Energy and Buildings 74 (2014) 101–110

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A net zero emission concept analysis of a single-family house

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ARTICLE INFO

Article history:
Received 5 November 2013
Received in revised form 16 January 2014
Accepted 23 January 2014

Keywords:
Zero energy building
Zero emission building
ZEB
Building concept
Life cycle analysis
Cold climate

ABSTRACT

The paper aims to investigate whether it is possible to achieve a net Zero Emission Building (nZEB) by balancing emissions from the energy used for operation and embodied emissions from materials with those from on-site renewables in the cold climate of Norway. The residential nZEB concept is a so-called *all-electric* solution where essentially a well-insulated envelope is heated using a heat pump and where photovoltaic panels (PV) production is used to achieve the CO_{2eq} balance. In addition, the main drivers for the emissions are revealed through the CO_{2eq} calculation for a typical Norwegian, single-family house. This concept building provides a benchmark rather than an absolute optimum or an architectural expression of future nZEBs. The main result of this work shows that the criteria for zero emissions in operation (ZEB-O) is easily met, however, it was found that the only use of roof mounted PV production is critical to counterbalance emissions from both operation and materials (ZEB-OM). The results show that the single-family house has a net export to the electric grid with a need for import only during the coldest months. In the next stage of the work, the concept will be further optimised and the evaluation method improved.

1. Introduction

It is well known that the environmental performance of buildings needs to be drastically improved, especially in terms of energy use and CO_{2eq} emissions. In order to face this challenge, the concept of zero energy building has emerged. Significant efforts to define these buildings have been done in the IEA SHC Task 40 [1]. For example, the paper of Marzal et al. [2] gives an overview of existing net zero energy definitions, while the work of Sartori et al. [3] proposes a concrete framework for their definition. At the European level, the revised directive on Energy Performance of Buildings (EPBD) [4] requires that all new buildings should be *nearly* zero-energy by 2020. This has led to extensive work about zero energy buildings and their definition in which Norway plays an active role. For instance, the Norwegian Research Council has recently funded the Research Centre on Zero Emission Buildings (ZEB). The ZEB Centre has chosen to mainly focus on CO_{2eq} emissions, the goal being to minimise the impact of buildings on the global warming.

The approach followed by the ZEB Centre is a holistic one. For example, all emissions related to the energy used for operation should be accounted for, as well as, embodied emissions from materials. Given these ambitious objectives, a large set of measures should be taken at the level of the building starting from the envelope efficiency to building services including the onsite renewable energy conversion. In practice, only a coherent set of these measures may lead to the ZEB balance. It then leads the Centre to investigate *ZEB concepts*. The present article reports on these developments, especially regarding new residential buildings.

The first stage involves the evaluation of the current available technology. This is done by taking a realistic ZEB concept together with a reasonable ZEB definition, applied to a typical residential building typology. A so-called *all-electric* solution has been selected as it is a common strategy often found in the zero energy building community [5]: solar thermal panels combined to heat pumps covers heating needs while photovoltaic panels (PV) produces electricity. The objective of this research is to investigate whether the current technology enables us to build a ZEB that balances the energy used for operation (ZEB-O), and ultimately, that counterbalances embodied emissions from materials (ZEB-OM). Furthermore, the goal of these calculations is to estimate, and thus provide an overview, of the materials and systems which contribute the most to the CO_{2eq} emissions over the building lifetime (here taken as 60 years). Results of this work will provide a benchmark for Nordic conditions (i.e. cold climate) thus providing a starting point of comparison. It is important to note that the investigated concept should neither be considered as an absolute optimum nor as the

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http://dx.doi.org/10.1016/j.enbuild.2014.01.037

architectural expression of future nZEBs, yet it is a realistic concept from a functional performance point of view.

The remainder of the article is organised as follows. Firstly, the ZEB definition within the Centre is given along with the underlying philosophy (Section 2). Secondly, the methodology used to evaluate CO_{2eq} emissions and the ZEB balance is described (Section 3). Thirdly, the evaluation is done on a concept building using an *all-electric* strategy (Section 3). Finally, results are presented and discussed (Sections 4 and 5) before conclusions are given (Section 6). For ease of clarity, the terminology of the EN 15603 [6] is followed. Finally, a technical report with comprehensive description of the methodology and results is available in the public domain [7].

2. ZEB definition

In order to develop solutions and concepts for zero emission buildings, it is necessary to first have a sound definition of ZEB (for single buildings, and also cluster of buildings). The most relevant aspects of the Norwegian ZEB Centre definition are described below, while the interested reader can refer to more detailed information in Dokka et al. [8]:

1. *Ambition level*: Four different ambition levels are defined, where the lowest ambition level is *ZEB-O-EQ*, equivalent to a zero emission level for operation of the building (O), but excluding the energy use for appliances and equipments (EQ). ZEB-COM is the highest ambition level where construction (C), operation and embodied emissions including demolition (M) are taken into account. Two intermediate levels, ZEB-O and ZEB-OM, are also defined and are the levels investigated in the present study.
2. *Rules of calculation*: Building energy needs should be calculated according to the Norwegian official standards [9–11]. The lifetime of the building is assumed to be 60 years.
3. *System boundaries*: Local renewable electricity shall be produced on-site, but off-site renewables (e.g. bio-fuels) can be used in this electricity production. Thermal energy production for the building or area (cluster of buildings) can be both on-site and off-site, but emission from the real energy mix shall be used and the total system losses from production to emission in the building shall be taken into account.
4. *CO_2 factors*: The paper only reports on an *all-electric* approach for the energy supply, therefore only the CO_{2eq} factor for the electricity mix will be introduced here. This calculation procedure requires defining a CO_{2eq} factor corresponding to the building lifespan of sixty years. No official value or consensus on a CO_{2eq} factor currently exists in Norway. However, the main assumptions used here are that Nordic and European grids will be strongly interconnected. An average European mix is therefore considered. Furthermore, in line with the long-term political goals for the electricity production in Europe [12,13], a 90% reduction of the CO_{2eq} emissions is assumed for 2050. By extrapolating this trend, assuming a lifetime of 60 years for buildings as well as constant building needs over this period, the average CO_{2eq} factor for electricity can be calculated at 0.132 $kgCO_{2eq}$/kWh for a building constructed in 2013 [14].
5. *Energy efficiency*: To assure a minimum level of energy efficiency, the criteria for *low energy buildings* in NS3700 [10] and NS3701 [11] shall be a minimum requirement. These standards give a maximum allowed heating-, cooling- and artificial-lighting demand, and, in addition, a maximum specific heat loss. There is also a minimum requirement for windows, doors, thermal bridges and ventilation (heat recovery and fan power).
6. *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 can 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), a so-called *symmetric* weighting [3]. However, load match factors can be used to estimate the mismatch between demand and production [3].
7. *Indoor climate*: All ZEB-buildings (within the ZEB-Centre) should comply to the indoor climate requirement in the Norwegian building code [15]. In addition the requirement on local discomfort for category B in appendix A in ISO 7730 [16] shall be met.

3. Methodology

3.1. Evaluation of the CO_2 emissions

A typical building typology is first established as a base case. The design of the building envelope and service systems is defined in detail in order to make a proper evaluation of the loads in operation, as well as, the embodied CO_{2eq} emissions of the materials (used in the envelope and technical systems). The evaluation of the delivered energy is divided into two consecutive steps. Firstly, the building needs are established using the current Norwegian regulation (i.e. NS 3031 [9]). Practically, simulation of the annual heating and cooling demand, peak heating and cooling loads has been done using SIMIEN [17]. Secondly, the systems efficiency, including auxiliaries, is computed in order to determine the resulting energy use by building service. By summing these energy uses, the delivered energy to the building is known and converted into CO_{2eq} emissions. A single PV installation that maximizes the production on the flat roof is designed. Its embodied emissions are accounted for, while its electricity generation is used to offset the total CO_{2eq} emissions.

3.2. Choice of emission factors for electricity mix

In agreement with the ZEB Centre definition, the current symmetric emission factor of 0.132 $kgCO_{2eq}$/kWh is used to calculate the emissions from the electricity used for operation, as well as, in the calculation of emissions from the electricity from the PV cells. However, for materials, the Ecoinvent database [18] is used to source the emission factors for each specific material depending on its country of production. The emission factors are dependent on the current emission factor for the electricity mix in each respective country. For example, the concrete used in the analysis is based on a concrete process from Switzerland using the Switzerland electricity mix as an input, whereas the solar cell production is based on the UCTE electricity mix (average European mix). These emission factors for materials are assumed constant throughout the lifetime of the building.

3.3. Building model

The concept building is a timber frame two storey's single-family house, see Fig. 1. With the present test case, there is no intention to promote an architectural expression for future nZEBs. In practice, the building typology was designed to be generic enough to enable a realistic CO_{2eq} assessment to be completed, whilst its flat roof was selected in order to accommodate a large area of PV.

The 3D architectural drawings and 3D BIM modeling have been done in Revit [19]. The building footprint is approximately 8 m × 10 m. Each floor has a heated floor area (BRA) of 80 m^2, giving a total area of 160 m^2, see Fig. 2. The total windows and door