Ecological Indicators 69 (2016) 66–77

Contents lists available at ScienceDirect

Ecological Indicators

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

Toward the Ecological Footprint of the use and maintenance phase of buildings: Utility consumption and cleaning tasks

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ARTICLE INFO

Article history:
Received 13 January 2016
Received in revised form 1 April 2016
Accepted 4 April 2016

Keywords:
Ecological Footprint
Maintenance and cleaning of buildings
Utility consumption

ABSTRACT

Due to poor design of buildings in terms of maintenance, there are a number of buildings today that remain extremely expensive to maintain, both economically and environmentally. In order to mitigate these overheads, the development of a cost database is needed with which the resources required to clean and maintain buildings can be estimated. This paper presents a methodology to estimate these costs and the environmental impact, in terms of Ecological Footprint (EF), associated to the utility consumption and to the cleaning tasks necessary during the service life of buildings. Given the numerous peculiarities identified for this type of activity compared to the construction of buildings, it is necessary to define a new methodology of calculation, with its own assumptions and formulae. This methodology is then applied to the case of a college hall of residence that houses up to 139 residents. The results show that the annual EF of cleaning tasks accounts for 11.42% of the EF of utility consumption. Together they total 67.334 global hectares per year (gha/yr), 88% of which corresponds to the carbon footprint. Within the EF of cleaning, about 71% is due to food consumed by labor, while 26% is due to the manufacture of cleaning products and tools, which are equally divided among the six categories of productive land. The development of this methodology is essential for the detailed quantification of the environmental impact of utility consumption and cleaning tasks that occur during the service life of buildings. The use of discount rates on results is included in terms of the EF of a baseline year, as an equivalent to the discount rate in economic terms.

1. Introduction

The crisis in the construction sector in Spain in recent years has forced a new approach to business models, since the highest priority today is not the construction of new buildings, but the maintenance and renovation of existing buildings, as predicted by Kohler and Hassler (2002). However, during the earlier ‘housing bubble’ stage, the frenetic activity of construction companies failed to allow time to be taken to consider the maintenance cost that the buildings would impose. Today, cities have several buildings that exemplify absurd maintenance costs mainly due to a thoughtless initial design in this aspect, such as the City of Sciences in Valencia, the Bankia Tower in Madrid, and the Sevilla Tower in Seville.

Provoked by this turn of events, the role of the Facility Manager (FM) has become of major importance, especially in tertiary buildings, such as offices, shopping malls, hotels and hospitals (Heng et al., 2005). The FM is responsible for the control and coordination of various tasks, which include the proper functioning of the installations, the maintenance, and the regular cleaning of the building. For the economic management and control of these tasks, the FM usually employs internal calculations as a product of experience, or maintenance and operating cost databases, which require the acquisition of a license that is not freely available to all buyers: these include BCIS On-line (Royal Institute of Chartered Surveyors, 2015), BLCC (National Institute of Standards and Technology, 2013), ECONPACK (U.S. Army Corps of Engineers, 2014), CostLab (CBRE and Whitestone Research, 2015), and CYPE’s decennial maintenance module (CYPE Ingenieros, 2015). The lack of open-access databases imposes additional obstacles to the estimation of these costs from the design phase of buildings. Advance awareness of this information would be invaluable to both the owner and the manager of the building, and would provide a breakthrough in the study of Life-Cycle Costs (LCC) of buildings (ISO 15686-5, 2008).

In recent years, a number of research studies have been presented on the application of environmental indicators, such as Ecological Footprint and Carbon Footprint, to construction processes (González-Vallejo et al., 2015a; Solís-Guzmán et al., 2015, 2013), whereby this analysis is extended to other life-cycle phases

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http://dx.doi.org/10.1016/j.ecolind.2016.04.007
1470-160X/

of the building, such as the transformation of land use (urbanization previous to construction) (Freire and Marrero, 2014), and rehabilitation vs. demolition (Alba Rodríguez et al., 2015), as they are defined in the Life-Cycle Assessment (LCA) methodology for buildings (UNE-EN 15978, 2012). Other existing studies evaluate buildings through ecological indicators, such as the Ecological Footprint (Bastianoni et al., 2007), Carbon Footprint, and Emergy Analysis (Marchi et al., 2015; Martínez-Rocamora et al., 2014; Pulselli et al., 2014, 2007), which all focus on the construction phase, operation, or the implications of adding Vertical Greenery Systems to improve the envelope behavior.

These calculation models attempt to predict the environmental impact of the construction process through the project's bill of quantities. In the bill of quantities, the various tasks are broken down into three key elements: manpower, materials and machinery (Marrero and Ramirez-De-Arellano, 2010). Emission or embodied energy factors are then applied to these elements, which are subsequently converted into environmental impacts using the methodology of the corresponding ecological indicator (González-Vallejo et al., 2015b).

However, the calculation models above cannot be applied when an attempt to tackle the cleaning of buildings is made, since no cost database quantifies the three elements of manpower, materials and machinery in a disaggregated way. These tasks present so many unique features that it remains impossible to apply the same methodology of the construction process. Moreover, it is essential to treat cleaning separately from maintenance because, despite pertaining to the same life-cycle phase, the nature of the activities differs so widely that the assumptions and formulation to be applied cannot be the same.

Environmental impact studies focused on the use and maintenance phase of buildings generally consider that the impact sources corresponding to this stage can be divided into three distinct branches: utility consumption (electricity, water, and fuel); regular cleaning tasks; and periodic maintenance and renewal of elements (Fuller, 2010). Due to the high complexity of calculating the resources necessary for the maintenance and cleaning of buildings, the vast majority of studies calculate solely the impact of the utility consumption. In certain cases, the renovation of materials is also included, whereby the materials are assigned a specific service life (Adalberth, 1997a,b; Pulselli et al., 2007); manpower and machinery, however, are not taken into account.

Given the problematic above, this paper focuses on the utility consumption and cleaning tasks. To this end, in the following section, the system boundaries for this study are defined. Secondly, the peculiarities of cleaning tasks are determined and the method to structure these tasks is defined, thereby justifying the need for the separate analysis applied in this model. The methodology for the application of the EF indicator to utility consumption and cleaning tasks is then described. In Section 4, the case study of a college hall of residence is presented for the application of the methodology for economic and environmental costs. Finally, results obtained from this case study are shown and discussed, and a number of conclusions are drawn from the present study.

2. System boundaries

The standard UNE-EN 15978 (2012) establishes, in the first place, that the use phase extends from the end of the construction works until the building is about to be deconstructed/demolished.

In order to set the transversal system boundaries, the possible impact drivers during this phase of the building's life cycle have been studied. These have been classified into three main sectors: industry, building, and the occupants (Fig. 1). Impacts from the manufacture of furniture, appliances, decoration and other objects are associated to the industrial sector, while the consumables and occupants' food consumption, mobility and Municipal Solid Waste (MSW) all belong to the occupants' EF and not to that of the building. All these impact drivers remain outside the system boundaries of the present study. The remaining elements, as can be observed in Fig. 1, are attributed to the building, and are divided into those corresponding to its use and those referring to maintenance and cleaning tasks.

This paper focuses on the utility consumption and cleaning tasks. In the following section, a methodology is proposed to structure the tasks pertaining to this phase of the building's life cycle, and a number of peculiarities of the cleaning tasks are determined. The methodology for the application of the EF indicator to the use and cleaning of buildings is then defined.

3. Methodology

3.1. Cleaning costs singularities

The actions carried out during this phase are divided into cleaning, maintenance (predictive, preventative and corrective), and renovation. In order to classify the tasks related to these five types of action, the structure defined in previous advances of the study (Martínez-Rocamora et al., 2015) is used. This structure relies on the Andalusian Construction Costs Database (ACCD) (Andalusia Government, 2014) as a reference of structure and of a classification system of information in the construction sector.

Focusing on cleaning tasks, these feature certain peculiarities compared to construction and maintenance of constructive elements. Firstly, there is a multitude of different products and tools with which a surface or piece of furniture can be cleaned. Unfortunately, if single costs for every different combination of products, tools, and surfaces to be cleaned were developed, then an excessive amount of costs would appear for the same task.

In order to provide a simplified solution to this issue, the contents of a professional cleaning trolley have been studied (Table 1). For each tool or product its frequency of renewal, cost, weight and main material have been obtained. In the same table, the emission factor for each material, obtained from Ecoinvent, is included, which after an exhaustive study (Martínez-Rocamora et al., 2016) was confirmed as the most suitable Life-Cycle Assessment (LCA) database for use in the construction sector. By using a value of 1515 h worked per year from the regional collective agreement of the cleaning sector (Andalusia Government, 2013), the hourly cost (0.69 €/h), CO_2 emissions (0.227 kg CO_2/h), and MSW generation (0.057 kg MSW/h) of the cleaning trolley as a whole were obtained (bottom line in Table 1).

The second singularity is that the performance on cleaning a surface depends on its rugosity, position, the percentage occupied by obstacles, and the untidiness of users, which can slow the cleaning process. Moreover, the quantity of obstacles depends on the type of room to be cleaned. This leads to another peculiarity of cleaning that differs from that of the construction phase. The ACCD classifies tasks per constructive element, but what is actually cleaned are spaces containing some of these elements. At the same time, a single space is cleaned with several different periodicities, and in each of these periodicities, only a number of the elements contained are cleaned. It is therefore necessary to include both the periodicity and type of functional space in the cost description.

This method of dividing a building into functional spaces was created as an idea named MaClar (Revuelta Marchena et al., 2015), despite the fact that it can also be found in international standards, such as Omniclass (2012) and ISO 12006-2 (2015). The MaClar model proposes the estimation of costs in construction from the design phase by dividing the building into functional cells, which