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Energy life-cycle approach in Net zero energy buildings balance: Operation and embodied energy of an Italian case study

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ABSTRACT

The paper starts from the results of one of the six case-studies of the SubTask B in the International Energy Agency joint Solar Heating and Cooling Task40 and Energy Conservation in Buildings and Community Systems Annex 52, whose purpose is to document state of the art and needs for current thermo-physical simulation tools in application to Net Zero Energy Buildings.

The authors extend the Net Zero Energy Buildings (Net ZEB) methodological framework, introducing the life-cycle perspective in the energy balance and thus including the embodied energy of building and its components. The case study is an Italian building, tailored to be a Net ZEB, in which the magnitude of the deficit from the net zero energy target is assessed according to a life-cycle approach. The annual final energy balance, assessed with regard to electricity, shows a deficit which makes the case study a nearly Net ZEB, when the encountered energy flows are measured at the final level. Shifting from final to primary energy balance the case-study moves to a non-Net ZEB condition, because of the large difference between the conversion factors of photovoltaics generated electricity and imported electricity. The adoption of a life cycle perspective and the addition of embodied energy to the balance causes an even largest shift from the nearly ZEB target: the primary energy demand is nearly doubled in comparison to the primary energy case.

1. Introduction

The reduction of energy requirement and the mitigation of environmental impacts in the building sector have become key targets of energy policies in different countries, to be matched by means of strategies aimed at enhancing energy efficiency and renewable energy technologies. In this context, the Net zero energy building (Net ZEB) is a new building concept that recently has gained significant international attention both by researchers and by governments [1–7].

The recast of the EU Directive on Energy Performance of Buildings (EPBD) establishes the 'nearly zero energy building' as the target within 2018 for all public owned buildings and within 2020 for all new buildings, pointing out that the energy required should be produced on-site or nearby renewable energy systems [8].

Thus "Net ZEB" has become the most effective definition to represent the synergy between an energy-efficient building and the employment of the renewable sources to match the energy balance over one year, including in its scope strategies to increase the share of renewable sources in the utility grids, and thereby to reduce the consumption of primary energy and the related emission of greenhouse gases. However, the consistency of the renewables share is different in each country, depending on factors as the local climate and the specific energy infrastructure, thus implying the need of suitable conversion factors for each country with regard to primary energy and carbon emissions for energy carriers.

Despite the concept of Net ZEB is considered the future target of the building design, the energy balance calculation of a building equipped with on-site renewable energy generation systems and interacting with the utility grid to fulfil the neutral balance is a complex task with a number of already existing approaches that spotlight different items [9,10].

1.1. Net ZEB concept

The main framework of a Net ZEB concept is based on the idea of a low-energy building that produces energy and interacts with the energy grid. Such a building is conceived as energy-efficient building, equipped with energy efficient systems and effective insulation materials to curb the heating and electricity demand and with on-site renewable energy systems (typically solar thermal and PV systems). The energy generation over a year balances the energy use and the excess energy from renewables, which is not self-consumed, is exported to the grid.

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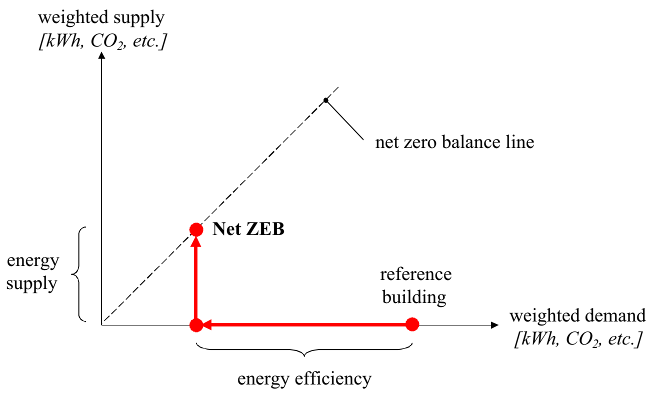

Fig. 1. Schematic presentation of demand/supply balance of a Net ZEB, reproduced from [11].

A critical issue on which the debate on Net ZEBs has been addressed is whether the term "Net Zero Energy" has to be referred to final energy, measured at end uses or to primary energy, estimated at the natural resource level [11]. However a common acknowledgement is that the calculation of primary energy in Net ZEBs balance allows differentiation between electricity and fossil fuel use and includes an indication of the efficiency of delivering heating, domestic hot water, lighting, etc.

The current core topic of a Net ZEB is to use the electricity grid both as a source and a sink of electricity, thus avoiding the on-site electric storage systems. The term "Net Zero" underlines a balance condition between the energy delivered from the grid and the energy supplied to the grid. The energy balance is verified when weighed supply matches or overcomes weighed demand over a period, generally one year, as described in the following equation (Fig. 1):

$$\text{NetZEB balance} = \left|\text{weighed supply}\right| - \left|\text{weighed demand}\right| = 0 \quad (1)$$

which represents the focus concept in the definition of Net ZEB. Absolute values are conventionally used to indicate that supply and demand are taken into account without their own algebraic sign.

The term "weighed" means that the physical units of the different energy carriers are converted into the same metrics.

In [11] a framework, which allows to perform the energy balance of Net ZEBs in the operation phase both in the building monitoring and in the design phase, is presented. Such a framework is built upon the energy balance conditions between: (1) the energy exported to the grid and the energy imported by the building (import-export balance), or (2) the whole renewable energy generation and the energy load (load-generation balance). The application of the first balance is suitable if the building monitoring allows a detailed estimation of delivered energy from and exported energy to the grid. The second balance condition may be applied during the design phase, or when the estimation of the delivered and the exported amounts is lacking for each energy carrier, but global annual data on load and generation are available [12–15].

1.2. Life-cycle perspective in Net ZEB balance: embodied energy and operating energy in literature

The two previously described energy balances undertake only the energy uses which occur in the operation step, thus neglecting the embodied energy in building materials, components and technical equipment.

Until recently, only operating energy has been considered in many literature studies [16–27], owing to its significant share in the total life-cycle energy consumption of standard buildings (70–90%). Conversely, embodied energy of building materials and components has been traditionally neglected in building energy analyses, as in standard buildings it amounts to a small fraction of the life cycle energy consumption (10–20%). This made most building regulations and directives overlook this issue.

According to a general definition a low-energy building is one having a total operating energy of 120 kW h/(m^2 y) when expressed in end-use energy, or 200 kW h/(m^2 y), in terms of primary energy [28]. In an earlier study [29], a building is defined low-energy if the related energy consumption for operation is 45 kW h/(m^2 y), not clarifying if such a threshold refers to end-use or primary energy. In fact expressing energy consumption as primary or end-use energy involves a relevant difference. End-use energy is measured at final use level, and expresses the performance of a building. Primary energy is measured at the natural resource level, including losses from the processes of extraction of the resources, their transformation and distribution, thereby expressing the environmental load induced by a building.

The definition of low-energy building strictly depends on climate, country, indoor climate and, not less important, the user behaviour, which affects the energy consumption in each end-uses. Furthermore conversion factors from end-use to primary energy depend on the energy carriers used and the energy system of a specific country.

Design of low energy buildings directly addresses the target of reducing the operating energy. This is done by improving the thermal insulation of the building envelope, reducing infiltration losses, recovering heat from ventilation air and/or waste water, installing alternative energy using systems and renewable energy technologies for heating, domestic hot water and electricity generation, However, the reduction of the operating energy demand involves an increase in embodied energy of the building due to energy intensive materials used in the building shell and technical equipment.

When shifting from standard houses to low energy buildings and to Net ZEBs the relative share of operating energy decreases, while the relative share of embodied energy increases [30–34].Therefore, the lower the operating energy, the more important it is to adopt a life cycle approach to compare the energy savings achieved in the building operation with respect to the overall life-cycle energy consumption.

Literature on LCE case studies shows that low energy buildings have embodied energy in the range10-100 kW h/(m^2 y) [20–26]. Fig. 2 shows the embodied energy vs. the operating energy for a number of representative residential buildings [27–41]. They are distinguished for cold, and temperate and hot climate. In the most of the reviewed case studies the operating energy varies from nearly 0 to around 350 kW h/(m^2 y), moving from the Net ZEBs to conventional houses in both climatic zones. With regard to embodied energy cold climate buildings are characterized by the lowest value range (10–55 kW h/(m^2 y)), while the most part of the buildings located intemperate and hot climate zones, which require more massive envelopes, show values from 30 to around 70 kW h/(m^2 y).

In the Net ZEB definition the energy life-cycle perspective is not included in energy balances, thus neglecting the incidence of the increased embodied energy on the energy saving in Net ZEB operation.

2. Case study: the life-cycle net energy balance of the leaf house

Starting from the results of one of the six case-studies of the Sub Task B in the International Energy Agency (IEA) joint Solar Heating and Cooling (SHC) Task40 and The Energy Conservation in Buildings (ECB) Annex 52 titled "Towards Net Zero Energy Solar Buildings"