Building and Environment 103 (2016) 215–227

Contents lists available at ScienceDirect

Building and Environment

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

Simplification in life cycle assessment of single-family houses: A review of recent developments

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ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form
12 April 2016
Accepted 13 April 2016

Keywords:
Life cycle assessment
Simplified LCA
Environmental assessment methods
Environmental assessment impacts
Review

ABSTRACT

Life Cycle Assessment (LCA) is globally recognized as one of the most complete methods for environmental assessment of buildings. Literature assumes that its applications in the building sector are prejudiced regarding complexity and difficulty. However, simplification is necessary, since it can facilitate LCA application in buildings. Moreover, growing interest on reducing environmental impact in the building sector, as well as the relevance of single-family houses on CO_2 emissions have become key points on the wide spread of LCA. Therefore, this paper presents a research study about simplification in LCA recent studies applied to single-family houses. The review focuses on 20 cases that were analyzed according to ISO 14040, ISO 14044, EN 15978, and EN 15804 standards. The main objective was to identify the simplification strategies assumed in each paper, to clarify and to help to promote further developments on LCA. This paper examines system boundary definition, data sources, life cycle phases included, and environmental impact indicator calculated in case studies. Results show the variety of simplifications identified. They affect physical model definition, life cycle scenario definition and communication of results. In most cases, the functional unit was the complete building, the life cycle scenario definition included production, use and demolition phases, and the most considered environmental impact indicator was GWP. Finally, new challenges and recommendations were defined in order to establish common criteria to develop simplification strategies that allow results comparability in LCA of single-family houses.

1. Introduction

Current environmental problems have led to the development of measures for reducing the impact of human activities in the environment. These measures aim to control CO_2 emissions, improve efficiency and save resource consumption. The last COP21 -also known as 2015 Paris Climate Conference- reinforced global compromises to reduce Global Warming and concluded by the signature of an agreement for reducing Carbon Emissions [1]. The building sector represents 19% of all global 2010 GHG emissions [2]; as well it is also a major consumer of natural sources [3]. Moreover, single-family houses have an important role in reducing environmental impacts of the building sector, since for example 60% of the EU CO_2 emissions of residential sector come from single-family houses [4].

LCA is recognized as a useful method to assess environmental impact in the building sector. Wiessenberger et al. [5] demonstrated the growing interest in LCA of building by the increasing number of publications of scientific studies in the last 20 years. Cabeza et al. [6] review, also demonstrated the use of LCA in the building sector through the organization of a large number of literature that includes construction products, systems, buildings, and civil engineering constructions. Lotteau et al. [7] developed a critical review of LCA applications at neighborhood level. The review exposes the trend towards the application of LCA on an urban scale, although literature about the subject is still scarce. The study demonstrates the heterogeneity of methodological choices and also develops recommendations to promote future research.

Buyle et al. [8] review focused on building applications of LCA and evidenced that LCA involves making a model that simplifies

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Abbreviations: AP, acidification potential; BIM, building information modelling; CC, climate change; CED, cumulative energy demand; EPD, environmental product declaration; ET, ecological toxicity; GHG, green house gases; GW, global warming; HTP, human toxicity potential; LCA, life cycle assessment; LCI, life cycle inventory; LCIA, life cycle impact assessment; MRR, maintenance repair and replacement; PMF, particulate matter formation; WD, water depletion; POCP, photochemical ozone creation potential.

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http://dx.doi.org/10.1016/j.buildenv.2016.04.014
0360-1323/

reality. Various LCA studies recognize that complexity and uncertainties are barriers for the widespread use of LCA of the built environment [9,10]. Moreover, "typical" applications of LCA in buildings are admitted as time-consuming and complex processes [11]. In the European Context several projects have been developed aiming to adapt LCA methods to the building sector. Moreover, the standardization work on LCA of buildings -CEN TC 350- defines EN 15804 [12] and EN 15978 [13] standards; and provides a methodological framework of the information to be included, stages and communication of results [14]. However, the advances identified on LCA of buildings, studies about simplification strategies focusing on single-family houses are still scarce.

It is assumed that application of the LCA method necessarily involves the simplification of reality; the challenge is the definition of a model so that simplifications do not considerably modify the final results [15]. Several studies [9–11,16–19] recognize the need of reliable simplifications in the application of LCA methods in buildings; especially to extend the scope to early stages of design, reduce effort in data acquisition, enable comparability of results, and allow results to be interpreted independently from the degree of specialization of the technicians. The key aspect is to know how simplifications can modify the representativeness of the results.

Therefore, this paper analyses recent developments in the application of LCA in single-family houses, focusing on methodological aspects and simplification strategies according to ISO 14040 [20], ISO 14044 [21], and EN 15978 [13] LCA standards. The main objective was to identify the simplifications and modelling assumed on each study, to clarify and to help promote further developments on LCA. Twenty selected cases are included in the following review. Some of them are complete building LCA application and others are focused on representatives systems, elements or parts of the building.

2. LCA applied to buildings

2.1. Barriers on LCA applied to buildings

The LCA method is based on the quantification of environmental impacts of a product throughout its life cycle, from "cradle to grave" [20,21]. In general terms, ISO 14040 standards establish the stages for LCA application. LCA approach adapted to building is defined in EN 15978 [13] that represents a methodological guide for the quantification of environmental impacts on buildings.

EN 15978 [13] is organized according to the "modules principle" of building life cycle, including the four stages of life cycle –product, construction, use, end of life- [13,19]. These stages and modules are shown in Fig. 1 and cover from A1 to C4 "impacts and environmental aspects" developed within the system boundary, while D modules cover benefits and loads that go beyond the system boundary.

The standards also provide the guidelines for functional unit, system boundary and scenario definitions. The functional unit is a "quantified performance of a product system for use as a reference unit" [21], and it includes the physical and functional characteristics of the building. System boundary limits the processes included in the assessment. The scenarios are hypothesis applied to the subject of study that relates physical characteristics with time variable [13]. EN 15978 [13] also defines the structure of results communications and a list of environmental indicators that have to be considered as shown in Table 1. Results have to be expressed according to the list of indicators included in Table 1, separated by stage (production, construction, use, end of life, recycle) and by modules (A1-D) [13].

EN 15804 [12] provides calculation rules for Environmental Product Declarations (EPD) and it also includes a methodological framework of Modules A1-A3 of EN 15978 standard [13]. Otherwise, the EPD of building products can be used as product stage modules in EN 15978 [13]. Passer et al. [22] shown the growing interest in EPD of building products, evidenced by the high number of EPD programs that guide CEN/TC 350 standards "Sustainability of construction works".

In the European context the application of LCA method in building sector is promoted by several projects as: REGENER [23], Annex 31 IEA [24], PRESCO [25], IMPRO-Building [26], ENSLIC Building [27], LoRe-LCA [28] and EeB Guide Project [14]. The EeB Guide Project [14] defines three types of LCA in buildings: Screening, Simplified and Complete. The classification is developed according to system boundary definition, the experience of the practitioner, data availability and the state of development of the product or building being assessed [14].

EeB Guide Project [14] also establishes a life cycle stages definition for each LCA study types. For Complete LCA study, all stages and modules defined in EN 15978 [13] are compulsory. In Screening and Simplified LCA types, several stages and modules are optional; depending on the relevance and data availability. For Screening LCA only the following modules are compulsory: Product stages for the building envelope, structure and foundation (A1-3), Operational use of energy (B6) and water (B7). For Simplified LCA type, in addition to compulsory modules considered in Screening type (A1, A2, A3, B6 and B7), the use and end of life stages are also partially included; modules as Replacement (B4), Waste treatment (C3) Disposal (C4) and Benefits (D) are even considered compulsory [14].

Despite the fact that LCA is the most complete tool for the environmental assessment of buildings, their application in buildings is not yet widespread. Some of the main difficulties are the extensive and exhaustive amount of information required, as well as the required experience of the practitioner for calculating impacts [17]. Moreover, architects and technicians involved in the early stages of the design have prejudices about the complexity, precision and arbitrary results [17].

Another difficulty in LCA application is the existence of different methods for impact calculation, so depending on the method different results for identical cases [8] can be obtained. Each method has differences in weighting impact categories; this can lead to different measures for reducing environmental burdens [8].

2.2. Simplifications in LCA

In the Spanish context, 150041-1998EX UNE [29] establishes general criteria to simplify the LCA method. The regulation establishes the simplifications that can be carried out in the life cycle inventory phase and the life cycle impact assessment phase. It means that the life cycle inventory analysis can be reduced to the main elements and processes, and the impact assessment phase can be simplified to a few impact categories –mandatory and optional- [29]. Zabalza et al. [17] assessed a residential building in Spain by developing a simplified LCA method. The study focuses on the calculation of operational energy consumption and CO_2 emissions.

Relevant research papers about LCA of residential buildings and building materials have also simplified the application of LCA. Malmqvist et al. [9] recommend for simplifying the LCA method of buildings: (1) reducing the data acquisition phase –e.g. focusing on larger building elements-, (2) simplifying inventory analysis –e.g. focusing on the most important substances that contribute to a certain impact category-; (3) simplifying the calculation by focusing on a few impact categories and finally, (4) reducing the time of data applications by using CAD applications.

Time-reduction of data acquisition strategies are developed in Basbagill et al. [11]. In this study, the uses of Building Information Modelling (BIM) applications to quantify building materials were developed to assess a residential building in USA. The study proposes a method that integrates BIM, LCA, energy simulation, Maintenance, Repair and Replacement (MRR) schedule, and