requirements of the BREEAM certification is to produce a building user guide. The credit that is available for this was achieved for Koggen 2, see Appendix B. The user guide helps the tenants to understand the technical solutions of the building and how to operate them (BRE Global, 2009, pp. 53-56). On the other hand it cannot be guaranteed that the tenants read the user guide, and therefore the effects on the environment might change when the building is taken in service.

In this study it is assumed that the parking spaces for cars, electric cars and bicycles are used fully. In this way it is possible to investigate what difference it makes to have requirements regarding parking capacity. For the study to be valid it is necessary that the tenants use the available parking space, which is difficult to ensure.

6.4 Country specific choices

The location of the buildings contributes a lot to the results of this study. The studied buildings are situated in Malmö, Sweden, but it can be discussed how the results would be affected if the buildings would have been situated elsewhere. In this section country specific electricity is discussed, followed by the BREEAM manual *Europe Commercial 2009* and its effects on transportation, the Green Guide, district heating, green roofing, the fictive building and Kaggen and finally an alternative study with German electricity and German district heating.

6.4.1 Electricity

The electricity grid mix used for the fictive building is the Swedish electricity grid mix, which generates GHG emissions of 0.104 kg $CO_{2,eq}$/kWh, see Appendix I (PE International, 2010j). Sweden is one of the countries in the world that uses an electricity grid mix with low CO_2 emissions and the electricity grid mix in other countries looks quite different. The British electricity grid mix, which originally was a basis for the BREEAM certification concept, generates GHG emissions of 0.56 kg $CO_{2,eq}$/kWh, see Appendix I (PE International, 2010e). The German electricity grid mix, which is applied for a majority of the materials in the database for the software tool, generates GHG emissions of 0.68 kg $CO_{2,eq}$/kWh, see Appendix I (PE International, 2010a).

During the data collection and inventory analysis big efforts have been put on finding country specific data for Sweden. For some of the building materials this has been difficult to find in the GaBi databases and in some situations data for other countries have been selected. Since the software tool GaBi together with its databases are developed by German consultants, most of the data have German origin, which needs to be considered when looking at the results.

Another interesting question that can be raised by that report is the stability of the Swedish electricity grid mix. The Swedish electricity grid mix contains a low amount of fossil fuels. It can be discussed though if the Swedish electricity grid mix is durable over time. If nuclear power would be phased out, what would replace it? Hydro power, which contributes to a big part of the Swedish electricity grid mix, is developed to 75 percent of what is thought to be feasible in Europe (Schiermeier et al., 2008). Other renewable energy sources need to be further developed to solve future changes in the energy system.

6.4.2 BREEAM Europe Commercial 2009 and transportation

BREEAM is a British certification system and was therefore first constructed for the British housing sector. There are national versions of the schemes, for instance a Swedish one. There is also a European scheme, *BREEAM Europe Commercial*, which can be used for commercial and industrial buildings (Heincke & Olsson, 2012). This scheme is used for Koggen 2, which means that the manual is constructed for Europe instead of for Sweden specifically. This can lead to issues in different areas, for instance when it comes to traffic.

The requirements from *BREEAM Europe Commercial 2009* considering parking capacity are not strict enough compared to practice in Sweden. The subcategory *Tra 3 – Alternative modes of transport* requires 30 parking spaces for bicycles for Koggen 2, whereas the city of Malmö recommends 256 parking spaces. At the construction of Koggen 2 a bigger amount of parking spaces for bicycles was chosen, 155 parking spaces. Still, it is a weakness of the certification system when the country specific recommendations are stricter than the requirements in the certification system.

Compared to other Swedish cities Malmö has quite high recommendations though for bicycle parking capacity. The city of Gothenburg, which has a similar climate as Malmö, has requirements of approximately 228 parking spaces for a location and building similar to Koggen 2 (Trafikkontoret, 2008). The municipality of Östersund, which is located over 1 000 km north of Malmö and therefore have a different climate, has requirements of 96 parking spaces for bicycles for a location and building similar to Koggen 2 (Östersunds kommun, 2007). From those examples it becomes clear that the requirement of 30 parking spaces is much lower than the recommendations from the Swedish cities.

The question if it is reasonable to assume that available parking spaces are fully used can be raised and alternative methods of taking transportation into account can be discussed. Commuting is not a natural part of the building, but since it has been shown to contribute to a big amount of emissions it is definitely relevant to include it in the certification system. An alternative method to calculate the emissions from commuting could be to interview the tenants of the building and in that way investigate the commuting patterns.

6.4.3 BREEAM and the Green Guide

The subcategory *Mat 1 – Materials Specification (Major Building Elements)* encourages using building materials that contribute to as low environmental impact as possible. In *BREEAM Europe Commercial 2009* two options can be chosen to evaluate the environmental impact of building materials. One option is the Green Guide, which is further described in Section 2.2.3. The other option is to use an embodied CO_2, energy or carbon foot printing tool to reach one BREEAM-credit, and to use a nationally recognised LCA tool to reach two BREEAM-credits (BRE Global, 2009). In the certification of Koggen 2 the Green Guide was used.

Since the Green Guide is developed in Britain it can be difficult to find Swedish building materials in the guide. The materials used in a Swedish construction project do not necessarily have to be produced in Sweden, but in the cases they are it can be discussed if the Green Guide is accurate enough, given that a British electricity mix is used. Moreover, materials that are imported from countries other than Great Britain also make the application of the Green Guide difficult.

In 2013 a new manual for Europe was released, *BREEAM International New Construction 2013* (BRE, 2013). This scheme will be used for new construction projects in Europe. For refurbishment, retail and industry the *BREEAM Europe Commercial 2009* manual remains (BREEAM, 2014). In the new scheme, the Green Guide is excluded and replaced with an LCA software tool. Different tools can be chosen but need to follow certain requirements. By excluding the Green Guide the issue with country specific data is solved.

6.4.4 District heating

District heating is used in densely built areas to distribute heat, but it can be based on different sources of energy (Bakalders & Block, 2009, p. 284). In the area where the buildings are situated district heating has been used for more than 50 years and almost 90 percent of the households use district heating for heating their homes (E.ON, 2013b). The division between energy sources used for district heating in Malmö can be seen in Appendix I.

The energy sources used for district heating vary in the world, but also in Sweden. To be able to compare the energy sources used, the average for Sweden can be seen in Appendix I. The choices of energy sources affect the amounts of emissions generated from district heating, which means that district heating as such is not a solution that generates fewer emissions. District heating in Malmö contributes to 0.15 kg $CO_{2,eq}$/kWh (E.ON, 2013a). This can be compared to district heating in Germany with a higher share of coal, which contributes to 0.224 kg $CO_{2,eq}$/kWh (PE International, 2012d). For the distribution between energy sources used for district heating in Germany, see Appendix I.

6.5 Green roofing and carbon dioxide emissions

A report by Saiz et al. (2006) describes the environmental benefits of a green roof by comparing a green roof with a conventional roof of an eight story residential building. The building is used for other purposes than Koggen 2 and is situated in Madrid, where a different climate prevails. Therefore the results of this report cannot be applied immediately for this study, but a discussion can be held about the effects of a green roof.

In the report by Saiz et al. (2006) the green roof results in a reduced solar absorption. This leads to a reduced need of cooling in the summer by 6 percent and a reduced need of energy by one percent annually. The report concludes that choosing a green roof reduces the emissions by 1 to 5.3 percent.

Another benefit from the green roof is the uptake of CO_2. The green roof is covered with various plants, which naturally extract CO_2 from the atmosphere (König et al., 1997). The reduction of CO_2 in the atmosphere that the green roof contributes to is not included in the study and is something that should be considered while looking at the results.

6.6 Fictive building and Kaggen

To be able to compare the results for Koggen 2, a fictive building is constructed. To reach a just comparison the fictive building is constructed as average as possible. BBR is used for energy matters, assumptions are made based on common solutions for office buildings and an existing building, Kaggen, is used as a reference building. The choice of Kaggen as a reference building and other choices can be discussed. Kaggen is situated at the same site as Koggen 2 and also constructed by NCC, which results in similar choices for the two buildings. Kaggen is a few years older than Koggen 2, which is relevant for instance when investigating energy matters. If other choices would have been made, the results would have been different.

It also needs to be considered that additional building materials potentially would have been necessary for the fictive building after calculations on the structure would have been made. These additional building materials would presumably cause an increase of emissions from the fictive building, since additional building elements would be necessary to bear the light weight Masonite roof.

6.7 German electricity grid mix and district heating

To present what difference it makes to choose German data instead of Swedish and also to show which effect the building would have had on the environment if it would have been built in Germany, a new model has been conducted where the Swedish electricity and district heating is changed to German. Other differences, such as climate differences, transportation distances and commuting habits are neglected.

In Figure 22 the total GHG emissions produced during the use phase of Koggen 2 and the fictive building, if they would have used the German electricity grid mix and German district heating, can be compared. Koggen 2 contributes to 43.2 kg $CO_{2,eq}$ per functional unit whereas the fictive building contribute to 52.7 kg $CO_{2,eq}$ per functional unit. If the results in Figure 22 are compared with the results in Figure 16, where the total GHG emissions from the use phase with Swedish electricity and district heating are calculated, a major increase of emissions can be seen in Figure 22. To use German electricity and German district heating instead of Swedish generates 2.1 times more GHG emissions for the entire use phase for Koggen 2 and 1.6 times more emissions for the fictive building.

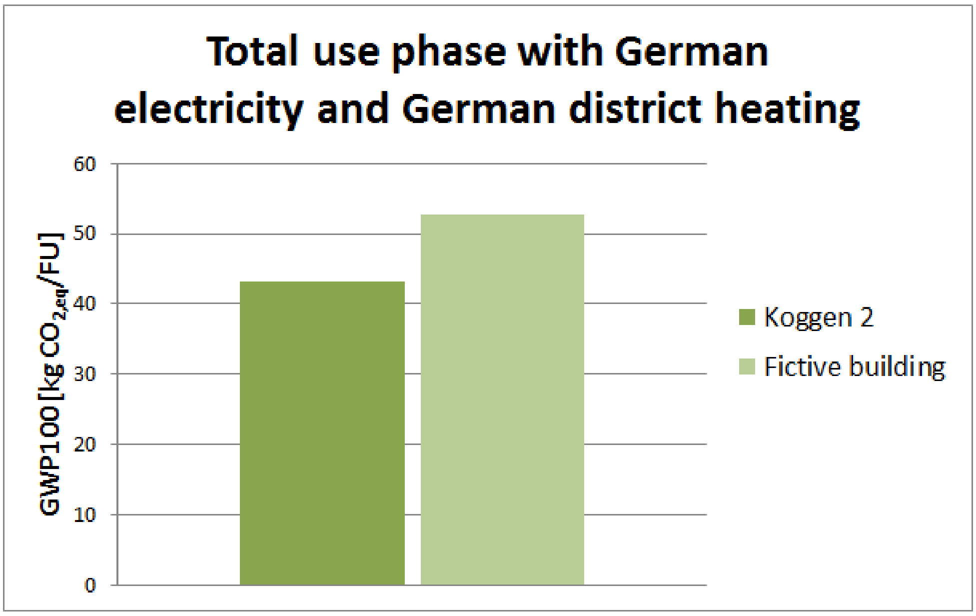


Figure 22: Total GHG emissions from the use phase of Koggen 2 and the fictive building. For Koggen 2 the Swedish electricity grid mix is changed to the German electricity grid mix. For the fictive building the Swedish electricity grid mix and Swedish district heating is changed to the German electricity grid mix and German district heating.

To distinguish where the biggest differences in emissions are found, the processes of the use phase for Koggen 2 and the fictive building are separated, see Figure 23. From this figure the increasing importance of operational electricity and heating is recognized. The major source of GHGs from commuting that can be seen in Figure 18, decreases when German electricity and German district heating is used. The advantages of the heat pumps concerning GHG emissions are also better shown in Figure 23, since the choice of electricity is equal for the two buildings. The only difference here when investigating heating, is the choice of district heating for the fictive building and heat pumps for Koggen 2.

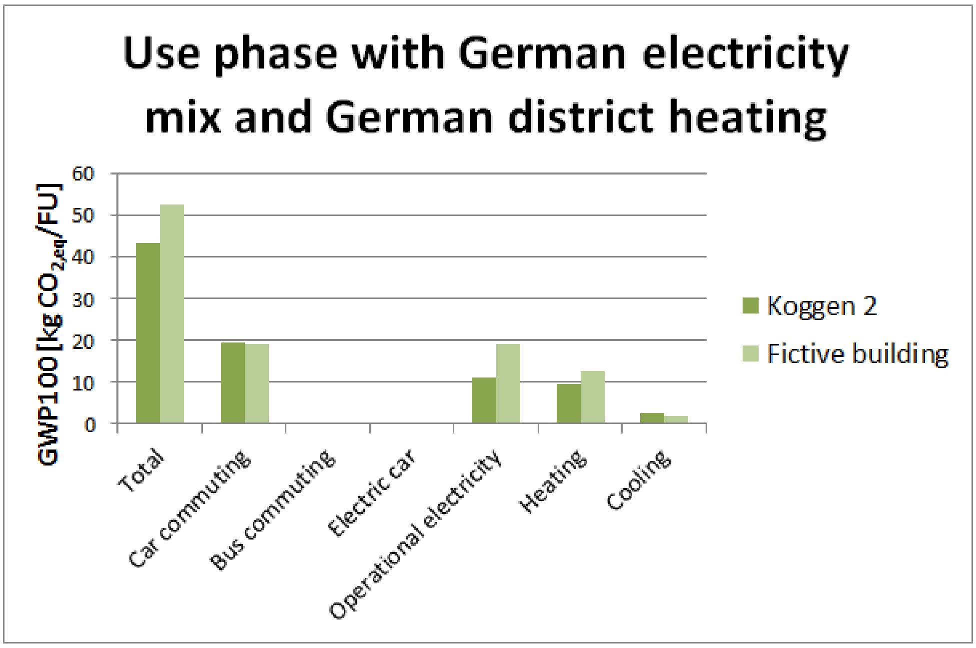


Figure 23: GHG emissions from the use phase of Koggen 2 and the fictive building, separated between the categories of processes. For Koggen 2 the Swedish electricity grid mix is changed to the German electricity grid mix. For the fictive building the Swedish electricity grid mix and Swedish district heating is changed to the German electricity grid mix and German district heating.

7 Conclusions and Recommendations

In the conclusion the results of the study are used to formulate an answer to the questions posed in the goal of the study. Furthermore, recommendations on how to proceed and suggestions of further studies are given.

7.1 Conclusions

The goal with this study is to understand the difference in GHG emissions between the two buildings and in that way learn how efficient the BREEAM certification system for newly constructed buildings is regarding reduction of GHG emissions. The study also aims at answering the question: Does environmental certifications of buildings contribute to a reduction in GHG emissions?

The results in Section 5.3 show that 22.0 kg $CO_{2,eq}/m^2 \cdot$year are generated from the certified building Koggen 2 and 33.8 kg $CO_{2,eq}/m^2 \cdot$year are generated from the non-certified, fictive building. The most emissions (61 percent) are generated from the fictive building. Furthermore the GHG emissions are significantly higher for the use phase, where 20.4 kg $CO_{2,eq}/m^2 \cdot$year are generated for Koggen 2 and 32.7 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building. This stands for 93 percent of the total emissions for Koggen 2 and 97 percent for the fictive building, which can be compared to other studies where around 80 percent of the GHG emissions can be allocated to the use phase. The emissions are higher for Koggen 2 than for the fictive building during the production phase (with 59 percent of the total emissions of 2.7 kg $CO_{2,eq}/m^2 \cdot$year from the production phase of the two buildings), but higher for the fictive building during the use phase (with 62 percent of the total emissions of 53.1 kg $CO_{2,eq}/m^2 \cdot$year from the use phase of the two buildings). Since the total emissions are significantly higher for the use phase, this phase is more important to investigate.

During the production phase the production of the external walls generates an absolute majority of the emissions, with 0.80 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 0.94 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building. This stands for 50 percent of the total emissions from the production phase for Koggen 2 and 85 percent for the fictive building. The roof constructions also generate relatively high amounts of emissions, (0.58 kg $CO_{2,eq}/m^2 \cdot$year for Koggen 2 and 0.07 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building) with the exception of the prefabricated lightweight Masonite roof. This stands for 36 percent of the total emissions from the production phase for Koggen 2 and 6 percent for the fictive building. The content of concrete in the construction elements is the main reason for the high amounts of emissions. For Koggen 2, production of concrete generates 0.96 kg $CO_{2,eq}/m^2 \cdot$year, which stands for 60 percent of the emissions from the production phase of this building.

Looking at the external walls, a conclusion can be reached that the prefabricated sandwich wall is the preferable choice from the perspective of CO_2 emissions. The transportation distance is longer for the prefabricated sandwich wall than for the external wall of the fictive building, but there are less material losses and fewer material components necessary.

The external wall is the biggest source of emissions during the production phase and therefore important to consider. On the other hand the normalized chart of the production phase, see Figure 14, concludes that the roof constructions imply the biggest difference between the two buildings when it comes to GHG emissions during the production phase. Therefore the choice of materials for the roof constructions is also important.

During the use phase commuting by car is the definitely biggest source of GHGs. Commuting stands for 19.5 kg $CO_{2,eq}/m^2 \cdot year$ for Koggen 2 and 19.1 kg $CO_{2,eq}/m^2 \cdot year$ for the fictive building, which means 96 percent of the total emissions from the use phase for Koggen 2 and 59 percent for the fictive building. Commuting is included in the study since it is part of the BREEAM certification. The difference between the two buildings is small and if this category would be excluded, the difference between the use phase and the production phase would be much smaller. The difference in emissions between Koggen 2 and the fictive building would still be similar to before.

Other processes that emit relatively big amounts of GHGs, at least for the fictive building, are heating, cooling and operational electricity. The Swedish electricity grid mix together with district heating and district cooling are used for the fictive building and hydro power, wind power and biomass power together with heat pumps are used for Koggen 2. Heating generates 0.253 kg $CO_{2,eq}/m^2 \cdot year$ for Koggen 2 and 8.4 kg $CO_{2,eq}/m^2 \cdot year$ for the fictive building, which stands for 1 percent of the total emissions from the use phase for Koggen 2 and 26 percent for the fictive building. Cooling generates 0.074 kg $CO_{2,eq}/m^2 \cdot year$ for Koggen 2 and 1.79 kg $CO_{2,eq}/m^2 \cdot year$ for the fictive building, which stands for 0.4 percent of the total emissions from the use phase for Koggen 2 and 5 percent for the fictive building. Finally, the operational electricity generates 0.29 kg $CO_{2,eq}/m^2 \cdot year$ for Koggen 2 and 3.33 kg $CO_{2,eq}/m^2 \cdot year$ for the fictive building, which stands for 1 percent of the total emissions from the use phase for Koggen 2 and 10 percent for the fictive building. The production of the heat pumps generates 0.119 kg $CO_{2,eq}/m^2 \cdot year$. These emissions together with the actual emissions from heating and cooling of Koggen 2 are still far lower than the alternative of not using the heat pumps, see Figure 19. A distinct difference can be seen between the two buildings, which indicates that energy efficiency together with smart energy choices is important.

Since the total emissions from Koggen 2 are significantly lower than from the fictive building, the conclusion can be drawn that the BREEAM certification system for newly constructed buildings is efficient regarding reduction of GHG emissions in the case of Koggen 2 compared to the fictive building. Guidance is given of what difference a BREEAM certification can contribute to concerning reduction of GHG emissions, but the results of the study are only specifically valid for the investigated buildings.

The methodology of the BREEAM certification system allows the person working with the certification to choose which credits to achieve for the building. This means that a certification in itself does not necessarily reduce the emissions, but is an incentive to do so. The categories generate different amounts of emissions and depending on the choices that are made, different amounts of GHG emissions are generated. Only two different constructions for external walls and three different roof constructions are investigated in this study. Other constructions would generate a different amount of emissions. The choice of energy sources and technology also affects the results. The question if environmental certifications of buildings contribute to a reduction of GHG emissions can therefore only be answered for BREEAM certifications and for Koggen 2.

The use of hydro power, wind power, biomass power and the Swedish electricity grid mix is relevant for the results of this study. If the British or German electricity grid mix would have been used, which is the case in several of the data sets in the databases integrated with GaBi, an increase of emissions of about six times would occur.

There are several different certification systems for buildings used in Sweden, for instance the Swedish certification system Miljöbyggnad (Heincke & Olsson, 2012). This system might be better to use in Sweden, to avoid issues related to country specific data and regulations. Miljöbyggnad is not investigated in this study though and the differences between the two systems can therefore not be defined.

The conclusions from the compared studies are similar, but the results vary to quite a large extent. The main reasons for this are the different processes and life cycle phases investigated, but also the different choices of energy and technologies used. Koggen 2 has comparably low energy consumption and uses electricity from energy sources with a low contribution of greenhouse gas emissions. The fictive building has more traditional energy consumption for Sweden and uses district heating, district cooling and the Swedish electricity grid mix, which also generates relatively low amounts of greenhouse gases. If the preconditions for the fictive building are alternated, the results will be different. If for instance the German electricity grid mix is used together with German district heating, the greenhouse gas emissions will be almost seven times bigger due to the choice of electricity and an additional almost two times bigger due to the choice of technology for heating (PE International, 2010a), (PE International, 2010j). This results in emissions of 52.7 kg $CO_{2,eq}/m^2 \cdot$year for the fictive building with the alternative choices, which shows what kind of difference the different choices can make and somewhat explains the different results from the investigated studies.

7.2 Recommendations

From the results and the conclusions certain recommendations can be made to the intended audience.

- If there are roof constructions that do not need more maintenance than concrete and have the same lifetime, an alternative without concrete is the preferable choice from an environmental perspective.
- Prefabricated external walls are in the case of these circumstances the preferable choice before constructions built on site.
- Commuting with car is a big emitter of GHGs. Carpooling, biking or public transportation are good alternatives for commuting. The importance of location is not directly shown in this study since the buildings are assumed to be located at the same location, but the high amounts of GHG emissions from commuting indirectly indicate the importance of this question.
- Since the environmental certification with BREEAM has shown to make a difference concerning GHG emissions for Koggen 2, this method is recommended from an environmental perspective. The economic perspective also needs to be considered before this method is chosen.

7.3 Further studies

To develop the study, more impact categories than GWP can be investigated. In that situation the BREEAM categories need to be evaluated again since some of them were excluded due to their lack of impact on GWP.

Another development of the study can be to add processes so that a complete LCA of the building is obtained. This would not just enable a comparison of the two buildings, but also generate figures of how big the effect from the buildings is on the environment.

References

Alexander, D. & Fairbridge, R. (1999): Encyclopedia of Environmental Science. Kluwer Academic Publishers, Dordrecht, Netherlands.

Ballast (2014). [online] Available at: http://www.ballastsverige.se/skicka-forfragan/Skane/ [Accessed 9 April 2014].

Baumann, H. & Tillman, A. (2004): The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application. Studentlitteratur AB, Lund, Sweden.

BE Group (2014). [online] Available at: http://www.begroup.com/sv/BE-Group-sverige/Produkter/Stal_ror/Sortiment/Halprofiler-VKRKKRVCKR/Halprofiler_VKR/ [Accessed 25 March 2014].

Bokalders, V. & Block, M. (2009): Byggekologi: Kunskaper för ett hållbart byggande. Svensk Byggtjänst, Stockholm, Sweden.

Boverket (2011): Boverkets byggregler, BBR: BBR 18, BFS 2011:6. Boverket, Karlskrona, Sweden.

BRE (2014). [online] Available at: http://www.bre.co.uk/greenguide/page.jsp?id=2069 [Accessed 27 February 2014].

BREEAM (2014). [online] Available at: http://www.breeam.org/page.jsp?id=633 [Accessed 12 May 2014].

BRE Global (2008): Methodology for Environmental Profiles of Construction Products. SD6050 Issue 1.0. [online] Available at: http://www.bre.co.uk/filelibrary/greenguide/PDF/Methodology_for_Environmental_Profiles_2008_SD6050.pdf [Accessed 23 May 2014].

BRE Global (2009): BREEAM Europe Commercial 2009 Assessor Manual, SD 5066A: issue 1.1. [online] Available at: http://www.breeam.org/filelibrary/Technical%20Manuals/BREEAM_Europe_Commercial_2009.pdf [Accessed 21 January 2014].

BRE Global (2013): BREEAM International New Construction 2013 Assessor Manual, SD 5075 issue 1.0. [online] Available at: http://www.breeam.org/BREEAMInt2013SchemeDocument/ [Accessed 8 May 2014].

Brunklaus, B., Thormark, C. & Baumann, H. (2010): Illustrating limitations of energy studies of buildings with LCA and actor analysis. Building Research & Information, Vol. 38, No. 3, 2010, pp. 266-280.

British Standards Institution (2011): PAS2050:2011, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

Burström, PG. (2007): Byggnadsmaterial – Uppbyggnad, tillverkning och egenskaper. Studentlitteratur AB, Lund, Sweden.

Cembrit (2012). [online] Available at: http://www.cembrit.se/Produkter-5895.aspx?ProductID=PROD1466 [Accessed 25 March 2014].

CEWEP (2006a): EU-27: Waste incineration of untreated wood (10,7% water content), GaBi-database Professional/Construction.

CEWEP (2006b): EU-27: Waste incineration of wood products (OSB, particle board), GaBi-database Professional/Construction.

COWI (2013a). [online] Available at: http://www.cowi.se/menu/Nyheter-och-medier/Nyheter/Pages/COWI-leder-svenska-BREEAM-ligan.aspx [Accessed 14 November 2013].

COWI (2013b): BREEAM-0043-8572: BREEAM Commercial 2009 Final Assessment Report – Koggen 2, Gothenburg, Sweden.

CPM database (1994): Treatment of hazardous waste from industries and municipalities [online] Available at: http://cpmdatabase.cpm.chalmers.se/Scripts/sheet.asp?ActId=1997-08-13848 [Accessed 27 March 2014].

CPM database (2000): Transport with a diesel bus. ESA-DBP [online] Available at: http://cpmdatabase.cpm.chalmers.se/Scripts/sheet.asp?ActId=KI-2010-09-06-211 [Accessed 28 February 2014].

Domone, P. & Illston, J. (2010): Construction Materials-Their nature and behaviour. Spon Press, Abingdon, Britain.

Egger (2008): DE: High density fibre board HDF, GaBi-database Professional/Construction.

Ene1a (2013): Energiberäkning, Effektbehovsberäkning, NCC. *Document included in reporting of BREEAM certification*.

Ene5a (2013): Intyg bra miljöval energi Sverige, Energi Försäljning Sverige AB. *Document included in reporting of BREEAM certification*.

Engström, B. (2007): Beräkning av betongkonstruktioner. Institutionen för bygg- och miljöteknik, Avdelningen för konstruktionsteknik, Chalmers Tekniska Högskola, Göteborg, Sweden.

E.ON (2013a). [online] Available at: http://www.eon.se/privatkund/Produkter-och-priser/Fjarrvarme/Miljovarden/ [Accessed 18 Mars 2014].

E.ON (2013b). [online] Available at: http://www.eon.se/varme-malmo [Accessed 12 May 2014].

Eternit (2009): DE: Fiber cement building board bluclad -Eternit, GaBi-database Professional/Construction.

Eurogypsum (2008): EU-27: Gypsum plasterboard, GaBi-database Professional/Construction.

Gyproc (2011). [online] Available at: http://www.gyproc.se/files/PDF/Sweden/PRI/PRI_ProfilesForAquaroc_SE.pdf [Accessed 25 March 2014].

Gyproc (2008b). [online] Available at: http://www.gyproc.se/files/PDF/Sweden/PRD/SE_GUEGUDataBlad.pdf [Accessed 25 March 2014].

Gyproc (2008a). [online] Available at: http://www.gyproc.se/produkter/gyproc+gipsskivor/standardgipsskivor/normal+tjocklek [Accessed 25 March 2014].

Gyproc (2014). [online] Available at: http://www.gyproc.se/g%C3%B6r+det+sj%C3%A4lv/produkter/v%C3%A4lj+r%C3%A4tt+st%C3%A5lprofiler/de+vanligaste+st%C3%A5lprofilerna/slitsad+regel [Accessed 25 March 2014].

Heincke, C. & Olsson, D. (2012): Simply GREEN – A quick guide to environmental and energy certification systems for sustainable buildings. Conny Nilsson, SWEGON AIR ACADEMY, Kvänum, Sweden.

Humbert, S., Abeck, H., Bali, N. & Horvath, A. (2007): Leadership in Energy and Environmental Design (LEED): A critical evaluation by LCA and recommendations for improvement. Int J LCA 12 (special issue 1) pp. 46-57.

Icopal (2011). [online] Available at: http://www.beijerbygg.se/wcsstore/BeijerCAS/HPMAssets/d120001/medias/docus/9/icopal_pb_akvaden_110413_130213_151319_0013.pdf [Accessed 25 March 2014].

International Organization for Standardization (2006): ISO 14040:2006 (E), Environmental management – Life cycle assessment – Principles and framework.

IPCC (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdon and New York, NY, USA. [online] Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf [Accessed 14 November 2013].

Isover (2008): DE: Glass wool insulation material – ISOVER, GaBi-database Professional/Construction.

Isover (2014). [online] Available at: http://www.isover.se/produkter/takisolering [Accessed 7 April 2014].

Josephson, PE. & Saukkoriipi, L. (2005): Slöseri I byggprojekt – Behov av förändrat synsätt [online] Available at: http://www.sbuf.se/documents/Rapport_Sloseri.pdf [Accessed 25 March 2014].

Junnila, S. (2004): The Environmental impact of an office building throughout its life cycle. Doctoral dissertation. Department of Civil and Environmental Engineering, Helsinki University of Technology Construction Economics and Management, Espoo, Finland.

Karlsson, S, Azar, C., Berndes, G., Homberg, J. & Lindgren, K. (1997): Man and Materials Flows – Towards sustainable materials management. Chalmers University of Technology & Göteborg University, Göteborg, Sweden.

Kraftringen (2011). [online] Available at: http://www.kraftringen.se/Om-Kraftringen/Miljo/Produkter-och-hallbarhet/Varme-och-kyla/Fjarrkyla/ [Accessed 18 Mars 2014].

Kruse, C. (2004): IIGCC Briefing Note; Climate Change and the Construction Sector.

König, H., Kohler, N., Kreiβig, J. & Lützkendorf, T. (2010): A life cycle approach to buildings: principles, calculations, design tools. Institut für internationale Architektur-Dokumentation GmbH & Co. KG, Munich, Germany.

Lättelement (2012). [online] Available at: http://lattelement.se/mediamaterial/Lattelement_miljodeklaration.pdf [Accessed 1 April 2014].

Malmö stadsbyggnadskontor (2010): Parkeringspolicy och parkeringsnorm – för bil, mc och cykel i Malmö [online] Available at: http://www.malmo.se/download/18.4027ea8b12af75326fc80003800/1383644417068/Parkeringspolicy+och+parkeringsnorm+slutligt+f%C3%B6rslag+antagen+av+KF.pdf [Accessed 18 February 2014].

Man3a (2013): Tabell elförbrukning total, NCC. *Document included in reporting of BREEAM certification*.

Miljödepartementet (2007): Förordning (2007:846) om fluorerade växthusgaser och ozonnedbrytande. [online] Available at: http://www.notisum.se/rnp/sls/lag/20070846.HTM [Accessed 16 May 2014].

Google maps (2014). [online] Available at: https://www.google.se/maps/preview [Accessed 24 March 2014].

NCC (2014). [online] Available at: http://www.ncc.se/sv/OM-NCC/ [Accessed 3 February 2014].

Outokumpu Stainless Steel (2011): RER: Stainless steel - Hot rolled coil, GaBi-database Professional/Construction.

Paroc (2012). [online] Available at: http://www.paroc.se/~/media/Files/Brochures/Sweden/Productcatalogue-Buildinginsulation-2012-SE.ashx [Accessed 26 March 2014].

PE International (2010a): DE: Electricity grid mix, GaBi-database Professional/Construction.

PE International (2010b): EU-27: Diesel mix at refinery, GaBi-database Professional/Construction.

PE International (2010c): EU-27: Heavy fuel oil at refinery (1.0wt.% S) , GaBi-database Professional/Construction.

PE International (2010d): FI: Electricity mix (energy carriers, generic), GaBi-database Professional/Construction.

PE International (2010e): GB: Electricity grid mix, GaBi-database Professional/Construction.

PE International (2010f): SE: Crude oil mix, GaBi-database Professional/Construction.

PE International (2010g): SE: Electricity from biomass (solid), GaBi-database Professional/Construction.

PE International (2010h): SE: Electricity from hydro power, GaBi-database Professional/Construction.

PE International (2010i): SE: Electricity from wind power, GaBi-database Professional/Construction.

PE International (2010j): SE: Electricity grid mix PE, GaBi-database Professional/Construction.

PE International (2010k): SE: Hard coal mix, GaBi-database Professional/Construction.

PE International (2010l): SE: Thermal energy from biomass (solid), GaBi-database Professional/Construction.

PE International (2011): GaBi Database and Modelling Principles. Version 5.0, Leinfelden, Echterdingen, Germany. [online] Available at: http://www.gabi-software.com/fileadmin/gabi/documentation5/GaBi_5_Modelling_Principles.pdf [Accessed 14 May 2014].

PE International (2012a): DE: Car petrol EURO 4 (EN15804 A4), GaBi-database Professional/Construction.

PE International (2012b): DE: Concrete C20/25, GaBi-database Professional/Construction.

PE International (2012c): DE: Construction waste dumping (EN15804 C4), GaBi-database Professional/Construction.

PE International (2012d): DE: District heating mix (EN15804 B6), GaBi-database Professional/Construction.

PE International (2012e): DE: Electrical heat pump (Water-Water) 20 kW (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012f): DE: Excavated soil with digger (EN15804 A5), GaBi-database Professional/Construction.

PE International (2012g): DE: Film for green roof (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012h): DE: Plastic profile SBR (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012i): DE: Prefabricated concrete ceiling, 40cm (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012j): DE: Prefabricated concrete wall, 12cm (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012k): DE: Steel profiles (I/U/H/L/T), GaBi-database Professional/Construction.

PE International (2012l): DE: Timber oak (12% moisture / 10.7% water content) (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012m): DE: Timber spruce (12% moisture / 10.7% water content) (EN15804 A1-A3), GaBi-database Professional/Construction.

PE International (2012n): EU-27: Commercial waste in municipal waste incinerator, GaBi-database Professional/Construction.

PE International (2012o): EU-27: Steel sheet EG, GaBi-database Professional/Construction.

PE International (2012p): GaBi 6 user manual. [online] Available at: http://www.gabi-software.com/fileadmin/GaBi_Manual/GaBi_6_manual.pdf [Accessed 4 February 2014].

PE International (2012q): GLO: Container ship, GaBi-database Professional/Construction.

PE International (2012r): GLO: Truck, GaBi-database Professional/Construction.

Plastics Europe (2003): RER: Polystyrene expandable granulate (EPS), GaBi-database Professional/Construction.

Ports (2014). [online] Available at: http://ports.com/sea-route/ [Accessed 15 April 2014].

Rockwool (2006): DE: Stone wool – Rockwool, GaBi-database Professional/Construction.

Saiz, S., Kennedy, S., Bass, B. & Pressnail, K. (2006): Comparative Life Cycle Assessment of Standard and Green Roofs. Environmental Science & Technology, Vol. 40, No. 13, 2006, pp. 4312-4316.

Samaras, C. & Meisterling, K. (2008): Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy. Environmental Science & Technology, Vol. 42, No. 9, 2008, pp. 3170-3176.

Schiermeier, Q., Tollefson, J., Scully, T., Witze, A. & Morton, O. (2008): Energy alternatives: Electricity without carbon. Nature, Vol. 454, pp. 816 – 823.

Shell (2013): New Lens Scenarios by Shell – A shift in perspective for a world in transition (2013).

SITA (2014). [online] Available at: http://www.sita.se/sv-SE/Guider--Hjalp/Kallsortera/ [Accessed 12 Mars 2014].

Svensk fjärrvärme (2014): [online] Available at: http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/ [Accessed 8 Mars 2014].

Trafikanalys, Sveriges officiella statistik (2013): RVU Sverige – den nationella resvaneundersökningen 2011-2012, [online] Available at: http://www.trafa.se/Statistik/Resvanor/ [Accessed 18 February 2014].

Trafikkontoret (2008): Förslag till Göteborgs cykelparkeringsriktlinje samt underlag för dimensionering. Göteborg, Sweden.

United Nations Environment Programme (2007): Buildings and climate change – Status, Challenges and Opportunities.

Ürge-Vorsatz, D., Danny Harvey, L.D., Mirasgedis, S. & Levine, M. (2011): Mitigation CO_2 emissions from energy use in the world's buildings.

Veg Tech (2010). [online] Available at: http://denklokarevillan.com/Takbel%C3%A4ggning,%20VegTech,%20Xeroflor%C2%AE%20Moss%20Sedummatta,%20BVD.pdf [Accessed 7 April 2014].

Veg Tech (2012). [online] Available at: http://denklokarevillan.com/Takdetalj,%20VegTech%20Kantavslut%20med%20ek,%20BVD.pdf [Accessed 7 April 2014].

Wallhagen, M., Glaumann, M. & Malmqvist, T. (2011): Basic building life cycle calculations to decrease contribution to climate change – Case study on an office building in Sweden. Building and Environment, Vol. 46, 2011, pp. 1863-1871.

World Commission on Environment and Development (1987): Our Common Future. [online] Available at: http://www.un-documents.net/our-common-future.pdf [Accessed 27 May 2014].

Wst1a (2011): Avfallsplan för Koggen 2, Malmö, NCC. *Document included in reporting of BREEAM certification*.

Wst1b (2013): Technical checklist A15b, NCC. *Document included in reporting of BREEAM certification*.

Östersunds kommun (2007): Parkeringstal för Östersunds kommun. Östersund, Sweden.

Appendices

Appendix A – Greenhouse gases and characterization factors

In Table A.1 the GHGs that contribute to GWP is listed together with the chemical formulas and the characterization factors for GWP for 100 years relative to CO_2.

Table A.1: GHGs and characterization factors for GWP for 100 years relative to CO_2 (IPCC, 2007, p. 33-34).

Industrial designation	Chemical formula	Charact-erization factors GWP100
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Substances controlled by the Montreal Protocol		
CFC-11	CCl_3F	4 750
CFC-12	CCl_2F_2	10 900
CFC-13	$CClF_3$	14 400
CFC-113	CCl_2FCClF_2	6 130
CFC-114	$CClF_2CClF_2$	10 000
CFC-115	$CClF_2CF_3$	7 370
Halon-1301	$CBrF_3$	7 140
Halon-1211	$CBrClF_2$	1 890
Halon-2402	$CBrF_2CBrF_2$	1 640
Carbon tetrachloride	CCl_4	1 400
Methyl bromide	CH_3Br	5
Methyl chloroform	CH_3CCl_3	146
HCFC-22	$CHClF_2$	1 810
HCFC-123	$CHCl_2CF_3$	77
HCFC-124	$CHClFCF_3$	609
HCFC-141b	CH_3CCl_2F	725
HCFC-142b	CH_3CClF_2	2 310
HCFC-225ca	$CHCl_2CF_2CF_3$	122
HCFC-225cb	$CHClFCF_2CClF_2$	595
Hydrofluorocarbons		
HFC-23	CHF_3	14 800
HFC-32	CH_2F_2	675
HFC-125	CHF_2CF_3	3 500
HFC-134a	CH_2FCF_3	1 430
HFC-143a	CH_3CF_3	4 470
HFC-152a	CH_3CHF_2	124
HFC-227ea	CF_3CHFCF_3	3 220

HFC-236fa	$CF_3CH_2CF_3$	9 810
HFC-245fa	$CHF_2CH_2CF_3$	1 030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640
Perfluorinated compounds		
Sulphur hexafluoride	SF_6	22 800
Nitrogen trifluoride	NF_3	17 200
PFC-14	CF_4	7 390
PFC-116	C_2F_6	12 200
PFC-218	C_3F_8	8 830
PFC-318	$c\text{-}C_4F_8$	10 300
PFC-3-1-10	C_4F_{10}	8 860
PFC-4-1-12	C_5F_{12}	9 160
PFC-5-1-14	C_6F_{14}	9 300
PFC-9-1-18	$C_{10}F_{18}$	>7 500
Trifluoromethyl sulphur pentafluoride	SF_5CF_3	17 700
Fluorinated ethers		
HFE-125	CHF_2OCF_3	14 900
HFE-134	CHF_2OCHF_2	6 320
HFE-143a	CH_3OCF_3	756
HCFE-235da2	$CHF_2OCHClCF_3$	350
HFE-245cb2	$CH_3OCF_2CHF_2$	708
HFE-245fa2	$CHF_2OCH_2CF_3$	659
HFE-254cb2	$CH_3OCF_2CHF_2$	359
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	575
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	580
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	110
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	297
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	59
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	1 870
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	2 800
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	1 500
Perfluoropolyethers		
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	10 300
Hydrocarbons and other compounds – Direct Effects		
Dimethylether	CH_3OCH_3	1
Methylene chloride	CH_2Cl_2	8.7
Methyl chloride	CH_3Cl	13

Appendix B – BREEAM categories with subcategories

In the following appendix the BREEAM categories and subcategories are described and defined. Available and achieved credits for the BREEAM certified building Koggen 2 can also be found.

B.1 List of BREEAM categories and subcategories

In Table B.1 the categories and subcategories included in the manual *BREEAM Europe Commercial 2009* are listed together with available and achieved credits for Koggen 2.

Table B.1: BREEAM categories with subcategories included in the manual *BREEAM Europe Commercial 2009*, available credits and achieved credits for Koggen 2 (Based on BRE Global, 2009 and COWI, 2013b).

BREEAM CATEGORIES AND SUBCATEGORIES	CREDITS AVAILABLE	CREDITS ACHIEVED
MANAGEMENT:		
Man 1 - Commissioning	2	1
Man 2 - Constructors' environmental and social code of conduct	2	2
Man 3 - Construction site impacts	4	3
Man 4 - Building user guide	1	1
Man 12 - Life Cycle Cost Analysis	2	2
HEALTH AND WELLBEING:		
Hea 1 - Daylight	1	1
Hea 2 - View out	1	1
Hea 3 - Glare control	1	1
Hea 4 - High frequency lighting	1	1
Hea 5 - Internal and external lighting levels	1	1
Hea 6 - Lighting zones and controls	1	1
Hea 7 - Potential for natural ventilation	1	0
Hea 8 - Indoor air quality	1	1
Hea 9 - Volatile organic compounds	1	1
Hea 10 - Thermal comfort	2	2
Hea 11 - Thermal zoning	1	1
Hea 12 - Microbial contamination	1	1
Hea 13 - Acoustic performance	1	0
Hea 14 - Office space	0	0
ENERGY:		
Ene 1 - Energy Efficiency	15	10
Ene 2 - Sub-metering of substantial energy uses	1	1
Ene 3 - Sub-metering of high energy load and tenancy areas	1	0
Ene 4 - External lighting	1	1
Ene 5 - Low or zero carbon technologies	3	3

Ene 6 - Building fabric performance and avoidance of air infiltration	0	0
Ene 7 - Cold storage	0	0
Ene 8 - Lifts	2	2
Ene 9 - Escalators and travelling walkways	1	0
Transport:		
Tra 1 - Provision of public transport	2	2
Tra 2 - Proximity to amenities	1	1
Tra 3 - Alternative modes of transport	2	2
Tra 4 - Pedestrian and cyclist safety	1	1
Tra 5 - Travel plan	1	1
Tra 6 - Maximum car parking capacity	2	2
Tra 7 - Travel information point	0	0
Tra 8 - Deliveries and manoeuvring	0	0
WATER:		
Wat 1 - Water consumption	3	1
Wat 2 - Water meter	1	1
Wat 3 - Major leak detection	1	1
Wat 4 - Sanitary supply shut off	1	0
Wat 6 - Irrigation systems	1	1
Wat 7 - Vehicle wash	0	0
Wat 8 - Sustainable on-site water treatment	2	0
MATERIALS:		
Mat 1 - Materials specification (major building elements)	4	1
Mat 2 - Hard landscaping and boundary protection	1	1
Mat 3 - Re-use of facade	1	0
Mat 4 - Re-use of structure	1	0
Mat 5 - Responsible sourcing of materials	3	1
Mat 6 - Insulation	2	2
Mat 7 - Designing for robustness	1	1
WASTE:		
Wst 1 - Construction site waste management	3	3
Wst 2 - Recycled aggregates	1	0
Wst 3 - Recyclable waste storage	1	1
Wst 4 - Compactor / Baler	0	0
Wst 5 - Composting	1	0
Wst 6 - Floor finishes	1	1
LAND USE AND ECOLOGY:		
LE 1 - Reuse of land	1	1
LE 2 - Contaminated land	1	1
LE 3 - Ecological value of site and protection of ecological features	1	1

LE 4 - Mitigating ecological impact	5	3
LE 6 - Long term impact on biodiversity	2	2
POLLUTION:		
Pol 1 - Refrigerant GWP - Building services	1	0
Pol 2 - Preventing refrigerant leaks	2	0
Pol 3 - Refrigerant GWP - Cold storage	0	0
Pol 4 - NOx emissions from heating source	3	3
Pol 5 - Flood risk	3	2
Pol 6 - Minimising watercourse pollution	1	1
Pol 7 - Reduction of night time light pollution	1	1
Pol 8 - Noise attenuation	1	1
INNOVATION:		
Inn 1 - Innovation	10	3

B.2 Description of categories and subcategories

To be able to evaluate the importance of each BREEAM category and subcategory, concerning GHG emissions, they need to be defined. This is done in Section B.2.1 to Section B.2.10.

B.2.1 Management

The *Management* category includes five subcategories where the three main ones are *Commissioning*, *Construction site impacts* and *Building user guide*.

- The aim of the subcategory *Commissioning* is to get optimal performance of the systems in the building and to get the right amount of building service (BRE Global, 2009, p. 43).
- The subcategory *Construction site impacts* aims at investigating resource use, pollution and energy consumption during the production phase and how these areas are handled from an environmental point of view (BRE Global, 2009, p. 50).
- The subcategory *Building user guide* aims at providing a guide for the users of the building to enable efficient operation of it (BRE Global, 2009, p. 53).

B.2.2 Health and Wellbeing

The *Health and Wellbeing* category includes 14 subcategories where the five main ones are *Daylight*, *Occupant thermal comfort*, *Acoustics*, *Indoor air and water quality* and *Lighting* (BRE Global, 2009, pp. 60-100).

- The aim of the subcategory *Daylight* is to give the users of the building the possibility of getting exposed to daylight while being in the building (BRE Global, 2009, p. 60).

- The subcategory *Occupant thermal comfort* aims at providing a good level of thermal comfort in the indoor environment (BRE Global, 2009, p. 86).
- The subcategory *Acoustics* aims at providing an acoustic performance suitable for the specific building (BRE Global, 2009, p. 95).
- The subcategory *Indoor air and water quality* aims at providing air and water of good quality to the indoor environment, free of for instance waterborne bacteria such as *Legionella* (BRE Global, 2009, pp. 80-92).
- The subcategory *Lighting* aims at providing comfortable lighting that does not create health risks due to for instance flickering (BRE Global, 2009, pp. 70-72).

B.2.3 Energy

The *Energy* category includes nine subcategories where the four main ones are *CO_2 emissions*, *Low or zero carbon technologies*, *Energy sub metering* and *Energy efficient building systems* (BRE Global, 2009, p. 14).

- The aim of the subcategory *CO_2 emissions* is to reduce the environmental load, in the form of CO_2 emissions, from the building.
- The subcategory *Low or zero carbon technologies* aims at choosing renewable, locally produced energy to be able to reduce emissions (BRE Global, 2009, p. 118).
- The subcategory *Energy sub metering* aims at documentation of energy consumption (BRE Global, 2009, pp. 110-113).
- The subcategory *Energy efficient building systems* aims at minimising the buildings energy consumption (BRE Global, 2009, p. 101).

B.2.4 Transport

The *Transport* category includes eight subcategories where the four main ones are *Public transport network connectivity*, *Pedestrian and Cyclist facilities*, *Access to amenities* and *Travel plans and information*.

- The aim of the subcategories *Public transport network connectivity*, *Pedestrian and Cyclist facilities* and *Access to amenities* is to reduce emissions from traffic by encouraging the development of public transport and alternative modes of transport (BRE Global, 2009, pp. 134-141).
- The subcategory *Travel plans and information* aims at facilitating the use of public transport for the users of the building (BRE Global, 2009, pp. 152-156).

B.2.5 Water

The *Water* category includes seven subcategories where the three main ones are *Water consumption*, *Leak detection* and *Water re-use and recycling*.

- The aim of all of these subcategories is to minimize water usage (BRE Global, 2009, pp. 160-179).

B.2.6 Materials

The *Materials* category includes seven subcategories where the four main ones are *Embodied life cycle impact of materials*, *Materials re-use*, *Responsible sourcing* and *Robustness*.

- The aim of the subcategory *Embodied life cycle impact of materials* is to encourage the use of materials with as small environmental impact as possible (BRE Global, 2009, p. 180). This can be done by using The Green Guide, an environmental rating system for building materials, which is further described in Section 2.2.3. Alternatively, an embodied CO_2, energy or carbon foot printing tool or a nationally recognised LCA tool can be used (BRE, 2014).
- The subcategory *Materials re-use* aims at encouraging re-use of façade material and existing structures (BRE Global, 2009, pp. 191-194).
- The subcategories *Responsible sourcing* and *Robustness* aim at purchasing materials in a responsible manner and at designing in a way that contributes to less material damage (BRE Global, 2009, pp. 195-211).

B.2.7 Waste

The *Waste* category includes six subcategories where the three main ones are *Construction waste*, *Recycled aggregates* and *Recycling facilities*.

- The aim of the subcategory *Construction waste* is to encourage resource efficiency concerning construction site waste (BRE Global, 2009, p. 213).
- The subcategories *Recycled aggregates* and *Recycling facilities* aim at encouraging recycling and the use of recycled materials (BRE Global, 2009, pp. 219-222).

B.2.8 Land use and Ecology

The *Land use and Ecology* category includes five subcategories where the three main ones are *Site selection*, *Protection of ecological features* and *Mitigation/enhancement of ecological value*.

- The aim of the subcategory *Site selection* is to encourage reuse of already developed land and contaminated land (BRE Global, 2009, pp. 232-234).
- The subcategories *Protection of ecological features* and 'Mitigation/enhancement of ecological value' aim at protecting the existing ecology on site during the building phases (BRE Global, 2009, pp. 238-242).

B.2.9 Pollution

The *Pollution* category includes eight subcategories where the five main ones are *Refrigerant use and leakage*, *Flood risk*, *NO_x emissions*, *Watercourse pollution* and *External light and noise pollution*.

- The aim of the subcategory *Refrigerant use and leakage* is to reduce the amounts of refrigerants used and leaked to the atmosphere because of their high GWP (BRE Global, 2009, pp. 251-255).
- The subcategory *Flood risk* aims at taking measures to support buildings in vulnerable flooding areas and to support development in areas without risk of flooding (BRE Global, 2009, p. 268).
- The subcategory *NO_x emissions* aim at reducing the NO_x emissions from the heating system.
- The subcategory *Watercourse pollution* aims at reducing water run-off from buildings containing chemicals, metals, silt and oil pollution (BRE Global, 2009, p. 275).
- The subcategory *External light and noise pollution* aims at reducing disturbing noises and light during night time (BRE Global, 2009, pp. 279-283).
- The aim of the subcategories *Exemplary performance levels* and *Use of BREEAM accredited professionals* is to encourage innovation in the field of sustainability.

B.2.10 Innovation

The *Innovation* category includes two subcategories: ‘Exemplary performance levels’ and *Use of BREEAM accredited professionals*.

- The aim of the subcategories *Exemplary performance levels* and *Use of BREEAM accredited professionals* is to encourage innovation in the field of sustainability.

Appendix C – External inventory data sets

When data is missing in the databases Professional and Construction, integrated in the software tool GaBi, external data sets is collected. The data sets can be seen in Table C.1 to Table C.7.

In the third column from the left the information is documented as it is collected. In the fourth column from the left the data has been normalized per activity and in the fifth column from the left the flows have been normalized per functional unit. The bold flows are linked flows and the rest are flows passing the system boundary.

C.1 District cooling

Table C.1 shows input flows and output flows from the process district cooling.

Table C.1: Inventory data set for district cooling (Based on E.ON, 2013a & PE International, 2010j).

Activity: District cooling	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
		[%]	*[MJ]*	*[kWh/m²·yr]*
Nuclear	Resource	38.910	8.26E-01	3.444
Peat	Resource	5.00E-01	1.06E-02	4.43E-02
Hard coal	Resource	6.90E-01	1.47E-02	6.11E-02
Coal gases	Resource	6.40E-01	1.36E-02	5.66E-02
Natural gas	Resource	1.940	4.12E-02	1.72E-01
Heavy fuel oil	Resource	1.190	2.53E-02	1.05E-01
Biomass	Resource	6.900	1.47E-01	6.11E-01
Biogas	Resource	1.50E-01	3.19E-03	1.33E-02
Waste	Resource	1.970	4.18E-02	1.74E-01
Hydro	Resource	44.750	9.50E-01	3.960
Wind	Resource	2.360	5.01E-02	2.09E-01
Photovoltaic	Resource	1.00E-02	2.12E-04	8.85E-04
Output flows				
				[/m²·yr]
Cooling *[kWh]*	Energy	**1**	1	**15**
$CO_{2,eq}$ *[g]*	Emissions to air	75	75	1 125

C.2 District heating

Table C.2 shows input flows and output flows from the process district heating.

Table C.2: Inventory data set for district heating (Based on E.ON, 2013a).

Activity: District heating	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
		[%]	*[MJ]*	*[kWh/m²·yr]*
Natural gas	Resource	32.900	5.09E-01	4.951
Waste	Resource	59.500	9.21E-01	8.955
Heat from heat pump	Resource	4.00E-01	6.19E-03	6.02E-02
Electricity to heat pump	Resource	1.00E-01	1.55E-03	1.51E-02
Electricity	Resource	1.500	2.32E-02	2.26E-01
Waste heat	Resource	4.000	6.19E-02	6.02E-01
Flue gas condensation	Resource	1.200	1.86E-02	1.81E-01
Output flows				
				[/m²·yr]
Heat *[kWh]*	Energy	**1**	1	**35**
$CO_{2,eq}$ *[g]*	Emissions to air	150	150	5 250

C.3 Transport of people with diesel bus

Table C.3 shows input flows and output flows from the process transportation of people with diesel bus.

Table C.3: Inventory data set for diesel bus (Based on CPM database, 2000)

Activity: Transport of people with diesel bus	**Flow type**	**Data as collected**	**Normalized per activity**	**Flows, normalized per F.U.**
Input flows				
		[/veh.km]	*[/person km]*	*[/$m^2 \cdot yr$]*
Oil *[MJ]*	Refined resource	18.700	0.312	79.475
Output flows				
		[veh. km]	*[person km/ veh. km]*	*[person km/ $m^2 \cdot yr$]*
Distance	Distance	**1**	0.0167	**4.250**
		[g]	*[/person km]*	*[/$m^2 \cdot yr$]*
CH_4 *[g]*	Emissions to air	0.0350	0.000583	0.149
CO_2 *[g]*	Emissions to air	1250.000	20.833	5312.500
N_2O *[g]*	Emissions to air	0.00230	0.0000383	0.0098
NO_x *[g]*	Emissions to air	6.120	0.102	26.010
Particles *[g]*	Emissions to air	0.0314	0.000523	0.133

C.4 Transport of people with electric car

Table C.4 shows input flows and output flows from the process transportation of people with electric car.

Table C.4: Inventory data set for electric car (Based on Samaras & Meisterling, 2008 & PE International, 2010j).

Activity: Transport of people with electric car	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
		[%]	*[MJ/veh.km]*	*[kWh/m²·yr]*
Nuclear	Resource	38.910	2.80E-01	2.88E-01
Peat	Resource	5.00E-01	3.60E-03	3.70E-03
Hard coal	Resource	6.90E-01	4.97E-03	5.11E-03
Coal gases	Resource	6.40E-01	4.61E-03	4.74E-03
Natural gas	Resource	1.940	1.40E-02	1.44E-02
Heavy fuel oil	Resource	1.190	8.57E-03	8.81E-03
Biomass	Resource	6.900	4.97E-02	5.11E-02
Biogas	Resource	1.50E-01	1.08E-03	1.11E-03
Waste	Resource	1.970	1.42E-02	1.46E-02
Hydro	Resource	44.750	3.22E-01	3.31E-01
Wind	Resource	2.360	1.70E-02	1.75E-02
Photovoltaic	Resource	1.00E-02	7.20E-05	7.40E-05
Output flows				
				[km/m²·yr]
Vehicle km *[km]*	Distance	**1**	1	**3.7**

C.5 Roof: Light weight element Masonite Koggen 2

Table C.5 shows input flows and output flows from the process Light weight Masonite roof for Koggen 2.

Table C.5: Inventory data set for Light weight Masonite roof for Koggen 2 (Based on Lättelement, 2012).

Activity: Light weight Masonite roof - Koggen 2	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
			[/building]	*[/$m^2 \cdot yr$]*
Oil *[MJ/m^2]*	Resources	75.140	51 395.760	1.28E-01
Diesel *[MJ/m^2]*	Resources	3.750	2 565.000	6.41E-03
Biomass *[MJ/m^2]*	Resources	44.250	30 267.000	7.57E-02
Biomass (round wood) *[MJ/m^2]*	Resources	90.000	61 560.000	1.54E-01
Biomass (natural gas) *[MJ/m^2]*	Resources	76.936	52 624.224	1.32E-01
Primary electricity *[MJ/m^2]*	Resources	124.330	85 041.720	2.13E-01
Coal *[MJ/m^2]*	Resources	1.75E-02	11.970	0.0000299
Output flows				
			[/building]	*[/$m^2 \cdot yr$]*
Light weight Masonite roof element *[m^2]*	Materials	**1**	684	**1.71E-03**
Dust *[kg/m^2]*	Emissions to air	4.61E-02	31.532	7.88E-05
Carbon dioxide *[kg/m^2]*	Emissions to air	9.847	6 735.348	1.68E-02
Carbon monoxide *[kg/m^2]*	Emissions to air	1.08E-01	73.530	1.84E-04
Hydrocarbons *[kg/m^2]*	Emissions to air	2.85E-02	19.494	4.87E-05
Nitrogen oxides *[kg/m^2]*	Emissions to air	5.03E-02	34.405	8.60E-05
Sulphur dioxide *[kg/m^2]*	Emissions to air	1.35E-02	9.234	2.31E-05
VOCs from wood *[kg/m^2]*	Emissions to air	9.50E-03	6.498	1.62E-05
VOCs from other *[kg/m^2]*	Emissions to air	1.00E-04	6.84E-02	1.71E-07
Hydrogen chloride *[kg/m^2]*	Emissions to air	2.00E-04	1.37E-01	3.42E-07
Methane *[kg/m^2]*	Emissions to air	9.00E-04	6.16E-01	1.54E-06
Formaldehyde *[kg/m^2]*	Emissions to air	3.80E-03	2.599	6.50E-06
Organic acids from wood *[kg/m^2]*	Emissions to air	8.00E-03	5.472	1.37E-05
Phenol *[kg/m^2]*	Emissions to air	3.20E-03	2.189	5.47E-06
Suspended solids *[kg/m^2]*	Emissions to water	6.30E-03	4.309	1.08E-05

Biological oxygen demand (BOD) *[kg/m^2]*	Emissions to water	1.03E-01	70.110	1.75E-04
Chemical oxygen demand (COD) *[kg/m^2]*	Emissions to water	2.26E-01	154.584	3.86E-04
Total organic carbon (TOC) *[kg/m^2]*	Emissions to water	1.00E-04	6.84E-02	1.71E-07
Nitrogen *[kg/m^2]*	Emissions to water	8.00E-04	5.47E-01	1.37E-06
Chloride *[kg/m^2]*	Emissions to water	2.30E-03	1.573	3.93E-06
Fluorine *[kg/m^2]*	Emissions to water	0.00E+00	0.00E+00	0.00E+00
Phosphorus *[kg/m^2]*	Emissions to water	2.00E-04	1.37E-01	3.42E-07
Sulfate *[kg/m^2]*	Emissions to water	1.00E-04	6.84E-02	1.71E-07
Phenolic substance *[kg/m^2]*	Emissions to water	2.00E-04	1.37E-01	3.42E-07
Metals *[kg/m^2]*	Emissions to water	5.00E-02	34.200	8.55E-05
Mineral waste (gravel) *[kg/m^2]*	Emissions to soil	3.25E-02	22.230	5.56E-05
Ash *[kg/m^2]*	Emissions to soil	1.23E-01	83.790	2.09E-04
Industrial waste *[kg/m^2]*	Emissions to soil	2.69E-01	184.270	4.61E-04
Hazardous waste *[kg/m^2]*	Emissions to soil	5.00E-03	3.420	8.55E-06
Waste bark *[kg/m^2]*	Emissions to soil	2.50E-02	17.100	4.28E-05

C.6 Roof: Light weight element Masonite Fictive building

Table C.6 shows input flows and output flows from the process Light weight Masonite roof for the fictive building.

Table C.6: Inventory data set for Light weight Masonite roof for the fictive building (Based on Lättelement, 2012).

Activity: Light weight Masonite roof - Fictive building	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
			[/building]	*[/m^2· yr]*
Oil *[MJ/m^2]*	Resources	75.140	103 693.200	2.59E-01
Diesel *[MJ/m^2]*	Resources	3.750	5 175.000	1.29E-02
Biomass *[MJ/m^2]*	Resources	44.250	61 065.000	1.53E-01
Biomass (round wood) *[MJ/m^2]*	Resources	90.000	124 200.000	3.11E-01
Biomass (natural gas) *[MJ/m^2]*	Resources	76.936	106 171.680	2.65E-01
Primary electricity *[MJ/m^2]*	Resources	124.330	171 575.400	4.29E-01
Coal *[MJ/m^2]*	Resources	1.75E-02	24.150	0.0000604
Output flows				
			[/building]	*[/m^2· yr]*
Light weight Masonite roof element *[m^2]*	Materials	**1**	1 380	**3.45E-03**
Dust *[kg/m^2]*	Emissions to air	4.61E-02	63.618	1.59E-04
Carbon dioxide *[kg/m^2]*	Emissions to air	9.847	13 588.860	3.40E-02
Carbon monoxide *[kg/m^2]*	Emissions to air	1.08E-01	148.350	3.71E-04
Hydrocarbons *[kg/m^2]*	Emissions to air	2.85E-02	39.330	9.83E-05
Nitrogen oxides *[kg/m^2]*	Emissions to air	5.03E-02	69.414	1.74E-04
Sulphur dioxide *[kg/m^2]*	Emissions to air	1.35E-02	18.630	4.66E-05
VOCs from wood *[kg/m^2]*	Emissions to air	9.50E-03	13.110	3.28E-05
VOCs from other *[kg/m^2]*	Emissions to air	1.00E-04	1.38E-01	3.45E-07
Hydrogen chloride *[kg/m^2]*	Emissions to air	2.00E-04	2.76E-01	6.90E-07
Methane *[kg/m^2]*	Emissions to air	9.00E-04	1.242	3.11E-06
Formaldehyde *[kg/m^2]*	Emissions to air	3.80E-03	5.244	1.31E-05
Organic acids from wood *[kg/m^2]*	Emissions to air	8.00E-03	11.040	2.76E-05
Phenol *[kg/m^2]*	Emissions to air	3.20E-03	4.416	1.10E-05
Suspended solids *[kg/m^2]*	Emissions to water	6.30E-03	8.694	2.17E-05

Biological oxygen demand (BOD) *[kg/m²]*	Emissions to water	1.03E-01	141.450	3.54E-04
Chemical oxygen demand (COD) *[kg/m²]*	Emissions to water	2.26E-01	311.880	7.80E-04
Total organic carbon (TOC) *[kg/m²]*	Emissions to water	1.00E-04	1.38E-01	3.45E-07
Nitrogen *[kg/m²]*	Emissions to water	8.00E-04	1.104	2.76E-06
Chloride *[kg/m²]*	Emissions to water	2.30E-03	3.174	7.94E-06
Fluorine *[kg/m²]*	Emissions to water	0.00E+00	0.00E+00	0.00E+00
Phosphorus *[kg/m²]*	Emissions to water	2.00E-04	2.76E-01	6.90E-07
Sulfate *[kg/m²]*	Emissions to water	1.00E-04	1.38E-01	3.45E-07
Phenolic substance *[kg/m²]*	Emissions to water	2.00E-04	2.76E-01	6.90E-07
Metals *[kg/m²]*	Emissions to water	5.00E-02	69.000	1.73E-04
Mineral waste (gravel) *[kg/m²]*	Emissions to soil	3.25E-02	44.850	1.12E-04
Ash *[kg/m²]*	Emissions to soil	1.23E-01	169.050	4.23E-04
Industrial waste *[kg/m²]*	Emissions to soil	2.69E-01	371.772	9.29E-04
Hazardous waste *[kg/m²]*	Emissions to soil	5.00E-03	6.900	1.73E-05
Waste bark *[kg/m²]*	Emissions to soil	2.50E-02	34.500	8.63E-05

C.7 Treatment of hazardous waste

Table C.7 shows input flows and output flows from the process Treatment of hazardous waste.

Table C.7: Inventory data set for treatment of hazardous waste (Based on CPM database, 1994)

Activity: Treatment of hazardous waste	Flow type	Data as collected	Normalized per activity	Flows, normalized per F.U.
Input flows				
			[/building]	*[/m^2·yr]*
Hazardous waste *[tonne]*	Refined resource	**1**	3.00E-03	**3.75E-09**
Degreasing agents *[l]*	Refined resource	5.67E-02	1.70E-04	2.13E-10
Demulsifier *[l]*	Refined resource	1.89E-02	5.67E-05	7.09E-11
Diesel *[m^3]*	Refined resource	1.37E-02	4.10E-05	5.13E-11
Electricity *[GWh]*	Refined resource	2.27E-04	6.80E-07	8.50E-13
Emulsifier *[l]*	Refined resource	3.78E-02	1.13E-04	1.42E-10
Fuel oil *[m^3]*	Refined resource	1.89E-04	5.67E-07	7.09E-13
Gasoline *[m^3]*	Refined resource	1.11E-03	3.32E-06	4.15E-12
Slaked lime *[kg]*	Refined resource	1.04E-01	3.12E-04	3.90E-10
White spirit *[l]*	Refined resource	3.31E-02	9.92E-05	1.24E-10
Output flows				
			[/building]	*[/m^2·yr]*
Aromatics *[kg]*	Emissions to techn.	6.61E-04	1.98E-06	2.48E-12
COD *[tonne]*	Emissions to techn.	8.79E-03	2.64E-05	3.30E-11
Cr *[g]*	Emissions to water	9.54E-03	2.86E-05	3.58E-11
Cu *[g]*	Emissions to water	1.00E-02	3.00E-05	3.76E-11
Hg *[g]*	Emissions to water	2.36E-04	7.09E-07	8.86E-13
Mineral oil *[tonne]*	Emissions to techn.	3.31E-04	9.92E-07	1.24E-12
Ni *[g]*	Emissions to water	9.26E-03	2.78E-05	3.47E-11
Pb *[g]*	Emissions to water	1.61E-03	4.82E-06	6.02E-12
Phenol *[kg]*	Emissions to techn.	9.45E-04	2.83E-06	3.54E-12
Susp solids *[kg]*	Emissions to water	5.76E-04	1.73E-06	2.16E-12
TEX *[tonne]*	Emissions to techn.	4.63E-04	1.39E-06	1.74E-12
Zn *[g]*	Emissions to water	7.28E-03	2.18E-05	2.73E-11

Acid or alkaline waste *[tonne]*	Residue	1.32E-03	3.97E-06	4.96E-12
Dewatered hydroxide sludge *[tonne]*	Residue	2.65E-03	7.94E-06	9.92E-12
Emulsified concentrate *[tonne]*	Residue	1.42E-03	4.25E-06	5.32E-12
Filtered waste water *[m^3]*	Residue	1.86E-02	5.58E-05	6.98E-11
Laboratory waste *[tonne]*	Residue	1.13E-03	3.40E-06	4.25E-12
Mixed waste *[tonne]*	Residue	4.44E-03	1.33E-05	1.67E-11
Oil-contaminated scrap *[tonne]*	Residue	1.30E-02	3.91E-05	4.89E-11
Oil-contaminated waste water *[m^3]*	Residue	8.61E-01	2.58E-03	3.23E-09
Scrap *[tonne]*	Residue	3.14E-02	9.41E-05	1.18E-10
Unwashed package *[tonne]*	Residue	1.24E-02	3.71E-05	4.64E-11
Waste biocide *[tonne]*	Residue	1.23E-03	3.69E-06	4.61E-12
Waste containing cadmium *[tonne]*	Residue	2.83E-04	8.50E-07	1.06E-12
Waste containing cyanide *[tonne]*	Residue	5.86E-03	1.76E-05	2.20E-11
Waste containing heavy metals *[tonne]*	Residue	5.67E-03	1.70E-05	2.13E-11
Waste containing mercury *[tonne]*	Residue	5.67E-04	1.70E-06	2.13E-12
Waste containing PCB *[tonne]*	Residue	9.45E-04	2.83E-06	3.54E-12
Waste glue *[tonne]*	Residue	4.35E-03	1.30E-05	1.63E-11
Waste oil *[tonne]*	Residue	7.00E-02	2.10E-04	2.63E-10
Waste oil *[m^3 fub]*	Residue	3.69E-01	1.11E-03	1.38E-09
Waste paint *[tonne]*	Residue	1.21E-02	3.63E-05	4.54E-11
Waste paper and wood *[tonne]*	Residue	2.65E-03	7.94E-06	9.92E-12
Waste solvents *[tonne]*	Residue	1.79E-02	5.36E-05	6.70E-11

Appendix D – Calculations inventory data

Calculations necessary for the Life Cycle Inventory are shown in this appendix. Details about the origin of the numbers can be found in Section 3.2.8 and Section 4.1.

For materials, quantification is made for the building materials after which the amount of material is calculated for one functional unit. The functional unit is set to

1 m^2 office floor area · year.

The office floor area of Koggen 2 is 8 000 m^2 and the assumed lifetime of the building is 50 years.

The floor area of Kaggen, which in some cases is used as a reference building for the fictive building, is 8 500 m^2 and the assumed lifetime of the fictive building is 50 years.

Information about the origin of production of the different materials is collected from contact with producers of the specific materials.

Data have been included from the databases Professional and Construction integrated in the software tool GaBi 6. The information found there is then used as a generic data module that is connected to site specific data and data from other sources to complete the inventory. For a majority of the data sets used from GaBi, average production in Europe, Germany and Sweden has been assumed, including the electricity grid mix that is valid for that region. Transport distances have been adapted to be representative for Malmö. For drawings of the construction and building elements, see Appendix J.

D.1 Production phase – Koggen 2

The processes included in the production phase where calculations are necessary are *Electricity at the construction site*, *Heat pumps*, *External wall*, *Roof* and *Waste at construction site*.

D.1.1 Electricity at the construction site – Koggen 2

The use of electricity at the construction site was 307 094 kWh during the entire production phase, which lasted for 22 months during 2011 and 2012 (Man3a). The electricity per functional unit is given in equation (D.1).

$$\frac{\frac{307\ 094\ \text{kWh}}{22\ \text{months}} \cdot 12\ \text{months}}{(8\ 000\ \text{m}^2 \cdot 50\ \text{years})} = 0.419\ \text{kWh}/\ \text{m}^2 \cdot \text{year} \qquad \text{(D.1)}$$

D.1.2 Heat pumps – Koggen 2

The heat pumps are produced in Shizuoka, Japan and transported to Malmö by ship. The distance is 25 300 km (Ports, 2014).

Operational electricity is included in the use phase, but the production of the heat pumps is included in the production phase.

16 heat pumps are installed in Koggen 2 (Ene1a, 2013). The average lifetime of the heat pumps is 20 years (PE International, 2012e). During the lifetime of the building a

change of heat pumps is therefore necessary. The number of heat pumps per functional unit is given in equation (D.2).

$$\frac{16\ \text{heat pumps} \cdot \frac{50\ \text{years}}{20\ \text{years}}}{8\ 000\ \text{m2} \cdot 50\ \text{years}} = 0.0001\ \text{heat pumps/m}^2 \cdot \text{year} \tag{D.2}$$

D.1.3 External wall – Koggen 2

The external wall of Koggen 2 which is included in the calculations is the prefabricated concrete sandwich wall. The sandwich wall contains of concrete and the insulation Isover OL-E, see Appendix J for detail drawing.

The prefabricated concrete sandwich wall is produced in Riga, Latvia and transported to Malmö by truck and ship. The distance is 871 km, where 461 km is covered by truck and 410 km by ship (Google maps, 2014).

The concrete have a weight of 291 kg/m² for a thickness of 120 mm (PE International, 2012j). In this structure a total thickness of 240 mm is necessary, which results in a weight of 582 kg/m². The total surface area of the prefabricated concrete sandwich wall is 2 903 m². The weight of the concrete per functional unit is given in equation (D.3).

$$\frac{2\ 903\ \text{m}^2 \cdot 582\ \text{kg/m}^2}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 4.224\ \text{kg/m}^2 \cdot \text{year} \tag{D.3}$$

The insulation has a weight of 6.9 kg/m² for a thickness of 150 mm (Mat6d). The weight of the insulation per functional unit is given in equation (D.4).

$$\frac{2\ 903\ \text{m}^2 \cdot 6.9\text{kg/m}^2}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.0501\ \text{kg/m}^2 \cdot \text{year} \tag{D.4}$$

D.1.4 Roof constructions – Koggen 2

The roof constructions at Koggen 2 that are included in the calculations are the prefabricated lightweight Masonite roof, the prefabricated concrete roof with paperboard and the green roof.

D.1.4.1 Prefabricated lightweight Masonite roof – Koggen 2

The prefabricated lightweight Masonite roof is produced in Örnsköldsvik, Sweden and transported to Malmö by truck. The distance is 1 138 km (Google maps, 2014).

The roof construction consists of light weight Masonite elements and gypsum plasterboard and covers 684 m² of the total roof area of Koggen 2. The weight of the lightweight Masonite element is 29 kg/m² (Lättelement, 2012). The weight of the lightweight Masonite element per functional unit is given in equation (D.5) and the area per functional unit is given in equation (D.6).

$$\frac{684\ \mathrm{m}^2 \cdot 29\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0496\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.5}$$

$$\frac{684\ \mathrm{m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.00171\ m^2/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.6}$$

The weight of the gypsum plasterboard is 10 kg/m² (Eurogypsum, 2008). The weight of the gypsum plasterboard per functional unit is given in equation (D.7) and the area per functional unit is given in equation (D.8).

$$\frac{684\ \mathrm{m}^2 \cdot 10\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0171\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.7}$$

$$\frac{684\ \mathrm{m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.00171\ m^2/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.8}$$

D.1.4.2 Prefabricated concrete roof with paperboard – Koggen 2

The roof construction consists of high density fibre board, glass wool and prefabricated concrete elements and it covers 488 m² of the total roof area of Koggen 2.

The high density fibre board is produced in Åstorp, Sweden and transported to Malmö by truck. The distance is 80 km (Google maps, 2014).

The density of the fibre board is 900 kg/m³ (Egger, 2008) and the thickness is 0.025 m, see Appendix J. The weight of the fibre board per functional unit is given in equation (D.9) and the volume per functional unit is given in equation (D.10).

$$\frac{(488\ \mathrm{m}^2 \cdot 0.025\ \mathrm{m}) \cdot 900\ \mathrm{kg/m}^3}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0275\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.9}$$

$$\frac{488\ \mathrm{m}^2 \cdot 0.025\ \mathrm{m}}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0000305\ m^3/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.10}$$

The Isover glass wool insulation is produced in Billesholm, Sweden and transported to Malmö by truck. The distance is 63 km (Google maps, 2014).

The density of the insulation is 85 kg/m³ (Isover, 2014) and the thickness is 0.225 m, see Appendix J. The weight of the insulation per functional unit is given in equation (D.11).

$$\frac{488\ \mathrm{m}^2 \cdot 0.225\ \mathrm{m} \cdot 85\ \mathrm{kg/m}^3}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0233\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.11}$$

The prefabricated concrete elements are produced in Riga, Latvia and transported to Malmö by truck and ship. The distance is 871 km, where 461 km is covered by truck and 410 km by ship (Google maps, 2014).

The weight of the concrete elements is 1008 kg/m² (PE International, 2012i). The weight of the concrete elements per functional unit is given in equation (D.12).

$$\frac{488\ \mathrm{m}^2 \cdot 1\ 008\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 1.230\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.12}$$

D.1.4.3 Green roof – Koggen 2

The roof construction consists of border closure with oak strip, Veg tech Xeroflor moss, drainage material Nophadrain 5+1, film for green roofs, high density fibreboard, glass wool insulation, concrete and prefabricated concrete elements. The green roof covers 208 m² of the total roof area of Koggen 2.

The border closure with oak strip is produced in Vislanda, Sweden and transported to Malmö by truck. The distance is 175 km (Google maps, 2014).

The stainless steel is installed along the sides of the green roof, which have a circumference of 58 meters. The weight of the stainless steel is 1.395 kg/m (Veg Tech, 2012). The weight of the stainless steel per functional unit is given in equation (D.13).

$$\frac{58\ \mathrm{m} \cdot 1.10 \cdot 1.395\ \mathrm{kg/m}}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.000223\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.13}$$

The weight of the oak is 1.705 kg/m (Veg Tech, 2012). The weight of the oak strip per functional unit is given in equation (D.14).

$$\frac{58\ \mathrm{m} \cdot 1.10 \cdot 1.705\ \mathrm{kg/m}}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.000273\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.14}$$

The Veg tech Xeroflor moss, the drainage material Nophadrain 5+1 and the film for green roofs are produced in Vislanda, Sweden and transported to Malmö by truck. The distance is 175 km (Google maps, 2014).

The weight of the moss sedum vegetation is 30 kg/m² (Veg Tech, 2010). The weight of the moss sedum vegetation per functional unit is given in equation (D.15) and the volume per functional unit is given in equation (D.16).

$$\frac{208\ \mathrm{m}^2 \cdot 30\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.00312\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.15}$$

$$\frac{208\ \mathrm{m}^2 \cdot 0.030\ m}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0000156\ m^3/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.16}$$

The weight of Nophadrain 5+1 is 1.4 kg/m² (Veg Tech, 2010). The weight of Nophadrain 5+1 per functional unit is given in equation (D.17).

$$\frac{208\ \mathrm{m^2} \cdot 1.4\ \mathrm{kg/m^2}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.000728\ \mathrm{kg/m^2} \cdot \mathrm{year} \tag{D.17}$$

The weight of the film for green roofs is 0.1 kg/m². The weight of the film per functional unit is given in equation (D.18).

$$\frac{208\ \mathrm{m^2} \cdot 0.1\ \mathrm{kg/m^2}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.000052\ \mathrm{kg/m^2} \cdot \mathrm{year} \tag{D.18}$$

The high density fibreboard is produced in Åstorp, Sweden and transported to Malmö by truck. The distance is 80 km (Google maps, 2014).

The density of the fibreboard is 900 kg/m³ (Egger, 2008). The weight of the fibreboard per functional unit is given in equation (D.19) and the volume per functional unit is given in equation (D.20).

$$\frac{208\ \mathrm{m^2} \cdot 0.030\ \mathrm{m} \cdot 900\ \mathrm{kg/m^3}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0140\ \mathrm{kg/m^2} \cdot \mathrm{year} \tag{D.19}$$

$$\frac{208\ \mathrm{m^2} \cdot 0.030\ \mathrm{m}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0000156\ m^3/\mathrm{m^2} \cdot \mathrm{year} \tag{D.20}$$

The Isover glass wool insulation is produced in Billesholm, Sweden and transported to Malmö by truck. The distance is 63 km (Google maps, 2014).

The density of the insulation is 85 kg/m³ (Isover, 2014). The weight of the insulation per functional unit is given in equation (D.21).

$$\frac{208\ \mathrm{m^2} \cdot 0.270\ \mathrm{m} \cdot 85\ \mathrm{kg/m^3}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0119\ \mathrm{kg/m^2} \cdot \mathrm{year} \tag{D.21}$$

The concrete is produced in Södra Sandby, Sweden and transported to Malmö by truck. The distance is 27 km (Google maps, 2014), (Ballast, 2014).

The density of the concrete is 2 200 kg/m³ (Burström, 2007, p. 30). The weight of the concrete per functional unit is given in equation (D.22).

$$\frac{208\ \mathrm{m^2} \cdot 0.080\ \mathrm{m} \cdot 2\ 200\ \mathrm{kg/m^3}}{8\ 000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0915\ \mathrm{kg/m^2} \cdot \mathrm{year} \tag{D.22}$$

The prefabricated concrete elements are produced in Riga, Latvia and transported to Malmö by truck and ship. The distance is 871 km, where 461 km is covered by truck and 410 km by ship (Google maps, 2014).

The weight of the concrete elements is 1 008 kg/m² (PE International, 2012j). The weight of the concrete elements per functional unit is given in equation (D.23).

$$\frac{208\ \mathrm{m}^2 \cdot 1\ 008\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.524\ \mathrm{kg/m}^2 \cdot \mathrm{year} \qquad \text{(D.23)}$$

D.1.5 Waste at construction site – Koggen 2

The waste that is produced at the construction site is summarised in Table D.1.

Table D.1: Waste produced at the construction site of Koggen 2.

Waste Koggen 2	**Quantity**	**Quantity/F.U.**	**Destination**
	[kg/24 months]	*[kg/m2 · year]*	
Other disposal	54	6.75E-05	Landfill
Batteries	2	2.50E-06	Hazardous waste
Concrete	5 580	6.98E-03	Recycling
Mixed scrap	21 330	2.67E-02	Recycling
Combustible waste	41 230	5.15E-02	Incineration
Deposition fraction	830	1.04E-03	Landfill
Gypsum	13 980	1.75E-02	Recycling
Industrial waste	1 510	1.89E-03	Landfill
Fluorescent lamps and mercury-containing waste	1	1.25E-06	Hazardous waste
Metal packaging	24	3.00E-05	Recycling
Unsorted waste with gypsum	22 520	2.82E-02	50 % incineration/ 50 % landfill
Sortable waste	34 220	4.28E-02	Landfill
Wood treated	12 260	1.53E-02	Incineration treated wood
Wood untreated	7 150	8.94E-03	Incineration untreated wood

The waste has different destinations, which is summarised in Table D.2.

Table D.2: Destinations of waste from the construction site of Koggen 2.

Total amount of waste	Quantity
	[kg/m^2 · year]
Landfill	5.98E-02
Hazardous waste	3.75E-06
Incineration	6.56E-02
Incineration treated wood	1.53E-02
Incineration untreated wood	8.94E-03
Recycling	5.11E-02

D.2 Production phase – Fictive building

The processes included in the production phase where calculations are necessary are *Electricity at the construction site, External wall, Roof* and *Waste at construction site*.

D.2.1 Electricity at the construction site – Fictive building

The use of electricity at the construction site for the reference building Kaggen was 174 727 kWh during the entire production phase, which lasted for 12 months during 2006 and 2007 (Man3a). The electricity per functional unit is given in equation (D.24).

$$\frac{174\ 727\ \text{kWh}}{(8\ 500\ \text{m}^2 \cdot\ 50\ \text{years})} = 0.411\ \text{kWh/m}^2 \cdot \text{year} \tag{D.24}$$

D.2.2 External wall – Fictive building

The external wall of the fictive building that is included in the calculations consists of Cembrit Zenit Urban nature fibre cement building board, Gyproc VAP 25/110 ventilated steel profiles, Gyproc GU 9 Wind protection, Gyproc THR THERMOnomic steel joists, 195 MU Paroc UNS 37 insulation, plastic film, wooden joist, Gyproc GN 13 Normal plasterboard, steel beams and load bearing steel pillars. See Appendix J for detail drawings. The surface area of the external wall is 2 903 m². Material losses of ten percent are included in the calculations.

The Cembrit Zenit Urban nature fibre cement building board is produced in Helsinki, Finland and transported to Malmö by truck and ship. The distance is 1 090 km, where 850 km is covered by truck and 240 km by ship (Google maps, 2014).

The weight of the fibre cement building board is 14.6 kg/m² (Cembrit, 2012). The weight per functional unit is given in equation (D.25).

$$\frac{2\ 903\ \text{m}^2 \cdot 1.10 \cdot 14.6\ \text{kg/m}^2}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.117\ \text{kg/m}^2 \cdot \text{year} \tag{D.25}$$

The Gyproc VAP 25/110 ventilated steel profile is produced in Anderslöv, Sweden and transported to Malmö by truck. The distance is 32 km (Google maps, 2014).

The ventilated steel profile is included in the process *EU-27: Steel sheet EG* in GaBi. The weight of the steel profiles is 0.75 kg/m and they are installed horizontally along the building at a c/c distance of 400 mm (Gyproc, 2011). In equation (D.26) the necessary amount of steel profiles is quantified. The weight per functional unit is given in equation (D.27)

$$\frac{20\ \mathrm{m}}{0.4\ \mathrm{m}} \cdot 155\ \mathrm{m} + \frac{15\ \mathrm{m}}{0.4\ \mathrm{m}} \cdot 43\ \mathrm{m} + \frac{1\ \mathrm{m}}{0.4\ \mathrm{m}} \cdot 49\ \mathrm{m} = 9\ 485\ \mathrm{m} \tag{D.26}$$

$$\frac{9\ 485\ \mathrm{m} \cdot 0.75\ \mathrm{kg/m}}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0178\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.27}$$

The Gyproc GU 9 wind protection is produced in Bålsta, Sweden and transported to Malmö by truck. The distance is 656 km (Google maps, 2014).

The wind protection is included in the process *EU-27: Gypsum plasterboard* in GaBi. The weight of the wind protection is 7.2 kg/m² (Gyproc, 2008b). The weight per functional unit is given in equation (D.28) and the area per functional unit is given in equation (D.29).

$$\frac{2\ 903\ \mathrm{m}^2 \cdot 1.10 \cdot 7.2\ \mathrm{kg/m}^2}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0575\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.28}$$

$$\frac{2\ 903\ \mathrm{m}^2 \cdot 1.10}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.00798\ \mathrm{m}^2/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.29}$$

The Gyproc THR THERMOnomic 195/1.0 steel joists are produced in Anderslöv, Sweden and transported to Malmö by truck. The distance is 32 km (Google maps, 2014).

The steel joists are included in the process *EU-27: Steel sheet EG* in GaBi. The weight of the steel joists are 2.21 kg/m and they are installed vertically along the building at a c/c distance of 600 mm (Gyproc, 2014). In equation (D.30) the necessary amount of steel joists are quantified. The weight per functional unit is given in equation (D.31).

$$\frac{155\ \mathrm{m}}{0.6\ \mathrm{m}} \cdot 20\ \mathrm{m} + \frac{43\ \mathrm{m}}{0.6\ \mathrm{m}} \cdot 15\ \mathrm{m} + \frac{49\ \mathrm{m}}{0.6\ \mathrm{m}} \cdot 1\ \mathrm{m} = 6\ 323\ \mathrm{m} \tag{D.30}$$

$$\frac{6\ 323\ \mathrm{m} \cdot 2.21\ \mathrm{kg/m}}{8\ 000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0349\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.31}$$

The 195 MU Paroc UNS 37 insulation is produced in Hässleholm, Sweden and transported to Malmö by truck. The distance is 88 km (Google maps, 2014).

The density of the insulation is 29 kg/m³. The surface area of one insulation board is 0.7442 m² (Paroc, 2012, p.25). The weight per insulation board is given in equation (D.32) and the weight per functional unit is given in equation (D.33).

$$(0.7442\ m^2\ \cdot 0.195\ \mathrm{m}) \cdot 29\ \mathrm{kg/m^3} = 4.21\ \mathrm{kg/insulation\ board} \qquad \text{(D.32)}$$

$$\frac{\frac{2\,903\ \mathrm{m^2} \cdot 1.10}{0.7442\ \mathrm{m^2}} \cdot 4.21\ \mathrm{kg/insulation\ board}}{8\,000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0452\ \mathrm{kg/m^2}\ \cdot\ \mathrm{year} \qquad \text{(D.33)}$$

The plastic film is produced in Malmö, Sweden and transported to Sweden by truck. The distance is 10 km (Google maps, 2014).

The weight of the plastic film is 0.180 kg/m² (Icopal, 2011). The weight per functional unit is given in equation (D.34).

$$\frac{2\,903\ \mathrm{m^2} \cdot 1.10 \cdot 0.180\ \mathrm{kg/m^2}}{8\,000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.00144\ \mathrm{kg/m^2} \cdot \mathrm{year} \qquad \text{(D.34)}$$

The Norway spruce wooden joist Södra 45x45 is produced in Åstorp, Sweden and transported to Malmö by truck. The distance is 80 km (Google maps, 2014).

The density of the wooden joist at moisture of 12 percent is 390 kg/m³ and they are installed horizontally along the building at a c/c distance of 450 mm (Domone & Illston, 2010, p. 441). In equation (D.35) the necessary amount of wooden joist is quantified. The weight per functional unit is given in equation (D.36).

$$\frac{20\ \mathrm{m}}{0.45\ \mathrm{m}} \cdot 155\ \mathrm{m} + \frac{15\ \mathrm{m}}{0.45\ \mathrm{m}} \cdot 43\ \mathrm{m} + \frac{1\ \mathrm{m}}{0.45\ \mathrm{m}} \cdot 49\ \mathrm{m} = 8\,431\ \mathrm{m} \qquad \text{(D.35)}$$

$$\frac{(0.045\ \mathrm{m} \cdot 0.045\ \mathrm{m} \cdot 8\,431\ \mathrm{m}) \cdot 1.10 \cdot 390\ \mathrm{kg/m^3}}{8\,000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0183\ \mathrm{kg/m^2} \cdot \mathrm{year} \qquad \text{(D.36)}$$

The Gyproc GN 13 Normal plasterboard is produced in Bålsta, Sweden and transported to Malmö by truck. The distance is 656 km (Google maps, 2014).

The plasterboard is included in the process *EU-27: Gypsum plasterboard* in GaBi. The weight of the plasterboard is 9 kg/m² (Gyproc, 2008a). The weight per functional unit is given in equation (D.37) and the area per functional unit is given in equation (D.38).

$$\frac{2\,903\ \mathrm{m^2} \cdot 2\ \mathrm{pieces} \cdot 1.10 \cdot 9\ \mathrm{kg/m^2}}{8\,000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.144\ \mathrm{kg/m^2}\ \cdot\ \mathrm{year} \qquad \text{(D.37)}$$

$$\frac{6\,387\ \mathrm{m^2}}{8\,000\ \mathrm{m^2} \cdot 50\ \mathrm{years}} = 0.0160\ \mathrm{m^2/m^2} \cdot \mathrm{year} \qquad \text{(D.38)}$$

The load bearing steel pillars VKR S355J2H EN10210 140x140x10 are produced in Korby, Great Britain and transported to Malmö by truck and ship. The distance is 897 km, where 811 km is covered by truck and 86 km by ship (Google maps, 2014).

The load bearing steel pillars are included in the process *DE: Steel profiles (I/U/H/L/T)* in GaBi. The load bearing steel pillars are calculated for the entire building, with a height of 24 meters. The weight of the load bearing steel pillars is 40 kg/m (BE Group, 2014). The weight per functional unit is given in equation (D.39).

$$\frac{39\ \text{pillars} \cdot 24\ \text{m} \cdot 40\ \text{kg/m}}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.0936\ \text{kg/m}^2 \cdot \text{year} \tag{D.39}$$

The steel beam Gyproc THR THERMOnomic 195/1.0 is produced in Anderslöv, Sweden and transported to Malmö by truck. The distance is 32 km (Google maps, 2014).

The steel beams are included in the process *DE: Steel profiles (I/U/H/L/T)* in GaBi. The steel beams are used to carry the concrete floor slabs and are therefore calculated for the entire building. 1 168 meters of steel beams are necessary and they have a density of 7 850 kg/m³ (Domone & Illston, 2010, p. 532). The weight per functional unit is given in equation (D.40)

$$\frac{0.485\ \text{m} \cdot 0.015\ \text{m} \cdot 1\ 168\ \text{m} \cdot 7\ 850\ \text{kg/m}^3}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.167\ \text{kg/m}^2 \cdot \text{year} \tag{D.40}$$

D.2.3 Roof constructions – Fictive building

The roof construction at the fictive building that is included in the calculations is the prefabricated lightweight Masonite roof.

D.2.3.1 Prefabricated lightweight Masonite roof – Fictive building

The prefabricated lightweight Masonite roof is produced in Örnsköldsvik, Sweden and transported to Malmö by truck. The distance is 1138 km (Google maps, 2014).

The roof construction consists of light weight Masonite element and gypsum plasterboard and covers 1 380 m² of the total roof area. The weight of the lightweight Masonite element is 29 kg/m² (Lättelement, 2012). The weight per functional unit is given in equation (D.41) and the area per functional unit is given in equation (D.42).

$$\frac{1\ 380\ \text{m}^2 \cdot 29\ \text{kg/m}^2}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.100\ \text{kg/m}^2 \cdot \text{year} \tag{D.41}$$

$$\frac{1\ 380\ \text{m}^2}{8\ 000\ \text{m}^2 \cdot 50\ \text{years}} = 0.00345\ m^2/\text{m}^2 \cdot \text{year} \tag{D.42}$$

The weight of the gypsum plasterboard is 10 kg/m² (Eurogypsum, 2008). The weight per functional unit is given in equation (D.43) and the area per functional unit is given in equation (D.44).

$$\frac{1\,380\ \mathrm{m}^2 \cdot 10\ \mathrm{kg/m}^2}{8\,000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.0345\ \mathrm{kg/m}^2 \cdot \mathrm{year} \tag{D.43}$$

$$\frac{1\,380\ \mathrm{m}^2}{8\,000\ \mathrm{m}^2 \cdot 50\ \mathrm{years}} = 0.00345\ m^2/\mathrm{m}^2 \cdot \mathrm{year} \tag{D.44}$$

D.2.4 Waste at construction site – Fictive building

The waste that is produced at the construction site is summarised in Table D.3.

Table D.3: Waste produced at the construction site of Kaggen.

Waste Kaggen	**Quantity**	**Quantity/F.U.**	**Destination**
	[kg/20 months]	*[kg/m2 · year]*	
Concrete	7 260	1.02E-02	Recycling
Combustible waste	30 010	4.24E-02	Incineration
Gypsum	3 130	4.42E-03	Recycling
Metal scrap	5 040	7.12E-03	Recycling
Unsorted waste with gypsum	8 030	1.13E-02	50 % incineration / 50 % landfill
Sortable waste	97 760	1.38E-01	Landfill
Wood treated	12 910	1.82E-02	Incineration treated wood
Wood untreated	3 230	4.56E-03	Incineration untreated wood

The waste has different destinations, which is summarised in Table D.4.

Table D.4: Destinations of waste from the construction site of Kaggen.

Total amount of waste	Quantity
	[kg/m²· year]
Landfill	1.44E-01
Hazardous waste	0
Incineration	4.80E-02
Incineration treated wood	1.82E-02
Incineration untreated wood	4.56E-03
Recycling	2.18E-02

D.3 Use phase – Koggen 2

The processes included in the use phase where calculations are necessary are *Energy* and *Commuting*.

D.3.1 Energy – Koggen 2

The specific energy consumption of the building is 34.4 kWh/m² A_{temp} · year and A_{temp} is 8 964 m² (Ene1a). To reach the amount of energy necessary for one functional unit, equation (D.45) is used, see equation (D.46).

$$\frac{\text{Specific energy consumption} \cdot A_{\text{temp}}}{A} = \text{Energy/m}^2 \cdot year \tag{D.45}$$

$$\frac{34.4\ \text{kWh/m}^2\ A_{\text{temp}} \cdot \text{year} \cdot 8\ 964\ \text{m}^2\ A_{\text{temp}}}{8\ 000\ \text{m}^2} = 38.6\ \text{kWh/m}^2 \cdot \text{year} \tag{D.46}$$

16.2 kWh/m² A_{temp} · year is used for operational electricity, 14.1 kWh/m² A_{temp} · year for heating and 4.1 kWh/m² A_{temp} · year for cooling (Ene1a). These values include savings from the heat pumps for heating and cooling.

To reach the amount of energy necessary for one functional unit, equation (D.45) is used and the values 18.2 kWh/m² · year is reached for operational electricity, 15.8 kWh/m² · year for heating and 4.6 kWh/m² · year for cooling.

Operational electricity includes electricity for operation of the buildings installations such as elevators, fans and heat pumps, but also for exterior lighting and hot water use (Ene1a).

75 percent of the energy comes from hydro power, which can be seen in equation (D.47). 15 percent of the energy comes from wind power, which can be seen in equation (D.48). 10 percent of the energy comes from biomass power, which can be seen in equation (D.49) (Ene5a).

$$0.75 \cdot 38.6\ kWh/m^2\ A_{temp} \cdot year = 28.95\ kWh/m^2 \cdot year \tag{D.47}$$

$$0.15 \cdot 38.6\, kWh/m^2\ A_{temp} \cdot year = 5.79\, kWh/m^2 \cdot year \quad \text{(D.48)}$$

$$0.10 \cdot 38.6\, kWh/m^2\ A_{temp} \cdot year = 3.86\, kWh/m^2 \cdot year \quad \text{(D.49)}$$

By multiplying the values for operational electricity, heating and cooling with 75, 15 and 10 percent, the division between hydro power, wind power and biomass power will be reached.

13.65 kWh/m² · year of hydro power, 2.73 kWh/m² · year of wind power and 1.82 kWh/m² · year of biomass power is used for operational electricity.

11.85 kWh/m² · year of hydro power, 2.37 kWh/m² · year of wind power and 1.58 kWh/m² · year of biomass power is used for heating.

3.45 kWh/m² · year of hydro power, 0.69 kWh/m² · year of wind power and 0.46 kWh/m² · year of biomass power is used for cooling.

D.3.2 Commuting – Koggen 2

Emissions from commuting between the employees' residence and the office are calculated. The number of available parking spaces for cars, electric cars and bicycles are assumed to be used fully and the remaining employees are assumed to use public transportation in the form of busses. Since one person is assumed to be traveling in each car this results in 131 persons commuting by car, 155 persons by bicycle, 5 persons by electric car and the rest of the employees, 349 persons, by bus.

There were 225 work days during the year of 2013, which include the number of days in a year minus weekends, public holidays and 25 days of vacation.

640 people are assumed to be working in the office building.

The average distance traveled to and from work by car, electric car and bus during one day is assumed to be 26 km (Trafikanalys, 2013).

D.3.2.1 Bus – Koggen 2

349 persons are assumed to commute by bus. Most of the bus trips occur during rush hours, which results in the assumption of 60 persons traveling with each bus. The number of person kilometres travelled per functional unit is given in equation (D.50).

$$\frac{349\, persons \cdot 225\, work\ days/(person{\cdot}year) \cdot 26\, vehicle\ km/(person{\cdot}\ work\ day)}{8\ 000\, m^2 \cdot 60\, persons/vehicle} = 4.25\, person\ km/m^2 \cdot year \quad \text{(D.50)}$$

D.3.2.2 Car – Koggen 2

131 persons are assumed to commute by car and is assumed to travel alone in the car. The number of person kilometres travelled per functional unit is given in equation (D.51).

$$\frac{131\ persons \cdot 225\ work\ days/(person{\cdot}year) \cdot 26\ vehicle\ km/work\ day \cdot 1\ persons/vehicle}{8\ 000\ m^2} = 96\ person\ km/m^2 \cdot year \qquad \text{(D.51)}$$

D.3.2.3 Electric car – Koggen 2

5 persons are assumed to commute by electric car and is assumed to travel alone in the car. The number of person kilometres travelled per functional unit is given in equation (D.52).

$$\frac{5\ persons \cdot 225\ work\ days/(person{\cdot}year) \cdot 26\ vehicle\ km/work\ day \cdot 1\ persons/vehicle}{8\ 000\ m^2} = 3.7\ person\ km/m^2 \cdot year \qquad \text{(D.52)}$$

D.4 Use phase – Fictive building

The processes included in the use phase where calculations are necessary are *Energy* and *Commuting*.

D.4.1 Energy – Fictive building

The specific energy consumption for the fictive building is based on requirements in BBR and the distribution between operational electricity, heating and cooling is based on the reference building Kaggen. The fictive building is used as office building, is heated by district heating and is situated in climate zone III, which means that the maximum specific energy consumption should be 100 kWh/m² A_{temp} · year (Boverket, 2011, p. 101). This value is used as specific energy consumption for the fictive building. A_{temp} for the fictive building is 8 964 m². To reach the amount of energy necessary for one functional unit, equation (D.45) is used, see equation (D.53).

$$\frac{100\ \mathrm{kWh/m^2}\ \mathrm{A_{temp}}{\cdot}\ \mathrm{year} \cdot 8\ 964\ \mathrm{m^2}\ \mathrm{A_{temp}}}{8\ 000\ \mathrm{m^2}} = 112.1\ \mathrm{kWh/m^2} \cdot \mathrm{year} \qquad \text{(D.53)}$$

The specific energy consumption for the reference building Kaggen is 70 kWh/m² A_{temp} · year. A_{temp} is 9 367 m² and the office area is 8 500 m². To reach the amount of energy necessary for one functional unit, equation (D.45) is used, see equation (D.54).

$$\frac{70\ \mathrm{kWh/m^2}\ \mathrm{A_{temp}}{\cdot}\ \mathrm{year} \cdot 9\ 367\ \mathrm{m^2}\ \mathrm{A_{temp}}}{8\ 500\ \mathrm{m^2}} = 77.1\ \mathrm{kWh/m^2} \cdot \mathrm{year} \qquad \text{(D.54)}$$

To get a ratio between the energy necessary for the fictive building and for Kaggen, see equation (D.55).

$$\frac{112.1\ \mathrm{kWh/m^2}{\cdot}\ \mathrm{year}}{77.1\ \mathrm{kWh/m^2} \cdot \mathrm{year}} = 1.45 \qquad \text{(D.55)}$$

The specific energy consumption for Kaggen is distributed between operational electricity of 20 kWh/m² A_{temp} · year, heating of 35 kWh//m² A_{temp} · year and cooling of 15 kWh/m² A_{temp} · year. To reach the amount of energy necessary for one functional unit, equation (D.45) is used and the values 22.0 kWh/m² · year is reached for operational electricity, 38.6 kWh/m² · year for heating and 16.5 kWh/m² · year for cooling. These values are used as a reference to distribute the energy consumption of the fictive building between operational electricity, heating and cooling. See equation (D.56) for operational electricity, equation (D.57) for heating and equation (D.58) for cooling.

$$22.0\ \mathrm{kWh/m^2} \cdot \mathrm{year} \cdot 1.45 = 31.9\ \mathrm{kWh/m^2} \cdot \mathrm{year} \tag{D.56}$$

$$38.6\ \mathrm{kWh/m^2} \cdot \mathrm{year} \cdot 1.45 = 56.0\ \mathrm{kWh/m^2} \cdot \mathrm{year} \tag{D.57}$$

$$16.5\ \mathrm{kWh/m^2} \cdot \mathrm{year} \cdot 1.45 = 23.9\ \mathrm{kWh/m^2} \cdot \mathrm{year} \tag{D.58}$$

D.4.2 Commuting – Fictive building

Emissions from commuting between the employees' residence and the office are calculated.

The parking policy for the city of Malmö demands a minimum of 0.2 parking spaces for cars per employee and 0.4 parking spaces for bicycles per employee at offices in zone I, in which the fictive building is situated (Malmö stadsbyggnadskontor, 2010).

Since one person is assumed to be traveling in each car 128 persons are assumed to commute by car, 256 persons by bicycle and the rest of the employees, 256 persons, by public transport in the form of busses.

There were 225 work days during the year of 2013, which include the number of days in a year minus weekends, public holidays and 25 days of vacation.

640 people are assumed to be working in the office building.

The average distance traveled to and from work by car and bus during one day is assumed to be 26 km (Trafikanalys, 2013).

D.4.2.1 Bus – Fictive building

Most of the bus trips occur during rush hours, which result in the assumption of 60 people traveling with each bus. The number of person kilometres travelled per functional unit is given in equation (D.59).

$$\frac{256\ persons \cdot 225\ work\ days/(person{\cdot}year) \cdot 26\ vehicle\ km/person \cdot work\ day}{8\,000\ m^2\ \cdot 60\ persons/vehicle} = 3.12\ person\ km/m^2 \cdot year \tag{D.59}$$

D.4.2.2 Car – Fictive building

Each car is assumed to have one passenger. The number of person kilometres travelled per functional unit is given in equation (D.60).

$$\frac{128\ persons \cdot 225\ work\ days/(person{\cdot}year) \cdot 26\ vehicle\ km/work\ day \cdot 1\ persons/vehicle}{8\ 000\ m^2} = 94\ person\ km/m^2 \cdot year \tag{D.60}$$

D.5 Results of the calculations

To summarize the results from the calculations in Section D.1 to Section D.4 a table is done for the production phase and the use phase, see Table D.5. *N/A* stands for *Not Applicable* and is used when the material in question is not used for the building and therefore generates no emissions.

Table D.5: Results of the calculations for the production phase and the use phase.

Processes Production phase	Koggen 2	Fictive building	Unit
Electricity at construction site	4.19E-01	4.11E-01	*[kWh/m²·yr]*
Heat pumps	1.00E-04	*N/A*	*[nr. of pieces]*
External wall:			
Concrete sandwich element	4.224	*N/A*	*[kg/m²·yr]*
Insulation	5.01E-02	*N/A*	*[kg/m²·yr]*
Fibre cement building board	*N/A*	1.17E-01	*[kg/m²·yr]*
Ventilated steel profile	*N/A*	1.78E-02	*[kg/m²·yr]*
GU 9 wind protection	*N/A*	5.75E-02	*[kg/m²·yr]*
GU 9 wind protection	*N/A*	7.98E-03	*[m²/m²·yr]*
Steel joists	*N/A*	3.49E-02	*[kg/m²·yr]*
Insulation	*N/A*	4.52E-02	*[kg/m²·yr]*
Plastic film	*N/A*	1.44E-03	*[kg/m²·yr]*
Wooden joists	*N/A*	1.83E-02	*[kg/m²·yr]*
Plasterboard	*N/A*	1.44E-01	*[kg/m²·yr]*
Plasterboard	*N/A*	1.60E-02	*[m²/m²·yr]*
Load bearing steel pillars	*N/A*	9.36E-02	*[kg/m²·yr]*
Steel beam	*N/A*	1.67E-01	*[kg/m²·yr]*
Prefabricated lightweight Masonite roof:			
Prefabricated lightweight Masonite element	4.96E-02	1.00E-01	*[kg/m²·yr]*
Prefabricated lightweight Masonite element	1.71E-03	3.45E-03	*[m²/m²·yr]*

Gypsum	1.71E-02	3.45E-02	*[kg/m²·yr]*
Gypsum	1.71E-03	3.45E-03	*[m²/m²·yr]*
Prefabricated concrete element with paperboard:			
Fibre board	*2.75E-02*	*N/A*	*[kg/m²·yr]*
Fibre board	3.05E-05	*N/A*	*[m³/m²·yr]*
Insulation	2.33E-02	*N/A*	*[kg/m²·yr]*
Concrete element	1.230	*N/A*	*[kg/m²·yr]*
Green roof:			
Stainless steel	2.23E-04	*N/A*	*[kg/m²·yr]*
Oak	2.73E-04	*N/A*	*[kg/m²·yr]*
Moss sedum vegetation	3.12E-03	*N/A*	*[kg/m²·yr]*
Moss sedum vegetation	1.56E-05	*N/A*	*[m³/m²·yr]*
Nophadrain 5+1	7.28E-04	*N/A*	*[kg/m²·yr]*
Film	5.20E-05	*N/A*	*[kg/m²·yr]*
Fibre board	1.40E-02	*N/A*	*[kg/m²·yr]*
Fibre board	1.56E-05	*N/A*	*[m³/m²·yr]*
Glass wool insulation	1.19E-02	*N/A*	*[kg/m²·yr]*
Concrete	9.15E-02	*N/A*	*[kg/m²·yr]*
Prefab. concrete element	5.24E-01	*N/A*	*[kg/m²·yr]*
Waste at construction site:			
Landfill	5.98E-02	1.44E-01	*[kg/m²·yr]*
Incineration	6.56E-02	4.80E-02	*[kg/m²·yr]*
Incineration treated wood	1.53E-02	1.82E-02	*[kg/m²·yr]*
Incineration untreated wood	8.94E-03	4.56E-03	*[kg/m²·yr]*
Recycling	5.11E-02	2.18E-02	*[kg/m²·yr]*
Hazardous waste	3.75E-06	*N/A*	*[kg/m²·yr]*
Processes Use phase	**Koggen 2**	**Fictive building**	
Total energy consumption:	38.60	112.10	*[kWh/m²·yr]*
Hydro power	28.95	*N/A*	*[kWh/m²·yr]*
Wind power	5.79	*N/A*	*[kWh/m²·yr]*
Biomass power	3.86	*N/A*	*[kWh/m²·yr]*
Total operational electricity:	18.20	31.90	*[kWh/m²·yr]*
Hydro power	13.65	*N/A*	*[kWh/m²·yr]*
Wind power	2.73	*N/A*	*[kWh/m²·yr]*
Biomass power	1.82	*N/A*	*[kWh/m²·yr]*

Total heating:	15.80	56.00	*[kWh/m²·yr]*
Hydro power	11.85	*N/A*	*[kWh/m²·yr]*
Wind power	2.37	*N/A*	*[kWh/m²·yr]*
Biomass power	1.58	*N/A*	*[kWh/m²·yr]*
Total cooling:	4.60	23.90	*[kWh/m²·yr]*
Hydro power	3.45	*N/A*	*[kWh/m²·yr]*
Wind power	0.69	*N/A*	*[kWh/m²·yr]*
Biomass power	0.46	*N/A*	*[kWh/m²·yr]*
Commuting with bus	4.25	3.12	*[p.km/m²·yr]*
Commuting with car	96.00	94.00	*[p.km/m²·yr]*
Commuting with electric car	3.70	*N/A*	*[p.km/m²·yr]*

Appendix E – Flowcharts GaBi

The following flowcharts have been exported from the LCA software tool GaBi. Simplified flowcharts can be found in Section 4.3.

E.1 Koggen 2

For Koggen 2 there are flowcharts for the production phase and for the use phase, see Figure E.1 to Figure E.7.

E.1.1 Production phase

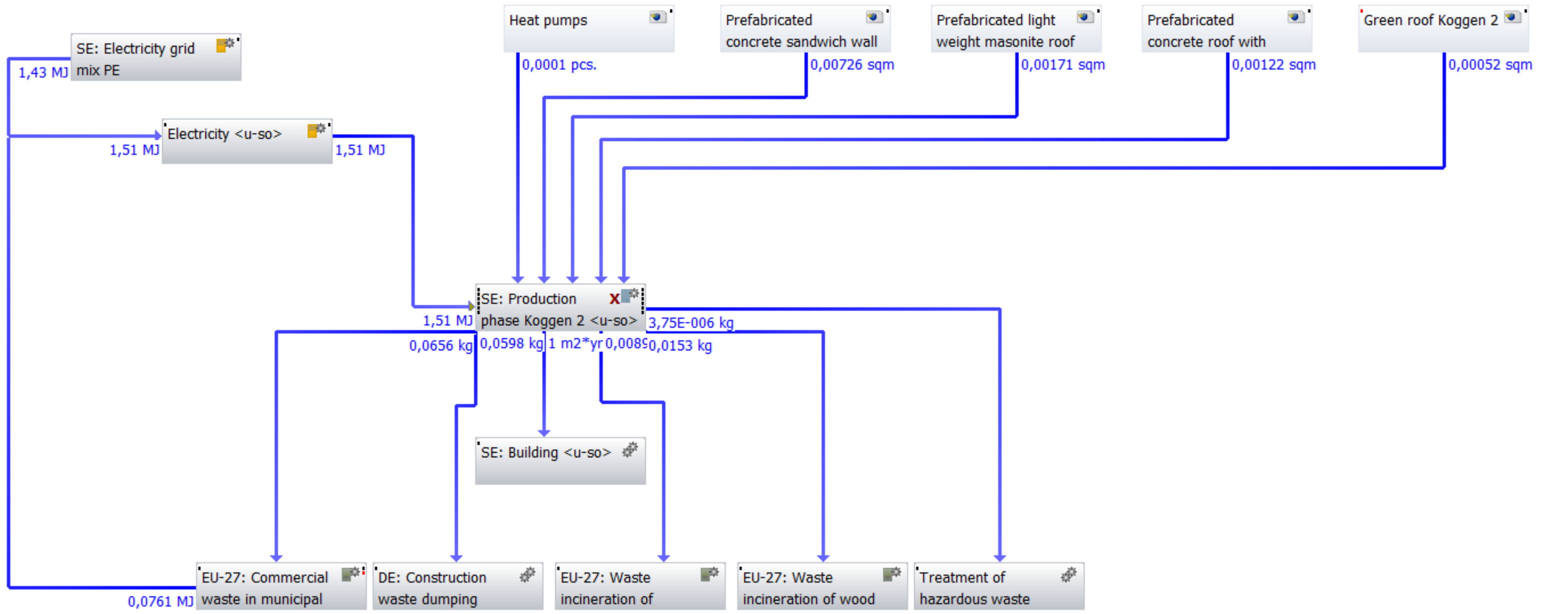


Figure E.1: Flowchart of the production phase for Koggen 2.

E.1.1.1 Heat pumps

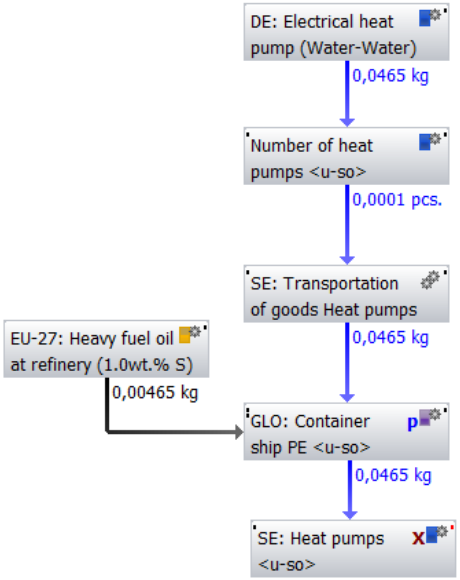


Figure E.2: Flowchart of heat pumps installed during the production phase for Koggen 2.

E.1.1.2 External sandwich wall

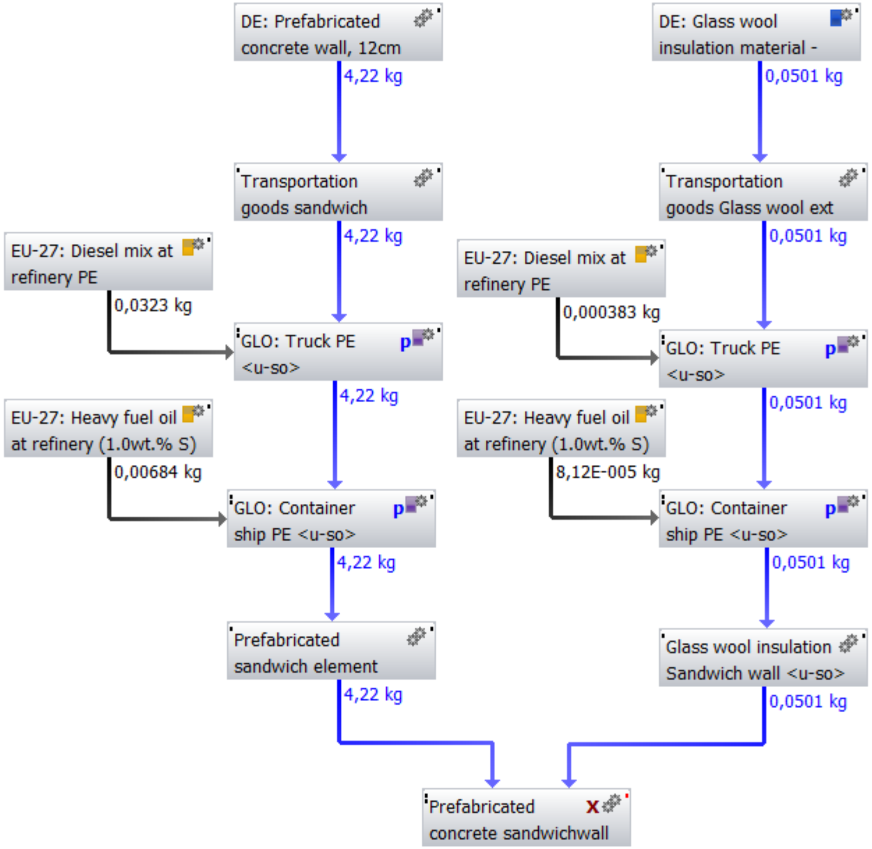


Figure E.3: Flowchart of external sandwich wall constructed during the production phase for Koggen 2.

E.1.1.3 Prefabricated lightweight Masonite roof

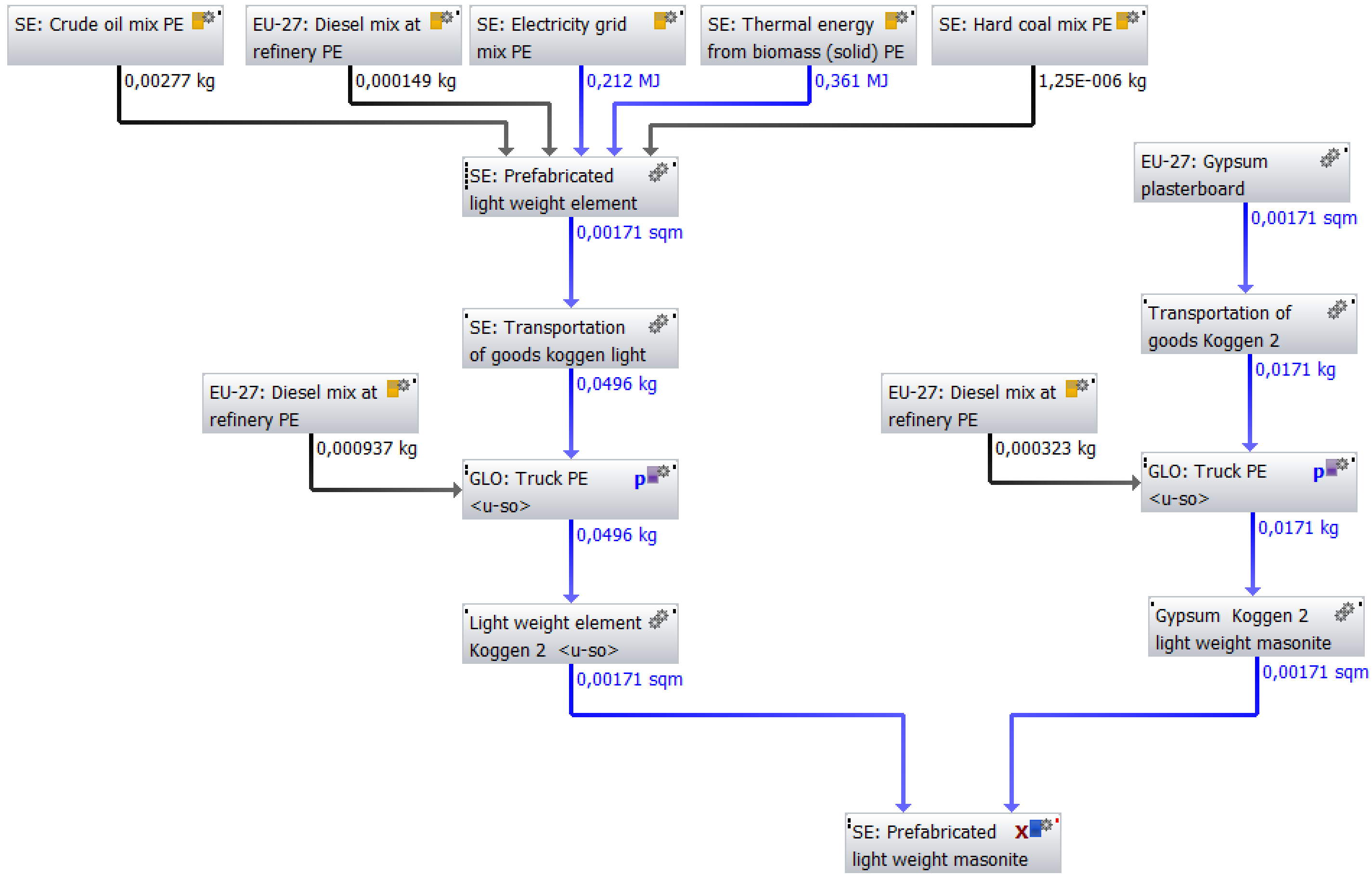


Figure E.4: Flowchart of prefabricated lightweight Masonite roof constructed during the production phase for Koggen 2.

E.1.1.4 Prefabricated concrete roof with paperboard

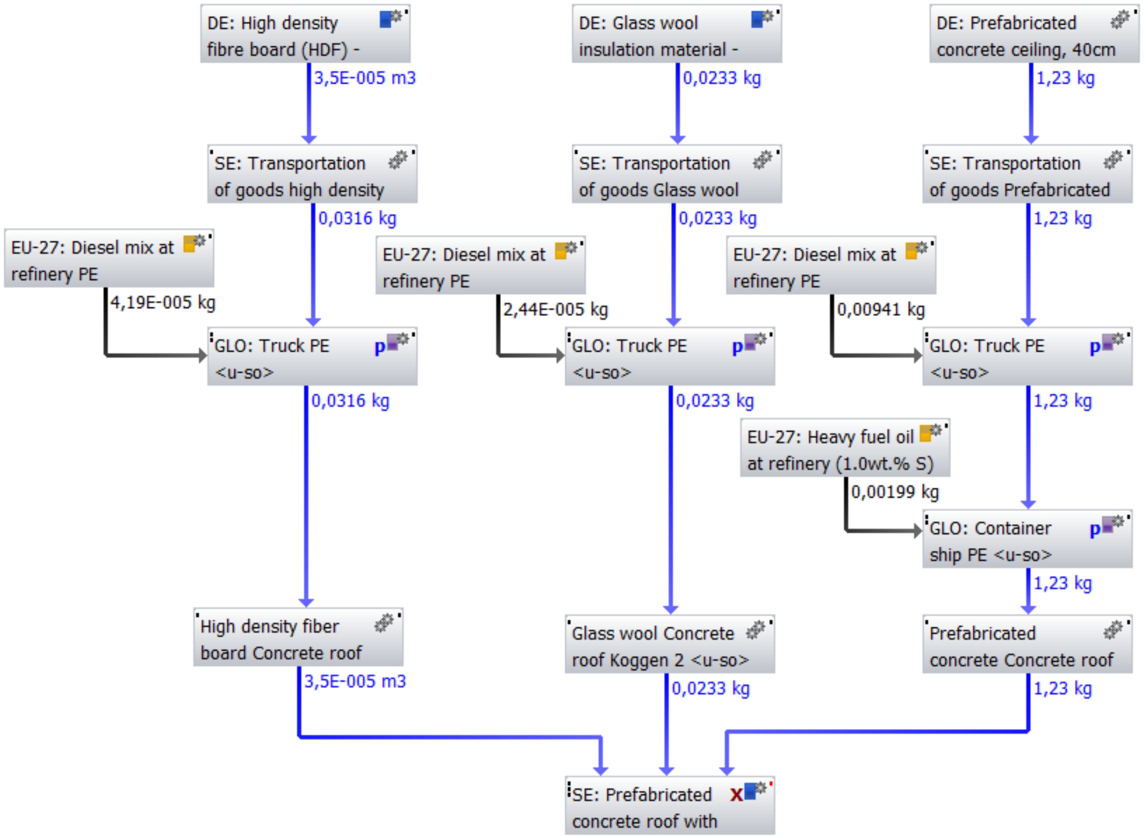


Figure E.5: Flowchart of prefabricated concrete roof with paperboard constructed during the production phase for Koggen 2.

E.1.1.5 Green roof

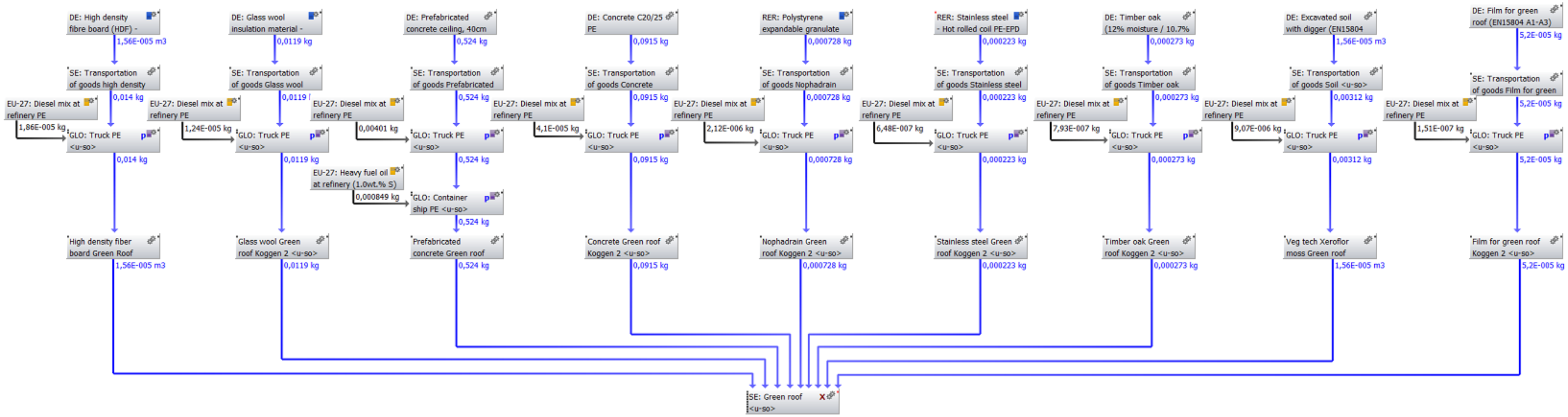


Figure E.6: Flowchart of green roof constructed during the production phase for Koggen 2.

E.1.2 Use phase

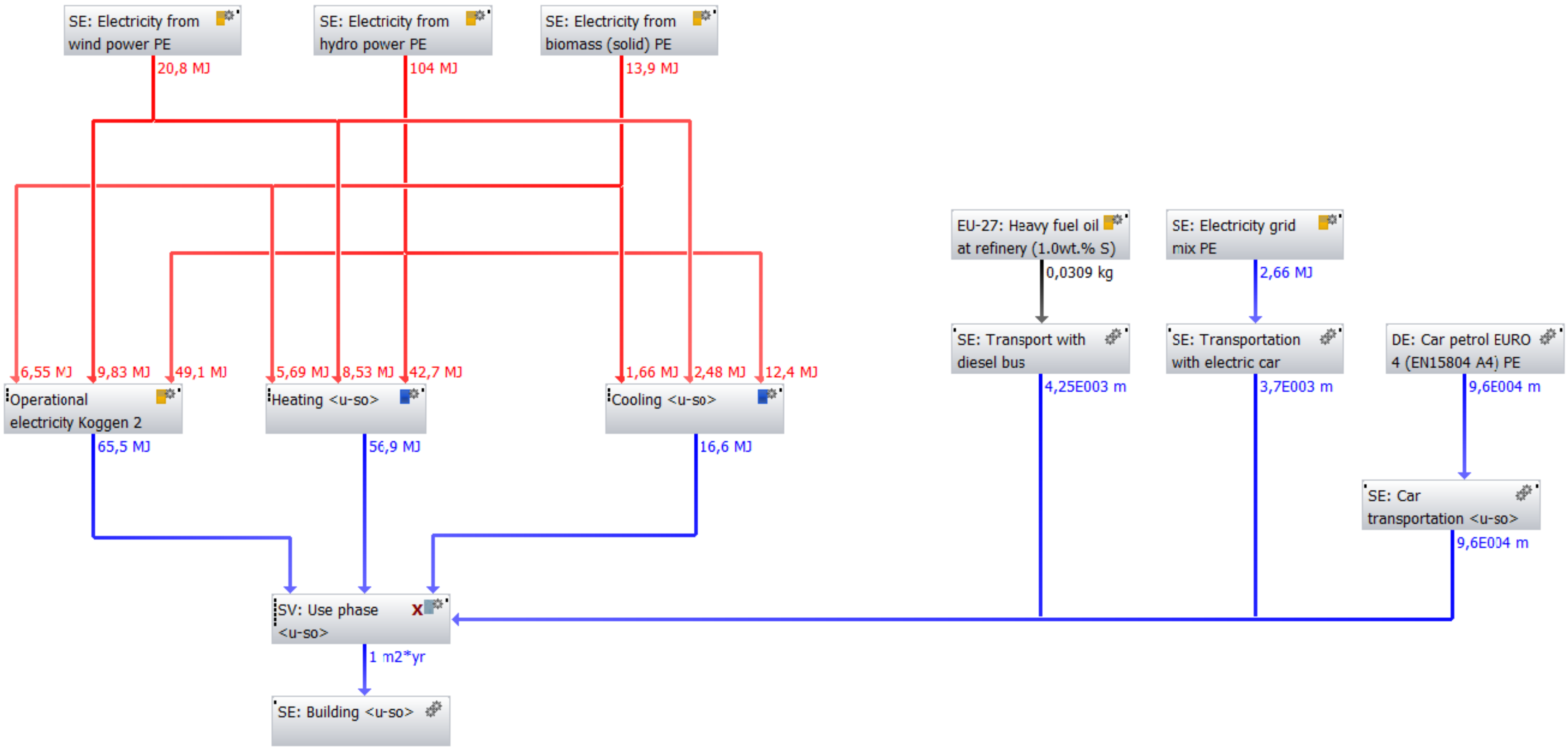


Figure E.7: Flowchart of the use phase for Koggen 2.

E.2 Fictive building

For the fictive building there are flowcharts for the production phase and for the use phase, see Figure C.8 to Figure C.11.

E.2.1 Production phase

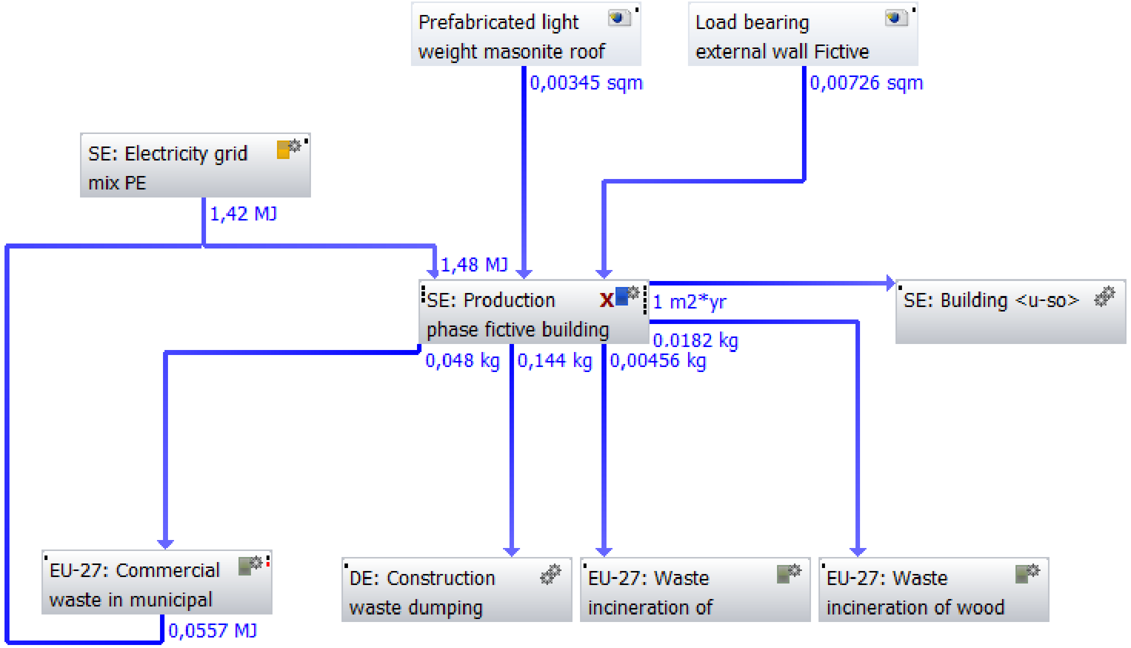


Figure E.8: Flowchart of the production phase for the fictive building.

E.2.1.1 Load bearing external wall

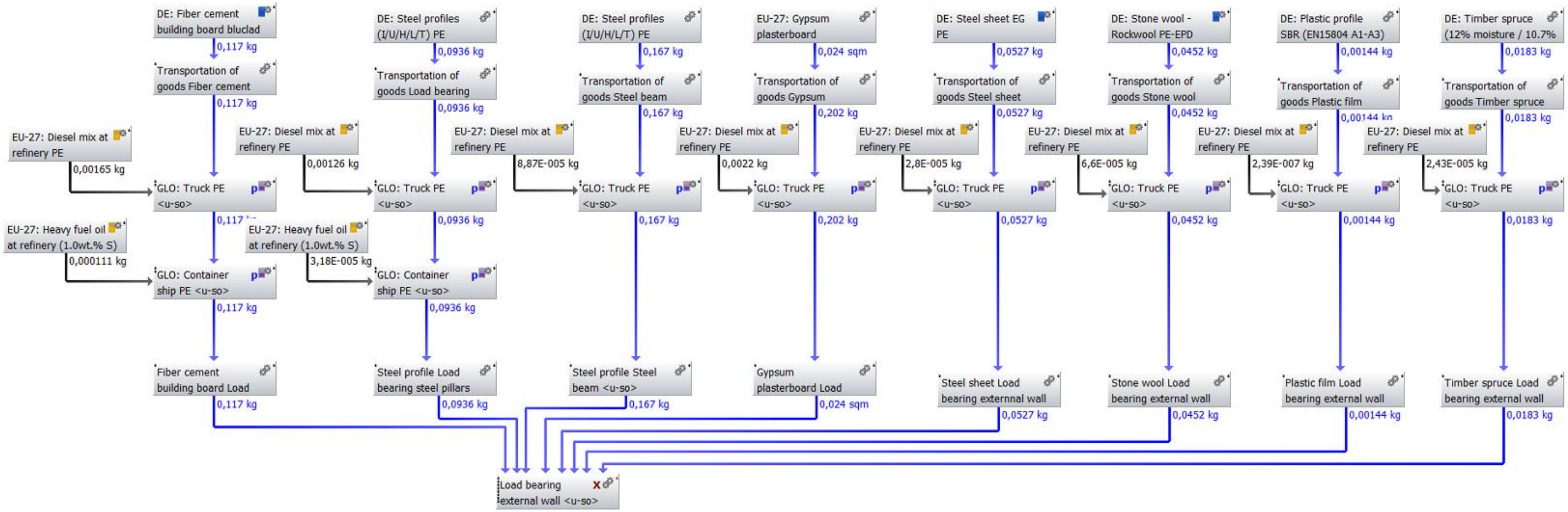


Figure E.9: Flowchart of load bearing external wall constructed during the production phase for the fictive building.

E.2.1.2 Prefabricated lightweight Masonite roof

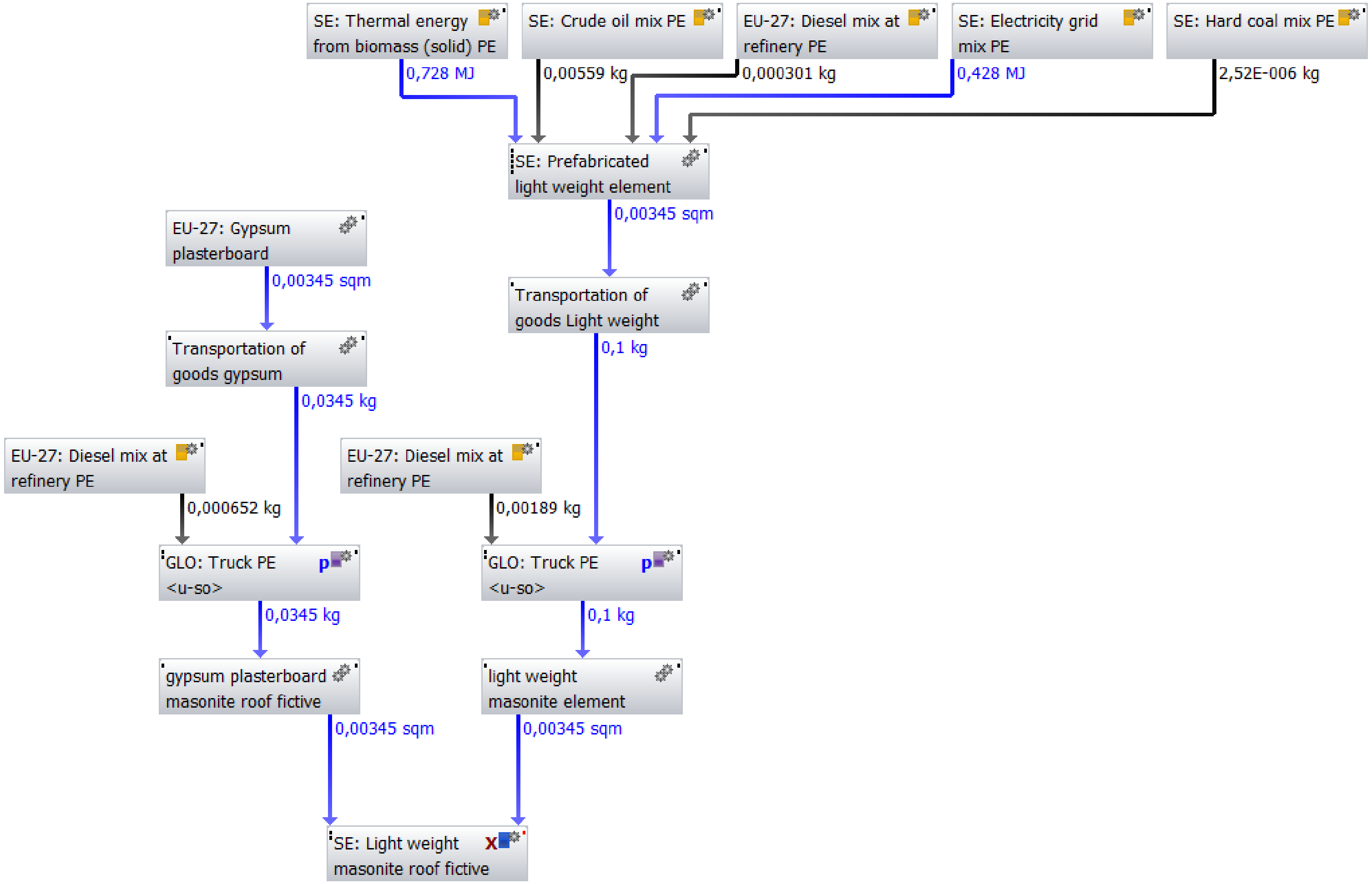


Figure E.103: Flowchart of prefabricated lightweight Masonite roof constructed during the production phase for the fictive building.

E.2.2 Use phase

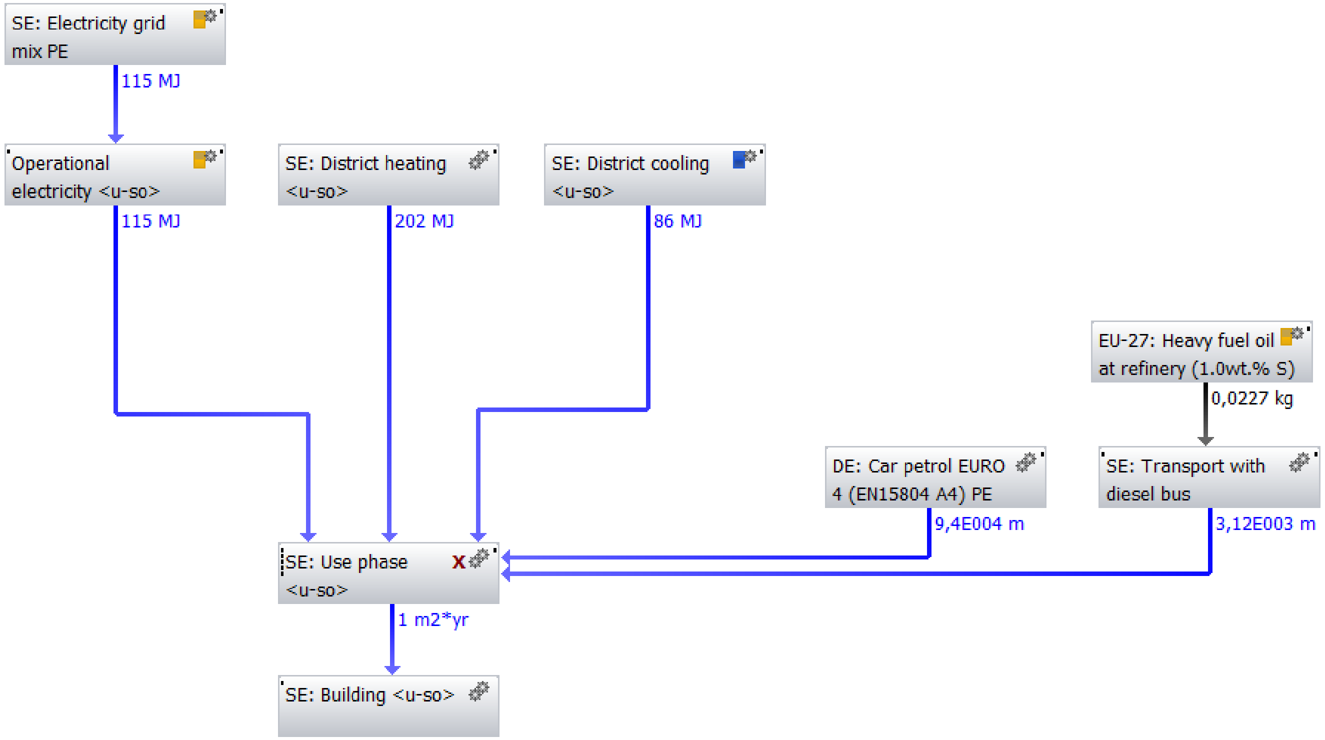


Figure E.11: Flowchart of the use phase for the fictive building.

Appendix F – Used processes

Table F.1 shows the processes used in the Life Cycle Analysis. First, the processes from the databases integrated in GaBi are listed, followed by the external processes.

Table F.1: The processes used in the Life Cycle Assessment.

Processes GaBi	Reference
EU-27: Waste incineration of untreated wood (10,7% water content)	(CEWEP, 2006a)
EU-27: Waste incineration of wood products (OSB, particle board)	(CEWEP, 2006b)
DE: High density fibre board HDF	(Egger, 2008)
DE: Fiber cement building board bluclad -Eternit	(Eternit, 2009)
EU-27: Gypsum plasterboard	(Eurogypsum, 2008)
DE: Glass wool insulation material – ISOVER	(Isover, 2008)
RER: Stainless steel - Hot rolled coil	(Outokumpu Stainless Steel, 2011)
EU-27: Diesel mix at refinery	(PE International, 2010b)
EU-27: Heavy fuel oil at refinery (1.0wt.% S)	(PE International, 2010c)
SE: Crude oil mix	(PE International, 2010f)
SE: Electricity from biomass (solid)	(PE International, 2010g)
SE: Electricity from hydro power	(PE International, 2010h)
SE: Electricity from wind power	(PE International, 2010i)
SE: Electricity grid mix PE	(PE International, 2010j)
SE: Hard coal mix	(PE International, 2010k)
SE: Thermal energy from biomass (solid)	(PE International, 2010l)
DE: Car petrol EURO 4 (EN15804 A4)	(PE International, 2012a)
DE: Concrete C20/25	(PE International, 2012b)
DE: Construction waste dumping (EN15804 C4)	(PE International, 2012c)
DE: Electrical heat pump (Water-Water) 20 kW (EN15804 A1-A3)	(PE International, 2012e)
DE: Excavated soil with digger (EN15804 A5)	(PE International, 2012f)
DE: Film for green roof (EN15804 A1-A3)	(PE International, 2012g)
DE: Plastic profile SBR (EN15804 A1-A3)	(PE International, 2012h)
DE: Prefabricated concrete ceiling, 40cm (EN15804 A1-A3)	(PE International, 2012i)
DE: Prefabricated concrete wall, 12cm (EN15804 A1-A3)	(PE International, 2012j)
DE: Steel profiles (I/U/H/L/T)	(PE International, 2012k)
DE: Timber oak (12% moisture / 10.7% water content) (EN15804 A1-A3)	(PE International, 2012l)
DE: Timber spruce (12% moisture / 10.7% water content) (EN15804 A1-A3)	(PE International, 2012m)
EU-27: Commercial waste in municipal waste incinerator	(PE International, 2012n)
EU-27: Steel sheet EG	(PE International, 2012o)
GLO: Container ship	(PE International, 2012q)
GLO: Truck	(PE International, 2012r)
RER: Polystyrene expandable granulate (EPS)	(Plastics Europé, 2003)
DE: Stone wool – Rockwool	(Rockwool, 2006)

Created processes	
SE: Transportation with electric car	(Samaras & Meisterling, 2008) & (PE International, 2010j)
SE: Transport with diesel bus	(CPM database, 2000)
SE: Prefabricated light weight element Masonite	(Lättelement, 2012)
SE: Treatment of hazardous waste	(CPM database, 1994)
SE: District heating	(E.ON, 2013a)
SE: District cooling	(E.ON, 2013a) & (PE International, 2010j)

Appendix G – Actor choices

Several different choices can be made for a building, concerning building materials, heating and cooling system, energy sources, etc. The choices that are made for Koggen 2 and for the fictive building are summarized in Table G.1, together with areas of building elements, amounts of necessary energy, weight of waste at construction site and amounts of vehicles for commuting.

Table G.1: The actor choices done for Koggen 2 and for the fictive building together with areas of building elements, amounts of necessary energy, weight of waste at construction site and amounts of vehicles for commuting.

	Koggen 2 - BREEAM certified	**Fictive building - uncertified**
Production phase:		
External walls	2 903 m² of prefabricated sandwich concrete wall	2 903 m² of external panel wall together with a load bearing steel frame
Roof constructions	488 m² of prefabricated concrete elements with paperboard	1 380 m² of prefabricated light weight Masonite elements
	684 m² of prefabricated light weight Masonite elements	N/A
	208 m² of green roof on prefabricated concrete elements	N/A
Electricity construction site	307 094 kWh of the Swedish electricity grid mix (for 22 months of construction)	174 727 kWh of the Swedish electricity grid mix (for 12 months of construction)
Waste construction site	47 874 kg to landfill (for 24 months of construction)	101 775 kg to landfill (for 20 months of construction)
	52 490 kg to incineration (for 24 months of construction)	34 025 kg to incineration (for 20 months of construction)
	7 150 kg to incineration of untreated wood (for 24 months of construction)	3 230 kg to incineration of untreated wood (for 20 months of construction)
	12 260 kg to incineration of treated wood (for 24 months of construction)	12 910 kg to incineration of treated wood (for 20 months of construction)

	40 914 kg to recycling (for 24 months of construction)	15 430 kg to recycling (for 20 months of construction)
	3 kg of hazardous waste (for 24 months of construction)	N/A
Use phase:		
Operation electricity	145 247 kWh/year, 75 % hydro power, 15 % wind power, 10 % biomass	192 099 kWh/year of Swedish electricity grid mix
Heating	126 392 kWh/year, 16 heat pumps of the model Mitsubishi Electric Mr Slim Zubadan R410A, 75 % hydro power, 15 % wind power, 10 % biomass	448 200 kWh/year of district heating
Cooling	36 752 kWh/year, 16 heat pumps of the model Mitsubishi Electric Mr Slim Zubadan R410A, 75 % hydro power, 15 % wind power, 10 % biomass	256 101 kWh/year of district cooling
Commuting	131 by car	128 by car
	5 by electric car	N/A
	349 by bus	256 by bus
	155 by bicycle	256 by bicycle

Appendix H – Results impact assessment

In Table H.1 the results of the Impact Assessment for the use phase of Koggen 2 and the fictive building is summarised. The categories of processes written in capital letters describe the total amounts of emissions for the category, with the separated compounds in italic letters underneath.

Table H.1: The results of the Impact Assessment for the use phase of Koggen 2 and for the fictive building.

Koggen 2 use phase	
	[kg $CO_{2,eq}$/FU]
TOTAL	20.40
COMMUTING	19.68
Car commuting	19.50
Bus commuting	1.02E-01
Electric car	7.73E-02
OPERATIONAL ELECTRICITY	2.90E-01
HEATING	2.53E-01
COOLING	7.40E-02
Fictive building use phase	
	[kg $CO_{2,eq}$/FU]
TOTAL	32.70
COMMUTING	19.17
Car commuting	19.10
Bus commuting	7.48E-02
OPERATIONAL ELECTRICITY	3.33
HEATING	8.40
COOLING	1.79

In Table H.2 the results of the Impact Assessment for the production phase of Koggen 2 and the fictive building is summarised. The categories of processes written in capital letters describe the total amounts of emissions for the category, with the separated compounds in italic letters underneath.

Table H.2: The results of the Impact Assessment for the production phase of Koggen 2 and the fictive building.

Koggen 2 production phase	
	[kg $CO_{2,eq}$/FU]
TOTAL	1.61
PREFABRICATED CONCRETE SANDWICH WALL	7.99E-01
Prefabricated concrete wall	5.72E-01
Glass wool insulation	8.70E-02
Transport	1.40E-01
PREFABRICATED LIGHT WEIGHT MASONITE ROOF	3.41E-02

Light weight element Masonite	2.61E-02
Gypsum plasterboard	3.64E-03
Transport	4.40E-03
PREFABRICATED CONCRETE ROOF WITH PAPERBOARD	3.74E-01
Glass wool insulation	4.05E-02
High density fibre board	2.51E-02
Prefabricated concrete	2.68E-01
Transport	4.04E-02
GREEN ROOF	1.75E-01
Concrete	8.62E-03
Veg tech moss and soil	1.70E-05
Film Green roof	1.43E-04
Timber oak	3.78E-05
Stainless steel	6.53E-04
Nophadrain	2.46E-03
Glass wool insulation	2.07E-02
High density fibre board	1.12E-02
Prefabricated concrete	1.14E-01
Transport	1.72E-02
HEAT PUMPS	1.19E-01
Transport	1.70E-02
ELECTRICITY CONSTRUCTION SITE	4.16E-02
WASTE CONSTRUCTION SITE	6.43E-02
Landfill	8.03E-04
Incineration	8.24E-02
Incineration treated wood	-1.20E-02
Incineration untreated wood	-6.89E-03
Hazardous waste	0
Fictive building production phase	
	[kg $CO_{2,eq}$/FU]
TOTAL	1.10
LOAD BEARING EXTERNAL WALL	9.44E-01
Fibre cement building board	9.34E-02
Steel profiles	5.97E-01
Gypsum plasterboard	5.11E-02
Steel sheets	1.16E-01
Stone wool	5.86E-02
Plastic film	5.46E-03
Timber	3.07E-03
Transport	1.94E-02
PREFABRICATED LIGHT WEIGHT MASONITE ROOF	6.88E-02
Light weight element Masonite	5.25E-02
Gypsum plasterboard	7.34E-03
Transport	8.99E-03
ELECTRICITY CONSTRUCTION SITE	4.13E-02

WASTE CONSTRUCTION SITE	4.45E-02
Landfill	1.93E-03
Incineration	6.03E-02
Incineration treated wood	-3.51E-03
Incineration untreated wood	-1.42E-02

Appendix I – Electricity and district heating

The distribution between energy sources used for the electricity grid mix and for district heating looks different in different countries. In this study the Swedish electricity grid mix and district heating in Malmö is used. To be able to discuss the results of the study, data of German and British electricity grid mixes and of Swedish and German district heating is also presented in this appendix.

I.1 Electricity grid mixes

The Swedish electricity grid mix is mainly based on nuclear power and hydro power and generates GHG emissions of 0.104 kg $CO_{2,eq}$/kWh. For the distribution between energy sources, see Figure I.1 (PE International, 2010j).

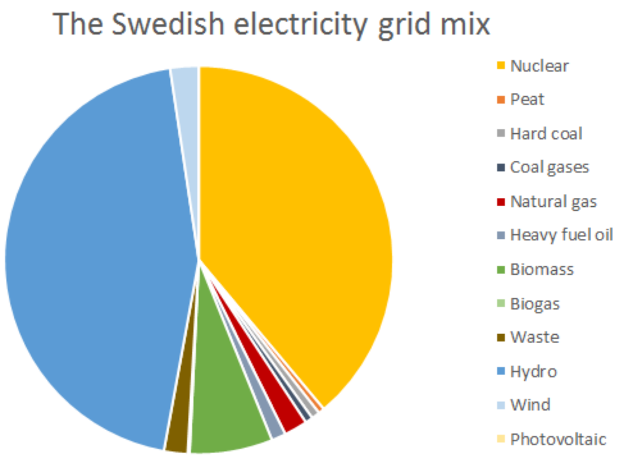


Figure I.1: The distribution between energy sources used for electricity in Sweden (PE International, 2010j).

The British electricity grid mix is mainly based on natural gas, hard coal and nuclear and generates GHG emissions of 0.563 kg $CO_{2,eq}$/kWh. For the distribution between energy sources, see Figure I.2 (PE International, 2010e).

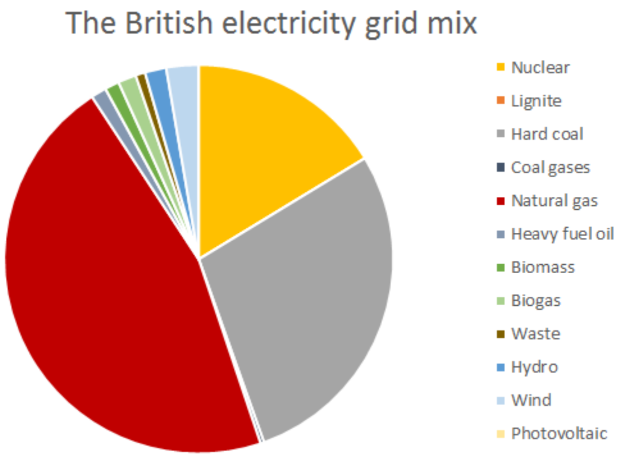


Figure I.2: The distribution between energy sources used for electricity in Britain (PE International, 2010e).

The German electricity grid mix is mainly based on nuclear, lignite, hard coal and natural gas and generates GHG emissions of 0.675 kg $CO_{2,eq}$/kWh. For the distribution between energy sources, see Figure I.3 (PE International, 2010a).

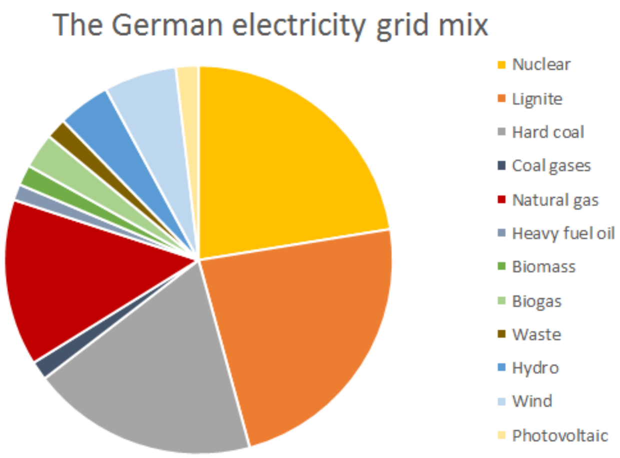


Figure I.3: The distribution between energy sources used for electricity in Germany (PE International, 2010a).

I.2 District heating – energy sources

District heating in Sweden is based on different mixes of energy sources. District heating in Malmö is mainly based on waste and natural gas and generates GHG emissions of 0.15 kg $CO_{2,eq}$/kWh. For the distribution between energy sources, see Figure I.4 (PE International, 2010e).

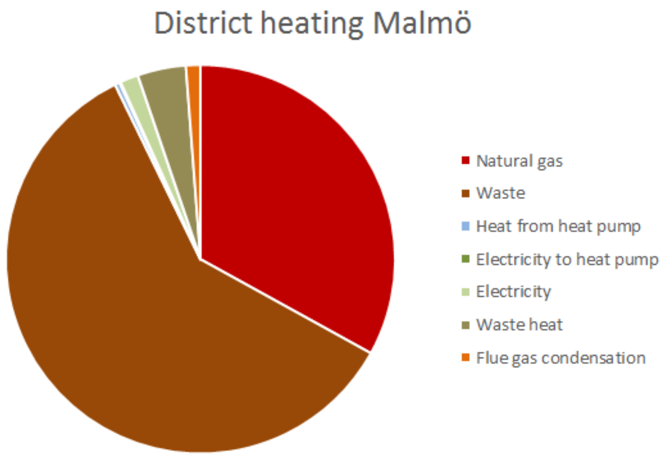


Figure I.4: The distribution between energy sources used for district heating in Malmö, Sweden (E.ON, 2013a).

In Figure I.5 a chart of the average distribution of energy sources for district heating in Sweden can be seen. The main energy sources are biomass and waste (Svensk Fjärrvärme, 2014).

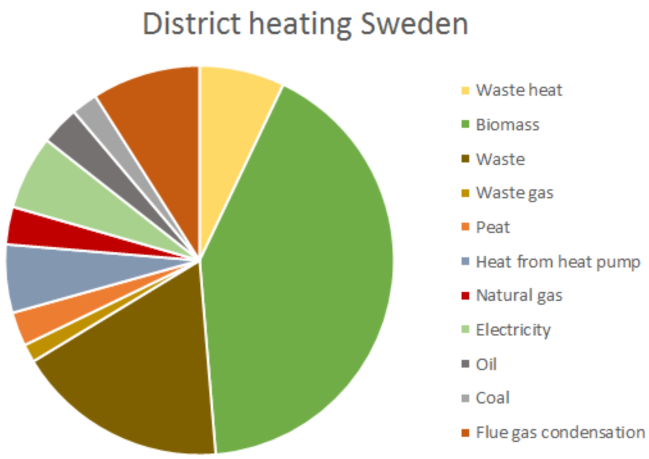


Figure I.5: The average distribution between energy sources used for district heating in Sweden (Svensk Fjärrvärme, 2014).

District heating in Germany is mainly based on natural gas and coal and generates GHG emissions of 0.224 kg $CO_{2,eq}$/kWh. For the distribution between energy sources, see Figure I.6 (PE International, 2010d).

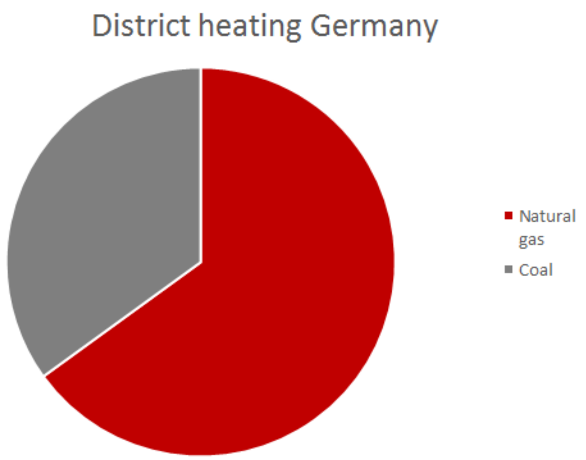


Figure I.6: The distribution between energy sources used for district heating in Germany (PE International, 2012d).

Appendix J – Architectural drawings

J.1 Fictive building

Detail drawings for the fictive building are shown in this appendix.

J.1.1 Details external wall

Detail 101: External wall

J.2 Koggen 2

Façade drawings, sections drawings, floor plan, detail drawings and site plan for Koggen 2 is shown in this appendix. The list bellow shows which drawings can be found in this appendix.

J.2.1 Façade drawings and sections

A-40.3-301: Façade facing west

A-40.3-302: Façade facing west

A-40.3-303: Façade facing north

A-40.3-304: Façade facing east

A-40.3-305: Façade facing east

A-40.3-306: Façade facing south

A-40.3-307: Façade facing north and south

A-40.2-202: Section

J.2.2 Details

A-40.6-401: External sandwich wall

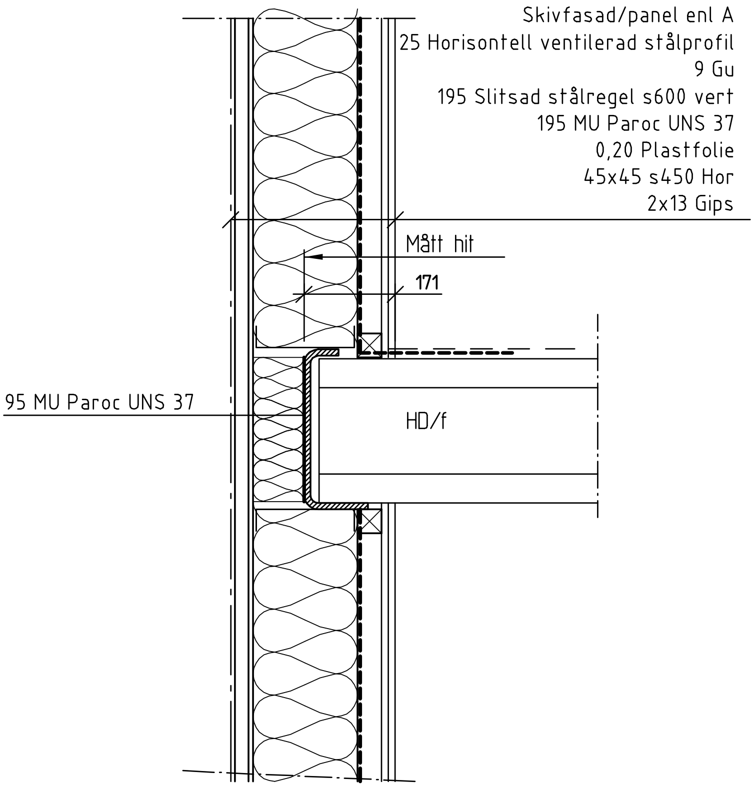
A-40.6-402: Green roof and prefabricated light weight Masonite roof

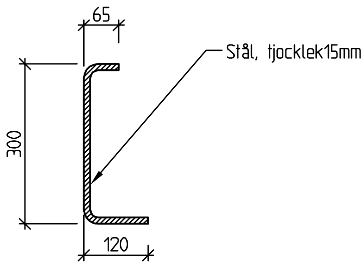
K-20.6-023: Green roof and prefabricated light weight Masonite roof

K-20.6-025: Prefabricated concrete roof with paperboard

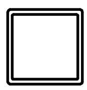
J.2.3 Site plan

M-1150-03: Site plan





Stålbalk, Fasad



Pelare VKR140x140x10 c/c 5,40m

Det. 101

1:10

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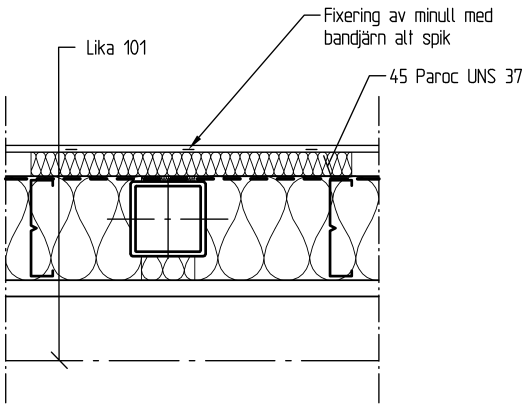


VKR 140x140x10
Brandskydd R60 stålpelare

1:10

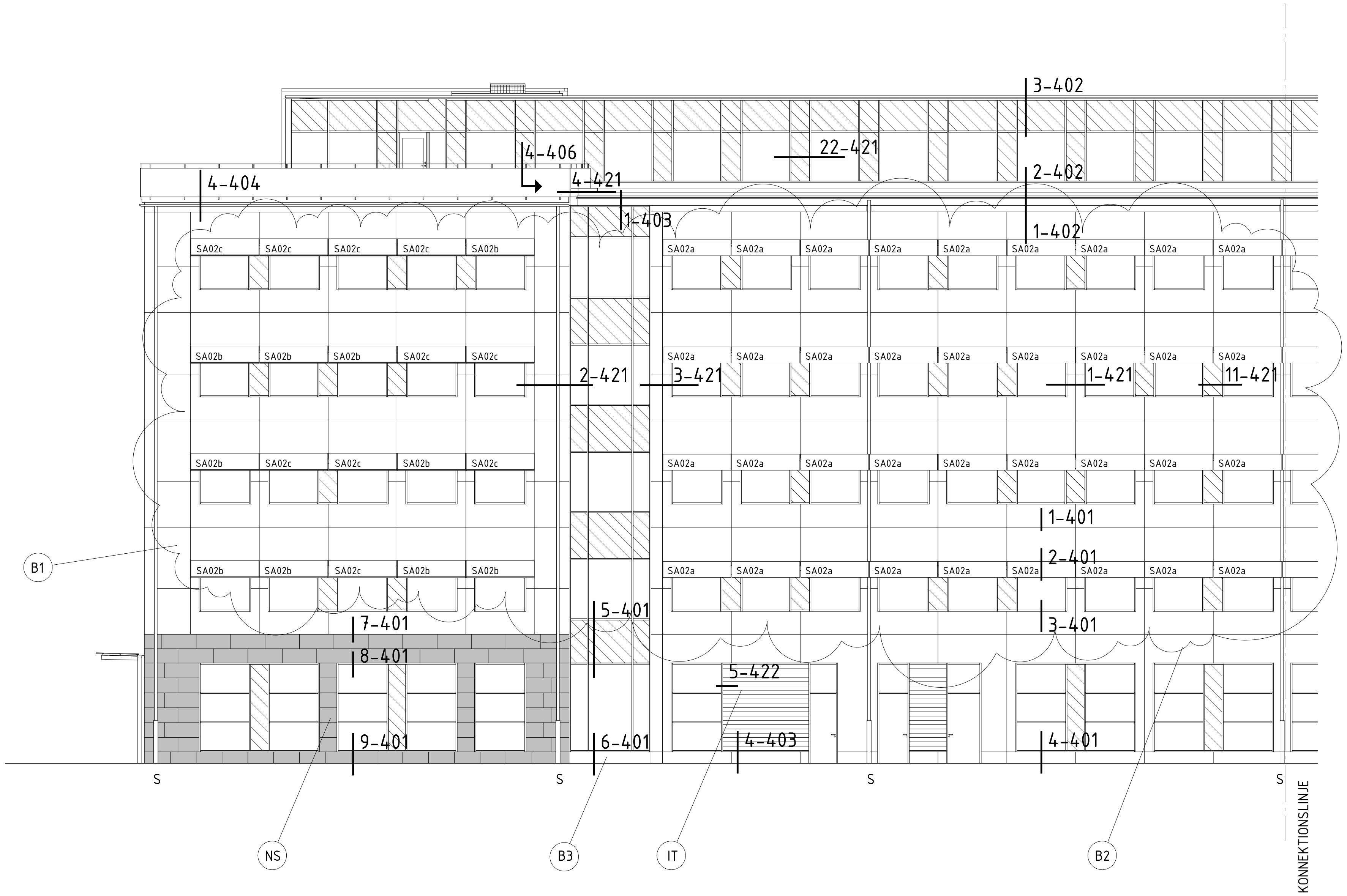
-

FÖRKLARINGAR

B1: Betongelement kulör 1
B2: Betongelement kulör 2
B3: Betongelement kulör 3
IT: Infällt trä / spaljé
NS: Natursten
PL: Plåt, bandtäckning
SA: Solavskärmning av glas
ST: Skärmtak

Blindfönster

Kulörer enligt separat färgsättnings-handling.



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BYGGHANDLING

N

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
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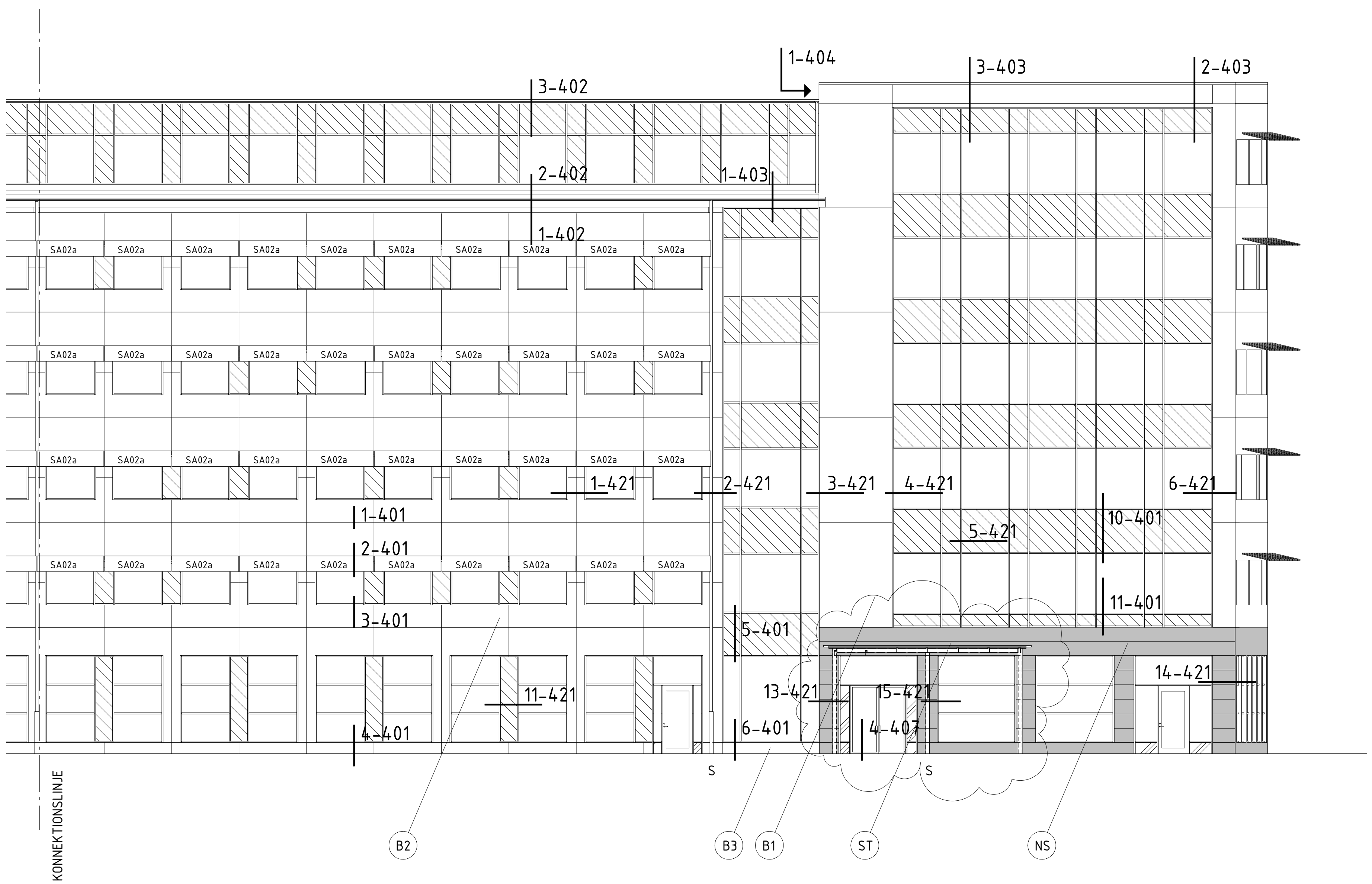

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BYGGHANDLING

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

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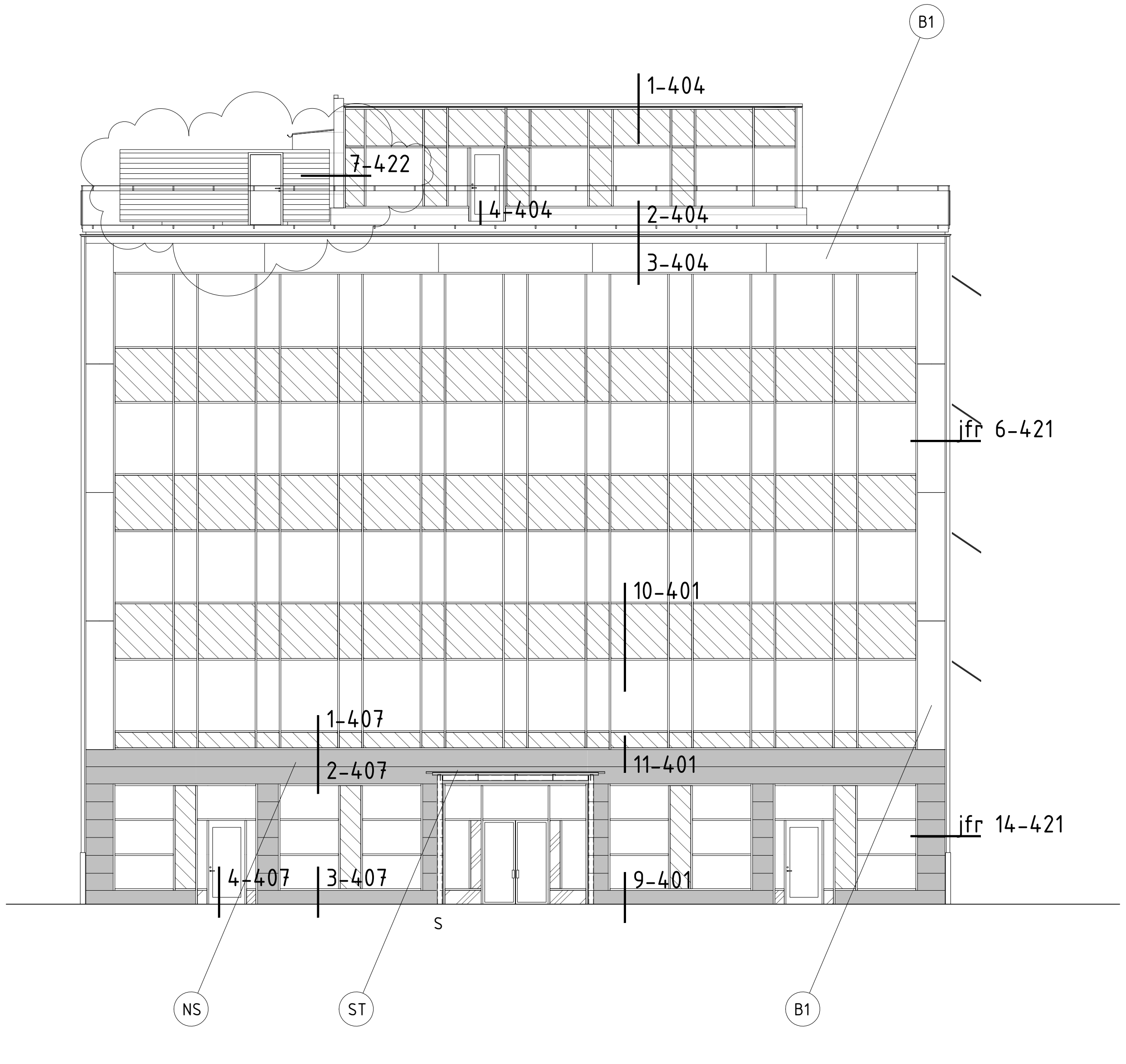

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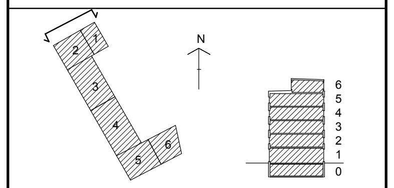

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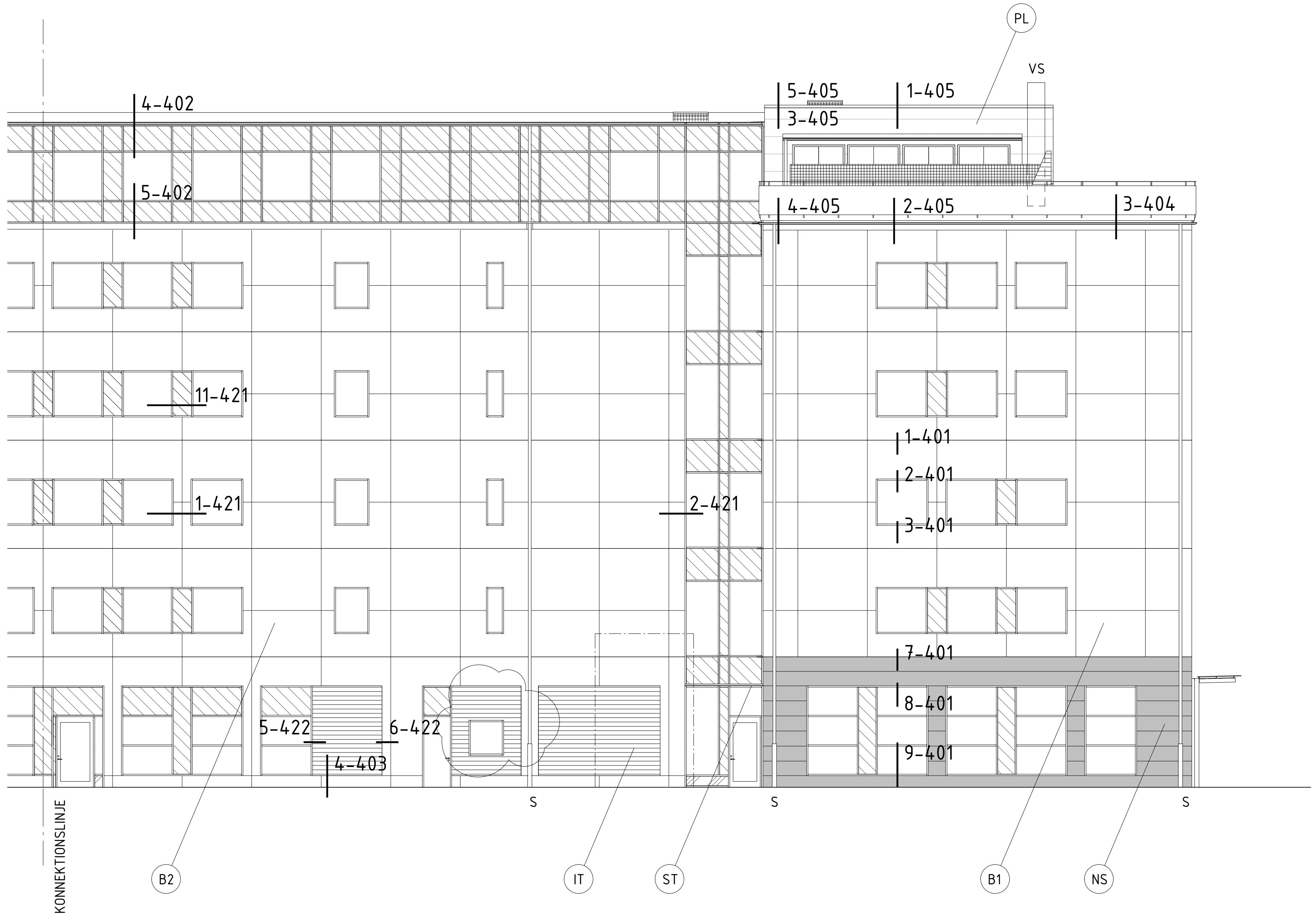

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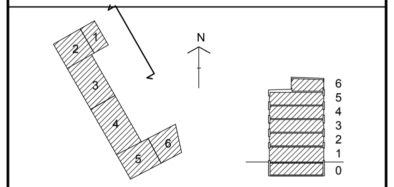

KOGGEN 2

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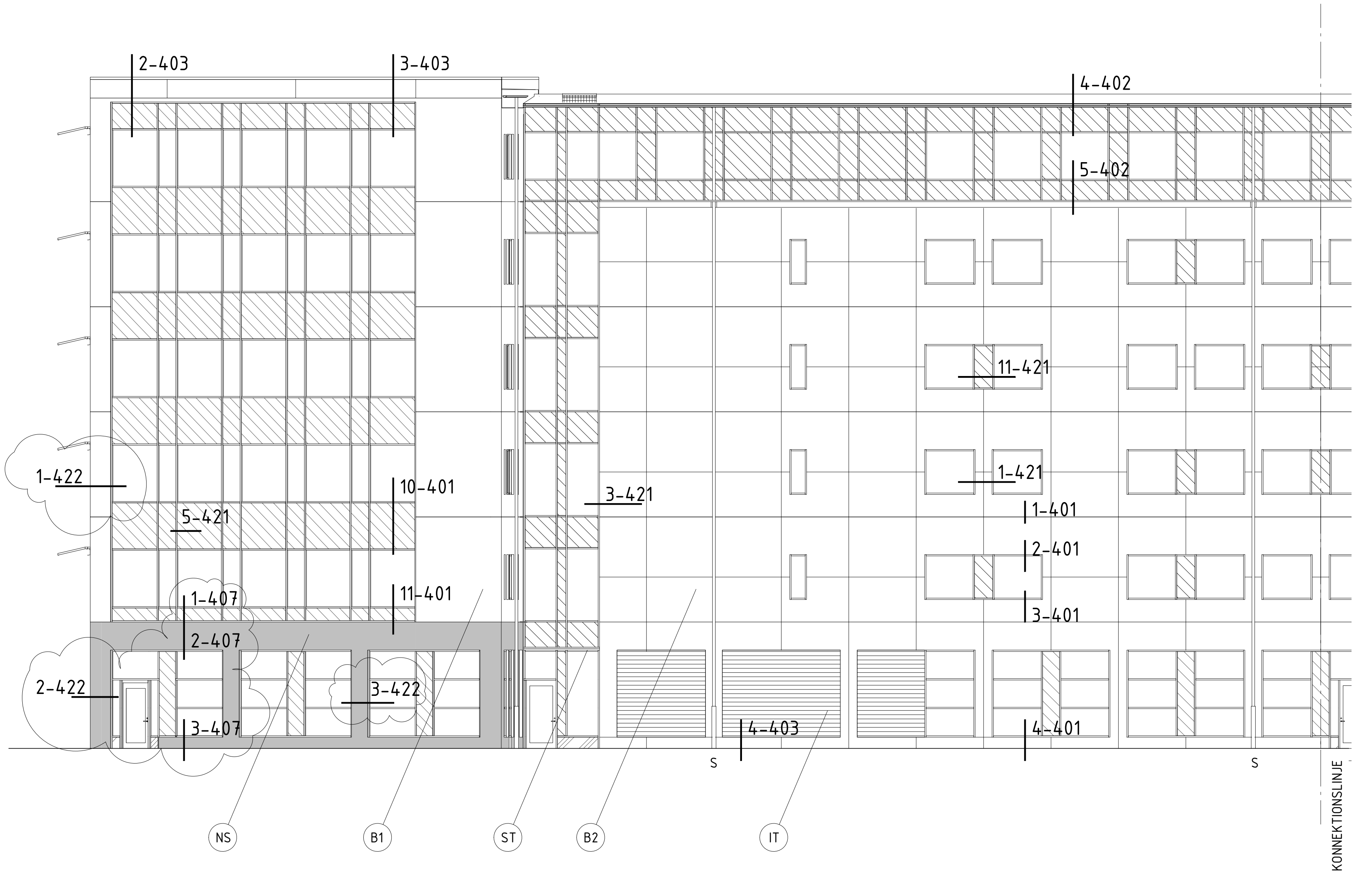

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A	ENLIGT ÄNDRINGS-PM A01	2011-07-07	AO

BYGGHANDLING

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

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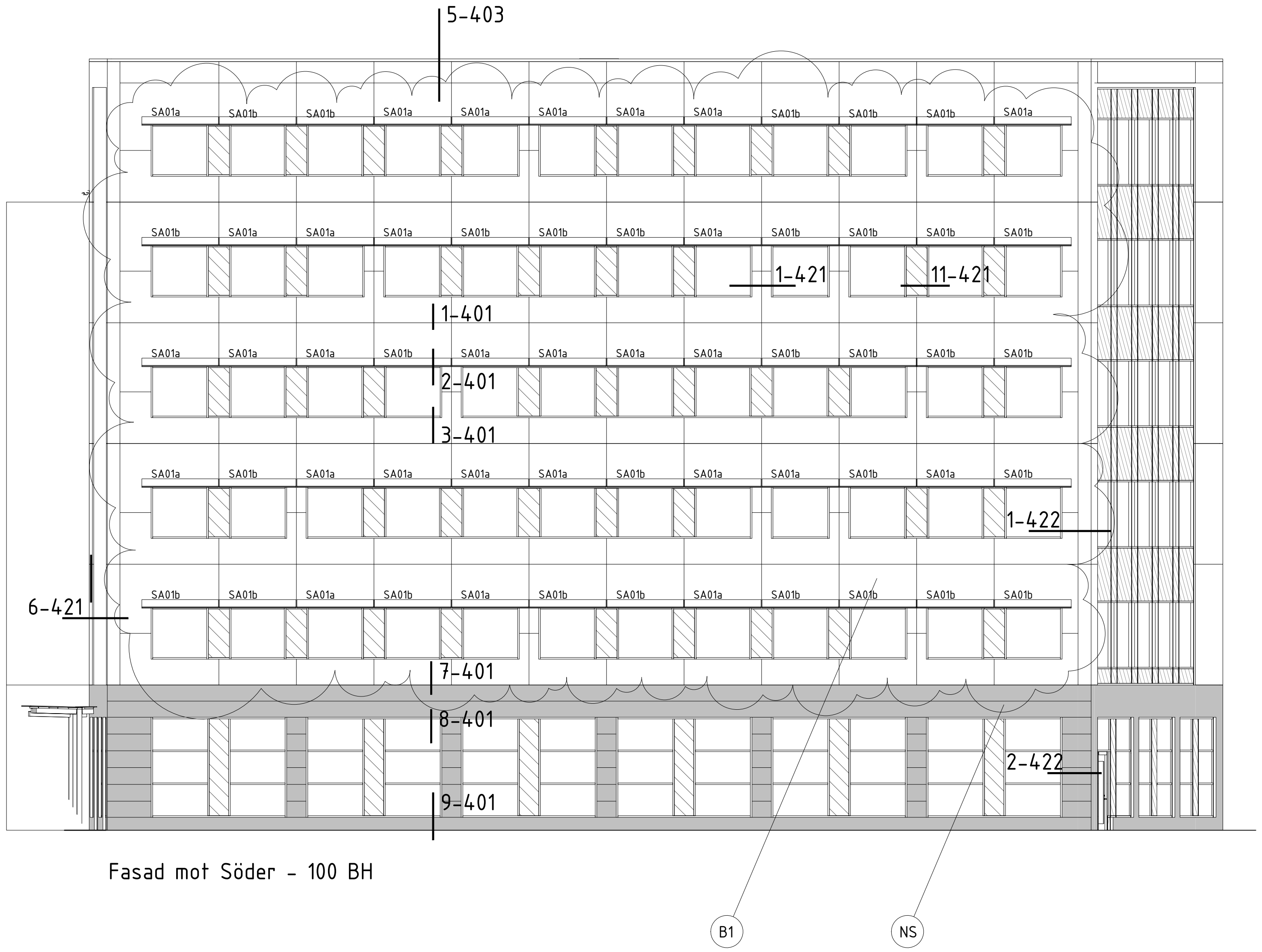


Fasad mot Söder - 100 BH

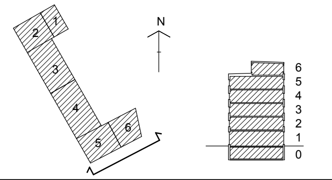
0 1 2 3 4 5 10 m

FÖRKLARINGAR

SE RITNING A-40.3-301.

BET	ÄNDRINGEN AVSER	DATUM	SIGN
C	ENLIGT ÄNDRIINGS-PM A07	2012-02-29	AO
B	ENLIGT ÄNDRINGS-PM A03	2011-09-28	AO
A	ENLIGT ÄNDRINGS-PM A01	2011-07-07	AO

BYGGHANDLING



KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR | RITAD/KONSTR. AV | HANDLÄGGARE AO YO

DATUM 2011-06-01 | ANSVARIG PER DAHLIN

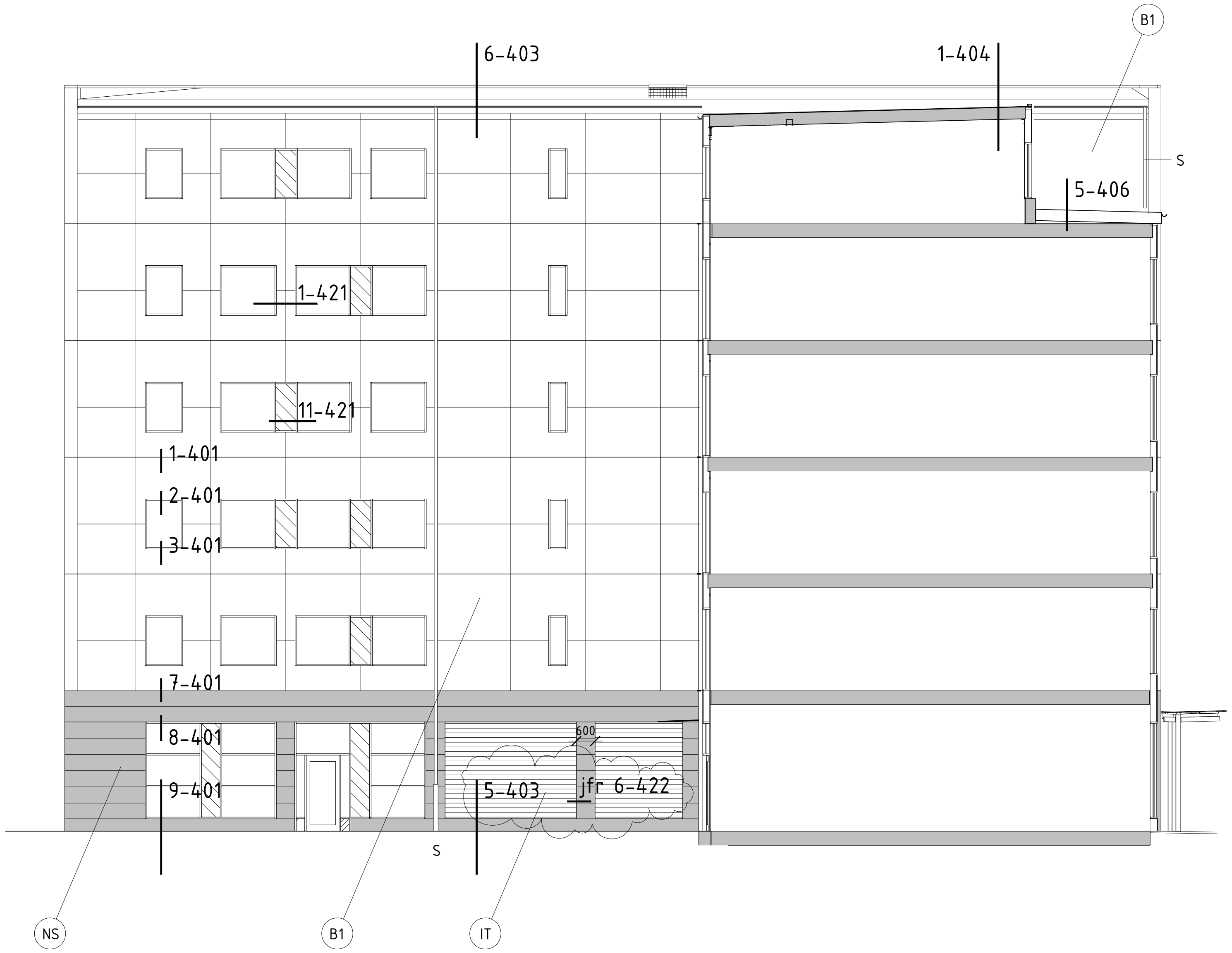
STAPELBÄDDEN 3, MALMÖ

FASAD MOT SÖDER

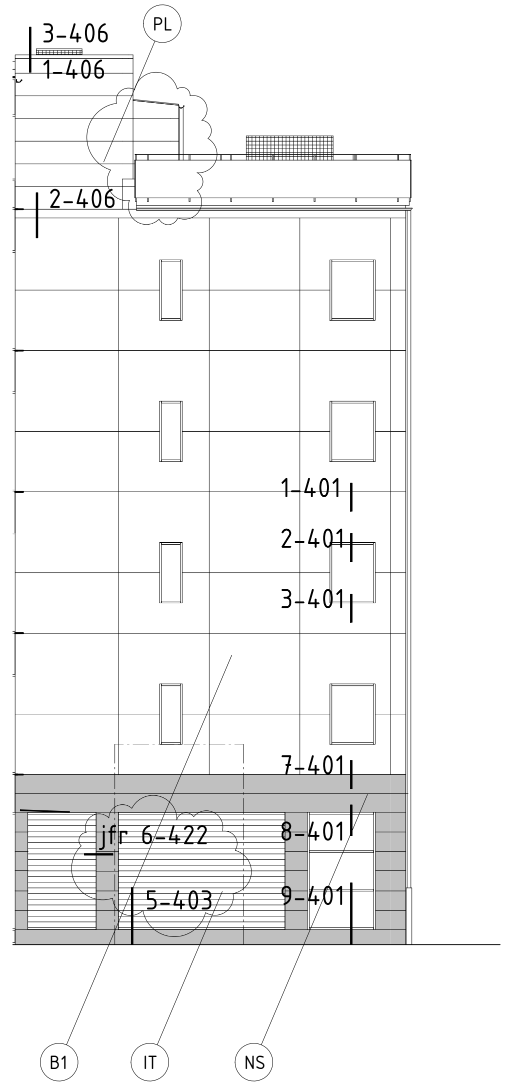
SKALA A1 1:100 A3 1:200 | NUMMER A-40.3-306 | BET C

FÖRKLARINGAR

SE RITNING A-40.3-301.



Fasad mot norr, gård



Fasad mot söder, gård

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BET	ÄNDRINGEN AVSER	DATUM	SIGN
C	ENLIGT ÄNDRINGS-PM A06	2011-11-30	AO
B	ENLIGT ÄNDRINGS-PM A03	2011-09-28	AO
A	ENLIGT ÄNDRINGS-PM A01	2011-07-07	AO

BYGGHANDLING

N

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR	RITAD/KONSTR. AV	HANDLÄGGARE
		AO YO

DATUM	ANSVARIG
2011-06-01	PER DAHLIN

STAPELBÄDDEN 3, MALMÖ

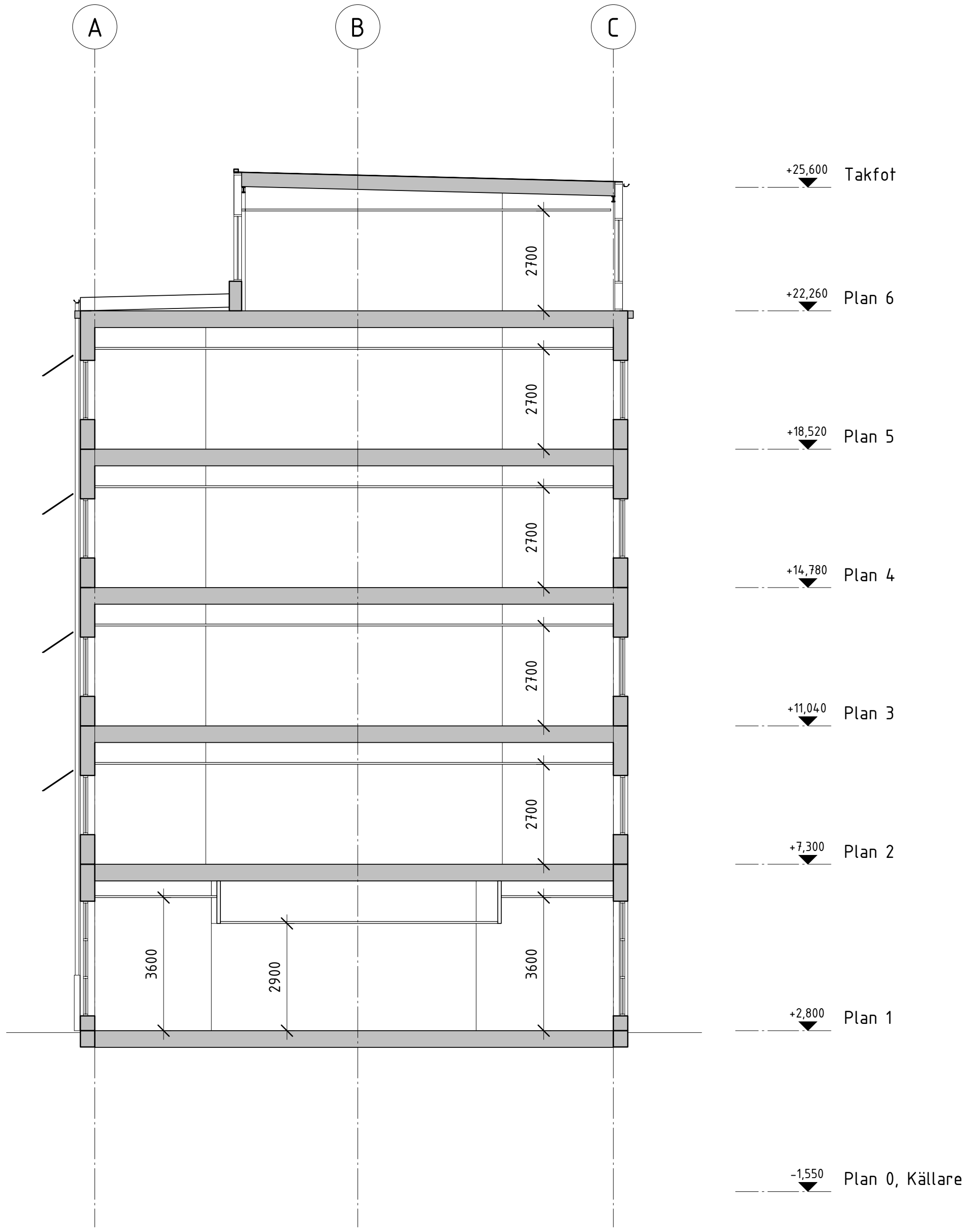
FASAD MOT GÅRD, NORR OCH SÖDER

SKALA	NUMMER	BET
A1 1:100 A3 1:200	A-40.3-307	C

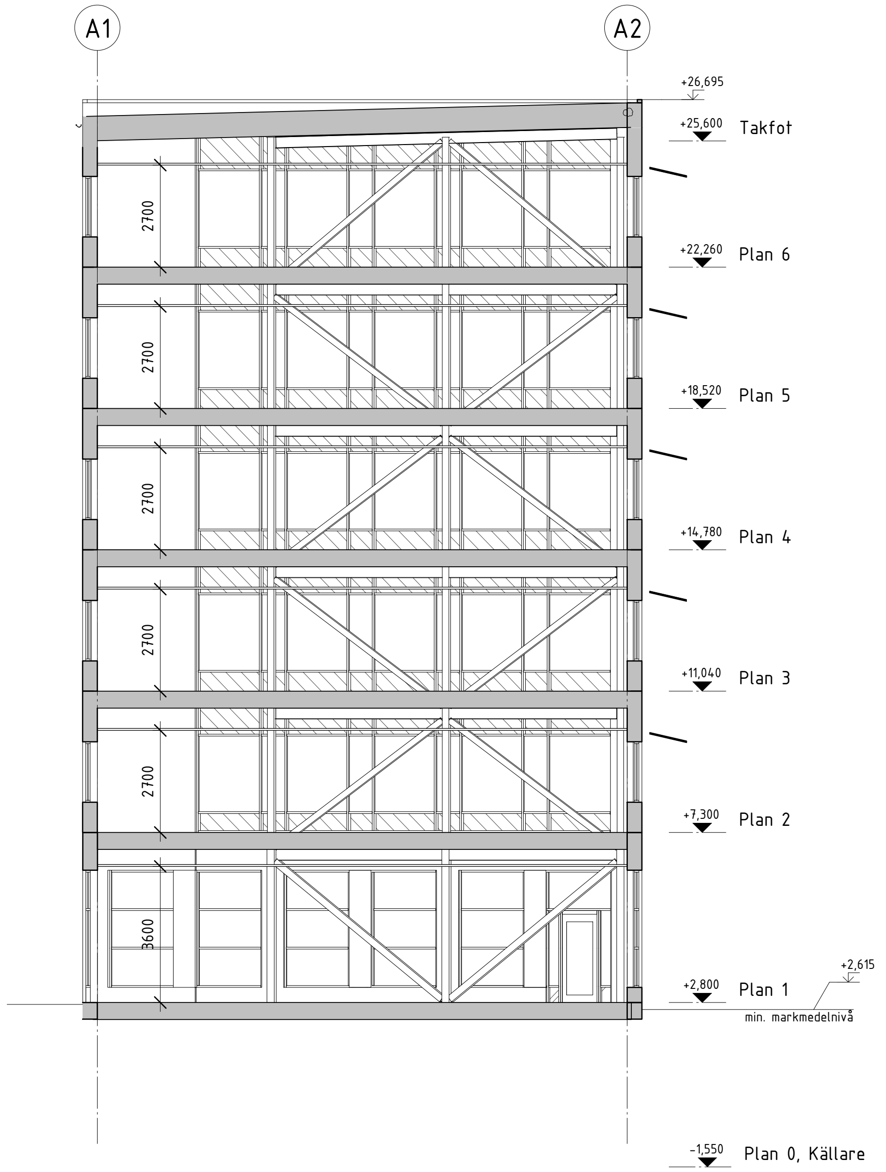
2011-11-30 09:42:44 C:\backup\A-40-V-Koggen2_ao.rvt

FÖRKLARINGAR

Se ritning A-40.2-201



Sektion C-C 100



Sektion D-D 100

0 1 2 3 4 5 10 m

BET	ÄNDRINGEN AVSER	DATUM	SIGN
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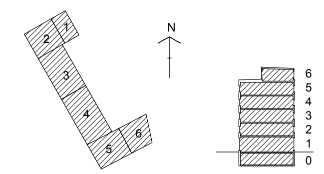
A	ENLIGT ÄNDRINGS-PM A01	2011-07-07	AO

BYGGHANDLING



KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR	RITAD/KONSTR. AV	HANDLÄGGARE
		AO YO

DATUM	ANSVARIG
2011-06-01	PER DAHLIN

STAPELBÄDDEN 3, MALMÖ

SEKTION C-C SEKTION D-D

SKALA	NUMMER	BET
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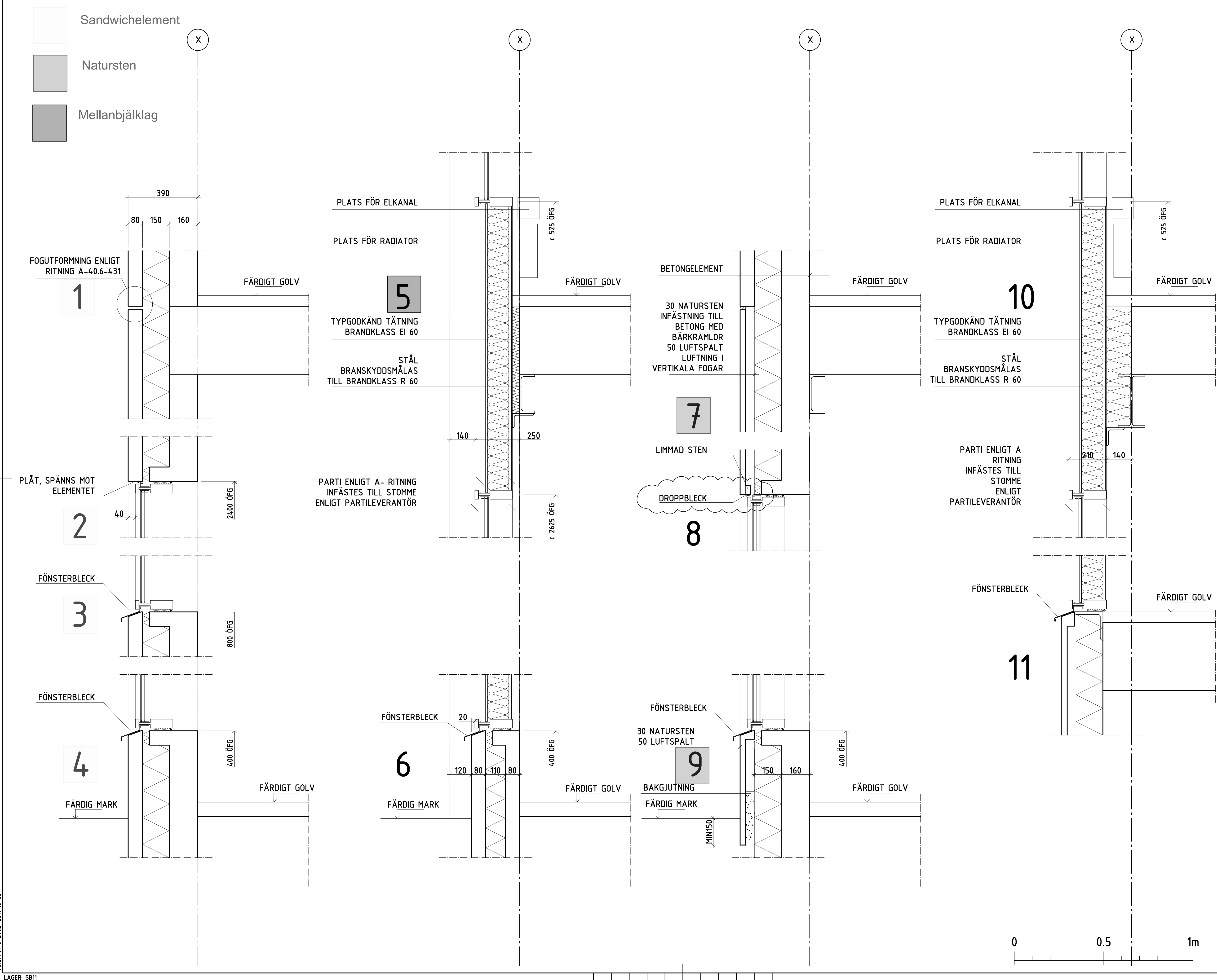

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A		ENLIGT ÄNDRINGS-PM A04	2011-10-06	AO

BYGGHANDLING

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC TEKNIK	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR	RITAD/KONSTR AV	HANDLÄGGARE
	SW	AO, YO

DATUM	ANSVARIG
2011-09-28	PER DAHLIN

STAPELBÄDDEN 3, MALMÖ

VERTIKALA DETALJER

SKALA	NUMMER	BET
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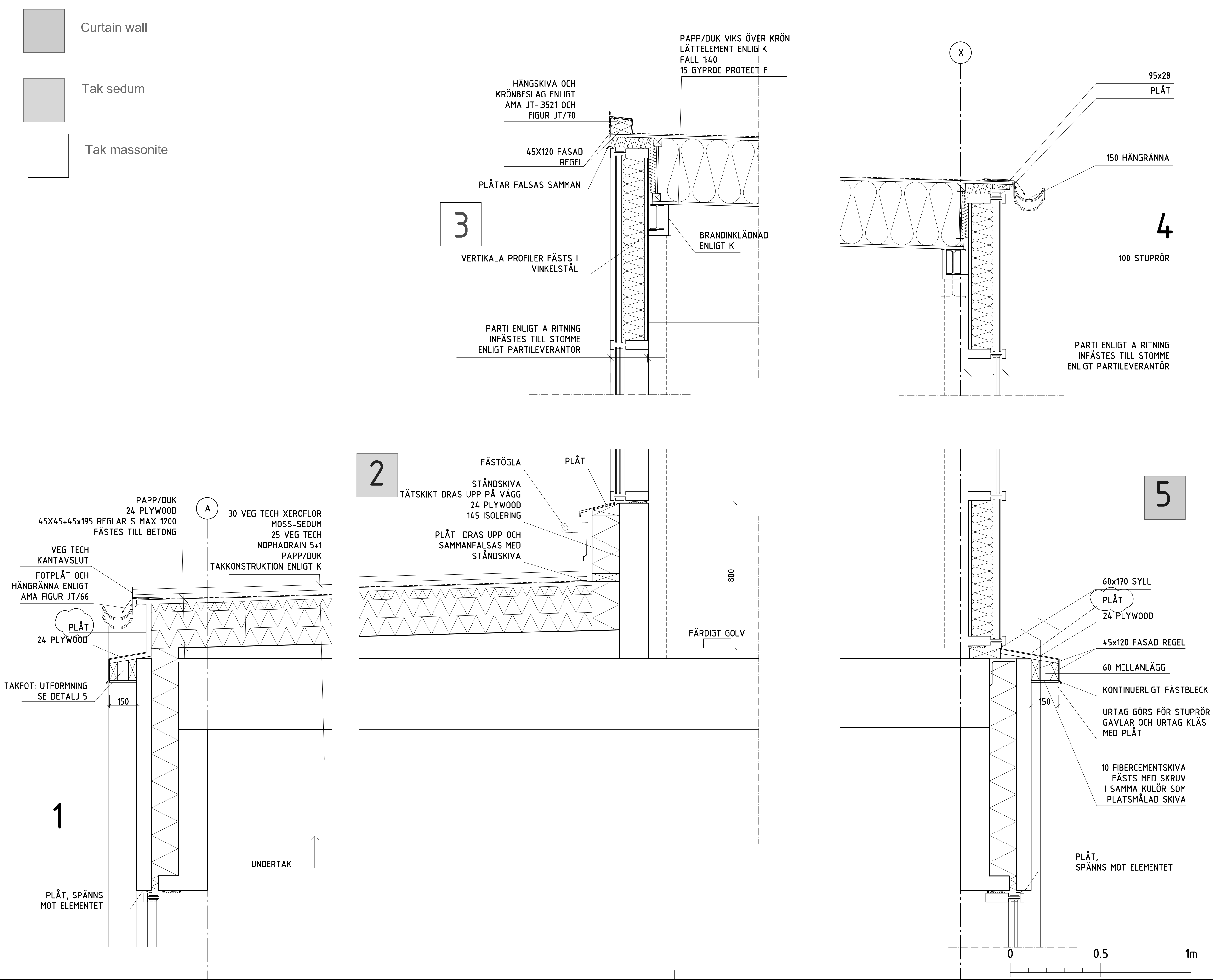

BET	ANT	ÄNDRINGEN AVSER	DATUM	SIGN
A		ENLIGT ÄNDRINGS-PM A04	2011-10-06	AO

BYGGHANDLING

N

KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC TEKNIK	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR	RITAD/KONSTR AV	HANDLÄGGARE
	SW	AO, YO
DATUM	ANSVARIG	
2011-09-28	PER DAHLIN	

STAPELBÄDDEN 3, MALMÖ

VERTIKALA DETALJER

SKALA	NUMMER	BET
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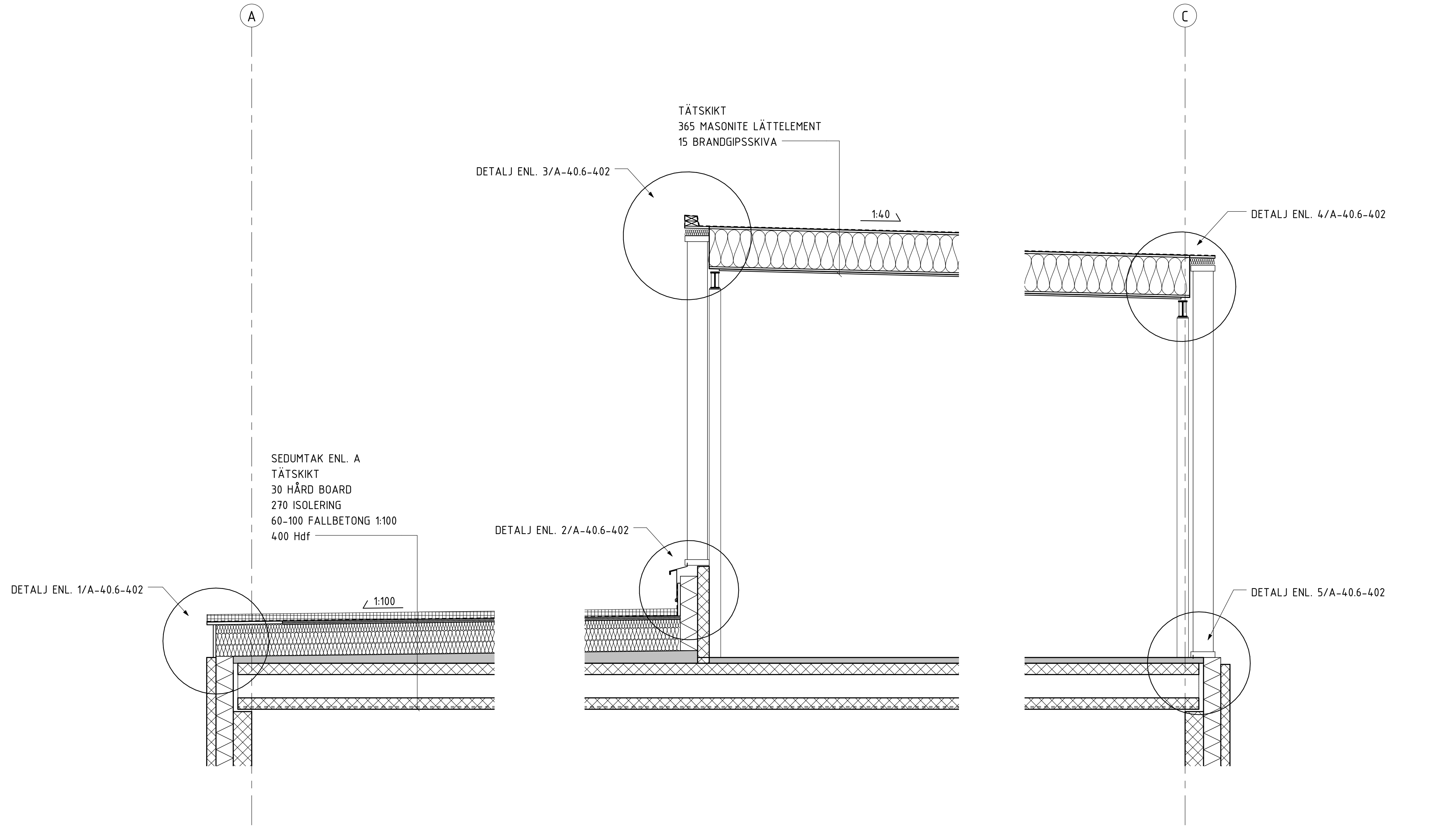
XREF: A40-D002 2011-10-06

LAGER: SB11

FÖRESKRIFTER:

ALLMÄNNA ANVISNINGAR K-01.0-001
TILL -003



A023
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BET	ÄNDRINGEN AVSER	DATUM	SIGN
	RELATIONSHANDLING	2012-09-21	AE

RELATIONSHANDLING

N
1 2 3 4 5 6
6 5 4 3 2 1 0

KOGGEN 2
VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR 7181209 | RITAD/KONSTR. AV AN | HANDLÄGGARE AN

DATUM 2011-10-19 | ANSVARIG ROGER PERSSON

KOGGEN 2

STOMDETALJER 3

SKALA A1 1 : 20 A3 | NUMMER K-20.6-023 | BET

2012-09-19 09:36:44

FÖRESKRIFTER:

ALLMÄNNA ANVISNINGAR K-01.0-001
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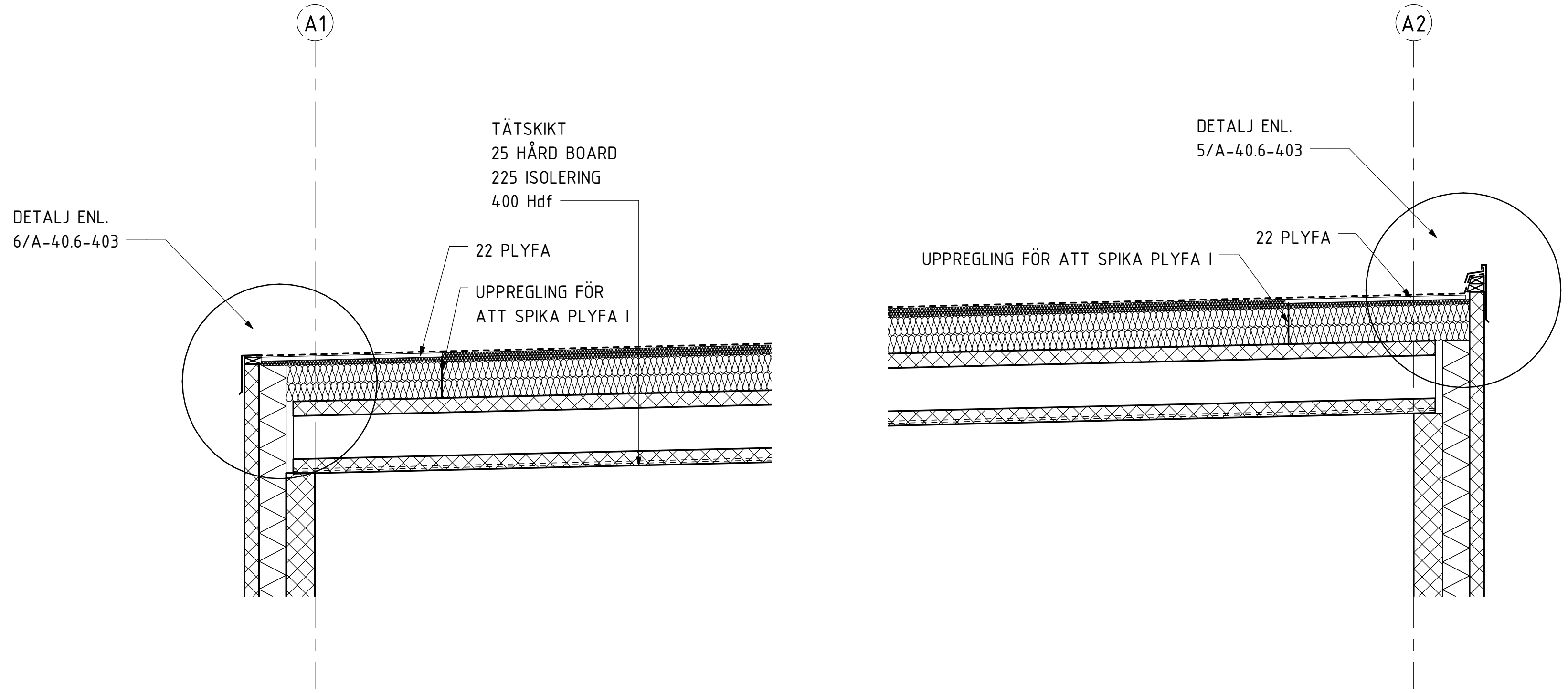

A025

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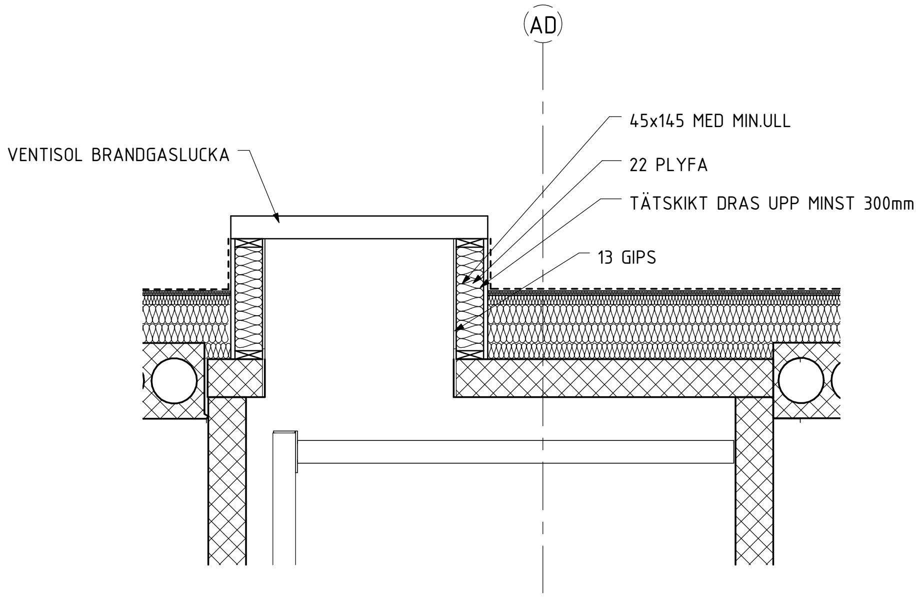

B025

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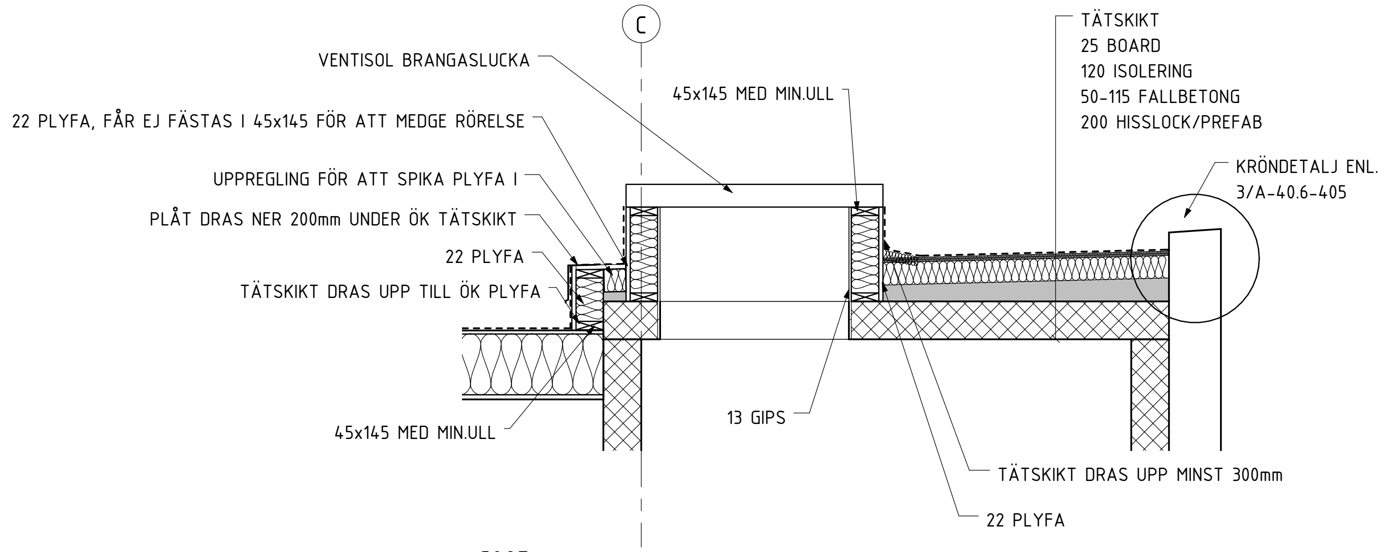

C025

1 : 20

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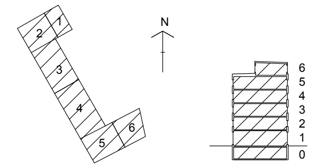
RELATIONSHANDLING



KOGGEN 2

VÄSTRA HAMNEN, MALMÖ

NCC

A	Arkitekturkompaniet	tel. 031-7449030
K	NCC Teknik	tel. 040-317000
VE	-	tel. -
VS	-	tel. -
E	-	tel. -
M	-	tel. -

UPPDRAG.NR	RITAD/KONSTR. AV	HANDLÄGGARE
7181209	AN	AN

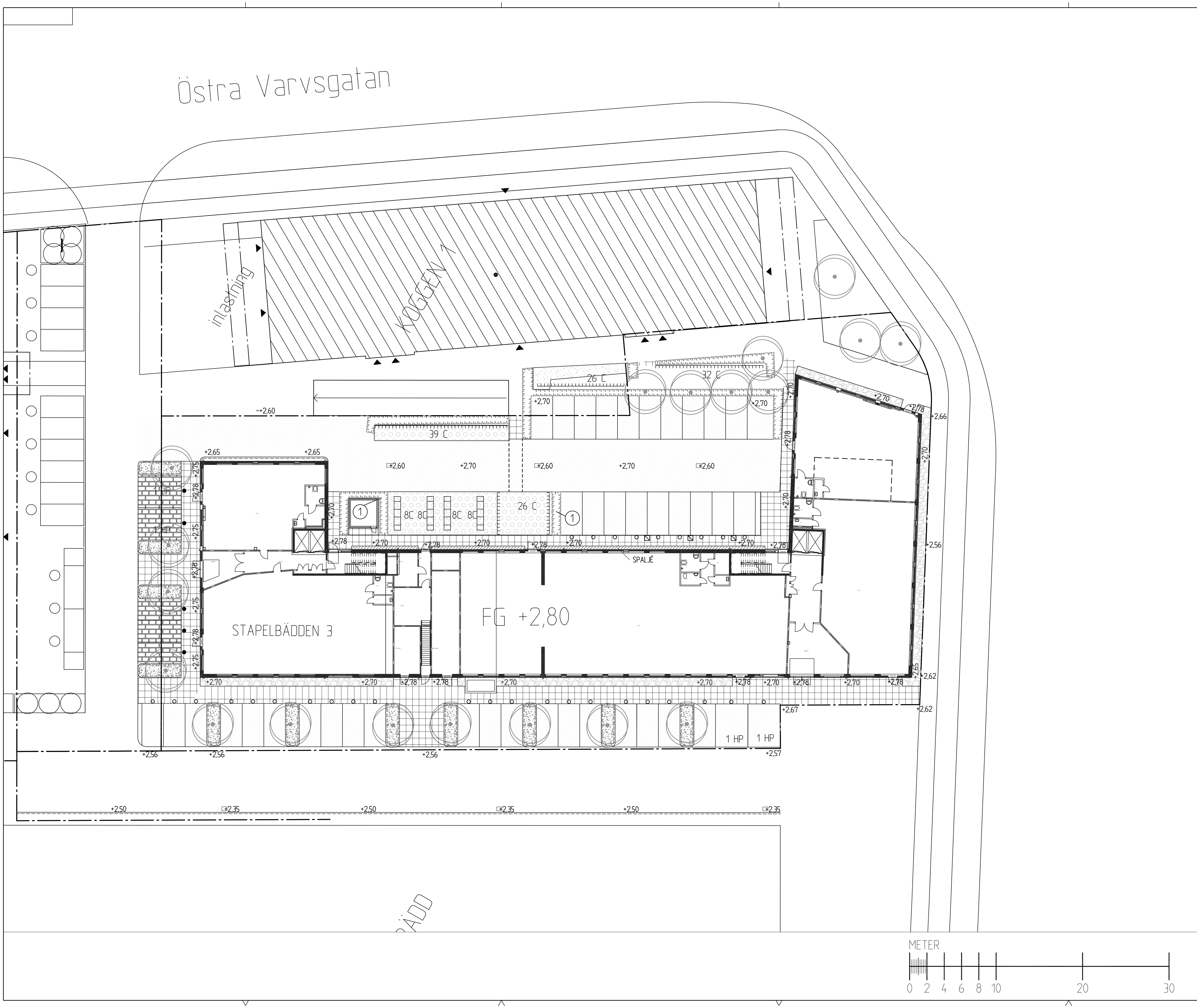
DATUM	ANSVARIG
2011-10-19	ROGER PERSSON

KOGGEN 2

STOMDETALJER 5

SKALA	NUMMER	BET
A1 1 : 20 A3	K-20.6-025	

2012-09-19 09:36:46



TECKENFÖRKLARING

+0,00	MARKHÖJD
	DAGVATTENBRUNN
	ÖPPEN ASFALT
	GRUSARMERING STENMJÖL 0-5 MM, RÖD
	PLATTYTA ST ERIKS PREMIUMPLATTA 50x50x5 CM
	GRUSYTA STENMJÖL 0-5 MM, RÖD
	BETONGSTEN STARKA UNI OPTILOCK ANTRACIT
	SJÖSTEN
	KANTSTÖD, BENDERS BETONGKANT
	KLÄTTERVÄXT PÅ SPALJÉ MURGRÖNA 'HEDERA HELIX'
	CYKELSTÄLL
	CYKELSTÄLL, GALAXY 34
	HÄCKAR, NAVERLÖNN 'ACER CAMPESTRE'
	MARKTÄCKANDE PLANTERING HAVTORN 'HIPPOPHAE RHAMNOIDES'
	TRÄD, OXEL 'SORBUS INTERMEDIA'
	P-SKYLTAR, HÖJD CA 1 M
	POLLARE MED BELYSNING. LIKA NCC:S P-PLATSER PÅ KAGGEN
	LADDNINGSSTOLPAR
	VÄGMÅLNING

BET	ANT	ÄNDRINGEN AVSER	SIGN	DATUM

RELATIONSHANDLING 2013-01-15

MARKLAGET AB
Drottninggatan 160
254 33 Helsingborg
Tel. 042-13 07 66
Fax 042-14 53 84
info@marklaget.se

UPPDRAG NR	HANDLÄGGARE	GRANSKAD AV
1150	MARTIN H	GÖRAN P

HELSINGBORG DEN	PROJEKTANSVARIG
2012-07-10	MARTIN HENRIKSSON

MALMÖ STAD
KOGGEN 2

MARKPLAN

SKALA	NUMMER	BET
A1 1:200 A3 1:400	M-03	