ZEB Project report 17 – 2014

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The Research Centre on
Zero Emission Buildings

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Abstract

This report deals with how to define what a Zero Emission Building (ZEB) is with explanation and analysis of different parameters related to embodied emissions of CO_2 equivalents. The report can be used as a guidance tool on how to assess embodied emissions, and also on what parameters should be evaluated in such an assessment.

Different ambition levels for ZEBs may include life stages, operation, material, construction and end-of-life and can be documented according to EN 15978. Calculation procedures should include system boundaries, embodied emissions from materials, transport, the construction process and waste handling according to the ambition level. $CO_{2\,eq}$ emissions factors, service life estimates and payback scenarios for CO_2 emissions need to be considered.

The report does not contain one single clearly defined method, but rather a state-of-the-art summary on the different issues and refers to other relevant national and international work in the field of ZEB definitions. The issues presented here are in early stages of development and will need to be verified and further developed.

Contents

APPENDICES

1. Introduction

The objective of the Norwegian Research Centre on Zero Emission Buildings (the ZEB Centre) is to develop materials and solutions for new and existing buildings resulting in zero greenhouse gas (GHG) emissions over the lifetime of the assets.

The ZEB Centre's research is limited to looking at solutions defined within a system boundary given by the building and the building site. The Centre focuses on residential and office buildings as well as school buildings. A ZEB is a highly energy-efficient building where on-site renewable energy production compensates for CO_2 emissions from the building.

Figure 1.1 from the EeBGuide (Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative) presents the primary energy use related to different life stages of buildings (Wittstock et al., 2011). For new energy-efficient buildings, such as a ZEB, the production and end-of-life phase can constitute around half of the primary energy use over the lifetime of the building. This means that the embodied emissions in materials make up a large percentage of the overall load from the building over its lifetime.

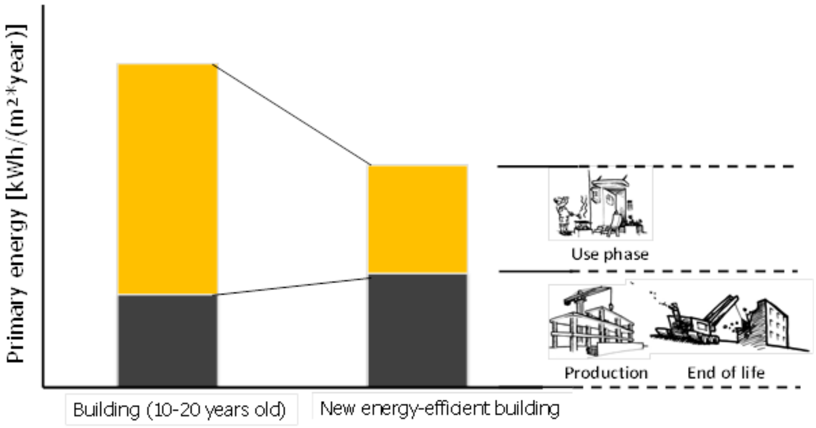

Figure 1.1 Primary energy related to life stages of a building

This report deals with how to define what a ZEB is with explanations and analysis of different parameters related to embodied CO_2 emissions. The report can be used as a guidance tool on how to assess embodied emissions and also on what parameters should be evaluated in such an assessment. The report does not contain one single clearly defined method, but rather a state-of-the-art summary on the different issues and refers to other relevant national and international work in the field of ZEB definitions.

The report does not attempt to answer all of the complex aspects of a ZEB, but rather to present current practice. The method suggested in the report will also be used to verify the design and performance of demonstration buildings within the research Centre.

The report presents results from interdisciplinary cooperation between researchers within the ZEB Centre and the ZEB partners, Statsbygg (Civitas) and Skanska AS. The group of interdisciplinary researchers and experts had several working meetings from March 2013 to October 2013. The report documents the conclusions from the discussions in the group as well as research and literature reviews done by the group members.

2. ZEB definition

The most common ZEB definition has evolved around the topic of energy use in the operational phase of a building over a period of one year (Sartori et al., 2012); thus, ZEB mostly refers to zero "energy" buildings using the weighting factors of primary energy.

The Norwegian work on a ZEB definition builds on previous and current work by the International Energy Agency (IEA) and the recast Energy Performance Building Directive (EPBD).[1]

The EPBD defines a nearly-ZEB as "*a building where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site*".

REHVA (Federation of European Heating, Ventilation and Air-conditioning Associations) has made a proposal for a uniformed national implementation of the EPBD recast:" How to define nearly net zero energy buildings nZEB" (Kurnitski et. al.,2011).

Marzal et al., (2011) give a review of definitions and calculation methodologies for ZEBs, revealing that many different approaches are still being used and that there has been limited inclusion of the aspects of embodied energy/emissions.

Hernandez and Kenny (2010) introduce the concept of life cycle ZEBs including the concepts of annualized initial embodied energy and annualized recurring embodied energy.

The paper by Dokka et al. (2013a) presents the ZEB Centre's procedures on how a ZEB should be calculated and documented in Norway. It also goes on to detail different ambition levels for Norwegian ZEBs.

Task 40 in IEA's Solar Heating and Cooling Program looked at the topic of net zero energy solar buildings. Perspectives from the work are given in the book on Net Zero Energy Buildings by Voss and Musall (2012).

Another IEA project, Annex 57 in IEA's Energy in Buildings and Communities Program[2], is currently looking at the evaluation of embodied energy and carbon dioxide emissions for building construction. The work started in 2011 and will finish in 2015. The conclusions and recommendations from this annex will provide important inputs into the calculations of embodied emissions in buildings.

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[1] European Parliament and the Council. 2010. Directive 2010/31/EU of The European Parliament and the Council of 19 May 2010 on the Energy Performance of Buildings. Official Journal of the European Union.

[2] http://www.ecbcs.org/annexes/.

3. Definition of embodied emissions (energy)

From the literature, the term “embodied energy” is more widely used than the term “embodied emissions”.

The term “embodied” can be confusing when used in relation to embodied emissions in buildings. The term does not refer to the carbon that is stored in the building material itself but rather to the emissions of greenhouse gases released into the atmosphere during the production of the materials.

According to Berge (2009), the “embodied energy” of a product means all the primary energy resources used to manufacture the product, from mining or harvesting the materials to finishing the product at the factory gate. This also includes energy use for packaging, transport and the combustion value of the raw materials themselves, often called the feedstock (Berge, 2009).

Looking at the embodied emissions, the emissions are both due to emissions of CO_2 eq (equivalents) from the use of energy as well as emissions from non-energy-related processes. For example, the embodied emissions for cement are not only related to the emissions from the energy combusted during the production, but also due to the calcination of limestone. According to Pade and Guimareas (2007) more than 50% of the CO_2 emitted during cement production originates from the calcination of limestone. These emissions are included in the embodied emissions for cement-based materials.

According to Ramesh et al., (2010), the term “embodied energy” for a building is the energy that goes into the production of the materials used in the building and into the construction process itself. In other words, that is the energy that goes into the initial raw material extraction, transport and production of the building materials, the construction energy and also the energy that goes into the materials used for replacements and upgrades throughout the lifetime of the building.

4. Ambition levels

The four different ambition levels previously presented by Dokka et al. (2013a) are defined as:

1. ZEB-O÷EQ: Emissions related to all energy use in operation (O) except energy use for equipment/appliances (EQ) shall be compensated with on-site renewable energy generation. Energy use for equipment is often regarded as the most user-dependent and most difficult to design for low energy use.
2. ZEB-O: Emissions related to all operational energy (O) shall be compensated for with on-site renewable energy generation as well as energy use for equipment.
3. ZEB-OM: Emissions related to all operational energy (O) use plus embodied emissions from the materials (M) and technical installations shall be compensated for with on-site renewable energy generation.
4. ZEB-COM: The same as ZEB-OM, but also taking into account emissions related to the construction (C) process of the building.

The expansion of the ZEB ambition level is based to a large extent on the standard *EN15978 (2011) Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method***.** The current defined ambition levels including emissions related to materials are also referred to this standard. In Table 4.1, the different life cycle stages are presented according to EN15978 (2011).

Table 4.1 The different stages of the life cycle of a building, defined by EN15978 (2011)

A1–3			**A4–5**		**B1-5**					**C1–4**				**Supplementary information beyond the building life cycle. D**
PRODUCT STAGE			**CONSTRUCTION**		**USE STAGE**					**END-OF-LIFE**				**Benefits and loads beyond the system boundary**
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
Raw material supply	**Transport**	**Manufacturing**	**Transport**	**Construction installation process**	**Use (B6 operational energy use and B7 operational water use)**	**Maintenance**	**Repair**	**Replacement**	**Refurbishment**	**Deconstruction demolition**	**Transport**	**Waste processing**	**Disposal**	**Reuse-Recovery-Recycling potential**

In the standard, the different life cycle stages of a building are divided into four main phases:

- Product stage (A)
- Use stage (B)
- End-of-life stage (C)
- Benefits and loads beyond the system boundary (D)

The standard *EN15804 (2012) Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products* is relevant for the product stage (A) of the building.

In the current definition, the "M" in the ambition levels presented in Dokka et al. (2013a) for ZEB-OM and ZEB-COM refers to embodied emissions from materials, without stating in more detail what these are. It is suggested that the EN15978 (2011) standard is used to clarify what the "M" in the ZEB-OM should refer to. The "M" should imply compensating for emissions related to the product phase of materials, A1–A3, and the product phase for scenarios for the replacement phase, B4. Further, it is suggested that the ambition level ZEB-COM includes the same phases as ZEB-OM, in addition to the emissions from the construction process where both A4, transport to building site, and A5, construction installation processes, are included and need to be compensated for. The level ZEB-COME should include the same as level ZEB-COM, in addition to scenarios for the end-of-life phases, C1-C4. The highest ambition level, ZEB-COMPLETE, should be based on an emission analysis that includes all the phases: A1–A5, B1–B6 and C1–C4, with scenarios for B2, B3 and B5 on maintenance, repair and refurbishment.

The following expansions are suggested:

1. ZEB-COME: Same as ZEB-COM though emissions related to a scenario for the end-of-life phase "E" have to be included and compensated for (phases A1-A5, B4, B6, C1, C2,C3 and C4 from the standard EN15978 (2011)).
2. ZEB-COMPLETE: Emissions related to a complete life cycle emission analysis have to be compensated for, namely all the phases, A1–A5, B1–B5, as well as B6- operational energy use and C1–C4, from the standard.

Note that the ZEB ambition levels refer to the first letter in the actual name of the phase included, where "C" is used for implying emissions due to the **C**onstruction phase and "E" is emissions for the **E**nd-of-life phase.

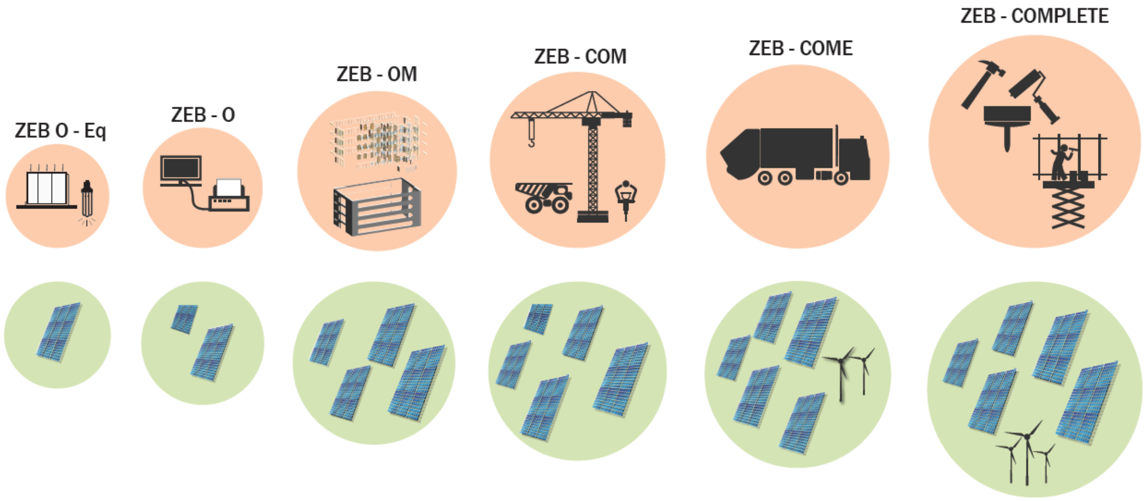

Figure 4.1 Illustration of the different levels with increased inclusion of life cycle phases and increased production of renewable energy on site

Figure 4.1 presents an attempt to visually describe the ambition levels. The green circles, below on the Figure, illustrate on-site renewable energy production and the red circles above illustrate different emission loads that need to be compensated for.

Even though phase “D” is not included in the ambition levels for compensation at this stage, information on the possible benefits of recycling, reuse and energy recovery are relevant when choosing appropriate materials in the product stage. Information connected to this phase for the main materials used should be calculated and included in the emissions analysis report to facilitate material choices based on holistic information.

Further, the “M” in ambition level ZEB-OM, ZEB-COM and ZEB-COME refers to the emissions related to all the building construction materials, such as the foundation, load-bearing systems, outer and inner walls, façade systems, windows and doors, flooring systems, stairs and technical units (such as electrical cabling, ventilation and heating systems and energy-producing units). Materials used for interior furnishings like wardrobe closets or kitchen cabinets do not have to be included, nor do water sewage and lighting systems. Table 4.2 provides a list of suggested inclusion of building components and materials in “M” for ambition levels ZEB-OM, ZEB-COM and ZEB-COME adapted from a simplified Life Cycle Assessment (LCA) analysis developed by the EeBGuide.eu. A ZEB-COMPLETE should however be based on the suggested inclusion from the EeBGuide.eu for a complete LCA (Wittstock et al., 2011).

Table 4.2 Suggested inclusion of building components and materials in “M” for ambition levels ZEB-OM, ZEB-COM and ZEB-COME adapted from the template for simplified LCA from EeBGuide.eu (Wittstock et al., 2011)

Inclusion of materials and construction parts	
Foundation	Windows and façade systems
Load-bearing structure	Decorative wall finishes/coatings
Roof	Doors: inner and outer
Floor slabs	Heating/cooling equipment
Surface finishes	Equipment for internal transport (elevator)
Coverings	Power-generating equipment
Walls: inner – outer	Electrical distribution systems
Ceiling's	

5. Procedures for calculation

This section focuses on clarifying the calculation methods currently being applied in the ZEB Centre. The section also documents the topics and reflections addressed by the working group.

5.1 Functional unit

When calculating life cycle emissions for a building, the first step is to define the goal and scope, as well as defining a suitable functional unit. The current approach within the ZEB Centre has been to analyse emissions for 1 m^2 of the heated floor area over a service lifetime of 60 years as the functional unit when analysing whole buildings.

When relating the emissions to the metric of one square metre, there is a risk of promoting solutions that are sub-optimized with regard to sustainability. The background for this functional unit is the commonly used metric for reporting energy use measured in kWh/m^2 of the heated floor area.

The primary objective for developing a ZEB is to mitigate climate change and at the same time provide the normal services required of a building. But is there a risk of promoting unsustainable solutions while focusing exclusively on one square metre? Occupants drive energy demand and thereby emissions. Increased occupancy per square metre increases emissions. By focusing only on one square metre, one can start to sub-optimize and reduce the number of occupants per square metre in order to minimize energy use and emissions. Large buildings with few occupants can be encouraged instead of smaller buildings with more occupants.

Energy per occupant is recognised as a complementary indicator to energy efficiency (Green Power Alliance, 2010). Measuring energy and emissions per occupant may provide a comprehensive picture of energy efficiency and emissions efficiency of buildings (KRD, 2010a). Switzerland's use of the Swiss 2000W society initiative puts people at the centre of energy-efficiency assessment (Marechal et al., 2005; 2000 Watt Society, 2013). The object of the 2000W society is to supply, with less energy, the energy services required by the population. The "people-centred" approach where the energy demand is normalized by the number of individuals makes people directly responsible for their actions, inciting them to adopt environmentally sound behaviours.

Currently it is recommended that the results from emission analysis for ZEB include both the emissions allocated per square meter per year of the estimated service life of 60 years and per user per year as well when possible.

It is further recommended that future work will include defining suitable functional units for the different construction parts and technical equipment used in buildings. This can able more detailed analysis of the different components, systems and construction parts that constitute a whole building.

5.2 System boundaries

The ILCD (The International Reference *Life Cycle* Data System) Handbook (2010) states: "*The system boundaries define which parts of the life cycle and which processes belong to the analysed system, i.e. are required for providing its function as defined by its functional unit. They hence separate the analysed system from the rest of the technosphere.*"

In the ZEB Centre the physical boundaries are defined as the building itself at the building site. This implies that only materials that are actually used in the building should be included in the emission analysis. Materials used for the technical installations are also only considered when included within the physical building boundaries. Electrical transmission lines outside the building are not included and neither are district heating systems that are outside the building. Components that are outside of the building but within the borders of the building site and that are a part of the on-site energy production should be included, such as photovoltaic panels and supplementary equipment.

With respect to life cycle boundaries, the specific emissions analysis is dependent on the ZEB ambition level defined in section 4. The life cycle boundaries of a ZEB-COME are different from the life cycle boundaries for a ZEB-OM. The ambition level and system boundaries according to EN15978 (2011) should be stated in the embodied emissions analysis.

5.3 Emission data for materials (life cycle inventory)

Finding reliable environmental data can pose a great challenge when performing emissions analysis concerning the use of materials. Houlihan Wiberg and Hestnes (2011) have emphasized the need for a transparent and robust calculation method for ZEBs.

The current status in Norway is that there is a continuously increasing availability of Environmental Product Declarations (EPDs) for building materials and components. However, for EPDs the background life cycle analysis report is not always openly accessible as it is owned by the commissioner of the study, who is usually the producer of the product or service. This can make it difficult to gain transparent information on the methodology applied for the EPD.

Statsbygg, a public sector administration company responsible to the Norwegian Ministry of Local Government and Modernisation (KMD) and a partner in the ZEB Centre, has developed version 4 of a GHG accounting tool called Klimagassregnskap (Selvig, 2012). The tool, www.klimagassregnskap.no, which is open access, can assist in early decision-making, enabling the development of buildings with reduced carbon footprints.

The Swiss-based European database, Ecoinvent, is widely used for life cycle inventory analysis in Europe. The methodology used in the inventories for Ecoinvent is presented in Frischknecht, et al., (2007). Version 3.0 is the latest Ecoinvent version, which was released in the spring of 2013. Version 2.2 of the Ecoinvent database (2010) was used in two recent ZEB concept studies on an office building and residential building presented in Dokka et al., (2013b) and Dokka et al., (2013c). The reason for choosing the Ecoinvent database was that the methodology used in the Ecoinvent processes is accessible, consistent and transparent.

The ideal situation for calculating embodied emissions for ZEBs would be an extensive operational database for all construction materials and technical system components used in Norway: a database based on consistent and robust methodological approaches for all of the different inputs.

As this database for calculations does not currently exist, the current embodied emissions calculations are based on the assumed best currently available environmental data. These data might include specific information from producers, EPDs, generic databases, scientific articles or available facts and statistics.

As emphasized by Houlihan Wiberg and Hestnes (2011), one of the most important aspects of having credible embodied emissions analysis is being able to perform the analysis transparently and in a way that can be verified by others. The aspect of transparency is also clearly stated in the ILCD Handbook (2010): "*Documentation of the methods, assumptions and data/data sources used in the LCI/LCA study shall be appropriate and transparent to the extent that would enable another LCA practitioner to sufficiently reproduce the results.*"

For the Powerhouse Kjørbo project, www.powerhouse.no, one of the ZEB pilot buildings in Norway, a database for the inventory was created. The calculations followed the numbering system provided by the *Table of building element standards, NS3451 (2009).* When creating a transparent database for a materials inventory, it is important to keep track of essential information. In the ZEB Kjørbo pilot database, the following information for the materials inventory was given: scope of the emission data, functional unit used, source of data reference (EPD, database, etc.), location of production, density used, expected service lifetime, year of data and comments regarding the actual data quality.

An example of a template for a transparent inventory table, provided by the EeBGuide.eu (Wittstock et al., 2011), is shown in Table 5.1.

Table 5.1 An example of a transparent inventory table (Wittstock et al. 2011)

	Components/ Surfaces/ materials	**LCA data set for production**	**LCA data set for EoL**	**Lifcycle stage**	**Total Amount**	**Service life**	**Comments**
e.g. Exterior wall	*e.g. 200 mm concrete*	*e.g. ESUCO* *Ready-mix concrete C20-25*	*e.g. ESUCO* *Construction waste processing including primary material credit*	*A1-A3; C3, C4, D;*	*xy kg*	*50 years*	
	e.g. 100 mm EPS	*e.g. ESUCO* *Expanded polystyrene (EPS) PS 20*	*e.g. ESUCO* *Polystyrene incineration in MWI incl. credit*	*A1-A3; C3, C4, D;*	*xy* m^3	20 years	
	e.g.10 mm plaster	*e.g. ESUCO* *Normal mortar*	*e.g. ESUCO* *Landfill construction waste*	*A1-A3; C3, C4, D;*	*xy kg*	20 years	
	[Add components]						

A list of available generic LCI databases, construction sector databases and EPD databases can be found on pages 319–321 in the EeBGuide Guidance Document for buildings, Operational guidance for life cycle assessment studies of the Energy Efficient Buildings Initiative.[3]

A short list of available LCI databases is also given in Table 5.2.

Table 5.2 Reference of available LCI databases

Name of database	**Reference**
ELCD database	ELCD core database version II http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
EAA (European Aluminium Association)	Environmental Profile Report for the European Aluminium Industry. April 2008. http://www.alueurope.eu/
Plastics Europe	Eco profiles and environmental declarations. http://www.plasticseurope.org
World Steel Association	Life cycle assessment methodology report. World Steel Association 2011. www.worldsteel.org
Ecoinvent	http://www.ecoinvent.ch/
Chalmers – CPM	http://cpmdatabase.cpm.chalmers.se/

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[3] http://www.eebguide.eu/eebblog/wp-content/uploads/2012/10/EeBGuide-B-FINAL-PR_2012-10-29.pdf

5.4 Uncertainty analysis of emission data

Critical use of data and good routines for quality assurance are necessary when calculating emissions from buildings. This is also especially important when making comparison between different solutions and strategies. For example when comparing two different bearing systems the difference can actually be insignificant depending on the quality of the input data. If the data quality is assessed to be of good quality, small differences can be credible, but if the data quality is poor, you need relatively large differences to be able to make a fair assumption of the differences between the systems. Often results from life cycle assessment are presented with out any assessment of the uncertainty of the analysis. In those cases it is necessary to assess the uncertainty discretionary. Geisler et al. (2005) presented a methodology to assess the uncertainty in life cycle assessments.

5.5 Transport and the construction process

There are two different considerations to take into account regarding transport and the construction process:

- The design phase
- The as-built reporting phase

A scenario must be made based on little and uncertain information in the design phase, which makes this phase challenging. No projects are alike, and the transport distances will vary as will the choice of concept, season for construction, etc., which will influence the construction process. In ZEB pilot projects managed by Skanska, the scenario for the emissions and energy use from the construction phase has been established by collecting as detailed data as possible from previous projects. Also, project managers document the differences between the projects' plans and how they actually end up and adjust the use of resources according to their knowledge of different processes.

The ambition level of the ZEB will determine the compensation level required for the emissions due to modules A4 and A5.

Early on in the design phase it is rarely known where the materials will come from. If an EPD exists for a material, the environmental impacts resulting from transport given in the EPD shall be used plus possible transport scenarios to the location in Norway. Details for possible calculation procedures are given in the EeBguide.eu (Wittstock et al., 2011).

Specific data for distance travelled and mode of transport should be collected for each input of material and waste generated. Intermediate transport between local warehouses should be included. Unless transport is likely to be very significant, generic datasets for transport per tonne/kilometre can be used. Wastage during transport should be included.

The construction phase is mainly relevant for ZEB-COM, ZEB-COME and ZEB-COMPLETE as the choice of materials has a minor influence on the construction process. This is supported by the EeBGuide created by Wittstock et al. (2011) which states that in general all the processes included in A5 can be considered negligible, at least for screening and simplified LCAs. A description of what should be included in ZEB-COM is listed below. For most construction projects, these aspects are likely to fall under cut-off rules.

The impact of land preparation and earthwork can be assessed using generic data accounting for the impact of construction machinery's fuel consumption. Detailed calculations based on LCI data should be used for product storage on site before installation, transport of construction workers, transport of construction machinery to the building site, installation of the product in the building, on-site capital goods (e.g. construction machinery, bungalows), water and energy demand during construction, construction waste and prefabrication of building products.

In practice the current lack of data will make it challenging to establish good scenarios in LCAs. The registration of data from the actual project can also be difficult. The main challenge is to establish systems to register data from the contractors working on the project. This will require careful planning and phrasing in the relevant contracts.

5.6 Waste

This section is mostly based on Bohne and Wærner's findings (2012), BNL(2007) and the Norwegian Technical Building Regulations, TEK 10, KRD (2010b) with a brief overview of current practice and advice on waste treatment of building materials in Norway. Emissions from waste treatment at the end of the building's service lifetime are not included in the ZEB-OM and ZEB-COM ambition levels; however, waste scenarios are relevant when choosing the most suitable materials. Also, waste treatment and emissions from the products that are replaced during the service lifetime of the building are relevant.

Brick, concrete, wood, metal and gypsum constitute around two-thirds of the construction waste in Norway. This waste is reusable, recyclable or is suitable for energy recovery. Other larger waste fractions are glass, insulation and plastics.

The low population density and the narrow shape and long coastline in Norway often mean long transport distances, which in turn can influence decisions regarding waste handling.

Legally, all waste should be delivered to waste handling stations, but some extra requirements need to be fulfilled if the projects are to meet the criteria from KRD (2010b):

- All new building projects larger than 300m^2, renovation or demolition projects larger than 100m^2, or construction projects that produce more than 10 tonnes of waste need to make a waste management plan.
- There is a general requirement for 60% on-site source separation and recycling of construction and demolition waste.

In general, the different waste fractions should be treated as follows:

- Bricks should be reused, or crushed as aggregate substitute.
- Concrete should be used as aggregate substitute.
- Wood should be incinerated for energy.
- Metals should be recycled.
- Gypsum should be recycled.
- Glass should be recycled.
- Combustible insulation should be incinerated using energy recovery. Other insulation products should be recycled when possible.

- Plastics should be recycled or incinerated using energy recovery. Plastics constitute a very mixed waste fraction. The fraction is generally divided into plastic for packaging or other use. Different plastic materials have different potential for recycling. Plastic is an inhomogeneous group with respect to the various additives necessary to give the plastic the various material properties needed for their intended use. Due to the amount of chemical additives in the different plastics used in construction, most of the plastics from renovation and demolition projects are treated as harmful waste.

Waste treatment and procedures are under constant development, which means that waste processing for construction materials in 60 years' time is not known, but the up-to-date analysis includes the currently known practice. The current recommendation is to rely on the current practice of waste treatment when including a scenario for the end of life phase in the ZEB- ambition levels ZEB-COME and ZEB-COMPLETE.

For further information on waste treatment in Norway see www.miljostatus.no.

6. CO_2 factors

This section focuses on CO_2 emission factors from electricity, bioenergy and district heating.

6.1 Electricity: General aspects

Materials used in buildings are produced in many different ways at many different geographic locations. In Norway, building materials are both locally produced and transported short and long distances. The electricity factor used for the different materials differs with changing production locations. Also, emission factors for electricity are calculated in different ways. Some emission calculations are detailed and based on the methodology of life cycle assessments, others consider only the emissions from the actual combustion processes.

The choice of electricity mix when conducting EPDs for building materials varies between different consultants and researchers. According to Holthe et al. (2011), some researchers and consultants use the production/consumption electricity mix for Norway based on an average for the last three years, while others use the Nordic electricity mix with a higher emission factor. Currently there is no consensus on which electricity mix should be used for Norwegian EPDs other than that the emission factor used for electricity in the production of the material should be stated on the EPD (EPD-Norge.no, 2013).

Data on the Norwegian electricity production can be gathered from the quarterly reports from the Norwegian Water Resources and Energy Directorate (www.nve.no), and import and export statistics for Norway can be found at www.statnett.no. The yearbooks from Entso-E (European network of transmission system operators for electricity) provide a detailed overview of the electricity production in Europe, www.entsoe.eu. Eurostat keeps track of the production and import statistics of electricity, and detailed information can be found on their website http://epp.eurostat.ec.europa.eu/.

The electricity market has a mechanism called "Guarantees of Origin" (GO). In Norway, Statnett (2013) (www.statnett.no) manages this mechanism. Such a certificate guarantees that 1MWh of electricity is produced with renewable sources at a given place and time and can be bought from the producers. If one takes the GO into account, the Norwegian residual mix for 2012 is 420 grams CO_2 eq/kWh according to the Norwegian Water Resources and Energy Directorate (NVE, 2013). This could suggest that those who do not have a GO certificate should use this factor. The topic of GOs has not been fully discussed in the ZEB Centre.

6.2 Emission factors: Electricity

Graabak and Feilberg (2011) conducted scenarios of the expected development to 2050 of the CO_2 emission factors for electricity in Europe based on policies already made for the region; in one of the investigated scenarios they assume that the electricity supply in Europe will be carbon neutral in 2050. If a linear development is assumed, the average emission factor is 132 grams of CO_2 eq/kWh. The average factor per decade is provided in Table 6.1.

Table 6.1 Simulated emission factors for electricity in Europe towards carbon neutrality in 2050 (Graabak and Feilberg, 2011)

Year	Emission factor average [grams CO_2 eq/kWh]
2010	360
2020	277
2030	194
2040	112
2050	29
Linear average over the period	132

The current emission factor for electricity used in ZEB is mostly based on this average factor from Graabak and Feilberg (2011) with the value of 132 g CO_2/kWh. However the use of electricity factors is dependent on the goal and scope of the analysis, and it is often relevant to include different scenarios for the emission factor.

6.3 Emissions from bioenergy and district heating

This section is based on the report from Lien (2013) on CO_2 emissions from biofuels and district heating in ZEBs.

The report recommends at this point that the basic assumption should be carbon neutrality for the direct combustion of biofuels, but that this needs to account for the use of fossil fuels in the production chain of those fuels. This is the current practice within the ZEB –Centre. Emission factors for different types of biofuels are listed in Table 6.2.

Table 6.2 Specific CO_2 emissions from selected biofuels, default values

Biofuel type	gCO_2/MJ	gCO_2/kWh
GROT(waste from wood harvesting) wood chips	1	3,6
EU wood chips	4	14,4
GROT pellets/briquettes	2	7,2
EU wood pellets/briquettes	4	14,4
EU wood pellets/briquettes	22	79,2
Wheat straw	2	7,2
Biogas from wet manure	8	28,8
Biogas from dry manure	7	25,2

According to Lien (2013), district heating should not be viewed as emission-free waste heat utilization but should instead be analysed on the basis of the actual GHG emissions associated with its production. The present composition of incinerated waste in Norway is around 50% fossil based. Specific GHG emissions from waste-incineration-based district heating are comparable to the combustion of natural gas. The specific CO_2 emissions from waste incineration are given in Lien (2013) to be 211 grams of CO_2 eq/kWh. For reduction of the GHG emissions from waste incineration used in district heating, the share of the fossil feedstock energy needs to be reduced. The recycling share of plastics should be increased from the present share of around 25 to 30%.

7. Service lifetime

This section focuses on giving a brief overview of different aspects related to the issue of service lifetime that have been deemed relevant for emissions calculations by the working group.

In general, the service lifetime of buildings, building components and materials are dependent on many different factors. This report does not go into the details on these aspects but acknowledges that these issues need further attention when improving emissions calculations over the estimated service lifetime of buildings.

The relevant service lifetime when looking at emissions over the lifetime of a building can be divided into different categories:

- The whole building (depending on the building type, use and function, maintenance and location)
- Building materials and construction parts (depending on durability, location, function, climate, usage, aesthetics)
- Technical equipment (heat pump, energy-producing units, electrical installations, etc.)
- Service lifetime of buildings after comprehensive refurbishment
- Degradation of technical function, such as u-values for windows and efficiency for energy-producing units and heat pumps

Some relevant standards and literature on this subject:

- ISO 15686:2011 Buildings and constructed assets: Service life planning
- ISO 6241:1984 Performance standards in building: Principles for their preparation and factors to be considered
- SINTEF Building Research Design Guides nr. 700.320 Interval for maintenance and replacements of building construction parts
- SINTEF Building Research Design Guides nr. 700.307 Definitions, establishments and use of service lifetime data for buildings and building components/construction parts

7.1 Whole building

As defined in section 5.1, the service lifetime for the whole building that is currently being applied within the ZEB Centre is 60 years.

The average age of the Norwegian building stock is difficult to assess because most of the existing building stock is relatively new. However, Bohne et al. (2006) used the lifetime distribution of the entire building stock and arrived at an expected lifetime of 126 years, which was expected to decrease. Later Bergsdal et al. (2007) and Sartori et al. (2008) used expected lifetime of buildings between 75 and 125 years based on a higher demand for more energy-efficient buildings and other factors.

The lifetime applied in the ZEB Centre does not seem to overestimate the likely service lifetime of average buildings in Norway.

7.2 Building materials and construction parts

The replacements scenario influences the emissions analysis over the service lifetime of a building. Are the windows replaced once, twice or never? And when components are replaced, are the emissions from the replacement based on the current production emissions? Or should the replacements' emissions also consider a greener electricity mix and more energy-efficient production processes?

The current approach regarding the service lifetime of components and construction parts with respect to calculating the embodied emissions has been based mostly on the guidelines from different product category rules, for example, a 60-year service lifetime is expected for different insulation materials (NPCR 012rev, 2012). Also, the design guidelines from SINTEF nr. 700.320 on "Intervals for maintenance and replacement of building components" have been used for calculating the replacement rate of different components and materials (SINTEF, 2010). The emissions due to replacements have been calculated with current available data, where no future scenarios have been included.

However, an exception was made in the ZEB concept studies as they estimated that the emissions related to the production of solar cells will decrease by 50% when they are expected to be replaced after 30 years of service (IEA, 2011) and (SENSE, 2008). It is never the less recommended that the base line scenario for the emissions calculations does not include future scenarios.

Different types of buildings need different types of refurbishment and maintenance. For shopping centres and other commercial buildings, modification of buildings is controlled largely by changes in the tenant mix and possible extensions. Certain buildings can stand unchanged for decades while others are in constant change. Even a newly built commercial building can require changes in tenant spaces shortly after opening. The degree of generality and flexibility are important aspects in limiting the scope of the interventions required.

According to EN15978 (2011), the number of replacements of a product should be calculated with the following formula:

$$\text{Number of replacements of product (i)} = E[R_{eqsl}/ESL_{(i)} -1]$$

Where R_{eqsl} is the required service life of the building, 60 years for example in ZEB, and ESL is the estimated service life for the product i.

The calculation method proposed by the standard also states that there is a need to think of the economic perspective. Is it likely that the product, material or component is replaced if it is getting close to the end of the estimated service lifetime of a building? In some cases it may be assumed that it is not likely that a component will be replaced.

When looking at the service lifetime of materials and construction parts, the question remains about what the actual service lifetime of the product, material and component in the market is. Based on market research performed by Prognosesenteret (Norwegian company working on construction marked analysis), the real lifetimes for the construction parts, flooring, inner wall coverings and inner wall surfaces in Norway are listed for different building types in Table 7.1. Table 7.1 also includes the expected technical lifetimes for the construction parts.

Table 7.1 Empirical and technical service life of selected building components in Norway in years (Prognosesenteret, 2013)

Construction part		Detached houses	Small buildings	Apartments	All residential	Non-residential
Flooring	Replacement freq.	29.3	32.2	32.3	30.3	22.4
	Technical lifetime	25.0	25.0	25.0	25.0	21.8
Inner wall covering	Replacement freq.	26.9	27.5	37.5	28.4	29.6
	Technical lifetime	27.0	28.0	30.0	26.5	28.2
Ceiling	Replacement freq.	63.1	68.9	147.6	70.3	30.7
	Technical lifetime	60.0	65.0	110.0	65.4	32.0
Inner doors	Replacement freq.	43.8	39.2	59.8	44.9	38.6
	Technical lifetime	50.0	50.0	50.0	50.0	41.0
Roofing	Replacement freq.	32.9	31.8	46.4	33.5	19.0
	Technical lifetime	30.0	32.0	35.0	30.7	25.0
Façade	Replacement freq.	41.7	45.9	43.1	42.4	49.6
	Technical lifetime	50.0	45.0	40.0	48.1	45.0
Outer doors	Replacement freq.	34.8	44.5	49,1	38.5	61.4
	Technical lifetime	50.0	45.0	40.0	48.1	45.0
Windows	Replacement freq.	37.8	45.5	50.7	40.1	39.8
	Technical lifetime	35.0	35.0	35.0	35.0	30.0

The data from Table 7.1 show that in some cases the actual service lifetime is longer than the expected technical service lifetime; for example, for windows it is on average over 40 years, but the estimated lifetime is often set to 30 years. However, in other cases it is shorter, for example with roofing in commercial buildings the service lifetime is around 20 years as opposed to the expected 30 years.

In appendix 1, service lifetime figures based on the experience of a manager working in a major Norwegian real-estate company are given. The numbers are meant to reflect the effects of the length of rental contracts on the replacement of building components and materials for office buildings.

It is, however, currently recommended to use the estimated technical service life when calculating the base line scenario for the emission analysis.

7.3 Refurbishment aspects

When a building undergoes renovation and refurbishment, parts of the building or the materials are reused. This represents a methodological question with respect to LCAs and allocation of the emissions from these materials. In many cases the materials in the existing building were produced using different methods and technologies than are used in the current production. The question is then: Should the embodied energy and emissions from the old building construction be accounted for in the refurbishment project?

To avoid new emissions it is recommended that as many building parts and components as possible should be reused. It is recommended that the reused materials are not accounted for in the emissions analysis. This is based on the general intention of encouraging reuse of construction parts, components and materials. This is not in accordance with EN15978 (2011) where it states that the emissions allocated from the previous use to the new building should be allocated according to the percentage of the estimated technical remaining lifetime. This topic needs further attention.

If a building undergoes comprehensive restoration and refurbishment, it is recommended that the lifetime of the restored building is renewed 100% and set to 60 years from the restoration date.

8. Time perspective

The emissions from a building occur over time for both emissions due to operational energy use and material emissions. A lot of a building's emissions occur when the materials to build the building are produced, that is in year 0. Emissions due to operational energy use occur in smaller amounts each year during the lifetime of the building. Emissions from materials also occur over time with operation, maintenance, replacements and repair of the building, as well as the corresponding waste handling and end-of-life of substituted materials. Which of these sources contribute the most depends on the choice of materials and producers, the energy performance of the building envelope and the choice of energy supply.

The surrounding environment is also in constant development, such as developments in energy efficiency of production of materials, increased transport efficiency and changes towards a cleaner energy supply system. Also, climate change will effect the surrounding environment with the possibilities of higher temperatures and increased rain or draft. The current approach at the ZEB Centre has been to use static emissions from the material emissions; however, in future developments the emissions factor for the energy supply to the material production should be analysed further.

8.1 Weighting future emissions: Discounting emissions in LCA

The temperature effect of different emissions scenarios presented by the IPCC 5th Assessment Report, Summary for Policymakers (2013) underlines the importance of early emissions reductions. The global emissions have to be near zero in the last half of the century (2050–2100).

Analysing the costs and benefits of climate change policy, such as the Stern report (2006), and evaluating alternative strategies to reducing GHG emissions by cutting the cost of emissions in each and every year has to be covered by the associated value to avoid damage, discounted by an exogenously chosen rate: the discount rate. Aaheim (2010) discusses the uncertainties in using different discount rates and proposes an alternative method of analysing abatement strategies. His results indicate that an early action (emission reduction) may be more beneficial than indicated by e.g. Stern (2006).

In general, LCA and carbon footprint make no explicit differentiation between emissions at different points in time (Hellweg et al., 2003); whether an emission contributes to increasing the concentration of GHGs today or in 60 to 100 years is treated equally. Hellweg et al., (2003) discussed different pros and cons. They concluded that discounting is only applicable when temporally differentiated data are available. In some cases, such a temporal differentiation is necessary to make sound decisions, especially when long emission periods are involved. An example is the disposal of nuclear or heavy-metal-containing waste. In these cases, the results might completely depend on the discount rate.

Given the timeframe in which carbon reductions need to be made, it is possible that carbon savings made at the start of a building's life could be more valuable than predicted savings in the future. The effect of future decarbonisation of energy supply could have a profound effect on future emissions, as could more effective lighting and other equipment in future refits. In Stern (2006) and Aaheim (2010), it is argued that the cost of measures to mitigate climate change increase for every year the measures are delayed.

Darby et al., (2011) discussed two methods based on PAS20150 and the UK Government's Markal-Med model scenarios for decarbonisation of electricity supply. Their conclusion was that weighting of future emissions appears to be an important factor to consider and that methods and which elements to include ought to be further investigated.

Is it possible to find a scientifically based method of giving more weight to reducing emissions in the early phase of the building's lifetime rather than the emissions in later phases?

One possible and easy way could be to adopt the economic science approach, where future costs and benefits are discounted to a present value in order to make them comparable to current costs and benefits (cost/benefit analysis). This is called the Net Present Value principle (NPV). The NPV of an investment is calculated as a function of benefits, costs and the discount rate as shown in Equation 8.1.

Equation 8.1

$$NPV = \sum_{t=0}^{T}((B_t - C_t) * \frac{1}{(1+r)^t})$$

Where B represents the benefits, C the costs, r the discount rate, and t the time index.

The magnitude of the discount rate is the crucial factor that determines the value of one unit in the future. If we substitute money (B and C) with GHG emissions, the discount rate r will be a weight factor. The magnitude of the factor illustrates the difference in importance of early emission reductions. If it is highly positive, early reduction is given a high value.

It is difficult to find the right level of such a weight factor, and it depends on which future temperature rise we can accept, which global emissions path we ought to follow and the uncertainties in these predictions. We have no intention of concluding the level of discount rate in this report but bring the discussion of the principle to the table.

An example modified from Civitas (2011) is used to illustrate how different weighting could change the conclusions. The model "klimagassregnskap.no" is used in combination with the NPV equation above.

The two buildings are a new low-energy building and an old log building refurbished to a lower energy level with renewable energy supply for parts of the space heating.

The first weighting is introduced when using a function/scenario to calculate emissions from electricity use. This scenario has lower emissions in the future, taking into account the European road map to meet near-zero emissions from electricity production in 2050 (Graabak and Feilberg, 2011). The second weighting is introduced as an NPV calculation, e.g. an extra discount rate of future emissions.

Figures 8.1 to 8.3 show the accumulated emissions from materials and operational energy use over the lifetime of the building: Figure 8.1 has no discounting of future emissions; Figure 8.2 has a discounting factor of 3%; and Figure 8.3 has a factor of 7%. These levels are normal in economic cost/benefit analyses.
The initial emissions in the refurbished log building are lower than in the new building because refurbishment needs fewer materials and the existing materials are set to zero emissions.

The non-discounted result gives the new building the best "score" over the lifetime. After 27–28 years the accumulated emissions from the two buildings are even. During the remaining 30 years of the lifetime, the new low-energy building emits about 40 tonnes CO_2-eq less than the old one. The conclusion is clear: we ought to build a new low-energy building.

But if the future emissions are discounted by 3% or 7%, which is an interpretation of the importance of emission reductions today and in the near future, the conclusion changes. With a 3% discount rate it is break-even during the lifetime and with a 7% discount rate it is obvious that the best alternative is to refurbish the old building to a better energy performance and shift in energy supply.

These results indicate that these questions can be important when we are discussing abatement strategies and how to prioritize measurements for climate mitigation. The topic needs further work and more research.

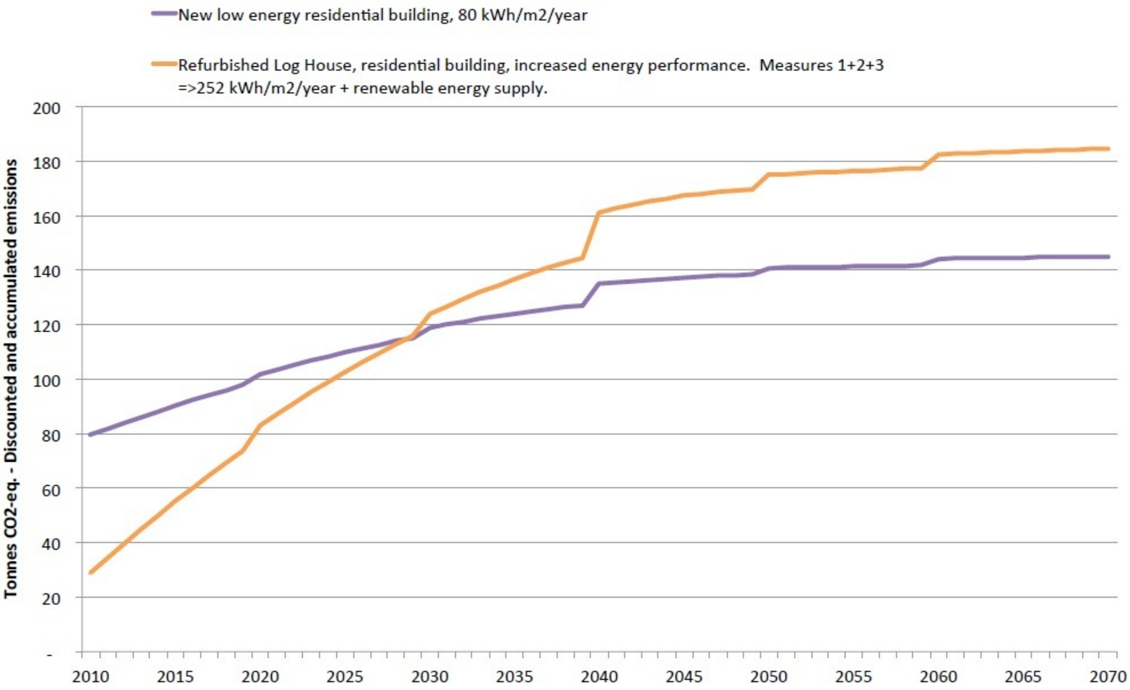

Figure 8.1 Weighting of future emissions by scenarios for electricity supply; no extra discounting

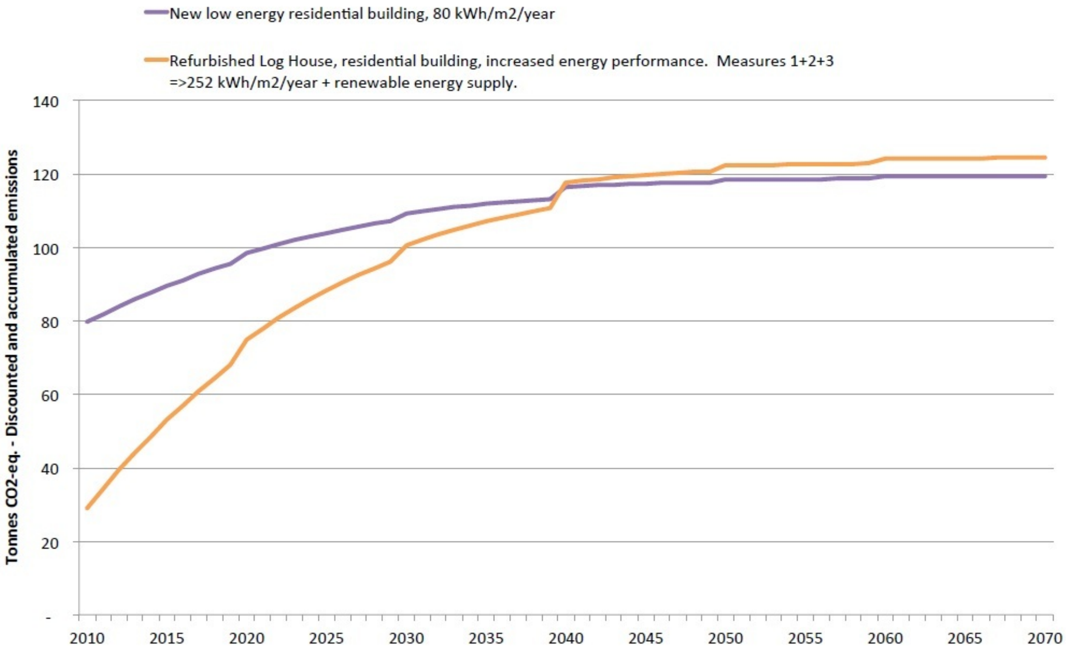

Figure 8.2 Weighting of future emissions by scenarios for electricity supply; discounting rate of 3%

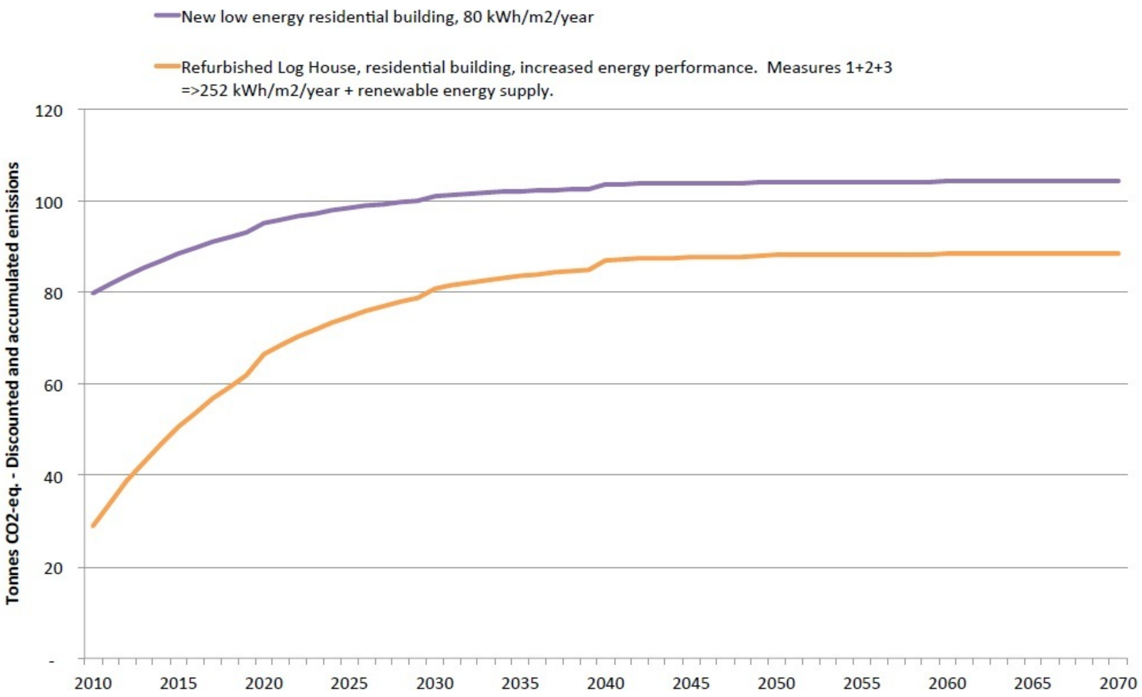

Figure 8.3 Weighting of future emissions by scenarios for electricity supply; discounting rate of 7%

9. Minimum requirements for ZEB-O and ZEB-O÷EQ

As the system boundaries of the ZEB-OM, ZEB-COME and ZEB-COMPLETE definitions all include material emissions; the production of energy during the lifetime has to compensate for the GHG emissions resulting from the operation and materials used. The inclusion of materials in this balance requires a target to be set for the GHG emissions from materials. No such target exists for ZEB-O and ZEB-O÷EQ as this system boundary only includes operation.

Even though the ZEB-O level has been defined to establish a stepping stone on the way to a full-scale ZEB, it will be necessary to avoid a ZEB-O building that has low GHG emissions in operation but high embodied emissions due to sub-optimized choices of structure and materials. The complexity related to materials and different types of buildings and design and the limited experience and uncertainty in the data used make it difficult to set robust quantitative requirements for embodied emissions for ZEB-O ambition level buildings.

Instead of focusing on quantifying the requirements for GHG emissions, requirements expressed in qualitative terms can be used to avoid complexity and at the same time avoid sub-optimization. This can be implemented by establishing a list of questions addressing important issues regarding solutions of construction, building elements, materials and installations that qualify as important contributors to the GHG emissions of buildings based on previous experience. The questions are meant to raise awareness in the design process of the big hitters contributing to the embodied carbon of a building based on previous experience; additionally, accumulated, these lists can potentially be a valuable source for best practice and the transfer of knowledge. As the questions are based on the big hitters in the current practice of building, they must be continuously updated as techniques evolve.

To obtain the level of a ZEB-O building, the design team must address the questions in the list and describe measures implemented and why these are considered to reduce the GHG emissions. A given number of these must be implemented to obtain the ZEB-O level. The questions are listed in Table 9.1.

The main goal of the questions will be to direct the focus of the builder and the design team towards the issues of the building which by experience will have the biggest impact on the GHG emissions at a time where they can be influenced. That is why the process for implementing these questions is of high importance and described below:

1. Before determining the requirements of a building and putting out a tender, the builder must address the issues in the “Conceptual phase” category.
2. Depending on the contract, the issues in both the “Conceptual phase” and the “Design phase” might be the responsibility of the design team early on in the design phase. In any case the design team must address the questions in the category “Design phase”.
3. The questions should be answered qualitatively and preferably with a quantitative description of reduction. The main goal is that the reporting should clearly show significant efforts to reduce the GHG emissions.
4. The results will be reported to a subject matter expert who is therefore able to determine if a significant reduction has been achieved.

Table 9.1 Questions to be addressed as minimum requirements to obtain the ZEB-O level

Conceptual phase	**What measures have been implemented to limit the GHG emissions resulting from the construction, building elements, materials and installations listed below over the lifetime of the building?**
	Need for piling and sheet piles
	Need for waterproof concrete in the basement
	The constructions made of concrete are designed to be used to their full load-bearing capacity without compromising the flexibility of the structure
	The constructions made of steel are designed to be used to their full load-bearing capacity without compromising the flexibility of the structure
	Solution for insulating structures below or at ground level
	Fire-resistant constructions
	Sound-insulating constructions
Design phase	Optimization of technical solutions and material quantities for inner walls
	Optimization of technical solutions and material quantities for external walls
	Flooring
	External cladding
	Choice of external windows
	Technical installations (energy-producing units, air handling units, etc.)
	Effective replacement of materials/components
	Reuse of components
	Achieving the optimal balance between embodied carbon and service life related to replacement
	Carbon intensity of the concrete
	Carbon intensity of the steel

10. Emissions payback calculation

The emission payback calculations and practice at the ZEB Centre and internationally are under continuous development. This report does not go into detail on this topic. The emission payback approach from the concept work from Dokka et al., (2013b) and Dokka et al., (2013c) is presented here.

The emission factor for electricity used for the emission payback calculations was 132 grams of CO_2 eq/kWh. This is a *yearly-averaged* factor with no daily, weekly or annual variation and was used to calculate emissions both due to import and export of electricity to and from the buildings. Payback calculations using the same factor for both import and export can be called *symmetric* weighting (Sartori, 2012).

The net emission balance (ΔE) for an all-electric ZEB building can be formulated in the following way:

Equation 10.1

$$\Delta \boldsymbol{E}(\boldsymbol{n}) = \boldsymbol{EE_p}(\boldsymbol{n}) + \mathbf{EE}_{\boldsymbol{c}}(\mathbf{n}) + \mathbf{EE}_{\boldsymbol{o}}(\boldsymbol{n}) + \boldsymbol{EE_e}(\boldsymbol{n}) + \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \mathbf{f}(\mathbf{i}) \times (\mathbf{Q}_{\mathrm{d}} - \mathbf{Q}_{\mathbf{e}})$$

Given the symmetric CO_{2eq} factor,

Equation 10.2

$$\Delta \boldsymbol{E}(\boldsymbol{n}) = \boldsymbol{EE_p}(\boldsymbol{n}) + \mathbf{EE}_{\boldsymbol{c}}(\mathbf{n}) + \mathbf{EE}_{\boldsymbol{o}}(\boldsymbol{n}) + \boldsymbol{EE_e}(\boldsymbol{n}) + \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \mathbf{f}(\mathbf{i}) \times \left(\mathbf{Q}_{\mathbf{u}} - \mathbf{Q}_{\mathbf{p}}\right)$$

Where

- ΔE (n) is the total net emission balance [kg CO_2 eq/m^2]
- n is the building lifetime expressed in year (60 years)
- EE_p is the embodied emissions in the product phase [kg CO_2 eq/m^2]
- EE_c is the embodied emissions in the construction phase [kg CO_2 eq/m^2]
- EE_o is the embodied emission during operation [kg CO_2 eq/m^2]
- EE_e is the embodied emissions from the end of life phase [kg CO_2 eq/m^2]
- Q_d is the yearly electricity delivered to the building [kWh/m^2 per year]
- Q_e is the yearly electricity exported to the grid by the building [kWh/m^2 per year]
- f(i) is the yearly-averaged CO_{2eq} factor in gCO_{2eq}/kWh for electricity for year i
- Q_u is the yearly electricity used by the building, [kWh/m^2 per year]
- Q_p is the yearly electricity produced by the renewable energy at the building site [kWh/m^2 per year]

If ΔE is zero or negative in Equation 10.1, the building has reached a ZEB balance, while the ZEB level is not reached if the balance is positive. If the embodied emissions terms E_p, E_c, E_o and E_e are removed in Equation 10.1 and in 10.2, the equation corresponds to the ZEB-O-Eq or ZEB-O balance, depending on the ambition level chosen.

Payback calculations can be based on dynamic approaches, for example hourly, daily, weekly or monthly emission variations in the energy system. The load mismatch between emissions from energy production (for example of a solar PV system) and emissions from energy use is an issue of concern when calculating emission payback for ZEBs. Lund et al., (2011) discuss this issue for zero energy buildings. The load mismatch is for example due to daily variations in production and use patterns but also due to seasonal variations. The solar PV system often produces most during the summer time, but in cold climates the winter time is often the season with the highest energy use. This issue is not within the scope of this report.

11. Verification

When conducting environmental assessments it is often necessary to have some form of verification of the calculations. This verification should be performed by an individual qualified in environmental assessment. The verification is a part of making sure that standard procedures have been followed. It is recommended that the emissions analyses made for ZEBs are verified and quality assured by an independent, qualified third party.

Calculation of embodied emissions from materials is often done in the design phase, where many of the details on the material use are not yet in place. To verify that the emissions analysis is based on the material that is actually used in the building, the embodied emission analysis should consider the emissions for the building “as-built”. Therefore, it is necessary to conduct emissions analyses in different steps. First an emissions analysis needs to be carried out in the design phase to assist in decision-making for material choices and design and also to dimension the energy-production systems. Then in the second step, the emissions analysis needs to be updated to include the actual material choices that are in place in the building. Some flexibility should be accounted for in the dimensioning of the energy-producing systems to be able to include possible adjustments in the material emissions calculation based on the actual material used.

12. Conclusions and further work

This report has focused on different aspects of calculating emissions over the lifetime of a ZEB, mainly focusing on emissions from the material use. The report has suggested new levels of ambition for a ZEB, ZEB-COME and ZEB-COMPLETE, where the ambition levels reflect different boundary conditions and levels of detail for the interior furnishings and equipment that need to be compensated for. Different calculation procedures on emissions have been presented and also challenged.

The subject of material emissions analysis is a complex and dynamic issue, and this report does not include all the relevant aspects at this stage. Topics that need further attention are, for example, the actual quality of the accessible data and development of new data for emissions from materials and technical equipment relevant for ZEBs. The electricity factor and payback calculations are currently simplified and need further attention. The issue of discounting emissions in relation to the importance of early emissions reductions was introduced; this subject is relevant when developing solid climate mitigation choices and policies.

The functional unit at the ZEB Centre is one square metre over a lifetime of 60 years; this means that the results for the emissions analyses carried out at the ZEB Centre need to include this functional unit as the baseline scenario. Furthermore, it is recommended to calculate the emissions that occur per user of the building to avoid sub-optimizing, and this should be included where ever possible.

The emissions analysis carried out by Graabak and Feilberg (2011) should be updated, perhaps every other year, to increase the reliability of the scenario. The aspects of emissions analysis in the design phase and in the report phase have been discussed briefly and need further attention.

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APPENDICES

APPENDIX 1 – Service life of selected components in office buildings according to length of rental contract

The figures below are based on the experience of managers working in a major Norwegian real-estate company. The values are meant to reflect the effects of the length of rental contracts on the replacement of building components and materials.

Building element	Service life for 10-year contract	Service life for 15-year contract	Comment
Window – wood	20–40	20–40	Independent of contract
Window – aluminium	20–40	20–40	Independent of contract
Door external	15–25	15–25	Partly independent of contract
External cladding	30+	30+	Independent of contract
Façade	30+	30+	
Inner separation walls	~ 9	~ 14	Shorter than the rental agreement due to minor modifications during the rental period
Inner curtain walls	~ 9	~ 14	Shorter than the rental agreement due to minor modifications during the rental period
Repainting of internal surfaces	~ 8	~ 12	Shorter than the rental agreement due to minor modifications during the rental period
Carpets	~ 8	~ 12	Shorter than the rental agreement due to minor modifications during the rental period
Wooden flooring	~ 8	~ 12	Shorter than the rental agreement due to minor modifications during the rental period
Floor tiles	15–25	15–25	Partly independent of contract
Vinyl/linoleum	~ 8	~ 12	Shorter than the rental agreement due to minor modifications during the rental period
Lighting	15–25	15–25	Partly independent of contract
Air handling unit	25–35	25–35	Partly independent of contract
Technical infrastructure	25–35	25–35	Partly independent of contract
Vinyl/linoleum	~ 8	~ 12	Shorter than the rental agreement due to minor modifications during the rental period
External shading devices	15–25	15–25	Partly independent of contract
Toilets	20–40	20–40	Independent of contract
Sinks	20–30	20–30	Independent of contract

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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