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ScienceDirect

Procedia Environmental Sciences 38 (2017) 554 – 561

Procedia Environmental Sciences

International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16

Embodied Energy and Nearly Zero Energy Buildings: A Review in Residential Buildings

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Abstract

Towards the EPBD recast 2010/31/EU and the nearly zero energy building (nZEB), this review addresses the whole life cycle energy analysis of residential buildings. Life Cycle Energy Analysis (LCEA) of 90 case studies of residential buildings is evaluated with a specific focus on the normalization procedure that follows the principles of Product Category Rule (PCR) 2014:02 for buildings. The normalization procedure provided a minimization of the sample by considering issues of comparability, the omissions in the boundaries of the system, the LCI method and the updating on the energy efficiency definition of the building. Results indicate that the use of different LCI methods leads to an important fluctuation in the absolute values of embodied energy as the embodied energy of an nZEB calculated with process analysis is lower than every case study calculated with hybrid input-output analysis without including nZEBs. The share of embodied energy in low energy buildings could reach up to 57% -or even up to 83% when renewable energy sources are used for electricity production- and in nZEBs up to 100% even though a significant reduction in the total life cycle energy is identified. The increase in embodied energy and a difference of at least 17% in the share of embodied energy between low energy and nearly zero energy buildings indicate that maybe LCEA should be considered in energy efficiency regulations along with further standardization.

Peer-review under responsibility of the organizing committee of SBE16.

*Keywords:*residential buildings;nZEB;LCEA;embodied energy

1. Introduction

Towards 2020 and the definition of the nZEB on a national level, according to the EBPD recast 2010/31/EU[1]

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Peer-review under responsibility of the organizing committee of SBE16.
doi:10.1016/j.proenv.2017.03.123

and the regulation 244/2012[2], member states of the European Union focus on fulfilling these requirements. The increased use of materials led to frameworks and concepts that consider not only the direct energy use but also the total life cycle energy of the building[3], by taking into account aspects such as the initial and recurring embodied energy[4,5], the transportation of the building's occupants[6] and the choice of materials[7]. This review examines the total life cycle energy of 90 case studies of residential buildings. The normalization procedure follows the principles of EN 15804:2012[8], EN 15978:2011[9], PCR 2014:02 for buildings[10] and ISO 14025:2006[11] in order to provide a common framework for the used metrics and the omissions in the boundaries of the system. The goal of this review is to examine the total energy intensity of residential buildings with a specific focus on the share of embodied energy through the whole life cycle of a building and towards the nearly zero energy building, as indicated also in international literature along with proposals for its standardization[6,12-16].

Nomenclature

nZEB	nearly Zero Energy Building
OE	Operating Energy
EE	Embodied Energy
LCI	Life Cycle Inventory
LCEA	Life Cycle Energy Analysis
LCA	Life Cycle Assessment
PCR	Product Category Rule
EPD	Environmental Product Declaration
PA	Process Analysis
I-OA	Input-Output Analysis
H-PA	Hybrid Process based Analysis
H-IOA	Hybrid Input-Output Analysis
RES	Renewable Energy Sources

1.1. LCA and LCEA

Life cycle energy analysis is used for the estimation of the total direct and indirect inputs and outputs of a building's life cycle. The calculation of embodied energy (manufacturing of materials, transportation, energy for the construction, maintenance, repair, replacement, energy for demolition and end of life management) and the addition of operating energy (cooling-ventilation, heating, lighting, how water and auxiliary systems) in order to expand the boundaries of the system provides the total energy intensity of the building (Fig. 1). Operating energy is defined by regulations on a national and international level. In embodied energy, even though its methodological framework is provided by the LCA method with ISO 14040:2006[17] and ISO 14044:2006[18], the LCI method for its quantification varies in the international literature between four main methods: process analysis, input-output analysis, process-based hybrid analysis and input-output hybrid analysis (Table 1). The LCI method appears to provide issues of uncertainty and significant differences in the calculated values of embodied energy with a 64% gap and underestimation between process and hybrid input-output analysis[19]. Furthermore, in LCEA issues of uncertainty and comparability -such as the boundaries of the system both in operating and embodied energy, the energy metric (primary or final), the year that a study is conducted along with the energy efficiency definition of the building and the functional unit (area and lifespan)- are identified[20]. In 2014 through the EPD framework PCR for buildings 2014:02, version 01, was published[10]. PCR is based on ISO 14040 and 14044, EN 15804 and EN 15978, promotes the basic structure and principles of sustainability, provides a common framework for the calculation of LCEA of buildings and appears to be a useful way for the calculation and presentation of LCEA results as indicated in case studies conducted by the same principles[20-23].