Energy and Buildings 80 (2014) 585–597

Contents lists available at ScienceDirect

Energy and Buildings

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

Design of a multipurpose "zero energy consumption" building according to European Directive 2010/31/EU: Life cycle assessment

Umberto Desideri [a,*], Livia Arcioni [a], Daniela Leonardi [a], Luca Cesaretti [b], Perla Perugini [a,b], Elena Agabitini [a,b], Nicola Evangelisti [a,b]

[a] University of Perugia, Department of Engineering, Perugia, Italy
[b] Municipality of Città della Pieve, Città della Pieve, Italy

ARTICLE INFO

Article history:
Available online 29 May 2014

Keywords:
Building life cycle
Life cycle analysis
Sustainability
Zero energy building
Energy efficient building

ABSTRACT

The Municipality of Città della Pieve in central Italy, promoted the creation of a "Renewable Energy Park" in a deprived area of its territory, to provide a space where the main technologies for the production of green energy could be installed. An educational/demonstration "zero energy consumption" building for multifunctional activities will also built with the most innovative techniques to save energy. This paper presents the results of the life cycle assessment (LCA) of the "zero energy consumption" building for a useful life of 50 years. All life cycle phases were included in the research: acquisition and production of materials, on-site construction and use/maintenance, demolition and material disposal. Moreover, a few different disposal scenarios were considered. The LCA modeling was performed using the SimaPro software application, connected to the Ecoinvent database. The environmental impact of the zero energy consumption building was assessed by using specific indicators.

1. Introduction

The energy crisis of the 1970s, and the growing problem of waste disposal led, in the late eighties, to the development of instruments to monitor, control and verify the environmental compatibility of human activities.

In Europe, 30–40% of the current total energy demand and approximately 44% of the total material use are due to the building sector which is a significant percentage of the total environmental load of human activities [1]. For this reason, the assessment of the building sector's impact is a priority for the achievement of a sustainable society and it is an issue generally addressed by most environmental policies. However, such analysis has been developed mainly for single products design. Compared to these products, buildings are totally different. As a matter of fact, they have a relatively long life, they are often subject to change, they may have multiple functions, they are not mass-produced, they are integrated with infrastructures and thus they do not have clearly defined boundaries, etc. For all these reasons, the life cycle analysis of a building (LCA) is not a simple process as for many other consumer goods [2]. As a matter of fact, a building can be defined in three different ways: a "product", or more exactly a complex combination of manufactured, used and disused products; a "process", because through its operation, it is intended to provide services to users; a "place to live", for which it is particularly important to assess the impact on the users health and comfort [3].

All life stages of a building (construction, operation/use, maintenance and recycling) contribute to the cost and environmental impact of the same [4]. His LCA analysis allows to understand on which of these phases is better to invest to reduce the overall environmental impact [5]. For example, by adjusting the recycling phase, it is possible to reduce greenhouse gases emissions and to reduce the environmental loads associated with energy consumption [6,7]. In addition, another factor that affects consumption, is the choice of building materials. Indeed, products intended for the same application, but with slightly different properties, can cause different energy consumption. However, in most cases, the analysis refers only to the energy used during the operation/use phase, ignoring the aspects related to the construction and delivery of the building [8].

Even if many European countries have developed a process of energy certification for residential and commercial buildings, the indicators considered for the energy qualification are not calculated with an LCA approach. However, the LCA approach is necessary to improve the environmental performance of the construction sector and thus to reduce the environmental global load [2].

* Corresponding author. Tel.: +39 0755853743; fax: +39 0755853703.
E-mail address: umberto.desideri@unipg.it (U. Desideri).

http://dx.doi.org/10.1016/j.enbuild.2014.05.027
0378-7788/© 2014 Elsevier B.V. All rights reserved.

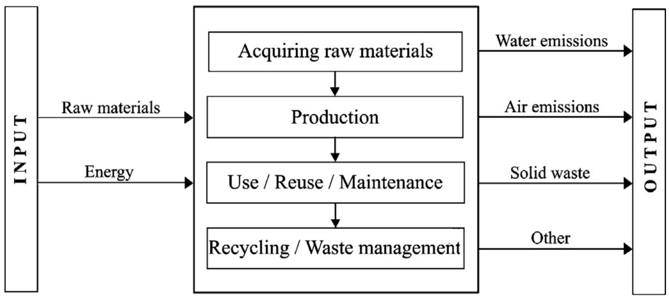

Fig. 1. Life cycle of a product.

To perform the LCA of a building, two major approaches can be lined out: a "bottom up" approach focusing on building material selection and a "top down" approach which considers the entire building as a starting point for further improvements. In this second case, if the operation phase shall be included, the environmental impact from the operation phase has to be estimated in relation to a generic context and then distributed down to the building material or to the building component level [1].

This paper describes the LCA study of a multipurpose building whose consumption and characteristics are given in "Design of a multipurpose 'zero energy building' according to the European Directive 2010/31/EU: architecture and plant solutions" [9]. In particular, the aim is to verify that a zero energy consumption building, i.e. a building in which the total amount of energy used is generated on the site by renewable sources [10,11], also represents the solution with the lowest environmental impact [12,13]. For this purpose, five different solutions, already developed to analyze the multipurpose building from the energy point of view [9], have now been analyzed in terms of environmental impact as detailed below.

2. Calculation methodology

The LCA methodology allows the evaluation of the life cycle of an activity, process or product based on all the phases of its existence (pre-production, production, distribution, use, recycling and final disposal) to identify the interactions and the effects it produces on the environment (Fig. 1) [14].

In this way it is possible to perform a transparent and detailed analysis of the studied system retracing, in a critical manner, the process that has led to the determination of the environmental impact of the above system. Examining the life cycle of a product "from cradle to grave" is important because the benefits obtained working on the single phase can be balanced in a negative way by the problems caused in the other phases. Furthermore, the global view of the cycle enables to improve its efficiency, even only reorganizing its components. The guidelines for the LCA analysis are the ISO 14000 series standards on the environmental management systems (EMS). In particular, among such guidelines the following are remembered for their importance:

- UNI EN ISO 14040:2006 Environmental management – life cycle assessment – principles and framework [15];
- UNI EN ISO 14044:2006 Environmental management – life cycle assessment – requirements and guidelines [16].

Along with these standards, different software has been developed. Through them it is possible to perform the analysis of environmental impact. In particular, the study was carried out through the SimaPro 7.1 software, an acronym for "System for Integrated Environmental Assessment of Products" [18,19]. The program allows to collect, monitor and analyze the environmental performance of products, services and anthropogenic activity through a transparent and systematic method. This method was conceived according to the UNI EN ISO 14040 and UNI EN ISO 14044. The software provides several databases that include a large number of processes and materials (e.g. Ecoinvent v2 which includes a large number of Switzerland and Western Europe processes, U.S. Input Output database with more than 400 sectors of the U.S. economy, etc.) and different methods for the results analysis and presentation. In SimaPro 7.1, to realize the analysis it's necessary to define, first of all, the assemblies, i.e. the materials used. These materials are defined in the inventory of the software or they are entered manually by the user. The assemblies are then combined together to define the functional unit. In the first phase of the analysis, assembly phase, the impact (score) of the functional unit is calculated, through the method chosen, considering only the materials and it is express in Points. In the second phase, i.e. LCA, the analysis of the functional unit is repeated. This time, however, the analysis takes into account not only the materials, but also the energy consumptions, the required maintenance during the service life, 50 years according to the national technical standards for construction [17], and the disposal of the functional unit at the end of the service life. For this study has been chosen the Eco-Indicator 99 method to determine the environmental impact of the building [18,19].

This method is one of the most popular in Europe and allows the interpretation of the results of an LCA analysis using specific parameters, eco-indicators, that consider emissions and land use in Europe [20]. In particular, the purpose of the Eco-indicator methodology is to assess the impact of a life cycle by estimating a single environmental index that quantifies emissions and consumption of any process. To achieve this, the inventory data are divided into three damage categories, i.e. endpoints:

- **Human health**, whose damage is expressed in DALY (disability adjusted life years) that measures the overall disease burden connected to environmental aspects. In particular, it is expressed as the number of years lost due to ill-health, disability or early death;
- **Ecosystem quality**, assessed in PDF m^2 year (potentially disappeared fraction of plant species) measuring the percentage of extinct or endangered plant species for an area and in a certain period due to changing environmental conditions;
- **Resources**, estimated in MJ surplus energy, i.e. extra energy demand that can balance a future reduction of mineral resources and fossil fuels.

Each endpoint is then divided into a different number of impact categories, i.e. midpoints that represent an indicator that is somewhere along the environmental mechanism and the LCI parameter [18–20]. In particular, the midpoints impact categories, or problem-oriented approach, translate impacts into environmental themes such as climate change, acidification and human toxicity. For the human health category damages are caused by this midpoint categories: carcinogens; respiratory organics; respiratory inorganics; climate change; radiation and depletion of the ozone layer.

Ecosystem quality, instead, is divided in the following impact categories: ecotoxicity; acidification and eutrophication and land use.

Finally, in resources category, damages are caused by: mineral depletion and fossil fuel depletion.

The results evaluation, according to the different category indicators, is conducted in the characterization phase. In this phase the results are converted, according to appropriate characterization