ISBN: 978-84-697-1815-5

Service life of UK supermarkets: origins of assumptions and their impact on embodied carbon estimates

Authors:
Richardson, S.[1]; Hyde, K.[2]; Connaughton, J. [2]; Merefield, D. [3]

[1] TSBE Centre, University of Reading, Reading, United Kingdom
[2] SCME, University of Reading, Reading, United Kingdom
[3] Sainsbury's Supermarkets Ltd., London, United Kingdom

Abstract: *Life cycle Assessment (LCA) methods have been gaining interest within the construction industry for assessing environmental sustainability, particularly carbon emissions. Understanding the relative significance of different lifecycle phases is important when making design decisions to reduce carbon emissions. For certain building types, such as offices, embodied carbon represents a significant proportion of whole-life carbon emissions, with some studies suggesting estimates of 50% or more of total emissions. This is not thought to be the case for Supermarkets where operational emissions are claimed to be predominant due to high annual consumption of energy.*

Crucial to the apparent significance of embodied carbon, relative to the whole lifecycle, are the assumptions made about building serice life. Yet despite their importance to assessment outcomes, a review of the literature shows that many studies provide little justification for these assumptions. Assertions about the relative weighting of different lifecycle phases within the overall carbon footprint are therefore questionable.

A new approach to the selection of service life is proposed that uses historic data on the service lives of similar buildings. This helps to identify an appropriate range of service lives for a parametric analysis of embodied carbon.

In a study of UK supermarkets, we find that service life can vary from 15 years to over 50 years. Applying the new approach for this range of service lives we show that the proportion of lifecycle carbon due to embodied emissions can more than double, compared to more conventional approaches. For one of the case-study buildings the embodied carbon would be over 55% of the lifecycle carbon emissions for the minimum service life case of 15 years.

We conclude that when estimating the whole-life carbon emissions of a building, assumptions about service life are critical, requiring evidence-based justification. The approach presented offers a new way to address this problem. This will lead to improved understanding of the importance of different lifecycle stages and facilitate better informed design decisions in regard to carbon reduction measures. Further work to understand the factors, such as obsolescence and competitor activity that affect the service life of supermarkets in practice is recommended.

Keywords: LCA; Embodied Carbon; Design Service Life; Supermarket Construction

Introduction

Reducing carbon emissions in the built environment has been identified as a key target in climate change mitigation efforts at both UK [1] and EU level [2]. Historically, much attention has been paid to energy and carbon emissions from the operation of buildings. More recently there is increasing concern about embodied energy and carbon, which is that 'associated with extraction, manufacturing, transporting, installing, maintaining and disposing

ISBN: 978-84-697-1815-5

of construction materials and products' [3, p. 28]. Some UK studies suggest that embodied carbon can represent more than 50% of the whole life carbon emissions of certain types of buildings, such as offices or warehouses, whilst acknowledging that more energy-intensive building types, such as supermarkets, will have a lower ratio of embodied carbon to operational carbon (henceforth EC:OC) [4], [5].

Understanding the relative contribution of different lifecycle phases to total carbon emissions is important when making carbon reduction design decisions. Life cycle assessment (LCA) and related techniques such as life cycle energy assessments and carbon footprinting, present 'a scientifically established method for generation of the necessary decision support' [6, p. 920]. Such techniques have been applied to the study of buildings as far back as the 1970s [7], [8]. However, assumptions made in the application of these methods can have a significant impact on the results and should therefore be clearly stated [9] and ideally justified. Of particular importance in determining EC:OC is the assumption made about service life length. In general, the longer the assumed service life the more significant the operational phase will appear. [10], [11]. This is clear from the formula for life cycle energy (LCE) given in Equation 1 below, adapted from Ramesh et al [12].

$$LCE = \langle \sum m_i M_i + E_c \rangle + \langle \sum m_i M_i [(L_b / L_{mi}) - 1] \rangle + \langle E_{OA} L_b \rangle + \langle E_D \rangle \quad (1)$$

The terms demarcated within chevrons (from left to right) represent embodied energy of initial construction, embodied energy of subsequent refurbishment, operational energy and embodied energy of demolition respectively. In these terms, m_i is the quantity of material i, M_i is the energy content of material i per unit; E_c is the construction energy requirement, L_b is the assumed service life of the building in years; L_{mi} is the assumed service life of components in years; E_{OA} is the annual operating energy demand; E_D is the energy requirements for demolition.

Building service life L_b (in years) is a multiplier in both the recurring embodied energy term and the operational energy term, and will have a noticeable impact on the results. A similar approach would apply to assessing lifecycle carbon emissions or indeed any other LCA impact category. Moreover the greater the contribution of operational impacts to the whole lifecycle, the greater will be the effect of varying the service life on the proportional contribution of initial embodied impacts. This is particularly germane for supermarket buildings where operational impacts are high relative to other building types [4], [5].

Terminology

In this paper the term service life is defined according to BS EN 15643 *Sustainability of construction works — Sustainability assessment of buildings* as 'the period of time after installation during which a building meets or exceeds the technical requirements and functional requirements [13]. It is assumed that the end of the period within which those requirements are satisfied will be marked by demolition or significant change of use of the building. The term *estimated service life*, according to BS EN 15643, involves consideration of the performance of a building and its components in specified conditions as compared to its durability under standard conditions [13]. In practice it was found that this approach is not currently widely applied at a building level and so when referring to the anticipated length of the building life applied to assess environmental impacts, the term *assumed rather than* *estimated service life* has been used. Finally, in all the literature reviewed, the reference study period over which environmental impacts of the building were assessed was the same as the building service life and so the same approach has been adopted in this research.

Methodology

Our review of the literature on LCA-based studies of buildings - including life cycle energy assessments and carbon footprint studies - illustrates a general lack of justification for service life assumptions, and suggests a need for a new approach. This review helps develop proposals for a potentially more robust approach by combining two of the more common methods found in practice. We then use this new approach on a case study of supermarket builings in the UK. Data for this is taken from unpublished commercial carbon footprint reports prepared for Sainsbury's, a UK supermarket chain. This carbon footprint data is reassessed using revised service life assumptions developed from the new approach.

Service life assumptions in LCA and related studies

Amongst the many LCA based studies of buildings published in the literature, which include lifecycle energy assessments and lifecycle carbon footprints, there is significant variation in the assumptions made about building service life. Reviews of such studies, have found assumptions range from 30 to 100 years for whole buildings [12], [14] and 10 to 100 years for buildings products [15]. Despite this wide variance, these reviews do not question or critique the service life assumptions or indeed make any reference to their justification.

In a study of US residential buildings, Aktas and Bilec find that 'many building LCA studies do not adequately address the actual lifetime of residential buildings and building products, but rather assume a typical value'[16, p. 338]. Among LCA-based studies of commercial buildings, unjustified assumptions about service life have also been observed [17]–[20].

In the specific case of supermarket buildings, only one study was found that assessed the whole lifecycle using an assumed service life of 20 years, stating that such buildings typically have a short life expectancy [21]. Five unpublished commercial studies covering six supermarket buildings undertaken privately for Sainsbury's Supermarkets from 2008-2012 were made available to the authors for analysis. Of these, four assumed a service life of 30 years whilst one, which covered two different buildings, assumed a 60 year service life for both. In all the studies, the assumed service life was stated without justification.

Options for defining service life assumptions

Approaches to defining service life for LCA studies found in the extant literature can be divided into three categories. One approach is to use design life assumptions as a proxy for service life. A second is to use data on the actual past service life of similar buildings. The level of methodological complexity with which such data is used to develop trends varies significantly from those which give no detail on how trends have been analysed to those which apply probability distributions using monte-carlo analysis [16] or the life table method [22]. And a third is to use a range of possible service lives [23], [24]. This final option can be

ISBN: 978-84-697-1815-5

considered a parametric approach because a range of results are generated for a range of input parameters, in this case, building service life.

The parametric approach provides a way to address the inherent uncertainty of assessing lifecycle impacts at design stage and is therefore preferred over the other two options. However, the choice of parametric input range for the service life remains to be justified and this could be done by applying one of the first two options.

In practice, claims about design life are often based on local structural building codes. For example, the Eurocodes quote 50 years as the indicative design life of 'building structures' [25, p. 28]. In many cases, this nominal design life bears no real connection to the actual durability of buildings [16], [26]. Furthermore, it takes no account of non-technical issues such as changing land values and occupant needs which often have a greater influence on actual service life than durability [26]. Design life is not, therefore a useful basis for assumptions about service life. Hence, the second option, which relies on observations about the actual service life of buildings similar to the one being assessed, may be preferable for defining the service life range to be applied in a parametric analysis.

This combined approach has been tested for the specific case of assessing the ratio EC:OC of UK supermarket buildings. The results of two studies undertaken for Sainsbury's Supermarkets, originally based on unjustified single service life lengths, have been reassessed using a range of service life lengths determined from data on the service life of actual supermarkets. The purpose being, on the one hand, to demonstrate that the use of such historical trends to define a parametric service life range for the assessment may lead to different conclusions than the original assumptions. On the other hand the challenges and possible barriers to successfully applying this technique are also highlighted.

Historical trends in supermarket service life

Data on the ages of almost 600 existing (still trading) supermarkets was gathered as well as additional data on supermarket closures. A range of sources was used including the supermarkets themselves and local records such as newpaper reports. Fifteen closures were identified, dating back to 2007. Of these, eight are known to have been demolished whilst the remaining seven are excluded because their current status could not be verified. The ages of the existing stores are presented in Table 1 and those of the 8 demolished stores are shown in Table 2 below.

Table 1: Age distribution of a selection of existing (operational) UK Supermarkets

Age Range	0-15 Years	15-25 Years	25-35 Years	35-45 Years	45-55 Years
Percentage of existing stores	40%	32%	19%	7%	2%

Table 2: Ages of eight UK supermarkets demolished in the last eight years

Store number	1	2	3	4	5	6	7	8	**Mean Age**
Age at demolition (years)	35	22	15	16	23	26	29	18	**23**

ISBN: 978-84-697-1815-5

The data for the store closures shows that the service life of these stores varied from 15 to 35 years with the mean age being 23 years. This suggests that the assumptions of 30 and 60 year service lives applied in the studies of new supermarket buildings need to be reviewed. According to this data, a parametric study using the range of 15 to 35 years would be more appropriate. However, Table 1 shows that just under 10% of the existing stores included in this study exceed this age range; the oldest store still operating being 52 years old. The mean age of existing stores is 18 years, and if those less than 15 years old (the earliest date of demolition recorded) are excluded, the mean value rises to 26 years. The two datasets may be combined to define an appropriate range for the assumed service life in a parametric study. For example, the range could be based on a minimum of 15 years, and a maximum 52 years, the highest age of the stores still in operation. Intermediate values can be selected whereby 25 years represents the rounded mean age of all stores older than 15 years, and 35 years is the age of the oldest store to have been demolished.

Parametric techniques for estimating embodied carbon contribution

The ratio EC:OC for two of the studies provided by Sainsbury's was recalculated using a parametric approach combined with the data on store ages. These two stores were chosen because they have the lowest and highest proportional embodied carbon for their original assumed service life of 60 and 30 years respectively. They represent a standard specification store (Store 1) built to meet UK building regulations in 2010 without any significant energy efficiency improvements, and a highly energy efficient store (Store 2) which had a range of measures applied to reduce operational energy and carbon emissions and achieved BREEAM 'Very Good'. The percentage contribution of embodied carbon (initial and recurring) to the whole lifecycle are plotted in

Figure *1* for the range of service life lengths determined from historical data and including the originally assumed service life.

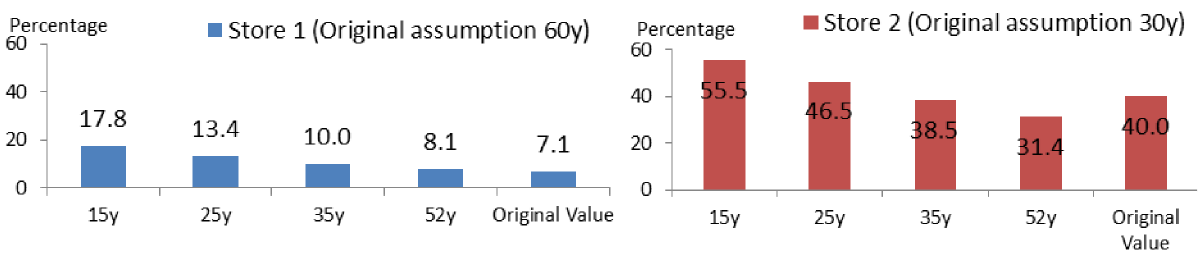

Figure 1: Impact of service life on calculated embodied carbon as a percentage of whole life carbon for two supermarkets

Compared to the original result, the embodied carbon proportion was higher in all but two of the eight modelled scenarios and in the case of Store 2, rose above 50% of whole life carbon emissions for the 15 year scenario. The proportional contribution of embodied carbon to whole life carbon increases as service life decreases: for store 1, there is an increase of 120%; and for Store 2 it is 77% between the maximum and minimum service life lengths assumed here. Thus the phenomenon described earlier whereby buildings with a more dominant operational phase are more sensitive to variance of the service life is clearly demonstrated.

ISBN: 978-84-697-1815-5

Discussion and conclusions

The results clearly highlight that the assumptions about service life length have a marked impact on ratio EC:OC. This is important because it calls into question assertions such as that of Scheuer et al., that 'the optimization of operations phase performance should still be the primary emphasis for design' [27, p. 1061]. Thus there is clearly a need for greater rigour in the justification of assumptions about service life. Of the three main options for justification found amongst published studies, design life is discounted on the basis that it is rarely a reliable indicator of the likely service life of a building. The proposed solution adopted here for the case study of UK supermarkets is to combine the remaining two approaches to use historic data from existing buildings as a basis for a parametric range for the service life.

There are drawbacks to this method, not least the requirement to gather significant amounts of data on existing buildings, which may be hard to obtain. Furthermore, drawing conclusions from the data was not straightforward in the case study presented. The data on existing stores is inconclusive as it cannot be proven how long these stores will last. Yet data on the store closures alone is not wholly representative, since a proportion of existing stores have already outlived the oldest store closure to date. Nevertheless, the research progress so far provides a good indication that the method has the potential to be developed in depth and breadth, leading to an improved understanding of the significance of different phases of the building lifecycle.

Further study of the technical and social factors that affect supermarket service life in practice could potentially allow for more case specific assumptions to be made for a given building. It could also lead to conclusions about how to minimise embodied impacts of supermarket construction, for example, if the non-technical aspects that limit service life can be mitigated. The technique should also be tested in other property sectors to ensure that it is applicable beyond the context demonstrated here of UK supermarket buildings.

References

[1] BIS, 'Low Carbon Construction Action Plan - Government response to the Low Carbon Construction Innovation & Growth Team Report'. HMSO, London, 2011.

[2] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050*. 2011.

[3] J. Anderson and J. Thornback, 'A guide to understanding the embodied impacts of construction products'. Construction Products Association, 2012.

[4] S. Sturgis and G. Roberts, *Redefining zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings*. London: RICS Research, 2010.

[5] RICS, *Methodology to calculate embodied carbon of materials: RICS information paper.* Coventry: Royal Institution of Chartered Surveyors, 2012.

[6] M. Erlandsson and M. Borg, 'Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs', *Build. Environ.*, vol. 38, no. 7, pp. 919–938, Jul. 2003.

ISBN: 978-84-697-1815-5

[7] P. C. Kreijger, 'Environment, pollution, energy and materials', *Matér. Constr.*, vol. 6, no. 6, pp. 411–432, Nov. 1973.
[8] A. Hallquist, 'Energy consumption: Manufacture of building materials and building construction', *Habitat Int.*, vol. 3, no. 5–6, pp. 551–557, 1978.
[9] British Standards Institution, *ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines*. Geneva, Switzerland: International Standards Organisation, 2006.
[10] N. Huberman and D. Pearlmutter, 'A life-cycle energy analysis of building materials in the Negev desert', *Energy Build.*, vol. 40, no. 5, pp. 837–848, Jan. 2008.
[11] L. Gustavsson, A. Joelsson, and R. Sathre, 'Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building', *Energy Build.*, vol. 42, no. 2, pp. 230–242, Feb. 2010.
[12] T. Ramesh, R. Prakash, and K. K. Shukla, 'Life cycle energy analysis of buildings: An overview', *Energy Build.*, vol. 42, no. 10, pp. 1592–1600, Oct. 2010.
[13] British Standards Institution, *BS EN 15643-1:2010 Sustainability of construction works — Sustainability assessment of buildings Part 1: General framework*. London: British Standards Institution, 2010.
[14] I. Sartori and A. G. Hestnes, 'Energy use in the life cycle of conventional and low-energy buildings: A review article', *Energy Build.*, vol. 39, no. 3, pp. 249–257, 2007.
[15] L. F. Cabeza, L. Rincón, V. Vilariño, G. Pérez, and A. Castell, 'Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review', *Renew. Sustain. Energy Rev.*, vol. 29, pp. 394–416, Jan. 2014.
[16] C. B. Aktas and M. M. Bilec, 'Impact of lifetime on US residential building LCA results', *Int. J. Life Cycle Assess.*, vol. 17, no. 3, pp. 337–349, Mar. 2012.
[17] M. Suzuki and T. Oka, 'Estimation of life cycle energy consumption and CO2 emission of office buildings in Japan', *Energy Build.*, vol. 28, no. 1, pp. 33–41, Aug. 1998.
[18] O. F. Kofoworola and S. H. Gheewala, 'Environmental life cycle assessment of a commercial office building in Thailand', *Int. J. Life Cycle Assess.*, vol. 13, no. 6, pp. 498–511, Sep. 2008.
[19] O. F. Kofoworola and S. H. Gheewala, 'Life cycle energy assessment of a typical office building in Thailand', *Energy Build.*, vol. 41, no. 10, pp. 1076–1083, Oct. 2009.
[20] S. Xing, Z. Xu, and G. Jun, 'Inventory analysis of LCA on steel- and concrete-construction office buildings', *Energy Build.*, vol. 40, no. 7, pp. 1188–1193, 2008.
[21] D. Densley Tingley, 'Design for Deconstruction: an appraisal', PhD, University of Sheffield, Sheffield, 2013.
[22] T. Yashiro, H. Kato, T. Yoshida, and Y. Komatsu, 'Survey on real life span of office buildings in Japan', in *Proceedings, CIB*, 1990, vol. 90, p. W55.
[23] R. J. Cole and P. C. Kernan, 'Life-cycle energy use in office buildings', *Build. Environ.*, vol. 31, no. 4, pp. 307–317, 1996.
[24] R. Fay, G. Treloar, and U. Iyer-Raniga, 'Life-cycle energy analysis of buildings: a case study', *Build. Res. Inf.*, vol. 28, no. 1, pp. 31–41, Jan. 2000.
[25] British Standards Institution, *BS EN 1990:2002+A1:2005 Eurocode. Basis of structural design*. London: British Standards Institution, 2002.
[26] J. O'Connor, 'Survey on actual service lives for North American buildings', in *Woodframe Housing Durability and Disaster Issues Conference*, Las Vagas, 2004.
[27] C. Scheuer, G. A. Keoleian, and P. Reppe, 'Life cycle energy and environmental performance of a new university building: modeling challenges and design implications', *Energy Build.*, vol. 35, no. 10, pp. 1049–1064, Nov. 2003.