A Norwegian Zero Emission Building Definition

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Abstract

The aim of the Norwegian research centre on Zero Emission Buildings(ZEB) is to develop competetive products and solutions of buildings with zero emission of greenhouse gases related to their production, operation and demolition.

However, to develope solutions and concepts for zero emission buildings it is first necessarry to develop a sound definition of ZEB (for single buildings, and also cluster of buildings). During the first 3 years of the centres running, significant work have been done to adress different issues related to the ZEB-definition, among them defining CO_2 factors for various energy wares. Work done in the International Energy Agency (IEA), and European organisations in light of the revised Energy Perfomance Buidling Directive (EPBD) have been an important basis for the ZEB-defintion work. Experience from the design process of 7- 8 ZEB pilot building projects comprising approximately 100 000 m^2 floor area has also been an important background for the agreed ZEB-definiton. The ZEB-definition consist of nine points:

1. Ambition level
2. Rules for calculation
3. System boundaries
4. CO_2-factors
5. Energy quality
6. Mismatch production and demand
7. Minimum requirement energy efficiency
8. Requirement indoor climate
9. Verification in use

For all these nine issues there have been taken concrete decisions on how ZEB should be calculated and documented.

Keywords: Energy, zero emissions, calculation, criteria, system boundaries, mismatch, energy quality, minimum requirements, CO_2-factors.

1. Introduction

1.1 The ZEB centre

The Research centre on Zero Emission Buildings(ZEB) is an eight year centre funded by the Norwegian research council along with around 22 industrial- and public partners. The centre is run by NTNU and SINTEF. The aim of the centre is: "to develop competetive products and solutions for existing and new buildings that will lead to market penetration of buildings with zero emission of greenhouse gases related to their production operation and demolition".

However, to develop solutions and concepts for zero emission buildings it is first necessarry to develop a sound definition of ZEB (for single buildings, and also cluster of buildings). During the first 3 years of the centres running significant work have been done to adress different issues related to the ZEB-definition, among them defining CO_2 factors for various energy wares. Experience from the design process of 7- 8 ZEB pilot building projects comprising approximately 100 000 m^2 floor area has also been an important background for the current ZEB-definiton.

1.2 Existing work on ZEB definitions

Work on defining net zero energy buildings have previously been done in IEA SHC Task 40 [1]. E.g. the paper of Marzal et al [1] gives an overview of existing zero energy definitions. The work of Sartori et al [3] gives a rather concrete five point definition framework for net zero energy buildings.

The revised Energy Perfomance Buidling Directive (EPBD2) [4] saying that all buildings by 2020 shall be nearly zero energy buildings (nZEB) have led to extensive work to define what nZEB is. Due to EPBD2 a large revision of approximately 40 CEN standards supporting the EPBD is currently carried out [5]. Probably the most important standard related to the definiton of nZEB is EN 15603 [6, 7], which gives the framework and rules of calculation of delivered- and exported energy, and also how to convert that to primary energy and CO_2 emissions. The report from the Building Performance Instiute Europe [8] set out principles for defining nZEB on a national level based on the qualitative definition of nZEB given in EPBD2[1]. The European HVAC organisation REHVA has also made definitions on both nearly zero energy buildings according to EPBD2 and also net zero energy- and plus energy buildings [9, 10]. The work of REHVA is focused on a primary energy balance of the building, in accordance with article 6 in the revised EPBD [4]. Most of this sited work has focus on energy use in operation and particulary primary energy, and not CO_{2eq} emissions in a life cycle perspective which is the focus in the ZEB centre. In addition a Norwegian ZEB-definition should take into account national standards for energy calculations, national derived CO_{2eq} factors, the Norwegian energy infrastructure situation etc., to make a sound Norwegian definition of ZEB, however still in accordance with European and international definition as far as possible.

[1] The EPBD2 defines a nearly Zero-Energy Building as a “building that has a very high energy performance... The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby.”

2. Methods

To develop a ZEB definition for Norwegian conditions different methods have been used:

- During the timespan between 2009-2012 around 7-8 seminars and workshops have been arranged where the partners in the ZEB centre have been participating together with other important actors working with high energy performance of buildings in Norway.
- Different studies related to scenarios on the European electricity grid towards 2050, and CO_{2eq} emissions related to bio-fuels and district heating systems has been initiated, resulting in background reports [11, 12] for the current ZEB definiton.
- Active participation in the definition work in IEA Task 40 [1]
- Active participation in governmental panels on energy efficient buildings [13, 14], which has been an important background for the proposed building code levels in 2015 and 2020 [15].
- Active participation in the Norwegian standardisation comittee on Energy performance of Buildings, e.g. leading to the development of the passive house and low energy standards NS3700 and NS3701 [16, 17].

Also experience from and discussions in the 7-8 pilot building projects within the ZEB centre have been an important basis for the current ZEB definition. Based on this work a nine criteria definition has been developed:

1. Ambition level
2. Rules for calculation
3. System boundaries
4. CO_2-factors
5. Energy quality
6. Mismatch production and demand
7. Minimum requirement energy efficiency
8. Requirement indoor climate
9. Verification in use

3. Discussion of the criteria

3.1 Ambition level

The final goal for the ZEB centre is: "buildings with zero emission of greenhouse gases related to their production, operation and demolition ". This final goal is denoted ZEB-COM, where the C is related to the construction process of the building, O the operation of the building, and M the emission related to the material use of the building (including demolition). This is a very ambitious goal which seems to be hard to achieve in real buildings with current available technology [18, 19, 20]. Since this ZEB-definition also will be used in upcoming real pilot buildings, definition of lower ambition levels is necessary. An ambitious yet attainable level [19, 20] seems to be a zero emission in operation, but excluding energy use from appliances and other equipment. This level is denoted ZEB-O÷EQ, and is regarded as the lowest ambition level for pilot buildings in the ZEB centre. Two other intermediate ambition levels have also been defined, ZEB-O also taking into account energy use from appliances and equipment, and ZEB-OM taking into account operation and materials but excluding the construction phase. Figure 1 illustrates the four ambition levels for an "all electric" (all delivered and exported energy is electricity) office building used in a concept analysis [20]. The emission on the

y-axis has to be balanced (offset) by renewable electricity production (e.g. PV), which is either used for self consumption (reducing delivered electricity) or exported electricity to the grid. CO_{2eq} factors and rules of calculation are given later in this paper.

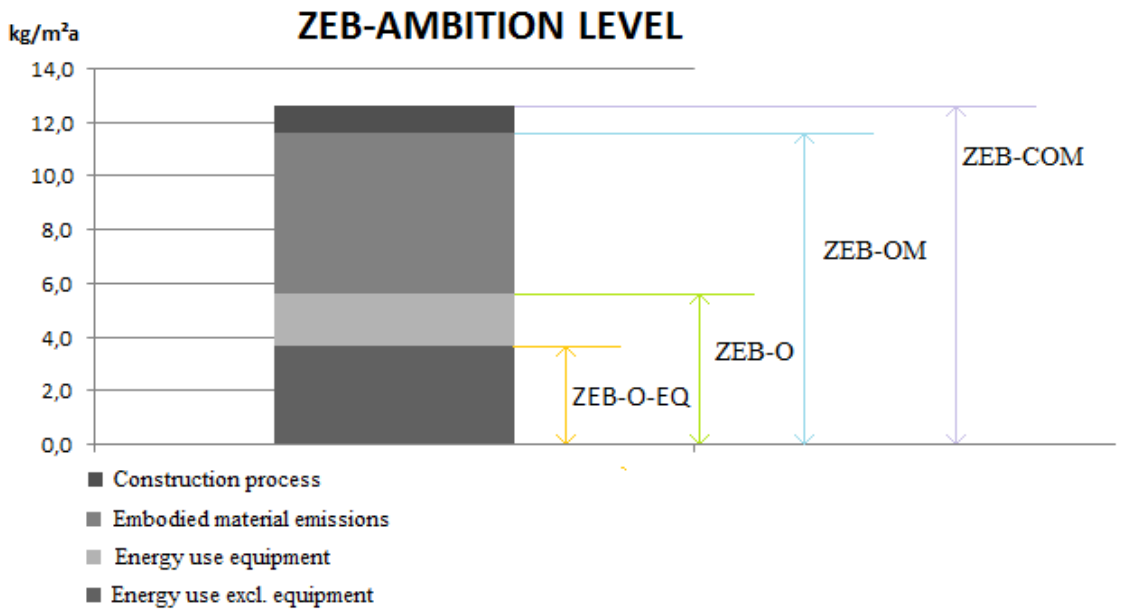

Figure 1 Levels of ambition in the proposed ZEB-definition for an "all electric building".

3.2 Rules for calculation

It is of high importance to have consistent and verifiable methods and rules for calculation of energy use and CO_{2eq} emissions, so that different projects and buildings can be compared in an equal and fair way. Further, a representative picture of the real energy performance of the building, i.e. calculated energy use, should preferably be close to monitored ("real") energy use in the building. A third goal for energy calculation methods is that it should not hinder new and innovative solution, i.e. be so stringent or simplified that new technologies, new solutions or new systems cannot be taken into account. These three conditions could be in conflict, and often one has to make compromises between them.

NS 3031 [21] is the official standard for calculation of energy performance in Norway. It is based on ISO 13790 [22] and the other EPBD standards [5], and the energy calculation can either be done according to the monthly stationary method given in ISO 13790 or be a dynamic (timestep 1 hour or less) simulation method validated according to EN 15265 [23]. In addition to calculation methods, NS3031 gives national values for user dependent values like setpoint temperatures, hours of operation for ventilation, lighting and equipment, DHW energy use, heat gain from occupants and more for thirteen different building categories. The passive house standards NS3700 [16] and NS3701 [17] give high performance criteria for heating and cooling demand, specific heat loss and energy use for lighting (non-residential), some building components (ventilation and windows) and also guiding values for air flow rates (assuming demand controlled ventilation) and energy use for equipment. The calculation procedures in NS3031 and the criteria and guiding values from NS3700/3701 are a

natural starting point for calculation of energy performance in ZEB-buildings. As used in NS3700/3701, local climate should be applied in the energy performance calculations (the current building code uses normalized Oslo climate). When innovative or new solutions not covered by the calculation methods in NS3031 (or background CEN or ISO standards), the performance of such solutions should be calculated with recognized methods.

With the high level of ambition in ZEB-buildings and the annual variation in energy demand and solar production, most often the building will export energy to the grid in summer and import energy in winter (delivered energy to the building). Currently there exists no calculation method for this in NS3031. However, the European standard NS 15603 [6, 7] has calculation procedures for this which can be used in the analysis of ZEB-buildings.

3.3 System boundaries

By system boundaries we mean the boundary where delivered- and/or exported energy to or from the building (or cluster of buildings) is calculated. Determination of system boundaries is of vital importance for ZEB-buildings. Figure 2 taken from Marzal et al [2] illustrates some possible options for system boundaries. In alternative V it is allowed to purchase certificates in "green energy" outside the site of the building (or cluster of buildings). An area with electrically heated dwellings built to the current building code could then easily be classified as zero emission buildings.

When it comes to local renewable electricity production the ZEB centre has chosen to use *level III* in Figure. 2, i.e. production on-site, and produced electricity with "off-site" renewables (e.g. bio-fuels) are accepted. Such solutions may reduce the need for new central power production in the energy system, and/or replace existing fossil power production

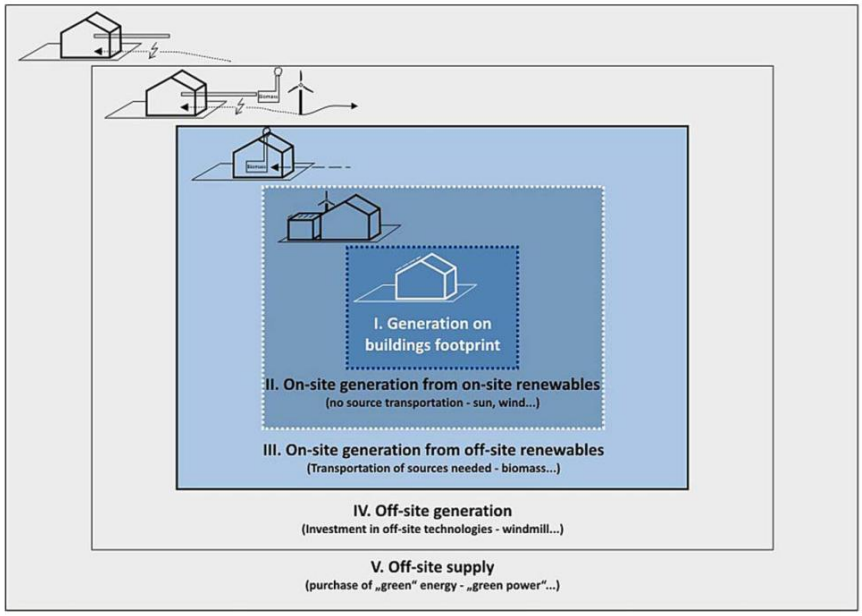

Figure 2 Different options regarding system boundaries, taken from Marzal et al [2].

When it comes to thermal energy production it seems hard to be as stringent on the system boundaries as for electricity production. Both a local on-site heating system covering a cluster of buildings, and a district heating system some kilometers away can both be good supply solutions for

a zero emission building. The local energy central can better be customized to the energy need of the buildings and optimize the temperature level in the system. However, a district heating system with a large energy central can achieve higher production efficiency, even though the distribution losses are higher. In practice it is impossible to say in general if a local energy central within the building, a local energy central on-site (supplying a cluster of buildings) or a central district heating system is best with regard to environmental issues and especially CO_{2eq} emissions. This argues in favor of *level IV* on Figure 2.2, where off-site generation is also allowed, but the real energy mix with accompanying CO_{2eq} factors should be used and all system losses from production to emission in the building should be taken into account.

3.4 CO_2-factors

In the ZEB centre an extensive discussion on how electricity from the grid should be considered with regard to CO_{2eq} emissions. With the renewable hydro power based electricity production system in Norway, one could argue that the CO_{2eq} factor should be low. However, so far the approach in the ZEB centre is as follows:

- Norway is already a fully integrated part of the Nordic electricity system and over time will be a fully integrated part of the European system. Hence, the emission from electricity use, also in Norway, should be the average emission per kWh produced electricity in Europe.
- Simulation of the European electricity system towards 2050 done by SINTEF Energy [11], strongly indicates that it is technically and economical possible to reduce the CO_2 emission by 90 % towards 2050.
- Approximately the same conclusion is given in "*A roadmap for moving to a competitive low carbon economy in 2050*" [24, 25], i.e. a 85-95 % reduction towards 2050 is a realistic goal.
- With current average European CO_{2eq} factor of approximately 360 g/kWh in 2010 [11], together with a 90 % reduction in 2050, and an assumed linear decarbonisation curve as shown in Figure. 3, the CO_{2eq} factor for a given year can be calculated according to ref. [26]. Assuming a further linear extrapolation after 2050, the electricity system will then be fully decarbonised in 2055.
- With an assumed life time of the building of 60 years (standard value used in the ZEB centre), and supposed constant energy use during the lifetime, the average CO_{2eq} factor for electricity can be calculated to 130 g/kWh (for a building constructed in 2013). More generally, the CO_{2eq} factors for electricity can be calculated with equations given in [26] which are corresponding to Figure 3.

The CO_2-curve in Figure 3 and the average factor of 130 g/kWh are based on a several choices, assumptions, simplifications and scenarios. Currently, no official value or consensus on a CO_{2eq} factor for electricity in Norway exists, however the approach taken here can be said to be in line with the long term political goals for the electricity system in Europe.

For other energy wares like district heating based on waste incineration, and bio-fuels there has been carried out a study to decide CO_{2eq} factors for these, see Lien [11]. CO_{2eq} factors for different biofuels are calculated according to the EUs renewable directive [27], where the bio-fuels themselves are regarded as renewable, but the process energy used to produce the bio-fuels (solid, liquid or gas) are defined as fossil and consequently causes a positive CO2 factor. Further, the study proposes to calculate emissions from district heating with the actual energy mix in the energy central (see section 3.3).

For incineration of waste, approximately 50 % of the calorific value of the waste comes from fossil plastic fraction, giving an emission factor of approximately 185 g/kWh [12]. One could argue that incineration of waste is useful for the society, and that the emissions should be allocated to those who sell or buy the plastic (fossil-based). However, this is problematic for a couple of reasons, he energy in the waste can be used in a more efficient way, e.g. by producing electricity (in addition to heat). In addition waste is now an international commodity, and should be used where it has minimal environmental impact, see [11] for further discussion.

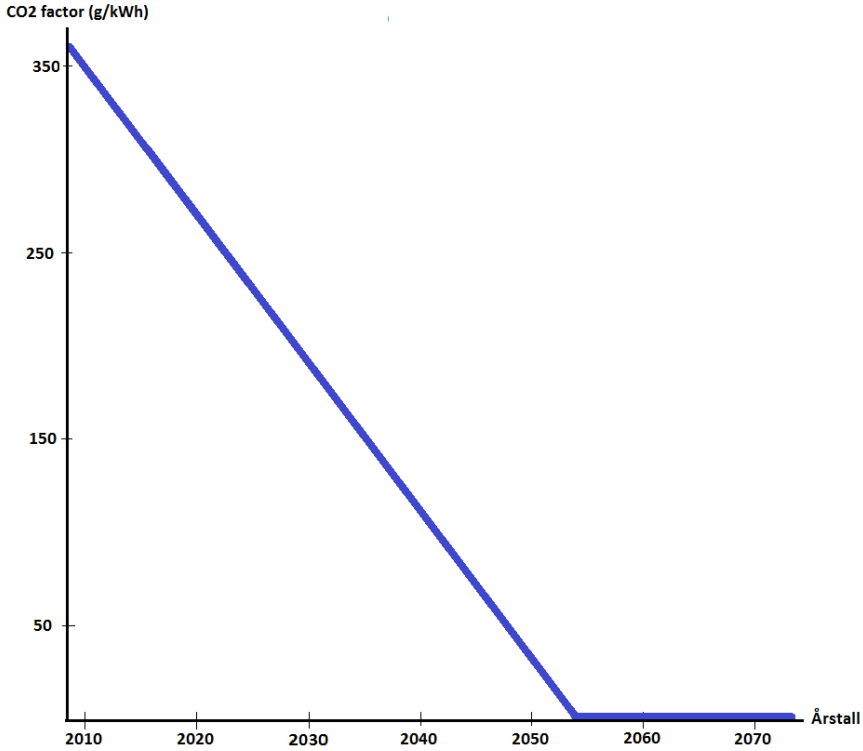

Figure 3 Assumed development for the average CO_{2eq} factor for electricity from 2010 towards 2055. [26].

3.5 Energy quality

Electricity is a high quality energy form that can be used for most purposes like heating, lighting, appliances and technical equipment, fans and pumps and also indirectly for cooling (through compressor cooling). In addition electricity may be transported long distances, both regional, national and international. Based on this argument, the renewable electricity produced on-site (or on the building) could both be used to meet the demand for electricity to the building(s) on-site, or be exported to the grid and there offset average (European) polluted electricity. Exported electricity from the building or cluster of buildings will then be charged with a negative CO_{2eq} emission factor, and then balance emissions emitted on-site from e.g. energy use, materials, construction and demolition.

Heat, in terms of heated water, has lower energy quality than electricity and can only be used for space heating and domestic hot water demand. The energy quality is dependent on the temperature; water with higher temperature can be used for more purposes than water with lower temperature.

Given a large geothermal heat pump producing water with a temperature of 35 ^{o}C, with an seasonal performance factor (SPF) of 4,will give an effective emission factor for each produced kWh heat of 130/4 = 32,5 g/kWh. If the building or a cluster of buildings is coupled to a district heating system based on a mix of waste incineration and oil and gas for peak load, the average emission factor for the district heating can be approximately 220 g/kWh. Exporting heat from the excess heat pump capacity to the district heating grid will then give a negative emission of 187 g (220-33) for each kWh exported. By designing a large heat pump with substantially export of heat to the district heating grid, one could easily design a zero emission building(s). The main problem with such a solution is that the temperature-level of the heat from the heat pump (35 ^{o}C) cannot be used in a district heating with typical temperatures of 70 – 100 ^{o}C, and is consequently of little value for the district heating company due to its low energy quality. Compared to electricity, heat also has limited transportability (most often a radius of a few kilometers) and therefore more limited possibility to offset more polluting heat production. Hence, there are strong arguments to limit the possibility for export of heat from a building or cluster of buildings.

3.6 Mismatch production and demand

Buildings with on-site generating systems have different ability to use local energy sources and consequently also different ability for exchanging energy with the local infrastructure – namely the power grid and in fewer cases the heating/cooling grid. In order to address these temporal mismatch factors several indicators have been developed which can be grouped in three main groups:

Mismatch Factor Group	Application
• *Load matching* The match between on-site generation and the building's load • *Energy carrier compensation* The compensation for other forms of energy	energy balance analysis time resolution: hour, month
• *Grid interaction* The exchange with energy grids	peak power analysis time resolution: minute, hour

The mismatch factors are evaluated for each energy carrier separately, and at different time resolutions. For example, monthly net metering is sufficient to describe and investigate seasonal performance, e.g. when a building uses the grid as an ideal battery to store electricity from summer to winter, while hourly and sub-hourly simulation or monitoring is needed to describe daily and hourly fluctuations to investigate issues such as peak loads. For the time being there is no widespread agreement on which indicators to use to address the three factors mentioned above, even though several are presented in the literature [31].

In this paper we propose three indicators to be used in design phase to evaluate the energy balance seasonal mismatch of ZEBs: *load match*, *unmatched generation* and *carrier surplus*, which cover the two factor groups for analysis of the energy balance mismatch. The grid interaction group is not discussed here because it refers to the peak power analysis and not the energy balance analysis. Explanation of the proposed indicators is given in Table 1 together with Figure 4 showing general monthly electricity 'load' and 'generation' profiles. The areas A, B and C can then be identified, giving A + C = electricity generation, and B + C = electricity load. (The explanation is valid for all energy carriers, but the graph and table shows results for electricity.)

Table 1 **Mismatch factors and indicators.**

Factor group	Indicator
Load matching	***load match =*** $\frac{C}{B+C}$ Match between on-site generation and load
	unmatched generation = $\frac{A}{A+C}$ Annual generation not matched by the load, which therefore need to be exported to the grid
Energy carrier compensation	***carrier surplus =*** $\frac{A-B}{A+C}$ (only if A > B) Part of unmatched generation that compensates for other energy carriers and/or embodied energy and/or gives a net surplus

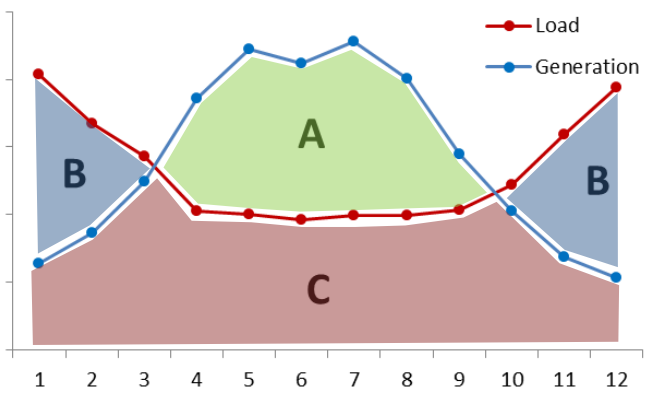

Figure 4 Monthly graphs of electricity load and generation

The indicators are useful when comparing alternative design solutions for the building and have thus an informative value. However, there is no inherent positive or negative value associated, for example, with high or low load match since that depends on the circumstances on the grid side. Therefore, whether that is 'good' or 'bad' for the energy infrastructure is to be evaluated only in combination with an analysis of the local grid conditions.

3.7 Minimum requirement energy efficiency

Measures to reduce energy use and emissions in buildings are often classified as either passive or active solutions. Typical passive solutions are insulation, thermal mass and low energy windows, examples of active solutions are heat pumps and PV. There exist solutions that are somewhat between, like heat recovery in ventilation systems. As a general rule passive solutions (without movable parts) are more robust and have a longer lifetime, even though there is exception to this. Based on this it is often reasonable to use passive measures to reduce the energy demands (increased energy efficiency) as much as technical and economical possible, before employing active solutions to reach the energy or emission ambition in the project (see section 3.1). This is also the principle applied in the current building code in Norway (TEK10, [28]), and in the passive house and low energy standards NS3700 and NS3701 [16,17]. NS3700 and NS3701 gives criteria for heating and cooling demand, artificial lighting demand, demand for maximum heat loss and minimum requirement for different components (ventilation, windows, doors and thermal bridges).

The criteria for *low energy buildings* in NS3700 and NS3701 seems to give a compromise between relative strict demand on energy efficiency, but still a flexibility to find an optimized combination of passive and active measures to achieve the wanted ambition.

3.8 Requirement indoor climate

The building code in Norway [28] gives relative strict requirements on indoor climate, and also ZEB buildings have to meet these requirements. Shortly summarized, TEK10 says that the operative temperature in occupied rooms should not exceed 26 °C more than 50 hours in a normal year, and the CO_2 level should not exceed 1000 ppm. The CO_2 level in non-residential buildings is normally well below 1000 ppm by supplying 26 m^3/h per person[2] + 2,5 m^3/hm^2, for material emissions (provided the use of low emission materials). The average daylight factor in rooms for lasting occupation should be 2 % or higher.

For local discomfort due to draft, radiant temperature asymmetry, floor temperatures and vertical temperature gradient, the requirement for category B in appendix A in ISO 7730 [29] should be met.

3.9 Verification in use

With the high ambition and often new solutions applied in ZEB projects, the designed performance and calculations should be verified by monitoring and evaluation, so lessons learned can be transferred to new projects. With regard to energy and emissions, the most basic level is to monitor delivered and possibly also exported energy for different energy wares, to see if the designed performance is achieved. Also energy use for the different energy purposes according to the calculation standard NS3031 [21] should be monitored (heating, domestic hot water, fans and pumps, artificial lighting, appliances/equipment and cooling) and compared to calculated values. In addition monthly and annual performance (COP) of renewable energy production (solar thermal, heat pumps, PV) should be monitored. Monitoring of the indoor climate in the building for shorter or longer periods of time should also be carried out, and supplemented by surveys of perceived indoor climate.

[2] 26 m^3/h per person + 2.5 m^3/hm^2, equals 7 l/s per person and 0.7 l/sm^2

4. Conclusion

The conclusions for the nine criteria are:

1. **LEVEL OF AMBITION**: Four different levels of ambition are defined, were the lowest ambition level is *ZEB-O÷EQ*, which equals a zero emission level for operation of the building, but excluding energy use for appliances and equipment, and the highest is ZEB-COM where construction, operation and embodied emission (including demolition) is taken into account. Two intermediate levels, ZEB-O and ZEB-OM are also defined (see fig. 1).
2. **RULES FOR CALCULATION:** Calculations of energy use and emissions should be done according to NS3031 [21], preferably with a validated dynamic simulation software. Hours of operation, heat gain from people, set-point temperatures and energy use for domestic hot water shall be taken from NS3031. Ventilation air flow rates and energy use for artificial lighting, appliances given in NS3700 [16] and NS3701 [17] can be used as a starting point, but values should be well documented. In the situation of new innovative solutions and technologies not covered by NS3031, NS3700 and NS3701, these should be calculated with standardized or recognized methods. Local climate shall be used in the simulation of energy use and emissions, and the calculation period is 1 year. In the case of export of energy to the grid, this shall be done in accordance with EN 15603.
3. **SYSTEM BOUNDARIES:** Local renewable electricity production shall be produced on-site, but off-site renewables (e.g. bio-fuels) can be used in the production. Thermal energy production for the building or area (cluster of buildings) can be both on-site and off-site, but emissions from the real energy mix shall be used and the total system losses from production to heat emission in the building shall be taken into account.
4. **CO_2 FACTORS:** Emission factor for electricity is based on a European average approach, with the assumption that the European electricity system is fully decarbonized in 2055. Emission factors for bio-fuels are calculated according to the renewable directive, and for waste incineration (district heating) the emission factor is based on the presumption that 50 % of the calorific value is fossil based plastic. Values are summarised in table 1. System losses (efficiencies) are not included in these values.
5. **ENERGY QUALITY**: Renewable electricity produced on-site and exported to the grid, is assumed to off-set average electricity production in the European grid with accompanying CO_{2eq} factors. Exported electricity is then charged with negative emissions, and can be used to balance the emissions from energy import, embodied emissions and construction of the buildings on-site. Due to its lower energy quality and limited transportability, exported heat from the building or area (cluster of buildings) to a district heating system or nearby buildings (off-site) can be taken into account, but limited so that exported energy shall not exceed imported energy (annually).
6. **ENERGY EFFICIENCY:** To assure a minimum level of energy efficiency, the criteria for *low energy buildings* in NS3700 [16] and NS3701 [17] shall be a minimum requirement. These standards give maximum allowed heating, cooling and artificial lighting demand, and in addition maximum specific heat loss and minimum requirement for windows, doors, thermal bridges and ventilation (heat recovery and fan power).
7. **MISMATCH:** Mismatch between the energy demand of the building(s) and the on-site energy production can be considerable on an hourly, daily, weekly and annual basis, and lead to stress on the grid and varying CO_{2eq} emissions. However, based on current available methods and data a first approach is to use a constant CO_{2eq} factor with no daily, weekly or annual variation, and use the same factor for both import and export of electricity to/from

the building(s) (symmetric weighting). Mismatch indicators given in section 3.6 should be calculated for each project, but primarily for informative purposes.

8. **INDOOR CLIMATE:** All ZEB-buildings (in the ZEB-centre) should comply to the indoor climate requirement in the Norwegian building code [28]. In addition the requirement on local discomfort for category B in appendix A in ISO 7730 [29] shall be met.
9. **VERIFICATION:** All ZEB-buildings (in the ZEB-centre) should be monitored and compared to designed and simulated performance. Both delivered and exported energy should be monitored, in addition energy use for different energy purposes (according to net energy budget defined in NS3031). The performance of renewable energy production on-site should also be monitored. Monitoring of the indoor climate in the building for shorter or longer periods should also be carried out, and supplemented by surveys of perceived indoor climate.

Table 1 CO_{2eq} factors for different energy wares.

Energy ware	**CO_{2eq}-factor (g/kWh)**
Electricity from the grid (average value next 60 years)	130
Oil (fossil), ref. [30]	285
Gas (fossil), ref. [30]	210
Waste incineration	185
Wood chips	4
Bio-pellets	7
Bio-ethanol	85
Bio-oil	50
Bio-diesel	50
Bio-gas	25

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