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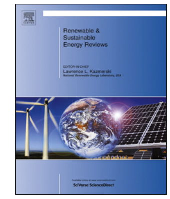

Different energy balances for the redesign of nearly net zero energy buildings: An Italian case study

Maurizio Cellura [a], Francesco Guarino [a,*], Sonia Longo [a], Marina Mistretta [b]

[a] Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici, Università di Palermo Viale delle Scienze, 90128 Palermo, Italy
[b] Dipartimento Patrimonio, Architettura, Urbanistica, Università Mediterranea di Reggio Calabria, Salita Melissari, 9124 Reggio Calabria, Italy

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ABSTRACT

The currently developing concept of a Net Zero Energy Building introduces new challenges and research problems. The calculation of a net zero energy balance is heavily influenced by the energy carrier weighting factors that are chosen, which can deeply influence the future energy market towards adopting specific energy technologies. The following paper proposes an analysis of different definitions and conventions for Net Zero Energy Buildings that employ different calculation methodologies and apply different weighting factors to an Italian case study. The case study, which is called "the Leaf House", is one of the first examples of a nearly net zero energy building in Italy. A building simulation and model calibration were performed using monitored data. Energy balances were calculated for the case study. Scenarios for a building redesign were then proposed, with the aim of reaching an electricity target of net zero energy. Reaching a primary energy building balance of net zero is easier when using symmetric weighting because it allows renewable energy to account for avoided national mix energy generation. The results show that symmetrical balances are nearly fulfilled for the existing building and asymmetrical ones are below zero. In the redesign scenarios, the symmetrical weighting scenarios exceed the zero target by 34.10 and 20.83 MWh/year. The asymmetrically weighted balances show a variable trend in that auto-consumption and high load-matching are highly favourable because the theoretical 'zero auto-consumption' scenario would yield the worst result and would be the only one below the Net Zero threshold. Although symmetric weighting approaches could be viewed as robust physical approaches for renewables (e.g., the primary energy conversion factors for PV are usually close to 1), they can become a heavy burden during the market development of renewable energy technologies, highly favouring auto-consumption and energy storage to minimise energy import from the grid.

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* Corresponding author.
E-mail address: francesco.guarino@unipa.it (F. Guarino).

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1. Introduction

Buildings account for approximately 40% of both primary global energy consumption and overall greenhouse gas emissions in Europe [1–11]. It may be difficult to reach high levels of decarbonisation [3,12–14] in the energy market if innovative building concepts coupled with distributed energy generation technologies [15–20] are not encouraged. In this context, the idea of Net Zero Energy Building (NZEB)[21–26] is of interest to move building design perspectives towards sustainability [27–33], environmental friendliness and energy efficiency. For the first time, The Energy Performance of Buildings Directive recast [5] has clarified the concept of nearly zero energy buildings as a very high energy performance building, the energy needs of which are covered at a very significant level by energy from a renewable source, including renewable energy that is produced on-site or nearby. However, the above EU directive does not account for many aspects such as system boundaries and energy import and export. EN 15603:2008 and its update focus more on these issues, defining in detail all of the terms included in a building's energy balance [34].

In addition, the typology of the balance to be performed is described in EN 15603, which considers both the different energy carriers for the calculation and the primary overall energy conversion, which is defined as energy from renewable and non-renewable sources that has not undergone any conversion or transformation process.

The International Energy Agency (IEA) has developed actions in the field of Net Zero Energy Buildings. IEA Solar Heating and Cooling (SHC) Task 40 and the Energy Conservation in Buildings and Community Systems (ECBCS) Annex 52 joint programme titled “Towards Net Zero Energy Solar Buildings” [21,35–48] has been applied towards a shared view of NZEBs among experts in the field in recent years. From a strictly mathematical point of view, many definitions have been explored; however, it is agreed that an NZEB is a building that fulfils a balance during a selected time period during which the production at least equals the energy use. The metrics used, the time-span and the nature of the balance itself (e.g., whether to consider the self-consumed energy by buildings that generate it) remain topics of debate between scientists.

Many different approaches have been developed in the literature, in which energy fluxes are computed and the weighting factors selected are different. The analysis of the impact that these definitions have on the results is important to understand the implications that specific weighting factors would have on the energy market if selected and implemented by local legislations and to orient policymakers towards the most appropriate action in every context. According to the authors' knowledge, few articles in the literature provide a detailed description of the influence from the chosen assumptions on the energy balance of a building. In [49], the authors propose an investigation of the influence that different weighting factors (e.g., EN 15603 factors) can have on the selection of different building energy systems. A parametric analysis is performed on different buildings and technical system configurations in several countries by means of steady state tools with a monthly depth level. For each combination, the amount of PV capacity that is necessary to achieve a net zero balance has been calculated and used as the primary indicator for comparison; a lower PV area indicates a more favourable condition. The results show that asymmetric weighting factors for electricity that are aimed at rewarding electricity export to the grid would facilitate the achievement of a zero balance for all technologies, and on the contrary, low weighting factors for electricity (e.g., in the case of the decarbonisation of the generation system) would make it challenging to reach the net zero target.

In [50], the fulfilment of four Net Zero Energy Building balances is performed for the primary energy, site energy, carbon equivalent emissions and energy cost. This study addresses five conventional energy systems and seven biomass-based standalone and shared combined heat and power systems. These systems are connected to a single family house located in Helsinki, Finland, and they were simulated using the TRNSYS software. The simulated results indicate that the easiest balances to fulfil are in the order NZEB-emission, NZEB primary energy, cost and site.

The present paper is one of the few studies available in the literature in which the influence from the weighting factors is explored in the context of a real case study. Here, an Italian case study of the IEA SHC TASK 40/ECB ANNEX 52, or the “Leaf House” [25,51,52], is used as a field test for the selected NZEB definitions. This building has been modelled in the TRNSYS 16.1 [15] environment and has been explored through sensitivity analysis [53] and by validating primary results from the available monitored data. This study addresses the most commonly used NZEB balances and checks on the importance of the assumptions and definitions used to achieve the Net Zero target for the existing building and the redesigned one. This paper assesses the energy balance of the building with regards to electricity as described by EN 15603. Balances are assessed in terms of final and primary energy. Because the building does not reach the NZEB target in its given state, re-design scenarios are proposed to optimise building energy performance and re-check whether the Net Zero final energy target was matched.

The primary goals of the paper can therefore be briefly summarised as follows:

– to develop a validated model for the existing nearly Net Zero Energy Building,
– to assess the energy balance for the case study by following the prescriptions in the EN 15603, and according to the definitions developed within the Net Zero Energy Buildings Task 40 for the existing building, and
– to redesign studies on the validated model to achieve a Zero energy level in the proposed balances and
– To assess the relevance of weighting factors and calculation methodologies for the fulfilment of the NZEB target.

2. The existing building

2.1. Construction features and thermal systems

The Leaf House (LH) is a single house located in S. Angeli di Rosora (Marche, Italy) and is one of the first examples of an Italian nearly Net Zero Energy Building. It has three levels and six