An Embodied Carbon Assessment of NW Bicester – Scoping a 40% Reduction

Authors: Dr. Craig Jones; Tilly Shaw

November 2011

Executive Summary

NW Bicester is one of the UK's first designated eco towns. As part of the development's advanced sustainability standards, constructors are required to deliver a 40% reduction in the embodied carbon of housing across the scheme, when measured against a baseline.

Sustain, who have industry leading expertise on embodied carbon assessment, were commissioned by Wilmott Dixon to scope out a 40% embodied carbon reduction for the houses at the NW Bicester eco town. The report outlines and quantifies the embodied carbon savings against the baseline which was taken from a Davis Langdon report.

Wilmott Dixon and Sustain worked together to analyse the embodied carbon of the design and to compare it against the baseline. The baseline results revealed that 75% of the embodied carbon was in the external walls, the substructure and the roof. These were the focus of the reductions. After analysing ways to reduce the embodied carbon of the roof it was determined that the most feasible way was changing the roof tiles. This would only result in a 1% embodied carbon saving over the baseline (at the most) but would require expensive tiles to be used. It was determined that concrete roof tiles should be used as a balance between cost and embodied carbon. They are considerably lower embodied carbon than clay tiles. The baseline also used concrete tiles and therefore the embodied carbon was the same as the baseline. The embodied carbon reduction measures therefore needed to come from the external wall and the substructure.

There were four external wall types, all on a timber frame; brick faced, reconstituted stone; render clad and timber clad walls. The brick and block walls had the highest embodied carbon due to the use of bricks, which are a high embodied carbon option. This was followed by reconstituted stone bricks and then render clad walls. Timber clad wall had by far the lowest embodied carbon and this was due to the carbon storage benefit of timber products. This benefit would only arise in timber products with a long lifetime and a timber weatherboard that lasts 60 years would be required (with appropriately high quality coatings). The mixture of these four walls types and the limited use of bricks allowed a large embodied carbon saving to be made over the baseline, which was a brick and block wall (also on a timber frame).

The substructures were a precast beam and lightweight block floor. This has a lower embodied carbon than a cast ground slab. Hanson Thermalites were selected as the lightweight block and they have considerably lower carbon than a typical AAC block and allow good U-Values to be achieved. Concrete was specified with at least a 25% cement replacement content of either Pulverised Fuel Ash (PFA) or Ground Granulated Blast Furnace Slag (GGBS). This requires longer curing times but has considerable embodied carbon benefits. The original design had a screed finish but the embodied carbon calculations revealed that this was a high embodied carbon option due to the cement content. Consequently a plywood or chipboard floor was specified and due to the carbon storage benefit with the long lifetime it provided an embodied carbon benefit.

The above measures were estimated to result in 41% reduced embodied carbon against the 3 bed semi-detached baseline and 43% reduced against the 4 bed detached baseline figures. The figures were calculated per m^2 GIFA. There were a number of issues with the baseline and these were highlighted in the report. These include inaccurate data for the embodied carbon of bricks and the baseline houses were not typical dwellings (i.e. timber frame). Concerns were also raised that construction waste wasn't included in the baseline and that with the waste management plan the NW Bicester development would have a considerable embodied carbon benefit. It was recommended that these could be considered for the next stages of the project.

Contents

1.0 Introduction

NW Bicester is one of the UK's first designated eco towns. As part of the development's advanced sustainability standards, constructors are required to deliver a 40% reduction in the embodied CO_2 of housing across the scheme, when measured against a pre-agreed baseline.

Sustain have been commissioned by Wilmott Dixon to scope out a 40% embodied carbon reduction for the houses to be constructed at NW Bicester eco town. This report outlines and quantifies the embodied carbon savings against the baseline.

Embodied carbon comes from the use of fossil fuels and chemical reactions in manufacturing processes. It typically includes energy and carbon required to extract raw materials, transport at all stages, material refining, processes and fabrication. It is a carbon footprint of a material.

This report has been lead by Dr. Craig Jones and Tilly Shaw of Sustain. Dr Jones is the UK's most recognisable figure in embodied carbon assessment and is the creator of the most widely used embodied carbon database, the Inventory of Carbon & Energy (ICE) from the University of Bath. A short author biography and Sustain's track record in embodied carbon are provided at the back of this report.

2.0 Embodied Carbon Reduction Requirements

The following brief has been defined by the client in regards to the 40% embodied carbon reduction.

> "The Client will be seeking specific proposals from the Constructor when issuing the Contract Sum Analysis/Price Framework and which should focus on materials used in highest quantities (such as concrete and aggregates) and those with the highest total embodied impact to achieve maximum benefit. The Constructor will be required to adopt construction processes which minimise carbon emissions.
>
> There is a specific requirement to deliver a minimum 40% reduction in the amount of embodied CO2 contained within in the materials used across the scheme and the Contract Sum/Agreed Maximum Price will be deemed to have included for this requirement.
>
> Section 3.2 (in particular pg 27) of the attached "Davis Langdon; Embodied CO2" publication (appendix E) sets out embodied CO2 baselines for typical 3 bed semi-detached, 4 bed detached and 2 bed mid floor flats; these are typical examples of then recent Scottish social and private housing developments. These should be used by the Constructor as the baseline on which to achieve the 40% reduction required by the Project Team.
>
> For dwellings which are not covered by these three categories, Constructors should use the procedures detailed within the document to ascertain a bespoke benchmark for each individual type. Once this benchmark has been calculated, the Constructor is required to present their proposed embodied carbon benchmark along with calculations to The Project team for ratification.
>
> This Guidance document is to be read in conjunction with The Sustainability Statement contained in Appendix S of the Project Brief. In particular, reference should be made to Appendix 4 of the Statement incorporating an Embodied Carbon Strategy and the

Constructors material proposals will facilitate an accurate carbon emissions calculation prior to implementation."

The scope of this work will therefore cover materials used in highest quantities and those with the highest total embodied carbon.

3.0 The Baseline for Reduction

The baseline for reduction has been set from a Davis Langdon report[1] which was commissioned by the Scottish Government in 2009. There are two baselines which are of relevance for this project, which are on p.27 of the Davis Langdon report.

Table 1 – The Embodied Carbon Baseline – $kgCO_2$ per m^2 GIFA

Element	3 Bed Semi (Type B – $88m^2$)		4 Bed Detached (Type H - 118 m^2)	
	$kgCO_2/m^2$ GIFA	% of Total	$kgCO_2/m^2$ GIFA	% of Total
Substructure	85	**25%**	96	**27%**
Frame & Uppers	15	4%	13	4%
Roof	35	**10%**	36	**10%**
Stairs	3	1%	2	1%
External Walls	142	**41%**	139	**39%**
Windows and external doors	7	2%	7	2%
Internal walls, partitions and doors	4	1%	4	1%
Wall finishes	16	5%	18	5%
Floor finishes	9	3%	8	2%
Ceiling finishes	5	1%	5	1%
Building services	28	8%	28	8%
Total per m^2 GIFA	**348**	100%	**357**	100%

Source: Davis Langdon report. Totals may differ due to rounding.

The main parts of the building that contribute to embodied carbon were the substructure, external walls and roof. In combination these are around 75% of the total embodied carbon. They were therefore the focus of the embodied carbon reduction measures.

The original report provided baselines for the amount of embodied carbon per m^2 gross internal floor area (GIFA) and for the total property (i.e. the former multiplied by the total GIFA). For this project the embodied carbon per GIFA was chosen as the baseline for the 40% reduction target. Of the property types described in the Davis Langdon report, only two are relevant; a 3 bed semi and a 4 bed detached house. These don't cover the full range of property types in the NW Bicester development and on further examination of the numbers in Table 1 it can be seen that the embodied carbon per m^2 GIFA for the two house types given are particularly close (348 $kgCO_2$ per m^2 GIFA and 357 $kgCO_2$ per m^2 GIFA).

The briefing requirements, given in Section 2, state:

[1] Davis Langdon, 2009. "Embodied CO2 and CO2 emissions from new buildings and the impact of possible changes to the Energy standards", a report for the Scottish Government, Directorate for the Built Environment, Building Standards Division.

"For dwellings which are not covered by these three categories, Constructors should use the procedures detailed within the document to ascertain a bespoke benchmark for each individual type."

The use of the embodied carbon per m^2 GIFA has therefore been adopted as a bespoke benchmark. This serves for all property types that are not detailed in the Davis Langdon report.

4.0 Methodology & Approach

To measure the NW Bicester specification against the embodied carbon baseline the following methods and approaches were adopted:

- An elemental approach to the embodied carbon reduction calculations was taken. This means that the embodied carbon of the external walls were calculated for NW Bicester and compared with the embodied carbon of the baseline.
    - This approach means that the total embodied carbon of the building doesn't need to be measured.
    - It assumes that the other contributors to the embodied carbon are identical to the baseline scenario. This is in line with the scope of concentrating on the volume items and largest wins.
- The NW Bicester development has many house types (227 houses for this part of the development) of different floor areas, bedrooms and detached, terraced and semi-detached types and with four different external wall types. This makes comparison against the Davis Langdon baselines unnecessarily complex. To remove this complexity but retain robustness, the embodied carbon took the elemental approach (as above) and used the quantities as applicable for the entire 227 houses.
    - E.g. for the external walls there were four wall types. The total area of each type was determined. The embodied carbon of 1 m^2 of each wall type was calculated and multiplied up for the entire embodied carbon in the development. This was then divided by the total GIFA of the 227 houses so that it can be compared with the Davis Langdon baseline.
- The measurement of embodied carbon only covers carbon dioxide (i.e. $kgCO_2$), rather than a basket of greenhouse gases (i.e. kg CO_2e). This is in line with the requirements to use the Davis Langdon baseline and the data from ICE V1.6a.

As shown in Section 3, the main parts of the building that contribute to baseline embodied carbon are the substructure, external walls and roof. These three elements therefore formed the initial focus of the study.

During the initial analysis, it was determined that the roof held limited potential for embodied carbon savings. Only a 1% embodied carbon saving would arise if natural slate tiles were used in place of concrete tiles. This comes with a cost implication and due to the small savings concrete tiles were specified. It should also be noted that clay tiles were far higher embodied carbon than a concrete tile and should be avoided.

The remainder of the study therefore concentrates on the embodied carbon savings to be made from the external walls and substructures.

5.0 Key Specifications

The development incorporates four types of external walls; brick faced, stone clad, timber clad and render clad. The specifications for each of these wall types are given in Table 2.

Table 2 – External Wall Specifications

Element	Material	Size
Brick Clad External Wall		
Outer Leaf cladding	brick	102 mm
Cavity	air	50 mm
Membrane	low emissivity breathable membrane	0.5 mm
Sheathing board	OSB	9 mm
Insulation fixed between studs	Kingspan Thermawall TW55	120mm
Inner leaf Wall	Timber frame	140 mm
vapour membrane	polythene	0.5 mm
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm
cavity (as EST detail)	timber batten	25mm
Finish	plasterboard	15mm
	skim	3mm
Render Clad External Wall		
Outer Leaf cladding	self-coloured render	25mm
Wall	medium dense block	100mm
Cavity	air	50 mm
Membrane	low emissivity breathable membrane	0.5 mm
Sheathing board	OSB	9 mm
Insulation fixed between studs	Kingspan Thermawall TW55	120 mm
Inner leaf Wall	Timber frame	140 mm
vapour membrane	polythene	0.5 mm
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	20 mm

Element	Material	Size
Cavity (as EST detail)	timber batten	25mm
Finish	plasterboard	15mm
	skim	3mm
Timber Clad External Wall		
Outer Leaf cladding	timber or render on board	20mm
Cavity batten	timber	45mm
Membrane	low emissivity breathable membrane	0.5 mm
Sheathing board	OSB	9 mm
Insulation fixed between studs	Kingspan Thermawall TW55	120 mm
Inner leaf Wall	Timber frame	140 mm
vapour membrane	polythene	0.5 mm
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm
cavity (as EST detail)	timber batten	25mm
Finish	plasterboard	15mm
	skim	3mm
Stone Clad External Wall		
Outer Leaf cladding	Beckstone bricks (reconstituted stone)	102 mm
Cavity	air	50 mm
Membrane	low emissivity breathable membrane	0.5 mm
Sheathing board	OSB	9 mm
Insulation fixed between studs	Kingspan Thermawall TW55	120mm
Inner leaf Wall	Timber frame	140 mm
vapour membrane	polythene	0.5 mm
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm
cavity (as EST detail)	timber batten	25mm
Finish	plasterboard	15mm

Element	Material	Size
	skim	3mm

The substructure is the other main contributor to embodied carbon. The substructure consists of the following items and quantities, Table 3:

Table 3 – Substructure

Building Element	**Amount**	**Unit**
Plain in-situ concrete; BS8500 standard mix GEN 1, Class AC-1; recycled aggregates; Clause 0.1	2513	m3
175mm Precast beam and infill block floor decking; BS8110 Part 1; working load under normal use 1.5 KN/m2; combined load of finishings 1 KN/m2; load from partitions 1 KN/m2; 6mm variation in camber between adjacent units (assumed specification)	15182	m2
Plywood, 22mm	15182	m2
DPM, 1200 G polyethylene	15182	m2
Kingspan TF70 insulation, 110mm	15182	m2
Facing bricks; light and dark buff to approval; 215 x 102.5 x 65; in cement-lime mortar (1:1:6); bucket handle pointing as work proceeds	1985	m2
WALLS: Concrete blocks; BS6073; 7N/mm2 crushing strength; 440 x 215; solid; in cement-lime mortar (1:1:6)		
100 thick	1653	m2
100 thick; in party walls	1186	m2
140 thick (assumed)	3667	m2
190 (assumed) thick; built honeycomb	801	m2

The total GIFA for the development is given in Table 4. The buildings have a total GIFA of 23,999m^2 across the portfolio.

Table 4 – Total Gross Internal Floor Area for NW Bicester

Element	Total m^2
Buildings	*23,999*
Attached garages	*1,271*
TOTAL	25,270

For the purposes of the embodied carbon calculations the floor area of garages wasn't included in the total GIFA of the development (i.e. the embodied carbon of all the external wall areas in the NW Bicester development was calculated. This was divided by the total GIFA of all the buildings and then compared with the baseline). The Davis Langdon baseline didn't include garages but for Bicester the materials necessary for the garages couldn't be separated out from the houses. This is a conservative approach.

6.0 Results

6.1 External Walls & Substructures

Appendix A contains the detailed spreadsheet calculations for the main building elements, external walls and substructures. The summary of results has been extracted here. As a reminder the Davis Langdon baseline is shown in Table 5.

Table 5 – The Embodied Carbon Baselines

Baseline	Embodied Carbon Baseline - $kgCO_2$ per m^2 GIFA
Baseline - 3 Bed Semi (Type B)	348
Baseline - 4 Bed Detached (Type H)	357

As discussed in Section 4 the embodied carbon reduction strategy has concentrated on the largest embodied carbon contributing parts of the buildings. These are predominantly the substructure and external walls. In total these contributed 66% of the total embodied carbon of the Davis Langdon baseline.

The roof contributed a further 10% embodied carbon. Alternative roof tiles were assessed but the embodied carbon savings were small (i.e. natural slate in place of concrete roof tiles would save 1% embodied carbon but have considerable cost implications). The roof tiles were assumed to remain concrete roof tiles, which have a considerably lower embodied carbon than clay roof tiles.

External walls

The baseline design was a timber frame brick faced external wall. The Bicester development has four external wall types, which are show by their total areas in Table 6.

Table 6 - Bicester external wall types, total areas and calculated embodied carbon (all on a timber frame)

External Wall Type	Total Area m^2 of external wall	Fraction - %	Embodied Carbon $kgCO_2/m^2$ wall
Facing Brickwork	6,265	19%	32.9
Stone Cladding	3,840	12%	26.2
Timber Weatherboarding	12,143	36%	0.4
Render	11,137	33%	18.4
TOTAL	**33,385**	**100%**	

As shown by the results above, brick walls have the highest embodied carbon per square metre of any of the four external wall types. However brick faced walls are only 19% of the external wall area at the Bicester development. To further reduce the embodied carbon contribution of bricks the Wilmott Dixon project team are investigating the use of a lower embodied carbon brick (Hanson Eco bricks) but it is understood that this would need approval from the planners. The second highest embodied carbon walls are the "stone" clad walls. These are assumed to comprise Bekstone-made reconstituted stone bricks. They also contain cement as the binder and are a bit like a concrete brick. Render clad walls are the next best option.

However the real savings come from the timber weatherboard clad walls. Because sustainable timber stores carbon, the embodied carbon results can be negative i.e. beneficial. The Davis Langdon baseline has used a figure of -1.408 $kgCO_2$ per kg of timber that lasts 100 years. This brings large embodied carbon reductions. However to get the full benefit of this carbon storage the timber must last 100 years or more. This was the assumed life for the timber frame, OSB board in the walls and plywood or chipboard in the floor.

The timber weatherboarding is unlikely to last 100 years; instead it has been assumed that the lifespan will be 60 years. This would require high class coatings on the timber and appropriate procurement. Neither the Davis Langdon report, nor the ICE database, provide emissions factors for timber with a 60-year carbon storage benefit. However the Timber Research and Development Association (TRADA) have published a guide[2] on the embodied carbon of timber, which was partially delivered by Davis Langdon. The guide contains a breakdown of the numbers so that a 60-year lifespan can be used. After analysing the report, an embodied carbon of timber weatherboard for 60 years was calculated to be -0.05 kg CO_2 per kg timber. It is only just carbon negative, but this is a large benefit over the other options. It is therefore clear that the use of timber for long lifetime products results in a considerable embodied carbon benefit.

Substructure

The substructure is a precast beam and block floor system. The blocks are Hanson Thermalites, which have a low density with a high recycled content and use Pulverised Fuel Ash (PFA). PFA is a waste product of coal fired electricity generation and may be used as a partial cement replacement (which saves considerable embodied carbon) or as an aggregate. The block densities are in the region of 700 kg per m3 (depending on the strength class), which compares with 1900 kg per m3 for dense concrete blocks. The low density of the blocks offers U-Value benefits to the design of the houses. The detailed BRE Environmental Profiles reports for the Thermalite blocks are not in the public domain, but these were provided by Hanson to enable the embodied carbon data to be extracted. The selected Hanson Thermalites had an embodied carbon of 0.16 $kgCO_2$/kg. This compares particularly well with the range in the ICE database of 0.28 to 0.38 $kgCO_2$/kg for autoclaved aerated concrete (AAC) blocks.

The foundations contain in-situ concrete of class Gen I. To reduce the embodied carbon of the concrete 25% cement replacement of either GGBS (Ground granulated blast furnace slag) or PFA should be used.

The substructures of the Davis Langdon baseline had a 150mm concrete ground bearing slab. The NW Bicester ground floors are the precast beam and block floors described above. The precast beams are 175mm deep but the infill blocks take up most of the floor

[2] TRADA Construction Briefings, "Timber Carbon Footprints, Calculated values", December 2009.

area. These are only 100mm deep, which in comparison with the 150mm concrete slab of the baseline requires considerably less material.

A plywood or chipboard floor should be used but not floor screed. The use of screed would result in a large increase in the embodied carbon of the substructure. The design originally started with a screed finish of 65 or 75mm thickness. The embodied carbon calculations indicated that this would have been 40% higher embodied carbon than the plywood or chipboard floor per m^2 of floor (and even with 25% PFA or GGBS in the cement to reduce the embodied carbon of the screed). The plywood/chipboard flooring option was chosen and it should be noted that both plywood and chipboard have similar embodied carbons. The reason for the lower embodied carbon is that timber products sequester carbon which provides an embodied carbon credit. The other reason is that screed contains cement and cement is a high embodied carbon material.

6.2 Embodied Carbon Savings

Table 7 shows the summary of embodied carbon savings against the baseline. For further details see Appendix A.

Table 7 – Calculated Embodied Carbon Savings for the Bicester Design

Building Element	NW Bicester Embodied Carbon - $kgCO_2/m^2$ GIFA	Baseline - 3 Bed Semi (Type B)			Baseline - 4 Bed Detached (Type H)		
		Element Baseline $kgCO_2/m^2$ GIFA	Saving - kg CO_2/m^2 GIFA	Total Saving for house - %	Element Baseline $kgCO_2/m^2$ GIFA	Saving - kg CO_2/m^2 GIFA	Total Saving for house - %
Substructure	53.1	85	31.91	9%	98	44.2	12%
External Walls	31.5	142	111.58	32%	139	108.8	30%
			TOTAL	**41%**		**TOTAL**	**43%**

The detailed spreadsheet calculations are in Appendix A. The estimated embodied carbon reduction from targeting the external walls and the substructure would result in over a 40% embodied carbon saving. A large amount of this saving comes from limiting the use of brick walls and using timber products with long lifetimes.

6.3 Issues with the Baseline

The baseline houses in the Davis Langdon report are timber framed with brick faced walls. The windows are timber framed and they have concrete roof tiles. These are not particularly typical houses. Timber-frame is far lower in embodied carbon than a brick and block house, and timber windows and concrete roof tiles already have lower embodied carbon than most typical alternatives.

It's also important to note that there is an issue with the baseline where an erroneous emissions factor has been applied from the ICE database V1.6a. The emissions factor for 'facing bricks' was selected from ICE V1.6a. This had an embodied carbon of 0.52 kgCO2/kg. However the more appropriate factor would be 0.22 kgCO2/kg for common bricks.

This has implications for the baseline because bricks have a high embodied carbon and external walls are typically the largest contributor to embodied carbon. This implies that original baseline is at present too high. The author of this report has used his experience and judgement to suggest how much lower the baseline should have been. It was estimated that the original baseline for the 3 bed semi should be closer to 308 $kgCO_2/m^2$ GIFA. This is in comparison to the actual baseline used of 348 $kgCO_2/m^2$ GIFA. Likewise the baseline of the 4 bed detached should be closer to 317 $kgCO_2/m^2$ GIFA in comparison to the baseline used of 357 $kgCO_2/m^2$ GIFA. This has implications for the embodied carbon reductions. The adjusted baseline was not used for this report but it has been highlighted as a concern by the authors.

Going forward into the next phases of this project it could be considered to use an adjusted baseline for the measurement of embodied carbon reduction efforts.

6.4 Further Measures to Save Embodied Carbon

Waste

Construction waste is often not modelled appropriately in embodied carbon assessments. Many studies fail to take account of the fact that to construct a building element, material waste arises. This can be significant; according to the WRAP Smart Waste tool the wastage rate for bricks is 20% of materials delivered to site. In other words for every brick in the building 25% extra was purchased and never used. Bricks have a high embodied carbon and one of the highest material wastage rates of all construction materials.

Neither the Davis Langdon report nor the embodied carbon guidance in Appendix 4 of the Sustainability Statement discusses this waste as part of the boundaries. However the author of this report firmly believes that this should be included in the embodied carbon reduction figures.

Previous work by Sustain, which was delivered for WRAP in collaboration with Davis Langdon, indicated that for a housing development made of typical brick and block houses construction waste accounted for 12% of the total embodied carbon of the development. Likewise previous work by Dr Jones, whilst at the University of Bath and which utilised BRE figures for waste, estimated waste to be 15% of the total embodied carbon. It is clear that that the waste management plan will offer significant embodied carbon savings.

The WRAP Smart Waste tool suggests that to go from average waste rates to “best practice” would result in a 50% waste material reduction. This would, in turn, yield a 50% embodied carbon reduction of the construction waste. This implies that by moving to best practice waste management the embodied carbon of the development could reduce by a further 6 to 7.5% in total. There could be further embodied carbon benefits by recovering waste for reuse and avoiding landfill for materials that would typically go to landfill. Considering that the Ecotown Standard ET19 – Waste; section 19.1(d) “sets out how developers will ensure that no construction, demolition and excavation waste is sent to landfill, except for those types of waste where landfill is the least environmentally damaging option.” This will offer further embodied carbon benefits.

In the author’s opinion waste should be included in the embodied carbon reduction measurement. It would result in embodied carbon savings larger than given in this report but it would produce a more realistic, complete and robust assessment of the embodied carbon savings associated with the development.

7.0 Summary

The measures analysed in this report are estimated to result in 41% reduced embodied carbon against the 3 bed semi-detached baseline and 43% reduced against the 4 bed detached baseline figures. The figures were calculated per m^2 GIFA. There were a number of issues with the baseline and these have been highlighted. These include inaccurate data for the embodied carbon of bricks and the baseline houses were not typical dwellings (i.e. timber frame). Concerns were also raised that construction waste wasn't included in the baseline and that with the waste management plan the NW Bicester development would have a considerable embodied carbon benefit. It was recommended that these could be considered for the next stages of the project.

8.0 Biographies

8.1 About Sustain

Founded in 1997, Sustain Ltd is a leading carbon reduction company. Our long term, trust-based relationships with clients are evidence of more than a decade of analysing, advising on and applying carbon reduction solutions. We focus on key sectors where we can make a big difference: utilities, buildings, food and drink, manufacturing, professional services, social housing and the public sector.

Among our clients we are proud to include Tullett Prebon, Thomson Reuters, EDF, Associated British Foods, The Co-operative, PHS, NPower, Honeywell, HSBC, Wolseley, Davis Langdon and Vaillant.

Sustain has a specialist expertise in the areas of carbon footprinting and LCA. We have been undertaking these assessments for over 12 years and have been working with a number of client groups including many in the construction, manufacturing, food, agricultural and retail sectors.

Sustain were part of the pilot phase of the development of carbon labelling working with the Carbon Trust and were employed by the Carbon Trust to help develop the PAS 2050 document, the first standard for product carbon footprint assessment. Sustain has also contributed to the development of the GHG Protocol – Product Carbon Footprint recently published by the World Resources Institute (WRI) and is a member of the technical committee for the development of the ISO 14067 (Product Carbon Footprint) which is due to be published in 2012.

8.2 Dr. Craig Jones

Craig is a Senior Associate at Sustain. He is widely considered as one of the leading worldwide experts on embodied carbon assessment in construction and is an expert LCA practitioner. Craig previously worked at the University of Bath where he created the leading embodied energy and carbon database for building materials (known as the ICE database) and which has been used by over 12,000 people around the world. He provided data to footprint the construction of the London 2012 Olympics and tailored an embodied energy and carbon database for the $22 billion Masdar city in Abu Dhabi, which aspires to be the first zero carbon, zero waste and car free city. Craig wrote the first book dedicated to embodied carbon in construction and has published many academic texts on LCA and embodied carbon. Craig gained his PhD by the exceptional and highly rare route of publication, which involved publishing 9 academic articles on the topic of embodied carbon and life cycle assessment. He has a broad and deep understanding of embodied carbon and sits on the embodied carbon working group at RICS. Craig continues to push the boundaries of knowledge and innovation in the whole life carbon assessment of construction.

8.3 Tilly Shaw

Tilly joined Sustain as an Associate in 2010 as a physics graduate with a background in investments and financial services. She has been working in the environmental sector for five years on a variety of projects involving carbon accounting, energy efficiency and communications. She has worked with companies of all sizes, in both public and private sectors.

Appendix A – Embodied Carbon Calculation Spreadsheets

NOTE: The external walls are presented per m^2 external walls. These were then converted to per m^2 GIFA of the Bicester development for comparison with the baseline.

Table A1 – Embodied Carbon of External Walls – Brick Clad External Wall

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon $kgCO_2$ per m^2 wall
Brick Clad External Wall					
Outer Leaf cladding	brick	102 mm	0.22	Assumes 60 bricks per m2; 2.3kg per brick	33.52
Cavity	air	50 mm			
Membrane	low emissivity breathable membrane	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Sheathing board	OSB	9 mm	-0.60	650 kg/m3; assumed particleboard in ICE database. Assumed 100+ years life for carbon storage. ICE database for carbon of production. Carbon storage of 100 years @ 800 kgCO2 stored per m3 of wood product. Assumed 90% by mass of plywood is timber, remainder adhesive.	-3.50
Insulation fixed between studs	Kingspan Thermawall TW55	120mm	3	Density 32 kg/m3, assumed polyurethane. Insulation 85% area, timber frame 15%	9.78
Inner leaf Wall	Timber frame	140 mm	-1.408	Embodied carbon taken from Davis Langdon report. Softwood density 500kg/m3;Insulation 85% area, timber frame 15% (assumption from TRADA). Assumed 100+ year life.	-14.78
vapour membrane	polythene	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm	3	Density 32 kg/m3, assumed polyurethane	2.40
cavity (as EST detail)	timber batten	25mm		Neglected, would likely be carbon negative in any case	
Finish	plasterboard	15mm	0.38	9.8 kg/m2	3.72

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Brick Clad External Wall					
	skim	3mm	0.12	Density 1300	0.47
				TOTAL	**32.9**

Table A2 – Embodied Carbon of External Walls – Render Clad External Wall

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Render Clad External Wall					
Outer Leaf cladding	self-coloured render	25mm	0.163	1:1:6 mortar assumed	6.72
Wall	medium dense block	100mm	0.16	Density 730, Hanson Thermalites 7N, assume 90% blocks, 10% mortar	12.76
Cavity	air	50 mm			
Membrane	low emissivity breathable membrane	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Sheathing board	OSB	9 mm	-0.60	650 kg/m3; assumed particleboard in ICE database. Assumed 100+ years life for carbon storage. ICE database for carbon of production. Carbon storage of 100 years @ 800 kgCO2 stored per m3 of wood product. Assumed 90% by mass of plywood is timber, remainder adhesive.	-3.50
Insulation fixed between studs	Kingspan Thermawall TW55	120 mm	3	Density 32 kg/m3, assumed polyurethane. Insulation 85% area, timber frame 15%	9.79
Inner leaf Wall	Timber frame	140 mm	-1.408	Softwood density 500kg/m3;Insulation 85% area, timber frame 15% (assumption from TRADA). Assumed 100+ year life.	-14.78
vapour membrane	polythene	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Render Clad External Wall					
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	20 mm	3	Density 32 kg/m3, assumed polyurethane	1.92
Cavity (as EST detail)	timber batten	25mm		Neglected, would likely be carbon negative in any case	
Finish	plasterboard	15mm	0.38	9.8 kg/m2	3.72
	skim	3mm	0.12	Density 1300	0.47
				TOTAL	**18.4**

Table A3 – Embodied Carbon of External Walls – Timber Clad External Wall

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Timber Clad External Wall					
Outer Leaf cladding	timber or render on board	20mm	-0.05	Density 500 kg/m3, 10% material overlaps, plus 2 coats of paint (1.06 kgCO2/sqm. 60 year life assumed, Davis Langdon embodied carbon data for wood modified for carbon storage of 60 years.	0.51
Cavity batten	timber	45mm		Neglected, would likely be carbon negative in any case	
Membrane	low emissivity breathable membrane	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Sheathing board	OSB	9 mm	-0.60	650 kg/m3; assumed particleboard in ICE database. Assumed 100+ years life for carbon storage. ICE database for carbon of production. Carbon storage of 100 years @ 800 kgCO_2 stored per m3 of wood product. Assumed 90% by mass of plywood is timber, remainder adhesive.	-3.50
Insulation fixed between studs	Kingspan Thermawall TW55	120 mm	3	Density 32 kg/m3, assumed polyurethane. Insulation 85% area, timber frame 15%	9.79
Inner leaf Wall	Timber frame	140 mm	-1.408	Softwood density 500kg/m3;Insulation 85% area, timber frame 15% (assumption from TRADA). Assumed 100+ years life.	-14.78
vapour membrane	polythene	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm	3	Density 32 kg/m3, assumed polyurethane	2.40
cavity (as EST detail)	timber batten	25mm		Neglected, would likely be carbon negative in any case	
Finish	plasterboard	15mm	0.38	9.8 kg/m2	3.72

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Timber Clad External Wall					
	skim	3mm	0.12	Density 1300	0.47
				TOTAL	**0.4**

Table A4 – Embodied Carbon of External Walls – Stone Clad External Wall

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon $kgCO_2$ per m^2 wall
Stone Clad External Wall					
Outer Leaf cladding	Beckstone bricks (reconstituted stone)	102 mm	0.13	It's a min C20 strength. Assume embodied carbon similar to RC20 concrete with 25% GGBS. Beckstone provided rough embodied carbon data. Density of the bricks 2100 kg/m3. and 85% area bricks and 23.2 kg mortar required per m2.	26.82
Cavity	air	50 mm	-	-	-
Membrane	low emissivity breathable membrane	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Sheathing board	OSB	9 mm	-0.60	650 kg/m3; assumed particleboard in ICE database. Assumed 100 years life for carbon storage. ICE database for carbon of production. Carbon storage of 100 years @ 800 kgCO2 stored per m3 of wood product. Assumed 90% by mass of plywood is timber, remainder adhesive.	-3.50
Insulation fixed between studs	Kingspan Thermawall TW55	120mm	3	Density 32 kg/m3, assumed polyurethane. Insulation 85% area, timber frame 15%	9.79
Inner leaf Wall	Timber frame	140 mm	-1.408	Softwood density 500kg/m3;Insulation 85% area, timber frame 15%. Assumed 100+ years life.	-14.78
vapour membrane	polythene	0.5 mm	1.9	LHPE film assumed, density 920 kg/m3	0.87
Insulation over face of studs, all joints taped	Kingspan Thermawall TW55	25mm	3	Density 32 kg/m3, assumed polyurethane	2.40
cavity (as EST detail)	timber batten	25mm		Neglected, would likely be carbon negative in any case	

Element	Material	Size	Embodied Carbon kg CO_2 / kg	Density or assumptions	Embodied Carbon kgCO_2 per m^2 wall
Stone Clad External Wall					
Finish	plasterboard	15mm	0.38	9.8 kg/m2	3.72
	skim	3mm	0.12	Density 1300	0.47
				TOTAL	**26.2**

Table A5 – Substructure (ply finish)

Building Element	Amount	Unit	Embodied Carbon - $kgCO_2/kg$	Assumptions	Embodied Carbon per Unit	Total Embodied Carbon - kgCO2	Per GIFA - kgCO2/m2
Plain in-situ concrete; BS8500 standard mix GEN 1, Class AC-1; recycled aggregates; Clause 0.1	2513	m3	0.077	25% PFA (or GGBS) as cement content replacement	180.95	454,727	18.95
175mm Precast beam and infill block floor decking; BS8110 Part 1; working load under normal use 1.5 KN/m2; combined load of finishings 1 KN/m2; load from partitions 1 KN/m2; 6mm variation in camber between adjacent units (assumed specification)	15182	m2		See worksheet with calcs	24.18	367,074	15.30
Plywood, 22mm	15182	m2	-0.50	Density 550 kg/m3. Assumed 100 years life for carbon storage. ICE database for carbon of production. Carbon storage of 100 years @ 800 kgCO2 stored per m3 of wood product. Assumed 90% by mass of plywood is timber, remainder adhesive.	-6.04	- 91,684	- 3.82
DPM, 1200 G polyethylene	15182	m2		LHPE film assumed, density 920 kg/m3	0	-	-

Kingspan TF70 insulation, 110mm	15182	m2	3	Density 32kg/m2; proxy embodied cabron data of polyurethane	10.56	160,322	6.68
Facing bricks; light and dark buff to approval; 215 x 102.5 x 65; in cement-lime mortar (1:1:6); bucket handle pointing as work proceeds	1985	m2	0.22	assumes 60 bricks per m2; 2.3kg per brick; 23.2kg mortar	33.5152	66,528	2.77
WALLS: Concrete blocks; BS6073; 7N/mm2 crushing strength; 440 x 215; solid; in cement-lime mortar (1:1:6)				Assume Hanson Thermalites			
100 thick	1653	m2	0.24	730 density. Carbon of Thermalite taken from BRE Profile, assume 90% blocks, 10% mortar, mortar density 1650	18.0	29,774	1.24
100 thick; in party walls	1186	m2	0.24		18.0	21,362	0.89
140 thick (assumed)	3667	m2	0.24		25.2	92,470	3.85
190 (assumed) thick; built honeycomb	801	m2	0.24		34.2	27,412	1.14
						TOTAL	**47.00**

Table A5a – Substructure (ply finish) Beam and block floor

For the average floor area:	Qty	Unit	Embodied Carbon - kg CO_2/kg	Assumptions	Embodied Carbon - kgCO_2 per average floor size
volume of precast beams	2.0	m3	0.215	2350 density	1004.1
Area of blocks required (on plan)	58.0	m2		Precast beams 60mm thick at top	
volume of concrete blocks	5.8	m3	0.16	Hanson Thermalites. 660 density. Carbon of Thermalite taken from BRE Profile	613.0
				Total EC	***1617.1***
				Per m^2 ground floor	**24.2**

Table A6 – Construction Energy

Indicator	3 bed semi	4 bed detached
Total Embodied Carbon - kgCO2 / m2 GIFA	348	357
Fraction for construction activities	7%	7%
Construction carbon - kgCO2 / m2 GIFA	24.36	24.99
Embodied carbon fraction in external walls (from Davis Langdon report)	41%	39%
Construction allocated to external walls – per m2 GIFA	9.99	9.75
Embodied carbon fraction in subs (from Davis Langdon report)	25%	27%
Construction allocated to subs – per m2 GIFA	6.1	6.7

NOTE: Original Davis Langdon report includes construction as an unknown quantity Appendix 4 of the Sustainability statement give construction as 7% of total embodied carbon. This is assumed here and added in proportion to the contribution each part of the building element makes to the embodied carbon of the building (i.e. external walls are 41% of the 3 bed semi baseline. They are also assumed to share 41% of the construction energy for simplicity).