ZEB Project report 34 – 2017

Reidun Dahl Schlanbusch, Selamawit Mamo Fufa, Inger Andresen,
Tore Wigenstad and Torger Mjønes

ZEB pilot Heimdal high school and sports hall
Design phase report

The Research Centre on
Zero Emission Buildings

SINTEF Academic Press

Reidun Dahl Schlanbusch, Selamawit Mamo Fufa, Inger Andresen,
Tore Wigenstad and Torger Mjønes

ZEB pilot Heimdal high school and sports hall
Design phase report

ZEB Project report 34 – 2017

ZEB Project report no 34
Reidun Dahl Schlanbusch [2], Selamawit Mamo Fufa [2], Inger Andresen [1], Tore Wigenstad [3] and Torger Mjønes [4]
ZEB pilot Heimdal high school and sports hall
Design phase report

Keywords:
Design phase, Embodied GHG emissions, Material and design choices, Operational energy and emissions, Reference building

Illustration on front page: Skanska

ISSN 1893-157X (online)
ISSN 1893-1561
ISBN 978-82-536-1551-6 (pdf)

Norwegian University of Science and Technology [1]
N-7491 Trondheim
Tel: +47 73 59 50 00
www.ntnu.no
www.zeb.no

Skanska [3]
Postbox 1175, Sentrum, N-0187 Oslo
Tel: +47 40 00 64 00
www.skanska.no

SINTEF Building and Infrastructure Trondheim [2]
Høgskoleringen 7 b, Postbox 4760 Sluppen, N-7465 Trondheim
Tel: +47 73 59 30 00
www.sintef.no/byggforsk
www.zeb.no

Sør-Trøndelag fylkeskommune [4]
Fylkeshuset, Erling Skakkes gt. 14, N-7013 Trondheim
Tel: +47 72 81 10 00
www.stfk.no

SINTEF Academic Press
c/o SINTEF Building and Infrastructure Oslo
Forskningsveien 3 B, Postbox 124 Blindern, N-0314 Oslo
Tel: +47 73 59 30 00, Fax: +47 22 69 94 38
www.sintef.no/byggforsk
www.sintefbok.no

Acknowledgement

This report has been written within the *Research Centre on Zero Emission Buildings* (ZEB). The authors gratefully acknowledge the support from the Research Council of Norway, BNL – Federation of construction industries, Brødrene Dahl, ByBo, DiBK – Norwegian Building Authority, Caverion Norge AS, DuPont, Entra, Forsvarsbygg, Glava, Husbanken, Isola, Multiconsult, NorDan, Norsk Teknologi, Protan, SAPA Building Systems, Skanska, Snøhetta, Statsbygg, Sør-Trøndelag Fylkeskommune, and Weber.

Abstract

This report summarizes and documents the pre-project competition and design phase life cycle greenhouse gas (GHG) emissions of Heimdal pilot building project. The report describes the calculation methodologies; including operational energy performance, embodied greenhouse gas emissions (including the emissions from transport of materials), the building design and material choices, measures taken to reduce emissions from operational energy, materials and transport, as well as the ZEB balance. Special focus is given to the lessons learned from pre-project competition and the design phase of the project.

Contents

1. Introduction

1.1 Background

The idea of Heimdal high school and sports hall project originated in 2008 when the County Council of Sør-Trøndelag (Sør-Trøndelag Fylkeskommune, hereby referred to as STFK) decided to start a large investment program for the schools in the county. In April 2013, STFK decided to build a new high school and sports hall at Heimdal outside the city of Trondheim as a part of the development plan of this area [1]. The school is planned to open in 2018.

STFK set out to build a new energy efficient high school with an ambition of good indoor environment and low GHG emissions. STFK decided that Heimdal school and sports hall would become a pilot project within the Norwegian Research Centre on Zero Emission Buildings (ZEB Centre) and that STFK would be the first County (Fylkeskommune) to be a partner in the ZEB Centre. STFK wrote in a press release that the partnership with the ZEB Centre and the choice to make Heimdal school a zero emission school was made to reach the goals of reducing the greenhouse gas emissions in the county's activities by 50% [2].

1.2 Project process and phases

In 2014 STFK opened a competition for the planning and construction of Heimdal high school and sports hall. The competition was carried out in two phases. In the first phase, 8 design teams competed in the development of the conceptual project of the school and sports hall building complex. Three of the eight teams were selected to continue to the second phase. In June 2015, the competition was closed and Skanska was selected as the winner with their team partners KHR arkitekter and Rambøll.

When the competition was completed, Skanska started the planning in what could be called the pre-project phase, formally denoted phase 3. Phase 4 is what we here refer to as the design phase. In the design phase, corrections and changes of the pre-projects were performed. For instance, it was decided to increase the number of audience seats in the sports hall, which considerably influenced the material consumption. An application for financial support from Enova (www.enova.no) was sent during phase 4.

The groundwork for the building started at the end of March 2016, but changes to the design is an ongoing, continuous process. For instance, the groundwork proved to be more demanding than foreseen. This report documents the status of the design phase of the project, phase 4, and does not take into consideration any changes that were decided later than August 2016.

1.3 ZEB definition and ambition levels

The aim of the Norwegian ZEB research center is to develop competitive products and solutions for new and existing buildings resulting in zero greenhouse gas (GHG) emissions over the lifetime of the building. The ZEB Centre has developed a definition framework for zero emission buildings, including calculation methodologies for operational energy and life cycle CO_{2eq}[1] emissions. The Norwegian ZEB definition is characterized through a range of ambition levels ranging from the lowest (ZEB-O÷EQ), to the highest (ZEB-COMPLETE) [3]:

[1]GWP is calculated in terms of carbon dioxide equivalent (CO_{2eq}). CO_{2eq} is a term for describing different greenhouse gases in a common unit. Greenhouse gases than CO2e signifies the amount of CO2 which would have the equivalent global warming impact.

1. ZEB-O÷EQ: Emissions related to all energy use in operation "O" except energy use for equipment/appliances (EQ) shall be compensated for with on-site renewable energy generation.
2. ZEB-O: Emissions related to all operational energy "O" shall be compensated for with on-site renewable energy generation.
3. ZEB-OM: Emissions related to all operational energy "O" use plus embodied emissions from the materials "M" shall be compensated for with on-site renewable energy generation.
4. ZEB-COM: Same as ZEB-OM, but also taking into account emissions related to the construction "C" are included and need to be compensated for.
5. ZEB-COME: Same as ZEB-COM though emissions related to a scenario for the end-of-life phase “E” has to be included and compensated for.
6. ZEB-COMPLETE: Emissions related to a complete life cycle emission analysis have to be compensated for, namely all the phases, product stage (A1-A3), construction process stage (A4–A5), use stage (B1–B7), and end of life stage (C1-C4) as well as information on benefits and loads beyond the system boundary (D), according to EN15978.

The system boundary has been defined in accordance with the modular system of life cycle stages as defined in EN 15978, and the Norwegian ZEB ambition levels. Table 1.1 illustrates the relationship between the ZEB ambition levels and the modular lifecycle stages in NS-EN15978: 2011.

Table 1.1 Description of ZEB ambition levels according to NS-EN15978: 2011 [3].

	System Boundary NS-EN 15978:2011																	
	A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Benefits and loads
	A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D: Reuse, recovery, recycling
ZEB - O/EQ											*						
ZEB - O											x						
ZEB - OM	x	x	x						**		x						
ZEB - COM	x	x	x	x	x				***		x						
ZEB - COME	x	x	x	x	x				x		x		x	x	x	x	
ZEB - COMPLETE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

* Does not include operational energy of electrical equipment
** Does not include transport to building site (A4), installation into building (A5) or end of life treatment of the replaced materials
*** Does not include end of life treatment of the replaced materials
NB: Biogenic carbon should only be included at a ZEB-COME or ZEB-COMPLETE level

The ZEB Centre has evaluated two concepts and nine pilot buildings according to ZEB targets and calculation methodologies to find solutions that would balance out embodied and operational emissions with on-site renewable energy production (see Table 1.2). The projects vary in terms of building type, size, materials, technologies, construction methods, and locations, and have used different strategies to accomplish ZEB-targets.

Table 1.2 ZEB concept and pilot building projects, adapted from [3]

ZEB concept buildings	Type of building	Ambition level	Location
Single family house	Single family house	ZEB-OM	Assumed to be located in Oslo
Office building	Four story office building	ZEB-OM	
ZEB pilot buildings	**Type of building**	**Ambition level**	**Location**
Haakonsvern	Small office building	ZEB-O÷EQ	Bergen
Skarpnes	37 dwellings	ZEB-O	Arendal
Ådland	+500 dwellings	ZEB-O	Bergen
Heimdal VGS	School	ZEB-O20%M	Trondheim
Powerhouse Brattøra	Large office building	ZEB-COM ÷ EQ	Trondheim
Powerhouse Kjørbo	Office building	ZEB-COM ÷ EQ	Sandvika
Multikomfort	Single family house	ZEB-OM	Larvik
Living Lab	Single family house	ZEB-OM	Trondheim
Campus Evenstad	School	ZEB-COM	Hedmark

1.3.1 Setting ambitions and goals in the Heimdal pilot project

As summarized in Table 1.3, the ambition level for the project has been subject to discussions and changes. In the first phase of the pre-project competition, the aim was to achieve a ZEB-O ambition level including qualitative assessment of embodied emissions from materials and technical installations.

In phase 2 of the competition, the ambition level was raised from ZEB-O to ZEB-O20% M (i.e. all greenhouse gas emissions associated with operational energy and 20% of material emissions should be compensated for with production of renewable energy). In addition, ZEB requested that the emissions associated with the transport of materials (initial materials and replacements) were to be calculated in addition. The transport emissions were to be declared separately, as transport is not included in the ZEB-OM ambition level definition [3]. The transport requirement was, however, interpreted by the design teams as a part of ZEB-O20% M. This and other communication challenges are discussed in chapter 9.6.

When the competition was completed in the spring 2015, the winning team started to plan the building in what could be called the pre-project phase or the design phase. Here, we will use the term design phase. See chapter 1.2 for an overview of the project phases. The material GHG emissions calculations results from the competition (10kg of CO_2eq/m^2/year) were set as the binding target in the project. In addition, the plan was to stick to the ZEB-O20%M ambition.

As mentioned in chapter 1.2, some important changes in the building design came across during the spring of 2016, including for instance a more elaborate groundwork than planned, more audience seats in the sports hall, more fire safety emergency exists, etc. The ZEB-O20%M ambition level was evaluated to be too difficult to achieve. It was then decided to set the target to ZEB-O, and at the same time STFK decided that an emission target should be articulated by the use of a comparison to a reference building. The reference building methodology is described in chapter 7. The goal was set on reducing the emissions for the Heimdal Pilot project with 20% compared to the reference building.

Table 1.3 Development of the emissions target for the Heimdal pilot project.

Project phase		Emission target
Competition	Phase 1	ZEB-O + qualitative assessment of M
	Phase 2	1. ZEB-O20%M, 20%M meaning 20% of emissions from materials should be compensated 2. ZEB-O20%M + transport of materials
Design phase	Phase 3	Keep ZEB-O20%M and stay below contractual total embodied emissions per year: 10 kg $CO_{2eq}/m^2/y$ – O, M and transport of materials included
	Phase 4	ZEB-O and reduce embodied emissions with 20% relative to a predefined reference building. Emissions from O, M, and transport of materials included.

The ambivalent nature of the ambition level in the project is discussed in chapter 9. Chapters 4 and 5 present the O and the M calculations for both the school building and the sports hall. We will also show the transport calculations. Chapter 6 presents the ZEB balance calculations and chapter 7 presents the comparison with the reference building.

1.4 Aim and scope of the report

The objective of this report is twofold:

1. To tell the story of the lessons learned from the pre-project competition and the design phase of the project
2. To document the embodied emissions and the projected operational energy emissions in the design phase of the Heimdal school and sports hall pilot project

The report describes the calculation methodologies; including operational energy performance, embodied greenhouse gas emissions (including the emissions from transport of materials), the building design and material choices measures taken to reduce emissions from operational energy, materials and transport, as well as the ZEB balance.

This report is divided into 9 Chapters. After the introductory chapter, two chapters follow summarizing the pre-project competition process, building envelope design and services including the description of design and material choices considered, and the energy supply system. The methodologies and results of the calculations of operational energy performance and the associated GHG emissions, and the embodied GHG emissions associated with the materials are presented in chapters 4 and 5 respectively, followed by the ZEB balance in chapter 6. Furthermore, the comparison of the embodied emissions of the design to a reference building and the indoor climate are presented in chapters 7 and 8. The lessons learned from this study are summarized in the discussions and conclusions part in chapter 9 of the report.

2. Pre-Project Competition

2.1 Competition and evaluation process

In the first phase, 8 design teams competed in the development of the conceptual project of the school and sports hall building complex according to the requirement set by STFK [4]. In terms of ZEB ambition levels, the requirement was set to ZEB-O including a qualitative description of reductions in embodied emissions.

In the first phase of the competition, ZEB contributed with advice and dialogue with STFK about competition requirements for sustainability. ZEB also interacted with the competitors through workshops, training, and advice. A common workshop was held on April 8th 2014 where ZEB provided training in calculation and documentation of operational energy, indoor environment, and greenhouse gas (GHG) emissions calculations of materials. The last part included a group work where the teams solved cases related to the usage of environmental product declaration (EPD) data. Examples of concepts and solutions for zero emission buildings were also shown. Three of the eight teams were selected to continue to the second phase. ZEB also contributed to the selection of the three winning teams by evaluating the projects with respect to the ZEB criteria.

In the second phase, the three teams developed their concepts further. Figure 2.1 shows illustrations of the three design contributions from phase 2.

a.

b.

c.

Figure 2.1 Illustrations of the three designs competing in the second phase of the competition: a) team Reinertsen/Hus Arkitekter, b) team Aasen bygg/LINK arkitektur, and c) team Skanska/Rambøll/KHR Arkitekter.

As a part of the requirements set by STFK for phase 2 [5], the ZEB Centre defined requirements for the evaluation of the energy performance and embodied emissions concepts of the three teams as described in Appendix 1. In terms of ZEB ambition levels, the requirement was set to ZEB-O20%M, including a separate greenhouse gas calculation of the transport of materials to the building site (See section 1.3.1 for more information on this ambition level). More important than the ambition level itself is the documentation of the measures taken to reduce emissions from operational energy, materials, and transport. STFK and the ZEB Centre accentuated that the documentation of the measures was given a heavier weighting in the evaluation of the final sum of CO_{2eq}/m^2 in the competition. The teams were given access to a spreadsheet tool developed by the ZEB Centre (see chapter 5.1) for calculating the embodied emissions in their designs. The spreadsheet allowed for entering different materials and transport distances in order to find the GHG emissions reduction potential. In a workshop on October 29th 2014, the spreadsheet tool was demonstrated and instructions were given by the ZEB Centre. The teams were asked to report and describe the measures taken to reduce embodied emissions in phase 2.

Representatives of the ZEB Centre evaluated the designs with regard to energy efficiency, indoor environment, and embodied emissions, and the input was used as part of the background information for selecting the winner of the competition. The evaluation and comparison of the projects with respect to GHG emissions was challenging due to a very varying quality of the documentation and uncertainties in the numbers. The quality of the documentation, methodology, and reporting was weighted heavily. The calculations and descriptions were thoroughly investigated and carefully compared. Several experts from the ZEB Centre were involved, and there was a close collaboration with STFK.

Some of the most important measures for material emission reductions that were suggested by one or more of the teams included:

- Placing the sports hall relative to the school building in a material efficient way (for instance, overlapping location reduces demand for roofing materials)
- Using low carbon concrete (with fly ash)
- Reducing the overall concrete demand through slimmer load-bearing structures and replacements with other materials.
- Covering large areas of the external walls with timber cladding
- Minimizing the areas of glazed external walls within the limits of the daylight requirements (glass is a relatively energy intensive material to produce)
- Applying recycled aluminum (recycled aluminum requires only 10% of the energy demand of producing virgin aluminum)
- Smaller dimensions of technical conduits (less metal demand)
- Electrochromic windows[2] as shading strategy to lowering the need for cooling Extended use of wood as a construction material
- Choosing building materials with long lifetimes in order to reduce emissions from replacements (replacements, module B4, is included in ZEB-OM, see chapter 1.3).

[2] Electrochromic windows able to regulate the solar radiation throughput by an application of an external voltage. They can decrease heating, cooling, and electricity loads in buildings by admitting the optimum level of solar energy and daylight into the buildings at any given time (Jelle and Arild, 2010).

Some of the teams also made an effort to pick local materials, a measure that would save emissions associated with transport. Some of the teams highlighted the importance of cooperation between the purchasing department of the entrepreneur, the contractor, and the architect when it comes to selecting low-carbon materials.

The team led by Skanska won the Heimdal school and sports hall design competition in June 2015. Figure 2.2 shows an illustration from Skanska's contribution to the competition.

Figure 2.2 Illustration showing the competition entry from Skanska [6].

3. Building Design and Services

3.1 Key information

The ZEB pilot buildings of Heimdal school and sports hall is located south of central Trondheim, more precisely in the Saupstad-Kolstad area, which is a part of the administrative center of Heimdal. The complex consist of a school building of 18 675 m² heated floor area (BRA) and the sports hall of 7 681 m² BRA. The new school will accommodate 1140 students when it opens in 2018. The building includes a sports hall and a parking space in the basement. Sports, arts, and culture will play central roles in the new building. The sports hall will be an arena used for both sports and cultural events with a capacity of up to 4000 people. The cultural hall includes a stage and 350 audience seats. The key data for Heimdal pilot building is summarized in Table 3.1. Figure 3.1 shows the cross section of model of the new Heimdal school and sports hall taken from the contribution of Skanska in the second phase of the design competition [6].

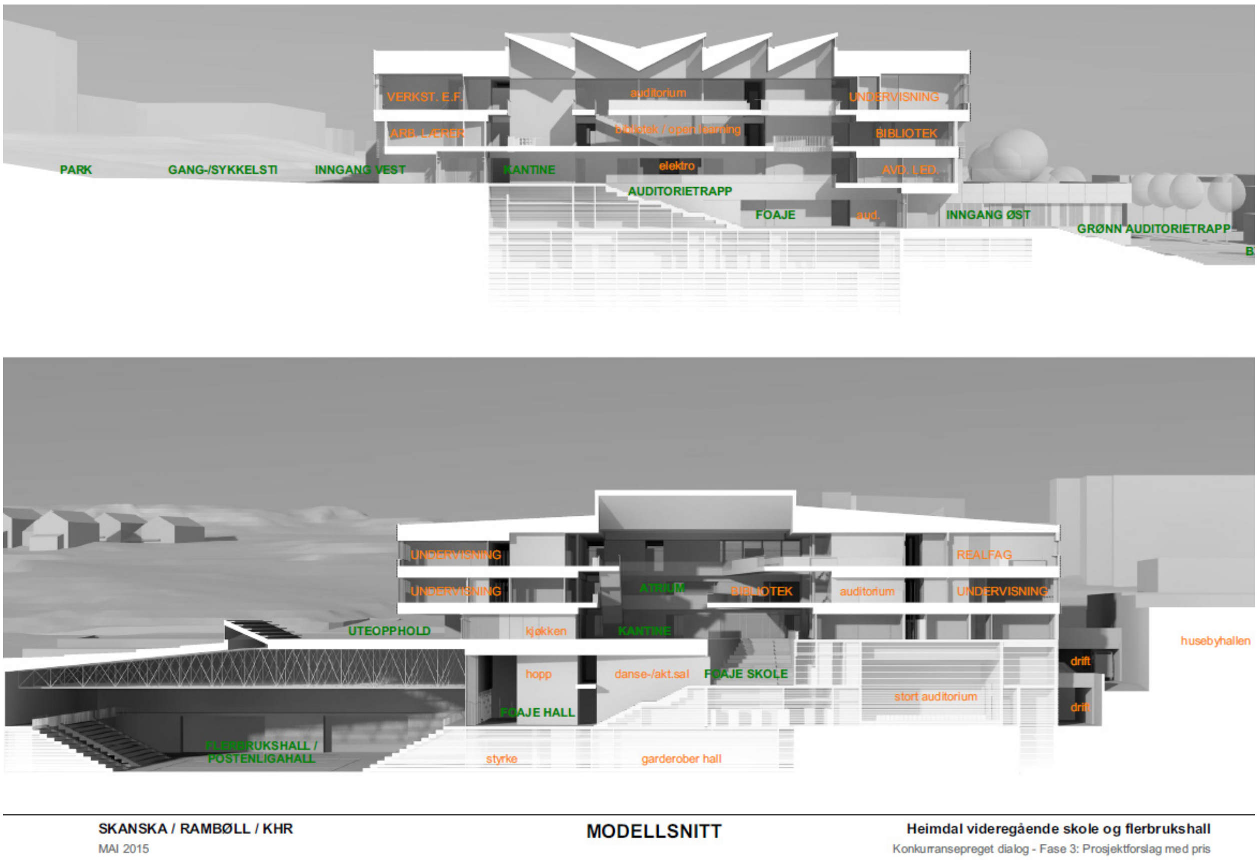

Figure 3.1 Cross section of model of the new Heimdal school and sports hall [6].

The base of the school and sports hall will have a polished concrete foundation, fiber cement boards, and wooden window frames. On top is the atrium with untreated wooden cladding. The building has some innovative elements, for instance electrochromic glass windows for dynamic shading – the first of its kind in Norway [6].

A ground-source-to-water heat pump is designed to supply heating to the building. Photovoltaic panels will be installed on the roof for production of electricity. A biogas-based combined heat and power (CHP) unit is to be installed to deliver heat and electricity to the building, and excess heat will be exported to a nearby swimming pool.

Table 3.1 Key data for Heimdal pilot building

Key Data	
Name and address	Heimdal high school and sports hall, Trondheim
Location data	Latitude 63°4'N, Longitude 10°4'E. Annual ambient temperature: 5.1 °C, Annual solar horizontal radiation: 890 kWh/m^2/year.
Building type	High school (with 18 675 m^2 BRA) and sports hall (with 7 681 m^2 BRA)
Heated floor area	26 356 m^2
Project type	New construction
Building owners	Sør Trøndelag county
Design team	KHR (architect), Rambøll (architect and technical consultant), Skanska (contractor and energy concept), and the ZEB Research Centre (energy and GHG emissions)
Design phase / Construction phase	2014-2016 / 2016-2018
Opening	2018

3.2 Building envelope

The main building components and materials used in the Heimdal pilot building is summarized in Table 3.2. See chapter 3.4 for more detailed descriptions including the measures taken to reduce embodied emissions of the building.

Table 3.2 Main building components and materials used in Heimdal pilot building

Building Parts	**Building materials**	
	School	**Sports hall**
Groundwork and Foundations	EPS insulation, strip- and pile foundations. Partly low-carbon concrete.	EPS insulation, strip- and pile foundations. Partly low-carbon concrete. Concrete piles.
Superstructure	***Lower floors***: Concrete load-bearing walls and columns partly made of low-carbon concrete. Structural decks of in-situ concrete. ***Higher floors***: elevator conduits of in-situ concrete, partly low-carbon. Hollow decks, steel columns, beams and trusses. ***Roof construction***: superstructure of steel and light roof elements	Concrete load-bearing walls containing low-carbon concrete. Steel trusses and concrete hollow decks in the roof, which is situated below ground level.
Outer Wall	Wooden studs and blow-in mineral wool insulation. Fiber cement building boards or plaster.	Mainly concrete walls as the sports hall is below ground level.
Inner Wall	Fibre gypsum and steel profiles. Wooden studs wherever possible. Fermacell gypsum boards.	Fibre gypsum and steel profiles. Wooden studs wherever possible. Fermacell gypsum boards.
Floor Structure	Slab on ground with insulation, radon membrane. Screed and flooring or polished concrete floor on top of the load-bearing concrete decks.	Slab on ground with insulation, radon barrier. Screed and flooring or polished concrete floor. Sport floor with plastic covering.
Roof	Light roof elements	Light roof elements
Technical Equipment	Pipework for heating, material for ventilation system, lighting and electrical system, CHP unit, PV, HP, elevator	Pipework for heating, material for ventilation system, lighting and electrical system

3.3 Building services

3.3.1 Ventilation

The ventilation system that was initially proposed was a displacement type applied to every room. The advantage of this system from the energy context is that it achieves the same ventilation effectiveness as that of mixing type ventilation, but with less supply air flow (less airflow per floor area). However, the displacement ventilation system may in some cases cause draft problems in the nearby area around the supply air diffusers, which could mean restrictions in utilizing the space. At the pre-project phase, the ventilation system was changed to a mixing type ventilation with supply and exhausted air diffusers placed in the ceiling. However, for the larger rooms in the school and sports hall, the displacement ventilation system was retained. The solution is based on decentralized systems where the spaces are divided into many relatively small ventilation zones, and all of these are supplied by separate air handling units (AHU). This system provides good opportunities for optimization and airflow control based on zonal load. Within each zone, the ventilation flow is controlled by several sub-zones or rooms, where a space with the highest load / airflow requirements governs the operation of the AHU.

3.3.2 Heating

The space heating solution was initially planned via the ventilation air. Due to challenges of controlling the heating at room level and uncertainties regarding the system efficiency, the proposed solution was changed to a more traditional solution with radiator/ or underfloor heating in the room /or zone level.

3.3.3 Cooling

Ventilation units are integrated with a combined heating and cooling coil, which enables cooling with ventilation air. Since schools are closed during the summer, it is expected that the cooling demand will be small.

3.3.4 Lighting

The building is designed to maximize daylight utilization in order to minimize the amount of artificial light required. Optimal management of the lighting need is considered using demand control lighting system and energy efficient lighting appliances. Automated lighting controls which automatically switch or dim lighting systems based on factors such as whether the space is occupied, the amount of available daylight, and the current level of light output from the lamp, are considered. Energy efficient lighting fixtures, such as LED technology, are used to reduce energy consumption for artificial lighting. In addition, an emergency lighting system was designed according to NS 3926-1:2009 [7].

3.3.5 Elevator

An elevator system which fulfils the universal design requirement is included in the design of the building. Three stainless steel passenger elevators in the school building and one from the parking area were considered in the design. In addition, one freight elevator is considered for transport of goods in and out of the sports hall.

3.3.6 Waste collection

An integrated waste collection system is considered in the building design. 12 pieces of waste bins with two rollers, one for paper waste and one for residual waste, are used in the building. The delivery point for the waste is the common public collection bins between the new building and the neighboring public building with a swimming pool (Husebybadet).

3.4 Building design and material choices

This chapter summarizes the design and material choices made to reduce the embodied emissions (M) in the project[3]. According to Jelle et al. [8], multiple measures can be implemented for low embodied emission design. Some of these measures are:

- *Reduce the amount of materials used.*
- *Reuse and recycle materials.*
- *Select materials with low embodied emissions.*
- *Source local materials.*
- *Choose durable materials.*

In order to obtain zero emission buildings, it is necessary to combine several of these strategies, if not all, and the Heimdal pilot building is a proof of this. Careful material selection alone is not enough, but must be combined with reuse and recycling, as well as generally using less materials. An example of what was done in the Heimdal project was designing a thinner retaining wall for the sports hall and a lighter roof construction in order to reduce the amount of structural steel needed in the building. This strategy demonstrates how designing a lighter construction can lead to reduced material use.

The question here is, how much impact do these design and material choices have on the global warming potential of the building? Quantifying the effect requires a comparison with alternative design choices or a hypothetical reference building. In some projects, greenhouse gas emission calculations are introduced to improve the sustainability of an existing design. In such cases, the improvement can be quantified. This was not possible in the Heimdal pilot project as the embodied emission optimization was considered from the very beginning of the design process. In chapter 7, we present Skanska's approach to compare the embodied emissions of the design to a reference building.

Complete life cycle inventory tables can be found in appendix 2. A summary of the building components and materials is found in Table 3.1. In this chapter, we present some of the measures taken for the reduction of greenhouse gas emissions associated with the materials.

3.4.1 Groundwork and foundation

In the initial GHG calculations during the competition (phase 2), it was shown that about 55% of the total emissions originating from the groundwork and foundation came from excavation works. In order to minimize these emissions, the potential reuse of excavation materials for drainage backfilling was evaluated. However, this solution was considered impractical because of challenges related to storage capacity and also because considerable amounts of the masses at the building site were suitable for backfilling. Low carbon concrete was applied.

[3] Chapter 3.4 is mainly based on:

- The report produced by Skanska "Heimdal VGS – Reduksjon av M", which was handed from Skanska to ZEB and STFK on August 19, 2016
- Greenhouse gas emissions calculation for the materials in the design phase as of August 19, 2016 (Spreadsheat ZEB M-Regneark Skole rev 18 and ZEB M-Regneark Flerbrukshall rev 18)
- The report produced by Skanska "Heimdal VGS og flerbrukshall - Klimagassutslipp fra materialer Fase 4", which was handed from Skanska to ZEB and STKF on January 15, 2016
- A memo produced by SINTEF " Heimdal VGS: Innspill fra ZEB", which was handed from SINTEF to Skanska on February 1, 2016
- E-mail correspondence and communication during the design phase.

3.4.2 Outer walls and windows

Two window solutions were compared, using Norwegian EPD data. The first window alternative has a simple wooden framework, whilst the second window alternative includes an aluminum cladding on the wooden frame. The wooden alternative has lower GWP in the product phase (A1-A3), resulting in emissions of 130 kg CO_{2eq} per functional unit compared to the aluminum clad timber frame alternative which has emissions of 155 kg CO_{2eq} per functional unit [31]. However, the first alternative has an estimated service life time (ESL) of 40 years, whilst the second alternative has an ESL of 60 years due to its protective aluminum cladding. For both cases, a glazing with ESL of 30 years is considered in the calculation. Since the reference service life of Heimdal school is set to 60 years, this gives one replacement for the first window frame alternative, zero replacements for window frame and one replacement for the glass for the second alternative. Thus, when the emissions from the product phase (A1-A3) and replacement phase (B4) are combined, the GWP results from the first alternative far exceed that of the second alternative (see Table 3.3). In the Heimdal pilot project, windows with aluminum cladding were used.

Table 3.3 Two window alternatives with different frames evaluated in Heimdal pilot building.

Window types	A1-A3 ($kgCO_{2eq}$)	B4 ($kgCO_{2eq}$)	A1-A3 and B4 ($kgCO_{2eq}$)	Reference
NorDan NTech Inward opening tilt & turn window 105/80- wooden frame without aluminum cladding	130	130*	260	NEPD00176ERev 1
NorDan NTech Inward opening tilt & turn window 105/80- wooden frame with aluminum cladding	155	83,5**	239	

** Emissions from replacement of the window frame and the glass*
***Emissions from replacement of the glass*

3.4.3 Inner walls

The greenhouse gas emission calculations from the phase 2 showed that the inner walls made up a large share of the total emissions. Similar to the process for the decks and floor structures, it was investigated if a massive wood wall system could reduce emissions. The walls surrounding the educational areas, as well as some specific walls in the 4th and 5th floor were identified as possible candidates for massive wood construction. Three different alternative inner wall constructions were considered. One based on fiber gypsum boards fixed with steel profiles, one based on fiber gypsum boards fixed with wooden studs, and one based on cross-laminated timber (CLT). The technical details and assumptions of the alternative wall constructions can be found in [9]. Figure 3.2 shows the comparison in terms of embodied emissions, from which it can be seen that the CLT solution has the lowest impact.

However, according to Skanska, only 30% of the wall area was available for two-sided massive wood constructions due to fire safety requirements and technical conduits [9]. Therefore, the total emission reduction impact of this measure on the total embodied emissions of the building was considered to be low. The effect of choosing CLT was considered too low considering the investment cost. Skanska chose the fiber gypsum/steel profiles alternative, but installed wooden studs in parts of the inner walls. The use of Hunton Fermacell fibre gypsum boards was assumed to substitute several layers of normal gypsum boards, but the effect of this on embodied emissions were not quantified.

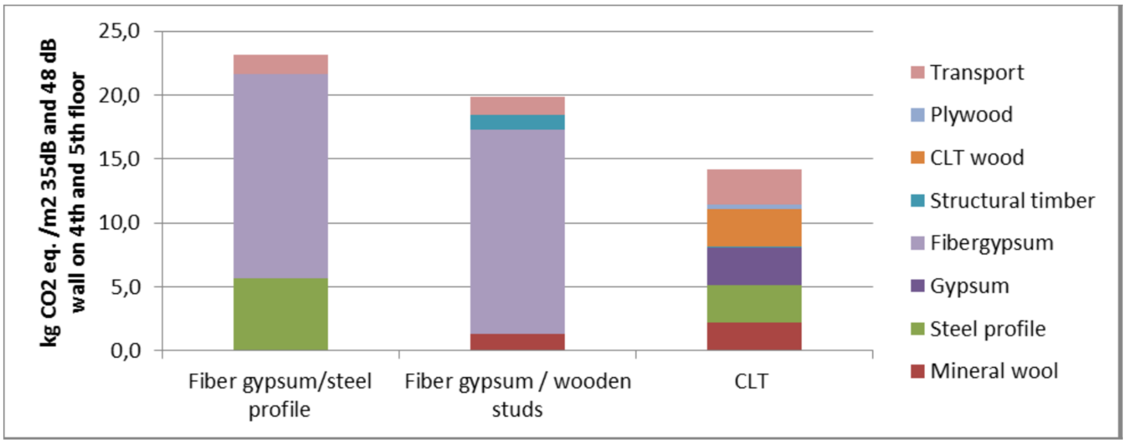

Figure 3.2 Comparison between different wall constructions.

3.4.4 Decks and floor structure

The ground floor consists of concrete cast on site, with insulation and a radon membrane due to load bearing, moisture, and radon gas considerations. The first floor contains functions that generate a lot of sound such as gymnasiums, rehearsal rooms, and dance studios. The originally planned floor structure based on hollow concrete decks (from the phase 2 competition) showed a high contribution to CO_{2eq} emissions in the early design phase. This was therefore a prioritized area for impact assessment, and different options were considered. NS-EN 15804:2012 states that comparisons at the sub-building level, e.g product systems, must ensure that the technical performance of the products is the same. In this case, this meant for instance that the environmental impact assessment and following comparison of the two solutions took into account:

- Load-bearing capacity
- Fire proofing
- Sound proofing
- The impact on the load-bearing structure as a consequence of the different weight of the two alternative solutions.
- Impact of the thickness of the deck on the building structure height

Furthermore, transport (A4) of the materials was included in the comparison. A cross-disciplinary workshop was held in October 2015 in order to evaluate alternative solutions that could minimize the emissions without compromising the structural and fire safety or changing the architectural quality. Based on a list of technical requirements, two alternative solutions were worked out. The two alternatives included one solution with concrete hollow decks (HD265) with 20 mm mineral wool insulation, a layer of low carbon concrete (0,14m^3/m^2 B30/35 MF40), 15 mm screed, and 2mm linoleum floor covering with a 2 mm of sound-proofing foam layer. The other solution is based on massive wood (KL330). It consist of a wooden hollow deck solution with 20 mm mineral wool insulation, 13 mm gypsum board, 20 mm sound proofing (Glava trinnlydsplate) 0.2 mm PE foil, 35 mm screed, and a 2 mm linoleum covering. Product specific EPDs have been used as background data in the impact assessment. Generic data from Ecoinvent 2.2 substituted missing EPD data. Specific products and suppliers had not been chosen at this stage. Therefore, the environmental impact assessment was performed using EPDs with a minimum (best case) and a maximum (worst case) value of CO_{2eq} for each of the two alternatives. The results are shown in Figure 3.3 below.

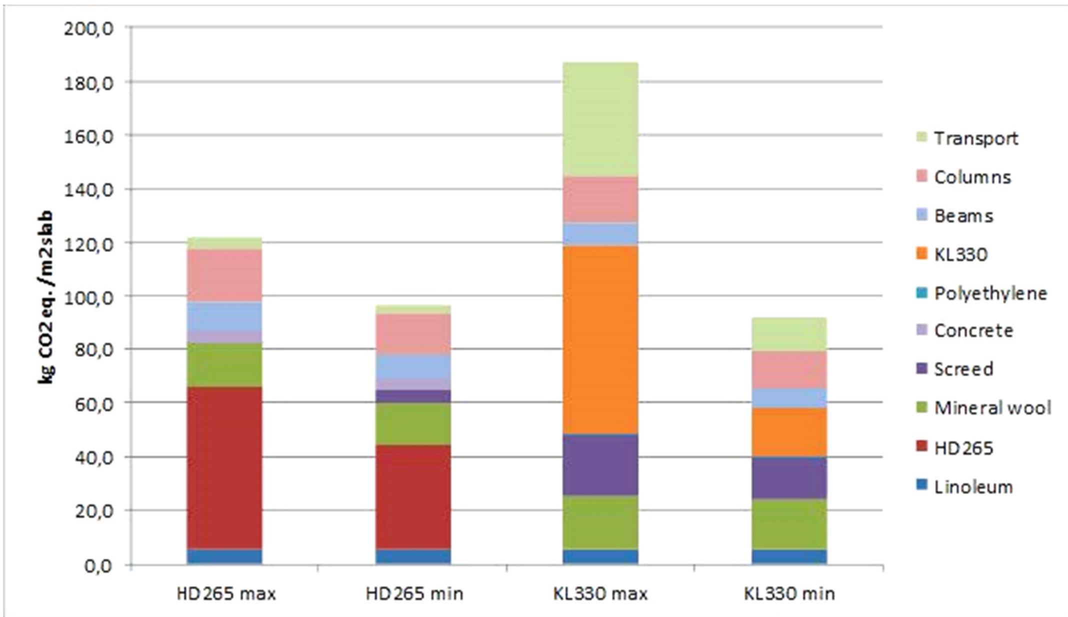

Figure 3.3 Comparison between best case (min) and worst case (max) scenarios of two load-bearing deck solutions. HD signifies concrete and KL signifies massive wood [9].

As can be seen in Figure 3.3, the best case scenario for the wooden solution has lower carbon footprint than the best case scenario for concrete. However, the worst case scenario for the wooden solution is by far the worst possible option. It is not possible to conclude which is the best option until the specific material deliverance from the specific supplier is clarified.

Skanska's final decision was to keep the concrete hollow decks solution. The decision was based mainly on the price, considering the economic investment of the massive wood solution compared to the uncertain and potentially low effect on the carbon footprint.

3.4.5 Outer roof

Lighter hollow decks replaced the compact deck that was projected for the roof in the phase 2 competition. The lighter construction allowed for steel beams of smaller dimensions. This led to a reduction of about 4% CO_{2eq} of the total embodied emissions. The amount of asphalt roofing used was also reduced.

4. Operational Energy and Emissions - O

4.1 General

This chapter summarizes the energy demand, supplied and exported energy calculation, and the related CO_{2eq} emissions calculations[4].

STKF aimed to introduce a range of energy efficiency measures and environmentally friendly energy generation concepts in the project, in order to provide a building with very low greenhouse gas emissions.

- ***Energy efficiency measures***: The target was set to reduce the building net energy need by about 70% compared to buildings built in accordance with the Norwegian building code TEK 10 (135 kWh/m^2/yr). This is to be achieved by designing a well-insulated, air tight, and relatively compact building envelope; a ventilation system with high efficiency heat recovery and using electrochromic windows for shading to lower the cooling demand.
- ***Local renewable energy generation***: Reduced emissions from energy supply systems by local renewable energy production. Energy production from on-site renewable energy sources (biogas, solar, and geothermal) are considered to cover the building energy demand and export excess energy to compensate for peak load energy demand, which is covered by energy imported form district heating and electricity from grid. Heat produced from a ground-source-to-water heat pump is considered to cover up to 92% of the heating (space heating and ventilation heating) and up to 99% of the domestic hot water demand. The remaining peak loads are to be covered by the thermal energy produced by CHP unit (4% of space and ventilation heating) and district heating (4% of room and ventilation heating and 1% of the domestic hot water (DHW)).

4.2 Energy demand

Energy demand calculations for the school building (with a heated floor area of 18 675 m^2) and sports hall building (with a heated floor area of 7 681 m^2) were performed separately. The energy demand is the electrical and thermal energy required for indoor climate control, the heating of household water, lighting, and the operation of equipment. The energy demand value represent the net energy need of the building without including the efficiency of the energy production and distribution system, according to NS 3031:2014[10].

Energy simulations were conducted to calculate the energy demand of the building in accordance with NS 3031:2014 [10] with the dynamic energy simulation tool SIMIEN (www.programbyggerne.no) and using Trondheim weather data. The input data used in SIMIEN for the energy demand calculation are shown in Table 4.1.

[4] Chapter 4 is based on the following reports prepared by SKANSKA:

- "Kap 10 Energi of miljø", February 29, 2016
- "Teknisk Notat-1", February 29, 2016
- "Underlag til ENOVA Støtteprogram; Støtte til energieffektive nybygg", April 04, 2016

Table 4.1 Input data for the energy demand calculation

Description	TEK 10 (minimum requirement)	School (18 675m² BRA)	Sports hall (7 681m² BRA)
U-value exterior walls, W/(m²K)	0.22	0.13	0.07
U-value roof, W/(m²K)	0.18	0.08	0.10
U-value ground floor , W/(m²K))	0.18	0.10	0.05
U-value windows and doors, W/(m²K), average	1.20	0.80	0.80
Normalized thermal bridge value, W(m²/K)	0.05	0.03	0.01
Air leakage rate (n50), 1/h	0.60	0.30	0.20
Total heat loss, W/(m²/K)		**0.22**	**0.23**

Thus, the total annual calculated energy demand is 38.7 kWh/m²/yr (with 15.4 kWh/m²/yr thermal and 23.3 kWh/m²/yr electricity demand) for the school building and 42.4 kWh/m²/yr (with 24.8 kWh/m²/yr thermal and 17.6 kWh/m²/yr electricity demand) for the sports hall (see Table 4.2).

Table 4.2 Energy demand and energy supplied.

School building, BRA=18 300 m²	**Energy demand***		**Energy supplied to the building from technical room**				
	kWh/m²/yr		**Supply system efficiency**	**kWh/m²/yr**		**kWh/yr**	
Space heating	4.3	15.4	0.96	4.5	17,4	81 935	317 540
Ventilation heating	7.7		0.96	8.0		146 720	
Domestic hot water	3.4		0.70	4.9		88 886	
Fans	5.2	23.3	1.00	5.2	23,3	95 160	426 390
Pumps	0.4		1.00	0.4		7 320	
Lighting	8.9		1.00	8.9		162 870	
Technical equipment	8.8		1.00	8.8		161 040	
Total	**38.7**			**40.7**		**743 930**	
Sports hall building, BRA=8 056 m²	**Energy demand****		**Energy supplied to the building from technical room**				
	kWh/m²/yr		**Supply system efficiency**	**kWh/m²/yr**		**kWh/yr**	
Space heating	1.5	24.8	0.90	1.7	30,9	13 403	249 100
Ventilation heating	10.4		0.96	10.8		87 237	
Domestic hot water	12.9		0.70	18.4		148 461	
Fans	7.5	17.6	1.00	7.5	17,6	60 420	141 786
Pumps	0.4		1.00	0.4		3 222	
Lighting	6.8		1.00	6.8		54 781	
Technical equipment	2.9		1.00	2.9		23 362	
Total	**42.4**			**48.5**		**390 886**	
School + Sports hall, BRA=26 356 m²	**Energy demand**		**Energy supplied to the building from technical room**				
	kWh/m²/yr		**Supply system efficiency**	**kWh/m²/yr**		**kWh/yr**	
Space heating	3.4	18.3	0.93	3.6	23,5	95 337	566 641
Ventilation heating	8.5		0.96	8.9		233 957	
Domestic hot water	6.3		0.70	9.0		237 346	
Fans	5.9	21.6	1.00	5.9	21,6	155 580	568 176
Pumps	0.4		1.00	0.4		10 542	
Lighting	8.3		1.00	8.3		217 651	
Technical equipment	7.0		1.00	7.0		184 402	
Total	**39.8**			**43.1**		**1 134 816**	

*The energy demand for the school building is calculated assuming an annual operation hour of 2420 (11hrs/day, 5 days/week, and 44 weeks/yr).
** The energy demand for the Sports hall is calculated assuming an annual operation hour of 4312 (14hrs/day, 7 days/week, and 44 weeks/yr).

The supplied energy from the technical room to the building is calculated considering system efficiencies and distribution losses in accordance with the values specified in NS 3031:2014 (see Table 4.2) [10]. Calculated supplied energy from "technical room" is therefore higher than the calculated energy demand of the building (see Table 4.2).

4.3 Energy supply systems

Several energy supply systems have been evaluated and considered during the competition and design phases of the project. Finally, biogas-based combined heat and power (CHP), roof mounted PV system, and ground-source-to water heat pump were chosen.

Combined heat and power (CHP): CHP is a system that generates both electricity and useful heat simultaneously from a single fuel source. CHP has a large potential for increasing the efficiency of electricity generation as it makes use of the heat that is otherwise lost in conventional thermal power plants and reduces fuel consumption. Using low emission fuels (such as biogas) further increases the environmental benefits of CHP. Although CHP is a well developed system for large scale plants, micro-CHPs in general and biogas based micro-CHPs in particular are not commonly used in buildings. This is because the energy cost of produced electricity is high for the energy carrier (biogas), particularly if the infrastructure is not well established. In the design phase of Heimdal pilot building, a biogas based CHP unit with an annual efficiency of 85% and power output of 50kW electricity and 80kW of heat is considered for producing electricity and heat.

Photovoltaic system: a PV system mounted on the maximum available roof area of the school building (1937 m^2) is used for the production of electricity. The PV system consists of 1088 modules (Si monocrystalline type) from SunPower and 22 invertors (Sunny Tripower) from SMA Solar Technology. The PV modules have a rated efficiency of 21.15% and their total peak power is 375.4 kWp. Figure 4.1 illustrates PV modules, peak power, and orientation of the PV system.

3D, Nettkoblet PV-anlegg med strømforbrukere		
Klimadata	Trondheim/Vaernes (-)	
PV-generatorytelse	375,37	kWp
PV-generatorflate	1 774,2	m²
Antall PV-moduler	1088	
Antall vekselrettere	22	

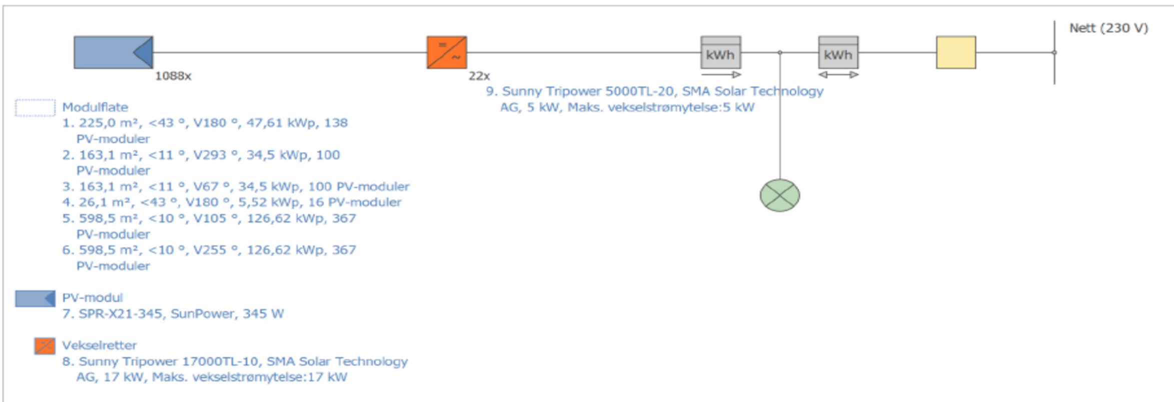

Figure 4.1 PV modules, peak power and orientation of the PV system

Heat pump: a ground-source heat pump, with a seasonal coefficient of performance (SCOP) of 4.05, is designed to cover up to 92% of the space heating and ventilation heating demand, and another DHW heat pump with SCOP of 3.50 is considered to cover about 99% of the domestic hot water demand. Electricity produced from the CHP and PV systems is considered to run the heat pumps. In the heat pumps, CO_2 is used as a working medium. The advantage of this technology is that the heat pump can be designed to deliver the hot water at a high temperature level (70-90˚C). The technology is known, but the application of the product is not common in the construction sector.

Grey-water was considered as a heat source for the hot water production (energy recovered from hot water leaving the building). This system and product is common in Norway (i.e. Swimming pools), in spite of the need of certain follow-up for cleaning works. A common solution for this system is to connect the grey-water directly to a heat pump (at the evaporator side). The system delivers hot water at a moderate temperature (30-35ºC). This means that an additional energy source is needed to raise the temperature of the water to the required temperature of 60-65ºC. Thus, it was considered that the grey-water heated up the working medium that takes heat from the ground before it is supplied to the heat pump.

District heating (DHS) and ***electricity from the grid*** is considered for covering the thermal and electricity peak loads, respectively. The excess energy production is considered to be exported to the local district heating network and the nearby building (Husebybadet) in order to compensate for the emission from energy supply systems (emissions from imported energy from DHS and electricity from the grid and emissions from energy sources of CHP and heat pump).

Electricity is a high quality energy that can be used for covering all the energy needs of a building, and it is convenient to export the excess electricity, as it is possible to transport electricity over long distances with relatively low losses. On the other hand, thermal energy is a lower quality energy source, and thus it is only used to compensate emissions for the amount of thermal energy demand of the building. That means that exported thermal energy should not exceed the imported thermal energy. Thus, in the design phase of the Heimdal pilot building, the maximum allowed exported energy for ZEB balance calculation was limited to the maximum amount of imported thermal energy.

4.4 Delivered energy and exported energy

Calculation of the amount of delivered energy (levert energi) to the technical room from the various energy supply systems is performed through dimensioning the capacity/efficiency of CHP unit, HP, and PV system [10]. Exported energy consists of two production units, CHP and PV, dimensioned to have enough capacity to produce sufficient energy for export.

4.5 CO_{2eq} emissions from operational energy

The greenhouse gas (GHG) emissions from operational energy was calculated using delivered and exported energy and related CO_{2eq} factors for each energy carrier. Locally produced electricity from the CHP and PV unit is considered to replace electricity imported from the grid, whilst the thermal energy produced from HP and CHP is considered to replace the energy from district heating. Excess energy production is considered to be delivered to a neighboring building (Husebyhallen) or the local grid.

The CO_{2eq} factors employed by the Norwegian ZEB research center [3] has been used as a basis to calculate the CO_{2eq} emissions from delivered energy. The total energy demand, delivered energy, local energy production, and exported energy and the associated CO_{2eq} emissions are summarized in Table 4.3 – Table 4.8 and Figure 4.2.

Table 4.3 CO_{2eq} emissions from delivered energy

Energy budget	Energy supplied from technical room		Energy supply systems			Delivered energy			GHG emissions		
									Emission factor	Emissions	
	kWh/yr	kWh/ m²/yr	Percentage share	kWh/yr	kWh/ m²/yr	System efficiency	kWh/yr	kWh/ m²/yr	gCO_{2eq}/ kWh	$kgCO_{2eq}$/yr	$kgCO_{2eq}$/ m²/yr
Space and ventilation heating	329 294	12.5	HP (92%)	305 171	11.6	4.05	75 351	2.9	130	9 796	0.37
			CHP (4%)	12 798	0.5	0.85	15056	0.6	25	376	0.01
			DHS (4%)	12 143	0.5	0.98	12 391	0.5	130	1611	0.06
Domestic hot water	237 346	9.0	HP (99%)	237 490	8.9	3.50	67 854	2.6	130	8821	0.33
			DHS (1%)	2 373	0.1	0.98	2 422	0.1	130	315	0.01
Fans	155 580	5.9	EL (100%)	155 580	5.9	1.00	155 580	5.9	130	20 255	0.77
Pumps	10 542	0.4	EL (100%)	10 542	0.4	1.00	10 542	0.4	130	1 370	0.05
Lighting	217 651	8.3	EL (100%)	217 651	8.3	1.00	217 651	8.3	130	28 295	1 07
Technical equipment	184 402	7.0	EL (100%)	184 402	7.0	1.00	184 402	7.0	130	23 972	0.91
Calculated energy	**1 134 816**	**43.1**		**1 135 777**	**43.1**		**738 827**	**28.0**	**Emission**	**94 467**	**3.59**

Table 4.4 CO_{2eq} emissions from local energy production, internally used.

Local energy production, internally used		kWh/yr	kWh/m2/yr	gCO_{2eq}/kWh	$kgCO_{2eq}$/yr	$kgCO_{2eq}$/m²/yr
Thermal energy	CHP_{th} (included in the delivered energy, Table 4.2)	0	0	0	0	0
	HP_{th} (included in the delivered energy, Table 4.2)	0	0	0	0	0
Electricity	PV_{el}	28 698	1.1	130	3 731	0.14
	PV_{el}	143 901	5.5	130	18 707	0.71
	CHP_{el}- HP	**47 059**	**1.8**	**130**	**4 706**	**0.18**
	CHP_{el}	**167 361**	**6.4**	**130**	**16 736**	**0.64**
Total		**387 019**	**14.7**		**43 880**	**1.67**
Total operational energy use, B6 (94 467 – 43 880)					**50 587**	**1.92**

Table 4.5 Limit for maximum accountable exported thermal energy

Imported (delivered) energy for thermal energy supply		kWh/yr
DHS	DHS	12 391
CHP_{th}	Biogas	15 056
CHP_{el-HP}	Biogas	55 364
El_{imp-HP}	El_{imp} + PV_{el-HP} + CHP_{el-HP}	**67 448**
Accountable exported thermal energy (ZEB requirements*)		**150 259**

** Exported thermal energy equal to the imported thermal energy*

Table 4.6 CO_{2eq} emission from local energy production, limited thermal export according to ZEB requirements*

Local energy production, limited exported thermal energy		kWh/yr	kWh//m²/yr	gCO_{2eq}/kWh	$kgCO_{2eq}$/yr	$kgCO_{2eq}$/m²/yr
Exported, thermal	$CHP_{th,}$ limited exported to Husebyhallen	150 259	5,7	-100	-15 026	-0,57
Exported, electricity	PV_{el}, exported to the grid	116 140	4,4	-130	-15 098	-0,57
	CHP_{el}, exported to the grid	198 407	7,5	-100	-19 841	-0,75
Total accounted exported energy		**464 806**	**17,6**		**-49 965**	**-1,90**

** Exported thermal energy equal to the imported thermal energy*

Table 4.7 ZEB-O Balance, with limited exported thermal energy

ZEB Balance	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2/yr$
ZEB-O	**50 587**	**1,92**
ZEB-Exported energy	**-49 965**	**-1,90**
ZEB-O Balance	**622**	**0,02**

Table 4.8 CO_{2eq} emission from local production, with total (unlimited) exported thermal energy

Local energy production, total (unlimited) exported energy		kWh/yr	$kWh/m^2/yr$	gCO_{2eq}/kWh	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2/yr$
Exported thermal	$CHP_{th,}$ exported to Husebyhallen	587 932	22,3	100	-58 793	-2,23
Exported electricity	PV_{el}, exported to the grid	116 140	4,4	-130	-15 098	-0,57
	CHP_{el}, exported to the grid	198 407	7,5	-100	-19 841	-0,75
Total exported energy		**902 479**	**34,2**		**-93 732**	**-3,56**

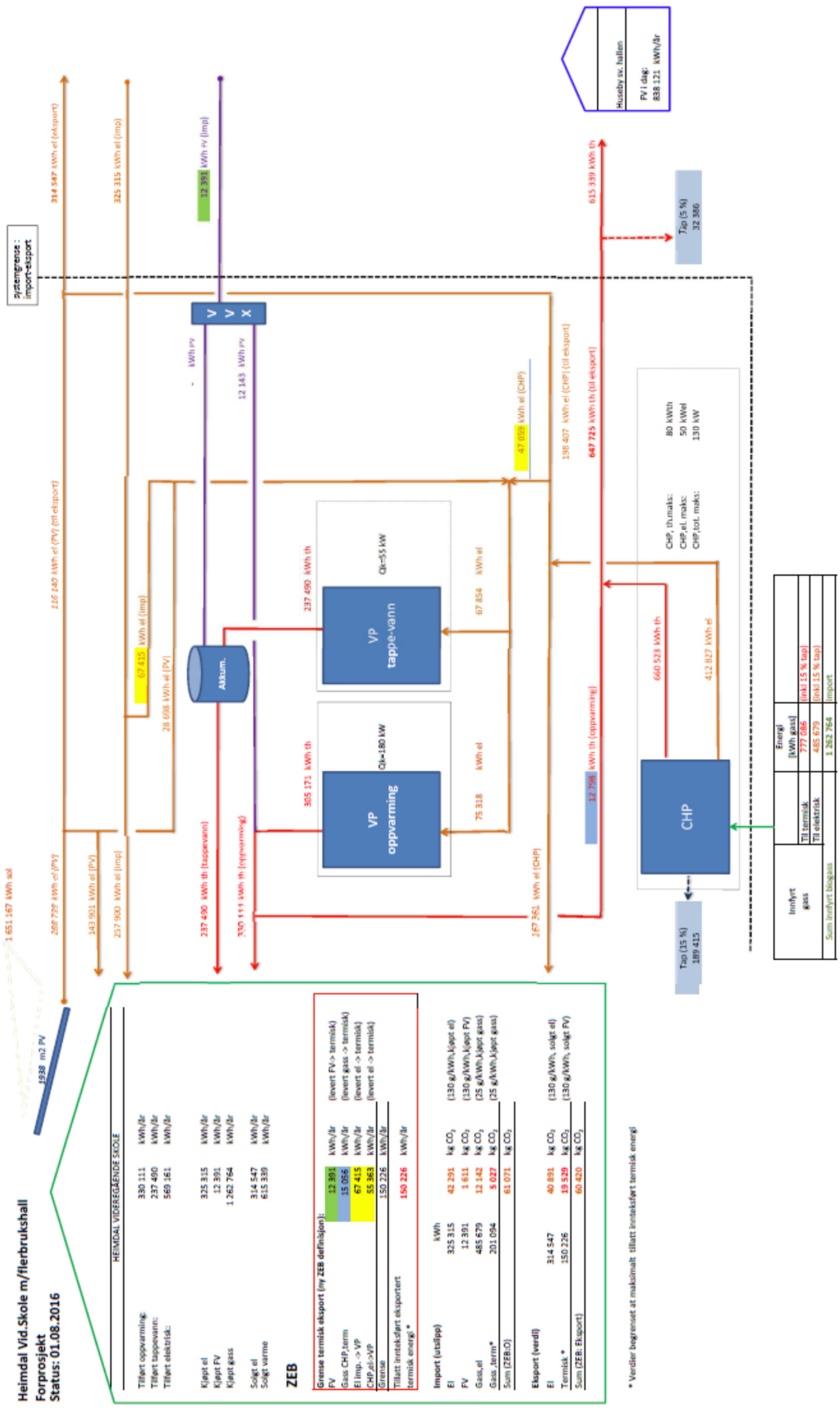

Figure 4.2 Annual energy supply systems, local production energy, exported energy, and the associated CO_{2eq} emissions, based on a sketch from Skanska.

5. Embodied Emissions - M

The emission calculation from the material use in Heimdal pilot building performed by Skanska during the design phase was evaluated by the Norwegian ZEB research center. This chapter summarizes the methodology used for GHG emissions calculations and the CO_{2eq} emission results.

5.1 Method

5.1.1 System boundary

A functional unit of 1m^2 heated floor area (BRA) over an estimated service life time of 60 years of the building was considered when evaluating the emissions from the Heimdal pilot building. The design phase calculation was performed for the school building with total heated floor area of 18 675 m^2 and sports hall with heated floor area of 7 681 m^2.

The system boundary was defined according to the Norwegian ZEB ambition level definition , the modular life cycle stages in NS-EN 15978 [11], and the Table of building elements[12].The system boundary included life cycle modules A1, A2, A3, A4, and B4 according to EN 15978 as illustrated in Table 1.1. The building elements included in the emission calculation are summarized in Table 5.1.

Table 5.1 Building parts (systemized according to NS 3451 [12]) considered in the study.

Building parts	2 Building envelope	3 Building services	4 Electric power supply	6 Other installations
Building components	21 Ground work and foundation	36 Ventilation and air conditioning	49 Solar thermal, PV system	62 Passenger and good transport (lifts etc.)
	22 Superstructure		49 Other renewable energy	
	23 Outer walls			
	24 Inner walls			
	25 Floor structure			
	26 Outer roof			

The biogenic carbon content (kg CO_{2eq}) of wood and carbonation (uptake or re-absorption of CO_2 from the atmosphere) of concrete was not considered in the calculation as the system boundaries do not cover the end-of-life phase. This is according to the ZEB Definition Guideline [3].

5.1.2 Tool

Skanska performed the design phase embodied emissions calculations of the Heimdal pilot building using an excel-based tool developed by the Norwegian ZEB research center for life cycle GHG emissions calculations (named the ZEB-M tool[13]). The tool was developed following the methodology for life cycle assessment (as outlined in ISO 14040 series), LCA standards for buildings (NS-EN 15978 [11]), and building products (NS-EN 15804 [14]). The tool is structured according to EN 15978 and EN 15804 modular approach to measure the cradle-to-grave impacts from four main life cycle stages: product stage (A1-A3), construction process stage (A4-A5), use stage (B1-B7), and end-of-life (C1-C4) (see Table 5.2). In addition, the optional stage (D) is defined to be counted in ZEB-COMPLETE for the potential positive impacts of processing or re-use of materials and components after the end-of-life.

Table 5.2 Life cycle stages [11, 13]

Building assessment information																			
Building life cycle information																Supplementary information			
A1–A3 Product stage			A4–A5 Construction Process stage		B1–B7 Use stage							C1–C4 End-of-life				D1–D4 Benefits and loads beyond the system boundary			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D1	D2	D3	D4
Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling	Exported energy /potential

The tool is also structured according to NS 3451: 2009 Table of Building Elements [12] in order to obtain an overview of the parts of the building that have been included, to facilitate the quantification of mass and energy flows and their corresponding CO_{2eq} emissions, as well as to facilitate a more structured and detailed comparison with other projects. The embodied material emissions are measured in terms of GWP ($kgCO_{2eq}/m^2/yr$), and are calculated according to the IPCC GWP 100-year method [15]. Product specific EPDs, mainly from EPD-Norway, and generic data from Ecoinvent database are used as background data in the LCI database as part of the tool.

The tool was in the early development phase at the time of the Heimdal pilot pre-project competition in 2015, and the tool named "ZEB M Regneark", version dated October 3rd 2014 was used. It was given to Skanska and the other teams in the second phase of the pre-project competition on October 29th. The material input quantities were exported from the building information module (BIM) to the excel tool. After the competition, Skanska continued using this adaptation of the excel tool throughout the design phase as a means to compare alternatives and to document the embodied emissions in the project. In other words, the embodied emission calculations were continuously updated with the assistance of the excel tool. The calculations in this report are based on the version (revision 18) dating from august 2016 [16, 17].

5.1.3 Life cycle inventory and data

Life cycle inventory define and quantify inputs such as raw materials, water, and energy, as well as outputs, including emissions to air, soil, and water. The main type and source of data used per each life cycle stage is summarized below. Complete life cycle inventory tables with the type and quantity of materials used in each building element (shown in Table 5.1), the service life of the products considered in the study, along with the CO_{2eq} emissions and the source of emission data are to be found in Appendix 2.

Product stage (A1-A3)

Environmental product declarations (EPDs) were used as the main data source to calculate the emission from the materials (A1-A3), where the supplier of the materials was known and EPDs were available. When product specific data was lacking, generic data from the LCI database Ecoinvent v.3.1 was sourced. Expired EPD data was used where this data was considered to be more representative than generic data, and registered as generic data. For HEB and HSK steel profiles, an average of EPD data from Skanska Norge AS, AK Mekaniske AS, EMV Construction AS og Contiga was taken. For low carbon concrete products, the common emission values described by the Norwegian concrete association were used [18].

Transport (A4)

The emissions from transport of materials from the factory to the building site (A4) were calculated using specific transport distances between the assumed suppliers and the building site. Emission factors for the transport mode were sourced from the Ecoinvent v3.1 database. Trucks were considered as means of transportation, and the emission factor from the Ecoinvent v3.1 process for transport "*Transport, freight, lorry 16-32 metric ton, EURO4 (RER)* | *Alloc Rec*" was chosen as a default. This was given in the ZEB spreadsheet tool. Where supplier or transport distance was unknown, a standard transport distance of 300 km was used.

Replacement (B4)

The number of replacement of materials and components (B4) over the life cycle of the building was calculated using estimated service life data from Norwegian EPDs and/or from technical guidelines developed by SINTEF Building and Infrastructure (SINTEF Building Research Design Guides (BKS) 700.320, (BKS 700.320 2010)). For some materials, Skanska found that the service life data listed in the EPD did not quite correspond to their practical experience. In these cases, Skanska applied their own, experience based service life data.

The number of replacements was calculated according to NS-EN 15978: 2011 using the following formula:

Number of replacements of product (j) = E [ReqSL/ESL(j) -1]

Whereby,

ReqSL is the required service life of the building,
ESL is the estimated service life,
j is the product,
E rounds the factor to the nearest whole integer.

EN 15978 further states that: "If, after the last scheduled replacement of a product, the remaining service life of the building is short in proportion to the estimated service life time of the installed product, the actual likelihood of this scheduled replacement should be taken into account". Thus, in the Heimdal pilot building, a whole number of replacements were used, and in the case of a partial number of replacements resulting from the estimated service life of the component and the reference study period of the building, the value obtained was rounded up to the higher integer. However, in most ZEB pilot cases, the number of replacements of products has been calculated without rounding up in order to avoid subjective evaluation of the likeliness that the last scheduled replacement takes place, as stated in the standard [3].

For the PV panels, with an estimated service life of 30 years, a 50% reduction in emissions (relative to A1-A3) for the replaced PV panels has been considered. This is in line with the methodology used in ZEB pilot cases and is based on the assumption that the PV system will be produced with a 50% better efficiency 30 years into the future, with half the amount of material emissions per m^2 [3, 19]. The 50% reduction was not considered for the emissions from the transport of replaced materials calculated in this project.

The emission from the transport of the replaced materials were also performed and included in B4 emission results.

5.2 Results

This section summarizes the GHG emission results from the Heimdal pilot building design phase calculation performed by Skanska. The embodied GHG emissions per each life cycle stages and building element is presented in Table 5.3. The embodied emission calculations were performed for the school building (with BRA[5]=18675m^2), sports hall (with BRA=7681m^2), and the whole building (with BRA=26356m^2).

The total embodied emissions from A1-A4 and B4 (including transport in B4) of the Heimdal pilot building (BRA= 26356m^2) is 15 435 652 kgCO_{2eq} or 9.76 kgCO_{2eq}/m^2/yr. The largest contributor to CO_{2eq} emissions is life cycle modules A1-A3 (71% or 6.97 kgCO_{2eq}/m^2/yr). This is followed by the replacement phase (27% or 2.69 kgCO_{2eq}/m^2/yr) and transport of materials to building site (2% or 0.23 kgCO_{2eq}/m^2/yr). From the life cycle module B4, replaced materials and transport of replaced materials represented 87% and 13% of CO_{2eq} emissions from B4, respectively.

Table 5.3 Embodied GHG emissions per each life cycle stage and building element.

Goal and scope of the study												
Databases Used	EPDs, EcoInvent v3.1											
Lifetime of Construction (years)	60											
Functional Unit	1sqm BRA over a 60 yr lifetime											
AREA BRA (m^2)	**Total building area (school + sports hall)***			**School building**				**Sports hall**				
	26356*			18675				7681				
Building Site	Trondheim											
Results												
Building Elements	**A1 - A3 (kgCO_{2eq})**			**A4 (kgCO_{2eq})**			**B4** (kgCO_{2eq})**			**Transport in B4 (kgCO_{2eq})**		
	School	**Sports hall**	**Total***	**School**	**Sports hall**	**Total***	**School**	**Sports hall**	**Total***	**School**	**Sports hall**	**Total***
2 Building												
21 Groundwork and Foundations	165297	306176	471473	1984	53424	55409	0	0	0	0	0	0
22 Superstructure	1121757	1697085	2818842	5698	13391	19089	0	0	0	0	0	0
23 Outer walls	480102	209702	689805	9819	2385	12204	224630	5223	229853	6089	235	6324
24 Inner walls	1138122	421553	1559675	156507	16852	173359	1386114	94076	1480189	284164	23731	307895
25 Floor Structure	1890379	665332	2555711	56216	15003	71219	96200	83478	179678	4047	2978	7025
26 Outer Roof	692959	530251	1223210	4845	6613	11458	27069	8894	35963	430	142	572
3 Heating, Ventilation and Sanitation												
36 Ventilation and Air Conditioning	577381	144345	721726	4414	1103	5517	944297	235541	1179839	7285	1812	9097
4 Electric Power												
49 Other electric power installations	945938	0	945938	10027	0	10027	580398	0	580398	10573	0	10573
6 Other Installations												
62 Passenger and Goods Transport	31792	0	31792	0	0	0	31792	0	31792	0	0	0
kgCO_{2eq}	**7043727**	**3974445**	**11018172**	**249510**	**108771**	**358282**	**3290500**	**427212**	**3717712**	**312588**	**28898**	**341486**
kgCO_{2eq}/yr	**117395,45**	**66241**	**183636**	**4159**	**1813**	**5971**	**54842**	**7120**	**61962**	**5210**	**482**	**5691**
kgCO_{2eq}/m^2	**377**	**517**	**418**	**13**	**14**	**14**	**176**	**56**	**141**	**17**	**4**	**13**
kgCO_{2eq}/m^2/yr	**6,29**	**8,62**	**6,97**	**0,22**	**0,24**	**0,23**	**2,94**	**0,93**	**2,35**	**0,28**	**0,06**	**0,22**
20%M (kgCO_{2eq}/m^2/yr)***	**1,26**	**1,72**	**1,39**	**0,04**	**0,05**	**0,05**	**0,59**	**0,19**	**0,47**	**0,06**	**0,01**	**0,04**

**Total building area (School building and Sports hall)*
*** Embodied emissions from the transport of replaced materials are not included.*
**** 20% of embodied emissions from A1-A4 & B4 is considered in the ZEB balance.*

The total embodied emissions (A1-A4 and B4) results from each building elements are depicted in Figure 5.1. The results show that inner walls are the most important contributor to CO_{2eq} emissions (22.8%) followed by superstructure (18.4%), floor structure (18.2%), ventilation systems (12.4%), energy system (10%), outer roof (8.2%), outer walls (6.1%), ground work and foundation (3.4%), and passenger and goods transport (<1%).

[5] Heated floor area (BRA)

About 84% of the total CO_{2eq} emissions from the ***inner walls*** originate from the school building and 16% from the sports hall. When considering the school building, the largest contributor to the total CO_{2eq} emissions are gypsum boards used in the cladding and surfaces (26%), followed by steel profile used in non-load bearing inner wall (16%) and steel used in the system walls (15%). The rockwool insulation used in non-load bearing inner wall, the aluminum used in the system walls, and the alkyd paint used in cladding and surfaces, each contributes about 5% of the total emissions from outer walls.

The concrete used in load bearing inner walls of the school building contributes about 9% of the total CO_{2eq} emissions from the inner walls.

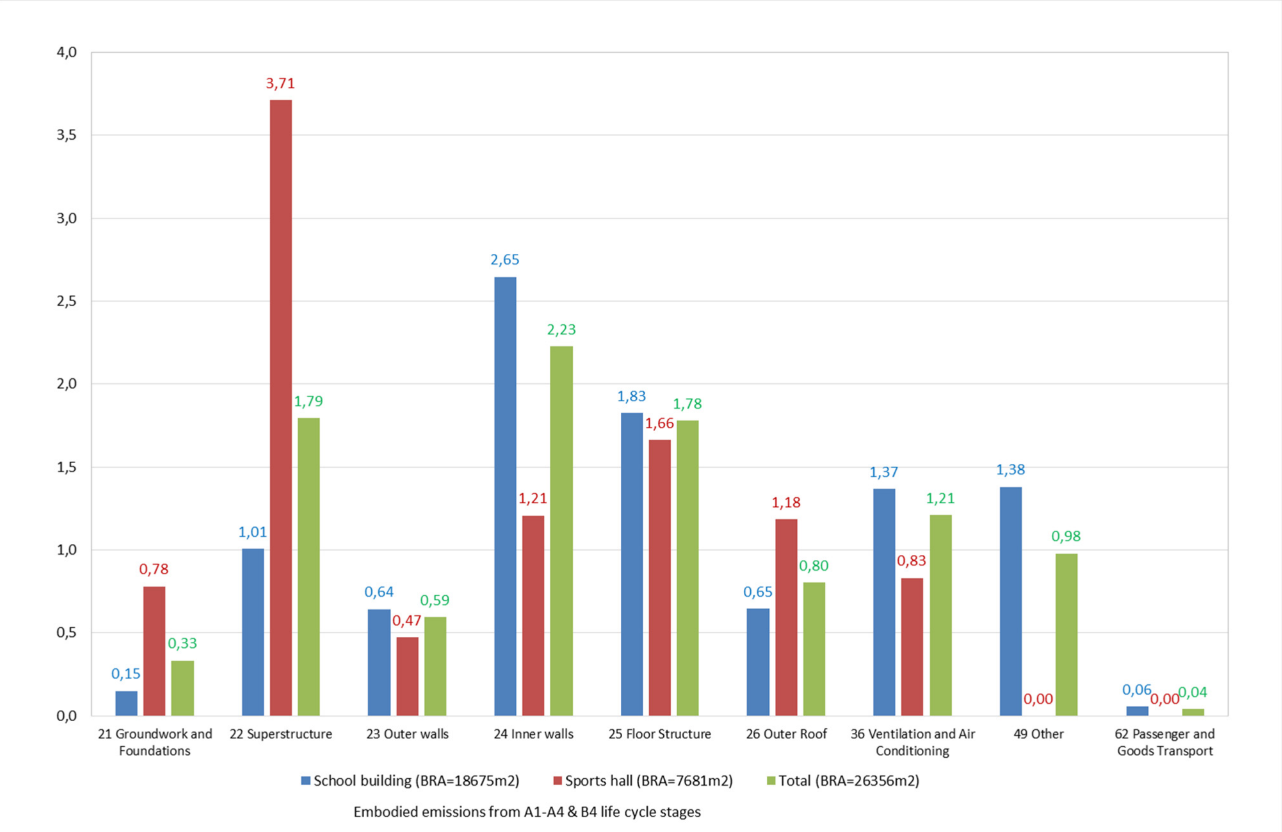

Figure 5.1 Embodied emissions from building elements from the school building and the sports hall.

From the ***superstructure***, about 60% of the total CO_{2eq} emissions originate from the sports hall and 40% from the school building. The largest contributor to the total CO_{2eq} emissions is steel beams in the sports hall (58%) followed by steel columns in the school building (20%) and steel beams in the school building (18%).

From the ***floor structure***, about 73% of the total CO_{2eq} emissions originate from the school building and 27% from the sports hall. The largest contributor to the total CO_{2eq} emissions is the low carbon concrete (22%) and hollow concrete decks (19%) used in the sports hall load bearing deck system followed by concrete floor screed in the school building (9%), concrete used in load bearing deck (7%) and concrete used in the slab (7%) of the sports hall, polyurethane used in the floor surface of the sports hall (5%) and steel used in load bearing deck of the school building (5%).

From the ***outer roof***, about 57% of the total CO_{2eq} emissions originate from the school building and 43% from the sports hall. The largest contributor to the total CO_{2eq} emissions is the rockwool used in the sports hall (26%) followed by the steel (21%) and rockwool insulation (18%) used in the school building and hollow deck concrete used in the sports hall (14%).

From the ***outer wall***, about 77% of the total CO_{2eq} emissions originate from the school building and 23% from the sports hall. The largest contributor to the total CO_{2eq} emissions is the concrete used in the sports hall (19%) followed by the concrete (18%), triple glazing (11%) and window frames (11%) used in the school building.

From the ***ground work and foundation***, about 68% of the total CO_{2eq} emissions originate from the sports hall and 32% from the school building. The largest contributor to the total CO_{2eq} emissions is the cinder aggregate used in the sports hall drainage system (61%) followed by the low carbon concrete used in the direct foundation of the school building (27%), concrete used in the direct foundation of the sports hall (6%), and reinforcement steel used in the direct foundation of the school building (4%)

From the ***ventilation system***, about 80% of the total CO_{2eq} emissions originate from the school building and 20% from the sports hall. The largest contributors to the total CO_{2eq} emissions are the steel equipment for the air treatment (30%), air conditioning (22%) and air distribution (10%) of the school building, and the aluminum in air treatment equipment of the sports hall ventilation system (12%).

The ***energy supply systems*** (given as ***49 others*** in Figure 5.1), represents the embodied CO_{2eq} emissions from local energy production systems (PV, CHP and heat pump) located in the school building. The largest contributors to the total CO_{2eq} emissions are the PV panels (53%) followed by the CHP unit (20%) and aluminum used for PV mounting frame (15%).

The ***passenger and good transport*** represent the embodied CO_{2eq} emissions from elevators used in the building and contributes <1% of the total CO_{2eq} emissions.

6. ZEB Balance

In an all-electric building, the focus of the ZEB balance definition and calculations has evolved around balancing out of the operational energy use with onsite renewable energy production (ZEB-O balance). This implies that over the period of one year, the energy export from the building should be in balance with or greater than its energy import [20].

$$\text{Net ZEB} = \sum(Qd,i*fd,i) - \sum(Qe,i*fe,i)| \leq 0 \qquad 6.1$$

Where

- Qd,i is the annual delivered energy [$kWh/m^2/year$]
- Qe,i is the annual exported energy [$kWh/m^2/year$]
- f(d,i) is the annual CO_{2eq} factor in gCO_{2eq}/kWh for the delivered energy carrier i
- f(e,i) is the annual CO_{2eq} factor in gCO_{2eq}/kWh for the exported energy carrier i

The net zero energy building definition may be further expanded by applying a life cycle perspective, whereby the operational emissions (O) plus the embodied emissions (e.g. life emissions from materials, transport, construction and end-of-life) are included depending on the ambition level [21]. If the sum is zero or negative, the building has reached a ZEB balance, while the ZEB level is not reached if the sum is positive.

The Heimdal pilot project is not an all-electric building but also have import and export of thermal energy from the CHP. For export of thermal energy, the following rule applies according to the ZEB centre requirements: in the ZEB balance calculation, export of thermal energy may not compensate for more than the building's own thermal energy demand.

The ZEB Centre GHG emissions calculation methodology is described in more details in Fufa et al. [3], Kristjansdottir et al. [19], and in the forthcoming SINTEF Building Research Design Guide 473.010 (to be published).

In this report, we present the ZEB balance for the ambition levels considered in the project (see Table 1.3), even if not all of them are within the final scope of the project. ZEB balance for three ambition levels are presented [3]:

- ***ZEB-O balance***, the net ZEB balance for all greenhouse gas emissions associated with operational energy should be compensated with production of renewable energy.
- ***ZEB-O20%M balance***, which states that all greenhouse gas emissions associated with operational energy and 20% of material emissions should be compensated for by generation of renewable energy. The material emissions calculation includes emissions from the product stage (A1-A3) and replacement (B4) phase of the materials.
- ***ZEB-O20% (M + transport of materials) balance***, this is similar to ZEB-O20%M definition, with additional emission consideration from transport of materials to the building site during construction phase (A4) and emission from transport of replaced materials in the use phase (B4).

Here it should be noted that, even if these ambition levels were considered at different stages of the project using different background data, in this case we have used the data given in Table 4.3 for the ZEB balance calculation. It should also be noted that the calculations are performed combining the results for the school building and the sports hall, evaluating the ZEB balance based on the sum of the two buildings. The results may look different if evaluating the ZEB ambition levels for the school building and the sports hall individually.

6.1 ZEB-O balance

Table 6.1 shows the summary of the energy balance and the associated GHG emissions calculated for evaluating ZEB-O balance. The results show that the design phase of Heimdal pilot building project was very close to reaching the ZEB-O ambition level by producing enough renewable energy for internal use and export (according to ZEB requirement for limited thermal exported energy) to compensate for emissions from the operation of the building.

Table 6.1 ZEB-O balance

	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2/yr$
Delivered energy	84 653	3,59
Local energy production, internally used	-43 880	-1,67
Local energy production, exported	-49 965	-1,90
ZEB-O balance	**622**	**0,02**

6.2 ZEB-O20%M balance

Table 6.2 shows ZEB-O20%M balance calculated for the design phase of Heimdal building. The results show that the design phase of Heimdal pilot building project was not able to reach ZEB-O20%M ambition level. That means the local energy produced from renewable energy sources for internal use and export (according to ZEB requirement for limited thermal exported energy) was not enough to compensate for emissions from the operational energy of the building and 20% of emissions from materials from product stage (A1-A3) and replaced materials (B4).

Table 6.2 ZEB-O20%M balance

	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2/yr$
ZEB-O balance	**622**	**0,02**
ZEB-20% M (A1-A3 & B4)	**49 120**	**1,86**
ZEB-O20%M balance	**49 742**	**1,89**

6.3 ZEB-O20% (M + transport of materials) balance

Table 6.3 shows the ZEB-O20%M balance calculated for the design phase of Heimdal building. The results show that the design phase of Heimdal pilot building project was not able to reach ZEB-O20% (M + materials transport) ambition level. That means, the local energy produced from renewable energy sources for internal use and export (according to ZEB requirement for limited thermal exported energy) was not enough to compensate for emissions from the operational energy of the building and 20% of emissions from materials (A1-A3, B4) and transport (A4 and transport of replaced materials in B4).

Table 6.3 ZEB-O20%(M+ Transport of materials in A4 and B4) balance

	$kgCO_{2eq}/yr$	$kgCO_{2eq}/m^2/yr$
ZEB-O balance	**622**	**0,02**
ZEB-20% M(A1-A3 & B4)	**49 120**	**1,86**
ZEB-20%Transport (A4+B4)	**2 333**	**0,09**
ZEB-O20%(M + transport of materials) balance	**52 075**	**1,98**

7. CO_{2eq} Comparison with a Reference Building

In some projects, GHG emissions calculations are introduced to improve the sustainability of an existing design. In such cases, the improvement can easily be quantified by comparing old and new solutions. However, this was not possible in the Heimdal pilot project, as the embodied emission optimization was considered from the very beginning of the design process. The minimizing of the embodied emissions in the project was steered by the ZEB ambitions and furthermore by the quantified, contractual total embodied emissions per year: 10 kg $CO_{2eq}/m^2/yr$ – O, M and transport of materials was included, see chapter 1.3. However, STFK wanted to communicate the environmental benefits obtained in the Heimdal School and Sports hall project compared to the business as usual approach. Therefore, it was decided to use a reference building to evaluate the percentage reduction from the design phase of Heimdal pilot building.

7.1 Reference building definition

Defining a good reference building was a difficult task, and was conducted by Henning Fjeldheim in Skanska, and the model he created was quality assured by Reidun Schlanbusch in SINTEF/ZEB. The model, the methodology, and the results are thoroughly described in the Skanska report “Heimdal VGS og Sports hall – reduksjon av ZEB-M” (see annex 3), and are shortly summarized here.

There is no national consensus on how to model a reference building for greenhouse gas emissions calculations in Norway today. According to klimagassregnskap.no v4,1[22], the reference building should be of the same building type and have the same geometrical measures as the current building, but is built according to minimum requirements from technical regulations. Klimagassregnkap.no applies the module "Materials used, in early phase" [23]. Building categories "63. High school" and "66. Sports hall building" are the options in Klimagassregnskap.no that come close to the Heimdal pilot project. In short, this model consists of a shoebox model based on input parameters with standard material choices for different building categories.

A reference building that is operational for the Heimdal pilot project must be comparable to the actual building. In this regard, there are a number of challenges with respect to the model from Klimagassregnskap.no [24]. One example is that the functional requirements for the reference building only partially match the Heimdal pilot project. This may cause significant differences in the material amounts, in a positive or negative direction. Another challenge is that the generic data in Klimagassregnskap.no is collected from various sources, and these data are in varying degrees representative of the Norwegian market for building materials. In order to address these challenges and to construct a robust and comparable reference building for the Heimdal pilot project, the following methods were applied:

1. The design phase LCI of the existing concept was used as a starting point. From that point, the emission reduction measures were calculated backwards and replaced with business-as-usual solutions.
2. The business-as-usual solutions were taken from "Materials used, in early phase" described in Klimagassregnskap.no 5 [23] Building category "63. High school" and "66. Sports hall".
3. Specific data from the design phase LCA was substituted with generic data from the renowned European LCI database Ecoinvent v.3.1 [25].
4. For selected processes, Ecoinvent data were substituted with national data that were considered to be more representative for the local conditions:
    a. Concrete cast in-situ: Industry reference LCA data from Norsk betongforening [26]

b. Structural wood: Norwegian EPD no 308-179 Structural wood of spruce and spine.
c. Beams, prefabricated concrete elements, reinforcement steel, windows, gypsum boards: average of available Norwegian EPDs
d. Due to lack of data for blocks of expanded clay in Ecoinvent, a process model was created by linearly extrapolating data for loose expanded clay from Ecoinvent, based on information from Norwegian EPDs for Leca expanded clay blocks.

5. The inner walls of the reference building were not remodeled with "Materials used, in early phase" described in Klimagassregnskap.no version 5, but kept as it is in the actual concept. Ecoinvent data were used for the impact assessment instead of the specific data applied in the design phase calculations.

More specific information on the method applied to define an operational reference building can be found in Skanska's report [24], which is to be found in Appendix 3.

7.2 CO_{2eq} emissions comparison with the reference building

Thoughtful design and emission reduction measures described in chapter **Error! Reference source not found.** and in reference [24] and [9] made sure that, compared to business as usual, embodied emissions associated with building materials and transport of these were considerably reduced in the Heimdal pilot project (design phase). The reference building model described in Chapter 7.1 allowed for a quantification of the reduction compared to a reference building representing business as usual. The results from the comparison with the reference building are summarized in Table 7.1, showing that a total greenhouse gas emission reduction of about 19.4% was obtained.

Here it should be noted that the numbers in Table 7.1 can differ somewhat from the results presented in chapter 5.2 because the calculations were performed at slightly different times within the design phase period.

Table 7.1 CO_{2eq} emissions comparison with the reference building [21].

	School building	**Sports hall**	**Transport**	**Total**	
Reference building	12 605 228	6 650 067	747 293	20 002 588	Total kgCO_2eq over 60 years lifetime
Designed building	10 878 039	4 537 372	699 768	16 115 179	
Difference	- 1 727 189	- 2 112 695	- 47 525	- 3 887 409	
Total reduction [%]				**19.4%**	

8. Indoor Climate Performance

The evaluation of indoor climate performance of the building was designed in accordance with NS-EN 15251: 2007 + NA2014. Indoor climate input parameters considered for design and assessment of energy performance of the building addressed indoor air quality, thermal environment, daylight and acoustics[6].

8.1 Indoor air quality

The simulation is performed by choosing representative rooms and areas. Winter and summer simulation was performed in SIMIEN for the selected zones.

8.2 Daylight

The design considered satisfactory daylight for all living areas in the building according to the requirements of both TEK10 and tender documents (minimum 2% up to 5%), and most rooms were assessed to have daylight conditions well beyond the minimum requirements.

Windows are well used in all living areas. Except for a room which has an average daylight factor of about 2%, the rooms' average daylight factor is well above 2%. The daylight factors of the building were calculated for the following types of rooms (category A and B, see Table 8.1):

- Category A: rooms with the lowest daylight level as a result of external shielding in combination with room layout and window design. This is used to show that all the rooms as a minimum meet the criteria in the tender documents. There are few such rooms.
- Category B: Examples of room with average daylight factor at least 5%, both corner and rooms with only one facade.

Calculations was made for critical or selected rooms on level 1, 4, and 5 floor plans with an objective that all living spaces should have an average daylight factor above 2.0%. According to the Norwegian building code TEK 10, daylight requirement is exempted for rooms with limited occupancy time.

Table 8.1 A daylight factor calculation output for category A and B rooms[6].

Type rom	Beregnet snitt dagslysfaktor (%)
Kategori A (de mest kritiske rommene mht. dagslys). Vist med rød markering på tegningene	
A01.01. Plan 1, mot nord. Behandlingsrom	2,8
A02.01. Plan 2, mot øst. Kontor. De øvrige kontorene (rom for varig opp-hold) på samme rekke har bedre dagslysforhold	2,4
A03.01. Plan 3 mot øst. Kontor	2,4
A03.02. Plan 3 mot vest. Kontor	2,3
A03.03. Plan 3 mot sør. Kontor (ble sjekket pga. utkraging, men rommet har rikelig med dagslys)	5,4
A03.04. Plan 3 mot vest. Undervisningsrom (delvis skjermet av utvendig trapp)	3,5
Kategori B (eksempler rom med snitt dagslysfaktor større enn 5 %). Vist med grønn marke-ring på tegningene	
B01.01. Plan 1, mot lysgård (inne i hjørne). Behandlingsrom	9,1
B02.01. Plan 2, hjørnerom mot sør-øst. Øvingsrom akustikk	5,4
B03.01. Plan 3, hjørnerom nord-øst. Elenergi	5,4
B04.01. Plan 4, mot vest. Arbeidsrom (uten gjennomgående korridor)	5,2
B04.02. Plan 4, mot nord. Undervisningsrom	10,9

[6] Chapter 8 is based on "Kap 10 Energi of miljø", report prepared by SKANSKA, February 29, 2016.

9. Discussion and Conclusions

In this chapter, some of the main characteristics and lessons learned from the GHG emissions calculation evaluation of Heimdal pilot building projects are summarized.

9.1 Emissions reduction measures

The most efficient design strategies and material choices for achieving low embodied emissions identified through the pilot projects are; area and material reduction, application of reused and recycled materials, using materials with low embodied carbon, sourcing local materials, and adopting materials with high durability and a long service life [8]. The Heimdal pilot project is a good example in which several design and material choices were considered in order to reduce embodied emissions from an early design phase to detailed design of the project. The building was designed as flexible as possible to adapt easily to future changes. The project also highlighted the importance of a holistic evaluation in the choices of materials and technical solutions in order to avoid problem shifting. For example, the amount of concrete and steel used was reduced by implementing thinner retaining walls in the sports hall and a lighter roof construction in the school building. Another example is the timber window frame with protective aluminums cladding that was selected in place of timber window frames without aluminum protection, due to the lower total emissions when replacements are considered over a 60 year building lifetime.

However, the project also shed light on how challenging it can be to hold on to the focus on embodied emission reduction in a complex project process. Decisions regarding design and material alternatives are based on many criteria of which economy and time consumption are of course highly prioritized. Special building physics requirements applies to school buildings, e.g. durability and soundproofing. Challenges in the project also included unforeseen changes in the design and construction due to ground conditions and new requirements.

A special dedication to the environmental perspective from the building owner STFK, the ZEB ambition and competence from the ZEB Centre, and the application of special LCA competence within Skanska were key factors for the emission reductions obtained in the project. At the same time, we would have wished to achieve even more material emission reductions.

9.2 ZEB ambition level definition

In ZEB pilot buildings, the first step is defining the ambition level of the project in accordance with the ZEB ambition levels definition. In the research produced by the ZEB Centre, the ZEB ambition levels has proven to be useful in the ZEB pilot projects, because they have contributed to important learning outcomes and emission reductions. Here it should be noted that the Norwegian ZEB research center has continuously been revising the Norwegian ZEB definition guideline based on the relevant national and international work and experiences gained from the ZEB pilot building projects. Thus, there has been a development within the research on ZEB definitions and methodology running in parallel with the Heimdal pilot project which has been challenging to communicate to Skanska and STKF in a clear and systematic way (see section 9.5).

The ambition level of the Heimdal pilot project has been a somewhat moving target. As is the case for most of the ZEB pilot buildings, the development of the definitions, methods, and knowledge has run in parallel with the building process. Discussions, revisions, and continuous learning, rather than a straight line towards a clearly defined goal, often characterize the processes. A range of energy efficiency measures and environmentally friendly energy generation concepts have been considered for designing and achieving ZEB goals.

The original aim of the Heimdal pilot building was achieving ZEB-O20%M ambition level. This ambition level is not set under the official ZEB ambition level categories. According to ZEB ambition level definition [3], ZEB-OM includes operational energy (O) plus embodied emission from materials (M). That means, the M includes the emissions from product phase of materials (A1 – A3) and scenarios for the replacement phase (B4**, considers only scenarios related to the production of materials used for replacement), according to NS-EN 15978: 2011. In the project, ZEB-O20%M was defined as ZEB-OM with consideration of only 20% emission compensation from M.

Furthermore, the emissios from transport of materials and products to the building site (A4) was included in the material emission calculations performed by Skanska. This is not in line with the definition of ZEB-OM. According to the ZEB definitions, transport of materials to the building site (A4) is included in the ZEB-COM ambition level. There are good reasons to include emissions from material transport, as transport can have a large impact on global warming. In some building components, the emission reduction compared to the reference building was due to A4 (from the selection local materials).

A specific material emissions target (10 $kgCO_{2eq}/m^2$/year) was set. This target was based on the very early design phase (competition phase 2). This approach was found to be challenging as a more detailed GHG calculation is required in the next phase of the project, which can lead to higher emissions compared with a simplified analysis performed in Phase 2 of the project.

Here, a lesson learned is the importance of clearly defining a realistic ambition level in the early design phase of a project with interdisciplinary teamwork.

9.3 Replacement intervals

The replacement interval calculation was performed according to EN 15978, where a full number of replacements of products is allowed. In the case of a partial number of replacements resulting from the estimated service life of the component and the reference study period of the building, the value obtained is rounded up to the higher integer. Furthermore, EN 15978 states that: "If, after the last scheduled replacement of a product, the remaining service life of the building is short in proportion to the estimated service life time of the installed product, the actual likelihood of this scheduled replacement should be taken into account". In most of the ZEB pilot cases, the number of replacements of products has been calculated without rounding up. The reason for using this approach is to avoid the subjective evaluation of the likeliness that the last scheduled replacement takes place, and also because decimal numbers are considered representative when not all products of a type, for instance windows, are changed at the same time [3]. The replacement interval calculation can have a significant impact on the embodied emission calculation results and affects the comparison of the ZEB pilot studies. Thus, it is important to notice the whole number replacement interval factor used in life cycle module B4 when using the results from Heimdal pilot building. Decision on which methodology to use for the replacement interval calculation is important for future works to increase the transparency and comparability of LCA studies.

Another important discussion in building LCA research is the sourcing of service lifetime data for building products. Skanska used estimated service life data from Norwegian EPDs and/or from technical guidelines developed by SINTEF Building and Infrastructure (SINTEF Building Research Design Guides (BKS) 700.320, (BKS 700.320 2010)). For some materials, Skanska found that the service life data found in the EPD did not quite correspond to their practical experience. In these cases, Skanska applied their own, experience based service life data. This is in line with the principle of substituting the data in scenarios after cradle-to-gate (life cycle module A4 and onwards) with project-specific data or knowledge that is more representative than generic or EPD-based information.

9.4 LCI data sources

In the Heimdal pilot project, EPDs were used as a main data source for embodied emission calculations during the design phase. due to a lack of EPDs, generic Ecoinvent data (Ecoinvent v3.1) were used. Expired EPDs have been used where these data were considered to be more representative than generic data.

During the early design phase of a building, there is limited detailed information available about the exact products to be used. Using EPDs of specific products with lower emissions may underestimate the actual emission from the building, unless the exact product in which the EPD data is considered is used during the construction phase. One way of avoiding uncertainty from using EPDs during the design phase, where the type of product used in the building is unknown, is to consider different scenarios and perform sensitivity analyses. For example, one may use average emission data as a basis and perform sensitivity analyses to compare the average EPD emission data with the lower emission product EPDs and product EPDs with highest emission. This gives worst case and best case scenarios and also encourages the use of materials with lower emission data during the construction phase.

Using expired EPDs can also increase the uncertainty of the result, for example, some of the expired EPDs used for concrete product in the Heimdal project no longer exist. An expired EPD can be a good data source for products still in use. However, it would be important to contact EPD owners and evaluate if any of the environmental indicators changed compared to the published data. Thus, care should be taken during selection of LCI data sources in the design phase of a project.

9.5 Reference building

The methodology used for defining the reference building considered in the project in order to evaluate the 20% emission reduction from Heimdal pilot building was developed by Skanska and quality assured by the ZEB Centre. However, there are some important limitations to the model. One important concern is that two aspects are compared simultaneously; i.e. the design (e.g choice of construction solutions) of the building compared to the reference and the materials/product choices. The latter will in many cases merely reflect the difference in choosing specific data compared to generic data. Generic data are often slightly higher in global warming potential than their specific counterparts found in the EPDs. Thus, reductions in greenhouse gas emissions obtained through design measures, for instance material reductions through lighter roof and slimmer load-bearing structures, are associated with less uncertainty than emission reductions obtained by comparing specific data to generic data. From the information given in [17], it can be assumed that large parts of the obtained 19,4% emission reductions stem from the choice of data source. The ZEB Centre would therefore have preferred to differentiate between the emission reductions originating from design measures and emission reductions originating from the different data applied to the design phase LCI compared to the data applied to the reference building.

It is also important to be aware of this when setting emission targets. For example, if the emission target is set in early design phase based on an emission calculation performed using generic data, the calculated emissions can be lower when product specific EPD data are used in the design or as-built phase.

9.6 Team work and communication

Tine Hegli, senior architect and project manager in Snøhetta, said in her speech at the final ZEB conference in January 2017 that one of the most important lessons learned from the ZEB Centre was the importance of close, cross-disciplinary teamwork between the stakeholders in a the building process. In addition, she accentuated the need for communication as a means to break down barriers between the disciplines and to share the knowledge efficiently.

A challenge in the Heimdal project in this regard was the lack of information flow between the executive parties of the project and the ZEB Centre researchers. It was challenging to follow the latest developments and changes of the building design changes as the researches were not a part of the project meetings and conversations. It was also challenging to synchronize calculations, feedback and reporting to the different phases and deadlines in the building process, as plans were changed and developed.

In the competition phase, the researchers in the ZEB Centre encountered challenges in communicating the requirements and to transfer the knowledge to the teams. The knowledge of LCA varied considerably in the teams. Workshops including practical training in LCA and the use of EPD data proved to be very useful. The workshop about handling EPD information held in the first phase of the project proved to be valuable. Knowledge transfer through practical workshops proved to be efficient compared to messages delivered in oral presentations, even if the information was meticulously repeated and noted on slides. It was especially difficult to communicate the meaning of performing embodied emission calculations with the ZEB M tool (chapter 5.1.2). The teams did not comply with the requirement of showing the measures taken and the reasoning behind their choices of materials and/or the alternatives considered. The competitors had merely filled in the calculation tool with numbers. Maybe they thought that the LCA experterts at the ZEB Centre were able to look at a list of material amounts and directly visualize the innovations of the design. More probable, not enough effort was placed in this task in general. A similar experience came out of a university course led by the ZEB Centre, in which the student group work was similar to the phase 2 competition of the Heimdal project. The group work consisted of designing a ZEB-OM building using the ZEB Centre methodology and the same (or similar) ZEB-M tool described in chapter 5.1.2. The students hastily filled in the tables and seemed eager to know if their results were "correct". Of course, there is no correct answer as the calculations are meant to be used as a means to understand ones embodied emissions and as a tool to reduce them. This was very difficult to communicate.

Another important challenge in evaluating the embodied emission calculations in the Heimdal project was finding the balance between low total emissions and the thoroughness of the calculations. It is one of the major dilemmas of LCA work: a thorough and detailed analysis will result in a larger environmental impact than a simpler analysis.

These experiences and lessons learned will be useful input to further work on zero emission buildings and furthermore in the new research center ZEN – Zero Emission Neighborhoods.

10. References

1. *Områdeprogram for Saupstad-Kolstad 2013-2020*. 2013, Trondheim Kommune.
2. Cobut, A., R. Beauregard, and P. Blanchet, *Using life cycle thinking to analyze environmental labeling: the case of appearance wood products.* The International Journal of Life Cycle Assessment, 2013. **18**(3): p. 722-742.
3. Fufa, S.M., R.D. Schlanbusch, K. Sørnes, M. Inman, and I. Andresen, *A Norwegian ZEB Definition Guideline. The Research Centre on Zero Emission Buildings. ZEB Project report no 29.* 2016..
4. Peng, J. and L. Lu, *Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits.* Renewable and Sustainable Energy Reviews, 2013. **27**(0): p. 149-162.
5. *Heimdal videregående skole og flerbrukshall. Konkurransepreget dialog. Totalentreprise NS 8407. Konkurransegrunnlag del 1. Konkurransegrunnlag og generell informasjon*. 2014, Bygge-og eiendomstjenesten, Sør Trøndelag Fylkeskommune.
6. Skanska, Rambøll, and KHR, *Heimdal VGS. konkurransepreget dialog - Fase 3: Prosjektforslag med pris, Skanska/Rambøll/KHR*. 2015.
7. NS-3926-1:2009, *Visuelle ledesystemer for rømning i byggverk - Del 1: Planlegging og utforming*. 2012, Standard Norge.
8. Jelle, B.P., T. Gao, M.K. Wiik, and R.D. Schlanbusch, *The right materials: More important than ever*, in *Zero Emission Buildings*, Anne Grete Hestnes and Nancy Lea Eik-Nes, Editors. 2017 Fagbokforlaget: Bergen, Norway.
9. Fjeldheim, H., *Heimdal VGS og flerbrukshall - Klimagassutslipp fra materialer Fase 4. Skanska report delivered to STFK on 15.01.2016*. 2016d.
10. NS-3031:2014, *Beregning av bygningers energiytelse - Metode og data*. 2014, Standard Norge.
11. NS-EN 15978:2011, *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method* 2011, European Committee for Standardization, Brussels, Belgium.
12. NS-3451:2009, *Bygningsdelstabell*. 2009, Standard Norge.
13. Wiik, M.K., R.D. Schlanbusch, A.H. Wiberg, and T. Kristjansdottir, *ZEB Tool Manual. User Guide. Version 1. External memo. The Research Centre for Zero Emission Buildings.* 2017.
14. NS-EN 15804:2012+A1:2013, *Sustainability of construction works Environmental product declarations Core for the product category of construction products*. 2014, Standard Norge, Oslo, Norway.
15. IPCC, *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. 2007.
16. Fjeldheim, H., *ZEB M-Regneark Skole rev 18. Skanska GHG emission calculation performed in spreadsheet delivered to STFK on 19.08.2016*. 2016b.
17. Fjeldheim, H., *ZEB M-Regneark Flerbrukshall rev 18. Skanska GHG emission calculation performed in spreadsheet delivered to STFK on 19.08.2016*. 2016c.
18. Norsk betongforening, *Lavkarbonbetong. Publikasjon nr. 37*. 2015.
19. Kristjansdottir, T.F., C.S. Good, M.R. Inman, R.D. Schlanbusch, and I. Andresen, *Embodied greenhouse gas emissions from PV systems in Norwegian residential Zero Emission Pilot Buildings.* Solar Energy, 2016. **133**: p. 155-171.

20. Sartori, I., A. Napolitano, and K. Voss, *Net zero energy buildings: A consistent definition framework.* Energy and buildings, 2012. **48**: p. 220-232.
21. Kristjansdottir, T., H. Fjeldheim, E. Selvig, B. Risholt, B. Time, L. Georges, T.H. Dokka, J. Bourrelle, R. Bohne, and Z. Cervenka, *A Norwegian ZEB-definition embodied emission. ZEB Project report no 17, The Research Centre on Zero Emission Buildings (ZEB)*. 2014.
22. Statsbygg, *Beskrivelse referansebygg, klimagassregnskap.no v4.1.* *http://www.klimagassregnskap.no/wordpress/wp-content/uploads/2015/04/Beskrivelse-referansebygg-kgr.no-materialmodul-v4.1.pdf*.
23. Civitas, Numerika, Context, and Statsbygg, *klimagassregnskap.no*. 2014, Statsbygg.
24. Fjeldheim, H., *Heimdal VGS og flerbrukshall - Reduksjon av ZEB-M. Skanska report delivered to STFK on 19.08.2016*. 2016a.
25. Ecoinvent, *Ecoinvent data v3.1*. 2014, Swiss Centre for Life Cycle Inventories: Dübendorf.
26. Sverre Smeplass, S., N. Tom Fredvik, U. Øyvind Sæther, V. Ragnar Skagen, F. Hallvard Magerøy, S. Ingrid Hegseth, S. Nina P. Borvik, C. Lars Hansson, S.v. Hedda Vikan, R. Sunniva Barnes, M.S. Kristin Holthe, N. Knut Ose Kjellsen, M.F.B. Margrethe Ollendorff, and N. Christoffer Moen, *Lavkarbonbetong*. 2015, Norsk betongforening.

APPENDICES

Appendix 1	ZEB requirements for energy performance and GHG emissions evaluation in phase 2 competition
Appendix 2	ZEB Heimdal pilot building life cycle inventory table
Appendix 3	Heimdal VGS og Sports hall – Reduksjon av ZEB-M. Skanska report dated 19.08.2016

Appendix 1: ZEB requirements for energy performance and GHG emissions evaluation in phase 2 competition

NOTAT

Vurdering av energibruk og klimagassutslipp for Nye Heimdal VGS_28.02.2014

Dette notatet beskriver krav og forutsetninger for vurdering av energibruk og klimagassutslipp for Nye Heimdal VGS. Notatet er utarbeidet av forskningssenteret *Zero Emission Buildings*, ved NTNU og SINTEF, i samarbeid med Sør-Trøndelag Fylkeskommune.

Overordnet målsetning

Bygget skal som minimum regnes som «nullutslippsbygg» mht utslipp av klimagasser fra energibruk i driftsfasen, definert som ZEB-O nivå (**Z**ero **E**mission **B**uilding – **O**peration) i henhold til forskningssenteret Zero Emission Buildings (www.zeb.no). I tillegg skal det tas hensyn til klimagassutslipp fra materialbruk[7].

Energibruk i driftsfasen

ZEB-O nivå er definert som følger:
Beregnet klimagassutslipp fra energibruk relatert til drift av bygningene skal over året kompenseres gjennom produksjon av fornybar energi.

Energibruk til drift omfatter alle energiposter gitt i NS 3031:2007.
Faktorer for konvertering fra beregnet levert energi til klimagassutslipp (CO_2-faktorer) er gitt i tabell 1.

Fornybar elektrisitet skal produseres lokalt, dvs være integrert i bygningsmassen eller på tomta, men energivarer som benyttes til produksjon av fornybar energi på stedet kan være produsert annensteds (f.eks. biobrensel). Termisk fornybar energiproduksjon kan skje på eller utenfor tomta, men ved beregning av klimagassutslipp skal det tas hensyn til eventuelle overføringstap fra produksjonsstedet. Fornybar elektrisitet som er produsert på tomta og som leveres inn på nettet, kommer til fratrekk i CO_2-regnskapet med samme CO_2-faktor som benyttes til import av elektrisitet fra nettet. Eksport av fornybar varme kan også krediteres klimagassregnskapet på tilsvarende måte, men begrenset slik at "inntektsført" eksportert fornybar varme over året ikke kan overstige årlig importert varme. Ref [Dokka m.fl. 2013] for en nærmere forklaring av beregning av klimagassutslipp

Bygningene skal minst tilfredsstille passivhusnivå som angitt i NS 3701:2012.

Netto energibehov og levert energi skal beregnes og dokumenteres iht NS 3031:2007 og NS 3701:2012. Det skal utføres energiberegninger med et anerkjent dynamisk simuleringsprogram som er tilgjengelig på markedet og som er validert etter NS-EN 15265. Eventuell eksport av energi til nettet skal dokumenteres iht NS-EN 15603:2008. Hvis det benyttes nye og innovative systemer som ikke dekkes av NS 3031 eller NS 3701, skal disse beregnes med anerkjente metoder og beregningsprogrammer, og dokumentasjon skal leveres. Alle energiberegninger skal gjøres med utgangspunkt i statistiske klimadata for Trondheim («normalår»). Klimadata som er benyttet i beregningene skal dokumenteres med kilde.

[7] Krav til klimagassutslipp fra materialbruk vil bli spesifisert nærmere i Fase 2 av konkurransen.

For dokumentasjon ift nullutslippsregnskapet skal det benyttes standardiserte driftstider som gitt i NS 3031:2007. Ved beregning av netto energibehov skal det benyttes ventilasjonsluftmengder dimensjonert ut i fra reelle materialbelastninger (emisjoner fra bygningsmaterialer, inventar og installasjoner). Emisjoner fra materialbelastninger skal dokumenteres iht NS-EN 15251:2007. Benyttede luftmengder og luftkvalitet (se under) skal dokumenteres ut i fra valgte materialer og komponenter, ventilasjonsstrategi og behovsstyring, samt dokumentert termisk komfort (se under).

Alle inndata til energiberegninger skal dokumenteres, og inndatafiler samt resultatfiler skal være en del av leveransen.

Ved valg og utforming av energikonsept- og løsninger skal det legges vekt på robusthet og enkelhet i bruk.

Det vil bli satt krav mht måling og etterprøving av energibruken til drift av byggene. En EPC-modell (Energy Performance Contract) vil bli etterspurt i neste fase.

Det vil bli satt krav om tetthetsprøving og termografisk undersøkelse for å bekrefte beregningsforutsetninger mht luftlekkasjer og varmeisolering av klimaskall.

Tabell 1. CO_2-faktorer for ulike energivarer, gitt i utslipp av g CO_2-ekvivalenter per kWh, fra [Dokka m.fl. 2013].

Energibærer	CO_2-faktor (g/kWh)
Elektrisitet fra nettet	130
Olje (fossil)	285
Gass (fossil)	210
Avfallsforbrenning*	185
Treflis	4
Trepellets	7
Bio-etanol	85
Bio-olje	50
Bio-diesel	50
Bio-gass	25

**For fjernvarme fra anlegget til Statkraft Varme i Trondheim kan det benyttes en CO_2-faktor på 130 g/kWh.*

Innemiljø

Innemiljø skal dokumenteres iht krav og veiledning i TEK'10.

Det skal leveres beregninger som viser at gjennomsnittlig dagslysfaktor på arbeidsplanet er minst 2% i alle oppholdsrom, og helst opp i mot 5%. Dagslysberegninger skal utføres med anerkjent metode/ beregningsprogram som Radiance[8] eller tilsvarende. Alle inndata til dagslysberegning skal dokumenteres, og inndatafiler samt resultatfiler skal være en del av leveransen.

I fase 2 skal det leveres beregninger som dokumenterer at operativ temperatur i oppholdsrom ikke overstiger 26°C i mer enn 50 timer i et normalår, samt at CO_2-nivået ikke overstiger 1000 ppm. I tillegg skal det vises at kriterier for trekk, strålingsasymmetri, gulvtemperatur og vertikal temperaturgradient er iht NS-EN ISO 7730:2005, kategori B i appendix A.

[8] http://radsite.lbl.gov/radiance/HOME.html

Det vil i fase 2 bli satt krav om utarbeidelse av kontrollplan for kvalitetssikring som beskriver hvordan man har sikret bygget mot fuktskader i prosjekterings- og byggefasen.

Klimagassutslipp fra materialbruk

I konkurransens fase 1 skal det foretas en overordnet vurdering av klimagassutslipp mht alternative løsninger for materialbruk. Overslagsberegninger for klimagassutslipp for de foreslåtte løsningene skal leveres, sammen med inputdata og forutsetninger for beregningene (mengder, utslippsfaktorer, levetider, etc).

I fase 2 av konkurransen vil det bli definert mer spesifikke krav til klimagassutslipp for hele bygningsmassen iht ZEB-OM nivå, definert som at: *Klimagassutslipp fra energibruk relatert til drift av bygningene og klimagassutslipp forbundet med materialbruk, skal kompenseres gjennom produksjon av fornybar energi.* Det vil bli utarbeidet nærmere definerte kriterier som prosjektene vil bli evaluert etter.

Referanser

Dokka, T.H., I. Sartori, M. Thyholt, K. Lien og K.B. Lindberg (2013): "A Norwegian Zero Emission Building Definition", Artikkel presentert på konferansen PassivhusNorden 2013, Göteborg, ref: http://www.laganbygg.se/UserFiles/Presentations/18._Session_5_T.Dokka.pdf.

Appendix 2: ZEB Heimdal pilot building life cycle inventory table

Building parts	*Building type*	*Material input*	*Amount*	*Unit*	*Service life (years)*	*Data source*
21 Ground work and foundation						
213 Ground Reinforcements	School	Steel	20	pcs	60	Bolter 3,5 m - Polyester resin, unsaturated {RER} | Production + EPD Celsa Armering(Heimdal project data)
	Sports hall	Steel	130	Pcs	60	
216 Direct foundation	School	Low carbon concrete	718	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	School	Reinforcing Steel	57440	kg	60	S-P-00305
	Sports hall	Low carbon concrete	150	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	Sports hall	Reinforcing steel	12000	kg	60	S-P-00305
217 Drainage	Sports hall	Leca aggregates	5000	kg	60	EPD Leca lettklinker
22 Superstructure						
222 Columns	School	Steel	63500	kg	60	Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
	School	Low carbon concrete	146	m3	60	Lavkarbon betong B25 M90 (norsk betongforering report, 2015)
	School	Reinforcing steel	23360	kg	60	S-P-00305
	Sports hall	Steel	7000	kg	60	Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
	Sports hall	Low carbon concrete	138	m3	60	Lavkarbon betong B25 M90 (norsk betongforering report, 2015)
	Sports hall	Reinforcing steel	22080	kg	60	S-P-00305
223 Beams	School	Steel	175550	kg	60	Skanska: Welded Plated Beams HSQ, ISQ, HSK Sections
	School	HEB	16593	kg	60	HEB
	School	Steel	98000	kg	60	NEPD 325-205-EN
	School	concrete	32,8	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	School	Steel	4786	kg	60	S-P-00305 (2015)
	Sports hall	steel	577500	kg	60	NEPD 325-205-EN (2015)
23 Outer walls						
231 Load bearing outer wall	School	Reinforcing steel	57869,00	kg	60	S-P-00305 (2015)
	School	Low carbon concrete	826,70	m3	60	Lavkarbon betong B35 M60 (norsk betongforering report, 2015)
	School	Rockwool insulation (300mm)	370,00	m2	60	NEPD-00131E rev1
	Sports hall	Reinforcing Steel	61138	kg	60	S-P-00305
	Sports hall	Low carbon concrete	873	m3	60	Lavkarbon betong B35 M60 (norsk betongforering report, 2015)
	Sports hall	Rockwool insulation (300mm)	130	m2	60	NEPD-00131E rev1
232 Non load bearing outer wall	School	Knauf insulation	846	m3	60	BREG EN EPD NO.: 000052
	School	Sawn wood	412	m3	60	NEPD-307-179-NO
	School	Knauf insulation	40	m3	60	BREG EN EPD NO.: 000052
233 Glass Façade	School	Triple glazing glass	850,00	m2	30	Triple glazing, U<0,5 W/m2K, generic
	School	Aluminum	4581,00	kg	30	Aluminum, cast alloy {GLO} + Avg metal working Alu {RER}
	Sports hall	Triple glazing	35,00	m2	30	Triple glazing, U<0,5 W/m2K, generic
	Sports hall	Aluminum	189	kg	30	Aluminum, cast alloy {GLO} + Avg metal working Alu {RER}

Building parts	Building type	Material input	Amount	Unit	Service life (years)	Data source
234 Windows and doors	School	Window (Nordan inward opening)	1203,5	m2	60	NEPD 00176E Rev 1
	School	Triple glazing	943,9	m2	30	Triple glazing, U<0,5 W/m2K, generic
	School	Steel door	408,2	kg	30	Door-Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
	School	Rockwool	2,4	kg	30	Rockwool insulation, generic
	Sports hall	Steel door	180,5	kg	30	Door-Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
235 Outer cladding and surfaces	School	Wooden cladding (MøreRoyal)	36,82	m3	60	NEPD 00243N
	School	Sawn wood	1,03	m3	60	NEPD-307-179-NO
	School	Fibre cement coated board (Cembrit)	525,20	m2	30	EPD-CEM-2012111-E
	School	Glass (12mm StoVentec)	269,60	m2	30	
	School	Concrete (10mm Stolit)	269,60	m2	30	
	School	Gypsumboard (Norgips)	2732,90	m2	20	NEPD-109-177-EN
	Sports hall	fibre cement	20,00	m2	30	EPD-CEM-2012111-E
	Sports hall	Gypsum	51,50	m2	20	NEPD-109-177-EN
	Sports hall	glass	31,50	m2	30	
	Sports hall	concrete	31,50	m2	30	
237 Solar Shading	School	Glass fibre	174	Pcs	10	Zip Screen - Glass fiber {RER} | Production
	School	PVC	174	Pcs	10	Zip Screen - PVC Polyvinylchloride, emulsion polymerized, at plant
	School	Aluminum	174	Pcs	20	Zip Screen - Aluminum, wrought alloy {GLO}
24 Inner walls						
241 Load bearing inner wall	School	Reinforcing steel	19061,00	kg	60	S-P-00305
	School	concrete M25M90	272,00	m3	60	Lavkarbon betong B25 M90 (norsk betongforering report, 2015)
	Sports hall	Reinforcing steel	120141,00	kg	60	S-P-00305
	Sports hall	concrete M25M90	1716,30	m3	60	Lavkarbon betong B25 M90 (norsk betongforering report, 2015)
242 Non load bearing inner wall	School	Sawn wood	419,50	m3	30	NEPD-307-179-NO
	School	Steel profile (Norgips)	186000,00	m	30	NEPD00171N rev1
	School	Rockwool insulation (Flex A,100mm)	20700,00	m2	30	NEPD-00131E rev1
	School	Leca (basicblock 150mm)	75,20	m3	60	NEPD00278E
	Sports hall	Sawn wood	36,50	m3	30	NEPD-307-179-NO
	Sports hall	Steel profile (Norgips)	700,00	m	30	NEPD00171N rev1
	Sports hall	Rockwool Insulation (Flex A,100mm)	1800,00	m2	30	NEPD-00131E rev1
	Sports hall	Leca (basicblock 150mm)	6,50	m3	60	NEPD00278E
243 System Walls (glass panels)	School	Glass, uncoated	53214,60	kg	30	Flat Glass, Uncoated, generic
	School	Aluminum	9996,70	kg	30	Aluminum, cast alloy {GLO} + Avg metal working Alu {RER}
	School	Steel (wall system)	64499,40	kg	30	Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
	Sports hall	Glass, uncoated	4627,40	kg	30	Flat Glass, Uncoated, generic
	Sports hall	Aluminum	869,30	kg	30	Aluminum, cast alloy {GLO} + Avg metal working Alu {RER}
	Sports hall	Steel (wall system)	5608,60	kg	30	Steel , low alloyed, hot rolled (RER)+avg metal working (RER)

Building parts	*Building type*	*Material input*	*Amount*	*Unit*	*Service life (years)*	*Data source*
244 Windows, Doors, Folding Walls	School	Inner wooden door	336,00	m2	30	Door Inner Wood, generic
	Sports hall	Inner wooden door	29,00	m2	30	Door Inner Wood, generic
246 Cladding and surfaces	School	Standard gypsumboard (Norgips 13mm)	9476,00	m2	15	NEPD-113-177-EN
	School	Gypsum fireboard (Norgips 15mm)	1251,20	m2	15	NEPD-111-177-EN
	School	OSB	560,00	m2	15	Oriented strand board (RER) production
	School	Gypsum fibreboard (hunton)	40802,00	m2	20	Hunton fermacell-Gypsum fiberboard
	School	Ceramic tile	53900,00	kg	30	Ceramic Tiles, generic
	School	Alkyd paint	87528,80	m2	15	Alkyd paint, white, 60% in H2O, at plant/RER U
	School	Glass, uncoated	866,60	kg	30	Flat Glass, Uncoated, generic
	Sports hall	Standard gypsumboard (Norgips 13mm)	824,00	m2	15	NEPD-113-177-EN
	Sports hall	Gypsum fiberboard (Norgips 15mm)	108,80	m2	15	NEPD-111-177-EN
	Sports hall	Gypsum fibreboard (hunton)	3548,00	m2	20	Hunton fermacell-Gypsum fiberboard
	Sports hall	Alkyd paint	7611,20	m2	15	Alkyd paint, white, 60% in H2O, at plant/RER U
	Sports hall	Glass, uncoated	75,40	kg	30	Flat Glass, Uncoated, generic
25 Floor structure						
251 Load bearing deck	School	Steel reinforcing (Celsa)	327300,00	kg	60	NEPD-434-305-EN
	School	Low carbon Concrete	2727,50	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	School	Concrete HD265	11089,29	m2	60	Expired EPDs
	School	Concrete HD320	316,09	m2	60	Expired EPDs
	School	Concrete HD400	602,65	m2	60	Expired EPDs
	School	Concrete HD500	374,47	m2	60	Expired EPDs
	School	Concrete HD820	173,00	m2	60	Expired EPDs
	Sports hall	Steel reinforcing (Celsa)	20400,00	kg	60	NEPD-434-305-EN
	Sports hall	Low carbon Concrete	170,00	m2	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	Sports hall	concrete HD200	4189,90	m2		Expired EPDs
252 Slab on ground	School	Steel	30075,00	kg	60	NEPD-434-305-EN
	School	Low carbon Concrete	601,50	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	School	HDPE	5653,20	m2	60	Polyethylene, high density, generic
	Sports hall	Steel	49015,00	kg	60	NEPD-434-305-EN
	Sports hall	Low carbon Concrete	980,00	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	Sports hall	HDPE	9210,53	m2	60	Polyethylene, high density, generic
253 Raised/Built-up Floor, screed	School	Steel	11150,00	kg	60	NEPD-434-305-EN
	School	Low carbon Concrete	223,00	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	School	Concrete	324900,00	m2	60	UniversalSpachtelmasse USP 32
	Sports hall	Steel	23526,00	kg	60	NEPD-434-305-EN
	Sports hall	Low carbon Concrete	470,50	m3	60	Lavkarbon betong B30 M60 (norsk betongforering report, 2015)
	Sports hall	Concrete	58800,00	m2	60	UniversalSpachtelmasse USP 32

Building parts	*Building type*	*Material input*	*Amount*	*Unit*	*Service life (years)*	*Data source*
255 Floor Surfaces	School	Vinyl	1345,00	m2	25	
	School	Linoleum	13710,00	m2	25	
	School	Epoxy resin	2177,00	kg	15	Epoxy Resin, Liquid {RER} | Production
	Sports hall	Vinyl	360,00	m2	25	
	Sports hall	Polyurethane (Boflex Pulastic 2000)	3768,00	m2	25	
	Sports hall	Polyurethane (Boflex Pulastic SP TP/W)	214,00	m2	25	
256 Fixed Ceiling and Surface	School	Standard Gypsumboard (Norgips, 15mm)	2205,00	m2	60	NEPD-113-177-EN
257 Suspended Ceiling	School	suspended ceiling (Rockfom)	14050,00	m2	15	
	Sports hall	suspended ceiling (Rockfom)	400,00	m2	15	
26 Outer roof						
261 Primary construction	School	Steel	61517,584	kg	60	Steel , low alloyed, hot rolled (RER)+avg metal working (RER)
	School	Plywood	90,25	m3	60	Plywood, indoor use, generic
	School	Sawn wood	55,176	m3	60	NEPD-307-179-NO
	Sports hall	Concrete HD200	3885,00	m2	60	
262 roof covering	School	Roof membrane	4750	m2	30	NEPD-32-203-NO
262 Insulation	School	Rockwool insulation (Flexi A plate 481mm)	4750	m2	60	NEPD-00131E rev1
	School	Rockwool insulation (Tungplate 150, 300mm)	4750	m2	60	NEPD-00131E rev1
	Sports hall	Rockwool insulation (Hardrock energy 120mm)	12950	m2	60	NEPD-00131E rev1
	Sports hall	XPS insulation	199,55	m3	60	Extruded Polystyrene (XPS) Rigid Foam Insulation, generic
263 Glass roof, roof opening	School	Triple glazing window (Glass)	98	m2	30	Triple glazing, U<0,5 W/m2K, generic
	School	Wooden window frame	18,23	m2	30	Window frame, wood, generic
	Sports hall	Triple glazing window (Glass)	98	m2	30	Triple glazing, U<0,5 W/m2K, generic
	Sports hall	Wooden window frame	18,62	m2	30	Window frame, wood, generic
266 ceiling and internal surfaces	School	Asfalt	11,27	m3	60	Asphalt,Bitumen {RER}+Gravel{CH}, generic
	Sports hall	Asfalt	9,83075	m3	60	Asphalt,Bitumen {RER}+Gravel{CH}, generic
36 Ventilation and air conditioning						
362 Duct system for air conditioning	School	Steel	48051	kg	30	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}
	Sports hall	Steel	12013	kg	30	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}
364 Equipment for air distribution	School	Steel	15000	kg	20	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}
	Sports hall	Steel	3750	kg	20	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}

Building parts	*Building type*	*Material input*	*Amount*	*Unit*	*Service life (years)*	*Data source*
365 Equipment for air treatment	School	Steel	43051	kg	20	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}
	School	Aluminum	8279	kg	20	Aluminum, cast alloy {Glo}+aveg metal working Al{RER}
	School	Copper	2759,7	kg	20	Copper {Glo}+aveg metal working copper
	School	HDPE	1103,8	kg	20	Polyethylene, high density, generic
	Sports hall	Steel	10763	kg	20	Steel, low alloywd {RER}+galvanized+aveg metal working{RER}
	Sports hall	Aluminum	2070	kg	20	Aluminum, cast alloy {Glo}+aveg metal working Al{RER}
	Sports hall	Copper	689,9	kg	20	Copper {Glo}+aveg metal working copper
	Sports hall	HDPE	276	kg	30	Polyethylene, high density, generic
366 insulation for air treatment	School	Glava lamellmatte	10896	kg	20	
	Sports hall	Glava lamellmatte	2724	kg	20	
49 Energy supply systems						
PV system	School	Aluminum (PV mounting frame)	1937	m2	60	Aluminum, cast alloy {GLO}
	School	Pv panel	1937	m2	30	Ecoinvent: Photovoltaic panel, single-Si wafer {RER}
	School	Invertor (ρ=3000kg/m^3 ,)	248	kW	15	Ecoinvent: Inventor
Others	School	Heat pump 180W	1	PC	20	Ecoinvent: Heat pump 180W:2500kg/PC
	School	Heat pump 60W	1	PC	20	Ecoinvent: Heat pump 60W:800kg/PC
	School	Energy well	5000	m	60	Ecoinvent: Energy well
	School	CHP	1	PC	20	Ecoinvent: Heat and power co-generation unit, 55kW electrical {GLO}
62 Passenger and goods Transport						
Lifts	School	Elevator	4	PC	25	

SKANSKA

Skanska Teknikk

Klima, energi og bygningsfysikk

Heimdal VGS og flerbrukshall - Reduksjon av ZEB-M

Prosjekt:	Heimdal VGS og flerbrukshall
Tema:	Reduksjon av ZEB-M
Rådgiver:	Henning Fjeldheim
Kvalitetssikring:	
Dato:	19.08.2016
Revisjonsnummer:	

1. Bakgrunn

Sør-Trøndelag Fylkeskommune er en partner i Zero Emission Buildings (ZEB) og har som følge av dette definert ambisiøse miljømål for Heimdal VGS og flerbrukshall. I henhold til kravene i konkurransegrunnlaget har prosjektet følgende krav til klimagassutslipp:

- ZEB O (Operation)
  Beregnet klimagassutslipp fra energibruk relatert til drift av bygningene skal over året kompenseres gjennom produksjon av fornybar energi i tråd med de kriterier ZEB har definerte.
- ZEB 20% M (Materials)
  20% av klimagassutslipp forbundet med materialbruk i prosjektet, kompenseres gjennom produksjon av fornybar energi gjennom byggets levetid, i tråd med de målemetoder for energibruk og klimagassutslipp i tråd med de kriterier ZEB har definert.

Gjennom utviklingen av prosjektet er det foretatt optimaliseringer av løsninger og materialvalg som har redusert ZEB-M. Denne rapporten presenterer resultater samt dokumenterer metode, beregnet ZEB-M og sammenligning med en relevant referanse for prosjektet Heimdal videregående skole og flerbrukshall.

2. Hensikt og omfang

2.1. Hensikt med studien

Hensikten med denne studien er å etablere klimagassutslippet fra ZEB-M for Heimdal VGS og flerbrukshall. Beregningsmetodikken er i henhold til notat «0.7 ZEB M BRUKERVEILEDNING 031114» og andre spesifiseringer fra Sør-Trøndelag Fylkeskommune (2014). Sentrale metodiske valg er oppsummert under.

2.2. Deklarert enhet

Den funksjonelle enheten er definert som 1 m^2 BRA over 60 års levetid.

2.3. Systemgrenser

2.3.1. Grenser mot teknosfæren

Beregningene omfatter modul A1,A2,A3,A4 og B4 i henhold til EN 15978 som illustrert i Figur 1. Beregningene tilfredsstiller denne standardens krav til hva modulene skal omfatte.

System Boundary EN 15978																			
A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Next Product System			
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance	B3: Repair	B4: Replacement	B5: Refurbishment	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D1: Reuse	D2: Recovery	D3: Recycling	D4: Exported energy / Potential
x	x	x	x					x											

Figur 1 Inkluderte moduler i henhold til EN 15978

Transport i A4 er beregnet fra fabrikk til byggeplass på Heimdal. Utslipp fra generisk transport er ikke benyttet direkte.

Tabell 1 Bygningsdeler som er inkludert i beregningene i henhold til NS 3420

Bygningsdeler som er inkludert i beregningene i henhold til NS 3420	**Kommentarer**
21 Groundwork and Foundations	Parkeringskjeller er ikke inkludert i henhold til Sør-Trøndelag Fylkeskommune (2014).
22 Superstructure	
23 Outer walls	
24 Inner walls	
25 Structural Deck	
26 Outer Roof	
28 Stairs, balconies etc.	
36 Ventilation and Air Conditioning	
491 Solar thermal, PV systems + PV Roof constructions	
492 Wind energy systems	
493 Other renewables	
62 Person and product transport (lifts)	

2.3.2. Grenser mot naturen

Biogent CO_2 er regnet på samme måte som fossilt CO_2. Tidseffekten av forsinket utslipp er ikke regnet med.

Karbonopptak i betong regnes ikke med i henhold til Sør-Trøndelag Fylkeskommune (2014) ettersom dette foreløpig ikke er inkludert i PCR for betong.

2.4. Verktøy

Regneark «0.6 ZEB M-REGNEARK_031114» er benyttet til beregningene.

2.5. Data

Der leverandør er kjent og EPD er tilgjengelig for aktuelt produkt, er spesifikke data benyttet. For alle andre produkter er generiske data benyttet. Disse er hovedsakelig hentet fra Ecoinvent v.3.1 (Swiss Centre for Lifecycle Inventories, 2014) analysert med metoden IPCC 2013 i Simapro Analyst v.8. I disse beregningene er modulene A1-A3 medregnet.

I noen tilfeller har forutsatte produkter hatt EPDer som har utgått. Der disse er regnet for å være mer representative enn generiske data er de benyttet i beregningene. Disse er da lagt under fliken «Generic Material Library» ettersom dataene regnes for å være av noe lavere kvalitet enn spesifikke og gyldige EPDer.

Bjelker av i HEB-profiler og HSK-profiler er beregnet som et gjennomsnitt av data fra publiserte EPDer fra Skanska Norge AS, AK Mekaniske AS, EMV Construction AS og Contiga. Disse er derfor lagt under fliken «Generic Material Library»

Klimagassutslipp fra produksjon av plasstøpt betong er basert på felles grenseverdier angitt av betongbransjen beskrevet i Norsk Betongforening (2015).

2.6. Inndeling av beregninger

STFK ønsket at beregningene for Fase 3 for Heimdal VGS og Heimdal flerbrukshall skulle gjøres separat slik at de enklere kunne sammenlignes med andre bygg i hver sin bygningskategori. Skillet mellom byggene er satt i akse 10.

2.7. Forutsetninger

Der leverandører og produksjonssted er kjent, er spesifikke data for transportavstand benyttet. Der leverandør eller transportavstand er ukjent, er en standard transportavstand på 300 km benyttet i henhold til Wittstock, et al. (2011).

I henhold til konkurransegrunnlaget er levetiden for solcellepanelene satt til 30 år samt at klimagassutslippet fra produksjon av disse er forutsatt redusert med 50 % ved B4. For resterende tekniske installasjoner for energiforsyning er levetid satt til 20 år i henhold til Direktoratet for byggkvalitet (2010).

Det er forutsatt 2 strøk med maling for hver omgang med maling.

2.8. Metode for estimering av referansebygg

Det er omfattende diskusjoner om hvilke retningslinjer som skal gjelde for et referansebygg. I Norge, hovedsakelig med modulen «Materialbruk, tidligfase» i klimagassregnskap.no (Statsbygg, 2016) som utgangspunkt. Denne generer en bokslingnende bygning basert på noen få inputparametre med standard materialvalg tilpasset ulike bygningskategorier. Liknende diskusjoner om etablering av referansebygg pågår også i andre land.

Noen utfordringer som bruk av metodikken som ligger til grunn for «Materialbruk, tidligfase» modulen i klimagassregnskap.no medfører er følgende:

- Funksjonskravene til det etablerte referansebygget er kun delvis tilpasset det aktuelle bygget gjennom relevant bygningskategori. Dette kan gi neglisjerbare til betydelige utslag på materialmengder i positiv eller negativ retning avhengig av funksjonskravene til det aktuelle bygget.
- Det ligger en generisk database for faktorer for klimagassutslipp for de ulike materialene til grunn for resultatene fra «Materialbruk, tidligfase» modulen. Disse er samlet fra forskjellige kilder med mer eller mindre konsistent beregningsmetode og er i varierende grad representativ for det norske markedet for bygningsmaterialer.

For å etablere en referanse som resultatet for konseptet for Heimdal VGS og flerbrukshall kan sammenlignes med, benyttes følgende metodikk:

- Det tas utgangspunkt i det utarbeidede konseptet og regnes bakover for å illustrere reduksjonene som er realisert gjennom optimaliseringer og materialvalg. Dette ansees som mer representativt enn å legge til grunn bygget som etableres i «Materialbruk, tidligfase» modulen i klimagassregnskap.no.
- Materialvalg baseres på det som er standard for bygningskategorien «(63) Videregående skole» i «Materialbruk, tidligfase» modulen i klimagassregnskap.no.
- Faktorer for klimagassutslipp fra materialer basert på Ecoinvent v3.1 (Swiss Centre for Lifecycle Inventories , 2014) legges til grunn for referansebygget der det ikke er identifisert at det finnes mer representative data. Disse er basert på europeiske gjennomsnitt, men det finnes ingen database for norske markedsrepresentative verdier som er godt dokumentert. For utvalgte ressurser er det tilstrebet å etablere verdier som er representative for produksjon og transport for det norske markedet basert på snitt av EPDer fra leverandører på det norske markedet uten å ta hensyn til markedsandel deres respektive markedsandeler. Disse er presentert sammen med best practice verdier for samme materialgruppe definert av Pettersen & Bramslev (2016) for materialgrupper hvor disse er etablert.
    - Plasstøpt betong: bransjereferansen angitt av Norsk Betongforening (2015) er lagt til grunn ettersom denne vurderes som mest representativ for markedet i Norge. De valgte verdiene er høyere enn de som er definert av Pettersen & Bramslev (2016) noe som er naturlig ettersom disse harmonerer med Lavkarbonklasse A.

Product	Unit	A1-A3 kgCO2eq/unit (Calculated)	A1-A3 kgCO2eq/unit (Pettersen & Bramslev, 2016)
Betong - Bransjereferanse B30 M60	m3	280	200
Betong - Bransjereferanse B35 MF40	m3	350	220
Betong - Bransjereferanse B35 M60	m3	345	220
Betong - Bransjereferanse B35 M45	m3	370	220
Betong - Bransjereferanse B25 M90	m3	280	Ikke definert

-
    - Bjelker av i HEB-profiler og HSK-profiler: beregnet som et gjennomsnitt av data fra publiserte EPDer fra Skanska Norge AS, AK Mekaniske AS, EMV Construction AS og Contiga.
    - Konstruksjonsvirke: lagt til grunn EPD for norsk konstruksjonsvirke da dette er mest representativt for markedet i Norge
    - Prefabrikkerte betongelementer: HD- og DT- elementer er regnet som snitt av tilgjengelige EPDer fra Kynningsrud, Nordland Betongelement, OPB, Spenncon, Contiga, Loe Betongelementer og Skonto prefab
    - Armeringsstål: beregnet som et gjennomsnitt av data fra publiserte EPDer fra Serfas, Celsa og Norsk Stål
    - Trelags åpningsbare vinduer med aluminiumskledde karmer: beregnet som et gjennomsnitt av data fra publiserte EPDer fra Lian, Nordan og Nordvestvinduet. Disse ligger noe høyere enn det som er definert av Pettersen

& Bramslev (2016) som best case. Kriteriene for disse vinduene er ikke kjent. Valg som 2 eller 3 lags rute og med/uten aluminiumskledning for ramme har stor påvirkning på referanseverdien.

Product	Unit	A1-A3 kgCO2eq/unit (Calculated)	A1-A3 kgCO2eq/unit (Pettersen & Bramslev, 2016)
Windows triple glazed openable: Average of Norwegian EPDS	kg	2,90	2,5

- Gipsplater: standard gips og branngips er beregnet som et gjennomsnitt av data fra publiserte EPDer fra Norgips, Knauf og Gyproc. Beregnet verdi for Standard gips er betydelig lavere enn referanseverdien gitt av Pettersen & Bramslev (2016) mens beregnet verdi for Branngips er betydelig høyere. Dette av disse to verdiene ligger på verdien gitt Pettersen & Bramslev (2016) noe som virker fornuftig ettersom dette også er presentert som snittet av gipsplater på markedet.

Product	Unit	A1-A3 kgCO2eq/unit (Calculated)	A1-A3 kgCO2eq/unit (Pettersen & Bramslev, 2016)
Standard Gypsum boards: Average of Norwegian EPDS	m2	2,39	3,0
Firegypsum: Average of Norwegian EPDS	m2	3,42	

- Det er avveket fra metoden ved etablering av innervegger av i referansebygget. Det er ikke prosjektert nye innervegger som tilfredsstiller tilsvarende krav for å følge valg av materialer i kgr.no. Referansebygget er basert på samme materialer men generiske data Ecoinvent v3.1 (Swiss Centre for Lifecycle Inventories , 2014)
- Ecoinvent v3.1 (Swiss Centre for Lifecycle Inventories , 2014) inneholder ikke prosesser som er dekkende for løs lettklinker, kun lettklinker blokker. Data for løs lettklinker er estimert ved å ta utgangspunkt i data for lettklinkerblokker fra Ecoinvent v3.1 og ekstrapolere lineært basert på EPDer for Leca Lettklinker og Leca Basicblokk 15cm, lightweight concrete.

Sammenligning av resultatene for konseptet for Heimdal VGS og flerbrukshall med en referanse basert på medtodikken beskrevet over vil antagelig resultere i en større reduksjon enn det som er reelt på grunn av mangel på markedsrepresentative data for Norge. Samtidig er det ikke mulig å illustrere alle tiltak som er gjennomført. For eksempel er ikke alle arealeffektiviserings øvelser kvantifisert i mengder og blir dermed ikke synlig.

3. Kvantifisering av reduksjoner er realisert gjennom optimaliseringer og materialvalg

I dette kapitlet forsøkes det å presentere reduksjonen av klimagassutslipp for ZEB-M som følge av løsnings- og materialvalg.

Det er fremdeles ikke endelig avklart leverandører for produkter som for eksempel bjelker og søyler. Den presenterte reduksjonen er derfor ikke endelig.

Det valgte oppsettet viser ikke den totale sammenhengen for noen av løsnings- og materialvalgene. For eksempel er det vanskelig å kvantifisere tiltak som er gjort for optimalisering av areal med tanke på brutto/nettofaktor, men disse kan ha store utslag på resultatet. Videre må følgende sees i sammenheng for at den reelle reduksjonen skal synliggjøres:

- Innervegger: stender, isolasjon og platekledning
- Grunnarbeider: Lettfylling og plasstøpte betongvegger og andre relevante konstruksjoner
- Takkonstruksjon: bjelker og primærkonstruksjon

3.1. Total reduksjon sammenlignet med referansebygg

					TRANSPORT - A4 AND B4	
	(kgCO2eq) lifetime 60yrs	(kgCO2eq) per year	(kgCO2eq/sqm) BRA lifetime 60yrs	(kgCO2eq/sqm) BRA per year	(kgCO2eq) lifetime 60yrs	Total reduksjon (%)
Skole - Referanse	12 605 228	210 087	675	11,250	295 189	
Flerbrukshall - Referanse	6 650 067	110 834	866	14,430	452 104	
Total - Referanse	19 255 295	320 922	1 541	12,176	747 293	
Skole - Prosjektert	10 878 039	181 301	582	9,708	562 098	
Flerbrukshall - Prosjektert	4 537 372	75 623	591	9,845	137 670	
Total - Prosjektert	15 415 411	256 924	1 173	9,748	699 768	
Reduksjon	3 839 884	63 998	368	2,428	47 525	20 %

3.2. 216 Direct foundations

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept fundamenter	B30 M60 Lavkarbonklasse A	B30 M60 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.3. 217 Drainage

Fra fase 2 til Fase 4 har RIB og GEO gjort tiltak for å optimalisere tykkelse av idrettshallens yttervegg mot stedlige masser i øst, sør og vest. Blant annet har messanin på innsiden av yttervegg blitt utnyttet som avstivende bjelke for betongvegg. Løsningen inkluderer en blanding av stedlige masser og Leca i tilbakefylling. Dette krever en økt veggtykkelse og støping av betongdragere under gulv i idrettshallen for å ta opp kreftene på ytterveggen. Løsningen gir et lavere klimagassutslipp totalt sett og er implementert i konseptet. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Lett fyllmasse	Leca lettklinker eller tilsvarende	Lightweight concrete block, expanded clay {CH}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.4. 222 Columns

I Fase 4 ble det valgt å implementere HD 200 som takkonstruksjon ettersom dette har lavere flatevekt enne enn kompaktdekket fra Fase 2. Dette har positive konsekvenser for dimensjoneringen av stålfagverkene. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept Innvendige vegger, dekker og søyler (tempererte soner)	B30 M60 Lavkarbonklasse A	B25 M90 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.5. 223 Beams/Fagverk

I Fase 4 ble det valgt å implementere HD 200 som takkonstruksjon ettersom dette har lavere flatevekt enne enn kompaktdekket fra Fase 2. Dette har positive konsekvenser for dimensjoneringen av stålfagverkene. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept Innvendige vegger, dekker og søyler (tempererte soner)	B30 M60 Lavkarbonklasse A	B30 M60 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS.

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert under i Vedlegg.

3.6. 231 Load bearing outer wall

Fra fase 2 til Fase 4 har RIB og GEO gjort tiltak for å optimalisere tykkelse av idrettshallens yttervegg mot stedlige masser i øst, sør og vest. Blant annet har messanin på innsiden av yttervegg blitt utnyttet som avstivende bjelke for betongvegg. Løsningen inkluderer en blanding av stedlige masser og Leca i tilbakefylling. Dette krever en økt veggtykkelse og støping av betongdragere under gulv i idrettshallen for å ta opp kreftene på ytterveggen. Løsningen gir et lavere klimagassutslipp totalt sett og er implementert i konseptet. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept Utvendige vegger, søyler og støttemurer	B35 MF45 Lavkarbonklasse A	B35 M60 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert under i Vedlegg.

3.7. 232 Non Load bearing walls

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Isolasjon	EPD: Knauf Insulation: Blåseull Supafil eller tilsvarende	Glass wool mat {CH}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert under i Vedlegg.

3.8. 234 Windows and doors

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Vindu	Nordan - NTech Inward opening tilt & turn window 105/80 eller tilsvarende	Windows triple glazed openable: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.9. 235 Outer Cladding and surfaces

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Kledning	EPD: MøreTre: MøreRoyal + EPD: Cembrit - Fibre Cement coated Flatboard Products + 12 mm StoVentec Trägerplatte/ 10 mm Stolit eller tilsvarende	Brick {RER}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.10. 241 Load bearing inner Walls

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept Utvendige vegger, søyler og støttemurer	B25 M90 Lavkarbonklasse A	B30 M60 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert under i Vedlegg.

3.11. 242 Non loadbearing inner walls

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Stender	EPD: Sawn dried timber +	EPD: Sawn dried timber

	EPD: STÅLPROFIL TIL INNERVEGG Norgips eller tilsvarende	
Isolasjon	EPD: Rockwool: Insulation Flexi A plate 100 mm innerwalls eller tilsvarende	Rock wool {RoW}| production | Alloc Def, S
Lettklinkerblokk	EPD: Weber: Leca Basicblokk 15cm, lightweight concrete eller tilsvarende	Lightweight concrete block, expanded clay {CH}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.12. 246 Cladding and surfaces

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	**Prosjektert**	**Referanse**
Gips	EPD: Norgips Standard type A (STD) eller tilsvarende	Standard Gypsum boards: Average of Norwegian EPDS
Branngips	EPD: Norgips Fireboard/Brann type DF (BRN) eller tilsvarende	Firegypsum: Average of Norwegian EPDS
Fibergips	Hunton fermacell - Gypsum fiber boards eller tilsvarende	Gypsum fibreboard {CH}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.13. 251 Load bearing deck

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	**Prosjektert**	**Referanse**
HD 200	HD200 Contiga 70% STD FA - 7 spenntau	HD 200 (Snitt EPD-norge)
HD 265	HD265 Contiga 70% STD FA - 6 spenntau	HD 265 (Snitt EPD-norge)
HD 320	HD320 Contiga 70% STD FA - 10 spenntau	HD 320 (Snitt EPD-norge)
HD 400	HD400 Contiga 70% STD FA - 14 spenntau	HD 400 (Snitt EPD-norge)
HD 500	HD500 Contiga 70% STD FA - 16 spenntau	HD 500 (Snitt EPD-norge)
DT 820	DT820 Contiga 100% STD FA - 18 spenntau	DT 820 EPD-Contiga

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.14. 252 Slab on ground

Fra fase 2 til Fase 4 har RIB og GEO gjort tiltak for å optimalisere tykkelse av idrettshallens yttervegg mot stedlige masser i øst, sør og vest. Blant annet har messanin på innsiden av yttervegg blitt utnyttet som avstivende bjelke for betongvegg. Løsningen inkluderer en blanding av stedlige masser og Leca i tilbakefylling. Dette krever en økt veggtykkelse og støping av betongdragere under gulv i idrettshallen for å ta opp kreftene på ytterveggen.

Løsningen gir et lavere klimagassutslipp totalt sett og er implementert i konseptet. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept Utvendige vegger, søyler og støttemurer	B30 M60 Lavkarbonklasse A	B30 M60 Bransjereferanse
Armering	Celsa eller tilsvarende	Steel reinforcing bars: Average of Norwegian EPDS

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

3.15. 261 Primary Construction

I Fase 4 ble det valgt å implementere HD 200 som takkonstruksjon ettersom dette har lavere flatevekt enne enn kompaktdekket fra Fase 2. Dette har positive konsekvenser for dimensjoneringen av stålfagverkene. I tillegg er følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Betongresept		Betong - Bransjereferanse B30 M60
Armering		Steel reinforcing bars: Average of Norwegian EPDS
HD 200	HD200 Contiga 70% STD FA - 7 spenntau	

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert under i Vedlegg.

3.16. 262 Insulation

Følgende valg av produkter/materialer er gjort:

Materialer/produkter	Prosjektert	Referanse
Steinull	EPD: Rockwool: Insulation Flexi A plate 481mm	Rock wool {RoW}| production | Alloc Def, S
Steinull, tung kvalitet	EPD: Rockwool: Insulation Tungplate 150	Rock wool {RoW}| production | Alloc Def, S

Beregnet reduksjon i klimagassutslipp som følge av tiltakene er presentert i Vedlegg.

4. (Pettersen & Bramslev, 2016)Referanser

Swiss Centre for Lifecycle Inventories , 2014. *Ecoinvent v 3.1.* , s.l.: s.n.
Sør-Trøndelag Fylkeskommune, 2014. *HEIMDAL VIDEREGÅENDE SKOLE OG FLERBRUKSHALL - Konkurransepreget dialog Totalentreprise - NS 8407 – KONKURRANSEGRUNNLAG FASE 2, 3 og 4 – Prosjektutvikling, Pristilbud og Tildeling av oppdraget.* s.l.:s.n.
Sør-Trøndelag Fylkeskommune, 2014. *Svar på skriftlige spørsmål mottatt uke 48 og 49 og individuell gjennomgang med ZEB 27. og 28.11,* s.l.: s.n.
Wittstock, B. et al., 2011. *EeBGuide Guidance Document - Part B: Buildings.,* s.l.: s.n.

The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.

NTNU – Trondheim
Norwegian University of Science and Technology

SINTEF

ZEB The Research Centre on Zero Emission Buildings

FME FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI

Partners

NTNU
www.ntnu.no

SINTEF
www.sintef.no

Skanska
www.skanska.no

Weber
www.weber-norge.no

Isola
www.isola.no

Glava
www.glava.no

Protan
www.protan.no

Caverion Norge
www.caverion.no

ByBo
www.bybo.no

Multiconsult
www.multiconsult.no

Brødrene Dahl
www.dahl.no

Snøhetta
www.snoarc.no

Forsvarsbygg
www.forsvarsbygg.no

Statsbygg
www.statsbygg.no

Husbanken
www.husbanken.no

Byggenæringens Landsforening
www.bnl.no

Direktoratet for byggkvalitet
www.dibk.no

DuPont
www.dupont.com

NorDan AS
www.nordan.no

Enova
www.enova.no

SAPA Building system
www.sapagroup.com

Sør-Trøndelag fylkeskommune
www.stfk.no

Entra Eiendom AS
www.entra.no