Embodied primary energy and carbon in offsite timber framed housing: A case study GreenGauge Design Lingwood.

A report prepared for Flagship Housing group

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Chapter 1 Introduction

Carbon is emitted as a result of the exploitation of raw materials, processing, manufacturing, transport, use and end-of-life management of a product. The energy and associated emissions of carbon linked with a building can be considered in three distinct, but inter-linked stages:

1. construction
2. occupation
3. end of life

Whilst considerable interest is given to the energy utilised by a building far less attention is paid to that associated with earlier stages associated with construction[1]. This hidden environmental burden is known as embodied carbon. Embodied carbon is not, in general practice, a consideration in designing, specifying and constructing a building.

Although the carbon emitted during the occupation of a building forms the majority of that buildings lifetime carbon footprint, there are significant carbon consequences involved in a buildings initial construction. Embodied carbon is of particular importance for low energy buildings for although less energy is used during their occupation, additional energy is required during the manufacture of insulation and the often greater thermal mass in the heavier materials required. The embodied energy of a low energy house is likely to contribute a greater proportion of the overall energy demand through its lifetime than would occur for a conventional house.

It has been suggested that between 8 - 10% of the UK's total energy demand is attributable to the winning of primary materials, manufacture, transport and construction of new buildings[1,2,3] . Very few studies on the embodied carbon of new build housing in the UK have been undertaken. Studies that are available suggest the embodied carbon of construction of an average house in the UK to be approximately 50 tCO_2 for the average new home[456].

The UK is committed to increasing the number of new homes to 3 million by 2020[7]. From 2016 these homes have to achieve zero carbon emissions, plus there needs to be a substantial increase in the thermal renovation of the existing housing stock. Any increase in construction will have implications for the UKs national carbon budget but the magnitude of the impact will be significantly dependent upon how the new homes are constructed.

A potential solution to reducing these embodied emissions whilst also saving emissions during occupation can be developed through careful design. One example of this is Greengage Homes whose design principles combine low energy, Modern Methods of Construction (MMC[8]) with the use of sustainable materials and a

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[1] Sustainable homes: embodied energy in residential property devlopment A Guide for Registered Social Landlords The Housing Corporation

[2] J. C. Morel, A. Mesbah, M. Oggero and P. Walker 2001: Building houses with local materials: means to drastically reduce the environmental impact of construction Building and Environment V 36 (10) 1119-1126

[3] Adalberth K. 1996: Energy demand during the life cycle of a building. CIB Symposium Energy Mass and Flow in the life Cycle of building, Vienna, 1996.

[4] Barrett J and Wiedmann T 2007: A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House. The Stockholm Environment Institute SEI & ISAUK Research Report 07-04 http://www.isa-research.co.uk/docs/SEI_ISA-UK_Report_07-04_OSM_House.pdf

[5] Empty Homes Agency 2008: New tricks with old brick: How using old buildings can cut carbon http://www.emptyhomes.com/documents/publications/reports/New%20Tricks%20With%20Old%20Bricks%20-%20final%2012-03-081.pdf

[6] Hacker JN, De Saulles TP, Minson AJ , and Holmes MJ 2008: Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change Energy and Buildings V 40(3) 375-384

[7] Department for Communities and Local Government 2007: Building a Greener Future: policy statement. July 2007 Department for Communities and Local Government: London

[8] MMC refers to offsite manufacture of building components. Varies in scale from individual components, to pods and entire homes.

commitment to using renewable energy sources where practical. The design approach has a central aim of providing cost effective mainstream housing with reduced environmental impacts during construction and in use. GreenGauge Homes are a major long term project of Flagship Housing Group, a housing association based in East Anglia.

GreenGauge homes are characterised by the following principles:

- Highly insulated: super insulated roof and additional site installed insulation to offsite manufactured walls and floors.
- Good ventilation: Well sealed homes need to be ventilated. Ventilation is through passively designed ventilation. Passi-vents were incorporated into the window frames to provide ventilation.
- Sustainable materials: Offsite manufactured timber frame, combing the benefits of low impact sustainable material and resource efficiency in production. All timber FSC certified. Avoidance of UpVc, using timber framed windows. Reduced use of high embodied energy materials such as masonry and concrete.
- Passive solar design: Design elements to maximise 'free' energy from the sun, using sunspaces and thermal mass to collect heat during the day to radiate out at night. Heat recovery to circulate the warm air into the living space.
- Renewable energy technologies: With ever tighter carbon standards for housing the use of renewable energy technologies is becoming more likely. The technologies used include solar hot water, photovoltaic's, and ground source heat pumps[9].
- Water efficiency: Low water use toilets, baths and taps. Rainwater collection for grey water use (toilets and washing machines).
- Affordable: A GreenGauge home is affordable to both build and to live in. Also it has to be replicable and not rely on additional grant funding to achieve its objectives. Cost efficiency at all stages in the delivery of GreenGauge homes is considered fundamental to its long term success.

Fifteen GreenGauge homes, a mixture of two and three bedroom terraced houses, were constructed at School Lane, Lingwood, in Norfolk. Working with researchers at the University of East Anglia, with funding support from Carbon Connections, the carbon footprint of the development and the energy performance during the first year of occupancy were monitored and evaluated.

This report presents the findings of a lifecycle assessment of the construction of a GreenGauge development at Lingwood, Norfolk. The study considers the primary energy required in the construction of the homes and the consequential embodied carbon of the methods and materials used in the Greengage design approach. The properties are low energy timber framed houses constructed using an offsite modular timber frame system. Maintenance, repair, renovation and the final end of life disassembly and disposal are beyond the scope of this report. The occupational energy and carbon emissions of the GreenGauge Lingwood development during occupation are considered in a separate report[10].

In addition to identifying and quantifying the embodied carbon in a GreenGauge Home the study aims to address:

i. whether offsite modular timber frame construction can reduce the environmental impact of constructing new homes
ii. what are the potential consequences for the UK's carbon mitigation targets of constructing 3 million new homes?

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[9] Heat pumps use electricity to condense heat, typically grid electricity is used therefore are not strictly a renewable energy technology.

[10] Powell J.C and Monahan J 2009: Energy use in occupation of low energy homes: A case study GreenGauge Design Lingwood. University of East Anglia.

This report consists of four chapters. The first chapter provides an overview of the methods used and the parameters and assumptions used in the study. The following chapter presents the results; the embodied carbon of a basic GreenGauge Lingwood offsite modular timber frame house plus the carbon consequences of the addition of a sunspace as part of a passive thermal design strategy. The third chapter presents a comparative analysis of alternative construction scenarios. The analysis considers the carbon consequences of different cladding materials and a conventional masonry home with the same thermal performance and dimensions. The fourth chapter discusses the results and draws some conclusions for future GreenGauge developments and the potential implications for the wider UK. The final chapter draws some conclusions.

Chapter 2 Methods

The growing importance of environmental issues, such as climate change, has created a need to evaluate the impacts of the products that we use. One of the principle techniques to enable the quantification of the environmental impacts of a product is Life Cycle Assessment (LCA).

LCA is a framework for evaluating the environmental impacts of a product, process or service from cradle to grave and is carried out according to an International Standard. ISO 14040 2006 defines LCA as the:

> 'compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.'

The LCA framework consists of four main phases:

1. Goal, scope and definition
2. Inventory analysis (LCI)
3. Impact assessment (LCIA)
4. Interpretation.

The initial phase defines the scope of the study, including defining the functional unit, the system boundary, the level of detail and how the environmental burdens will be allocated. It is dependent upon the subject and the intended use of the study and can vary considerable depending upon the particular LCA.

The second phase, life cycle inventory (LCI), is the compilation of an inventory of the input/output data with regard to the system under study. It is an iterative process, with data constantly being updated and added to as more is learnt about the system under study.

The third phase, Impact assessment (LCIA), evaluates the significance of potential environmental impacts using the LCI results and provides information for the final interpretation phase.

Life cycle interpretation is the final phase in the LCA framework. The results of an LCIA (or an LCI in a partial LCA study) are summarised to form a basis for conclusions, recommendations and decision making in accordance with the study as defined in the first phase.

Study outline

Goal

The study presented in this report uses the LCA framework as a tool to conduct a partial LCA, from 'cradle' to completion' of a Greengage home constructed using an offsite modular timber frame system. The study provides an account of the materials and energy involved to calculate the embodied carbon of the home.

Study boundaries

The full lifecycle and the boundary for this study are illustrated in Figure 2.1.
The study includes cradle to completion emissions from:

- materials and products used in construction
- the final transport of the materials and products to site
- the materials waste produced on site
- transportation of waste to disposal
- the fossil fuel energy used on site during construction

The following were outside the boundaries of the study and were not included:

- The infrastructure required in production, such as roads, factories, warehouses and machinery.
- The operation and other activities associated with administration and the workforce themselves (including their transport to site)

The environmental impacts where a process produces multiple or subsidiary products (such as timber production at a sawmill producing sawdust, woodchip and bark for use in wood fibre board manufacture or as fuels) are allocated by weight.

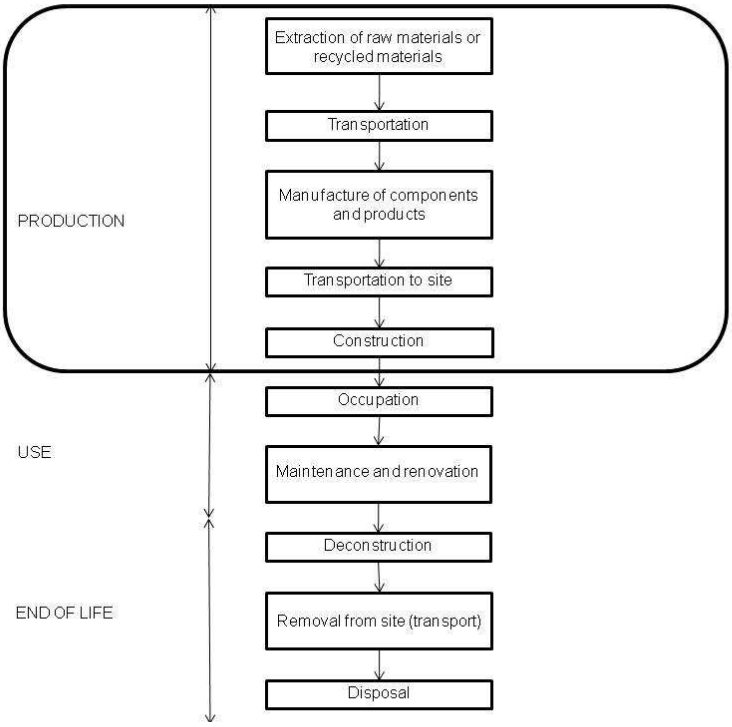


Figure 2.1: Process flow chart of lifecycle of a house with production boundary shown.

Description of the case study

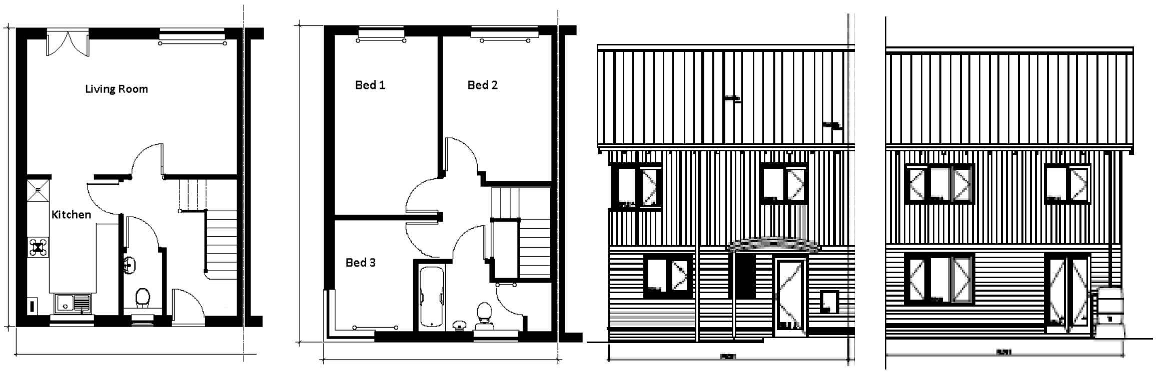
In order to be able to make a fair comparison between different materials and approaches used a unit of study has to be defined (termed a functional unit). The functional unit for this study is the external envelope of a 3 bedroom, semi-detached home with a total internal area of 85m^2 and a total internal volume of 220.5m^3.

The design and dimensions used for the GreenGauge Lingwood study home are given below (Table 2.1 and Figure 2.2).

The external envelope refers to the following elements: substructure; foundations; ground floor; external and shared party walls; roofs; openings (i.e. doors and windows). Internal fixtures, such as internal walls, finishes, lighting, plumbing, kitchens and bathrooms were considered equal regardless of construction and are, therefore, outside the scope of this study.

Table 2.1: design details of functional unit

		standard larch	**standard brick**	**masonry cavity**
number of floors		2	2	2
total internal floor area	m^2	85	85	85
total footprint area	m^2	45.3	46.6	46.8
total wall area	m^2	113.5	115.0	115.3
wall width	mm	273	319	327
opening area	m^2	16	16	16
framework		timber	timber	masonry
u-value (Wm^{2}k):				
wall		0.18	0.18	0.18
floor		0.16	0.16	0.16
roof		0.14	0.14	0.14
windows		1.80	1.80	1.80



Ground Floor First Floor South Elevation North Elevation

Figure 2.2: Plans of basic GreenGauge Lingwood Home

The standard GreenGauge design was constructed using an offsite modular timber frame system with additional insulation materials added onsite and clad in untreated larch weatherboarding (Figure 2.3). The timber frame was a factory constructed modular system consisting of wall modules of a standard ‘stick’ frame with factory installed phenolic foam insulation, cement wall board and a waterproof membrane. The first floor joist modules were constructed using engineered timber (known as I-beams and glulam beams[11]). Such an approach is considered to be more efficient in terms of reduced materials, waste and energy in manufacture than conventional on site construction.

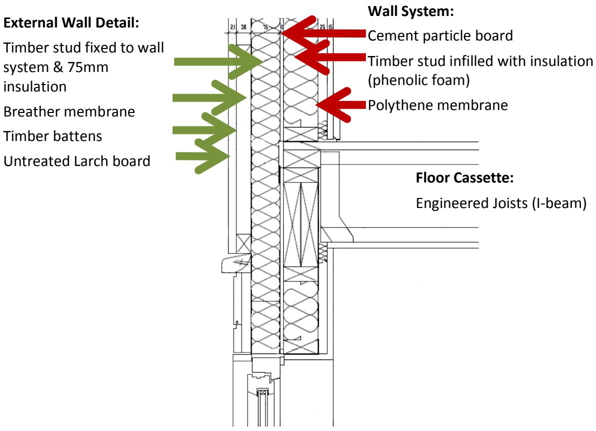


Figure 2.3: Offsite modular frame detail (source: Barefoot and Gilles Architects)

Three alternative scenarios were modelled to enable a comparison:

Scenario 1. Standard larch and sunspace: Modular timber frame as base model with an additional sunspace and internal brick wall as constructed

Scenario 2. Standard Brick: Modular timber frame as base model with brick facade replacing larch facade.

Scenario 3. Masonry: Conventional masonry cavity construction with brick exterior, insulated cavity and internal block

The same thermal standards are prescribed for each of the different scenarios (meeting a U-value of 0.18 Wm^2K). The internal volume, floor construction and roof construction are also the same in all the scenarios (Table 2.1), however to meet the same thermal standard

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[11] I-beams are beams with an I or H shaped cross section. The horizontal flanges are formed from solid timber (usually softwood) to which a vertical web (typically a plywood) is jointed and glued. Lighter, using cheaper low grade materials and as structurally strong as expensive solid timber. Glulam (or glue laminated timber) beams are structural timber beams comprised of several layers of dimensions timber glued together. Both these forms of engineered wood products represent an efficient use of available timber by making use of smaller, less desirable and waste timber.

the wall width and, consequently, the volume materials within the foundations and substructures vary.

Data

The inventory of materials and inputs into the construction of the Lingwood development were estimated from information provided by quantity surveyors, architects, the construction partner and other companies providing goods and services along the supply chain. The data was collected retrospectively, with varying degrees of quality.

Material quantities were obtained from quantity survey data, plans and information provided by supply chain partners. In cases, such as shared party walls, the materials were allocated by area.

Information regarding the offsite frame production process was obtained from the manufacturing company. Aggregated production data on energy and materials was provided. Some data were unavailable due to commercial confidentiality, in particular pertaining to the insulation. Data gaps were filled with published literature references where available or best guess estimates. Allocation of energy and waste from the manufacturing process was by units of production.

The timber materials were all imported and mineral materials were all produced in the UK. The Larch cladding was imported by boat from the Ikursk region of Siberia. The timber softwood was imported from Scandinavia. The structural engineered timber were produced and imported from the United States.

Data on waste generated during on on-site construction was limited to an aggregated volume. Estimation of different waste streams and disposal routes were made based on benchmark data from The SmartWaste Scheme (BRE, 2008) and from published literature (WRAP, 2007)[12]. Information on waste management practice and material separation was obtained from the site operators and waste management contractors. As data for onsite waste was also limited, the different waste streams and volumes were estimated from published data and information provided by the construction partner[13].

The energy in construction includes fossil fuels (petrol, diesel and gas) and electricity. Data for onsite energy use was limited. Quantities of energy and fuels used during construction were derived from receipts and meter readings. It was not possible to disaggregate the energy consumed to specific activities and, therefore, specific build components. Onsite energy is presented as an aggregated figure; more detailed analysis is beyond the scope of this report.

Primary energy and carbon emissions were derived from a number of sources including:

- The Inventory of Carbon and Energy (Jones 2008)[14].
- Econinvent Lifecycle Inventory database (Econinvent 2008[15])
- U.S. Life-Cycle Inventory (USLCI) (NREL 2008[16]).

Simapro V7.1 software was used in the analysis of the engineered timber components using the available inventory databases as above.

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[12] WRAP 2008: Offsite Construction Case Studies WAS031, WAS 003, WAS. Waste and Resources Action Programme 2008

[13] SmartWaste Benchmarks published 23rd April 2008 online: www.smartwaste.co.uk

[14] Hammond, G.P. and C.I. Jones 2008: Embodied energy and carbon in construction materials. Proc. Instn civil. Engrs : Energy in press

[15] Ecoinvent : Ecoinvent Centre, 2008. ecoinvent data v2.0. Final reports ecoinvent 2000 No. 1-15, CD-ROM; Dübendorf, Switzerland: Swiss Center for Life Cycle Inventories.

[16] US LCI http://www.nrel.gov/lci/

Chapter 3 Results

This chapter presents the results of the lifecycle inventory analysis of the GreenGauge Lingwood home. The results are given as MJ primary energy in the first instance and the remainder as embodied carbon (referred to in terms of CO_2). The results are presented by component (Table 3.1and Figure 3.1) and by material type (Figure 3.2 and Table 3.2).

The GreenGauge Basic Design

The standard GreenGauge home with larch cladding required 519GJ of primary energy. This equates to an embodied primary energy of approximately 5.7GJ per m^2 of usable floor area. Published studies give a range of between 1.3 – 14.3 GJ/m^2[17]. The results of this study fall mid range.

The remainder of this report presents the results in terms of carbon as kg or tonnes of CO_2.

The total carbon embodied in the GreenGauge home was 34.6tCO_2, (Table 3.1), approximately 381kgCO_2 m^2.

Table 3.1 Standard GreenGauge design by component

	tCO_2	primary energy/MJ
frame	3.5	69735
roof	4.1	61551
walls	4.4	70912
floor ground	3.4	48557
foundations	1.8	22629
substructure	8.8	85267
openings	2.2	45942
waste	4.7	93446
transport	0.9	13144
energy in construction	0.7	7531
totals	34.6	518713

82% of the carbon is embodied in the materials within the structure (Table 3.2 and Figure 3.2), with the remainder being produced by construction activities such as transporting materials from point of distribution to site, waste materials exported from the site and energy used onsite.

Table 3.2 Embodied carbon and energy from the construction of the standard design from different material (MMC components included)

	tCO_2	primary energy/ MJ
minerals	12.3	110856
timber	8.1	132279
plastics	1.6	47576
metals	2.8	48257
openings	2.2	45942
waste	4.9	97823
transport	1.1	14062
energy	1.5	21917
totals	34.6	518713

The largest share of emissions associated with the construction phase were attributable to the substructure and foundations (31%) (Figure 3.1). 23% of the emissions were associated with the walls with 56% of this being associated with the larch external walling elements (cladding, additional insulation etc) and the remainder associated with the offsite timber frame structure. Overall, the offsite timber frame structure was responsible for 10% (3.5tCO_2) of the total emissions.

In considering the total emissions the largest proportion of embodied energy is associated with minerals category (35%) (Figure 3.1). In considering the environmental impact of materials exclusive of the other related activities (i.e. energy on site, transport and waste) the proportion of emissions attributable to the use of minerals rises to 45%. The minerals category includes materials such as cement, gravels, sands and concrete products.

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[17] Nassen et al 2007: Direct and Indirect energy use and carbon emissions in the production phase of buildings: An input-output analysis. Energy 32 pp 1593-1602

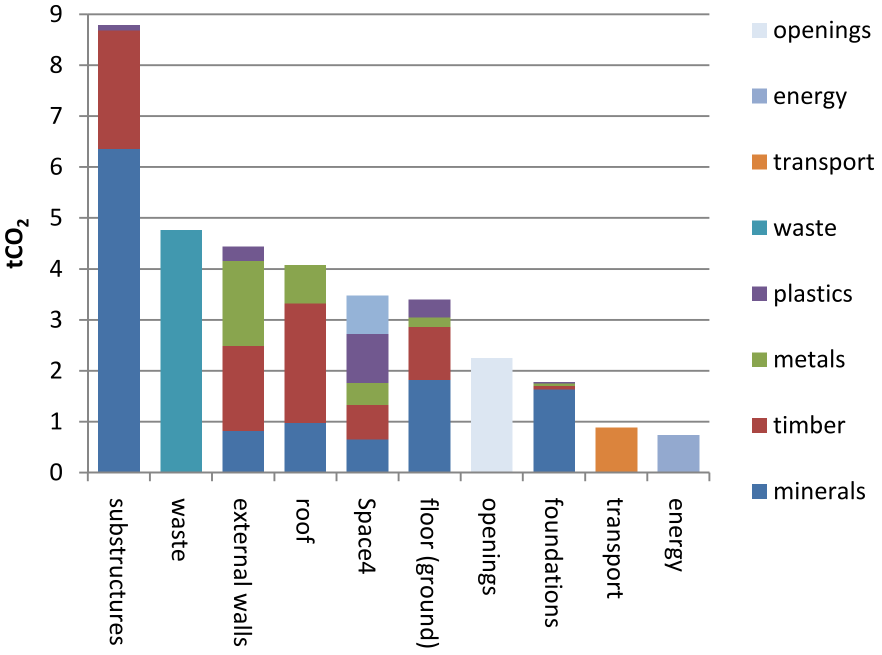

Figure 3.1 Proportions of embodied carbon by different components and materials of the building and the construction process for the standard design (tCO$_2$)

The principle material responsible for the majority of the embodied carbon is Portland cement, which has a high embodied energy, approximately 1 tCO$_2$ per tonne of cement[18]. A large proportion of these materials would have been UK produced with relatively low transportation distances[18]. The majority of minerals were used in the construction of the substructure and foundations. These elements were responsible for 71% of the emissions associated with the use of minerals. The remainder of the minerals were incorporated in the ground floor (concrete block and beam, 16% of minerals emissions) and the roofing tiles (concrete tiles, 9% of minerals emissions).

In considering the total emissions the largest proportion of embodied energy is associated with minerals category (35%) (Figure 3.2). In considering the environmental impact of materials exclusive of the other related activities (i.e. energy on site, transport and waste) the proportion of emissions attributable to the use of minerals rises to 45%. The minerals category includes materials such as cement, gravels, sands and concrete products. The principle material responsible for the majority of the embodied carbon is Portland cement, which has a high embodied energy, approximately 1 tCO$_2$ per tonne of cement[18]. A large proportion of these materials would have been UK produced with relatively low transportation distances. The majority of minerals were used in the construction of the substructure and foundations. These elements were responsible for 71% of the emissions associated with the use of minerals. The remainder of the minerals were incorporated in the ground floor (concrete block and beam, 16% of minerals emissions) and the roofing tiles (concrete tiles, 9% of minerals emissions).

Timber, a key material in the structure and external cladding, was responsible for 30% (8.1tCO$_2$) of the material s related embodied carbon, inclusive of the timber used in the offsite frame. The Larch cladding was imported from the Ikursk region of Siberia the majority of the transportation being by ship.

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[18] Josa, A, Aguado, A, Heino, A, Byars, E and Cardim, A 2004: Comparative analysis of available life cycle inventories of cement in the EU. Cement and Concrete Research 34 pp 1313-1320

Surprisingly only 12% of the total embodied carbon of the production and importation of Siberian larch is attributable to transportation from extraction to point of distribution. The timber softwood used in the production of the MMC frame was imported from Scandinavia. The structural engineered timber were produced and imported from the United States. For the other timber used in the construction no source could be identified, it was assumed that none of this timber used in the construction was UK grown.

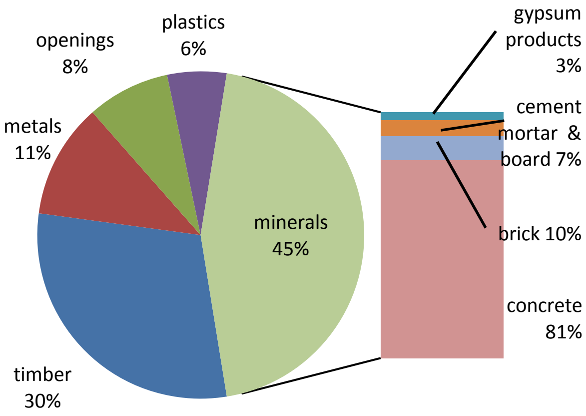

Figure 3.2 Proportions of embodied carbon from different materials (excluding waste, transport and energy in construction) for the standard design (tCO_2)

The remaining material categories were responsible for 25% ($6.7tCO_2$) of the material related embodied carbon. These include metals (fixings and flashings, 11%), openings (doors and windows, 8%) and plastics (insulation, membranes and vents, 6%).

21% ($7.6tCO_2$) of the total embodied carbon were attributable to site related activities (Figure 3.1). These include energy used in construction (4%), site waste (14%) and transport from factory gate to site (3%).

17m^{3}of waste materials were exported from site including excavated inert materials, construction materials and other waste. This was estimated to have an embodied carbon of $4.6tCO_2$ (Figure 3.3). The majority of emissions were associated with packaging materials (35%).

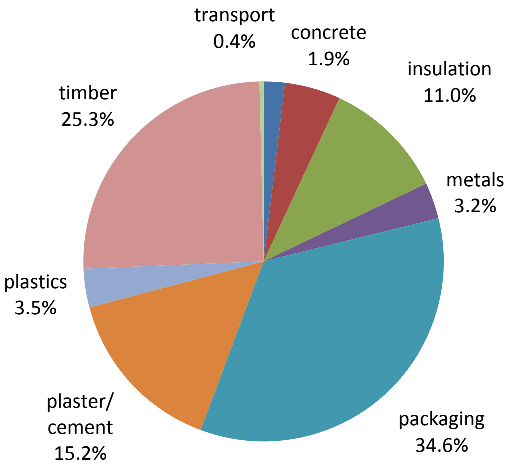

Figure 3.3 Estimated embodied carbon from onsite waste arisings excluding frame manufacture (tCO_2)

Transportation emissions associated with factory gate to in-situ transport accounted for 3% of the total emissions. This is similar to other studies which also found transport to have a relatively low share of the total emissions of CO_2[19].

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[19] K. Aldaberth 1997: Energy use during the LifeCycle of Single Unit Dwellings. Building and Environment 32 (4).

Chapter 4 Alternative scenarios

Three further scenarios were modelled. The first scenario considered the addition of a sunspace and internal brick thermal mass wall as part of a passive solar heating strategy. The second considered the use of an alternative, aesthetically conventional cladding material. In this scenario brick was used to replace the larch cladding. The third scenario considered a conventional masonry construction to the same dimensions and thermal standards (brick outer, fully filled cavity and block inner).

Scenario 1: Sunspace

The GreenGauge Lingwood development included the addition of a double height partially glazed sunspace on a number of the homes. The addition of a sunspace with an internal trombe wall was to test the application of passive solar as part of a passive design strategy. The sunspace required the construction of an additional 9.94m^2 floor space. The internal wall was clad in a dark solar brick, displacing the larch cladding to this elevation. The sunspace, though attached, was thermally separated from the main dwelling[20].

Table 4.1 additional materials embodied carbon and energy required for the construction of sunspace

	tCO$_2$	primary energy/MJ
frame	0.3	6954
metals	0.6	10244
minerals	5.5	63456
plastics	0.2	4802
timber	0.5	9180
openings	2.5	50305
waste	0.7	20580
transport	0.2	2886
energy	0.04	377
total	10.6	168781

The total embodied carbon in a home with an additional sunspace was 45.2 tCO$_2$. an increase of 10.6tCO$_2$ (169GJ of primary energy) (Table 4.1 and Figure 4.1).

77% of the additional emissions are attributable to the passive elements, the mass and glazing. Of which, 52% are attributable to the use of minerals in substructure, foundations and the trombe wall, with half attributable to the single skin brick trombe wall.

24% of the additional emissions are attributable to the double height glazed openings.

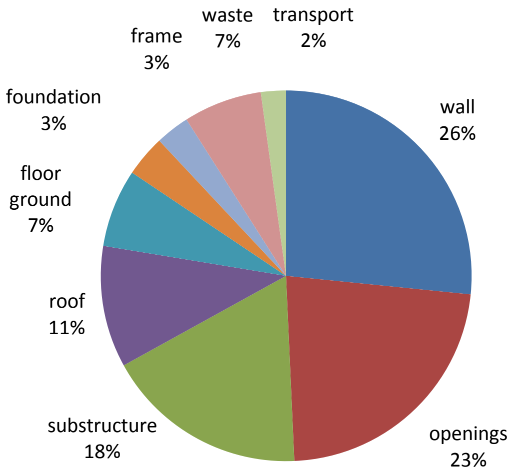

Figure 4.1 embodied carbon associated with the construction of an additional sunspace (tCO$_2$)

Scenario 2: Brick facing

In Scenario 2 the external larch weather boarding was replaced with a single skin brick exterior. The wall width was slightly wider and the foundations and substructures were increased in volume to accommodate this additional width and weight. All other parameters were held equivalent to the basic model.

The results are presented by component (Figure 4.2 and Table 4.2) and by material type (Figure 4.3 and Table 4.3).

The brick clad GreenGauge home required 656GJ of primary energy (Table 4.2). This equates to an embodied primary energy of

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[20] The sunspace as a passive design strategy is discussed in the sister report: Energy Use in The Occupation of Low energy Homes: GreenGauge Lingwood Case Study.

approximately 7.7GJ per m^2 of usable floor area. This is an increase of 35% in embodied energy compared to the standard design.

Table 4.2 Emissions CO_2 and energy arising brick facing scenario by component (tCO2)

By component	tCO_2	Primary energy/MJ
frame	3.5	69735
roof	4.1	61551
walls	15.0	203457
floor ground	3.4	48557
foundations	1.8	22629
substructure	8.8	85267
openings	2.2	45942
waste	4.9	95384
transport	1.1	14845
energy in construction	0.9	9037
Total	45.6	656404

The results of this scenario gave a total of 45.6tCO_2 embodied in the construction, approximately 535 $kgCO_2$ m^2. This is an increase in embodied carbon of 32% compared to the base model house.

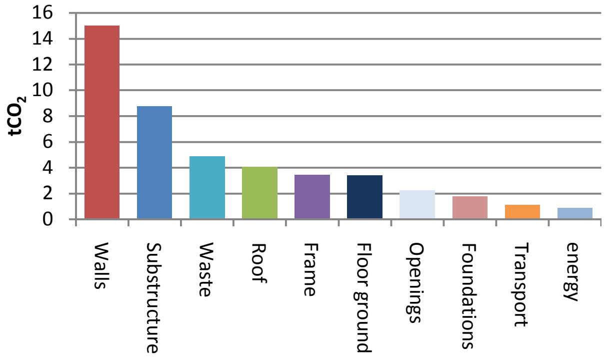

Figure 4.2 Emissions CO_2 arising from brick facing scenario by component.

The walls in this scenario are responsible for 41% of the total embodied carbon. Of this the non-frame elements (brick, additional insulation, membranes etc) formed 81% with the offsite frame responsible for the remainder. The substructure and foundations are accountable for 23% of the total emissions.

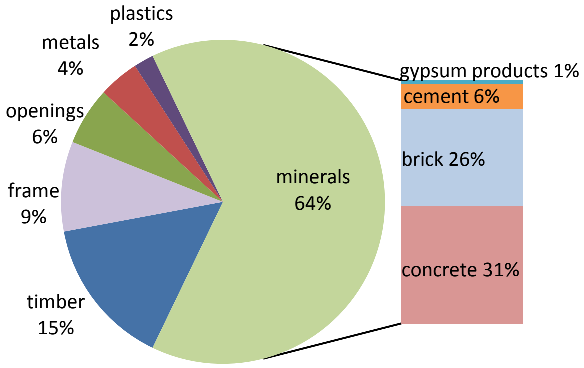

Figure 4.3 Emissions CO_2 arising from brick facing scenario by material (tCO_2)

Unsurprisingly the majority of this difference is accounted for by the increase in minerals (i.e. brick, cement and sand) with a resulting increase of embodied carbon. Typically, an increase in the total proportion of heavier materials in a construction project will increase transport emissions, in this case by 25%. The increase in construction energy is due to the increase in machinery required on site, such as mixers for the mortar.

Table 4.3 Emissions CO_2 and energy arising from brick facing scenario by material

By Material	tCO_2	primary energy/MJ
frame	3.5	69735
minerals	24.9	271355
timber	5.8	102120
plastics	0.8	21898
metals	1.6	26089
openings	2.2	45942
waste	4.9	95384
transport	1.1	14845
energy in construction	0.9	9037
total	45.6	656404

Scenario 3: Masonry

A third scenario considered a conventional construction approach of masonry brick and block for comparison purposes. It was assumed that the wall structure was altered and that the specification achieved the equivalent U-value of the standard timber frame design (Table 2.1) whilst all other dimensions remained unchanged (i.e. opening areas, internal floor area and volume). The substructure and foundations increased in volume to accommodate the additional wall width and weight. All other elements remained unchanged from the standard specification. The waste was altered according to published waste benchmark figures for this type of construction (SmartWaste2008)[21].

The results for the masonry scenario are presented by component (Figure 4.4 and Table 4.4) and by material type (Figure 4.5 and Table 4.5).

Table 4.4:Emissions CO_2 and energy arising from masonry scenario by component

component	tCO_2	primary energy/MJ
roof	4.1	61551
walls	22.4	123828
floor ground	3.5	50076
foundations	3.9	37855
substructure	8.8	85267
openings	2.2	45942
waste	5.3	197497
transport	1.2	16296
energy in construction	0.9	9037
total	52.2	627349

The primary energy embodied in this construction was 627GJ, 7.3GJ/m^2, which is 21% greater than the standard model.

The embodied carbon in this construction approach was 52tCO_2, approximately 612kgCO_2 m^2, which is 34% greater than the base model.

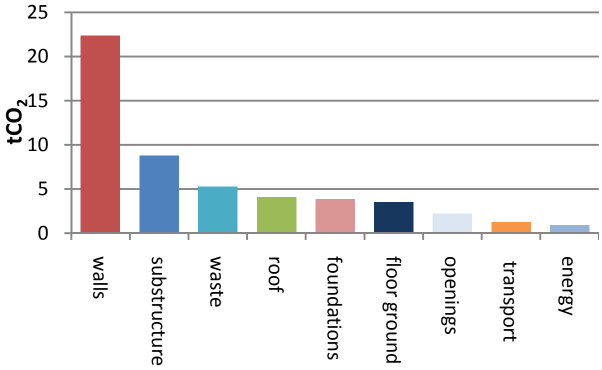

Figure 4.4 Emissions CO_2 arising from masonry scenario by component

The majority of total embodied carbon was accounted for by the walls, and the foundations and substructure, 43% and 24% respectively.

Table 4.5:Emissions CO_2 and energy arising from masonry scenario by material

material	tCO_2	primary energy/MJ
minerals	34.5	209904
timber	5.8	102120
plastics	0.7	19718
metals	1.6	26835
openings	2.2	45942
waste	5.3	197497
transport	1.2	16296
energy in construction	0.9	9037
total	52.2	627349

Materials accounted for 86% of the total embodied carbon. 77% of which was attributed to minerals.

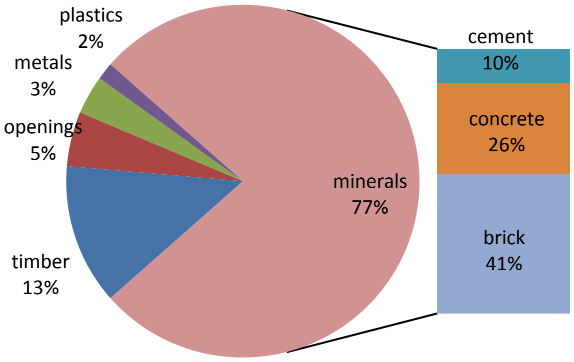

Figure 4.5 masonry scenario CO_2 emissions by material

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[21] SmartWaste Benchmarks published 23rd April 2008 online: www.smartwaste.co.uk

Chapter 5 Discussion

The study aimed to address three questions:

i. What, and where, is the embodied carbon of a GreenGauge home
ii. Whether offsite timber frame construction can reduce the environmental impact of constructing new homes
iii. What will be the potential consequences for the UK's carbon mitigation targets of constructing 3million new homes.

The following discussion considers the results of the lifecycle inventory and reflects on the implications for each of these questions in turn.

What and where is the embodied carbon in a GreenGauge home?

The construction of a GreenGauge Lingwood home resulted in emissions of CO_2 of approximately 35tCO_2 (381kgCO_2 m^2). Of this, 40% was associated with the materials used to construct of the substructure, foundations and ground floor

These structural elements, in particular cement and bricks, have a high energy input during manufacture and, consequently a relatively high embodied carbon. The amount of CO_2 associated with cement production depends upon the materials and energy source used in its production. There are products available that can significantly reduce these emissions, such as those using ground granulated blast furnace slag, fly ash and other pozzolanic materials. These sub structural elements and the materials used are a potential target for reducing the embodied carbon in a GreenGauge home.

The walls and frame structure constituted 23% of the embodied carbon (the MMC structural frame 10%). The largest contributor to the wall and frame were plastics associated with the manufacture of insulation and membranes. Rigid polyisocyanurate (PIR) insulation was used in both the wall manufacture and the additional site installed insulation. This has a high energy demand in manufacture; however the thermal performance for a given thickness is far superior to other products[22]. The lifetime benefits may more than outweigh the initial environmental costs of manufacture. Further study on the full lifecycle (including end of life disposal) embodied energy and carbon of alternative insulation materials is needed to qualify this intuitive assumption.

Can offsite modular timber frame reduce the construction carbon footprint of housing?

In this study the use of panellised timber frame modular system produced buildings with a 34% reduction in embodied carbon when compared with a conventional heavy masonry construction. The use of a high proportion of timber in the structure was the principle actor behind the reduced embodied carbon.

Further reductions in embodied energy and carbon occurred through the efficiency of design and volume production reducing input materials (no contingency and error related over ordering) and waste. Savings were derived from the efficiencies of volume production in reduced waste per unit of production. A recent WRAP report estimated the waste reduction through the substitution of timber frame systems with traditional methods to be between 20 – 40% [23], the greater the prefabrication the greater the savings. The limited data available from this study and from the WRAP study suggests that with would equate to approximately 0.3tCO_2. The data collected is not sufficiently detailed to draw any robust conclusions. Further research is needed to quantify the savings.

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[22] Tseng, Chung-jen and Kuo, Kuang-te 2002: Thermal radiative properties of phenolic foam insulation. J. Quantitative Spectroscopy & Radiative Transfer, 72 pp 349 -359.

[23] WRAP, Waste Reduction through the use of Timber Frame at SmartLIFE WAS0031: Offsite Construction Client Exemplars. 2008, Waste Resources and Action Programme. p. 13

The frame manufacturer used for the Lingwood homes is a relatively young enterprise. The manufacturing process used was constantly undergoing efficiency reviews in order to drive production costs down in such a competitive industry. Electricity inputs into the production process were reduced by 46% after the study period[24].

Production waste at the manufacturer was either returned to the manufacturing process or, being produced in quantities that are viable for export offsite, recycled into other alternative processes and products. Conversely on a small construction site, such as those typical to GreenGauge, any 'waste' or surplus materials from unused contingency or over ordered materials are produced in relatively small quantities. Anecdotal evidence from observation of site operations suggests significant barriers, such as time, lack of local infrastructure and health and safety legislation, exist to hinder the reuse of these materials locally or recycled back into the supply chain.

Further research on the lifecycle of off-site manufacture of timber frame housing is needed to investigate this issue further.

In considering the difference between the base case and the alternative scenarios, the majority of the difference is accounted for by the wall component (Figure 5.1). For example, the panellised timber frames with timber weatherboard walls resulted in 65% lower embodied carbon than conventional masonry cavity walls.

In all the scenarios modelled the largest contributor to the embodied carbon was minerals, in particular those products containing Portland cement or with high embodied energy, such as bricks. Cement in its many forms, is essential in most buildings. The use of cementitious materials, in bricks, blocks, mortars and concrete products, is of significance in all three scenarios, ranging from 41 - 77%.

However, it is too simplistic to consider the embodied carbon issue in isolation as these materials have a high thermal mass that will help reduce occupational heating and cooling loads if used judiciously and in the right place, as demonstrated by the sunspace[25]. The additional embodied carbon from construction of the sunspace can be considered a carbon investment to be paid back in reduced heating and cooling costs.

The GreenGauge design, typical of timber frame construction, has the majority of its mass hidden within the substructure, in a conventional concrete oversite slab, and strip foundations. As this is separate from the main thermal structure, it is consequently, unavailable for thermal mass.

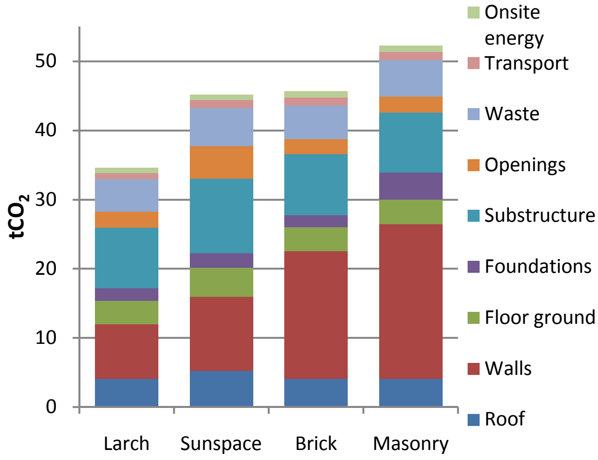

Figure 5.1: Embodied carbon (tCO$_2$) from the four scenarios by component.

Reducing the environmental burden further by using lightweight construction can be achieved in two ways. Firstly, reducing the use of Portland cement by substituting with lower carbon alternatives, such as Pozzolanas or lime based products. Secondly, by reducing the amount of cement required with the use of alternative approaches to conventional foundations and substructures, such as pad foundations or screw piles. Although a relatively high embodied energy product steel screw piles are reusable and recyclable. Both

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[24] Space4 personal communication 13 June 2008

[25] Brown, GZ and DeKay, M 2001: Sun Wind & Light Architectural Design Strategies 2nd Ed. John Wiley and Sons Ltd.

these strategies would radically reduce the use of carbon intensive materials where no additional mass related benefit to their use is possible in lightweight construction. There would also be other additional benefits such as reduced earthworks requiring less spoil and waste material for export off site and lower energy inputs and further benefits at end of life deconstruction.

What are the implications for the UK carbon targets?

The average area of a domestic building in the England is 69.5m^2 [26]. The projected new build target of 200,000 new homes a year, (3 million in total) current economic climate notwithstanding, represents a growth of 14 million m^2 of additional housing area.

If all this new construction was entirely traditional masonry this would equate to an annual rise in carbon emissions of 8.5MtCO$_2$ as embodied energy.

If all these new homes were constructed in the same way as the timber weather boarded panellised timber frame system in this case study this represents an annual rise embodied carbon emissions of at least 5.3MtCO$_2$.

It is unlikely that such intensive timber homes will be the norm. Currently timber frame has 22.2% of the market share of new house building [27], No data was available to identify how much of this was brick veneer. If an assumption is made that the majority of these new homes were brick clad timber frame and (97%) and the remaining 77.8% traditional masonry cavity, the embodied carbon load related to new housing is likely to be 82.6MtCO$_2$.per annum.

If the targeted 3 million new homes are built the overall impact in terms of the UK's carbon emissions will be between 89MtCO$_2$ to 135.5 MtCO$_2$ depending on the proportions of lightweight timber frame or heavyweight mineral intensive traditional construction. The drive towards zero carbon by 2016 will negate a proportion of this increase through reduced energy demand in use. Whether this reduced demand will offset the increased embodied carbon will depend upon the materials used, the technologies used to supply services and the demands of the inhabitants.

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[26] There are 21.7m dwellings in England (Office of National Statistics) and the total area of domestic buildings in England is 1,507,704,900 m^2

[27] UK Timber Frame Association Interim Market Report April 08 www.timber-frame.org accessed 17th September 2009

Conclusions

This study has shown that a panellised offsite modular timber frame and timber clad construction has a significantly lower cradle to completion embodied carbon when compared to a conventional masonry construction.

Further research is needed to understand the carbon benefits and other environmental advantages derived from the use of the offsite manufacture.

Further reductions in embodied carbon are possible by targeting the use of bricks and cementitious materials. Replacing Portland cement with lower carbon alternatives and using different technologies and strategies to reduce the need for such materials in substructures and foundations are required.

Cementitious materials are useful, can be considered essential in economic, volume construction and are of benefit as thermal mass. Thermal mass benefits, even in timber frame, can be gained if situating these materials in the most advantages places in a build rather than isolated and hidden within the substructure.

The implications for the UKs overall carbon burden if the 3 million new homes target is achieved are significant. Currently embodied carbon is a hidden environmental burden of production. This is particularly the case when the materials and products are not manufactured domestically and are not accounted for in domestic carbon accounts.

It remains to be seen if the significant carbon investment in construction of new homes can be recouped in reduced energy consumption in use at the national level.

Appendix One: Inventory

			Material				Transport (distribution to site)			
Material	**material type**	**Component**	**Quantity (m3)**	**Weight (kg)**	**Embodied carbon (kg/CO$_2$)**	**Primary energy (MJ)**	**Distance to storage to site (km)**	**t/km**	**Transport emissions (kg/CO$_2$)**	**Transport primary energy (MJ)**
openings		Doors		0	246	4624		35	4.68	73.43
Mineral	brick	External Walls	0.387	743	387	6095	74	55	7.26	108.21
Mineral	cement	External Walls	0.074	123	26	191	35	4	0.56	8.40
Mineral	Gypsum plasterboard	External Walls	1.478	965	367	6516	43	42	5.54	82.48
Mineral	Plaster	External Walls	0.296	384	46	691	43	17	2.20	32.82
Timber	Larch	External Walls	2.631	1315	1421	15090	36	48	6.31	94.07
Timber	Softwood	External Walls	0.962	546	246	4038	36	20	2.62	39.03
Plastics	HD polyethylene/polypropylene	External Walls	107.500	28	45	2180	35	1	0.13	1.94
Plastics	HD polyethylene/polypropylene	External Walls	98.500	14	23	1095	35	0	0.07	0.98
Plastics	polyisocyanurate (PIR)	External Walls	91.500	70	210	5047	35	2	0.32	4.78
Metals	aluminium	External Walls	0.016	44	360	6780	35	2	0.20	2.99
Metals	aluminium	External Walls	0.050	135	1112	20925	35	5	0.62	9.23
Metals	steel	External Walls	0.005	42	118	1631	35	1	0.19	2.86
Metals	Steel	External Walls	0.135	12	76	633	35	0	0.06	0.84
Metals	steel	first floor	0.003	23	144	1205	35	1	0.11	1.60
Metals	steel galvanised	first floor	0.425	39	110	1519	35	1	0.18	2.66
Mineral	cement	Floor (ground)	0.036	52	9	70	35	2	0.24	3.58
Mineral	concrete	Floor (ground)	0.918	2111	469	3822	108	227	29.96	446.34
Mineral	concrete	Floor (ground)	3.485	4095	1341	14332	108	440	58.11	865.64

Timber	plywood	Floor (ground)	1.892	1293	1047	19393	36	47	6.21	92.47
Plastics	polyisocyanurate (PIR)	Floor (ground)	43.000	95	286	6883	171	16	2.15	32.08
Plastics	polyisocyanurate (PIR)	Floor (ground)	0.663	21	64	1548	171	4	0.48	7.21
Metals	steel/zinc coated	Floor (ground)	0.008	64	181	2510	35	2	0.30	4.40
Mineral	brick	Foundations	0.774	1487	773	12191	74	110	14.53	216.42
Mineral	concrete	Foundations	1.918	3740	299	2656	35	130	17.14	255.37
Mineral	concrete	Foundations	0.977	859	281	3008	35	30	3.94	58.67
Mineral	concrete	Foundations	0.500	1180	152	1121	56	66	8.77	130.70
Timber	Softwood	Foundations	0.325	150	67	1106	36	5	0.72	10.69
Plastics	Polythene	Foundations	46.500	13	24	1146	35	0	0.06	0.88
Metals	steel	Foundations	0.165	9	55	463	35	0	0.04	0.61
Mineral	cement	Foundations	0.367	605	129	938	35	21	2.77	41.33
Space 4		Frame			3085	64439			206.27	3017.82
Mineral	concrete tiles	Roof	4.915	4545	977	9090	104	471	62.18	926.24
Timber	chipboard	Roof	0.207	152	78	1448	36	6	0.73	10.90
Timber	plywood	Roof	0.034	23	19	346	104	2	0.32	4.70
Timber	Softwood	Roof	10.839	4986	2244	36897	104	517	68.21	1016.17
Metals	aluminium	Roof	0.030	81	667	12555	35	3	0.37	5.54
Metals	steel	Roof	2.150	31	88	1216	35	1	0.14	2.13
Mineral	brick	Substructures	0.031	34	16	224	35	1	0.16	2.35
Mineral	Concrete	Substructures	0.500	1180	152	1121	56	66	8.77	130.70
Mineral	Concrete	substructures	16.500	38940	6191	36993	56	2193	289.53	4313.05
Timber	OSB	Substructures	3.888	2862	2318	42930	36	104	13.74	204.69
Plastics	HD Polyethylene	Substructures	12.500	14	22	1055	35	0	0.06	0.94
Plastics	low density EPS	Substructures	38.500	29	72	2558	35	1	0.13	1.97
Plastics	polypropylene	Substructures		3	13	387	171	1	0.08	1.13
openings		Windows		1	1996	40584		319	42.13	660.89
Total				**73142.711**	**28054**	**401287**		**5022**	**869**	**12932**