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Environmental impacts of the UK residential sector: Life cycle assessment of houses

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ABSTRACT

This paper presents for the first time the results of a full life cycle assessment (LCA)[1] study for the three most common types of house in the UK: detached, semi-detached and terraced. All life cycle stages are considered, including house construction, use and demolition after 50 years. The results indicate that the use stage has the largest contribution to most environmental impacts. For example, the global warming potential (GWP)[2] over the 50-year lifetime of the detached house is 455 t of CO_2 eq.; 374 t CO_2 eq. of the semi-detached; and 309 t CO_2 eq. of the terraced house. Around 90% of the GWP is from the use, 9% from construction (embodied carbon) and 1% from the end-of-life waste management. A similar trend is noticed for all other impacts. Recycling the building materials at the end of life leads to an overall reduction of the impacts. For instance, the GWP reduces by 3% for the detached and semi-detached houses (to 441 t of CO_2 eq. and 363 t CO_2 eq., respectively) and by 2% (to 302 t CO_2 eq.) for the terraced house. The main environmental benefit is from reusing the bricks and recycling the aggregates. At the housing sector level, the total GWP is 132 million tonnes of CO_2 eq. per year with the semi-detached houses contributing 40%, terraced 37% and detached houses 27%. Over the 50-year lifetime, the total GWP from the sector is nearly 6.6 billion tonnes of CO_2 eq. The results also highlight the importance of decisions made in the design and construction stages as they determine the impacts of the house in the use and end-of-life stages.

1. Introduction

The construction industry plays an important role in meeting different human needs, including provision of housing, hospitals and transport infrastructure. However, these needs are provided at the expense of intensive use of mineral resources and energy as well as waste generation. For example, in the UK over 200 million tonnes of minerals are extracted and consumed by the sector each year, representing 84% of the country's annual mineral extraction [1]. Furthermore, the residential housing sector consumes around 500 million MWh/yr of energy [2], contributing 158 million tonnes of CO_2 eq./yr or 28% of the UK annual carbon emissions [1,3]. In addition, the sector produces over 100 million tonnes or 33% of waste per year [4]. As a result, the construction industry contributes significantly to different environmental impacts including global warming and natural resource depletion [5].

A number of Life Cycle Assessment (LCA) studies have been conducted to estimate the environmental impacts from the construction sector. In Europe these include studies of office buildings [6,7], universities [8,9], apartment buildings [10,11] and houses [12–19]. As far as the authors are aware, only four LCA studies have been conducted in the UK housing sector; however, neither considered the full life cycle from 'cradle to grave' or the full range of impacts normally included in LCA. For example, Monahan and Powell [17] considered the construction stage only and estimated the embodied carbon of a three bedroom semi-detached low-energy house in England while Asif et al. [13] determined the embodied energy and the associated emissions of CO_2, NO*x*, and SO*x* of the construction materials used for a three bedroom semi-detached house in Scotland. Hammond and Jones [16] considered several houses and apartments across the UK but also estimated only the embodied energy and carbon. However, neither study considered the use and end-of-life stages. The fourth study [15] went further by considering carbon emissions from both the construction and use stages for a two bedroom semi-detached house in England; however, the end of life of the house was not considered.

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[1] Life cycle assessment.
[2] Global warming potential.

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Table 1
General information on the three types of house under study.

	Detached house	Semi-detached house	Terraced house	Data sources
Number of bedrooms	4 bedrooms	3 bedrooms	2 bedrooms	[27]
Number of floors	2	2	2	–II–
Construction type	Traditional build: brick and block	Traditional build: brick and block	Traditional build: brick and block	–II–
Typical usable floor area (m^2)	130	90	60	[26]
Household size (no. of people)	2.3	2.3	2.3	[21]
Indoor temperature (°C)	19	19	19	[21,26]
Air exchange rate (1/h)	1	1	1	[26]
Specific heat loss (W/K)	220	170	120	[21, 26]

This study aims to contribute towards a better understanding of the full LCA impacts of the housing sector[3] in the UK by focussing on the existing stock and the most common types of house. The bulk of the existing housing stock is brick-built and is quite old and energy inefficient [20] so the environmental impacts could be quite significant. The most common types of house are detached, semi-detached and terraced. Together, they represent 72% of the stock, housing 18 million households; semi-detached and terraced houses each account for 28% and detached houses for the remaining 16% of the residential sector [21].

The following sections present and compare the life cycle impacts of each type of the house from 'cradle to grave'. This is followed by a discussion of the environmental impacts of the UK housing sector as a whole. It is hoped that the results of this work will be useful for a range of stakeholders, including house designers, developers and owners as well as policy makers.

2. Life cycle assessment of UK houses

This LCA study follows the ISO 14040/44 methodology [22,23]. The LCA modelling has been carried out in GaBi V4.3 [24] and the CML 2001 method [25] has been used to estimate the environmental impacts.

2.1. Goal and scope of the study

The goal of the study is to estimate the life cycle environmental impacts of typical types of house in the UK: detached, semi-detached and terraced house. These results are then used to estimate the overall impacts from the UK housing sector with the aim of identifying the hot spots and improvement opportunities along the supply chain.

The functional unit is defined as the 'construction and occupation of a house over its lifetime'. The lifetime of a house depends on many factors, making it a difficult parameter to standardise. However, for research purposes, many authors (e.g. [10,12,14,18]) have assumed the life span of 50 years. Therefore, this lifetime has also been assumed in this study. The following typical usable floor areas are considered [26]:

- detached house: 130 m^2;
- semi-detached house: 90 m^2; and
- terraced house: 60 m^2.

It has also been assumed that each house is occupied by an average UK household size, consisting of 2.3 people [21]. Table 1 provides further information on the houses under study.

The life cycle of the three types of house is outlined in Fig. 1. As shown, it comprises three main stages: house construction, its use and end-of-life waste management. Construction involves extraction and manufacture of construction materials and fuels, transportation through the supply chain and construction of the house. The use stage includes water and energy consumption for space and water heating, cooking, lighting and domestic appliances. Maintenance activities such as replacement of windows, doors and floor covering are also considered. Finally, the end-of-life stage involves house demolition and waste management activities, such as reuse, recycling and landfilling of construction waste.

2.2. System description, assumptions and data

General information for each type of house considered in this study is summarised in Table 1 and the floor plans are provided in Fig. 2. All houses have two floors (ground and first floor) and the layout is similar: the kitchen and living area are on the ground floor with the bathroom and the bedrooms on the first floor. In addition, the three houses have a pitched roof with fink truss and traditional strip footing foundations. The following sections provide an overview of the assumptions made for each house and the data estimation.

2.2.1. Construction stage

The types and quantities of material for the construction of each house have been calculated using construction guides and specifications [26], material specifications [28,29], direct observations and expert consultation. As shown in Table 2, it is estimated that 177 t of materials are used in the construction of the detached house, 135 t for the semi-detached and 89 t for the terraced house. The energy data for the construction machinery have been sourced from [12]. The total energy used in the construction of each house is estimated at 31.2 GJ for the detached, 21.6 GJ for the semi-detached and 14.4 GJ for the terraced house, respectively (see Table 3).

2.2.2. Use stage

Total energy use in different life cycle stages of each house is summarised in Table 3. As can be seen, over the lifetime of 50

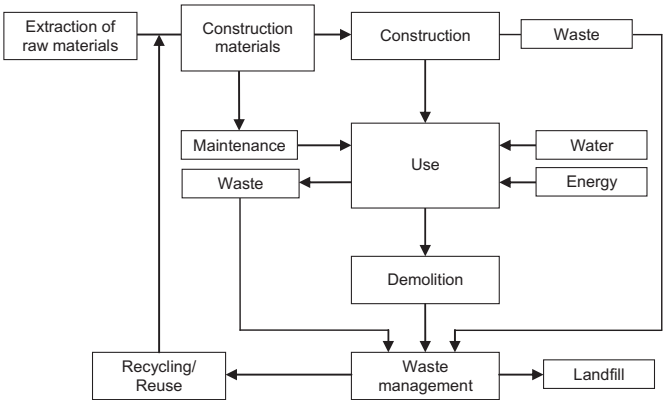

Fig. 1. System boundaries and life cycle stages considered for the three types of house (detached, semi-detached and terraced).

[3] For the purposes of this paper, the term 'housing sector' refers to houses only, excluding apartment buildings.