Energy and Buildings 109 (2015) 230–244

Contents lists available at ScienceDirect

Energy and Buildings

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

An assessment of the relationship between embodied and thermal energy demands in dwellings in a Mediterranean climate

Beatriz Rosselló-Batle*, Carlos Ribas, Andreu Moià-Pol, Víctor Martínez-Moll

Engineering Group of Building and Energy Management, Physics Department, Universitat de les Illes Balears, Ctra. Valldemossa, km 7.5, E-07122 Palma (Majorca), Balearic Islands, Spain

ARTICLE INFO

Article history:
Received 15 May 2015
Received in revised form
23 September 2015
Accepted 1 October 2015
Available online 9 October 2015

Keywords:
Embodied energy
Final thermal energy demand
Primary thermal energy consumption
Construction materials
Residential building

ABSTRACT

Currently, climate change has become a research priority. In many countries, new regulations have emerged with the aim of reducing energy consumption and CO_2 emissions. In this work, 92 sub-scenarios were evaluated in a case study building. The final goal was to obtain the relationship between the thermal energy demand and the initial embodied energy (IEE) when a change was made in the building typology, taking into consideration ten different facades, three roofing systems, and three window frame types. The results showed that the use of injected polyurethane or extruded polystyrene in facades, and the replacement of timber in window frames by lacquered aluminium, provided increases of the primary IEE equivalent to the final heating energy requirements of a detached house for more than 5 and 10 years, respectively. The insulation of thermal bridges at the junction of external walls and concrete floor slabs caused increases in the primary IEE, which were observed to be within 1.17 and 12 times lower than the final annual heating requirements of the building when not insulated. Finally, an estimation of the primary thermal energy requirements was made, taking into account three different energy systems and a 50-year building lifetime.

1. Introduction

Climate change is now a major research priority. Since 1972, when the first declaration of principles on the environment emerged as a result of the Stockholm Conference [1], a great number of reports and projects have been developed in order to meet and solve the problems caused by human impact on the environment. Sustainable Development, defined in the Brundtland Report as the one which "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [2] clearly summarises its overall objective. The challenge to meet greenhouse gas (GHG) emissions reduction targets in an effort to reduce global warming, after the adoption of the Kyoto Protocol [3] resulted in the adoption of national plans and strategies by many countries. The European Commission established the objectives known as "20-20-20", where Member States should reduce GHG emissions by 20% from 1990 levels, increase the share of renewable energy sources in energy production by 20%, and reduce primary energy consumption through increasing energy efficiency by 20% [4]. The GHG emissions reduction target, which could be increased to 30% if international agreements are achieved, was complemented by the publication of a roadmap by the European Commission to meet reductions between 80 and 95% for the year 2050 [5]. The Energy Performance of Buildings Directive (EPBD) [6] of the European Parliament and the Council of the European Union, established that Member States should implement minimum requirements for energy efficiency in buildings and create a methodology for energy certification. Its adaptation into Spanish law resulted, among others, in the approval of the Basic Documents for the Energy Efficiency included in the Spanish Technical Building Code (TBC) [7] and of a series of certification tools as CALENER [8] or CE3 [9], among others.

The embodied energy originating from the building materials is a forgotten issue in national energy conservation plans. Several authors have emphasised this fact. García-Casals [10], for instance,

Abbreviations: BESTEST, Building Energy Simulation Test; CDD, cooling degree days; DA DB-HE/1, Support Document of the Spanish Technical Building Code, Building Envelope Parameters; DA DB-HE/3, Support Document of the Spanish Technical Building Code, Thermal Bridges; DB-HE1, Basic Document of the Spanish Technical Building Code, Limitation of the Energy Demand; CB, ceramic brick; COP, coefficient of performance; EER, energy efficiency ratio; EPBD, Energy Performance of Buildings Directive; EPS, expanded polystyrene; GHG, Greenhouse Gas Emissions; GF, ground floor; HDD, heating degree days; HU-tool, Unified Tool LIDER-CALENER; IDAE, Spanish Institute for Energy Diversification and Saving; IEA, International Energy Agency; IEE, initial embodied energy; IF, internal floors; ITeC, Institute of Construction Technology of Catalonia; LCA, life cycle assessment; LCI, life cycle inventory; MW, mineral wool; PUR, polyurethane; PVC, polyvinyl chloride; PW, partition walls; TBC, Spanish Technical Building Code; XPS, extruded polystyrene foam.

* Corresponding author.
E-mail address: beatriz.rossello@uib.es (B. Rosselló-Batle).

http://dx.doi.org/10.1016/j.enbuild.2015.10.007
0378-7788/

pointed out the fact that embodied energy assessment had not been included in building certification and regulations, and highlighted it as a crucial component in order to achieve sustainable buildings. This author demonstrated that an efficient house could present greater overall energy consumption during the building's life cycle (100 years) than a conventional one, if construction materials had been chosen without taking into account their embodied energy. Zabalza Bribián et al. [11] discussed the contradictions that arise when higher energy consumptions could be obtained for better energy classified buildings when a life cycle assessment (LCA) was carried out. Gustavsson and Joelsson [12] in a life cycle primary energy analysis of residential buildings compared conventional and low-energy buildings, and they observed that the reduction of energy needs during the operational phase of a building resulted in an increase of the energy use from the construction materials. These authors stated the necessity for a LCA in order to obtain an optimisation of the energy use of buildings. Blengini and Di Carlo [13] observed that carrying out a LCA on a low energy family house in Italy revealed the high contributions of construction materials and maintenance operations, whereas the building was considered as "sustainable" because of their energy efficiency in its operational phase. These authors also discussed about the benefit of using life cycle approaches in energy certification schemes. Stephan et al. [14] showed that the system boundaries for building energy certification in Europe do not always result in an overall reduction in building energy consumption. For net-zero energy buildings, Cole [15] affirmed that the embodied energy assessment is also commonly ignored in their design because all attention is centred in their operational phase. Chau et al. [16] highlighted too the need to include life cycle studies in the building design stages in order to improve the energy efficiency policies.

Building design has been traditionally ruled by economical, technical or aesthetic aspects, but building environmental performance has been rarely considered [17]. The changes observed in the embodied energy using different construction materials have been assessed in numerous studies. Buchanan and Honey [18], for instance, compared the variation in embodied energy modifying materials as concrete and steel by timber, in different types of buildings in New Zealand. Ramesh et al. [19] evaluated the embodied and the operating energy of a residential house using different thermal envelopes and considering five climate zones in India. Hacker et al. [20] evaluated the embodied and operational CO_2 emissions of a semi-detached house in England. These latter authors compared four different types of construction and they observed that the medium and heavyweight ones provided the greater reductions in life cycle CO_2 emissions. In regards to building typologies, Debnath et al. [21] evaluated the material energy content of single, double and four-storey residential buildings in India, observing a decrease with the height of the building. The size and typology were identified by Fuller and Crawford [22] as key parameters in the study of the energy use of buildings from a life cycle perspective. Additionally, Stephan et al. [23] investigated the effect of the size and typology of buildings on the life cycle energy use. These authors proposed a series of scenarios and they observed a reduction of the total energy consumption by replacing single storey detached houses with apartment buildings, in a low-density neighbourhood in Melbourne.

The interest in the improvement of buildings environmental performance is clearly reflected in current ongoing research studies. Nevertheless, there are gaps in the methods used [24,25] and difficulties to apply LCA standards [26–28]. As discussed by Crawford et al. [29] there is a lack of reliable and consistent information available for the building designers to improve the environmental performance of their projects. Along this line, Stephan et al. [30] developed a software tool for carrying out life cycle energy evaluations, to be used by building designers to improve environmental performance of residential buildings.

1.1. Aim and scope

The main goal of this study is to evaluate the relationship between the embodied energy and the thermal energy demand in buildings. This assessment focuses on residential buildings and employs a case study to carry out the calculations. In order to achieve the overall aim, a series of partial objectives were set:

- To study the variations of the final thermal energy demand and the primary IEE, caused by material replacement and change of building typology.
- To compare the variations of the primary IEE and the primary thermal energy consumption for a 50-year building lifetime.

Assessment on the effect of thermal bridge insulation was included in this study, as it is a much neglected issue in embodied energy studies.

2. Method

2.1. Overall approach

This study is based on the assessment of a project for a single-family detached house designed to be located in Spain. In this work, both an embodied energy and a thermal energy demand assessment were carried out, considering the possible replacements and modifications that could be made on this case study building. Consequently, a proposal of alternative building enclosures was first made up, creating three major categories: facades, roofing systems and windows. Nine alternatives were defined for the facades, taking into account aspects such as: the type of insulation, its position (external-intermediate), or substitution of concrete blocks by ceramic ones. For the roofing systems, replacement of the existing sloping type for two kinds of trafficable roofs (inverted/conventional) was proposed, while for the window systems, two alternative frame materials (PVC and lacquered aluminium) were considered.

All enclosure compositions considered in the study were based on the Catalogue of Constructive Elements of the TBC [31]. This catalogue was an initiative of the Spanish Ministry of Development in collaboration with the Institute of Construction Technology of Catalonia (ITeC) [32] and includes information about the characteristics of individual materials, construction systems and their hygrothermal and acoustic performances, all according to TBC requirements [31]. *U*-value calculations were performed by following the procedure specified in the DA DB-HE/1 (Support Document of the TBC) [33] for the calculation of characteristic building envelope parameters, published by the Spanish Ministry of Development. Thermal conductivity values of individual materials were obtained from the database included in the Spanish official energy certification tool used for the thermal energy demand assessment, the "Unified Tool LIDER-CALENER" (HU-tool) version 0.9.958.791 [34].

One of the objectives of this study was to observe the variations produced in the thermal energy demand values by making hypothetical changes to the building typology. To do so, it was made a prerequisite to reduce the particular differences between the different buildings. Accordingly, it was proposed to convert the original detached house into two other residential building typologies: a terraced house and a duplex in a multi-storey building. In this conversion, only the strictly required modifications of the structure, enclosures and windows were carried out, while the same interior distribution and building element composition were maintained.