Energy and Buildings 76 (2014) 551–557

Contents lists available at ScienceDirect

Energy and Buildings

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

The convergence of life cycle assessment and nearly zero-energy buildings: The case of Germany

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ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form 4 February 2014
Accepted 9 March 2014
Available online 24 March 2014

Keywords:
Life cycle assessment
LCA
Life cycle view
Nearly zero-energy buildings
Historical development
Overview

ABSTRACT

This paper presents the historical development and background of life cycle assessment (LCA) and nearly zero-energy buildings in Germany. In order to plan and build responsibly for the future, it is necessary to have an overview of the topic at hand. Final energy demand during the operational phase of buildings has fallen steadily. According to European Union guidelines (2010/31/EU), starting in 2021 new buildings must achieve the nearly zero-energy standards. These buildings will have very low operational energy demand. As a consequence of this requirement, the relative impact of construction and disposal increases in terms of the entire life cycle. This is also the case currently for buildings with low operational energy demand. The research – based on a literature analysis and review – shows that LCA has existed since the 1970s as a tool to judge potential environmental impacts. Moreover, the energy building standards in Germany have developed continuously since 1977. This process will continue in the new German Energy Saving Ordinance in 2014, which will be tightened even further in 2016. As LCA is well established and sustainable buildings are becoming increasingly common, the next indispensable step is to consider the life cycle view of nearly zero-energy buildings.

1. Introduction

The two major challenges in the construction industry are the increasingly scarce raw materials that must be managed responsibly, as well as the energy efficiency and sustainability of the building stock. Thus building in a sustainable and energy-efficient manner is becoming increasingly important. In the future, this will dominate the building sector.

The global ecological footprint of humans, which considers human resource use, has increased by 80% from 1960 to 2000. Presently, every year 1.2 times more resources are consumed than can be renewed in the world [1]. The scarcity of natural resources is reflected in increases in the price of raw materials and natural substances. In Germany for example, the price of oil and gas has risen 5.4 times since 1995. Furthermore, in the last 10 years the price of reinforced concrete has nearly doubled and the price of copper has grown by a factor of 2.4 [2]. The construction and building sector accounts for the highest rates of resource consumption – renewable and non-renewable – through construction, utilization and disposal of residential and non-residential buildings. This has many environmental impacts. For instance, the construction industry requires a major amount of material (1), (3) and energy (2):

(1) ~50% of the world's processed raw materials [3],
(2) ~40% of the total energy in the European Union (EU) [4] and
(3) ~50% of total German waste [5].

Due to demographic change and the increasing costs of utilities, numerous buildings are renovated or entirely reconstructed. Furthermore, this effect is encouraged by the socially and politically supported energy transition (*Energiewende*) and the increasing use of renewable energy. Moreover, about three quarters of the German building stock is more than 35 years old [6]. These buildings were built without legal requirements for energy savings and energy efficiency [6].

For several decades, the reduction of energy consumption has progressed step by step, driven by research in the field of architecture and building services engineering and by improvements in

Abbreviations: LEGEP, German abbreviation for life cycle-building-design (Lebenszyklus-Gebäude-Planung); GaBi, German abbreviation for holistic balanced design (Ganzheitliche Bilanzierung); SimaPro, system for integrated environmental assessment of products; SBS, sustainable buildings specifier.

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http://dx.doi.org/10.1016/j.enbuild.2014.03.028

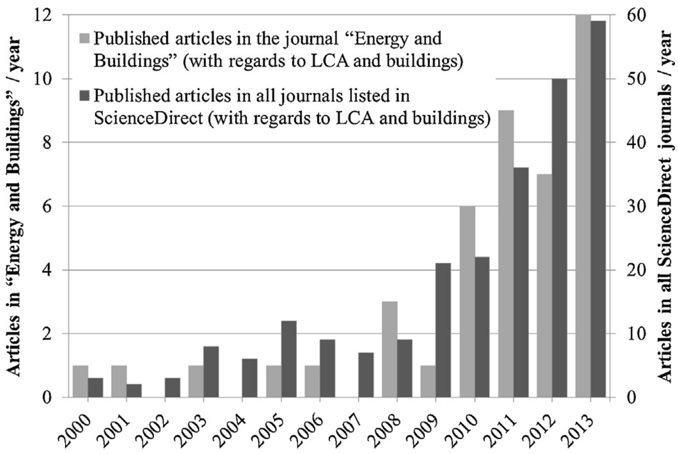

Fig. 1. Development of published articles, from the scientific databank ScienceDirect [23] by using the search keys "Life cycle assessment", "LCA" and "Building" in the category "Abstract, Title, Keywords" (all journals Elsevier).

construction practices. The energy consumption of buildings has been substantially reduced during this period as shown by Erhorn-Kluttig et al. [7] and by Hegger et al. [8] as well as by Fisch et al. [9]. Likewise, the use of life cycle assessments (LCA) is a result of research and development (e.g., the workshops of SETAC (Society for Environmental Toxicology and Chemistry) [10,11]). Today, a comprehensive ecological evaluation of buildings is possible. This clearly shows that successful practical research and development can effectively influence the building sector toward the goal of sustainability.

Recently, researchers [12–27] have shown an increased interest in analyzing buildings through LCAs. This fact is also shown in Fig. 1. The histogram indicates the number of published articles related to LCA and buildings in this journal as well as in all journals listed in ScienceDirect (Elsevier) [28]. The case studies (e.g., see above) and review papers (e.g., see [29–33]) mostly survey buildings without presenting the historical progress of LCA and building standards. Furthermore, there is very little information available on the process of the development of life cycle assessment and nearly zero-energy buildings in Germany.

Considering the wide range of opportunities to save energy and materials, the building sector could make a significant contribution. Thus, all parties (architects, building designers, building owners, etc.) have a social responsibility to plan, build, operate and dispose of buildings in a resource-saving and energy-efficient manner. In this context it is an advantage to have a historical overview of the topic at hand in order to combine these factors into a holistic view of the entire life cycle of the building.

The main ecological aspects of energy-efficient buildings are the lowest possible impact to the environment during their life cycle and the minimization of resource and energy consumption as well as land use [34]. The focus of this paper is on resource and energy consumption of various types of buildings (i.e., residential and commercial); land use is not part of this study. The main aim is to provide a detailed description of the history, the current situation and the future outlook regarding LCA and nearly zero-energy buildings. The research method used is a thorough literature review of mostly peer-reviewed papers and standard specifications.

2. Life cycle assessment (LCA)

2.1. 1970s–2000s: the past

Before the beginning of the modern era, humans primarily used natural (i.e., renewable resources) [35], thus environmental problems prior to the industrial era generally remained localized [36]. From the 19th century onwards, consumption, especially of non-renewable resources, constantly increased due to the commencement of industrial development and a change in life styles [35,36]. Since the 1960s, awareness about the limitation of natural resources has been growing [36]. Therefore, the resulting evidence of the limited capacity of nature of the energy supply and increasing waste problems are the two most important reasons for the development of LCA in the late 1960s and early the 1970s [11].

However, the first approach to a holistic consideration of energy and material flows came into being in approximately 1884 [37]. The Scotsman Patrick Geddes fundamentally improved the efficiency factor of coal use together with the upstream processes [37]. Considering that this was the first attempt to introduce LCA as a method, the current applied methodology for LCA is relatively young. According to Hunt and Franklin [10], the first modern LCA was created in 1969 by the Midwest Research Institute in the United States (U.S.) for the Coca-Cola Company. In this study, various beverage packaging materials were ecologically analyzed. Hunt and Franklin [10] mention also that the results were never published because of its confidential content. At the beginning of LCA packaging and especially the amount of waste were given prominence [10]. The information of energy consumption and environmental pollution of ecological considerations were given only incidental attention at this time [10]. In 1972, the Battelle Institute in Frankfurt am Main in Germany was first to analyze beverage packaging from an environmental point of view [38]. At almost the same time in Europe, various institutions also became occupied with the ecological balance of products [10]. There were LCAs in the United Kingdom, Switzerland and Sweden [11], and mainly packaging systems and materials were analyzed and evaluated.

The LCA then called "Resource and Environmental Profile Analysis (REPA)" provided the foundation for the current calculation methodology [10]. The term life cycle analysis was used in the U.S. for the first time in 1990 [10]. Life cycle assessment, ecological balance and ecobalance are more synonyms that are used to describe the methodology or rather the idea of cradle to grave. In the meantime, the term life cycle assessment (LCA) has been established internationally.

All involved participants became aware relatively quickly that the results of the REPA depended not only on the data collection, but also, for example, on methodology that was applied to the life cycle impact assessment or the conditions of the system boundaries [39]. For these reasons, among others, the process of an international standard was expedited at various conferences and workshops by SETAC [10,39]. This preliminary work was the background and basis [38,39] for the first series of standards which appeared between 1997 and 2000 (ISO 14040–ISO 14043 [40–43]). In 2006 – after these standards had been revised – content changed little [44], but the standard specifications were restructured. ISO 14040 (1997) [40], ISO 14041 (1998) [41], ISO 14042 (2000) [42] and ISO 14043 (2000) [43] were divided into the classification (ISO 14040 [45] and ISO 14044 [46]) that is used currently. Henceforward, the ISO 14040 [45] contains no binding instructions and these requirements are combined in ISO 14044 [44,46]. Today, LCA is the only internationally standardized method for the analysis and judgment of environmental aspects and their potential consequences [11].

2.2. 2010s: the present

In the early days of LCA studies, calculations were performed without the aid of modern computers [10]. This made, according to Hunt and Franklin [10], balancing and analysis very time consuming. For the first time in 1973, the U.S. used a computer program for LCA by using punch cards [10]. Nowadays, there are different calculation programs (e.g., LEGEP [47], GaBi [48], SimaPro [49],