ZEB Project report 36 – 2017

Marianne Kjendseth Wiik, Åse Lekang Sørensen, Eivind Selvik, Zdena Cervenka, Selamawit Mamo Fufa and Inger Andresen

ZEB Pilot Campus Evenstad, administration and educational building As-built report

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Abstract

This report describes the new ZEB Campus Evenstad pilot administration and educational building. The report summarizes and documents the as-built phase life cycle greenhouse gas (GHG) emissions of the administration and educational building at a ZEB-COM ambition level. The ZEB-COM ambition level means that all emissions from construction (C), operational energy (O), and materials (M) are compensated for through on-site, renewable energy production. The report describes the building design and calculation methodology, including operational energy performance and embodied GHG emission calculations from materials and construction. The as-built emission results are then presented, together with a ZEB emission balance. The results are discussed in terms of construction emissions, operational energy use, and material emissions before the conclusion is presented.

Contents

1. Introduction

1.1 Background

This report describes the new ZEB Campus Evenstad pilot administration and educational building. Campus Evenstad is a university college situated in Hedmark, Norway. Statsbygg has commissioned the building. Construction began at the end of 2015, and the building was completed by the end of 2016.

1.2 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 developed ZEB definition and calculation methodologies for operational energy and life cycle CO_{2eq} 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) [1, 2]:

1. ZEB-O÷EQ: Emissions related to all energy use for operation "O" except energy use for equipment and appliances (EQ), shall be compensated for with renewable energy generation. The definition of O÷EQ therefore includes operational energy use, except energy use for equipment and appliances (B6*), as outlined in NS-EN 15978: 2011 [3].

2. ZEB-O: Emissions related to all operational energy "O" shall be compensated for with renewable energy generation. The O includes all operational energy use (B6) according to NS-EN 15978: 2011 [3].

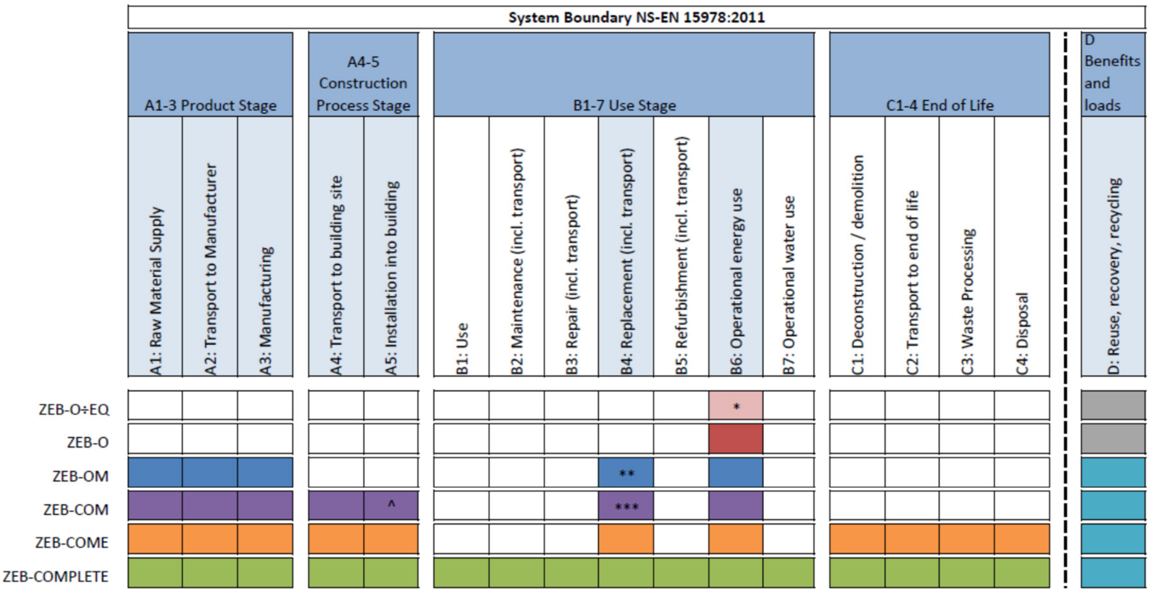
3. ZEB-OM: Emissions related to all operational energy "O" plus embodied emissions from materials "M" shall be compensated for with renewable energy generation. The M includes the product phase of materials (A1 – A3) and scenarios for the replacement phase (B4**), according to NS-EN 15978: 2011 [3]. Note that B4** in ZEB-OM considers only scenarios related to the production of materials used for replacement. The transportation (A4), installation (A5), and end of life processes for replaced materials are not included in B4**.

4. ZEB-COM: This is the same as ZEB-OM, but also takes into account emissions relating to the construction "C" phase. The phases included in C are transport of materials and products to the building site (A4) and construction installation processes (A5), according to NS-EN 15978: 2011 [3]. Note that B4*** in ZEB-COM is expanded to include the transportation (A4) and installation process (A5) of replaced materials. The end of life processes of replaced materials is not included in B4***.

5. ZEB-COME: This is the same as ZEB-COM, but also takes into account emissions relating to the end-of-life phase “E”. The end of life phase includes deconstruction/demolition (C1), transport (C2), waste processing (C3), and disposal (C4), according to NS-EN15978: 2011 [3]. Similarly, the end of life processes of replaced materials in B4 are to be included and taken to an end of waste state.

6. ZEB-COMPLETE: Emissions related to a complete lifecycle 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). If relevant and available, benefits and loads beyond the system boundary (D) can be included as additional information, according to NS-EN 15978: 2011 [3].

The system boundary has been defined in accordance with the modular system of life cycle stages as defined in NS-EN 15978: 2011, and by the Norwegian ZEB ambition levels outlined above [1-3]. Figure 1.1 illustrates the relationship between these Norwegian ZEB ambition levels and the modular life cycle stages in NS-EN 15978: 2011 [1-3]. Figure 1.2 demonstrates how the various ZEB ambition levels can be incrementally compensated for with on-site energy generation, which primarily meets the demand of the building (depicted in grey, up to a ZEB-O ambition level). Any additional on-site energy generation (depicted in turquoise) can then be exported to the grid, to compensate for the remaining embodied CO_{2eq}[1] emissions of higher ZEB ambition levels.



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											■						■
ZEB-OM	■	■	■						**		■						■
ZEB-COM	■	■	■	■	^				***		■						■
ZEB-COME	■	■	■	■	■				■		■		■	■	■	■	■
ZEB-COMPLETE	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

* 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.
^ At a ZEB-COM level, waste generated from installation (A5) does not include end-of-life treatment, but emissions from A1 - A5.
NB: Biogenic carbon should only be included at a ZEB-COME or ZEB-COMPLETE level.
Module D includes on-site energy production, required by the building during operation, and that which is exported to the grid.

Figure 1.1 Description of ZEB ambition levels according to NS-EN 15978: 2011 [3].

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[1] Embodied emissions are measured in terms of greenhouse gases weighted as CO_2 equivalents using the IPCC GWP 100-year method [4] IPCC, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in, 2007.

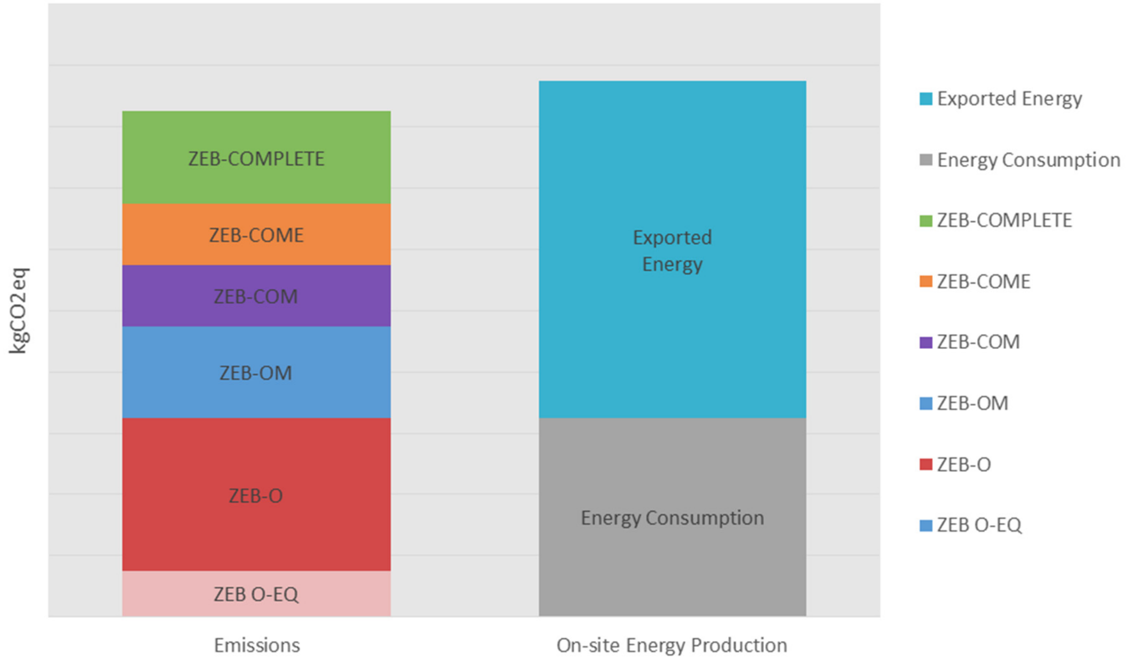

Figure 1.2 Example of a ZEB emission balance.

In all, the ZEB Centre has conducted nine pilot building projects according to ZEB targets and calculation methodologies. The pilot projects vary in terms of building type, size, materials, technologies, construction methods and locations. They have used different strategies to accomplish the various ZEB ambition levels. Campus Evenstad is the most ambitious of the ZEB pilot projects, and aspires to reach the ZEB-COM ambition level. This means that all 'emissions relating to operational energy use (O), embodied emissions from materials and technical installations (M), and the construction process (C) of the building shall be compensated for by on-site renewable energy generation' [1].

1.3 Aim

The aim of this report is to document the life cycle greenhouse gas (GHG) emissions of Campus Evenstad administration and educational building at an as-built, ZEB-COM ambition level. The report describes the calculation methodologies; including information relating to operational energy performance, embodied greenhouse gas emissions, the building design and material choices, as well as the ZEB balance. As this is the first ZEB-COM building designed and constructed in Norway, special focus is given to the calculation of CO_{2eq} emissions during the construction phase. Through documenting the ZEB balance between operational energy use, embodied emissions from materials and construction against on-site energy generation, we aim to reveal the main drivers of high CO_{2eq} emissions in a ZEB-COM building.

2. Project Description

2.1 The building

Campus Evenstad is one of two campuses belonging to Hedmark University of Applied Sciences (HUAS), at the Department of Applied Ecology and Agricultural trades, and accommodates approximately 60 employees and over 200 students. The campus consists of several buildings including: teaching, administration, education, and sports buildings, as well as student housing and various outbuildings (see Figure 2.1).

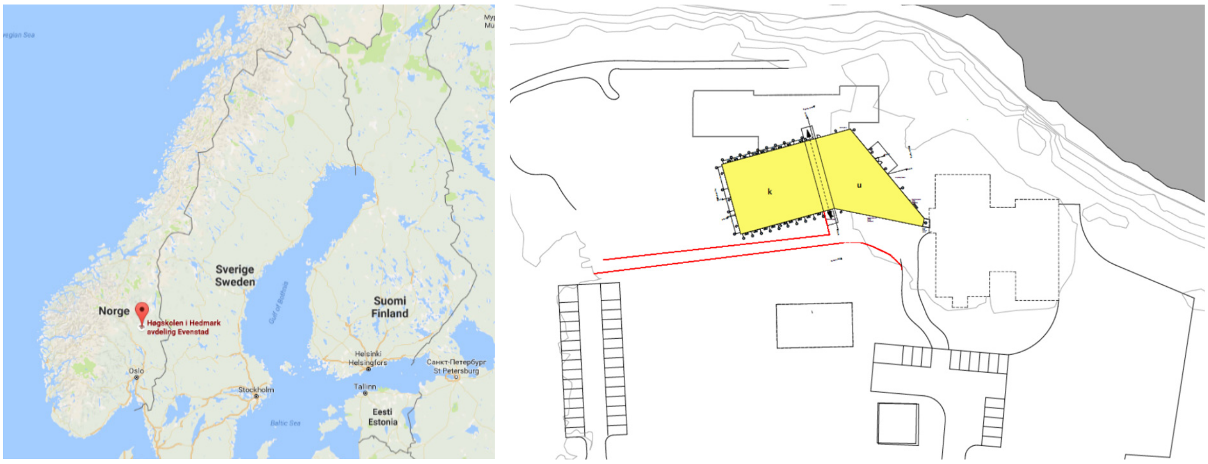

Figure 2.1 Location and site plan for Campus Evenstad [5], site plan courtesy of Ola Roald AS.

The new building is linked to the existing library, administrative and education buildings and includes the following:

- 24 offices and meeting rooms for academic staff
- 7 offices for PhD students and guests
- A reception area
- 5 meeting rooms and classrooms
- Conference rooms with capacity for 250 people, and a possibility of dividing the space into 2 or 3 smaller rooms and a lobby

The pilot building has a total heated floor area (BRA) of 1141 m^2, with an office area of 580 m^2 and educational area of 225 m^2. The building has a net floor area (NTA) of 1097 m^2, a gross floor area (BTA) of 1202 m^2, and a built up area (BYA) of 886 m^2 [6]. Figure 2.2 depicts the ground and first floor plans, while Figure 2.3 shows the elevations of the new administration and educational building. Figure 2.4 shows the building in section. Appendix A includes a selection of photographs from the construction process.

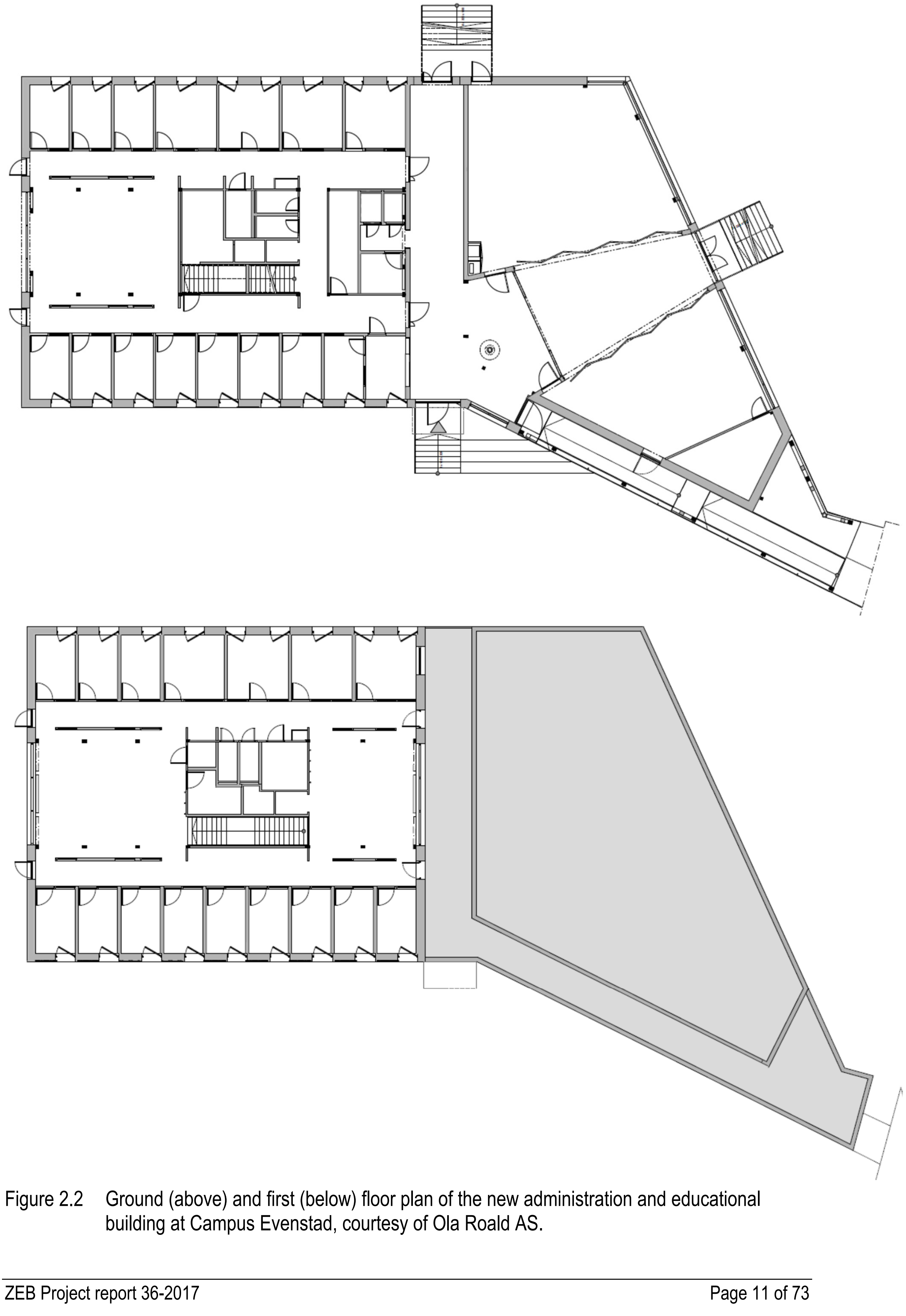

Figure 2.2 Ground (above) and first (below) floor plan of the new administration and educational building at Campus Evenstad, courtesy of Ola Roald AS.

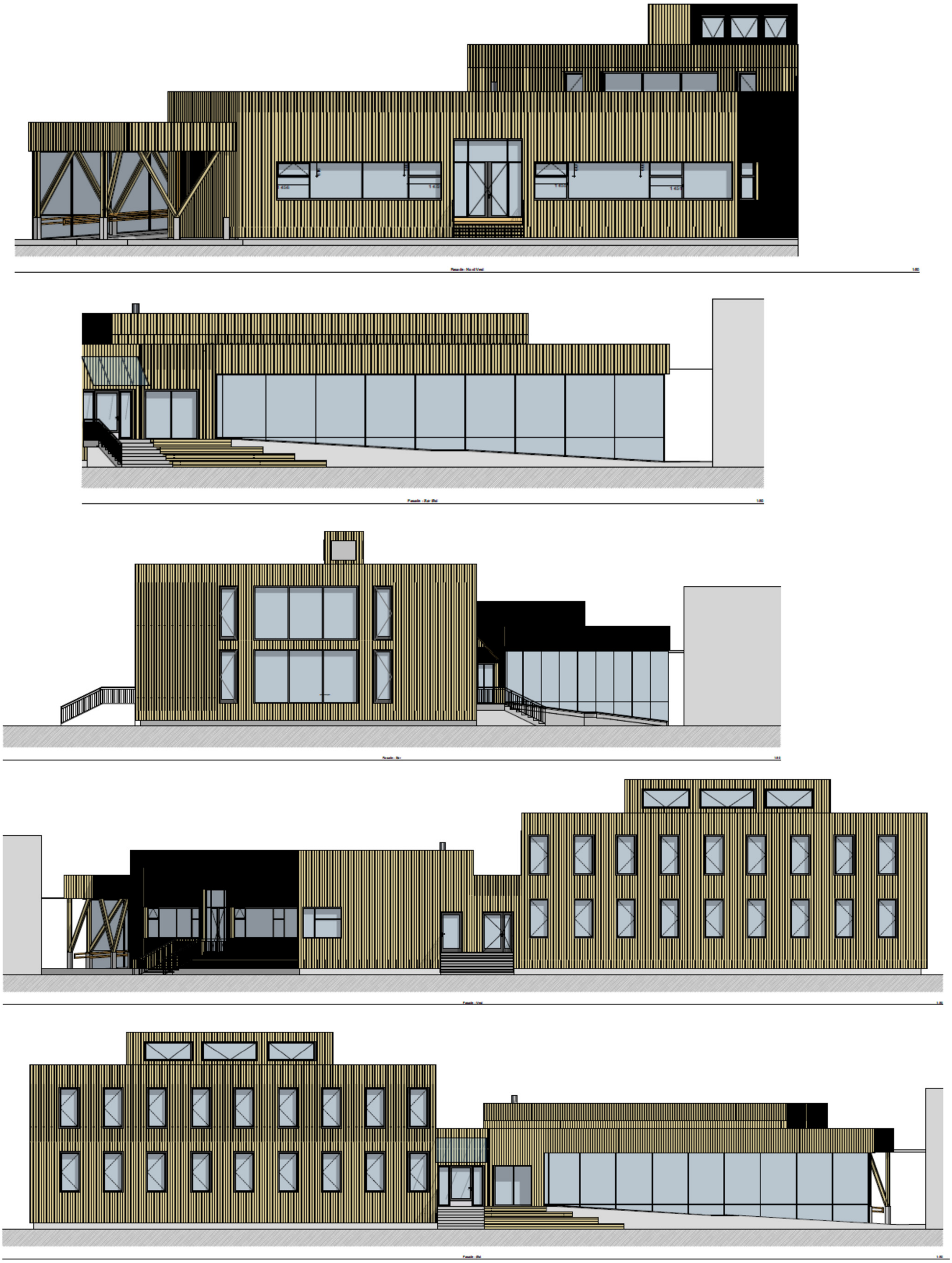

Figure 2.3 Elevations of the new administration and educational building at Campus Evenstad, courtesy of Ola Roald AS.

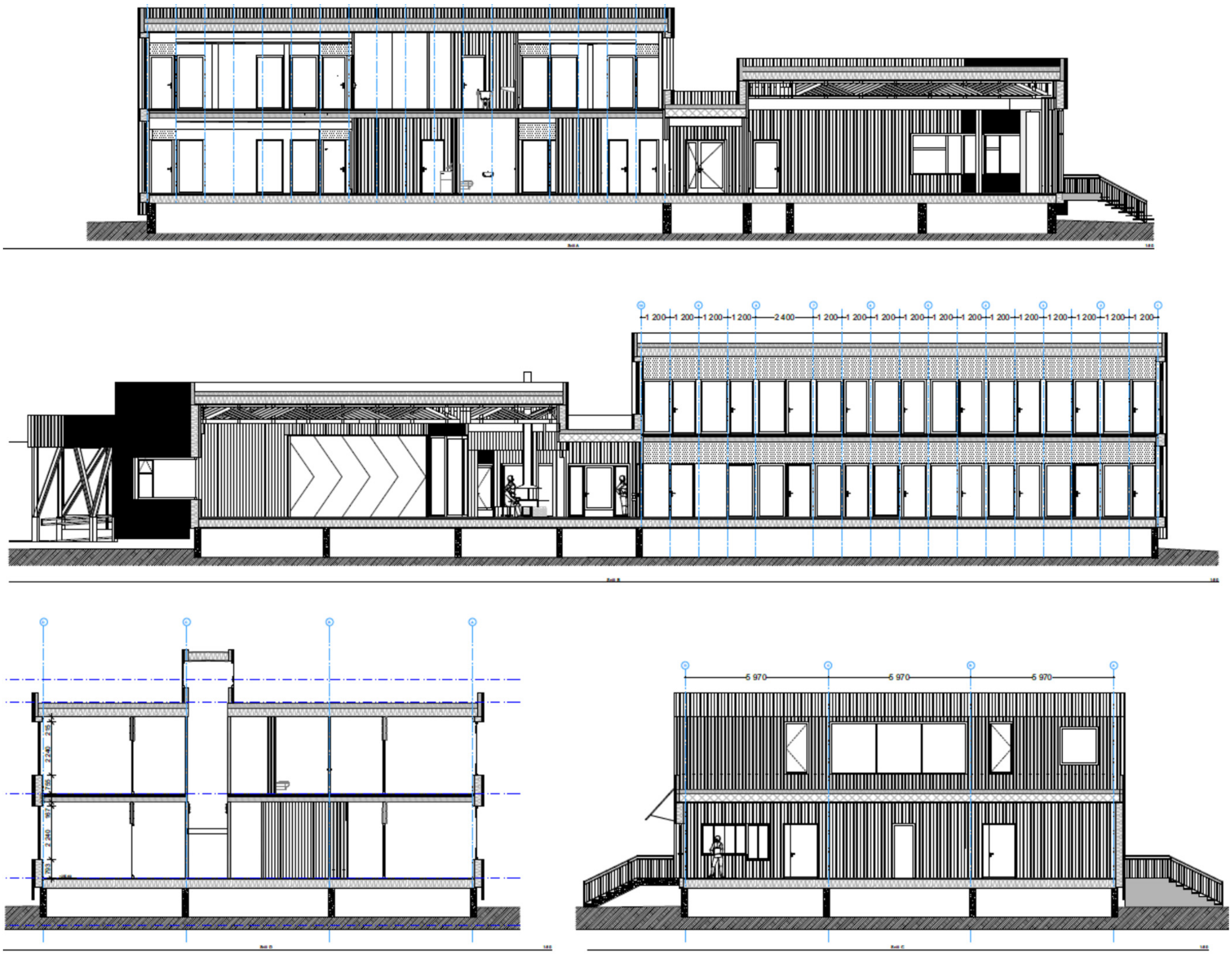

Figure 2.4 Sections of the new administration and educational building at Campus Evenstad, courtesy of Ola Roald AS.

2.2 Early design phase

A detailed description of the early design phase and construction process has been reported to Statsbygg [7]. Since no ZEB-COM building has previously been built in Norway, none of the stakeholders involved were familiar with what this would entail. Nevertheless, experiences from previous projects (e.g. passive house buildings, ZEB-O, and ZEB-OM buildings) were drawn upon through a series of workshops in the design phase to aid the stakeholders involved. Consequently, life cycle assessment (LCA) has been used in the early design decision-making process to make informed choices concerning the building envelope, technical installations, and on-site renewable energy generation. Thus, the following measures were taken into consideration to achieve the ZEB-COM ambition level:

- Minimize emissions arising from transport, energy, construction and material use.
- Significantly lower the net energy need compared to the building code TEK10 (pre revision)[8], through optimizing the building's operational energy.
- Implement passive and active design strategies relating to the building geometry, orientation, and natural ventilation, with a view to facilitate the above [9].
- Consider energy efficiency measures.

- Select construction materials with low embodied emissions that also meet fire safety, sound, and ventilation requirements.
- Supply energy based on a high degree of on-site generation from renewable energy sources. The building is also connected to an ordinary electric power grid for both purchase and sale of electricity.

Construction

In the early design phase, emissions from the construction phase were calculated with a high degree of uncertainty, due to limited previous experience and a lack of basic data [10]. In addition, the system boundary considered for the calculation of construction emissions [11] was not in line with the system boundary later defined by the ZEB Centre in [2]. Table 2.1 gives an overview of the construction phase emissions calculated in the early design phase of Campus Evenstad administration and educational building.

Table 2.1 GHG calculations for the construction phase of the pilot project in the early design phase [11].

Construction process	Amount		Emission factor	$kgCO_{2eq}$	$kgCO_{2eq}/m^2/yr$
	litre (diesel)	kWh			
Clearing of land	0	-	3.24	0	0
Groundworks - construction machinery	2 194	-	3.24	7 109	0.10
Transport of reinforcement steel	22	-	3.24	71	0.001
Transport of concrete	584	-	3.24	1 892	0.03
Transport of solid wood	4 237	-	3.24	13 728	0.20
Mobile cranes and telescopic trucks	2 250	-	3.24	7 290	0.11
Other transport	4 550	-	3.24	14 742	0.22
Personnell transport	5 500	-	3.24	17 820	0.26
Building heating and drying with pellets	-	40 000	0.017	680	0.01
Electricity	-	60 000	0.132	7 920	0.12
Omitted + 10%	2 000		3.24	6 480	0.09
TOTAL	**22 137**	**100 000**	**-**	**77 732**	**1.14**

Operational energy

In the early design phase, the following four energy supply solutions were considered [11]:

- Option 1: Highly efficient photovoltaic panels and a biomass boiler.
- Option 2: Highly efficient photovoltaic panels and an electric boiler.
- Option 3: Photovoltaic panels from recycled material and an electric boiler.
- Option 4: Gasification of biomass with combined heat and power (CHP) unit.

The first three options consider using photovoltaic (PV) panels to provide a net zero emission balance through the export of electricity. These are supplemented with either a biomass or electric boiler to provide heating. The photovoltaic panel area required to achieve a net zero emission balance at a ZEB-

COM ambition level for Campus Evenstad administration and educational building was calculated to be approximately 580m^2 for Option 1 and 2, and 800m^2 for Option 3. Note that Option 3 has a slightly lower efficiency level since it uses recycled components in the PV modules. In contrast, Option 4 considers covering both the electric and heat needs through replacing the existing pellet and electric boilers with a combined heat and power unit. Any additional heat generated by the CHP can then be exported to other buildings on campus.

In the end, Option 4 was chosen. This is partly because Campus Evenstad already had PV modules on another building at campus, which generates energy during the summer season. The energy generation from the new CHP unit will mainly be during the heating season, which gives a good match with the existing solar energy system. In addition, this is the first small scale wood chip based CHP unit in Norway, and Statsbygg wishes to demonstrate a new technology based on renewable energy resources. Given that this is a new technology, it was also possible to apply for financial support from Enova, reducing the cost and risk associated with implementing this new technology.

Materials

In the early design phase, embodied material emission calculations were carried out in klimagassregnskap.no v.3 [11, 12], the Norwegian free online GHG emission calculation tool developed by Civitas for Statsbygg. The data in klimagassregnskap.no is largely derived from the European ILCD database, but does also contain some generic data from Ecoinvent [13] and some product specific data from EPD-Norway's EPD database [14]. The material emission calculations are structured according to NS 3451:2009 Table of Building Elements [15]. An overview of the material inventory and emission results can be found in Appendix B. Figure 2.5 shows the distribution of the material emissions between building parts.

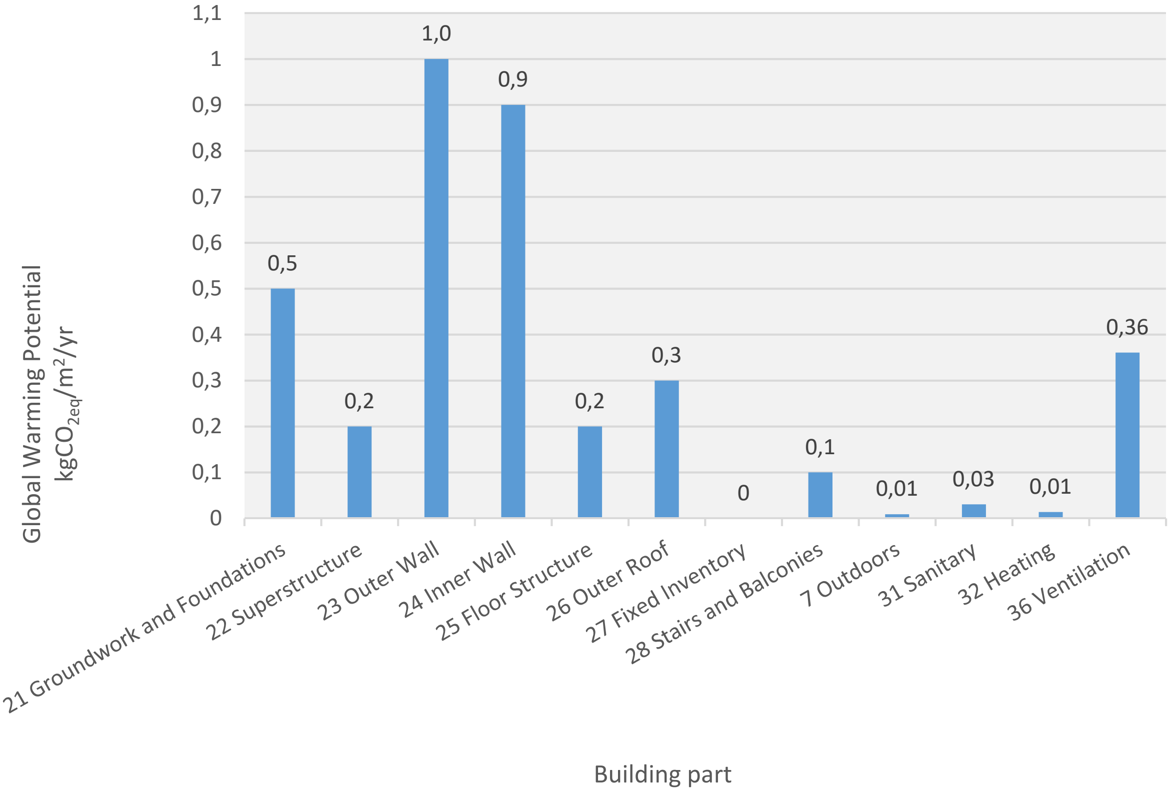

Figure 2.5 Embodied CO_{2eq} emisssions from materials as calculated in the design phase.

ZEB-COM balance

From the early design phase calculations, it is possible to put together a preliminary net ZEB-COM balance for each of the on-site energy generation alternatives for the new administration and educational building at Campus Evenstad. The results in Table 2.2 show the results for the four alternatives, and show that Option 4 has the lowest net ZEB-COM balance. This early net ZEB-COM balance also acts as a reference building for the as-built life cycle GHG emission calculations.

Table 2.2 Summary of emission results and net ZEB balance for the four energy generation scenarios.

Life cycle stages		**Emissions $kgCO_{2eq}/m^2/yr$**			
		Option 1	**Option 2**	**Option 3**	**Option 4**
A1 – A3, B4	Raw material supply, transport to manufacturing site, and manufacturing. Replacement during the building life cycle.	9.29	9.64	9.09	3.88
A4	Transport of materials to the building site.	0.42	0.42	0.42	0.42
A5	Construction and installation.	1.14	1.14	1.14	1.14
B6	Operational energy.	-11.71	-12.06	-11.51	-9.94
ZEB-COM balance		-0.86	-0.86	-0.86	-4.5

3. Methodology

3.1 Bakground

The aim of this report is to document the life cycle greenhouse gas (GHG) emissions of Campus Evenstad administration and educational building at an as-built, ZEB-COM ambition level. We aim to reveal the main drivers of high CO_{2eq} emissions in Campus Evenstad's new administration and educational building through documenting the net ZEB balance between operational energy use, embodied emissions from materials and construction against on-site energy generation.

The Norwegian ZEB research center has developed its own in-house methodology for calculating embodied CO_{2eq} emissions arising from a building parallel to the design and construction of the ZEB concept and pilot buildings. In addition, the ZEB methodology has been influenced by the development of national and international standards. Table 3.1 provides a timeline of these methodological developments parallel to the design and construction of the administration and educational building.

Table 3.1 Timeline of developments parallel to the new administration and educational building.

Timeline	**Administration and educational building project**	**ZEB calculations**	**Methodological developments**
2011 – 2012	Brief and concept design.	Energy ambition level exceeds TEK10.	NS-EN 15978: 2011. NS-EN 15804: 2012 + A1: 2013.
September 2014 – March 2015	Developed design.	ZEB-OM calculations on building parts to aid design decisions.	ZEB project report no. 17. A Norwegian ZEB Definition. Embodied Emissions.
April 2015	Technical design.	Design phase ZEB-COM calculations based on BIM model.	
May 2015 – December 2015	*No activity.*	*No activity.*	*Revision of TEK10 energy requirements.*
2016	Construction.	As-built ZEB-COM calculations, including collection of EPDs from manufacturers.	ZEB project report no. 29. A Norwegian ZEB Definition Guideline.
2017	Handover and in use.	Future ZEN monitoring and calculations.	prNS3720: 201x. Method for GHG emission calculations for buildings (draft).

Alongside these developments, the ZEB Centre has developed an excel-based tool for life cycle GHG emission calculations. This tool has been used for the as-built embodied emission calculations of the administration and educational building at Campus Evenstad. The method used in this tool is in accordance with the methodology for life cycle assessment outlined in ISO 14044: 2006, the methodology for evaluating the environmental performance of buildings in NS-EN 15978: 2011, NS 3451:2009 Table of Building Elements, and the Norwegian ZEB ambition levels [1-3, 15, 16]. The tool uses greenhouse gas (GHG) emission factors mainly from Norwegian environmental product declarations (EPDs) according to the core product category rules (PCR) for construction products given in NS-EN 15804: 2012 [17]. When EPD data was lacking, generic life cycle inventory data from Ecoinvent version 3.1 has been used [13].

3.2 Scope

A functional unit of 1 m^2 of heated floor area (BRA) over an estimated lifetime of 60 years is used. This functional unit is used across all the ZEB pilot buildings to harmonize results. The as-built total heated floor area of Campus Evenstad's administration and educational building is 1141 m^2. The embodied emissions are measured in terms of greenhouse gases weighted as CO_2 equivalents (CO_{2eq}) using the IPCC GWP 100-year method [4].

The system boundary of the study is defined in accordance with NS-EN 15978: 2011 and the Norwegian ZEB ambition levels [1-3]. The ZEB-COM system boundary is summarised in Figures 3.1 – 3.3, and as follows:

- **Construction (C)** phase includes emissions associated with the transport of building materials to the construction site (A4) and emissions from materials, energy, and transport during the construction process (A5), see Figure 3.1. For Campus Evenstad, person transport is also considered during the construction phase (A5).
- **Operation (O)** phase includes emissions associated with the consumption of electricity and thermal energy (B6), see Figure 3.2. Person transport during the operational phase is not included in the calculations.
- **Material (M)** phase includes emissions associated with the production of building materials, appliances, and technical equipment (A1 – A3) and the materials used in the replacement of building materials, appliances, and technical equipment during the service life of the building (B4), see Figure 3.3.
- **On-site renewable energy generation.** Emissions from the construction, operation, and material phases are compensated for with on-site, renewable energy generation.

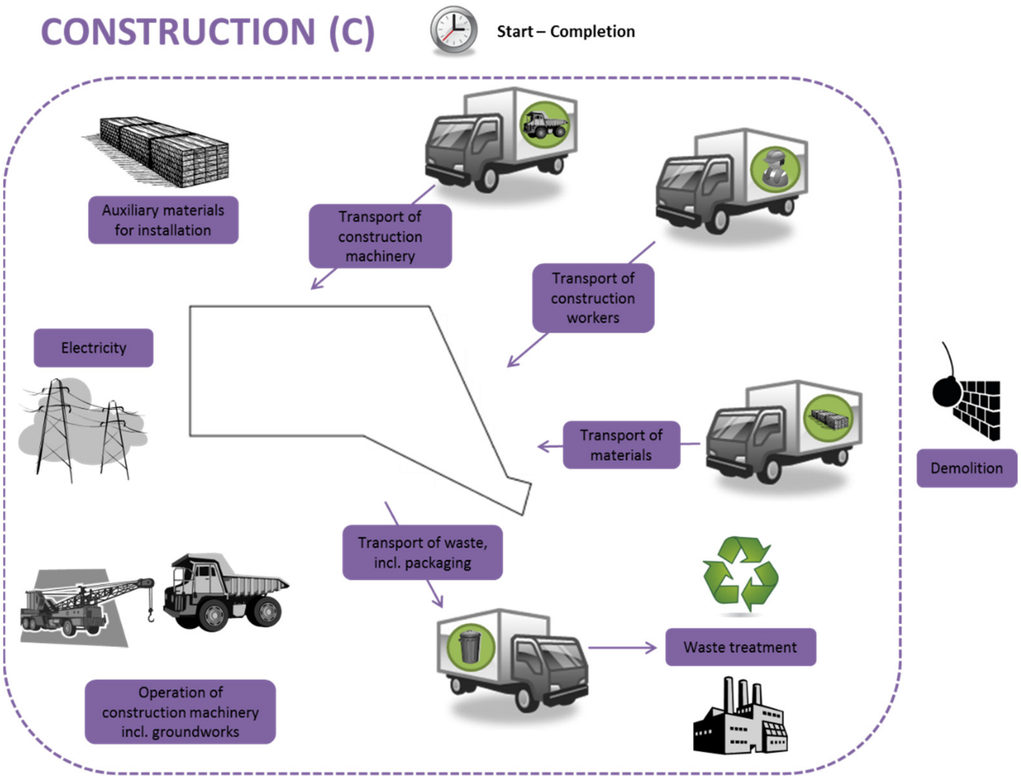

Figure 3.1 Diagram showing the system boundary for the as-built construction phase, courtesy of Asplan Viak [11]. Translated and modified into English.

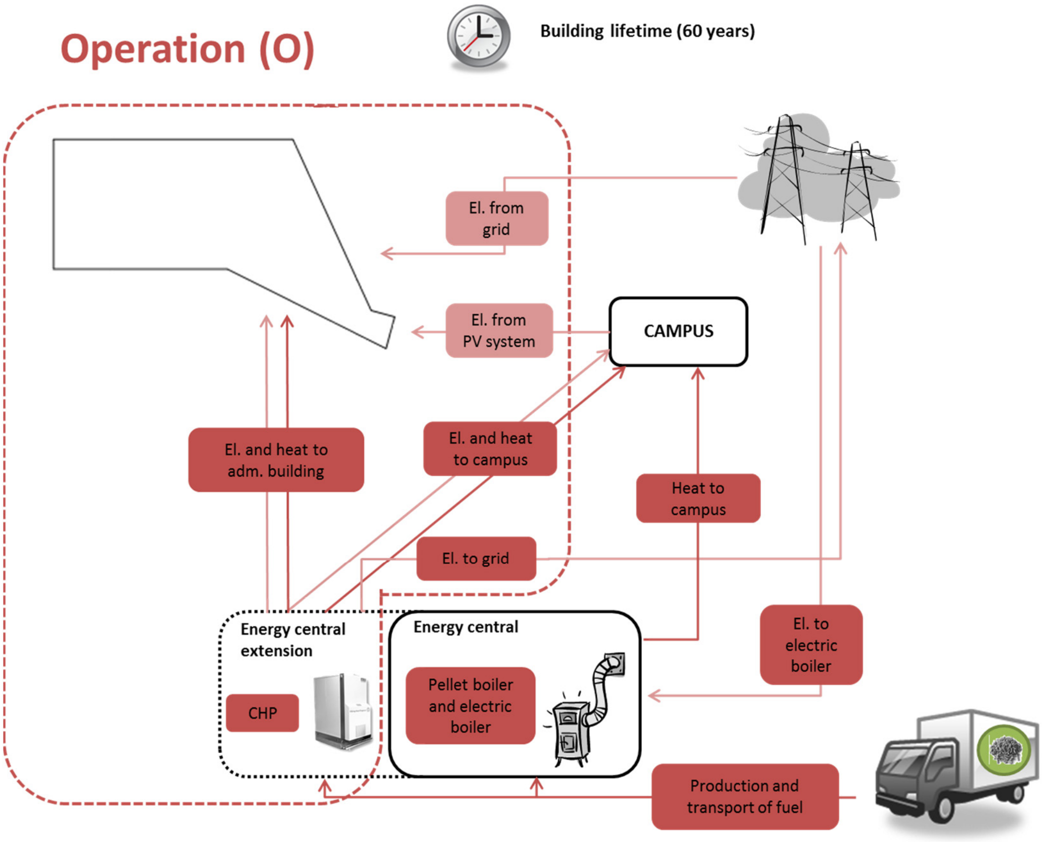

Figure 3.2 Diagram showing the system boundary for the as-built operation phase, courtesy of Asplan Viak [11]. CHP stands for combined heat and power. Translated and modified into English.

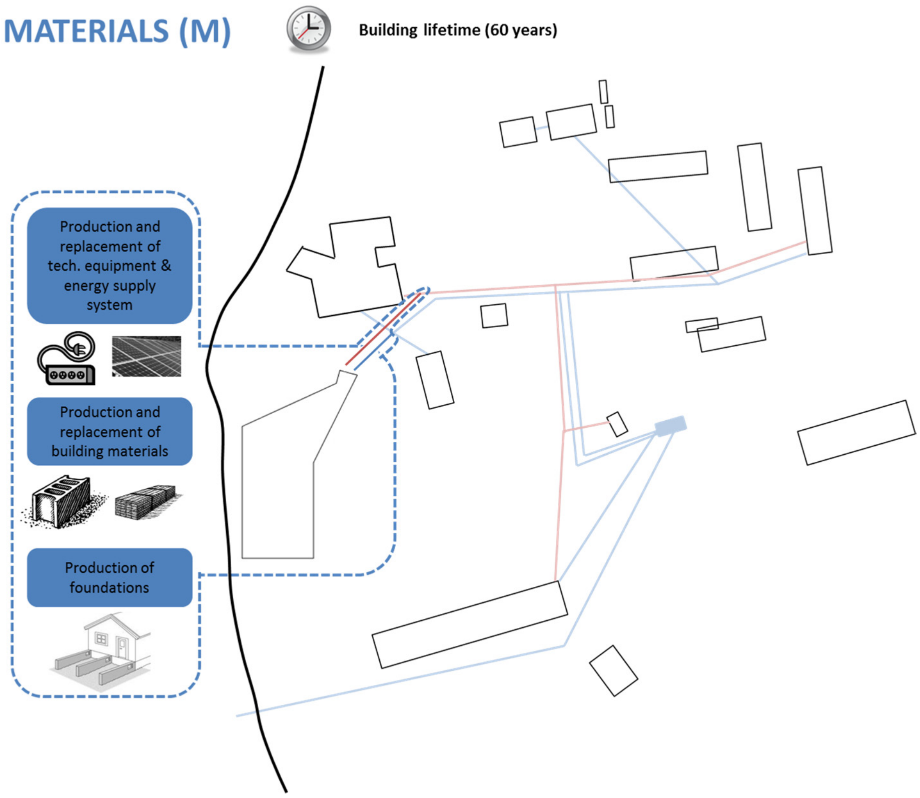

Figure 3.3 Diagram showing the system boundary for the as-built material phase, courtesy of Asplan Viak [11]. Translated and modified into English.

3.3 Life cycle inventory

The building materials included in the calculations are structured according to NS 3451:2009 Table of Building Elements [15]. This standard facilitates for an overview of the building parts included, the quantification of mass and energy flows from the building, as well as their corresponding CO_{2eq} emissions. It also provides a structured and detailed inventory for comparison with other projects [15]. NS 3451:2009 is used to classify all building parts to a 2-digit code level, for example '21 groundwork and foundations' or '23 outer walls'. The building elements included in this life cycle assessment are summarized in Table 3.2.

Table 3.2 Building elements in the as-built embodied emission calculations for Campus Evenstad.

Building element
21 Groundwork and foundations
22 Superstructure
23 Outer walls
24 Inner walls
25 Floor structure
26 Outer roof
27 Fixed Inventory
28 Stairs and balconies
31 Sanitary
32 Heating
36 Ventilation
44 Lighting
45 Electric heating
49 Electric Other (CHP)

Construction

The as-built construction emission calculations are based on data collected during the construction phase, as summarized in Section 4. This is the first time a Norwegian ZEB pilot project has gained access to real data from the construction site. To avoid double counting of CO_{2eq} emissions; activities relating to the construction phase are classified and registered as either a building material activity (i.e. transportation and installation of building materials at the construction site) or as a building site activity (i.e. lighting, heating, drying, diesel use, and construction machinery at the construction site). Activities included in the as-built, construction phase system boundary include (see also Figure 3.1.):

- Transportation of building materials from the factory/warehouse to the construction site.
- Transportation of construction equipment to and from the construction site.
- Transportation of materials, products, waste, and equipment on the construction site.
- Transportation of workers to and from the construction site.
- Installation of building materials, including additional materials (e.g. screws, adhesives and tapes) and energy (e.g. electricity for a hand drill).
- Temporary structures.
- Storage of building materials, including heating, cooling, ventilation, humidity control, and lighting.
- On-site energy consumption.
- Transport and disposal of waste and packaging.

The construction data collection includes transport log data from the contractor and sub-contractors, detailing the types of construction machinery used, diesel use and hours of operation for the various construction machinery, as well as diesel use for heating and drying of the building. Person transport to the construction site is also based on transport log data from the contractor and sub-contractors. This data contains the number of trips to and from the site, as well as the average distance per trip. Emissions calculations are completed using well-to-wheel emissions factors from the EU's Joint Research Centre which are adapted by Civitas to reflect the Norwegian fleet [7]. To aid calculations SINTEF has developed a transport calculator that calculates all emissions associated with the transport of construction materials to the building site (A4) [18]. In addition, SINTEF has developed an installation scenario calculator for embodied emissions from the installation of building materials (A5) [18]. This information is typically project specific data that is unobtainable from EPDs.

Operation

In several of the previous ZEB pilot projects, photovoltaic system has been used to compensate for embodied GHG emissions from energy (O) and material use (M). A conscience decision was made in the Campus Evenstad pilot project to use an alternative on-site renewable energy generation technology that compensates for both heat and electricity, namely combined heat and power (CHP).

The physical system boundary for local energy generation at Campus Evenstad is valid for the entire campus area, whereby the local energy generation is not bound to the administration and educational building, but can be located anywhere on campus. Thus, the operational energy need is defined as the operational energy need of the administration and educational building, and any additional electricity or heat generated and supplied to other buildings on campus, is considered as exported energy outside of the system boundary (see Figure 3.2). The background data for net operational energy need calculations as well as renewable energy generation is summarized in Section 5.

Locally generated electricity from the CHP unit replaces electricity from the grid, and electricity is delivered to neighboring buildings or the local grid. Therefore, for exported electricity, the ZEB emission factor of 132 gCO_{2eq} per kWh of electricity is used [19, 20]. For the CHP unit, an emission factor of 30.4 gCO_{2eq}/kWh is used, representing the emissions related to the operation of the CHP unit. In addition, there are embodied emissions related to the CHP unit itself, but these emissions are included in the material emission calculations. Further information on the CHP system is given in Section 5 of this report.

Locally produced heat requires some further consideration. Current guidelines from the ZEB Centre does not allow compensation for the net export of excess heat annually. During a year, it is only possible to compensate emissions for heat the building uses itself. This measure is put into place to avoid circumstances whereby electricity needs of a building are compensated for with lower grade heat generation.

In this case, the reference emission for exported heat is based on current energy generation at Campus Evenstad. This heat generation system is based partly on pellets (90%) and partly on an electric boiler (10%). The combination of these heat sources provides a reference emission factor of 30.4 gCO_{2eq} per kWh[2], whereby the emission factor for pellets is 19.9 gCO_{2eq}/kWh[3]. The amount of heat that can be compensated for in the GHG emission calculations is limited according to the following conditions:

1. Renewable heat generation shall compensate for the net heat need of the building.
2. Renewable heat generation shall compensate for emissions from heat generation connected with the production or replacement of materials (M) and the construction phase (C).

The underlying criterion for the export of heat is that is should meet an actual need for heat in the local vicinity. At Campus Evenstad, this criterion is met through the heat need of other buildings on campus. The proportion of exported heat that can be accounted for in embodied emission calculations for the administration and educational building at Campus Evenstad is limited to the heat required from material production and replacement (M), the need for thermal energy during construction (C), and the need for thermal energy during operation (O). The CHP unit has a fixed relationship between produced electricity and produced heat. When one unit of electricity is produced, 2.5 units of heat are also produced. It is not acceptable to produce waste heat; all heat production should be used either by the administration building itself or by other buildings on campus. Because of these criteria, the amount of electricity that may be exported is limited by the excess amount of heat produced by the CHP unit. Similarly, it is not possible to gain credits for exported electricity if the corresponding ratio of heat generation is not also exploited.

Materials

The material inventory for building materials and technical installations has been extracted from the building information model (BIM) provided by the architect, Ola Roald AS and from the bill of quantities provided by the contractor, ØM Fjeld AS and other stakeholders such as Statsbygg, Asplan Viak, and Høyer Finseth AS. Central sub-contractors who have also contributed to data collection include Silvinova AS, Massivlust AS, Svensgaard Installasjon AS, YC Rør AS, Betong Øst AS, and ETA Norge AS. The type of materials used in each building element, as identified in Table 3.2, are summarized in Section 6, along with quantities, estimated service lifetimes and CO_{2eq} emission data. No emission benefits are given to materials whereby the reference service life (RSL) is longer than that of the building's lifetime of 60 years. This phenomenon occurs typically in steel products, which have an RSL

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[2] The pellets have an emission factor of 14.4 gCO_{2eq}/kWh [2], which supply 90% of the current energy generation at Campus Evenstad, and have a 77% efficiency rate. The electric boiler has an emission factor of 132 gCO_{2eq}/kWh [19, 20], which supplies 10% of the current energy generation, and has a 97% efficiency rate. Thus, (0.9 * (14.4 / 0.77)) + (0.1 * (132 / 0.97)) = 30.4 g CO_{2eq}/kWh.

[3] The emission factor for pellets is calculated by taking the emission factor for the combustion of wood chips (14.4 gCO_{2eq}/kWh) and dividing it by the sum of the power of heat (100kW with 7kW loss) and electricity (40kW with 2kW loss) generation including the losses, over the total effect of the CHP system (181 kW). Thus, 14.4 / (38 + 93) / 181 = 19.9 gCO_{2eq}/kWh.

of up to 100 years, and presents an area for potential future emission savings if the demountability and reusability of materials beyond the current building service life are considered.

Data quality

Product specific environmental product declarations (EPDs), sourced mainly from the program operator in Norway, EPD-Norway, have been used as a source of emission factors in the life cycle inventory (LCI) [14]. When EPD data was lacking, generic data from Ecoinvent and technical datasheets from producers have been sourced [13].

The property developers, Statsbygg, had set up an environmental requirement that at least 10 key building materials used in the project must have EPD documentation. The building contractors, ØM Fjeld AS had the responsibility for collecting this EPD documentation. Both Civitas and SINTEF have quality assured the collection of EPD documentation, against a list of criteria developed by SINTEF. The list of criteria includes seven questions. The first three questions quality assure whether or not the EPD was developed in line with international and European standards, namely ISO 14025:2010, ISO 21930: 2007 and NS-EN 15804: 2013 [17, 21, 22]. The next two questions check whether the EPD is registered with a recognized EPD program operator (such as EPD-Norway, the International EPD System or IBU) and whether the EPD has been verified by an impartial third party. The last two questions check that the EPD has a valid declaration number, which is usually given by the program operator, and that the EPD has not expired. EPDs are usually valid for a period of five years. For an EPD to be used in a life cycle assessment, and count as specific data, it must meet these requirements. A copy of the EPD criteria checklist can be found in Appendix C.

Appendix C also includes a table summarizing the EPDs collected by ØM Fjeld AS from building material manufacturers, and evaluates each EPD against the criteria in the checklist. It was found that 10 of the 12 EPDs collected meet the criteria in the checklist. There were two instances whereby the EPDs collected by ØM Fjeld AS did not meet the criteria listed in Appendix C. The first EPD (no.3) does not reference any of the international or European standards, is not registered with an EPD program operator or third part verified, and does not have a declaration number or expiry date. Furthermore, although the document is labelled as an environmental product declaration, it does not include any emission data. The second EPD (no. 5) was originally published in 2002, and has not been revised since. Therefore, the EPD does not reference any of the standards since these were published after 2002, it is not registered with an EPD program operator or third part verified, it does not have a declaration number and has expired. There was one instance whereby an EPD expired in May 2016. However, since the construction works for the administration and educational building at Campus Evenstad began in early 2016, it was deemed acceptable to use this EPD in the embodied emission calculations. There were also two instances whereby European EPDs did not refer to ISO 21930: 2007; however, these EPDs were still accepted as they meet equivalent European standards.

There were two cases whereby product specific emission data for central building products was lacking:

- Massive wood from Massivlust AS
- Wood fiber insulation from Hunton AS

However, both Massivlust AS and Hunton AS have commissioned detailed life cycle assessments of their products that satisfy international and European standards. The life cycle assessments are no older than five years and use product specific production data in their calculations. In addition, recognized Norwegian LCA experts have completed these life cycle assessments. The author of this article has contacted the two parties and discovered that the LCAs are not registered or approved as EPDs for purely organizational and cost reasons. Thus, it is assumed that the emission factors reported in these LCA reports are sufficient and representative of the building products and may be used in the embodied GHG emission calculations for Campus Evenstad. It is considered that product specific LCA reports are preferable to generic European data from the Ecoinvent database.

When looking at the quality of data used in the life cycle inventory, it was found that 94.5 % of all building materials (based on weight) use specific data from EPDs, while 5.5% of all building materials (based on weight) use generic data from the Ecoinvent database. From the 94.5% of building materials that use specific data from EPDs, 48% come from the ten EPDs sourced by the building contractor. This accounts for 45.5% of the entire building (based on weight).

Biogenic carbon

The administration and educational building at Campus Evenstad is characterized by its solid wood construction. It has therefore been desirable to document the carbon storage properties of wood in the GHG emission calculations, even though this is defined as outside of the ZEB system boundary at a ZEB-COM ambition level.

Wood obtained from sustainably managed forests, is part of the natural carbon cycle, whereby biomass absorbs carbon during the growth phase through photosynthesis. This absorbed carbon will remain stored in the timber until it is released back into the atmosphere, at the wood's end of life, via incineration or rotting. Diagram 3.7 depicts the carbon life cycle for wood-based products. Thus, the wood is a temporary carbon sink that removes a given amount of carbon from the atmosphere, thus providing a *negative* climate impact. At the wood's end of life, these carbon emissions (CO_2 or CH_4) are released back into the atmosphere and create a *positive* climate impact. However, during the total life cycle, the wood is considered carbon neutral, meaning that the net climate impact of the material is zero, since the amount of carbon absorbed during growth is returned to the atmosphere after its service life. To calculate the absorption of CO_{2eq} that takes place during wood growth, without including emissions from the end-of-life phase, would provide a net *negative climate impact* gain per m^3 of wood material used. Thus, the temporary carbon storage of wood materials in buildings is relevant when assessing GHG emission calculations. However, this is subject to end-of-life disposal of materials being included in the system boundary. The ZEB-COM ambition level does not include the end of life phase.

In the results section, the embodied emissions are reported according to the ZEB-COM system boundary, and do not take into account the biogenic carbon storage properties of wood or wood-based building products. However, calculations have been carried out to ascertain how much CO_{2eq} emissions have been delayed through the implementation of a primarily wooden construction. These calculations have been carried our according to NS-EN 16449: 2014 [23].

In all, wood and wood-based building materials used in the production and construction phases of the administration and educational building at Campus Evenstad absorb approximately -7.24 $kgCO_{2eq}/m^2/yr$ of biogenic carbon. This corresponds to approximately -8250 $kgCO_{2eq}/yr$ for the entire building or -495 650 $kgCO_{2eq}$ for the entire building lifetime. It is assumed that these emissions are then released (via incineration) during the end of life phase of the building's lifetime in module C and will release an equal amount of biogenic carbon, namely 7.24 $kgCO_{2eq}/m^2/yr$.

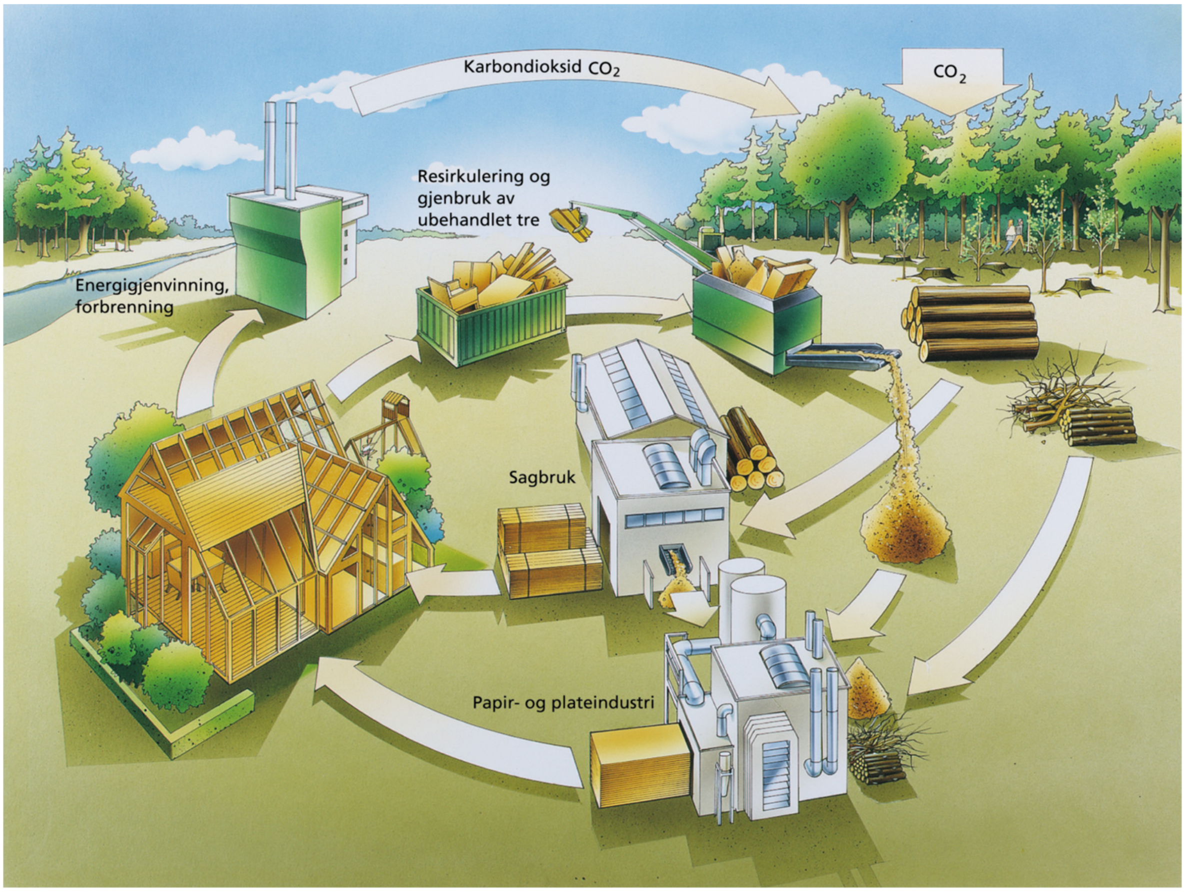

Figure 3.4 Wood-based products as a part of the carbon life cycle, illustration courtesy of Treindustrien / CEI-Bois.

3.4 Life cycle impact assessment

The embodied emissions are measured in terms of greenhouse gases weighted as CO_2 equivalents using the IPCC GWP 100-year method [4]. Emission factors and scenario descriptions from product specific EPDs, sourced from EPD-Norway, have been used as background data for life cycle modules A1-A3, B4 and B6 wherever possible. The quality of EPD data sourced by the contractor was evaluated using the validity checklist, as shown in Appendix C. When product specific EPD data was lacking, generic data from the Ecoinvent v3.1 database has been sourced [13]. Since the quality and transparency of a life cycle assessment is mainly dependent on the quality of life cycle inventory data collected, the complete building inventory used in these CO_{2eq} emission calculations, in terms of construction, operation, and material specifications are documented in Sections 4 to 6. The construction, operation and material emission results are presented in Section 7, while the ZEB-COM results are presented in Section 8. The results are then discussed and interpreted in Section 9.

4. Construction Site (C)

To carry out embodied construction emission calculations it was necessary to collect data on the building construction activities taking place at Campus Evenstad. The total amount of construction days was 374, from 15th December 2015 until 22nd December 2016. Figure 4.1 contains an aerial plan of the construction rig. The construction inventory data has been split into six components, namely; temporary works, material transportation, construction machinery, construction waste, energy use, and person transport.

It is important to note that any demolition work belongs to the previous life cycle of the existing building and is not accounted for in the embodied construction emission calculations for the administration and educational building at Campus Evenstad. This also includes any asbestos decontamination work of the demolished building. In addition, any cleaning services carried out during the construction period have not been included in the calculations.

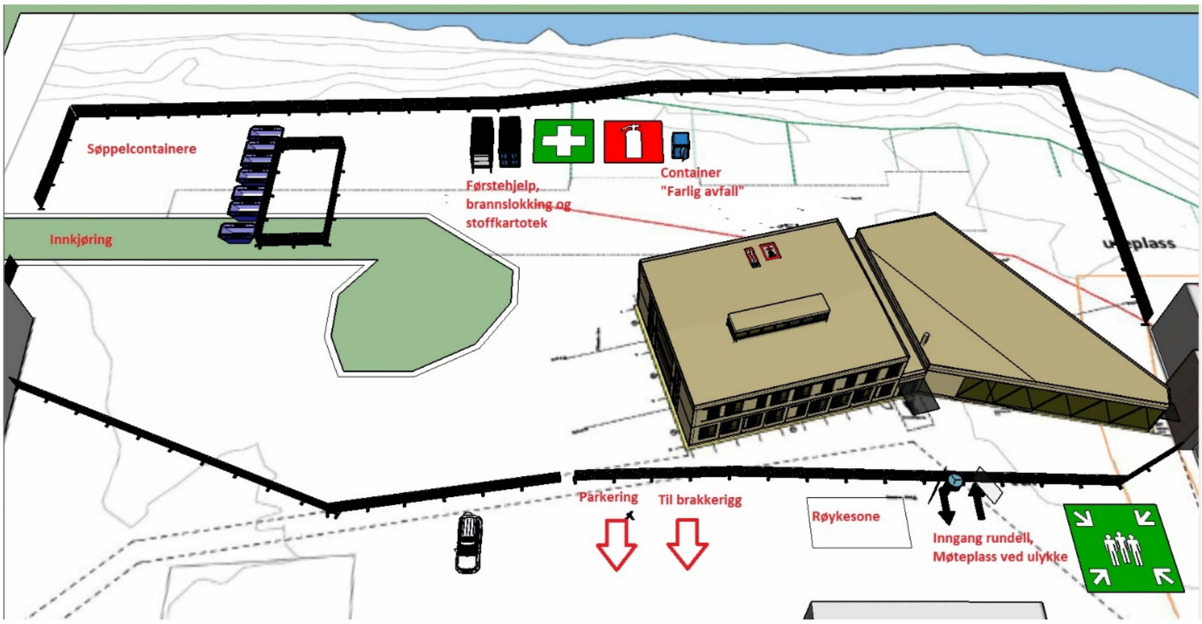

Figure 4.1 Aerial plan of the construction rig, courtesy of ØM Fjeld AS/Statsbygg.

4.1 Temporary works

Temporary works are installations at the construction site that aid the construction process, this can include amongst other items; construction cabins, security fences, and scaffolding. The material inventory for temporary works has been collected from observations from the construction works diary, which includes weekly reports on construction site activities. The temporary works included in embodied construction emission calculations include:

- Approx. 90 security fences (2 x 3.5m @ 14kg/pc)
- 1 storage container (6 x 2.4 x 2.6 m)
- 2 storage containers (12 x 2.4 x 2.6 m)

It was soon found that emission data for temporary construction works is almost non-existent. Thus, the embodied emission calculations have been performed by considering the raw materials used to produce the temporary works and multiplying this with a factor for the proportion of time the temporary work is on site during its entire service lifetime. A scenario is then developed for the transportation of the temporary work to the construction site.

For example, a 2 x 3.5m stainless steel security fence weighs approximately 14 kg, and is on site for 374 days of its 21900-day assumed service life. It is possible to use the generic emission factor for stainless steel (4.81 $kgCO_{2eq}/kg$) and multiply it by the weight of the security fence (14 x 4.81 = 67.34 $kgCO_{2eq}$). So, that the embodied construction emissions are shared across multiple construction jobs, the emissions need to be multiplied by a service life factor (374 days / 21900 days = 0.017) (0.017 x 67.34 $kgCO_{2eq}$ = 1.14 $kgCO_{2eq}$ per security fence). The security fence is then transported 142 km from storage or the previous construction site to Evenstad by a >32t EURO 4 class truck. The weight of the security fence can then be multiplied by the distance and emission factor for >32t EURO 4 class trucks (14 kg x 142 km x 0.0000837 $kgCO_{2eq}/kgkm$ = 0.16 $kgCO_{2eq}$). The sum of these two factors (1.3 $kgCO_{2eq}$) provides a rough estimate for the production (A1 – A3) and transport to site (A4) emissions of one security fence used for 374 days on-site at Campus Evenstad.

This method is labor intensive for the LCA practitioner, and has thus only been carried out for the larger, more significant temporary works identified at Campus Evenstad, as listed above. However, it is acknowledged that this segment of embodied construction emissions is under-researched and requires further attention in the future. Some of the temporary works that have fallen outside of the system boundary because of lack of data include the following (this list also includes common building site equipment):

- Construction office, canteen, and on-site accommodation for construction workers
- Security double gate and security entrance carousel
- Diesel tank
- Safety helmets, high visibility clothing, protective footwear, gloves, glasses ,and ID cards
- HMS and SHA boards
- Hand tools: spirit level, broom, spray cans, industrial hoover, wheelbarrows, snow shovels, paint brushes, buckets, stepladders, crosscut saw, and scissor lift
- Scaffolding: straps, poles, flooring, fasteners, railings, and mobile scaffolding
- Temporary lighting
- Temporary tent over roof construction, tarpaulins, insulating mats, and road grit
- Approx. 50+ storage pallets
- Waste containers (wood, metal, plastic, mixed waste, and hazardous waste)
- Provisional makeshift timber stairs for access to the first floor during construction

4.2 Material transport

The material inventory described in Section 6 has been used to ascertain how much of each building material is transported to the construction site. This information is combined with the transport scenarios described in each EPD for each building product. As aforementioned, SINTEF has developed a transport calculator that takes into consideration the production factory of the building material, any intermediary storage warehouses, and the construction site locations to ascertain the actual transport distances travelled by the building material. This is then multiplied with the weight of the construction material being transported (as given in the material inventories in Section 6), and later multiplied with the emission factor for the transportation mode prescribed in the EPDs. In scenarios where the transport mode is unknown, the vehicle with the lowest technological class has been used (e.g. >32t EURO 3). If the warehouse location is unknown, then Oslo has been used as proxy. It has been assumed that any auxiliary materials required for the installation of the product are transported together with the building material. This measure has been implemented to avoid any double counting from the transportation of materials.

It is acknowledged that the construction site location is sensitive to embodied transport emissions. Thus, a simple sensitivity analysis has been carried out that assesses the same administration and educational building built in various locations around Norway. The locations considered include Evenstad as a base case, Oslo, Trondheim, and Hammerfest. It was found that moving the administration and educational building to Oslo decreases total embodied emissions from construction works by 13%, while moving the building to Trondheim and Hammerfest increases total embodied emissions by 22% and 65% respectively. It is assumed that there is an embodied emission saving in Oslo, because the capital is located closer to the rest of Europe and is central to shipping ports, such as Drammen. However, this may also be a consequence of setting Oslo as a proxy location. In contrast, we see a significant increase in total embodied emissions when the building is moved to Trondheim (500km further north than Oslo) and Hammerfest (1878km further north than Oslo).

4.3 Construction machinery

The material inventory for construction machinery has been collected from a series of weekly transport logs completed by the contractor, subcontractors, and suppliers (ØM Fjeld AS, AF Dekom AS, Per Hagen AS, Svensgard Installasjon AS, Massivlust AS, OH Ventilasjon AS, Taktekker, ETA Norge AS, and YC Rør AS). A summary of this information can be found in Table 4.1. The data collected from the construction site is of good quality and has been quality assured against the weekly construction diary reports. Construction machinery data collected during the demolition phase has been removed from the inventory; as demolition works are outside of the system boundary as defined by ZEB, see Figure 3.1. It has been assumed that all construction machinery has been transported from a local construction park in Gjøvik, with an average distance travelled to the construction site of 142 km and with an assumed transportation mode of >32t EURO 4 vehicle. All construction machinery use diesel fuel apart from the Bell 75 vibroplate, which uses petrol. The well-to-wheel emission factor used for diesel is 3.24 kgCO_{2eq}/liter, while the well-to-wheel emission factor used for petrol is 2.88 kgCO_{2eq}/liter [24]. A visual overview of the different types of construction machinery can be found in Appendix D.

Table 4.1 Summary of construction machinery used on-site at Campus Evenstad

Type of Construction machinery	Duration on site (days)	Fuel consumption (litres)
Caterpillar 312E Crawler Excavator	71	2410
Caterpillar 307D Crawler Excavator	20	396
Caterpillar 324 Crawler Excavator	82	6455
Moxy MT31 Dumpertruck (28t)	33	1605
Vibroplate: Atlas Copco 800	40	200
Vibroplate: Atlas Copco 250	5	5
Vibroplate: Bell 75 (petrol)	92	34
Bobcat Digger E26	19	102
Doosan dx140W Excavator	5	115
Telescopic lift	112	897
Potain Igo50 Towercrane	170	unknown
Tractor: Fendt vario 716	12	200
Remko heat aggregate CLK 120 (stationary)	95	4220

4.4 Construction waste

ØM Fjeld AS has estimated the amount and type of construction waste generated on-site, in the 'avfallsplan' or waste plan that they have submitted to the local authorities in February 2016. This estimation provides a good basis for embodied construction emission calculations and is surmised in Table 4.2. In all, 80% of all construction waste is sorted for recycling. The amount of construction waste generated corresponds to 21.65 kg/m^2 of heated floor area. The distance from Campus Evenstad to the recycling plant, Ragn-Sells AS, in Elverum is 74km; the mode of transport is a 16-32t EURO4 lorry. The distance to the final disposal site is not included. This waste estimate includes packaging, and the transport of all waste to final disposal. As aforementioned, all demolition works and waste belong to the previous life cycle.

Table 4.2 Summary of construction waste plan. ØM Fjeld AS, February 2016.

Type of Construction Waste	Preconstruction estimates	Unit
Timber, not creosote or CCA-impregnated	14522	kg
Paper, cardboard and carton	365	kg
Glass	130	kg
Iron and other metals	3640	kg
Gypsum based materials	1000	kg
Plastic	30	kg
Concrete, brick, Leca and other heavy building materials	5000	kg
Polluted concrete and brick (under the limit for dangerous substances)	0	kg
Other ordinary construction waste	0	kg
Electric and electronic waste	10	kg
Mixed construction waste	6200	kg
Asphalt	0	kg
Hazardous or special waste	21	kg

4.5 Energy use

From the start of construction until 6th September 2016, electricity has been supplied directly from the electricity grid. From 6th September 2016 until the end of construction, electricity has been supplied from the combined heat and power (CHP) unit. The corresponding emission factors for electricity from the grid (132 g CO_{2eq}/kWh) and from the CHP unit (30.4 gCO_{2eq}/kWh) have been used. The emission factor for the CHP unit is based on operation only. In addition, there are emissions related to the CHP unit itself, but these emissions are included in the material emission calculations. The amount of electricity used specifically during the construction process has not been measured; however, the operations manager at Campus Evenstad has provided an estimate for the electricity consumed on-site by taking the annual electricity consumption for the entire campus and finding the difference in electricity consumption between 2015 and 2016. This estimate corresponds to 246 840 kWh, and corresponds to 23% of the total energy use at Campus Evenstad. It is assumed that 169 400 kWh is used directly by the administration and educational building, while 77 440 kWh is used in the construction offices. Of the 246 840 kWh of electricity consumption, 164 560 kWh are supplied from the electricity grid and 82 280 kWh are supplied by the CHP unit. This on-site electricity use includes electricity for heating, cooling, ventilation, drying, and lighting. All on-site fossil fuel use has been accounted for under construction machinery.

4.6 Person transport

Although person transport is not defined in the system boundary for any ZEB ambition level, it was decided at an early design stage to include it in the embodied construction calculations for the administration and educational building at Campus Evenstad [11] as person transport is included in the draft standard prNS3720: 201x Method for GHG emission calculations for buildings. To facilitate for future comparisons with other pilot studies, the embodied construction emission results for person transport will be treated as a sensitivity analysis and reported here instead of in the results section of this report, in much the same way that biogenic carbon has been reported in Section 3 for materials. Person transport to the construction site is also based on transport log data collected from the contractor and sub-contractors, as described under Section 4.3 Construction Machinery. A summary of this data can be found in Appendix E. There is an assumption that all person transport is based on diesel fuel. There is also an assumption that there are two people in the vehicle when the number of people has not been specified. An emission factor of 0.240 $kgCO_{2eq}$/p.km is used for the percentage of journey that takes place under 50 km/hour while an emission factor of 0.160 $kgCO_{2eq}$/p.km is used for the percentage of journey that takes place over 50 km/hour. These emission factors have been adapted by Civitas from the European JRC (2014) to represent the Norwegian transport park [7]. The system boundary defines person transport as one way. In all, person transport contributes 11,439 $kgCO_{2eq}$ to total embodied emissions. This corresponds to 0.2 $kgCO_{2eq}/m^2/yr$, and is responsible for 8% of total construction emissions. This result may be due to the rural location of Campus Evenstad, which has led to longer travel distances for construction professionals compared to their city-based counterparts. Given the significance of this result, it is thought that person transport should be included in future construction emission calculations.

5. Operational Energy System (O)

This section is divided into three parts. The first provides information on the input data for energy simulations, the second part describes the heating, ventilation, and lighting systems installed, while the third part provides detailed information on the energy supply system.

5.1 Operational energy calculations

Table 5.1 summarizes the building envelope in terms of specific input data for energy simulations (O) and emission calculations. The net energy need and indoor comfort has been calculated by Asplan Viak AS in the simulation programs SIMIEN [25] and IDA-ICE [26], based on the data provided in Table 5.1. The results of the energy performance simulations are shown in Table 7.2. A more detailed report of the energy calculations can be found in [27].

Table 5.1 Building envelope summary (design values).

Component	Value	Descrition
Outer wall	U-value 0.12 W/m^{2}K	Solid wood frame with 300mm wood fiber insulation and a ventilated timber cladding.
Windows	U-value 0.80 W/ m^{2}K	Triple-glazed units.
Doors	U-value 0.80 W/ m^{2}K	-
Ground floor	U-value 0.13 W/m^{2}K	Solid wood frame with 350mm wood fiber insulation, sound proofing and 10mm industrial parquet flooring.
Outer roof	U-value 0.10 W/m^{2}K U-value 0.12 W/m^{2}K	Administration building Educational building
Thermal Bridges	Ψ = < 0.02 W/m^{2}K	Detailed thermal bridge design.
Ventilation	85% heat recovery 0.70/0.62 specific fan power 8.2/9.9 m3/m^{2}h ventilation rate in operation 1.0/2.0 ventilation rate outside of operation	Hybrid ventilation system.
Heating	70% system efficiency 19-21 C set point temperature 0.5 specific pump effect	
Operation hours	12 / 5 / 52	hours a day/days a week/weeks a year
Lighting	4.3 W/m^2	Internal heat gains
Appliances	5 W/m^2	Internal heat gains
Domestic hot water	0.8 W/m^2	Internal heat gains
People	6 W/m^2	Internal heat gains
Solar factor for windows Solar shading factor	0.55 / 0.5 1 / 0.91 / 1 / 1	Without/with solar shading North / east / south / west
Ratio of window frame	0.2	
Normalised heat capacity	40 Wh/m^{2}K	Massive wood construction
Infiltration	0.74 ACH at 50Pa	Detailed design of a continuous vapor and wind barrier, pressure tested.

5.2 Building services

5.2.1 Heating system

The heating need of the administration and educational building is provided by the CHP unit. In the building, there are water based radiators with a supply and return temperature of 60 - 40°C [28]. The various supply pipes, pumps, and valves have been insulated to reduce heat losses. In the energy calculations, indoor air temperature setpoints are 21°C during the day and 19 °C at night. The location of the radiators was decided through IDA ICE simulations [28]. The radiator locations are shown in Figure 5.1, while Figure 5.2 shows photographs of the wood-burning fireplace and wall mounted radiator.

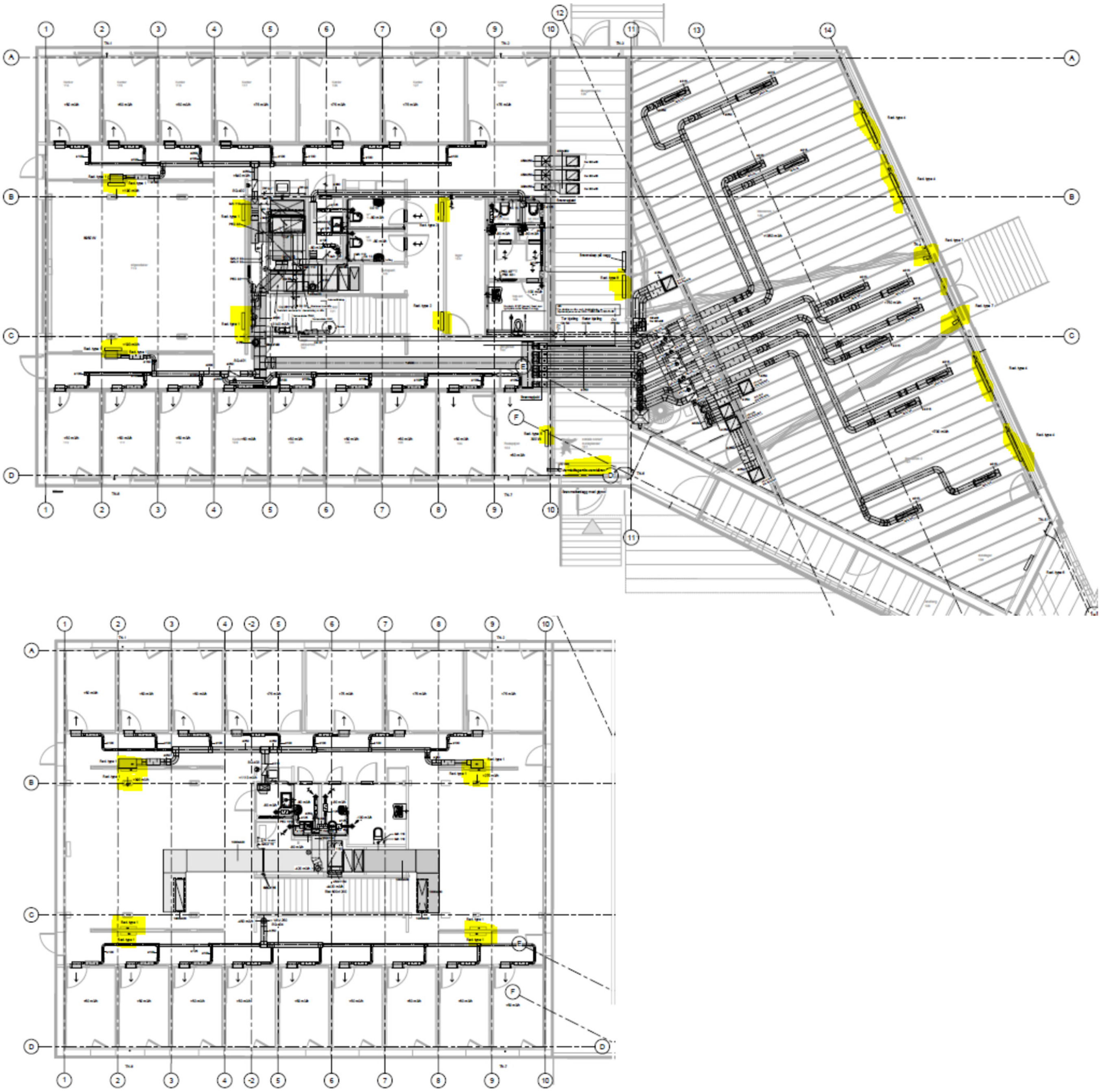

Figure 5.1 Radiators for heat distribution in the ground (above) and first (below) floor plans [28].

Figure 5.2 Photographs of the wood-burning fireplace and wall mounted radiator. SINTEF.

5.2.2 Ventilation

The ventilation system is based on mechanical balanced ventilation. This is combined with hybrid ventilation and includes the manual opening of windows during warm days. There is no other cooling system installed in the offices. In the educational building, the ventilation system is equipped with a cooling coil, which enables cooling through the water mains. This cooling system will only operate if the educational building is used during periods of high occupancy on hot days [28]. The specific fan power (SFP) is measured to be 1.23 kW/m^3/s in full operation, and this is calculated to provide an average SFP of 0.81 kW/m^3/s during operational hours from 6am to 6pm [28]. Outside of operational hours, exhaust air will be extracted from opened windows and the SFP of air supply will be reduced to 0.44 kW/m^3/s [28]. The ventilation system has an 85% heat recovery rate [28].

5.2.3 Lighting

Demand controlled energy efficient lighting has been installed. The need for lighting and solar shading has been calculated using light energy numeric indicators (LENI) according to NS-EN 15193, which provides a more accurate calculation methodology for lighting energy demand [28, 29]. LENI has been calculated to 10.8 kWh/m^2 for the whole building, or 13.4 kWh/m^2 for the educational building and 9.6 kWh/m^2 for the office building; given operational hours of 12 hours a day, 5 days a week, 52 weeks a year [28]. The lighting system uses a digital addressable lighting interface (DALI) which can include a range of smart programmable solutions and be controlled via a mobile app. The system uses light emitting diode (LED) lighting.

5.3 Local energy generation

For energy supply, it was decided to use a combined heat and power (CHP) unit based on gasification of wood chips. The CHP system produces electricity and heat at the same time. The ratio between electricity and heat generation is approximately 2:5. The energy source used is locally produced wood chips from a sustainably managed forest, which is transformed into biogas and burnt in an internal combustion engine.

The CHP unit is supplied by Volter and has a power of 40 kW electricity (45 kW generator) and 100 kW heat. The efficiency rate of the unit is approximately 20% for electricity generation and 50% for heat generation, which means that around 70% of the energy in the wood chips becomes useful energy that can be used on-site at Campus Evenstad. The heat generated is delivered to the local district heating network and is thereafter distributed to the buildings on campus as required. The electricity generated is used directly on campus, and if there is more electricity generated than needed, then any excess electricity is delivered to the utility electricity network (Eidsivas). A two-way utility owned energy meter measures any exported electricity, whereby Campus Evenstad is reimbursed for any surplus electricity.

The CHP unit is controlled according to the heating need on campus. The total heating need on campus thus controls the number of operational hours, and this in turn affects the amount of electricity and heat generated by the CHP unit and consequently the emission calculations. The system can essentially be operated from 30 to 100% of the nominal power, and during the early design phase, it was estimated that the CHP unit would have an annual operational time of 3500 hours with 100% power output. However, the CHP will probably have more operational hours than this, with a lower power level than 100%. In this scenario, the annual energy generation of the CHP unit was estimated to be 133 000 kWh electricity and 325 500 kWh heat.

The CHP unit was installed in the summer of 2016 and has been operational since 6th September 2016. After one month of operation, it has been possible to estimate the actual annual operation time and energy generation. The operating staff estimates an annual electricity generation of between 200 000 and 230 000 kWh and an annual heat generation of between 500 000 and 576 000 kWh. This means that the CHP unit is estimated to have up to 6000 hours of operation a year. This projection assumes that the CHP unit will not be used in the summer and will operate at 50% max power during the spring and autumn. The continued operation and monitoring of the CHP system will improve the knowledge of the performance of such systems. Figure 5.3 provides an image of the wood chip storage containers at Campus Evenstad, while Figure 5.4 provides an image of the CHP unit installed. Figure 5.5 depicts the production of wood chips used in the CHP unit.

The combustion of wood chip biomass takes place at around 1000 °C in a wood gas generator. Nitrogen (N_2), water (H_2O), carbon dioxide (CO_2), and surplus oxygen (O_2) are released into the atmosphere when the wood is completely combusted. The gasification of wood occurs when an incomplete combustion takes place. With an incomplete combustion, flammable gases such as carbon monoxide (CO), hydrogen (H_2), methane (CH_4), dust, and tar are released. The released gases are cooled down and cleaned. This clean wood gas is then used as a fuel to power an internal combustion engine that operates an electric generator that produces electricity. The generator is connected to a converter that converts the electricity so that it can be distributed to consumers. The CHP system also produces heat. The heat comes from the cooling of the gas, motor, and exhaust. The CHP unit is a closed-loop system. The heat is extracted via a heat exchanger and is subsequently distributed to the local district heating network. Figure 5.6 and Figure 5.7 provide an overview of the CHP unit, while Table 5.2 provides a description of the required quality of wood chips. The CHP system requires good quality wood chips to produce good quality electricity and heat. Given 3500 operational hours, it is estimated that the CHP system will require between 800 – 1000 m^3 of wood chips per year.

Figure 5.3 Storage silos for the CHP unit at Campus Evenstad, courtesy of ETA Norge AS.

Figure 5.4 CHP unit at Campus Evenstad, photo courtesy of ETA Norge AS.

Figure 5.5 Wood chips for the CHP unit, courtesy of ETA Norge AS and Statsbygg.

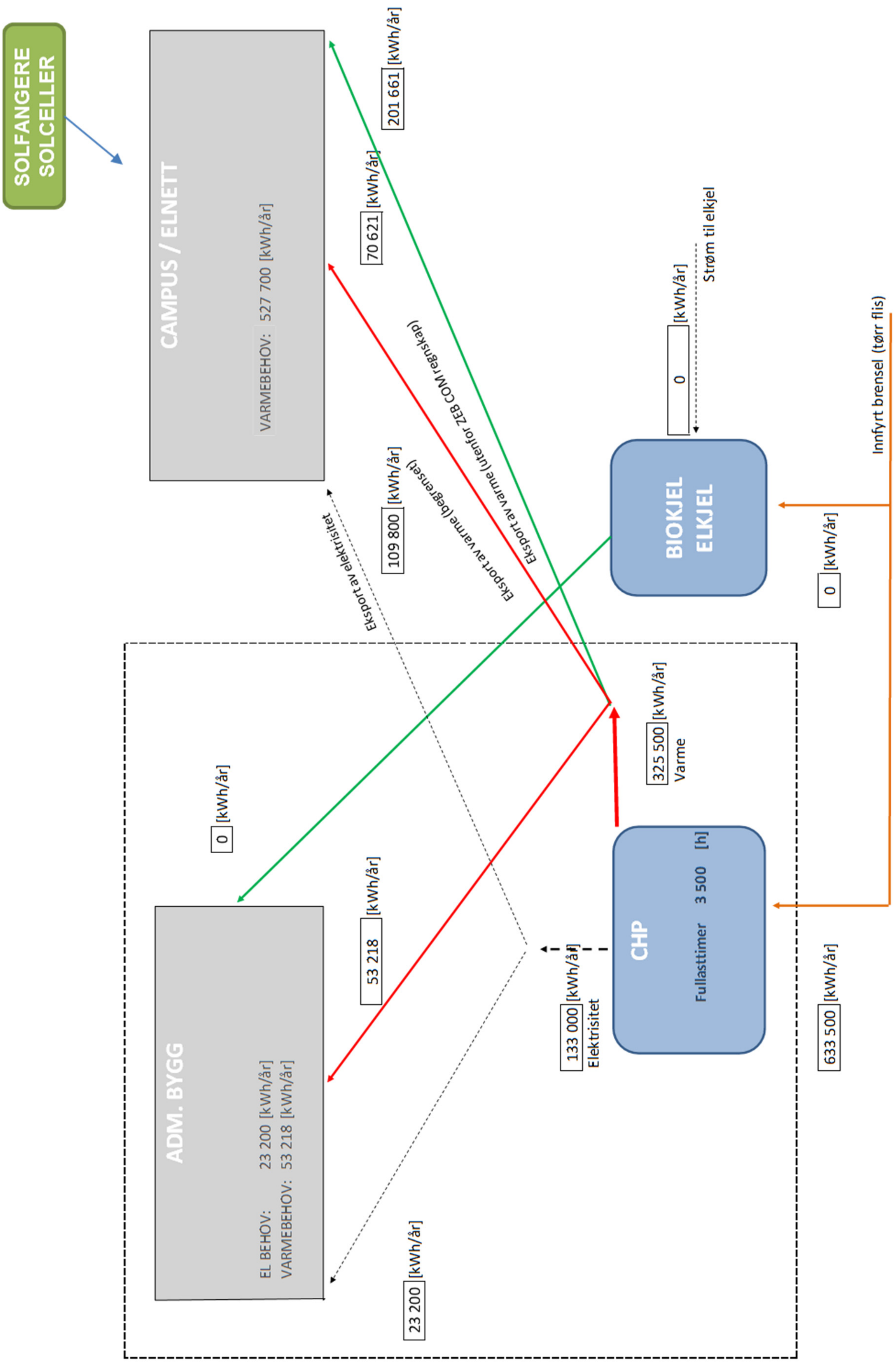

Figure 5.6 Energy flow on campus, including energy supply and demand for the as-built phase, based on a sketch from Asplan Viak AS.

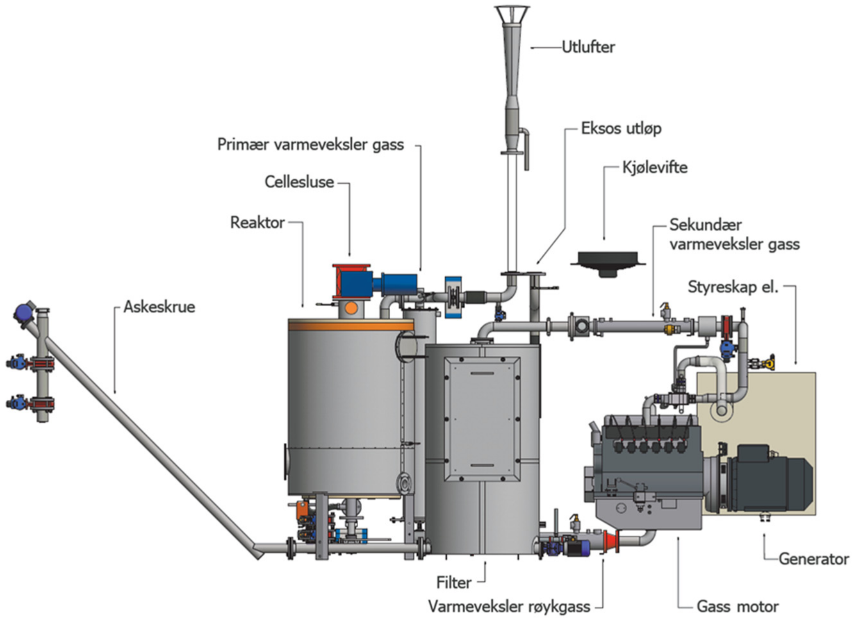

Figure 5.7 A detailed diagram depicting the CHP system, courtesy of ETA Norge AS.

Table 5.2 Specification of wood chip quality in the tender documentation.

Specification	Description
Origin	Wood biomass from forest or plantation according to ISO 17225.
Dimensions	Main fraction size 8mm ≤ P ≤ 50mm. Content smaller than 3.15mm < 1%. Maximum fraction size < 63mm. All according to ISO 17827-1.
Moisture content	Maximum moisture content M15 (≤ 15%) according to ISO 18134-1 and ISO 18134-2.

The CHP unit is a part of a much larger local energy generation network on campus. The CHP heat is distributed to a local district heating network that is also supplied by heat from a 300-kW wood chip boiler and 100 m^2 of solar thermal collectors on campus. In addition, a 315 kW electric boiler acts as back up. A 10,000-litre hot water tank stores heat to ensure the best possible daily operations. Further information on the energy system can be found in [7].

Table 5.3 shows the calculated energy demand for the administration and educational building at Campus Evesntad, based on the Oslo climate, following NS 3031 and the national building code, TEK 10 [8, 28, 30]. Table 5.4 shows the calculated energy demand for the administration and educational building at Campus Evenstad, based on the local climate, and following NS 3701 [28, 31].

Table 5.3 Calculated energy demand, Oslo climate, NS 3031 and TEK10.

Administration building, Oslo climate, NS 3031	Calculated energy demand (kWh/m^2)
Space heating	16.6
Ventilation heating	6.7
Domestic hot water	5.0
Fans	6.3
Pumps	0.8
Lighting	9.7
Appliances	34.5
Server room (IT)	0
Space cooling	0

Server room cooling	0
Ventilation cooling	0
Total	79.6
Educational building, Oslo climate, NS 3031	**Calculated energy demand (kWh/m^2)**
Space heating	31.6
Ventilation heating	8.3
Domestic hot water	5.0
Fans	7.0
Pumps	0.7
Lighting	13.5
Appliances	34.5
Server room (IT)	0
Space cooling	0
Server room cooling	0
Ventilation cooling	0
Total	100.7

Table 5.4. Calculated energy demand, local climate, NS 3701.

Administration building, local climate, NS 3701	**Calculated energy demand (kWh/m^2)**
Space heating	26.6
Ventilation heating	5.7
Domestic hot water	5.0
Fans	4.9
Pumps	0.8
Lighting	9.7
Appliances	18.8
Server room (IT)	0
Space cooling	0
Server room cooling	0
Ventilation cooling	0
Total	71.5
Educational building, local climate, NS 3701	**Calculated energy demand (kWh/m^2)**
Space heating	46.8
Ventilation heating	7.1
Domestic hot water	5.0
Fans	5.9
Pumps	0.8
Lighting	13.5
Appliances	15.7
Server room (IT)	0
Space cooling	0
Server room cooling	0
Ventilation cooling	0
Total	94.8

6. Building Envelope and Building Services (M)

To follow is a description of the material inventory used in embodied material emission calculations for each of the building parts outlined in Table 3.2.

6.1 Building envelope

6.1.1 Groundwork and foundations

The groundwork and foundations are characterized by cast in-situ strip foundations. Steel reinforced low carbon concrete has been used throughout, with 100mm EPS insulation and a damp-proof membrane. Hard core gravel has been used as a backfill between the strip foundations. As part of the climate adaptation strategy, and to avoid any future flood risk, the foundations were raised approximately 1m compared to the design phase details. A selection of the foundation designs used in the educational part of the building is shown in Figure 6.1. The material inventory for the groundwork and foundations is shown in Table 6.1.

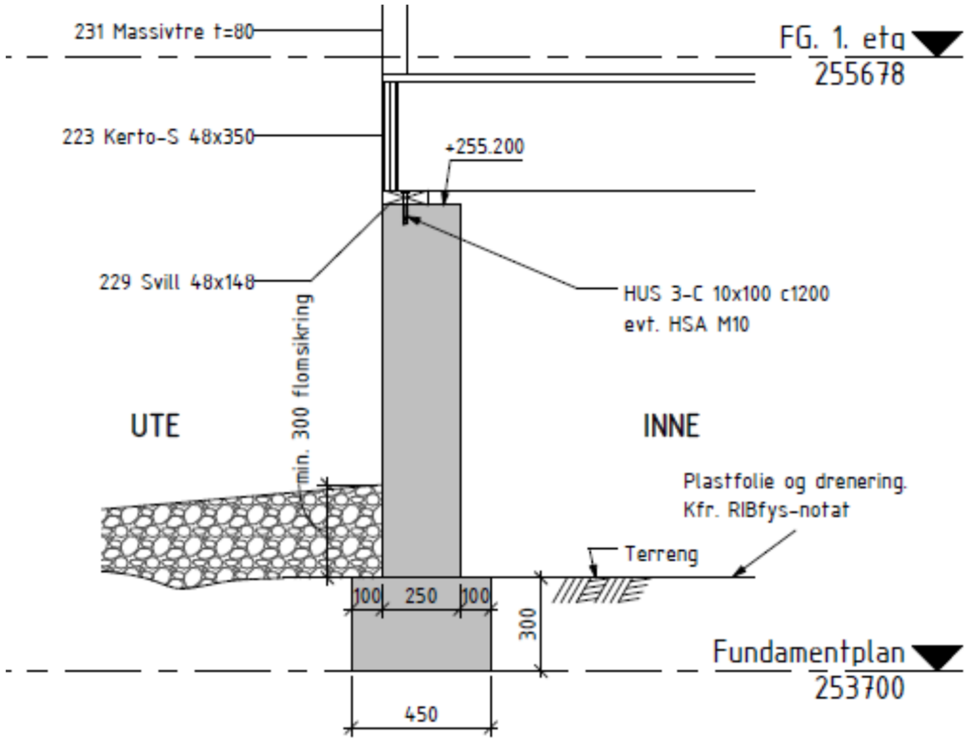

Figure 6.1 A detail of the strip foundation design, courtesy of Høyer Finseth AS.

Table 6.1 Material inventory for the groundwork and foundations.

Material	Quantity	Reference Service Life	Data Source
Concrete	144.7 m^3	50	NEPD no. 123N (2015)
Steel shuttering	720 kg	100	NEPD no. 236E (2014)
Reinforcement steel	11860 kg	60	NEPD no. 347-238-EN (2015)
EPS insulation	315.8 m^2	60	NEPD no. 322-185-NO (2015)
Damp proof membrane	1300 m^2	60	NEPD no. 273N (2014)
Hardcore gravel	30 m^3	60	NEPD no. 120N (2013) rev. 1

6.1.2 Superstructure

The load-bearing structure is characterized by a solid wood construction, including solid wood elements, glue laminated timber, and structural timber, which is joint together by a series of stainless steel plates, washers, and screws. A selection of axonometric drawings of the superstructure for the administration (left) and educational (right) building is shown in Figure 6.2. The material inventory for the superstructure is shown in Table 6.2.

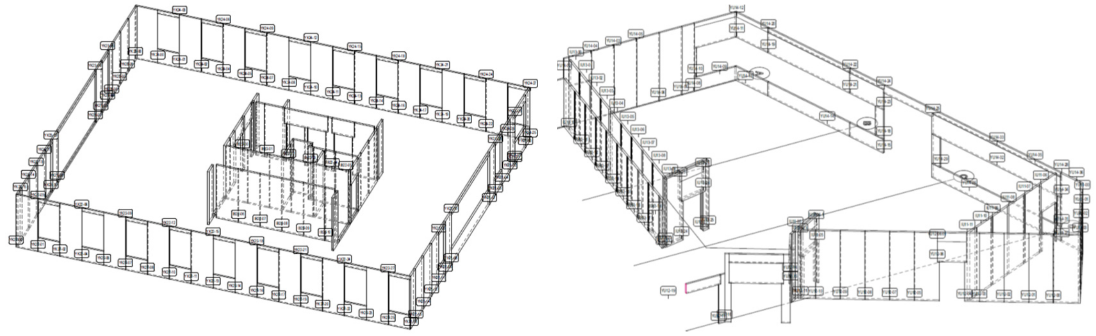

Figure 6.2 A selection of axonometric drawings of the superstructure for the administration (left) and educational (right) building, courtesy of Massivlust AS.

Table 6.2. Material inventory for the superstructure.

Material	Quantity	Reference Service Life	Data Source
Solid wood beams	1.24 m^3	60	NEPD no. 308-179-NO (2015)
Solid wood elements	3.45 m^3	60	LCA report (2015)
Glue laminated timber	64.7 m^3	60	NEPD no. 336-222-NO (2015)
Copper impregnated timber	4.8 m^3	60	NEPD no. 472-330-NO (2016)
Steel connections	2001 kg	100	NEPD no. 236E (2014)
Structural pine	9.5 m^3	60	NEPD no. 308-179-NO (2015)

6.1.3 Outer walls

The outer walls were originally designed to be of a Norwegian, prefabricated massive wood construction (80mm internal massive wood, 200mm wood fiber insulation, 60mm external massive wood). One of the advantages of this type of construction includes a more compact design that is thinner and more robust, which is also quicker, cheaper, and easier to install. However, this construction has never been built before in Norway, and after much deliberation and testing, it was decided to not use this construction. This was mainly because it was not possible to guarantee the construction against vapor infiltration. The test results showed a potential risk for water storage and moisture damage in a ventless design. Further details on this massive wood construction can be found in [7].

Instead, a more traditional wall construction was used, that involves a ventilated wooden cladding, consisting of 80mm massive wood, 300mm wood fiber insulation, 18mm wind barrier, 23 x 48mm battens, 36 x 48mm counter batten, and a 19mm external pine cladding. A depiction of these two-wall construction alternatives are displayed in Figure 6.3. In addition, the outer wall component includes a glazed walkway consisting of triple glazing and an aluminum frame, as well as well-insulated doors, and triple glazed windows with a timber frame and protective aluminum layer. The windows are positioned in the inner insulating layer of the wall to reduce the thermal bridge effect. An overview of the outer wall material inventory can be found in Table 6.3.

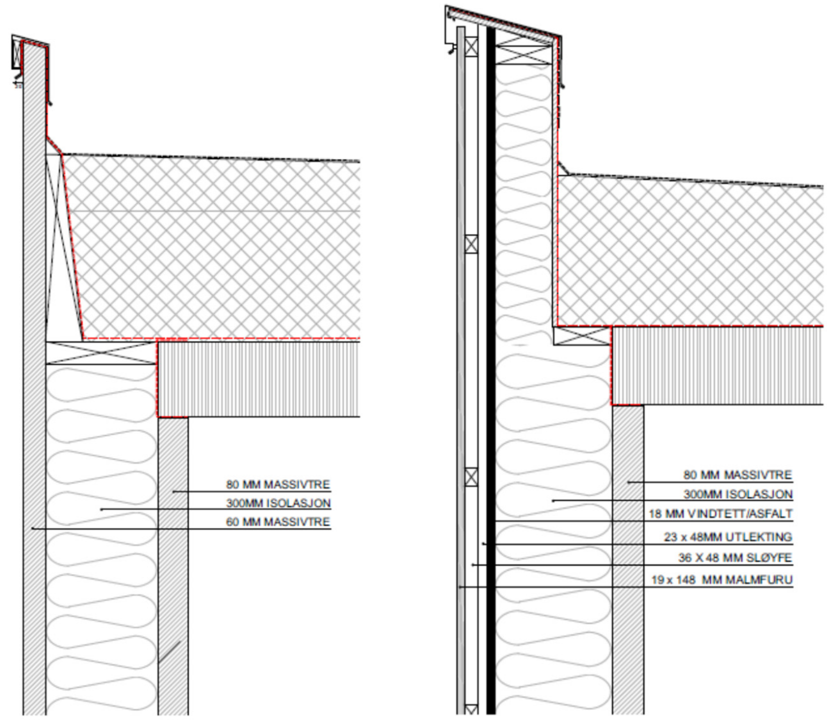

Figure 6.3 Outer wall from the design phase (left) and as-built phase (right), courtesy of Ola Roald AS.

Table 6.3 Material inventory for the outer walls.

Material	Quantity	Reference Service Life	Data Source
Solid wood elements	41 m^3	60	LCA report (2015)
Wood fiber insulation	5131 m^2	60	LCA report (2014)
I-beams	710 m	60	NEPD no. 311-186-NO (2015)
Wind barrier	753 m^2	60	NEPD no. 214N (2011)
Structural pine	19 m^3	60	NEPD no. 308-179-NO (2015)
Glazed walkway			
- Glass	85 m^2	30	Ecoinvent v.3.1. (2014)
- Alu frame	5.2 m^2	60	Ecoinvent v.3.1. (2014)
Windows	Varies	60	NEPD no. 176E (2014) rev. 1 NEPD no. 245E (2014)
Doors	varies	60	NEPD no. 258E (2014)

6.1.4 Inner walls

In all, there are twelve different inner wall specifications (see Figure 6.4). These vary between a traditional inner wall construction consisting of 98mm glass wool insulation encased in 13mm plasterboard, 25mm wood fiberfiber board or 14mm wood panel, to a 100mm solid wood construction with 70mm wood fiberfiber insulation. The various inner wall details are designed to meet a range of aesthetic, fire, and sound requirements. In addition, there are several internal glass partitions (some of which use reclaimed glass) and internal doors. A summary of the inner wall material inventory can be found in Table 6.4.

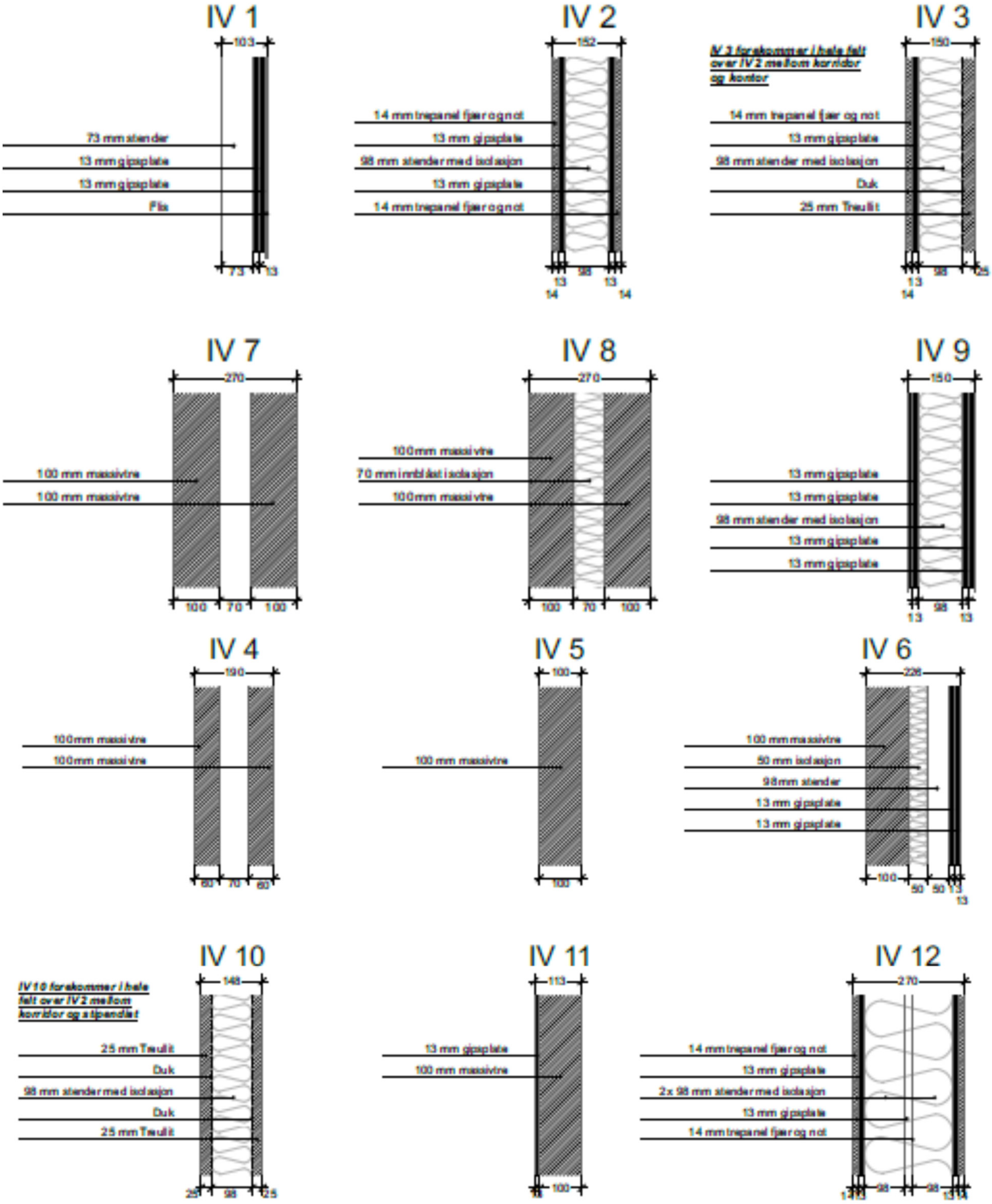

Figure 6.4 Inner wall details, courtesy of Ola Roald AS

Table 6.4 Material inventory for the inner walls.

Material	Quantity	Reference Service Life	Data Source
Plasterboard	824 m^2	60	NEPD no. 223N (2011)
Structural pine	209 m^3	60	NEPD no. 308-179-NO (2015)
Glass wool insulation	1030 m^2	60	NEPD no. 221N (2013) rev.2
Solid wood elements	75 m^3	60	LCA report (2015)
Wood fiberfiber insulation	204 m^2	60	LCA report (2014)
Acoustic panels	2 tonne	50	NEPD no. 295E (2014)
Windows	varies	60	NEPD no. 245E (2014)
Doors	varies	30 60	NEPD no. 157N (2012) NEPD no. 258E (2014)

6.1.5 Floor structure

The ground floor structure is characterized by 15mm timber boards, a waterproofing player, 350mm massive wood frame and wood fiber insulation, 22mm oriented strand board, 36mm sound proofing, 12mm oriented strand board and 10mm industrial parquet flooring. The first-floor structure is characterized by 200mm massive wood and wood fiberfiber insulation, 70mm gravel, 12mm oriented strand board, 36mm sound proofing, 22mm floor plasterboard, and 10mm industrial parquet flooring. The gravel has been tested for radon, washed and dried, and has a grain size of 8-11mm. The gravel is inserted via machine and raked out manually. Both floor constructions are detailed in Figure 6.5. A summary of the material inventory for the floor structure can be found in Table 6.5.

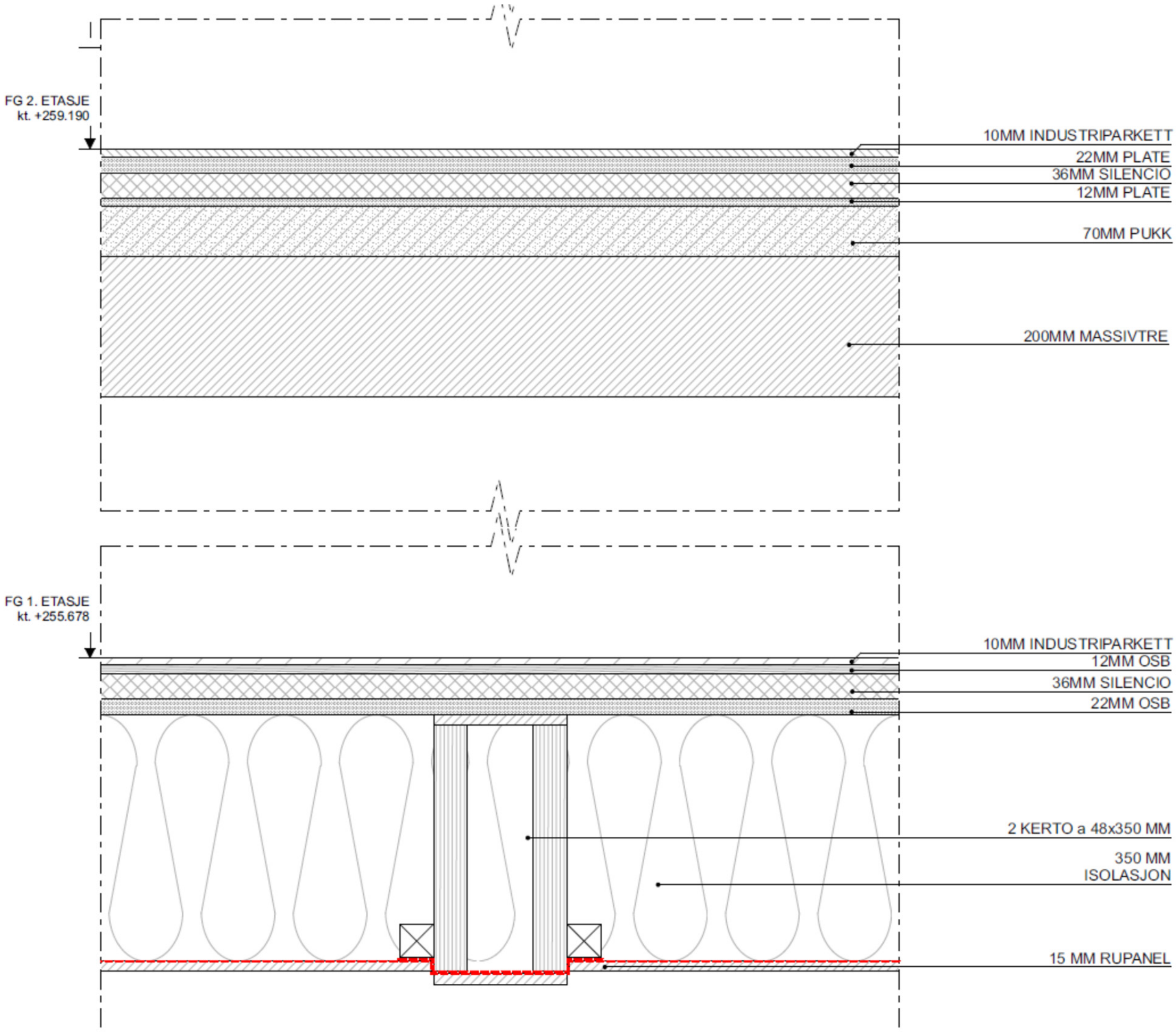

Figure 6.5 Detail of ground floor (below) and first (above) floor, courtesy of Ola Roald AS.

Table 6.5 Material inventory for the floor structure.

Material	Quantity	Reference Service Life	Data Source
Wood fiberfiber insulation	6705 m^2	60	LCA report (2014)
Solid wood elements	75 m^3	60	LCA report (2015)
Oriented strand board	66 m^3	60	NEPD no. 274N (2014)
Gravel	25 m^3	60	NEPD no. 120N (2013) rev. 1
Plasterboard	1057 m^2	60	NEPD no. 110-177-EN (2015)
Laminate flooring	35 m^2	30	IBU EPD-EHW-20130012-IBC1-DE
Ceramic tiles	28 m^2	50	IBU EPD-IKF-2011111-EN
Industrial parquet floor	993 m^2	60	NEPD no. 377-264-NO (2015)

6.1.6 Outer roof

The outer roof is characterised by 25mm acoustic panels fixed directly to 200mm massive wood, a waterproofing layer, 350mm massive wood with either stone wool or EPS insulation, and a waterproof roofing membrane. The ceiling includes 13mm acoustic panels, with an acoustic layer and 50mm glass wool insulation fixed to battens. The roof construction is detailed in Figure 6.6. A summary of the material inventory for the roof structure can be found in Table 6.6. A proxy polyethylene membrane has been used to represent the acoustic layer.

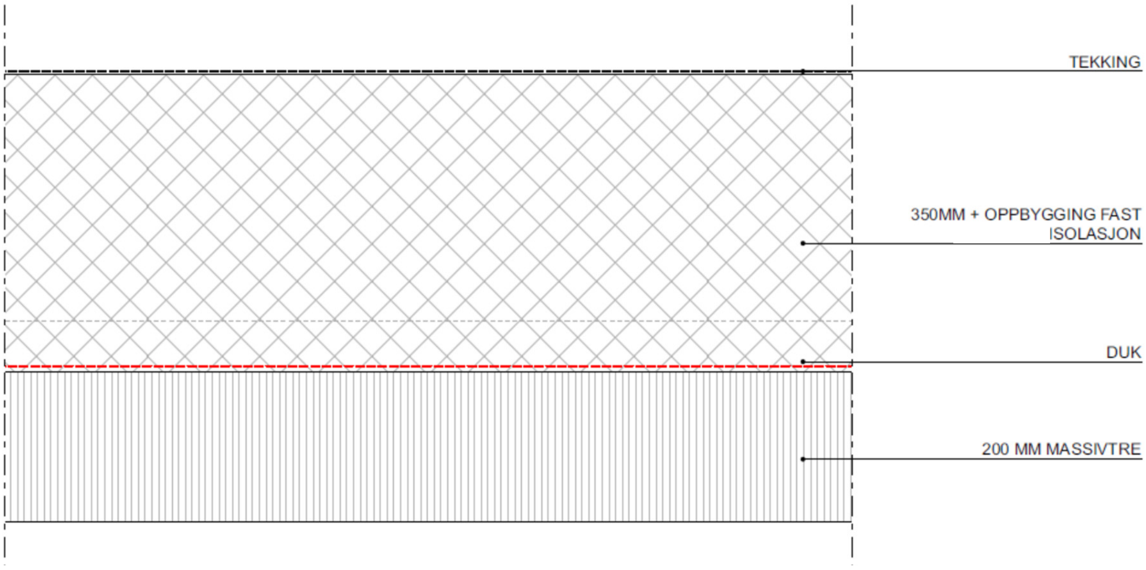

Figure 6.6 Detail of outer roof, courtesy of Ola Roald AS.

Table 6.6 Material inventory for the outer roof.

Material	Quantity	Reference Service Life	Data Source
Acoustic panels	4 tonne	50	NEPD no. 295E (2014)
Oriented strand board	4.5 m^3	60	NEPD no. 274N (2014)
Stone wool insulation	8752 m^2	50	NEPD no. 267E (2014)
Acoustic layer	419m^2	60	NEPD no.: 341-230-NO (2015)
Glass wool insulation	348 m^2	60	NEPD no. 221N (2013) rev. 2
EPS insulation	2564 m^2	60	NEPD no. 322-185-NO (2015)
Solid wood	80 m^3	60	LCA report (2015)
Roofing membrane	830 m^2	30	NEPD no. 186N (2013)

6.1.7 Fixed inventory

So far, the material inventory for the fixed inventory includes solid wood for the fixed, inbuilt cupboards and shelving. A summary of the material inventory for the fixed inventory can be found in Table 6.7.

Table 6.7 Material inventory for the fixed inventory.

Material	Quantity	Reference Service Life	Data Source
Solid wood	0.3 m^3	60	LCA report (2015)
Oak handrails	30.4 m	30	NEPD no. 246N (2014)

At the time in which embodied material emission calculations were carried out, there was not enough inventory data information available to include the following: fireplace, kitchen cupboards, fridges, dishwashers, sinks, taps, coffee machines, and kitchen worktop.

6.1.8 Stairs and balconies

The stairs consist of a reinforced concrete foundation, with Kebony [32] pine clad steps and steel railings. The stairs and balconies building part also includes two lifts, but no balconies. A summary of the material inventory for the stairs and balconies can be found in Table 6.8.

Table 6.8. Material inventory for the stairs and balconies.

Material	**Quantity**	**Reference Service Life**	**Data Source**
Concrete	37 m^3	50	NEPD no. 123N (2015)
Reinforcement steel	2744 kg	60	NEPD no. 347-238-EN (2015)
Steel			
- Lifts	2000 kg	60	NEPD no. 236E (2014)
- Railings	600 kg	60	NEPD no. 236E (2014)
Kebony pine	1.3 m^3	30	NEPD no. 408-287-EN (2016)

6.1.9 Sanitary

Asplan Viak AS has provided a detailed material inventory for the sanitary installations, much of this inventory includes pipework for sanitary ware. However, the material inventory used article numbers and abbreviations instead of specifying raw materials, which proved difficult to decode. For simplicity, it has been assumed that the entire material inventory consists of steel. This presents a weakness in the embodied emission calculations and highlights an area for further study. A summary of the material inventory for the sanitary installations can be found in Table 6.9.

Table 6.9 Material inventory for sanitary installations.

Material	**Quantity**	**Reference Service Life**	**Data Source**
Steel	2058 kg	60	Ecoinvent v3.1 (2014)

At the time in which embodied emission calculations were carried out, there was not enough inventory data information available to include the following: sinks, toilets, mirrors, soap dispensers, towel dispensers, and wall mounted waste paper bins.

6.2 Building services

6.2.1 Heating

Asplan Viak AS has provided a detailed material inventory for the heating installations, much of this inventory includes pipework for heating. However, the material inventory used article numbers and abbreviations instead of specifying raw materials, which proved difficult to decode. For simplicity, it has been assumed that most of the material inventory consists of steel. This presents a weakness in the embodied emission calculations and highlights an area for further study. A summary of the material inventory for the heating system can be found in Table 6.10.

Table 6.10 Material inventory for the heating system.

Material	**Quantity**	**Reference Service Life**	**Data Source**
Steel	320 kg	60	Ecoinvent v3.1 (2014)
Hot water tank	1 pc	60	Ecoinvent v3.1 (2014)
Battery	106 kg	60	Ecoinvent v3.1 (2014)

6.2.2 Ventilation

Asplan Viak AS has provided a detailed material inventory for the ventilation system. However, there are next to no environmental product declarations and very few generic datasets for ventilation products. Thus, it has been assumed that the entire material inventory consists of steel. This presents a weakness in the embodied emission calculations and highlights an area for further study. A summary of the material inventory for the ventilation system can be found in Table 6.11.

Table 6.11 Material inventory for the ventilation.

Material	**Quantity**	**Reference Service Life**	**Data Source**
Steel	5009 kg	60	NEPD no. 236E (2014)

6.2.3 Lighting

Asplan Viak AS has provided a detailed material inventory for the lighting and electrical system. However, there are next to no environmental product declarations and very few generic datasets for lighting and electrical products. Thus, the material inventory has been reduced to its raw material components. This presents a weakness in the embodied emission calculations and highlights an area for further study. A summary of the material inventory for the lighting can be found in Table 6.12.

Table 6.12 Material inventory for the lighting.

Material	**Quantity**	**Reference Service Life**	**Data Source**
Steel	380 kg	60	NEPD no. 236E (2014)
Aluminum	75 kg	60	Ecoinvent v3.1 (2014)
Polyethylene, high density	52 kg	60	Ecoinvent v3.1 (2014)
Cable	1972 kg	30	Ecoinvent v3.1 (2014)
LED light fitting	320 kg	30	Ecoinvent v3.1 (2014)

6.2.4 CHP

The CHP unit was previously described in Section 5.2 of this report. A summary of the material inventory for the CHP infrastructure can be found in Table 6.13.

To facilitate for the installation of the CHP unit, it was necessary to extend the energy central at Campus Evenstad. The energy central extension is shown in Figure 6.7. A part of these extensions includes extensions for the continuation of Campus Evenstad as a pilot project in the research center for zero emission neighborhoods in smart cities (ZEN). The additional construction required for the extension of the energy central is not included in the ZEB emission balance.

Table 6.13 Material inventory for the CHP system.

	Material	Quantity	Reference Service Life	Data Source
CHP unit	Steel	5000 kg	20	Ecoinvent v.3.1 (2014)

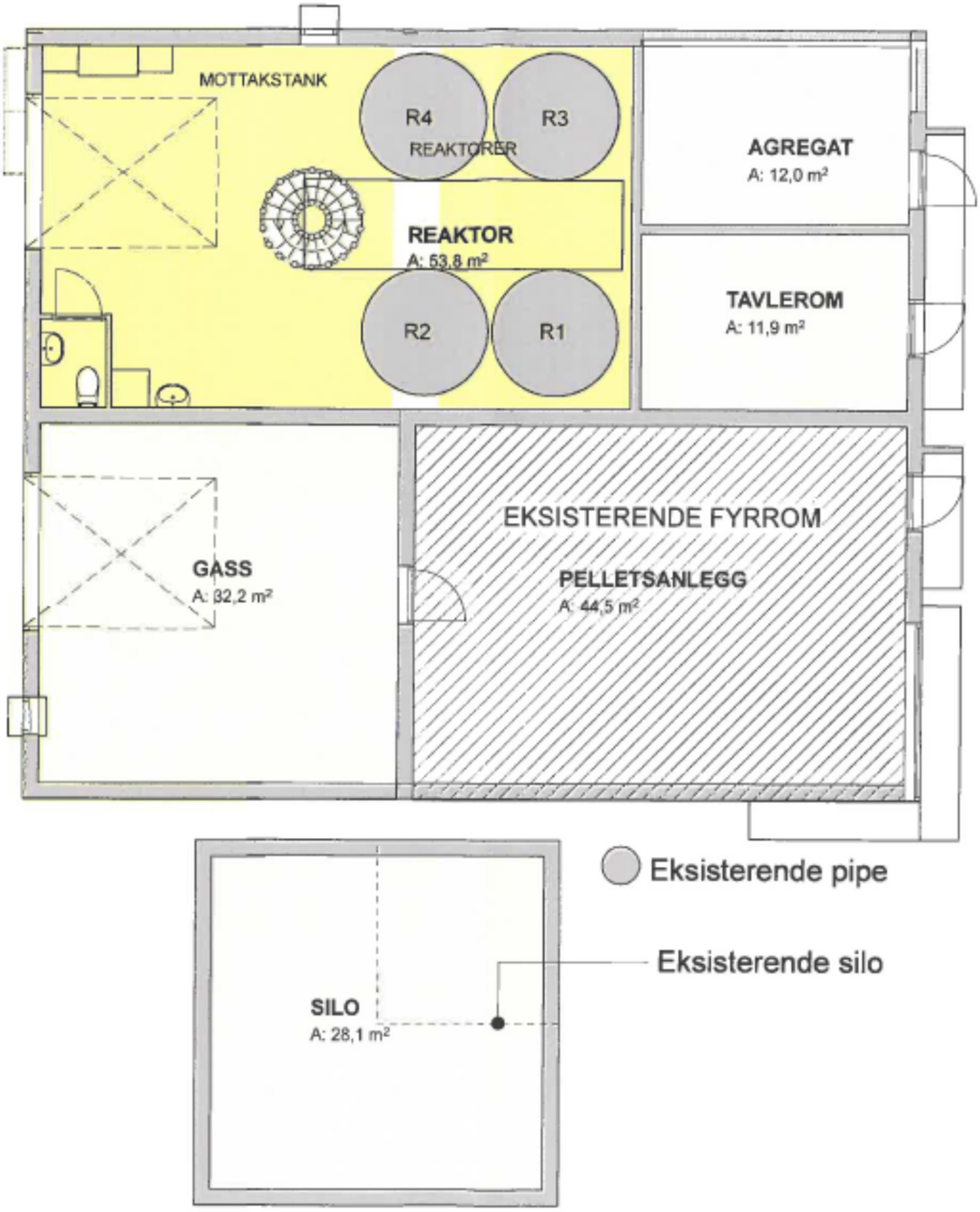

Figure 6.7 Energy central plan, courtesy of Plan og Prosjekt Arkitekter.

7. Results

This section presents the emission results from the current material inventory for the administration and educational building at Campus Evenstad. The total carbon dioxide emissions for the functional unit are presented in the last column of Table 7.1. The embodied emissions are calculated as 23.9 $kgCO_{2eq}/m^2/yr$, as 1 433 $kgCO_{2eq}/m^2$ over a 60-year lifetime, as 27 259 $kgCO_{2eq}/yr$ for the whole building, and 1 635 591 $kgCO_{2eq}$ for the whole building over the entire lifetime of the building. The results do not include biogenic carbon or person transport.

Table 7.1 Carbon dioxide equivalent emissions from the new administration and educational building.

Life Cycle Stage	**$kgCO_{2eq}$**	**$kgCO_{2eq}/yr$**	**$kgCO_{2eq}/m^2$**	**$kgCO_{2eq}/m^2/yr$**
Production phase (A1 – A3)	438 492	7 308	384	6.4
Transport to site (A4)	20 597	343	18	0.3
Construction installation process (A5)	104 603	1 743	92	1.5
Replacement phase (B4)	133 595	2 227	117	2.0
Operational phase (B6)	938 304	15 638	822	13.7
TOTAL	**1 635 591**	**27 259**	**1 433**	**23.9**

Most emissions originate from life cycle module B6 (57%). However, these emissions are compensated for by on-site energy generation from the CHP unit. The sensitivity of operational time for on-site energy generation is discussed in Section 8. The production phase (A1 – A3) is responsible for 27% of total embodied emissions for the building, while the construction phase (A4 – A5) and the replacement phase (B4) are responsible for 8% each of total embodied emissions.

7.1 Construction

The construction phase is responsible for 104 603 $kgCO_{2eq}$ or 1.8 $kgCO_{2eq}/m^2/yr$ of total embodied emissions. Of these emissions, 16% or 0.3 $kgCO_{2eq}/m^2/yr$ arise from life cycle module A4, while 84% or 1.5 $kgCO_{2eq}/m^2/yr$ arise from life cycle module A5.

Within the construction phase, the largest contributor to CO_{2eq} emissions is the use of construction machinery on-site (51% or 0.93 $kgCO_{2eq}/m^2/yr$), electricity use on site (19% or 0.34 $kgCO_{2eq}/m^2/yr$), and the transport of building materials to site (16% or 0.3 $kgCO_{2eq}/m^2/yr$). This is followed by the installation of building materials on-site (11% or 0.2 $kgCO_{2eq}/m^2/yr$), transport of construction machinery to site (1% or 0.02 $kgCO_{2eq}/m^2/yr$), and temporary works on-site (1% or 0.01 $kgCO_{2eq}/m^2/yr$). The construction processes that contribute the least to CO_{2eq} emissions are final disposal of construction waste (1%) transport of construction waste to end of life (<1%), and transport of temporary works to site (<1%). Figure 7.1 provides an overview of these embodied construction emission results.

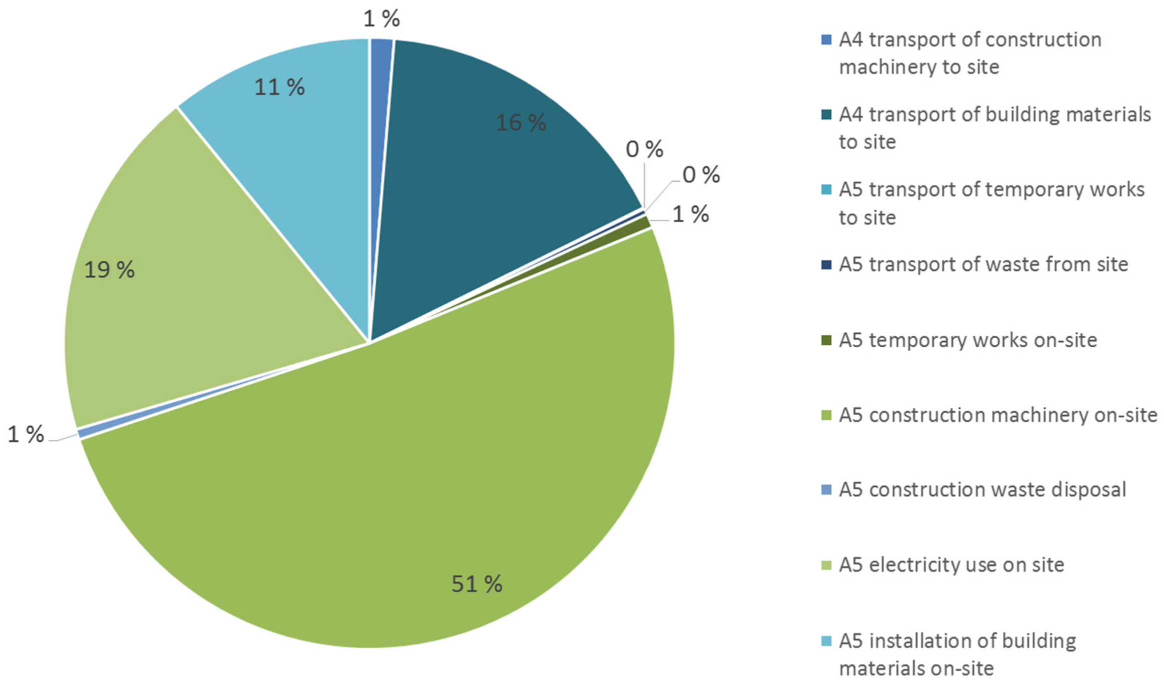

Figure 7.1 Pie chart showing the distribution of construction phase emissions.

In terms of the use of construction machinery on-site, the largest contributor to CO_{2eq} emissions is the burning of fossil fuels in the construction machinery (82%) followed by emissions from the production of construction machinery (18%). Out of the various construction machinery used, the largest contributor to CO_{2eq} emissions is the Caterpillar 324 crawler excavator (36%) followed by Remko heat aggregate CLK120 (21%), Caterpillar 312E crawler excavator (14%), Moxy MT31 dumper truck (10%), telescopic lift (7%), Potain Igo50 tower crane (5%) and Caterpillar 307D crawler excavator (2%). The Fendt vario 716 tractor, Doosan dx140W excavator, Bobcat digger E26 and Atlas Copco 800 vibroplate all contribute 1% to total construction machinery CO_{2eq} emissions. Photographs of the various construction machinery can be found in Appendix D.

In terms of transport of building materials to site, the largest contributor to CO_{2eq} emissions is the transportation of wood fiber insulation (19%), transport of wood and wood-based products (19%), and transport of concrete, brick, and ceramics (16%). The transport of massive wood contributes 13%, while the transport of waterproofing membrane and laminate contributes 10%. Window and door transport to site contributes 6%, followed by the transportation of mineral wool insulation (5%), transport of steel and aluminum (4%), transport of combined heat and power unit (3%), transport of gypsum (2%), transport of gravel and hardcore (2%), transport of electrical components and cables (1%), and transport of roofing membrane (1%).

7.2 Operation

The results from the operation phase are dependent on the net energy need of the administration and educational building, as well as the energy generation of the CHP unit. The calculated net energy need and delivered energy results are presented in terms of kWh in Table 7.2 for both the design and as-built phase. More detailed information can be found in [27]. The results reported in Table 7.2 need to be converted to CO_{2eq} emissions. Table 7.3 provides an overview of these operational emission results. The operation phase is responsible for 938 304 $kgCO_{2eq}$ or 13.7 $kgCO_{2eq}/m^2/yr$ of total embodied emissions.

Table 7.2 Calculated operational energy for the new building, courtesy of Asplan Viak AS.

	Design phase calculation results March 2015	**As-built phase calculation results September 2016**
Energy need calculated in SIMIEN with nominal data from NS 3701 (kWh/m^2)		
Administration building	69.9	79.7
Educational building	84.8	98.9
Energy need calculated with nominal data from NS 3701 and geographical placement of Evenstad (kWh/yr)		
Heating need in the administration building	25 087	27 519
Heating need in the educational building	15 251	18 619
Total heating need	40 338	46 138
Electricity need in the administration building	31 322	27 358
Electricity need in the educational building	13 097	12 386
Total electricity need	44 419	39 744
Total energy need	84 757	85 882
Total energy need (kWh/m^2/yr)	74.3	77.4
Energy need as above, however including room (90%) and distribution efficiency (96%), but not the efficiency of the energy central.		
Heating need	46 688	53 400
Electricity need	44 419	39 744
Total energy need	91 107	93 144
Total energy need (kWh/m^2/yr)	79.8	83.9

Of these emissions, 111 193 kgCO$_{2eq}$ or 1.6 kgCO$_{2eq}$/m^2/yr originate from net electricity and heat need in the new administration and educational building. The remainder are emissions from generating electrictiy and heat exported to the grid, in order to compensate for embodied material and construction emissions. Within the ZEB system boundary, the total energy generated by CHP replaces -22.9 kgCO$_{2eq}$/m^2/yr of electricity and heat from the grid and is thus represented by a negative result. In addition, there is an additional -12.3 kgCO$_{2eq}$/m^2/yr of heat produced that sits outside of the ZEB system boundary. It is intended to use this excess heat in other buildings in the ZEN pilot project for Campus Evenstad. Total energy generation is based on an annual operation of 6000 hours, based on the initial operational experiences.

Table 7.3. Summary of emissions from energy use

	Energy kWh/year	**Emission factor kgCO2eq/kWh**	**Operational emissions kgCO$_{2eq}$**	**Operational emissions kgCO$_{2eq}$/m^2/yr**
Total electricity generation CHP	228 000	0.0199	272 180	4.0
Electricity need	39 744	0.0199	47445	0.7
Exported electricity	188 256	- 0.132	-1 490 988	-21.8
Total heat generation CHP	558 000	0.0199	666 124	9.7
Heat need	53 400	0.0199	63 747	0.9
Exported heat included in ZEB	43 676	- 0.0304	-79 768	-1.2
Exported heat outside of ZEB	*460 924*	*- 0.0304*	*-841 816*	*-12.3*
Total emissions from CHP			938 304	13.7
Total exported energy from CHP			- 1 570 755	- 22.9

7.3 Materials

The material phase is responsible for 572 087 kgCO$_{2eq}$ or 8.4 kgCO$_{2eq}$/m^2/yr of total embodied emissions. The results are presented for each building component (Appendix F) and each building material (Appendix G). As seen in Appendix F, the components that drive the highest emissions are the outer roof (18%) followed by the inner walls (14%), lighting (14%), outer walls (12%), floor structure

(12%), CHP unit (10%), groundwork and foundations (9%), superstructure (3%), stairs and balconies (3%), ventilation system (2%), sanitary (1%), heating (1%), and fixed inventory (<1%). As seen in Appendix G, the materials that drive the highest emissions are massive wood (28%), electrical components and cables (14%), CHP unit (10%), concrete, brick and ceramics (9%), steel and aluminum (8%), windows and doors (8%), wood and wood-based products (8%), and mineral wool insulation (7%). This is followed by wood fiber insulation (3%), plasterboard and acoustic panels (2%), polyethylene and laminate (1%), roofing membrane (1%), EPS insulation (1%), gravel and hard core (1%), glass wool insulation (<1%), and ventilation batteries (<1%).

One aspect that has led to higher embodied material emissions, that has not been included in the total embodied emission results, is the consequence of increased energy and material use from water damage experienced on-site. During the spring and summer months, there was an unprecedented amount of precipitation. The rain penetrated the building skin, and it became very difficult to dry out the building envelope and regulate the moisture content of a primarily wooden construction. As a result, 750m^2 of oriented strand board was replaced in the first floor of the educational building, and 2800m^2 of exposed timber surfaces were treated. These two measures have led to an increase of embodied material emissions of 0.05 kgCO$_{2eq}$/m^2/yr and between 0.004 – 0.01 kgCO$_{2eq}$/m^2/yr respectively. These additional emissions could have been avoided if a tent was errected over the construction before the rain occured. The indirect emissions from the temporary tent structure have not been calculated.

To follow is a break down of the embodied material emission results for each building part.

Groundwork and foundations

The groundwork and foundations are responsible for 9% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is a 35% increase in embodied emissions compared to the design phase. Of these emissions, 80% originate from the production phase (A1 – A3), 6% from the construction phase (A4 – A5) and 14% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO$_{2eq}$ emissions is concrete (79%) followed by reinforcement steel (9%), steel shuttering (4%), hardcore gravel (4%), EPS insulation (2%), and vapor proof membrane (2%).

Superstructure

The superstructure is responsible for 3% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is a 17% increase in embodied emissions compared to the design phase. Of these emissions, 92% originate from the production phase (A1 – A3), 8% from the construction phase (A4 – A5) and 0% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO$_{2eq}$ emissions is solid wood and glue laminated timber (53%), followed by steel connectors (42%) and structural pine and copper impregnated timber (4%).

Outer walls

The outer walls are responsible for 12% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is similar to the embodied emissions calculated in the design phase. Of these emissions, 85% originate from the production phase (A1 – A3), 8% from the construction phase (A4 – A5) and 7% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO$_{2eq}$ emissions is solid wood (39%) followed by windows (39%), wood fiber insulation (8%), doors (6%), wind barrier (5%), I-beam (2%), and structural pine (2%).

Inner walls

The inner walls are responsible for 14% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is a 27% increase in embodied emissions compared to the design phase. Of these emissions, 85% originate from the production phase (A1 – A3), 9% from the construction phase (A4 – A5) and 6% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is solid wood (62%) followed by doors (16%), structural pine (15%), plasterboard (3%), glass partitions (2%), acoustic panels (1%), glass wool insulation (1%) and wood fiber insulation (0.3%).

Floor structure

The floor structure is responsible for 12% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is an 82% increase in embodied emissions compared to the design phase. Of these emissions, 86% originate from the production phase (A1 – A3), 11% from the construction phase (A4 – A5) and 3% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is solid wood (69%) followed by oriented strand board (20%), wood fiber insulation (10%), plasterboard (5%), solid wood flooring (3%), gravel (2%), ceramic tiles (0.4%), laminate flooring (0.3%).

Outer roof

The outer roof is responsible for 18% of total embodied material emissions (A1 – A3, A4, A5, and B4). This is an 82% increase in embodied emissions compared to the design phase. Of these emissions, 85% originate from the production phase (A1 – A3), 5% from the construction phase (A4 – A5) and 10% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is solid wood (49%), stone wool insulation (38%), EPS insulation (6%), roof waterproofing membrane (5%), acoustic panels (2%), oriented strand board (1%), and glass wool insulation (0.3%).

Fixed inventory

The fixed inventory is responsible for 0.04% of total embodied material emissions (A1 – A3, A4, A5 and B4). This building part was not previously measured in the design phase. Of these emissions, 89% originate from the production phase (A1 – A3), 6% from the construction phase (A4 – A5) and 5% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is solid wood (95%), followed by timber (5%).

Stairs and balconies

The stairs and balconies are responsible for 3% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is a 60% increase in embodied emissions compared to the design phase. Of these emissions, 85% originate from the production phase (A1 – A3), 5% from the construction phase (A4 – A5) and 10% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is concrete (58%) followed by the lift (36%) and reinforcement steel (6%).

Sanitary

The sanitary installations are responsible for 1% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is a 75% increase in embodied emissions compared to the design phase. Of these emissions, 97% originate from the production phase (A1 – A3), 3% from the construction phase (A4 – A5), and none from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is steel (100%).

Heating

The heating installations are responsible for 1% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is an 84% increase in embodied emissions compared to the design phase. Of these emissions, 47% originate from the production phase (A1 – A3), 1% from the construction phase (A4 – A5), and 52% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is steel (37%) followed by battery (29%), hot water tank (26%), grille (5%), and hot water taps and valves (2%).

Ventilation

The ventilation system is responsible for 2% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is an 86% decrease in embodied emissions compared to the design phase. Of these emissions, 97% originate from the production phase (A1 – A3), 3% from the construction phase (A4 – A5) and none from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is steel (100%).

Lighting

The lighting system is responsible for 14% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is building part was not previously measured in the design phase. Of these emissions, 34% originate from the production phase (A1 – A3), 1% from the construction phase (A4 – A5), and 65% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is LED lights (68%) followed by cables (26%), steel cable trays and floor boxes (3%), aluminum wall channels (2%), and polyethylene pipes (0.4%).

CHP

The combined heat and power unit is responsible for 10% of total embodied material emissions (A1 – A3, A4, A5 and B4). This is building part was not previously measured in the design phase. Of these emissions, 32% originate from the production phase (A1 – A3), 1% from the construction phase (A4 – A5) and 67% from the replacement phase (B4). When considering the production phase (A1 – A3), the largest contributor to CO_{2eq} emissions is the CHP unit (100%).

8. ZEB Balance

The results shown below in Figure 8.1 show the ZEB-COM emission balance for the new administration and educational building at Campus Evenstad. To the left, the total emissions per m^2 per year for each level of the ZEB-COM ambition level are shown; namely, the emissions from construction (C), operation (O), and material use (M) over an estimated building lifetime of 60 years. To the right, the on-site energy generation from the CHP unit is shown, and is divided up into electricity need (light green) and heat need (light turquoise), as well as exported electricity (dark green) and exported heat (dark turquoise) for the administration and educational building. The dotted line indicates the amount of excess heat generation that falls outside of the ZEB-COM system boundary. Other buildings on campus can potentially use this excess heat. The net ZEB-COM emission balance shows that the ZEB-COM ambition level is achieved.

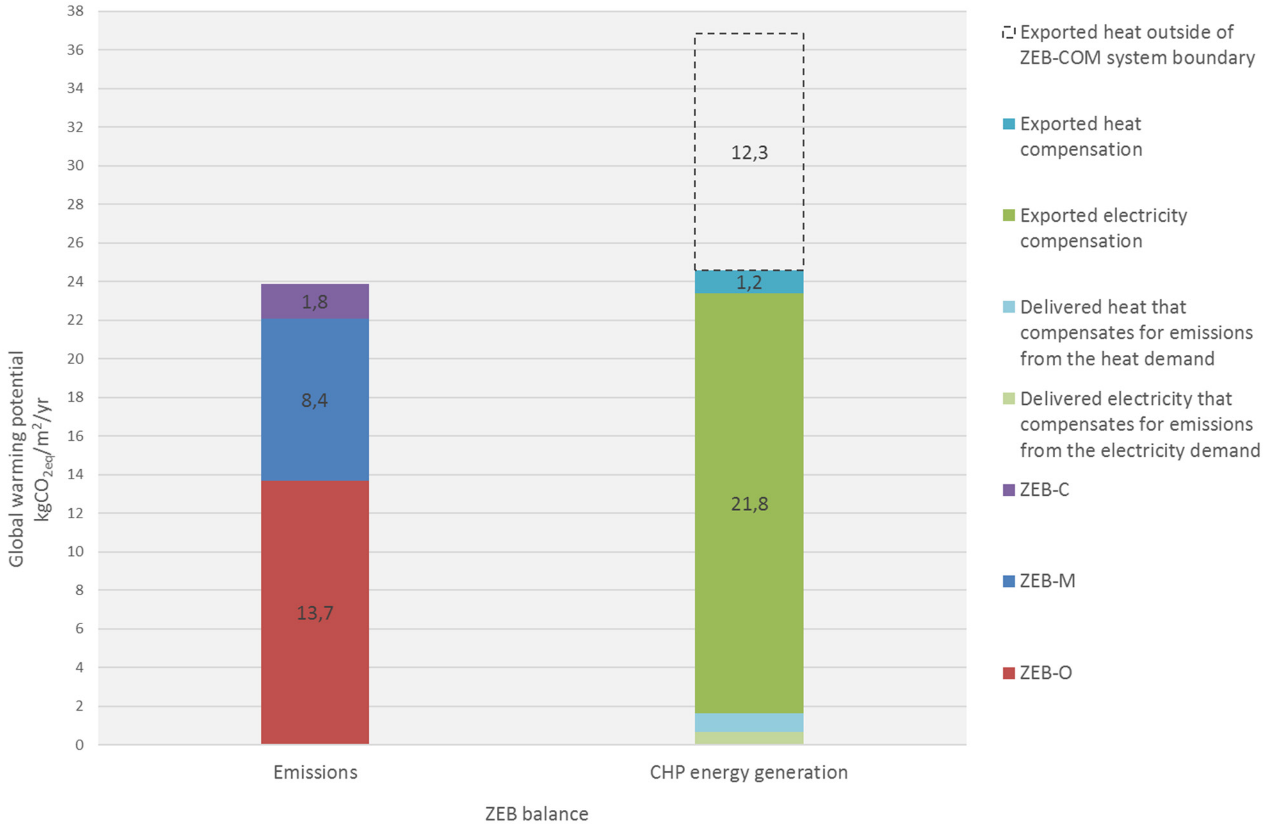

Figure 8.1 ZEB-COM emission balance for the new administration and educational building at Campus Evenstad, based on 6000 CHP annual operation hours. ZEB-O stands for operational energy use emissions, ZEB-M stands for material emissions, ZEB-C stands for construction emissions

However, the ZEB-COM emission balance is sensitive to the annual operation of the CHP unit. In the example above, it has been assumed that the CHP unit is operational for 6000 hours a year.

9. Discussion

This report has set out to document the life cycle greenhouse gas (GHG) emissions of Campus Evenstad administration and educational building at an as-built, ZEB-COM ambition level. It was found that the administration and educational building is responsible for 23.9 $kgCO_{2eq}/m^2/yr$. However, these emissions are compensated for through on-site renewable energy generation from a combined heat and power plant. These results show that the ZEB-COM ambition level has been achieved.

9.1 Construction

This report documents the first Norwegian specific calculations for embodied emissions arising from the construction phase. It also documents actual, specific inventory data from construction activities for embodied construction emission calculations. As a general observation, all embodied construction emissions have increased from the early design to the as-built phase. This is because there was lack of knowledge in the early design phase to estimate accurately embodied construction emissions. The results show that the construction phase (C) is responsible for a larger proportion of total embodied emissions than first anticipated. The results identify diesel use in construction machinery, electricity use, and transport of building materials to the construction site as the largest drivers of embodied construction emissions.

It is interesting to note that embodied emissions from the operational energy use of the administration and educational building at Campus Evenstad (1.6 $kgCO_{2eq}/m^2/yr$) are similar to the total embodied emissions from the construction phase (1.5 $kgCO_{2eq}/m^2/yr$). Traditionally, construction phase (C) emissions are not given the same attention as operational phase (O) emissions. However, the significance of construction phase emissions becomes clear when one considers that the construction phase emissions for the administration and educational building at Campus Evenstad occured during one year (2015/2016), while the operation phase emissions take place over the 60-year lifetime of the building. The results from this report highlight that embodied emissions from the construction phase may easily be underestimated and should be given more attention in the future.

It was also observed that most emissions from construction machinery originate from groundwork and foundation construction activities. This is demonstrated through the construction emissions arising from the operation of crawler excavators for digging out trenches, casting concrete foundations in-situ with the help of a tower crane, and from the heat aggregate used for thawing the ground during wintertime. Originally, the groundwork and foundations were planned to be built during the summer months, whereby some of the emissions from the thawing of ground and curing of concrete could have been avoided. However, because of a delayed project start, most groundwork and foundation activities took place during the winter months. It is therefore recommended that groundwork and foundation construction activities be designed in such a way as to streamline the installation of groundwork and foundations to minimize embodied emissions arising from these activities.

9.2 Operation

This report documents the calculated net energy need and on-site, renewable energy generation for the administration and educational building at Campus Evenstad. Compared to the other ZEB pilot studies it provides an alternative energy generation solution to photovoltaic panels, through a combined heat and power plant. The results show the emissions from the operational energy use of the building are 1.6 $kgCO_{2eq}/m^2/yr$. However, it is of interest to compare this result with the actual energy performance of the building when operational. The FME research center for zero emission neighborhoods in smart cities (ZEN) will provide an opportunity for this follow up and will allow for the monitoring and comparison of annual energy profiles.

9.3 Materials

This report documents the embodied emissions from material use in the administration and educational building at Campus Evenstad. This has been achieved by upgrading the BIM material inventory to specific material quantities obtained from the contractor and sub-contractors. This has been combined with product specific emission factors from environmental product declarations. Generic European emission factors have been used for the 5.5% of data not covered by specific EPD emission factors. From the results, it is possible to identify that the building envelope contributes the most to embodied material emissions. However, it is also observed that the material inventory for building services and energy generation is not as detailed. The outer roof, followed by the inner walls, contribute the most to embodied material emissions, whereby solid wood is the largest material contributor. This is to be expected considering that the administration and educational building is of a primarily wooden construction. It is also observed that there is a general increase in embodied material emissions from the early design phase to the as-built phase for most building parts. This is mainly due to a more detailed material inventory. Most embodied material emissions also come from the generation phase, which implies a focus on either low maintenance or long durability and longevity of building materials.

When considering the groundwork and foundations, previous studies have shown that strip foundations use less concrete than traditional raft foundations, which in turn leads to lower embodied CO_{2eq} emissions [33, 34]. For that reason, it was decided to use strip foundations for the administration and educational building at Campus Evenstad. However, the new administration and educational building at Campus Evenstad is located close to the river Glomma. Thus, it was necessary to raise the foundations to protect the building from any potential flooding within the next 200 years. Since this strip foundation raise took place before excavation works started, it was also decided to dig out the whole construction pit, to a depth of 2m below terrain, instead of just digging strips for the foundations. This decision has essentially led to an increase in construction machinery usage and an increase in the amount of materials used (i.e. hard core, concrete and steel), which has in turn led to increased emissions.

Another aspect that has affected the embodied emission calculations is the use of low carbon concrete in the foundations. Low carbon concrete typically has lower CO_{2eq} emissions compared to traditional concrete. However, concrete casting began in mid-February, and to achieve the required strength, the ground and concrete had to be heated and cured with a diesel aggregate, which has in turn led to increased embodied emissions. This measure could have been avoided if concrete casting took place in the summer months. Another option could have involved investigating alternative heating options based on renewable energies. Biofuel was investigated at an early design phase, but was later dismissed because of skepticism concerning the palm oil content of biofuels.

10. Conclusion

This report has documented the life cycle greenhouse gas (GHG) emissions of Campus Evenstad administration and educational building at an as-built, ZEB-COM ambition level. It was found that the administration and educational building is responsible for 23.9 $kgCO_{2eq}/m^2/yr$. However, these emissions are compensated for through on-site renewable energy generation from a combined heat and power plant. These results show that the ZEB-COM ambition level has been achieved.

It has been decided that Campus Evenstad will continue as a pilot project in the new FME research center on zero emission neighborhoods in smart cities (ZEN). ZEN aims to enable the transition to a low carbon society by developing sustainable neighborhoods with zero greenhouse emissions. In ZEN, it will be of interest to see how the various local energy sources at Campus Evenstad work together; from solar thermal collectors on the roof of the dormitories (heat), the photovoltaic system on the roof of the old barn (electricity), and the CHP plant (electricity and heat) through the gasification of wood chips. Campus Evenstad is also connected to the electricity grid, for both import and export of electricity. The various building's energy need profiles (daily, weekly, and annually) will be an important parameter for assessment.

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APPENDICES

Appendix A. Photographs from the construction process.
Appendix B. Material emissions from the design phase
Appendix C. EPD criteria checklist
Appendix D. Photographs of the construction machinery found on site
Appendix E. Summary of person transport to and from the construction site at Campus Evenstad
Appendix F. Total embodied material emissions of the administration and educational building – Building part
Appendix G. Total embodied material emissions of the administrtion and educational building – Material type

Appendix A. Photographs from the construction process.

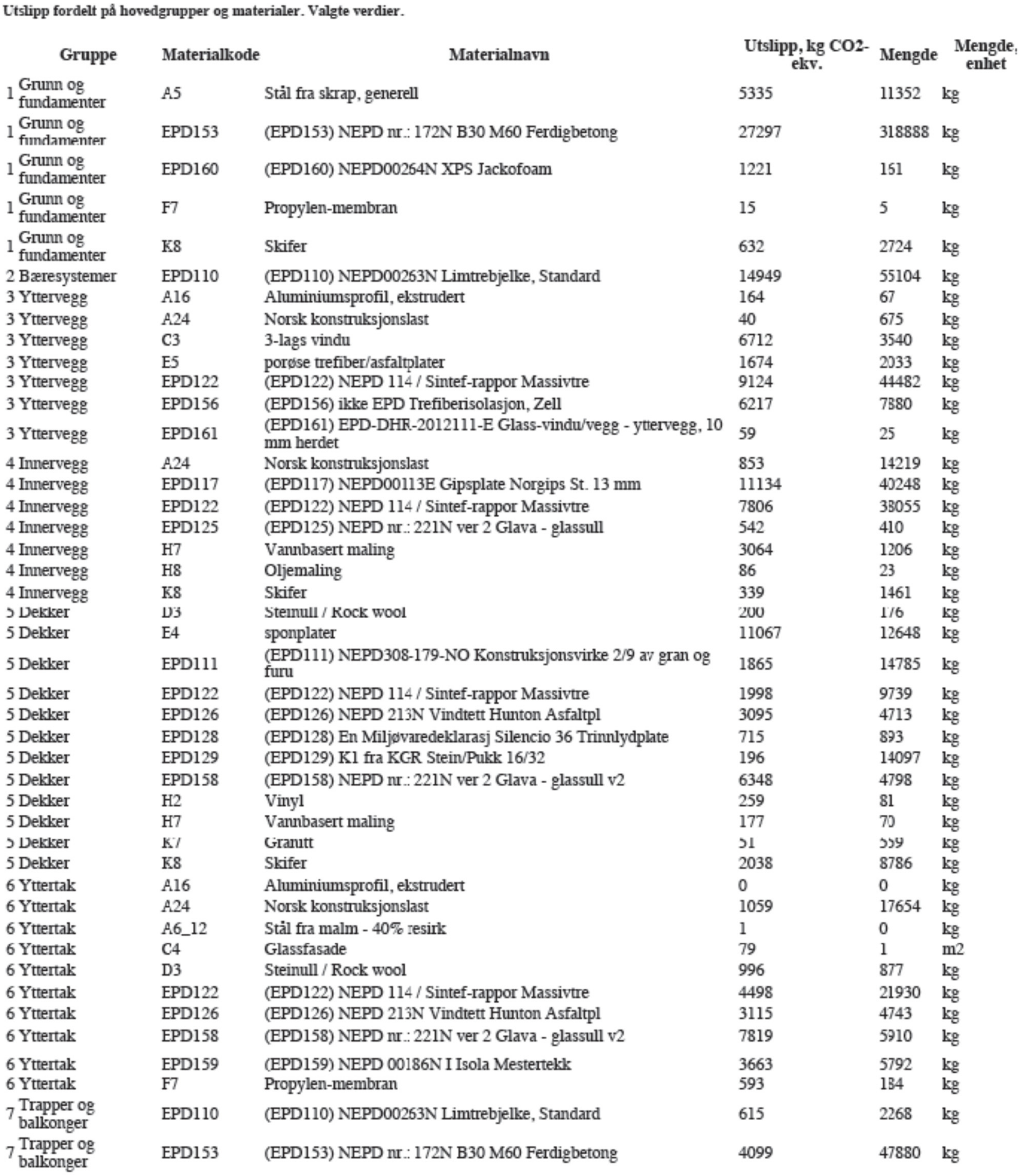









Appendix B. Material emissions from the design phase



Utslipp fordelt på hovedgrupper og materialer. Valgte verdier.

Gruppe	Materialkode	Materialnavn	Utslipp, kg CO2-ekv.	Mengde	Mengde, enhet
1 Grunn og fundamenter	A5	Stål fra skrap, generell	5335	11352	kg
1 Grunn og fundamenter	EPD153	(EPD153) NEPD nr.: 172N B30 M60 Ferdigbetong	27297	318888	kg
1 Grunn og fundamenter	EPD160	(EPD160) NEPD00264N XPS Jackofoam	1221	161	kg
1 Grunn og fundamenter	F7	Propylen-membran	15	5	kg
1 Grunn og fundamenter	K8	Skifer	632	2724	kg
2 Bæresystemer	EPD110	(EPD110) NEPD00263N Limtrebjelke, Standard	14949	55104	kg
3 Yttervegg	A16	Aluminiumsprofil, ekstrudert	164	67	kg
3 Yttervegg	A24	Norsk konstruksjonslast	40	675	kg
3 Yttervegg	C3	3-lags vindu	6712	3540	kg
3 Yttervegg	E5	porøse trefiber/asfaltplater	1674	2033	kg
3 Yttervegg	EPD122	(EPD122) NEPD 114 / Sintef-rappor Massivtre	9124	44482	kg
3 Yttervegg	EPD156	(EPD156) ikke EPD Trefiberisolasjon, Zell	6217	7880	kg
3 Yttervegg	EPD161	(EPD161) EPD-DHR-2012111-E Glass-vindu/vegg - yttervegg, 10 mm herdet	59	25	kg
4 Innervegg	A24	Norsk konstruksjonslast	853	14219	kg
4 Innervegg	EPD117	(EPD117) NEPD00113E Gipsplate Norgips St. 13 mm	11134	40248	kg
4 Innervegg	EPD122	(EPD122) NEPD 114 / Sintef-rappor Massivtre	7806	38055	kg
4 Innervegg	EPD125	(EPD125) NEPD nr.: 221N ver 2 Glava - glassull	542	410	kg
4 Innervegg	H7	Vannbasert maling	3064	1206	kg
4 Innervegg	H8	Oljemaling	86	23	kg
4 Innervegg	K8	Skifer	339	1461	kg
5 Dekker	D3	Steinull / Rock wool	200	176	kg
5 Dekker	E4	sponplater	11067	12648	kg
5 Dekker	EPD111	(EPD111) NEPD308-179-NO Konstruksjonsvirke 2/9 av gran og furu	1865	14785	kg
5 Dekker	EPD122	(EPD122) NEPD 114 / Sintef-rappor Massivtre	1998	9739	kg
5 Dekker	EPD126	(EPD126) NEPD 213N Vindtett Hunton Asfaltpl	3095	4713	kg
5 Dekker	EPD128	(EPD128) En Miljøvaredeklarasj Silencio 36 Trinnlydplate	715	893	kg
5 Dekker	EPD129	(EPD129) K1 fra KGR Stein/Pukk 16/32	196	14097	kg
5 Dekker	EPD158	(EPD158) NEPD nr.: 221N ver 2 Glava - glassull v2	6348	4798	kg
5 Dekker	H2	Vinyl	259	81	kg
5 Dekker	H7	Vannbasert maling	177	70	kg
5 Dekker	K7	Granitt	51	559	kg
5 Dekker	K8	Skifer	2038	8786	kg
6 Yttertak	A16	Aluminiumsprofil, ekstrudert	0	0	kg
6 Yttertak	A24	Norsk konstruksjonslast	1059	17654	kg
6 Yttertak	A6_12	Stål fra malm - 40% resirk	1	0	kg
6 Yttertak	C4	Glassfasade	79	1	m2
6 Yttertak	D3	Steinull / Rock wool	996	877	kg
6 Yttertak	EPD122	(EPD122) NEPD 114 / Sintef-rappor Massivtre	4498	21930	kg
6 Yttertak	EPD126	(EPD126) NEPD 213N Vindtett Hunton Asfaltpl	3115	4743	kg
6 Yttertak	EPD158	(EPD158) NEPD nr.: 221N ver 2 Glava - glassull v2	7819	5910	kg
6 Yttertak	EPD159	(EPD159) NEPD 00186N I Isola Mestertekk	3663	5792	kg
6 Yttertak	F7	Propylen-membran	593	184	kg
7 Trapper og balkonger	EPD110	(EPD110) NEPD00263N Limtrebjelke, Standard	615	2268	kg
7 Trapper og balkonger	EPD153	(EPD153) NEPD nr.: 172N B30 M60 Ferdigbetong	4099	47880	kg

Appendix C. EPD criteria checklist

Table C.1 EPD Criteria checklist filled out for the EPDs collected by the building contractor for the new administration and educational building.

[a] The EPD is produced via an EPD generator approved by the programme operator.

[b] The EPD was published before EN 15804, but is still valid.

[c] The EPD does not refer to ISO 21930. However, this was deemed ok as these were European EPDs that meet European requirements.

[d] The EPD expired in May 2016. However, since construction at Campus Evenstad began in early 2016 the EPD is deemed valid for the construction period.

Table C.2 Summary of EPDs collected by the building contractor for the new administration and educational building at Campus Evenstad.

EPD no.	Producer: product	Validity
1	Betong Øst concrete. NEPD no. 123N	VALID
2	Gyproc Plasterboard. NEPD no. 223	VALID
3	UPM-Kymmene Wood Oy kryssfiner	NOT VALID
4	Hunton Silencio 36, 2002	NOT VALID
5	Glava glass wool insulation. NEPD no. 221N ver2.1	VALID
6	Treindustrien construction timber. NEPD no.308-179-NO	VALID
7	Moelven copper impregnated timber. NEPD no.472-330-NO	VALID
8	Hunton underlay, NEPD no. 214N	VALID
9	Moelven glue laminated beam. NEPD no.336-222-NO	VALID
10	Isola Mestertekk roofing system. NEPD no.00186N	VALID
11	NorDan NTech fixed window 105/80	VALID
12	Paroc Insulation. NEPD no.00267E	VALID

Appendix D. Photographs of the construction machinery found on site


Caterpillar 312E Crawler Excavator


Caterpillar 307D Crawler Excavator


Caterpillar 324 Crawler Excavator


Moxy MT31 Dumpertruck

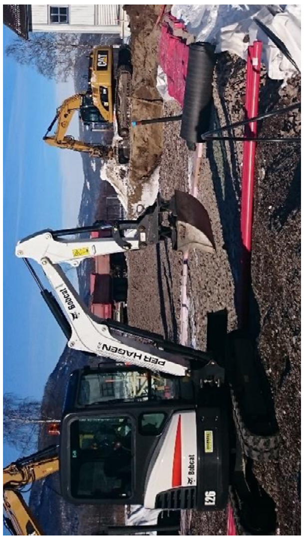

Tractor: Fendt vario 716


Telescopic lift


Vibroplate: Atlas Copco 800

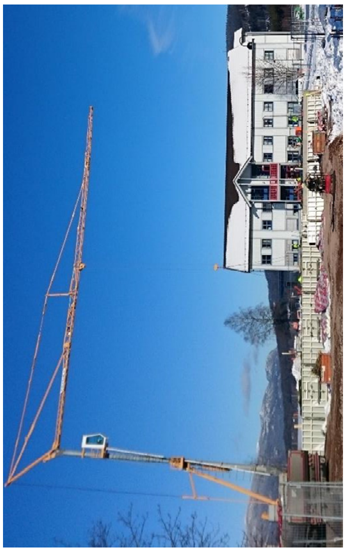

Vibroplate: Atlas Copco 250


Vibroplate: Bell 75



Bobcat Digger E26

Doosan dx140W Excavator [35]



Potain Igo50 Towercrane

Remko heat aggregate CLK 120

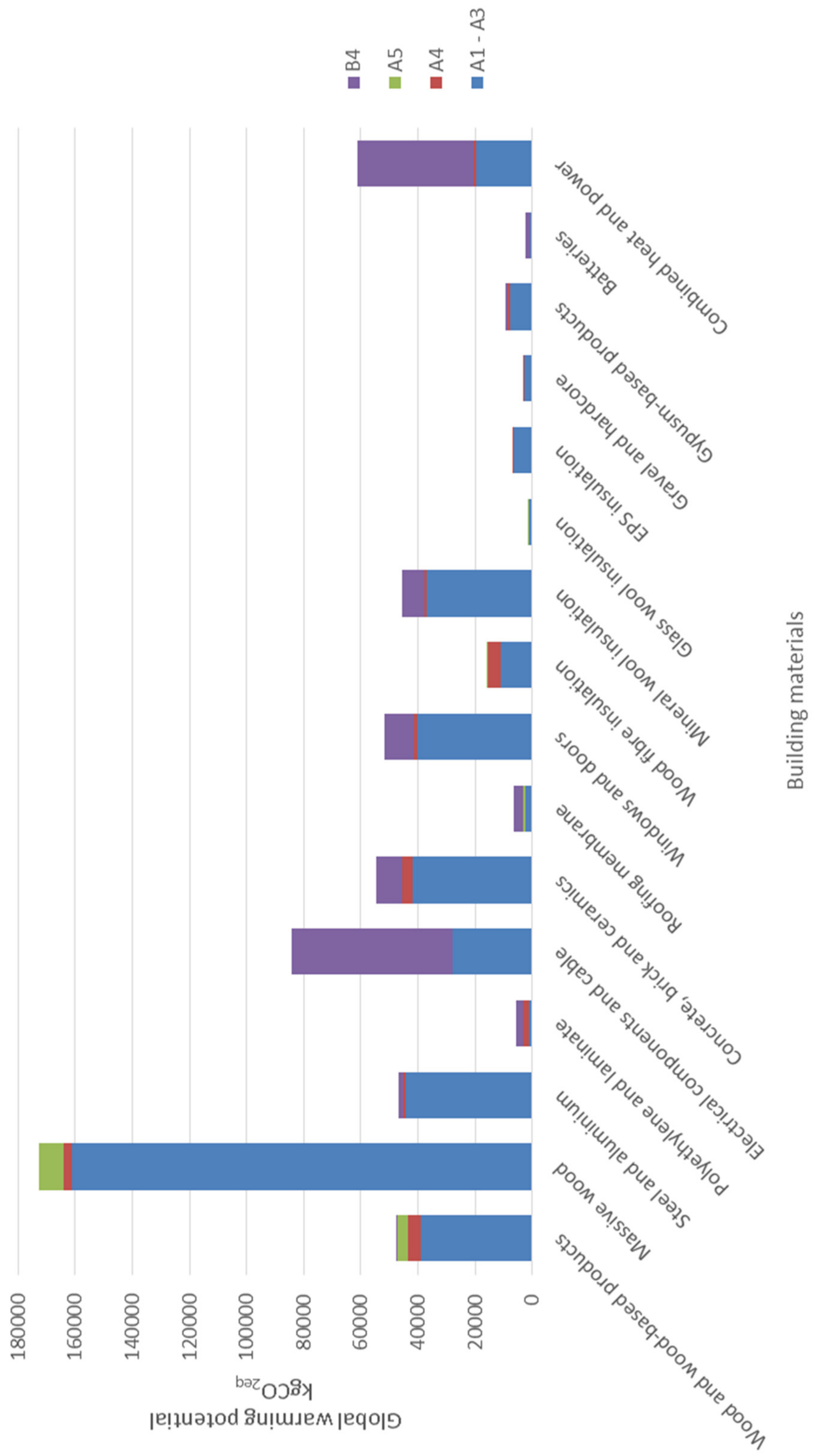
NB: The photographs may not be exact matches to the make and model listed, but instead provide a visual representation of the construction machinery used.

Appendix E. Summary of person transport to and from the construction site at Campus Evenstad

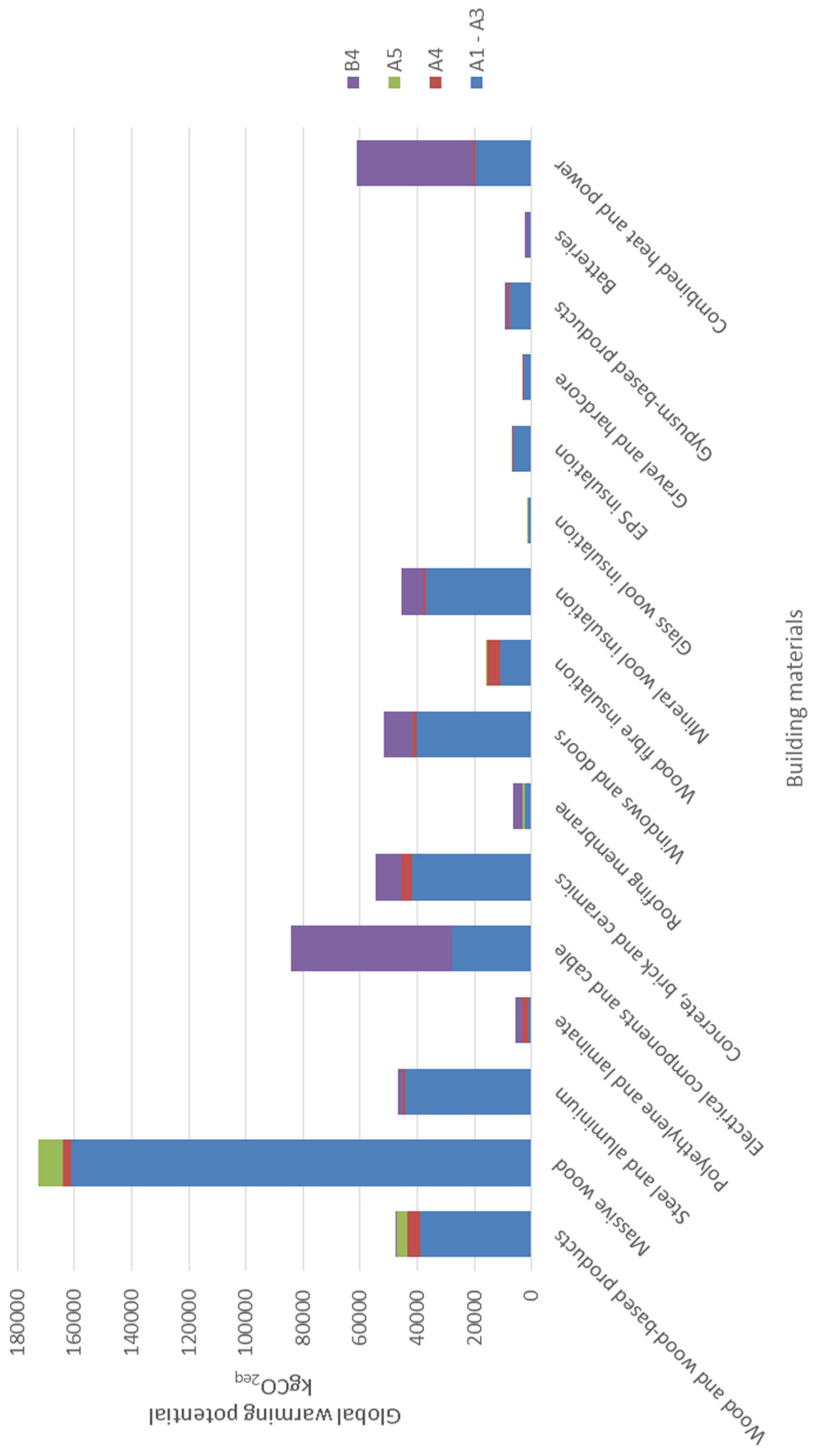
Amount of trips	Amount of people	Distance (km)	% speed under 50km/h	% speed over 50km/h
2	1	100	2	98
8	2	100	2	98
20	4	50	2	98
24	5	50	2	98
4	2	100	2	98
40	40	50	2	98
2	1	70	1	99
4	2	100	2	98
40	40	50	2	98
16	2	86	2	98
28	31	50	2	98
2	1	70	1	99
14	2	69	2	98
22	28	50	2	98
2	2	70	1	99
18	2	69	2	98
10	4	50	2	98
20	2	72	2	98
6	4	50	2	98
22	2	72	2	98
4	2	110	2	98
28	2	69	2	98
8	3	50	2	98
20	2	69	2	98
20	2	69	2	98
18	2	73	2	98
14	2	60	2	98
4	2	50	2	98
14	2	60	2	98
2	1	70	1	99
14	2	60	2	98
4	1	70	1	99
14	2	77	2	98
6	2	50	2	98
4	2	50	2	98
4	2	336	30	70
6	2	19	60	40
18	2	73	2	98
8	1	70	1	99
14	2	60	2	98
8	1	70	1	99
12	2	60	2	98
18	2	75	2	98
18	2	75	2	98
4	2	70	1	99
16	2	72	2	98
8	2	70	1	99
18	2	75	2	98
4	2	50	2	98

Amount of trips	**Amount of people**	**Distance (km)**	**% speed under 50km/h**	**% speed over 50km/h**
18	2	75	2	98
4	1	70	1	99
6	2	100	2	98
18	2	50	2	98
8	2	70	1	99
2	1	70	1	99
8	2	70	1	99
18	3	70	1	99
24	4	70	1	99
20	4	70	1	99
30	4	70	1	99
32	5	70	1	99
36	5	70	1	99
46	6	70	1	99
63	2	90	2	98
72	2	90	2	98
74	2	90	2	98
74	2	90	2	98
46	7	70	1	99
30	6	70	1	99
20	5	70	1	99
8	2	70	1	99
14	2	50	2	98
6	6	230	20	70

Appendix F. Total embodied material emissions of the administration and educational building – Building part



Appendix G. Total embodied material emissions of the administrtion and educational building – Material type



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.

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