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Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives

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HIGHLIGHTS

- With four metrics, the NZEB definition is investigated using Finnish and international data.
- Regarding the Finnish data, fulfilling the NZEB-emission is the easiest, then the NZEB-PE, the NZEB-cost, NZEB-site.
- Making the house high in thermal energy efficiency is not a step towards achieving NZEB-emission by shared biomass CHPs.
- The NZEB-PE is easier to fulfill by the international weighting factors than the Finnish ones.
- Generally, the NZEB balance is more attainable by the shared biomass than the standalone CHPs.

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ABSTRACT

This study aims to investigate the fulfillment of four Net Zero Energy Building (NZEB) balances, NZEB-PE, NZEB-site, NZEB-emission and NZEB-cost, considering the four metrics of primary energy (PE), site energy, CO_2-eqemissions and energy cost, respectively, using weighting factors based on Finnish and international reference data. The study analyzes five conventional energy systems and seven biomass-based standalone and shared combined heat and power (CHP) systems. These systems are connected to a single family house located in Helsinki, Finland, with two energy efficiency levels: a standard house and a passive house, simulated by Trnsys software. The annual balance of the import and export of the operational thermal and electrical energies is applied. The simulated results indicate that the NZEB-emission, NZEB-PE, NZEB-cost, and NZEB-site are arranged in that order according to the ease of fulfilling the annual balance. Making the house high in thermal energy efficiency (or adding solar thermal collectors) for all the studied systems is a step towards achieving NZEB-PE, NZEB-cost, and NZEB-site. On the contrary, achieving the NZEB-emission by the shared CHPs connected to the standard house is easier than the passive house. The NZEB balance is more attainable by the shared CHPs than the standalone CHPs. The NZEB-PE is easier to achieve using the international factors than using the Finnish PE factors.

Contents

Abbreviations: CCS, carbon dioxide capture and storage; CHP, combined heat and power; CO_2-eq, equivalent CO_2 emissions; DC-SE, Direct Combustion Stirling Engine; DH, district heating; DHW, domestic hot water; GSHP, ground source heat pump; HWT, hot water tank; ICE, Internal Combustion Engine; IFGT, Direct Combustion Indirect Fired Gas Turbine; NZEB, Net Zero Energy Building; ORC, Organic Rankine Cycle; PE, primary energy; PEMFC, polymer electrolyte membrane fuel cell; PH, passive house; P/H, power to heat ratio; PV, photovoltaic panels; RES, renewable energy source; SE, Stirling engine; SPF, seasonal performance factor of the GSHP; STC, solar thermal collectors; SH, standard House; UG-SE, Updraft Gasifier Stirling Engine; WP-SE, wood pellet Stirling engine.

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1. Introduction

The building energy needs in the European Union represent 40% of the final energy consumption [1]. This indicates the potential to make buildings highly energy efficient. The recast of the EU Directive on Energy Performance of Building (EPBD) specified that by the end of 2020, all new buildings shall be "nearly zero energy building" [2]. Additionally, the International Energy Agency (IEA) joint Solar Heating and Cooling (SHC) Task 40 and Energy Conservation in Buildings and Community systems (ECBCS) Annex 52 titled "Towards Net Zero Energy Solar Buildings" is making an international effort on the standardization of the Net Zero Energy Building (NZEB) definition [3]. The NZEB definitions and the compatibility of proposed definitions with current national building codes and international standards are reviewed in [4]. Mainly four balance metrics are used to define NZEB by different twelve methodologies.

In the northern countries of Europe, dependency only on the onsite solar energy as a renewable energy source to achieve the annual balance of the NZEB faces many obstacles, such as the mismatching between the energy production and consumption [5] and the limited area of roof and/or façade, primarily in the dense city areas [6]. In Finland, the abundance of biomass (wood) as the highest renewable energy source share (22% in 2011 [7]) encourages the investigation of using micro and small-scale biomass-based combined heat and power (CHP) systems as energy systems to achieve the NZEB balance or even reduce dependency on onsite solar energy.

Some aspects that must be described to put the NZEB definition in a consistent framework are highlighted in [5]. The balance metric is a key of NZEB definition. It can be primary energy (PE), site energy, CO_2-eq emissions or energy cost [8]. Moreover, the exergy and emergy are proposed as metrics by [9,10], respectively. However, these exergy and emergy metrics are not common popular indicators. The primary energy, site energy, and CO_2-eq emissions are widespread metrics used in many research studies. For instance, using primary energy as a metric presenting standard, low, passive, nearly and net zero energy buildings in relation to economic perspectives is studied by [11–15]. A new and renovated net zero energy buildings are assessed using primary energy and life cycle assessment in [16]. Both primary energy and CO_2-eq emissions of passive and low energy buildings are presented in relation to electric heating, wood boilers and stoves, and heat pumps as variant heating systems [17]. However, a zero site energy home in UK is studied in [18]. In Serbia, a negative, zero, and positive-net residential building energized by electricity from the grid and from the photovoltaic panels (PVs) are studied using site energy metric balance [19]. In Australia, fulfilling the definitions of zero site energy and emission is presented using monitoring results of energy self-sufficient houses in [20]. CO_2-eq emissions as an optimal objective besides the economic objective for low energy building is used in [21,22]. Additionally, the economic perspectives of zero carbon homes in UK are studied in [23].

The debate about which is the appropriate metric, PE or CO_2-eq emissions, is pointed out by [17,24]. Obviously, the national decision about the metric to be used varies from country to country. For example, the code for sustainable homes in the UK sets a target for all new homes to be zero carbon by 2016 [25]. Currently in Finland, the Finnish building regulation codes D3-2012 [26] and D5-2012 [27] indicate national primary energy factors that have to be used for any new building.

This study investigates fulfilling four NZEB definitions according to four different weighting factors based on Finnish reference data by comparing the NZEB balance achievement by five conventional

Table 1
The Finnish and international weighting factors for different energy carriers.

NZEB definition	Unit	Weighting factors					Ref.
		Electricity	District heating	Wood pellet/wood chips	Light oil	Local renewable sources (solar)	
Finnish weighting factors							
NZEB-Finnish PE	$kW\,h_{pe}/kW\,h_{end}$	1.7	0.7	0.5	1.0	0	[26]
NZEB-site	$kW\,h/kW\,h_{end}$	1	1	1	1	0	[8]
NZEB-Finnish emission	$g_{co2}/kW\,h_{end}$	456	226	18	267	0	[28]
NZEB-cost	$c/kW\,h_{end}$	13.24	6.29	5.47	10.66	0	[30]
International weighting factors							
NZEB–IEA–PE	$kW\,h_{pe}/kW\,h_{end}$	2.35	0.77	0.14/0.06	1.3	0	[29]
NZEB–IEA-emission	$g_{co2}/kW\,h_{end}$	430	241	43/35	311	0	[29]