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Economic implications of the energy issue: Evidence for a positive non-linear relation between embodied energy and construction cost

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ABSTRACT

The commitment toward energy efficiency has been taken seriously in several manufacturing sectors, specifically in the building industry. By the end of the seventies and during the early eighties, the research tackled the topic of the energy embodied in commodities and goods, the construction materials as well. In the last few years, embodied energy (EE) has gone back to be a prominent research field, due to the growing awareness that the energy initially used to produce goods and services might prevail in determining the whole amount of life-cycle energy. This is not at all surprising considering high-performance buildings as the passive houses.

Here we show that the EE level of several materials is already summarized by well-known and widely available parameters, namely their production costs or market prices. The ability to explain the EE level, through market data arising from production processes, sharply increases by dividing the building materials into clusters, according to their reference industry. The results show a logarithmic relation between EE and cost. Once the EE exceeds a certain threshold the cost increases more than proportionally. Therefore, the will to make rational consumption and production decisions entails the need to consider the energy-to-cost ratio.

1. Introduction

In a note published a few years ago [1], it has been argued that the adoption of advanced construction technologies could lead to saving an enormous amount of energy in comparison to the current use in US buildings, namely about 55% considering forthcoming technologies, up to 80% turning the gaze to those in early stages of development. Under a global perspective, although several improvements have been recorded during the recent years, other countries – not to say sectors – show an even greater energy-saving potential, especially those fast-growing [2], letting us take advantage of benefits beyond the economic sphere, as they directly affect the human health and well-being [3]. The aforementioned study [1] endorses the conclusion that, in the building industry, there should be a higher commitment to energy-efficient technologies and investments. Nevertheless, despite evidence for the saving potential on energy consumption are considerably increasing, a related issue still deserves further insights, since it appears to have been, at least partly, neglected. Indeed, it is known the trade-off (Fig. 1) between the energy demand for operation and the embodied energy (EE) [4–6], which constitutes a fundamental assumption of the research branch focusing on the relations between energy and economics [7].

Since the EE issue is rising importance and gaining attention, this study performs an attempt to extensively investigate the relations between the EE of a broad amount of construction materials and their production cost, as it results from market transactions. On the one hand, information about EE is gathered from the inventory developed by Hammond and Jones at the University of Bath [8,9]. On the other hand, data concerning production costs and market prices are collected by consulting a building materials price list [10], which is commonly used to assess construction projects by arranging their bill of quantities. Section 2 outlines a brief review of background studies dealing with this topic while the following Sections 3 and 4 provide further details on the data and their pre-treatment, as well as an insight into the analytical processing method. Section 5 presents the achieved results and Section 6 aims to discuss how the findings may drive the choices of firms and consumers.

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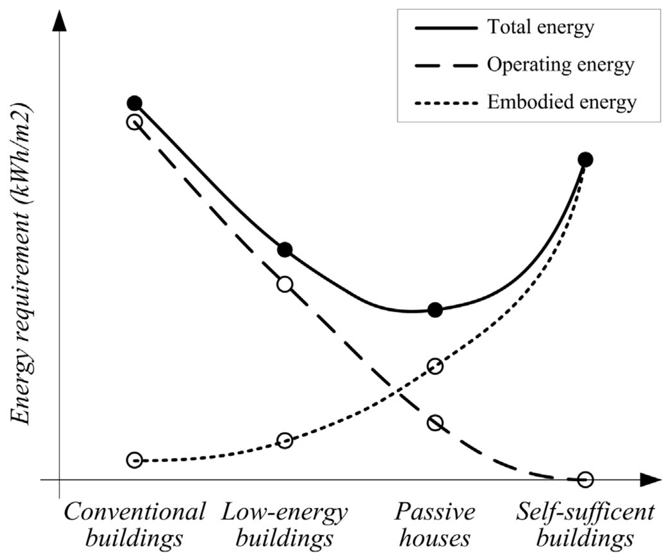

Fig. 1. The trade-off between embodied and operating energy for several kinds of buildings (adapted from Sartori and Hestnes [4] and Hammond [7]).

2. Background studies

In the recent past, most attention has been paid to the energy consumption intended for the building operation, because it is assumed to prevail [1,11]. Nevertheless, innovative construction materials, as well as rethought building installations, are progressively shifting the focus toward the EE topic [12]. These materials and installations are energy-efficient, but accordingly they – and their production process – have to be energy-intensive [4]. Therefore, a significant question now is as follows: shall we lower the energy consumption, in the building operation, whatever it takes? It may be not worthwhile if it entails a remarkable increase of the EE.

We are used to defining EE as the whole amount of direct and indirect energy needed to produce goods and services. Direct energy refers to that required by the manufacturing process, while the indirect one is absorbed by mining, transforming and transporting the production factors [13]. The expression is not new at all. Already between the sixties and the eighties, several studies tried to assess the EE by relying upon process-based or input/output-based analyses [14]. From its origin up to present days, the literature has been aware of the calculation difficulties, and the possible biases, in the form of incompleteness and unreliability [15,16]. Indeed, in spite of an apparently simple definition, the results are sensitive to where the boundaries of the economic system are placed [14,15]. Moreover, earlier than the measurement issues, the available studies in this research branch do not agree neither on the interpretation to be given to EE, nor on the assessment method to be adopted and the parameters to be taken into account [12]. According to several literature review surveys [12,17,18], other sources of uncertainty are both the geographic location and the manufacturing technology [19–22], as they affect the results because of differences in the material quality [23], in the arrangement of production processes [24] – capital-intensive or labour-intensive – as well as in the underlying economic data [25]. Besides, the data age [8,19,26] – namely referring to obsolete production processes and technologies – as well as the data quality and the adopted sources [27,28] – that is to say, primary data rather than already processed information [26] – provide support to explain the high variance in outcomes.

Despite the above-mentioned caveats, the EE cannot be disregarded, since it contributes to shape, among other things, the assessment and rating models adopted within the building industry [17]. The amount of energy sequestered is among the criteria used by several protocols, such as BEAM Plus in Hong Kong and others [29–31]. Some of them take a partly different perspective, toward the reduction of greenhouse gas emissions, as the BREEAM in the UK [30], or else to encourage waste minimisation and the use of recycled products, as in the US LEED rating system [32] with a discrepancy between the EE and the points it awards [31]. However, construction materials play a role in most current versions of the available protocols.

We should bear in mind that several analyses lead to deem EE as a major source of consumption in real estate [5,33,34], perhaps higher than operational energy when dealing with extremely efficient buildings as the passive houses [35]. Already between the mid-nineties and the early 2000s, a couple of case study articles highlighted that the EE may represent a substantial percentage of the total energy load [33,36,37]. For office buildings in Canada, the sum of initial and recurring energy needs, namely for construction and maintenance activities, resulted to be easily and by far overtaken by the operating energy, according to the performance standards of that time. Nonetheless, the embodied energy was foreseen to be gaining ever more importance, up to equal the operating energy, due to the commitment to reducing consumption [36]. For high-efficient apartment housing in Sweden, over a time span of 50 years, the embodied energy was estimated to represent up to about 45% of the total life-cycle energy [33]. A further case study analysis found the embodied energy to be about 60% of the life-cycle energy, in a 50-year period, for a campus dormitory complex in Israel [37].

Since we are moving toward very high-performance buildings, in order to meet ever stricter requirements, the trade-off between the energy spent to construct and maintain them and the energy in use leads to a paradox (as depicted in the previous Fig. 1). Let us consider the specific case of the passive houses and, to the extreme, of the self-sufficient buildings. A case study analysis performed within the Belgian context shows that the passive house model may be responsible for an embodied energy far higher than the operating one [35]: about 2-fold higher, being 67% the former and 33% the latter, for a base case over a time span of a century; up to nearly 3.5 time higher, being 77% the former and 23% the latter, for the best case over the same time period.

Once recognised the issue deserves to be considered, we may aim at a comprehensive view about EE. On closer inspection, already in the past, it was shown the relationship between the EE and the total output value of a series of economic sectors [14], suggesting an interesting proportional ratio between EE and market values of goods. The same consideration was implied in some other thermodynamic studies, relying on a simple evidence. The more the use of production factors is intense, the more expensive are the goods. Similarly, the EE should be a positive function of both size and complexity of the production system [4]. In this promising research branch, three recent studies represent somehow a turning point [38–40]. Langston and Langston [38] analysed 22 new buildings and 8 redevelopment projects in Melbourne, intended for several uses, whose construction works were carried out during the time span from 1997 to 2003. The authors' empirical findings added evidence to the hypothesis that the EE correlates with the cost incurred during the construction process. Jiao et al. [39] focused on three commercial buildings, two in China and the other in New Zealand, finding again a certain correlation between EE and cost, both at the individual building component level as well as at the whole-building scale. Bansal et al. [40] gathered data from more than hundred affordable houses in India and compared EE with cost over a series of building materials. The authors suggested the occurrence of a non-linear relation between EE and construction cost. Nonetheless, the findings from the aforementioned studies suffer from several limitations: weaker relations in the transition from