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An overall methodology to define reference values for building sustainability parameters

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ABSTRACT

The paper presents a methodology to define reference values regarding building environmental impacts, energy outputs, and global costs. Four exemplary Italian residential categories were analyzed, focusing on the recent existing stock and on the most common kinds of houses. Buildings were subjected to Life Cycle Assessment (LCA) analyses, through SimaPro software, in order to define specific values linked to the environmental impacts and to the total energy spent. The amount of energy related to the use phase, including heating, domestic hot water, and cooling systems, was estimated by using the energy simulation program EnergyPlus. Building economic performance was analyzed through Life Cycle Costing (LCC) analyses, with the global cost approach. The results showed that the use phase implied the largest contribution to the environmental and energy impacts; instead the pre-use phase was predominant in life cycle costs. Furthermore, since a considerable amount of consistent data was used for this study, the outcomes could be treated as reliable for the definition of benchmarks. For instance, the results indicated that, during the whole life cycle, Italian residential buildings could spend around 140 kWh/m^2, with a production of about 35 kg CO_2 eq/m^2 each year, reaching a global cost of nearly 1420 €/m^2.

1. Introduction

Since the 1990s, due to the growing attention to sustainability topics, the building sector began to recognize its potential impacts on the environmental, social, and economic spheres. All around the world, laws and policies started to incentivize the use of innovative products and processes to encourage the achievement of a sustainable built environment. Indeed, the improvement of the whole quality of buildings represents a required process on the way to an increasing awareness of both the environment and resource limits. To this aim, the development of methodologies to evaluate the building energy and environmental impacts is a concrete necessity. During the last two decades, many of these methods were developed, showing a considerable utility to assess, rate, and certify the energy and, more generally, the sustainability performance of buildings. Specifically, the construction sector was characterized by the spread of two kinds of sustainability assessment tools. The first group, mainly diffused in the research field, contains those tools that are based on the Life Cycle Assessment (LCA) methodology, such as: Eco-Quantum (Netherlands) [1], EcoEffect (Sweden) [2], Envest2 (U.K.) [3], BEES (U.S.) [4], ATHENA (Canada) [5], SimaPro (Netherlands) [6]. The second group, more common in the practice of the construction world, refers to criteria-based tools, which rely on the evaluation of several criteria, leading to the definition of a total building sustainability score. Among the criteria-based protocols, the most common are: BREEAM (U.K.) [7], LEED (U.S.) [8], CASBEE (Japan) [9], DGNB (Germany) [10], HQE (France) [11]. Furthermore, both the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) worked actively, during the last years, to delineate specific standard requirements related to the environmental and sustainability assessment of buildings. Particularly, the ISO instituted a technical committee, the ISO/TC 59 'building construction', to publish technical specifications on construction sustainability with a focus on the development of indicators for buildings and on the evaluation methods of environmental and economic efficiency. Moreover, the Technical Committee ISO/TC 207, 'environmental management', with the Subcommittee SC 5, 'life cycle assessment', was also instituted, in order to deal with requirements and guidelines to conduct LCA studies. Instead, the CEN established the Technical Committee CEN/TC 350, 'sustainability of construction works', which aims to define uniform methods for assessing sustainability aspects of new and existing buildings and to develop standards for Environmental Product Declarations (EPDs).

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The first generation of sustainability assessment tools accompanied the spread of the building energy certification schemes, which emerged in the early 1990s leading to a wide discussion on the benchmarking of buildings from an energy point of view [12]. Mainly this resulted from the high energy expenditure of the construction sector, which is responsible for around 40% of the global consumption in Europe [13]. Buildings employ energy throughout the whole life cycle, ranging from the construction phase to the use and the end-of-life phases. Many research works [14–18] pointed out how the main amount of the total energy spent during the life cycle is mostly related to the use phase. However, as emphasized by various studies [19,20], the energy consumed during the other life phases, particularly for low and zero energy buildings, is evidently increasing, reaching a high percentage of the energy amount characterizing the entire life cycle. Therefore, the overall energy use evaluation of buildings is gradually spreading beyond the use phase, with the evaluation of the embodied energy, linked to the resource extraction and construction activities, along with the building disassembling and waste disposal. As a result, an approach that takes into account all building stages is manifestly necessary for the definition of the overall sustainability level. In this regard, life cycle-based building assessment tool are needed, as well as the use of recognized objective methods, such as the LCA and life cycle costing (LCC) methodologies.

In the standards ISO 14040 and 14044 [21,22] LCA is defined as: 'a technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases'. Due to the multifaceted interaction between the built and the natural environment, LCA constitutes a complete and wide approach for the evaluation of the environmental outputs of a building, based on the definition of the specific material and energy flows. LCA was used in construction sector since 1990s, although its application in this sector is still characterized by a lack of standardization, compared to other fields. This is not only related to the complexity of a building itself, but also to other specific factors that contribute to make this field unique compared to other processes or products.

In the ISO 15686-5 standard [23] LCC is defined as: 'a methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope. Life-cycle costing can address a period of analysis that covers the entire life cycle or (a) selected stage(s) or periods of interest thereof'. The aim of LCC analyses on buildings is the estimation of the costs, during the whole life cycle, to be used as input of a decision making or evaluation process. Nevertheless, costs occurring at different periods of the building life cannot be combined directly, due to the varying time value of money. To this aim, economic evaluation methods are needed, such as, the Net Present Value (NPV) technique, which is one of the most used for LCC studies on buildings [24]. Despite the rise of LCC analyses on constructions, mostly related to the cost-optimal approach [25,26], the adoption and application of this methodology in the building sector is still restricted. Finally, for both LCA and LCC, standardized input data and calculation are highly necessary to obtain comparable and meaningful results. In this respect, although numerous attempts for harmonization and normalization were recently done to support the application of these methodologies [27], other investigations are strongly needed.

In recent years, a new approach for defining building sustainability level regarded the attempt to consider energy, LCA and LCC issues in an integrated manner. Indeed, a growing number of building assessment methodologies [28,29] started to include pre-use phase energy analyses, along with environmental and economic evaluations, throughout the entire lifecycle. This new approach clearly required the development of appropriate benchmarks for energy and environmental outputs, as well as for economic performance, with reference to all building life phases. A noteworthy example of the process towards the definition of benchmarks for BNB/DGNB sustainability assessment system is properly illustrated in [30].

In this study, four Italian representative building categories, derived from the recent European project TABULA [31], were analyzed. The aim was to define reference values for several sustainability parameters, such as: total energy, environmental impacts, and global costs. In the next section, the methodology is defined, firstly presenting the case studies and the specific building archetypes investigated. Afterwards, each sub-section introduces the different analyses performed, with a description of the data and the assumptions adopted. Finally, the last section concludes with a presentation of the results and a discussion on the possible implications.

2. Methodology

To evaluate some specific building sustainability-related parameters an overall methodology was developed and its main steps are shown in Fig. 1, which lists: input data, analyses performed, and results pursued.

The analysis of the initial information available in TABULA project led to the choice of some specific data to take into account for the paper aim. The analyzed buildings were chosen in the after-2005 construction period, so that they all presented the typical envelope construction components of the most recent period. Precisely, several building archetypes were built such that they were all characterized by the same shell elements and they were differentiated on the basis of the combination of three variables: the building typology (i); the climatic zone (j); the building systems (heating, cooling, and domestic hot water (DHW) plants) (k). Moreover for each archetype two models were analyzed, Model 1 (M1) and Model 2 (M2), which differ in the evaluation method of envelope thermal bridges. The building archetypes were subjected to three main analyses: (1) 'use phase' energy evaluations, through dynamic energy simulations performed with EnergyPlus software; (2) life cycle impact assessments, with the application of LCA methodology through SimaPro software; and (3) life cycle cost assessments, by means of economical evaluations based on the global cost approach, as suggested in EN 15459 [32]. First, the analyses related to the use phase energy demand were performed and then the results were integrated within the LCA and LCC analyses, leading to the final definition of the investigated specific indicators.

2.1. Case studies

The case studies were derived from TABULA project, which provides the definition of the Italian residential building types, aiming to represent specific building categories with their average energy performance and potential savings. The most common kinds of Italian constructions are considered, namely: single-family house (SFH), terraced house (TH), multi-family building (MFH), and apartment block (AB). Buildings are gathered in eight different construction periods (before-1900, 1901–1920, 1921–1945, 1946–1960, 1961–1975, 1976–1990, 1991–2005, after-2005) and are analyzed in a middle climatic Italian zone (2100–3000 degree-days (DD)). The features of the building envelope elements and plants are in accordance to the specific construction age.

In this paper, the initial data provided by the TABULA project were used in conjunction with some modifications and extensions, in order to define several archetypes. The buildings were drawn from the most recent construction age established in TABULA (after-2005), where they are characterized by the typical Italian