A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House

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Research Report 07-04

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Research Report
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Executive Summary

The political momentum to address the adverse effects of climate change through both mitigation and adaptation is mounting. At a national level the Stern Review has focused attention on the issue with the clear message that we need to act now, or literally pay the price at a later stage, stating that the overall costs and risks of climate change will be equivalent to loosing at least 5% of global GDP per year, now and forever.

This report explores one of the key issues related to climate change; achieving low Greenhouse Gas (GHG) Emissions in the housing sector. This report provides an understanding of the GHG emissions from both house building (the production of materials used in construction) and the direct energy requirements of housing. This is calculated for an average house in the UK. Using this analysis a simple scenario is presented that documents the future GHG emissions of the housing sector for both traditional construction techniques (on-site) and the “Off-Site Manufacturing” (OSM) of a house.

The OSM house clearly outperforms the on-site construction house in terms of its GHG emissions. The OSM house that achieves 2006 Building Regulations and is produced in the UK has 17% lower emissions. If the OSM house was to achieve Sustainable Homes Code Level 4 then the reduction would be over 30%. In terms of a comparison with BedZed, it is essential that the OSM house achieves Code Level 4 to perform alongside one of the best examples of sustainable construction in the UK to date. If this is the case then the light design combined with high levels of energy efficiency offers an excellent response to the climate change agenda.

Achieving the reduction required to move towards low carbon living is not easy. Achieving the required reduction to reach 0.5 tonnes of CO_2 per person is a significant challenge and the material used in the construction of the standard house exceeds this figure without even considering the energy use and maintenance. An OSM house does offer a unique opportunity to overcome this problem. However, the construction must stand the test of time for these savings to be realised. BedZed offers the solution of durability. If a house is built to last for more than 150 years then the GHG emissions from the material input do become negotiable. This is where flexibility in design becomes extremely important. There will be technologies that have not been invented yet that will allow us to achieve even higher levels of energy efficiency and the OSM house does allow the replacement of key components with relative ease. Retrofitting the existing housing stock has become one of the key challenges to reduce carbon emissions and anything that will make this easy in the future is very welcome.

Finally, the key challenge is to achieve a high level of energy efficiency. The energy use in the home is still the key issue and any type of design must prioritise this issue.

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1. Introduction

The political momentum to address the adverse effects of climate change through both mitigation and adaptation is mounting. At a national level the Stern Review has focused attention on the issue with the clear message that we need to act now, or literally pay the price at a later stage, stating that the overall costs and risks of climate change will be equivalent to loosing at least 5% of global GDP per year, now and forever.

The UK has a legally binding commitment under the Kyoto protocol to reduce greenhouse gas (GHG) emissions by 12.5% below base-year level (1990), over the first commitment period 2008-2012. The UK also has a domestic target to reduce carbon dioxide emissions by 20% below 1990 levels by 2010 and the Energy White Paper sets a longer term goal of reducing carbon dioxide emissions by 60% by 2050 with real progress to be achieved by 2020.

The emissions caused due to the direct energy requirements of homes have also been a significant contributor. Any climate change strategy has to consider how we can heat our homes, provide hot water and power our appliances in a way that significantly reduces carbon dioxide emissions. In addition to this there is also the carbon emissions emitted along the whole supply chain to produce all the materials and products used to build new homes. With the current UK Government driving forward an ambiguous house building programme, the challenge is in place to build low carbon houses that also provide low carbon living. With an average of 223,000 houses being built each year until 2026, this accounts for a total of 4.24 million houses being built in the UK (DCLG, 2007).

2. Scope of this report

This report provides an understanding of the Greenhouse Gas (GHG) emissions from both house building (the production of materials used in construction) and the direct energy requirements of housing. This is calculated for an average house in the UK. Using this analysis a simple scenario is presented that documents the future GHG emissions of the housing sector for both traditional construction techniques (on-site) and the "Off-Site Manufacturing" (OSM) of a house.

In both examples the materials used to build the houses are taken into account along with the issues of waste, contingency and over-ordering.

It is important to note that this is a first attempt to explore the contribution that OSM could make to the housing sector in addressing the issue of climate change mitigation. This report does not discuss the economic or social issues of OSM. It does not explore other environmental issues; it purely concentrates on the "carbon footprint"[1]. These are preliminary calculations and it is suggested that a more detailed study would be required to improve the precision and accuracy of these results. However, in support of the conclusions drawn in this report, the methodology used draws on some of the most advanced techniques to understand the carbon footprint of materials and energy. Using Economic Input-Output Analysis, combined with process life cycle analysis, the report provides a level of accuracy and precision that ensures that the results are meaningful.

[1] For a definition of the term 'carbon footprint' see Wiedmann and Minx (2007).

3. Current Situation – GHG Emissions

As with any issue, the reasons why the UK requires so many new houses are manifold. It is not possible to provide a detailed understanding of the issue within this report. However, one of the key reasons is the decline in average household occupancy. More and more, people want to live alone or in small family units. In 2004, the average household occupancy was 2.34. By 2026 this is expected to reduce to 2.09 (DCLG, 2007). This issue does cause difficulties when attempting to reduce the carbon footprint of a household. A single person household does use more energy per person than a four person household. Therefore, instead of seeing a decline in energy use by households there is still a small annual increase in the region of 1% per year.

In addition to housing, there are numerous other issues that contribute to the carbon footprint of the average UK household. The construction, maintenance and household energy requirements equate to 25% of total GHG emissions in the UK. Figure 1 provides a breakdown of the current situation.

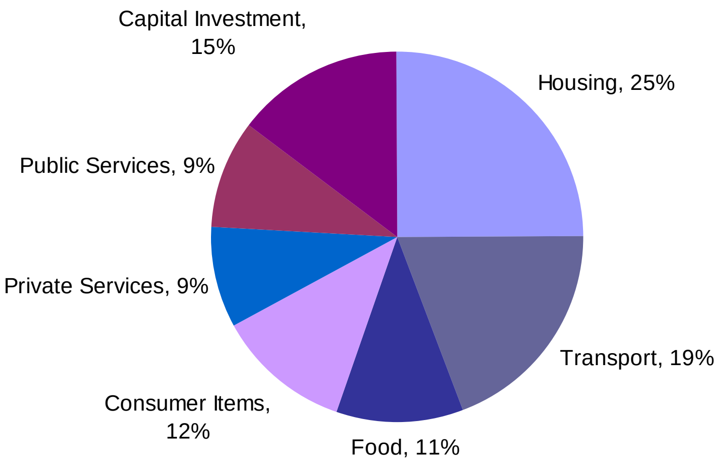

Figure 1: Breakdown of GHG Emissions in the UK (2001), Source: Stockholm Environment Institute, 2007, Resources and Energy Analysis Programme.

The total GHG Emissions in 2001 were 13.3 tonnes per person. This takes into the emissions incurred along the supply chain to provide all the products consumed in the UK, wherever they were produced. To achieve the 60% reduction documented by the UK Government, this would mean that the average person would only emit 5.3 tonnes. Further evidence from the IPCC suggests that this is simply not enough and is discussing a reduction in the region of 85% (2 tonnes per person).

Housing has to contribute significantly to this reduction. It is an area where the UK Government potentially has more control than over other consumption activities, such as the delivery of services from outside the UK. If housing was to reduce its GHG emissions by 85%, this would represent 0.5 tonnes per person, or 1.1 tonne per household.

It is useful to understand what makes up the housing category to understand how to achieve the 0.5 tonnes of GHG emissions target. Figure 2 provides this information.

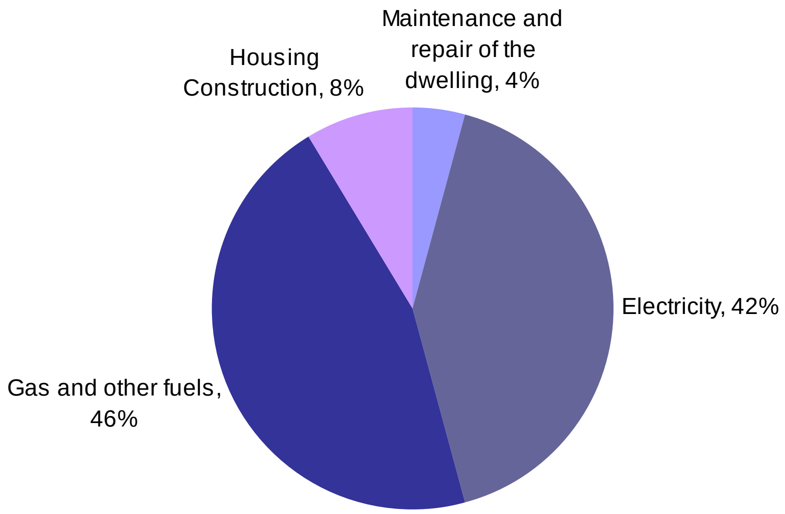

Figure 2: Breakdown of GHG Emissions in the UK (2001), Source: Stockholm Environment Institute, 2007, Resources and Energy Analysis Programme.

The category is dominated by the energy use of the house as opposed to construction and maintenance that accounts for 12%. However, this 12% accounts for 0.43 tonnes of GHG emissions. Therefore, if we were to ignore the emissions from the construction and maintenance of a house then we would have to reduce the emissions from the energy use of the home by 96%.

Therefore, the challenge is two fold:

1. Build homes that require less than 0.1 tonnes a year of GHG emissions to build and maintain.
2. Reduce energy use of homes to reach GHG emissions of 0.4 tonnes.

4. Policy Context – Building New Houses

Current UK Government policy has concentrated on the energy performance of housing more than the energy embodied in the materials used for construction. DCLG's proposed policy framework for the energy performance of new developments is based around 3 main policy levers:

- The planning system: DCLG's draft planning policy statement *Planning and Climate Change* sets out how the location and design of new developments can contribute to the reduction of the carbon footprint of a local area.
- The Code for Sustainable Homes is a voluntary standard with six levels of energy performance designed to increase the environmental sustainability of homes. All government funded housing will be built to at least Level 3 of the code.
- Building regulations provide mandatory baseline national standards for energy use in buildings. The regulations progressively raise the energy efficiency standards of new homes over time.

The UK Government has proposed targets for improving the energy performance of building regulations in line with the new Code for Sustainable Homes as follows:

- All homes built to Code level 3 by 2010 – 25% more efficient than existing building regulations
- All homes built to Code level 4 by 2013 – 44% more efficient than existing building regulations
- All homes built to Code level 6 by 2016 – ‘zero carbon homes’

We have established what this means in terms of carbon dioxide emissions from these new houses below in Figure 3.

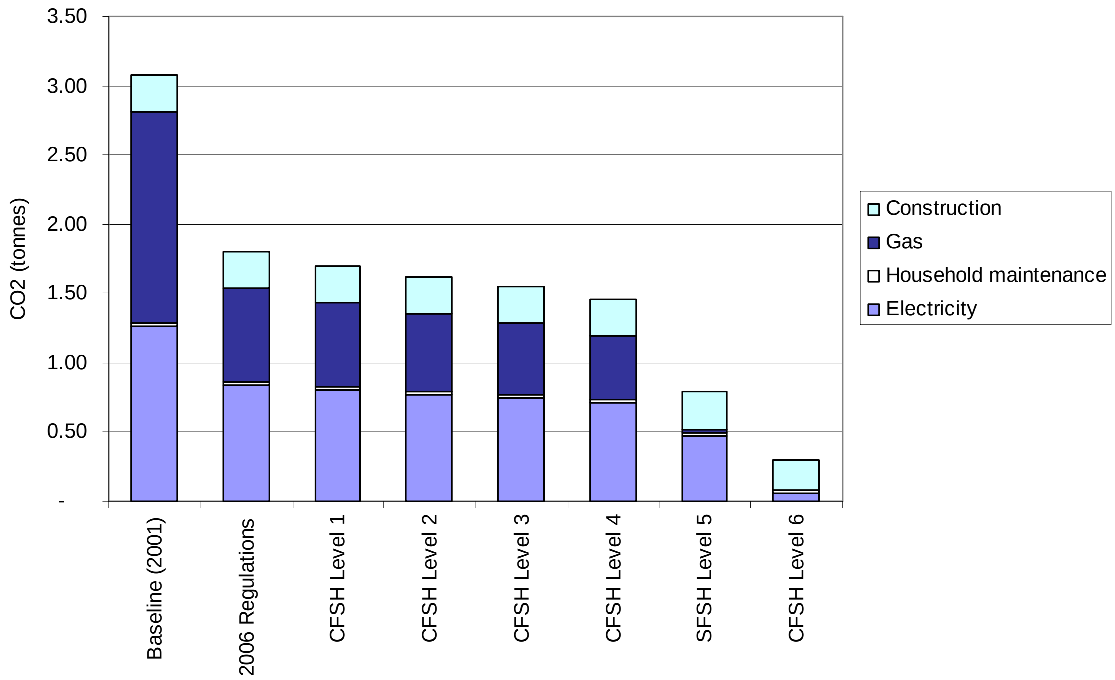

Figure 3: Carbon Dioxide Emissions of the Code for Sustainable Homes, Source: Stockholm Environment Institute, 2007.

The 2006 Regulations represented a significant shift in performance over the average home (nearly 50%). After this the Code for Sustainable Homes gradually tightens the regulation to achieve increasingly better efficiency rating. Level 1 to 4 shows this incremental improvement with level 4 delivering 20% saving from the 2006 Regulations. After this the improvements are even more substantial. However, at present, no examples can be found of a development that would reach Code levels 5 and 6. While level 6 is described as “Carbon Neutral”, the construction of the home along with the provision of renewable energy does have some carbon output.

There is also the issue to take into account that there has historically been an annual rise in energy demand from households. This equates to a 0.7% increase annual increase in energy demand. Therefore, these emission factors are an under-estimate of housing impact in 10 years time.

5. The Carbon Footprint of Constructing an On-Site House

To calculate the carbon footprint of an on-site construction house the assumptions and results have been divided into the three sections of construction, maintenance and energy performance.

5.1 Construction

Four key components have been taken into account in considering the carbon dioxide emissions of constructing a new home in the UK. These being:

- Material and product requirements of the building the home
- Contingency ordering (assumed to be an extra 10% of the final house)
- Over-ordering (considered to be 10% of the final house)
- Waste (considered to be 10% of the final house)

In 2003, SEI undertook an analysis of four different household categories (Wiedmann et al, 2003). This analysis calculated that the average weight of a new home in the UK was 117 tonnes. Taking into account the issues listed above, it is estimated that 152 tonnes of materials are required to build the average home in the UK. According to the English Housing Conditions Survey, produced by the DCLG, the average floor space of a new house is 85.5 m^2. This is marginally higher than the average in the UK, approximately 82 m^2. Therefore, providing one m^2 of floor space for an on-site site house requires 1.8 tonnes of materials.

There is a considerable variation in the carbon dioxide emissions of different materials meaning that the material composition of the house is extremely important. For example, the carbon dioxide emissions of one tonne of aluminium are approximately six times higher than a tonne of steel. Using co-efficients developed by SEI, using both Life Cycle Analysis and Input-Output Analysis, the carbon dioxide emissions per tonne of materials was developed. For further information on these methodologies please visit www.sei.se/reap. Table 1 provides an understanding of the material composition of an average house in the UK.

Table 1: Material Composition of an On-Site Construction House, Source: Wiedmann et al, 2003.

Materials, Bricks and Mortar	**kg**		**Bricks, Mortar and Frame**	**kg**		**Products**	**kg**
Spoil/fill	26,400		Steel	580		Mineral wool insulation	280
Concrete (mass/slab)	28,000		Paint	75		Polyurethene ins. (HCFC)	470
Hardcore	11,600		Glass	720		Aluminium	250
Sand	960		Timber	2,900		Windows/doors uPVC	1,500
Blocks (light)	9,100		Rein. beams/lintels	940		Windows/doors timber	500
Bricks	15,840		Linoleum	2		Plasterboard	1,350
Mortar	9,000		Ceramic tile	210		Plaster	3,000
			Membranes	1,200		Roofing tiles	2,400

The total carbon footprint of building a new house is nearly 56 tonnes. Therefore, to build a new house emits the same level of carbon dioxide as nearly five UK residents. Ten materials / products account for 90% of the carbon footprint of house. These have been shown below in figure 4.

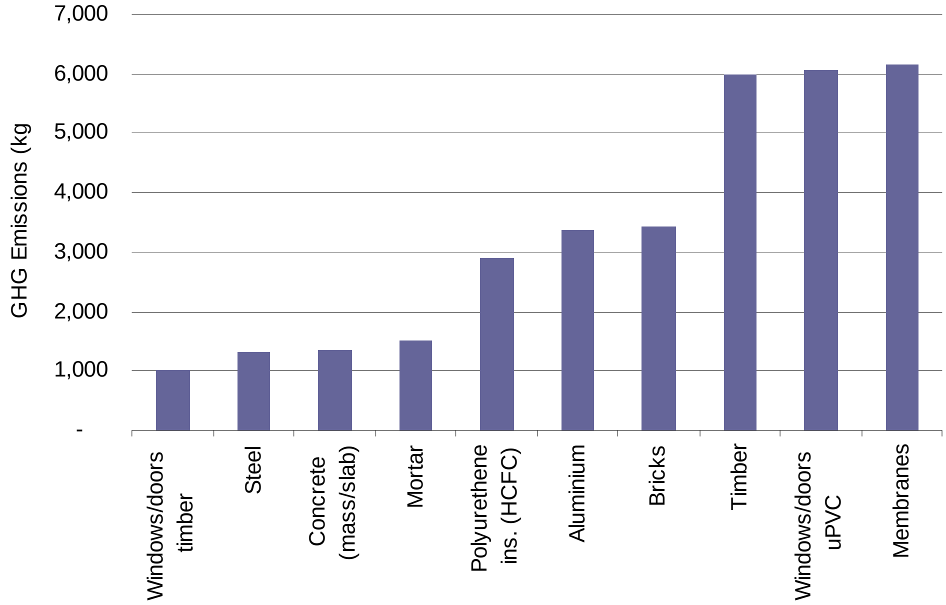

Figure 4: GHG Emissions by Material Type of an On-Site Construction House, Source: Stockholm Environment Institute, Resources and Energy Analysis Programme

In addition the carbon dioxide emitted along the supply chain to produce the materials, the transportation of materials to the construction site was also taken into account. It is assumed that the majority of the materials are from the UK. Due to the weight of the materials this is generally common practice. A further assumption is that the materials are brought by truck and if imported they shipped and then trucked to their final decision. In terms of the GHG emissions of the transport of all the materials it is estimated that these amount to 2.6 tonnes. Therefore, adding this to the total GHG emissions of all the materials and products gives a total of 58.5 tonnes. Transport impacts equate to a small percentage of the total impact (under 5%).

For comparative purposes, we can now consider the GHG emissions for m^2 of floor space. As previously mentioned, the average floor space of a new build house is 85.5 m^2, equating to 0.66 tonnes of GHG emissions per m^2 of floor space.

An additional issue to take into account is the longevity of the construction. Theoretically we can assume that if a house lasts for 100 years then we are, in effect, consuming one hundredth of the house each year. Evidence suggests that a house built today will last approximately 70 years. This is, of course, a very difficult figure to substantiate, however it is very important that the longevity is taken into account. Assuming that a house does last for 70 years, then the carbon dioxide emissions from the construction of house equate to 0.83 tonnes a year.

5.2 Maintenance

It is also important to take into account the maintenance requirements of a house. Using an Economic Input-Output approach we are able to calculate the materials requirements to maintain the average house in the UK. This methodology is employed within the Resources and Energy Analysis Programme, developed by the Stockholm Environment Institute. The GHG emissions from the maintenance of the average house are 0.14 tonnes per person.

5.3 Energy Performance

In addition to the carbon footprint of constructing a new home, this report also takes into account the energy used by the occupants of the house during its use. As highlighted the average person in the UK emits 2.8 tonnes of carbon dioxide from the energy use in their home. With an average household occupancy of 2.5, this equates to a household carbon footprint of 7 tonnes. As there has been significant improvement in building regulations, a new house performs remarkably better than this UK average. If a house is built to meet 2006 Building Regulations, it is estimated that the carbon dioxide emissions of an average household would be 4.5 tonnes, a reduction of 2.5 tonnes in comparison to the UK average.

6. The Carbon Dioxide Emissions of an Off-Site Manufactured House

The same structure has been used for the OSM house as above to allow easy comparability. There is potentially significant variation in the materials used to construct different OSM houses. This study is not in a position to investigate a range of OSM houses and is using one example provided by Hamson Partnership, designed by the architect John Prewer.[2]

In terms of the selection of the design, a "study bedroom" was selected, partly because of data issues but also because it offers a useful comparison as it is, in affect, a miniature house with a bathroom, bedroom, study etc. For comparability, all the results are shown in GHG emission per m^2.

6.1 Construction

In terms of the material requirements per m^2 the OSM house does require fewer materials. To produce the 10 m^2 house requires 1.8 tonnes of materials. There are also fewer materials used in the design. There is also less waste, over-ordering and contingency due to the fact that the houses are made in a factory. To produce a conservative estimate it is assumed that 15% of the weight of the house is generated as waste. Table 2 provides an understanding of the material composition of an average house in the UK.

Table 2: Material Composition of an Off-Site Manufactured House, Source: John Prewer (pers comm.)

Products	kg		Products	kg
Steel	306		Windows/doors uPVC	100
Paint	4		Windows/doors timber	292
Glass	17		Fermacell	747
Timber	138		Plaster	142
Rein. beams/lintels	45		Ceramic tile	10

[2] For further information on the design please contact Hamson Partnership.

Assumptions were made on the material composition of the bathroom unit that weighed 355 kg. In terms of the GHG emissions of these materials, the total output was 2.4 tonnes per unit. With the unit being approximately 10 m^2, this equates to 0.25 tonnes per m^2.

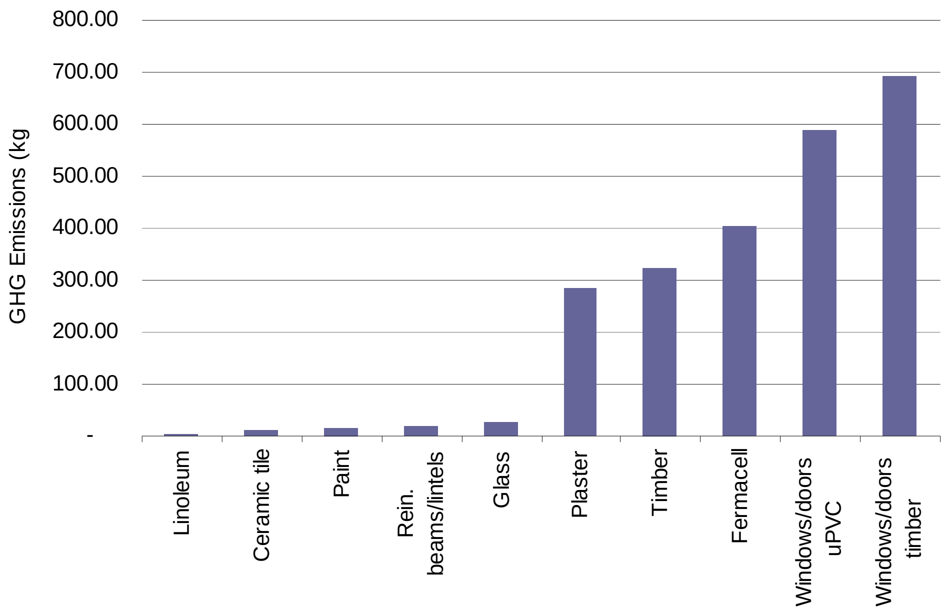

Figure 5: GHG Emissions of an OSM House of 10 m^2.

There is also the transport to take into account. The fact that the house is produced in a factory and designed to fit into a standard container does mean that it could be produced in any country. For comparative purposes, we have calculated the difference between producing the product in the UK and in China. It is important to note that only transport issues have been changed and not efficiency of production. If the house was produced in the UK then the transport emissions would equate to 0.17 tonnes. This accounts for 7% of the total impact of the house. If the product was produced in China the GHG emissions would be 0.52 tonnes, equating to 18% of the total impact.

6.2 Maintenance

With no specific figures of the maintenance requirements of the OSM house, the UK average is assumed as with the on-site construction house. It should be noted that durable products have been used where possible throughout the design so this does produce a conservative estimate. The GHG emissions from the maintenance of the average house are 0.14 tonnes per person.

6.3 Energy Performance

While fewer materials are required to construct an OSM house, it will still need to achieve a high level of energy performance. Ideally, it should be possible to construct an OSM house that would achieve a high level in the Code for Sustainable Homes. As a minimum the house must obviously achieve 2006 Building Regulations. The architect is convenient that the design will both meet and exceed the regulation. With design features such as vacuum insulation and the potential for renewable energy built into the design there is every possibility that this is the case. There is also the issue that the more features required the greater the weight of the structure. The renewable energy technology alone would mean increased weight. However many of the additional features are not the "heavy" construction materials that the OSM has avoided, such as concrete, mortar and bricks.

Again, to produce a conservative estimate it is estimated that a 20% increase in weight is required to achieve a high level of energy efficiency to achieve level 4 in the Code for Sustainable Homes. In the various examples shown below, it is assumed that the current design will meet Building Regulations 2006, and the slightly heavy design will achieve level 4. The examples of different production locations have also been included.

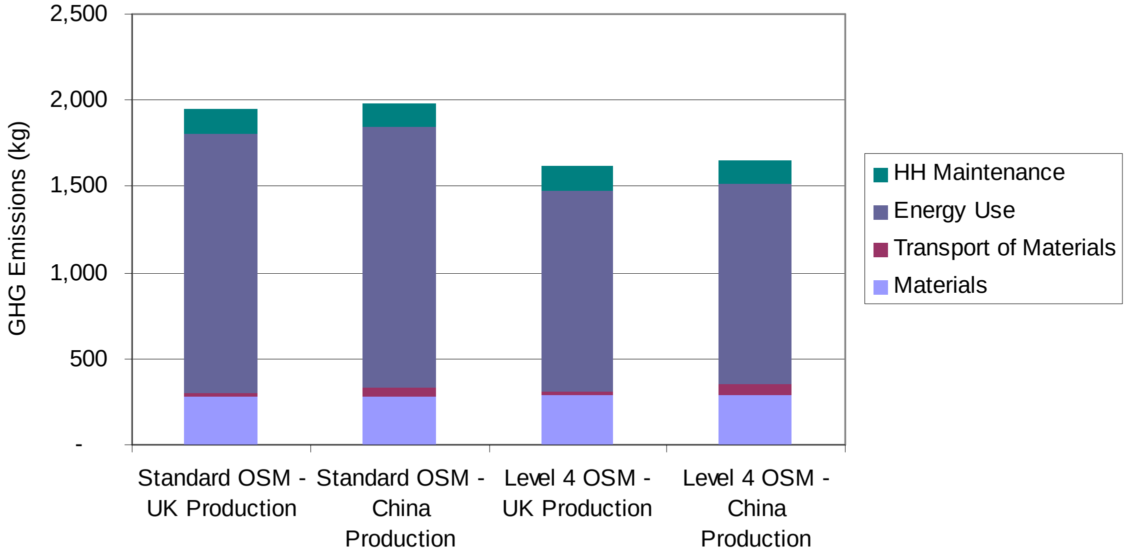

Figure 6: GHG Emissions of OSM Houses – Four Examples

The greatest reduction is GHG emissions are achieved through the UK produced, highly energy efficient house. In comparison it outperforms the China produced house that achieves Building Regulations 2006 by 17%.

7. Comparison of Results and Conclusions

To provide a meaningful comparison all the results have been are shown in GHG emissions per m2. Added to previously discussed examples documented in this report is "BedZed", the "Eco-Development" near London. The GHG emissions for construction, maintenance and energy use have been shown for each example.

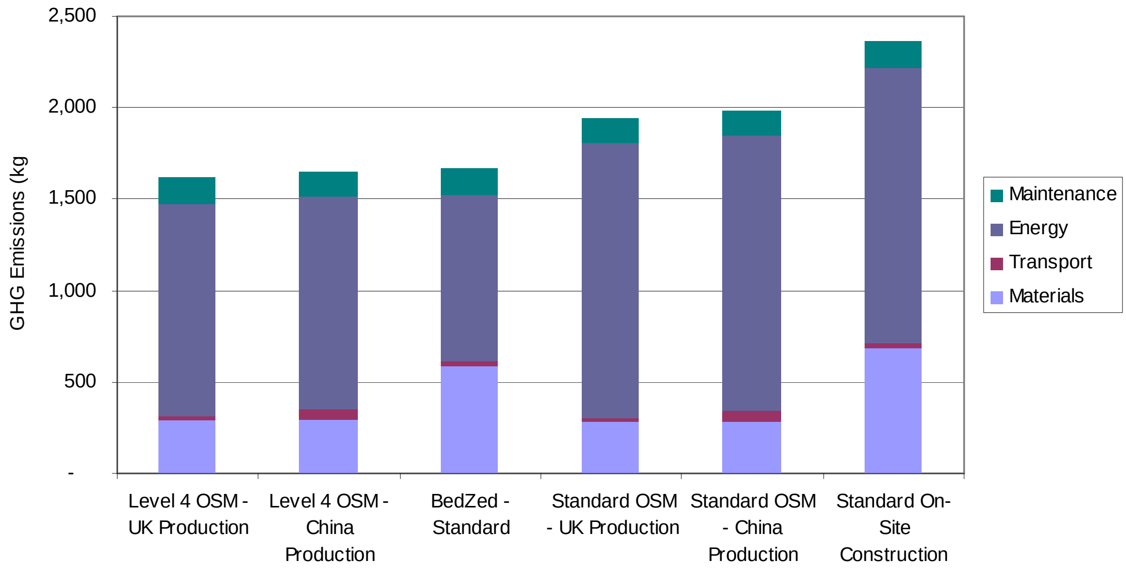

Figure 7: Comparative Analysis of Building Types

The OSM house clearly outperforms the onsite construction house in terms of its GHG emissions. The OSM house that achieves 2006 Building Regulations and produced in the UK has 17% lower emissions. If the OSM house was to achieve Code Level 4 then the reduction would be over 30%. In terms of a comparison with BedZed, it is essential that the OSM house achieves Code Level 4 to perform alongside one of the best examples of sustainable construction in the UK to date. If this is the case then the light design combined with high levels of energy efficiency offers an excellent response to the climate change agenda.

Other elements of the design also offer practical solutions to the reducing GHG emissions. The re-usability of the design ensures that the materials can either be recycled or the building itself can be transported to a new location. The style also presents an opportunity to achieve an important achievement of the BedZed Community Living. There is no doubt the social phenomenon of lower household sizes will result in greater energy use. Building shared places for leisure and living into design can help to reduce the impact of this trend.

Achieving the reduction required to mode towards low carbon living is not easy. Achieving the required reduction to reach 0.5 tonnes per person is a significant challenge and the materials used in the construction of the standard house exceeds this figure without even considering the energy use and maintenance. An OSM house does offer a unique opportunity to overcome this problem. However, the construction must stand the test of time for these saving to be realised. BedZed offers the solution of durability. If a house is built to last for more than 150 years then the GHG emissions from the material input do become negotiable. This is where flexibility in design becomes extremely important. There will be technologies that have not been invented yet that will allow us to achieve even higher levels of energy efficiency and the OSM house does allow the replacement of key components with relative ease. Retrofitting the existing housing stock has become when of the key challenges to reduce carbon emissions and anything that will make this easy in the future is very welcome.

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