Lifetime Emissions of Retrofit versus New Build

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Executive Summary

Radian Group has recently refurbished a small estate of so-called ‘hard-to-treat’ properties at Borough Grove, Petersfield, to an advanced energy performance standard. The best of these homes have lower CO₂ emissions than those allowed under the Code for Sustainable Homes Level 4 standard for new build, having reduced regulated CO₂ emissions by 88% and total emissions including electrical appliances by 71%. The homes were refurbished as part of an ERDF-funded project ‘Retrofit South East’ led by Radian Group, with project team Camco, GESB & Parity Projects.

This study compares the lifetime emissions projected for these homes over a 50 year period with an alternative scenario, where the homes are demolished and rebuilt to a range of modern new build standards and construction types. Fifty years is the period over which we might expect a home to be inhabited before a major refurbishment takes place. The ‘lifetime emissions’ of a project include the embodied emissions associated with the construction and refurbishment phase, as well as the ‘in-use’ emissions arising annually from heating, lighting and powering the home over the property’s lifetime.

Embodied Carbon Emissions

Advanced retrofit has the lowest embodied carbon emissions at 23.4 tCO₂e per house. Overall the embodied emissions associated with advanced retrofit are around half those of the alternative of demolition and replacement with traditional brick and block construction, for the same in-use energy performance standard. Timber framed new homes have significantly lower embodied emissions than their brick and block equivalents, largely to the carbon storage effect of the timber frame where the carbon that was absorbed by the trees during their growth phase is assumed to be effectively ‘locked up’ in the building during its lifetime.

‘In-Use’ Carbon Emissions

The highest in-use emissions are from the home built to 2010 Building Regulations, whose total in-use emissions over 50 years are 148 tCO₂e; around 30% higher than the advanced retrofit.
The lowest in-use emissions are associated with the advanced retrofit and the ‘Zero Carbon Hub Carbon Compliance 2016’ new build scenario, which have an identical energy performance standard.

Carbon emissions from the use of electrical appliances and cooking appear as identical in all three scenarios because of the identical assumptions made about number of occupants and floor area.

**Total Lifetime Carbon Emissions**

The advanced retrofit home has the lowest total lifetime emissions of 139 tCO\(_2\)e. This is 27% less than the brick and block new home built to 2010 Building Regulations (which has the highest lifetime emissions at 191 tCO\(_2\)e), and represents a total lifetime carbon emissions saving of 52 tCO\(_2\)e.

The advanced retrofit lifetime emissions are 13% less than the Brick & Block ‘ZCH 2016’ home (lifetime emissions 159 tCO\(_2\)e), and 6% less than the Timber Frame ‘ZCH 2016’ equivalent.

The difference in embodied carbon emissions between timber frame and brick and block construction is almost cancelled out by the significant effects of in-use emissions, which dominate total lifetime emissions for every house type. For the best performing homes, the projected in-use emissions from electrical appliance use and cooking represents the most substantial contribution to carbon emissions over the 50 year lifetime.

**Cost of Refurbishment versus New Build**

The total cost for this substantial refurbishment programme at Borough Grove averaged £91,900 across the 14 homes. This includes all material and labour costs, the cost of decanting residents while work was undertaken, and associated staff costs within Radian. By contrast the cost of demolishing and replacing these properties with an equivalent performing new build property would have been £144,700 for the same sized property.

The cost of delivering a tonne of lifetime CO\(_2\) is roughly half for the advanced retrofit project (£415/tCO\(_2\)), compared to the Building Regulations brick & block new home (£816/tCO\(_2\)), and significantly less than the other options.

**Regional Implications**

In the UK each year some 20,000 homes are demolished\(^1\). Assuming a pro-rata share based on number of households in the South East suggests a demolition rate of 2,600 homes per year across the region. If these 2,600 homes currently demolished and replaced were instead refurbished to the same advanced standards achieved at Borough Grove, it would deliver regional carbon emissions savings of up to 54,900 tCO\(_2\)/yr. This is equivalent to the annual emissions from 27,450 new homes.

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\(^1\) The 40% House Report, Environmental Change Institute, 2005.
1. Introduction

There has been a view expressed in recent years that the only way to reduce substantially the carbon emissions from the most poorly performing housing stock is to knock them down and start again. Replacement with new, more efficient housing stock, built to modern standards, has in the past been seen as key to achieving challenging Government targets on carbon reduction.

However recent examples of advanced, low carbon refurbishment have challenged this view. The combination of advanced insulation, improved air tightness, high performance windows and doors together with micro-generation can deliver substantial carbon emissions savings even for so-called ‘hard to treat’ homes. Such advanced retrofit projects equal and often exceed current new build energy performance standards. Given that the cost is invariably less than the cost of demolition and replacement, and that wider community benefits can be retained, advanced retrofit starts to look like an attractive solution.

In order to fully compare the benefits of refurbishment over new build, it is instructive to look over the lifetime of the projects and examine the cumulative carbon emissions arising from each option. The ‘lifetime emissions’ of a project include the embodied emissions associated with the construction and refurbishment phase, as well as the ‘in-use’ emissions arising annually from heating, lighting and powering the home over the property’s lifetime.

Recently Radian has refurbished a small estate of so-called ‘hard-to-treat’ properties at Borough Grove, Petersfield, reducing carbon emissions from space heating, hot water and lighting by between 79-88% (depending on the package of measures applied). The decision to refurbish, rather than to demolish and replace, was determined by the views of residents, who at Borough Grove chose to stay in their homes following a consultation by Radian. Residents elsewhere on the estate opted for demolition and replacement with 148 new homes equivalent to Code for Sustainable Homes Level 3 & 4 (which has resulted in Radian’s award winning Privett Green development).

This study compares the total lifetime emissions of the advanced retrofit project at Borough Grove with a range of new build scenarios where the same home has been demolished and replaced with new homes built to a number of different energy performance standards. It looks at the relative costs of refurbishment versus demolition and replacement, and considers the regional implications of scaling up the choice to retrofit rather than demolish over the whole of the South East.

This study forms part of a suite of research undertaken for the ERDF-funded project ‘Retrofit South East’ led by Radian Group, with project team Camco, GESB & Parity Projects.
2. Methodology for Calculating Lifetime Emissions

2.1 Retrofit at Borough Grove

The properties on Borough Grove form part of a former council estate in Petersfield built in the early 1950s. The precast reinforced concrete (REEMA) homes were originally built to meet the urgent demand for post-war housing, with an originally envisaged lifespan of only 30 years. The houses had considerably outperformed this life expectancy, but had become unmortgagable due to a number of defects. They were in need of considerable investment to bring them up to modern standards.

During a consultation exercise in 2004-5 Drum Housing Association consulted with residents of the estate on the possible options for redevelopment. Many residents opted for replacement of their old homes with new homes, and this resulted in the award winning ‘Privett Green’ development of 148 new homes which achieved an overall site rating of BREEAM EcoHomes ‘Very Good’ (with 10% of homes achieving an ‘Excellent’ standard, or Code for Sustainable Homes level 3 or 4, by virtue of micro-renewables installed). At neighbouring Borough Grove, also part of the estate, residents preferred to keep their existing homes, leading Radian Group to develop a programme for refurbishment instead.

Prior to refurbishment the homes at Borough Grove were all Energy Performance Certificate ‘E’ rated. Characteristics of the homes included:

- hollow precast concrete walls, solid concrete floors and concrete ceilings
- pitched roofs clad in concrete tiles
- no floor or wall insulation
- approximately 100mm loft insulation
- double glazing installed in the mid-90s
- gas boilers in need of replacement (some with back boilers of very low efficiency).

Residents’ energy bills typically ranged between £1000–£1500 per year. Residents struggled to achieve thermal comfort in winter and problems of condensation and mould growth were common. Energy modelling suggests that prior to refurbishment, carbon emissions for space heating, hot water & lighting were typically 5.8tCO\(_2\)/yr in each home, or 7.2tCO\(_2\)/yr in total including appliance based electricity use\(^2\).

Supported by the ERDF funded project ‘Retrofit South East’, a package of low energy and sustainability measures were applied to the homes at Borough Grove, sufficient to reduce carbon emissions for space heating, hot water & lighting by 79% in 8 properties and 88% in the remaining 6 (and total carbon emissions including appliances by 64% and 71% respectively).

The refurbishment programme involved a complete upgrade of internal and external finishings to make the homes Decent Homes compliant, including new kitchens and bathrooms, re-wiring, re-plastering and re-roofing.

Measures applied to the homes at Borough Grove as part of the major refurbishment included:

- 100mm external wall insulation (wall U-value 0.3 W/m\(^2\).K)
- 300mm loft insulation (U-value 0.13 W/m\(^2\).K)
- 50mm floor edge insulation (floor U-value 0.58 W/m\(^2\).K)
- new A-rated gas boiler & heating system (90% efficiency)

\(^2\) Under standard occupancy conditions, based on Standard Assessment Procedure 2009.
A-rated windows & doors (U value windows 1.3 W/m².K)

improved air tightness (5m³/m².hr)

thru-wall mechanical ventilation with heat recovery in wet rooms

solar PV (1.48 - to 2.1kWp) (depending on orientation)

solar water heating (3m²) (the 6 south-east facing properties only)

The ‘Advanced’ package applied to the 6 south-east facing homes at Borough Grove has been used as the starting point for this project. This includes solar water heating and the maximum area of solar PV.

Further detail of the package of measures applied at Borough Grove can be found in ‘Retrofit South East: Summary Programme Report’.

2.2 New Build Comparison

In order to compare lifetime emissions and costs against the retrofit at Borough Grove, assumptions must be made about the type of new build homes being considered.

In practice most new build developments are built to a higher density than the original layout at Borough Grove (which is based on the 1950s council estate model of semi-detached homes with generous gardens). This is driven by planning policy as well as commercial considerations, as a higher density layout provides a better financial return on the development. However, it also often results in a smaller floor area and a different built form. A loss of floor area can mean a loss of utility for residents – a hidden benefit of retrofit over demolition and replacement. A smaller floor area can also mean that less materials are used in construction, and that heat loss from the dwelling is lower, resulting in lower lifetime emissions compared to a lower density development with larger unit size.

In order to make a fair comparison based on dwelling performance, removing the effect of building density, an identical built form and layout to Borough Grove has been assumed for the new build properties. The new homes are assumed to be 3-bed semi-detached properties with pitched roofs, floor area 84.4m², located in Petersfield, Hampshire, with a south-east orientation, similar glazed area & seven rooms.

In order to reflect a number of different new build variables we have included the following scenarios in the analysis (NB scenarios relate to the energy performance component of the standard specified, rather than the whole standard):

- **Brick & Block (2010 BRegs)** - New build brick & block construction to 2010 Building Regulations
- **Timber Frame (2010 BRegs)** - New build timber frame construction to 2010 Building Regulations
- **Brick & Block (CSH Level 4)** - New build brick & block construction to Code for Sustainable Homes Level 4
- **Timber Frame (CSH Level 4)** - New build timber frame construction to Code for Sustainable Homes Level 4
- **Brick & Block (ZCH 2016)** - New build brick & block construction to Zero Carbon Hub’s recommended Carbon Compliance standard for 2016

2 Available on Radian’s retrofit web pages: http://www.radian.co.uk/201004072131/retrofit.html

• Timber Frame (ZCH 2016) - New timber frame construction to Zero Carbon Hub’s recommended Carbon Compliance standard for 2016

Assumptions about construction detail, material type and quantity for the calculation of embodied emissions were made in consultation with Radian staff.

2.3 Definition of Emissions Boundary

In order to determine the embodied Greenhouse Gas (GHG) emissions associated with the different developments, a project boundary has to be established to define which emissions are included and which are excluded. Emissions associated with the following activities are included within the scope of this project:

- Demolition (new build) and strip out (retrofit)
- Removal from site of demolition and construction waste
- Landfill and recycling of waste
- Extraction and manufacture of materials and products consumed during construction and retrofit
- Delivery of materials to site (via heavy and light goods vehicles)
- Energy consumed on site (natural gas, electricity & gas oil generators used during construction and retrofit)
- Heating, lighting and powering the homes over their assumed lifetime. (In this case a lifetime of 50 years is assumed before a major refurbishment takes place).

The following emissions sources have been excluded from the scope of this project:

- Emissions associated with the decommissioning of the building at the end of its life. There are too many uncertainties associated with how the properties will be treated at the end of the 50 year consideration period.
- Embodied emissions associated with construction of the original Reema home. Because these are identical in each case there is assumed to be no net difference between each scenario.
- Travel to and from work by construction workers during works period. This is complex and data was not available. It forms a relatively small proportion of the total and is likely to be similar in the case of both retrofit and new build.

2.4 Greenhouse Gas Emissions Factors

The calculations for embodied carbon in this report incorporate all greenhouse gas emissions (including carbon dioxide, methane and N₂O), and convert them into ‘CO₂ equivalent’ based on their relative global warming potential. Values in the embodied energy calculations have been drawn from a variety of relevant sources including the ‘Ecoinvent’ Life Cycle Inventory database (v2.2), the University of Bath’s ‘Inventory of Carbon & Energy (ICE)’, BRE, IPCC and others.

In particular there is a wide range of opinion and evidence available on the embodied emissions of timber, so specific mention is given to the treatment of timber here. The study has considered the longer term carbon storage benefit of timber (whereby carbon emissions sequestered in the timber are effectively ‘locked up’ at least for the lifetime of the building, and possibly longer if the timber is recycled or reused at the end of its life). This study has assumed a 50% weighting factor for long term carbon storage as recommended by the PAS: 2050 methodology which is widely accepted as the industry standard on this issue. This embodied carbon emissions value

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5 University of Bath (Hammond & Jones), ‘Inventory of Carbon & Energy (v1.6a)’, 2008.
for timber is taken from ICE, using the value for sawn softwood and assuming that sawmill residue burned for timber drying purposes is carbon neutral.

There are many complexities in the debate around the embodied carbon benefits of timber, with a range of views on the extent to which these benefits should be reflected in lifetime emissions analyses. Where no carbon storage factor is assumed for timber and related products, the embodied emissions for the timber frame constructions would closely approach those of brick and block construction, increasing the apparent relative benefits of advanced retrofit.
3. Lifetime Carbon Emissions Results

3.1 Embodied Carbon Emissions

A comparison of the total embodied carbon emissions from the different scenarios considered is shown in Figure 1 below. These emissions include the effects of all processes including demolition and strip-out, waste removal and landfill, site energy consumption and all materials used during construction and refurbishment. A breakdown of how these embodied emissions are made up is shown in the chart.

![Comparison of Embodied CO\textsubscript{2}e emissions between build types](image)

Figure 1: Comparison of embodied emissions for retrofit and replacement

Advanced retrofit has the lowest embodied carbon emissions at 23.4 tCO\textsubscript{2}e. The highest embodied carbon emissions result from the brick and block constructions. The highest is for the ‘Zero Carbon Hub Carbon Compliance 2016’ scenario, which has a similar energy performance standard to the advanced retrofit, but nearly twice the embodied carbon emissions at 44.5 tCO\textsubscript{2}e.

Overall then the embodied emissions associated with advanced retrofit are around half those of the alternative of demolition and replacement with traditional brick and block construction, for the same energy performance standard.

The timber framed new homes show as having substantially lower embodied emissions than their brick and block equivalents. This is due largely to the carbon storage effect of the timber frame where carbon is assumed to be effectively ‘locked up’ in the building during its lifetime. As discussed in Section 2.4, where this carbon storage effect is excluded, the embodied emissions of the timber frame constructions would more closely resemble those from brick and block.

The biggest portion of embodied emissions for all homes considered is made up by the superstructure materials. Even though the embodied carbon emissions from the retrofit are lowest overall, the emissions arising from the materials consumed in the retrofit of the superstructure are still significant. This is because in the refurbishment was substantial involving...
the replacement of most internal fittings, doors, windows, plasterboard, kitchen & bathroom, roof and loft insulation. The internal specification was thus similar to that of a newly constructed home. Compared to the nature of construction, energy performance standards make a relatively small difference to the embodied carbon emissions of the homes. However they make a much bigger effect on in-use emissions, as discussed in Section 3.2.

### 3.2 In-Use Carbon Emissions

For the purposes of considering the operational or ‘in-use’ carbon emissions from the different properties, we have set the time horizon to 50 years. This is the period over which we might expect a home to be inhabited before a major refurbishment takes place. In practice a house may undergo such a total refit, or even be demolished and replaced, on a shorter or a longer timescale. However for the purposes of making a fair comparison we have extended the same assumptions across all properties.

The in-use carbon emissions include both ‘regulated’ energy sources (space heating, hot water, lighting & ventilation, as covered by Building Regulations) as well as carbon emissions associated with electrical appliances and cooking (excluded from Building Regulations). In-use emissions over a 50 year period are shown in Figure 2 for the different energy performance standards considered.

![Comparison of In-Use CO$_2$e emissions over 50 years](image)

**Figure 2: Comparison of lifetime in-use emissions for retrofit and replacement**

The lowest in-use emissions are associated with the advanced retrofit and the ‘ZCH 2016’ new build scenario, which have the same energy performance standard. The total in-use emissions for these properties are projected to be 115 tCO$_2$e over 50 years.

The highest in-use emissions are from the brick and block home built to 2010 Building Regulations, whose total in-use emissions over 50 years are 148 tCO$_2$e; around 30% higher than the advanced retrofit. In particular the regulated in-use emissions are 70% higher in this home than the advanced retrofit.

Carbon emissions from the use of electrical appliances and cooking appear as identical in all three scenarios because of the identical assumptions made about number of occupants and floor area. For the advanced retrofit and ‘ZCH 2016’ property these non-regulated emissions come to dominate the total.

### 3.3 Total Lifetime Emissions

In order to determine total lifetime carbon emissions from the different properties, the embodied carbon emissions have been added to the predicted in-use emissions over the 50 year time horizon. Results are shown in Figure 3.
Comparison of Lifetime CO$_2$e emissions over 50 years between build types

**Figure 3: Comparison of total lifetime emissions for retrofit and replacement**

The advanced retrofit home has the lowest total lifetime emissions of 139 tCO$_2$e. This is 27% less than the brick and block new home built to 2010 Building Regulations (which has the highest lifetime emissions at 191 tCO$_2$e), and represents a total lifetime carbon emissions saving of 52 tCO$_2$e.

Total lifetime emissions for the ‘ZCH 2016’ homes look more similar to those of the advanced retrofit, largely due to the similarity in energy performance standards. The small difference is due to the smaller embodied emissions associated with retrofit.

The advanced retrofit lifetime emissions are 13% less than the Brick & Block ‘ZCH 2016’ home (lifetime emissions 159 tCO$_2$e), and 6% less than the Timber Frame ‘ZCH 2016’ equivalent.

It can be seen that the difference in embodied carbon emissions between timber frame and brick and block construction is almost cancelled out by the significant effects of in-use emissions, which dominate total lifetime emissions in every house type. For the best performing homes, the projected in-use emissions from electrical appliance use and cooking makes the most substantial contribution to carbon emissions over the 50 year lifetime.

### 3.4 Cumulative Emissions

In practice these lifetime emissions will not accrue evenly over the 50 year horizon. There will be a ‘development peak’ of embodied emissions which occurs when construction and retrofit work takes place, followed by a more gradual annual increase due to operational emissions.

The graph below shows the cumulative CO$_2$ emissions over the 50 year time frame from the different homes considered. The ‘development peak’ is shown by the place where the lines cross the y-axis, and the rate of increase in the in-use emissions by the slope of the line.
Figure 4: Cumulative total lifetime emissions for retrofit and replacement

From Figure 4 we can see that the advanced retrofit has the lowest cumulative carbon emissions at any point in time.

For the new homes, construction type has the biggest effect on emissions at the start, but over time the energy performance standard of the home begins to dominate and eventually has the most substantial effect on lifetime emissions. For instance, after 15 years the embodied emissions of a timber frame house built to 2010 Building Regulations will become greater than those from a brick & block house built to the Zero Carbon Hub 2016 Carbon Compliance standard.

3.5 Persistence Factor of Measures

The analysis presented above is based on a simple projection of annual ‘in-use’ carbon emissions which are assumed to remain the same each year over the property’s lifetime. In practice, annual emissions are likely to increase gradually over time the as energy saving potential of different measures is compromised to due to degradation and failure. Measures such as boilers, window casements, renewable energy and mechanical ventilation with heat recovery units have limited lifetimes and are all likely to require replacement at least once if not several times during the assumed 50 year timeframe. While we might assume that a housing association would seek to replace like for like, and that over time better performing alternatives will become widely available as the market matures, the actual performance of future replacement measures cannot be guaranteed. Some measures like solar PV or solar water heating may even not be replaced at all at the end of their useful life, resulting in a significant increase in annual emissions associated with the home.
A common way to compare the longevity of different energy saving measures is by their relative ‘persistence values’. Table 1 illustrates the assumed persistence values used by the Carbon Trust\(^6\) for the range of measures applicable in this analysis.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Persistence factor (years)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic wall external insulation</td>
<td>60</td>
<td>Assumed same as CWI in absence of factor for EWI</td>
</tr>
<tr>
<td>Mineral wool loft insulation</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>XPS vertical edge floor insulation</td>
<td>60</td>
<td>Assumed same as CWI in absence of factor for EWI</td>
</tr>
<tr>
<td>A-rated windows and doors</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Improved air tightness &amp; MVHR</td>
<td>10.3</td>
<td>Factor for heat recovery ventilation used. Assumes basic maintenance by residents / housing association</td>
</tr>
<tr>
<td>High efficiency gas boiler &amp; cylinder insulation</td>
<td>16.7</td>
<td>Assumes good maintenance by housing association</td>
</tr>
<tr>
<td>Low energy lights throughout</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Solar PV</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>Solar water heating</td>
<td>19.8</td>
<td>Assumes good maintenance by housing association</td>
</tr>
</tbody>
</table>

Table 1: Summary of persistence factors for measures considered in analysis

For the advanced retrofit property, the total increase in carbon emissions as a result of measures not being replaced at the end of their assumed lifetime has been calculated. The result is 88 tCO\(_2\)e, over and above the ‘simple’ total lifetime emissions already calculated at 139 tCO\(_2\)e. This represents a substantial 63% increase in total lifetime carbon emissions over the 50 year period.

It is beyond the scope of this study to include a full analysis of the effects of persistence value on total lifetime emissions. Where replacement does take place it will increase the embodied carbon emissions associated with the property. Therefore to give a truly accurate picture of lifetime carbon emissions over such a long timeframe, replacement cycles and the consequent increase in embodied carbon should be factored in for all property types.

The exclusion of persistence value from the analysis in this report can be justified as the measures included in both the new build and the advanced retrofit properties are similar and thus have a similar requirement for replacement over the 50 year timeframe considered. The effects of persistence value will thus be broadly similar (in absolute terms) for all properties, as there will be a similar increase in either annual emissions (assuming measures are not replaced) or embodied emissions (assuming measures are replaced) across all house types considered.

4. Cost of Carbon Reduction

4.1 Cost of Refurbishment versus New Build

The refurbishment programme at Borough Grove comprised a complete upgrade of internal and external finishings to make the homes Decent Homes compliant, including new kitchens and bathrooms, re-wiring, re-plastering and re-roofing. Structural work was undertaken to the basic building fabric to prolong the life of the properties for a further 40-50 years.

The total direct capital & installation cost for this substantial refurbishment programme at Borough Grove averaged £79,700 (£944/m²) across the 14 homes. This includes VAT (where applicable) and site management costs. The cost of decanting the residents during refurbishment work amounts to a further £10,060 per property. The cost of internal staff time, including a sustainability officer and surveyor, is estimated to have added a further £2,140 per property. This brings the total per property for the refurbishment to £91,900.

By contrast the cost of demolishing and replacing these properties with an equivalent performing new build property would have been £131,600 (£1,560/m²). In addition to this must be added the cost of decanting the residents which is estimated to amount to a further £10,030 per property, and internal staff time associated with the development team at £3,070 per property. This brings the effective total per property for demolition and replacement to £144,700.

Further detail on the cost assumptions used above is available in ‘Retrofit South East: Summary Programme Report’.

4.2 Cost of Lifetime Carbon Emissions Reduction

Before refurbishment the dwellings at Borough Grove were responsible for predicted annual ‘in-use’ carbon emissions of 7.2tCO₂/yr. Over a 50 year timeframe this corresponds to a total of

![Cost per tonne of lifetime carbon emissions saving](image)

Figure 5: Illustration of different costs per tonne of lifetime CO₂ emissions saving

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7 http://www.radian.co.uk/201004072131/retrofit.html
8 This includes regulated as well as non-regulated energy sources such as electrical appliances, and is based on SAP 2009. Predicted values have been used to enable a fair comparison with the predicted n-use figures used elsewhere within this report.
360 tCO$_2$/yr. The lifetime carbon emissions savings delivered by each of the retrofit and new build scenarios have been compared with this benchmark, to give the relative cost per tonne of lifetime carbon emissions saving.

Figure 5 illustrates the relative cost of saving a tonne of lifetime CO$_2$ over the 50 year time horizon. It can be seen that the cost of delivering a tonne of lifetime CO$_2$ is roughly half for the advanced retrofit project compared to the Building Regulations brick & block new home, and is also significantly less than all the other options. Advanced retrofit clearly represents excellent value for money for carbon reduction, when compared to demolition and replacement.

Over a 50 year time frame costs will be incurred with maintaining both the retrofitted and new build property. While a full lifetime cost analysis is beyond the scope of this report, it might be considered that items such as boilers, solar PV and windows are likely to have similar replacement cycles, and thus the lifetime maintenance costs will be similar between all properties.
5. Regional Implications

In the UK each year some 20,000 homes are demolished. Assuming a pro-rata share based on number of households in the South East would suggest a demolition rate of 2,600 homes per year in the region.

If these 2,600 homes currently demolished and replaced were instead refurbished to the same advanced standards achieved at Borough Grove, it would deliver a significant reduction in carbon emissions across the region. By 2016 the standard of new build (based on the Zero Carbon Hub’s recommendation for Carbon Compliance) is likely to equal the standard of advanced retrofit achieved at Borough Grove, so there is likely to be no net difference in annual in-use emissions. However the difference in embodied carbon emissions between an advanced retrofit and an equivalently performing brick and block new home would be 21.1 tCO$_2$.

Thus based on the findings of this report, the net annual saving on embodied carbon emissions arising from a policy of advanced retrofit rather than replacement could deliver regional carbon emissions savings of up to 54,900 tCO$_2$/yr. This is the same as annual emissions from 27,450 new homes.

It would also represent an annual regional cost saving of £137 million. Typically refurbishing existing homes is more employment intensive than new construction, requiring relatively more labour (generally local), and less materials (often manufactured outside the region). Therefore while this report has not attempted to quantify the impacts on employment of retrofit versus new build, such a regional saving would not necessarily be expected to translate into a loss of regional gross value added (GVA).

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9 The 40% House Report, Environmental Change Institute, 2005.
Appendix 1: Key assumptions for different stages of life cycle

The following provides detail on some of the key assumptions used in calculating emissions associated with each stage of the lifecycle.

**A 1.1 Demolition and strip out**

Carbon emissions associated with demolition and strip-out is considered below under ‘site energy consumption’. This mainly relates to diesel consumption by bulldozers and other site equipment necessary to demolish the pre-cast concrete homes, as well as diesel and electricity consumption from the less energy intensive strip-out process for the refurbished homes.

**A 1.2 Removal of waste**

It is assumed that site waste (including that sent for recycling) is removed from site using LGVs (in the case of retrofit) and HGVs (in the case of new build due to heavy nature of concrete demolition waste).

**A1.3 Landfill of waste**

It is assumed that all waste sent to landfill from both projects was inert (ie does not decompose to release methane after landfilling). For this reason there are no emissions arising from landfill of waste in any scenario.

Where waste is recycled it is also assumed to result in zero net carbon emissions as the responsibility for the emissions are passed further down the line. This approach avoids the double counting of emissions.

It is worth highlighting that the quantity of landfill waste will be significantly lower for a retrofit project than for a demolition and new build scenario. There will be consequent savings in landfill tax for a retrofit project relative to a new build project.

**A 1.4 Materials & products**

Within the substructure, Camco has calculated the GHG emissions from the following sources:

- Foundations
- Drainage
- Excavation of top soil
- Construction of roads and pavements

Within the superstructure, Camco has included emissions from the following sources:

- External walls
- Roofing materials
- Cladding
- Flooring
- Insulation
- Finishes
- Services

In terms of services and finishes, Camco has made the following assumptions during its calculations:
As specifics on the rainwater harvesting system could not be provided, Camco assumes that the unit weighs 170kg and is composed entirely from PVC. Fittings have been excluded as emissions are considered de minimis.

As specifics on the new kitchen could not be provided, Camco assumes that the materials weigh 850kg and are composed entirely from chipboard. Fittings have been excluded as emissions are considered de minimis.

As specifics on the new bathroom could not be provided, Camco assumes that the materials weigh 37.5kg and are composed entirely from PVC. Fittings have been excluded as emissions are considered de minimis.

As specifics on the light fittings could not be provided, Camco assumes that 16 pendent lights were installed, each weighing 227g and are composed entirely from PVC.

As specifics on the Vailliant condensing gas boiler could not be provided, Camco assumes that the unit weighs 36.8 kg and is composed entirely from stainless steel.

As specifics on the solar water heating panel could not be provided, Camco assumes the emissions from this material are equivalent on a m² basis to that of solar PV panels.

As specifics on the twin coil hot water cylinder could not be provided, Camco assumes the emissions are equivalent to the condensing gas boiler.

As specifics on the pipework and radiators could not be provided, Camco assumes the materials weigh 215 kg and are composed entirely from steel.

As specifics on the MVHR thru-wall unit could not be provided, Camco assumes the materials weigh 3.5 kg and are composed entirely from PVC.

A 1.5 Delivery of Materials
Materials are assumed to be transported to site using a combination of LGV and HGVs according to weight. Assumptions have been made about the distance travelled by each material.

A 1.6 Site Energy Use
This includes energy used on site during the construction and retrofit phase (including for instance the demolition phase outlined above, the powering of onsite equipment by electricity and diesel, and provision of heating during the later stages of work undertaken in winter months). It also includes the natural gas consumption associated with commissioning and set up of a new central heating system.

A 1.7 In-Use Emissions
To calculate the likely annual (operational) emissions from the different homes, NHER calculation software has been used to predict annual consumption for space heating, hot water, lighting and ventilation based on standard occupancy conditions. Energy use from electrical appliances and cooking has been predicted using the approach outlined in Appendix L of SAP 2009 (REF), which provides calculations linked to floor area and number of occupants. Using this approach allows us to compare likely annual carbon emissions resulting from the different homes as a result of their different energy performance characteristics, independent of the different lifestyle habits of potential occupants.

For the advanced retrofit dwelling the energy performance characteristics have been modelled on the specification applied at Borough Grove. This gives a Design Emissions Rate (DER) or 11.1 kgCO₂/m²·yr.
For the new build dwellings, scenarios have been constructed using NHER software based on the same floor area and built form as Borough Grove, but with insulation and microgeneration characteristics necessary to reach the required ‘Dwelling Emissions Rate’ (DER) under SAP 2009.

Based on the assumptions described in Sections 2.1 ad 2.2 on built form the Dwelling Emissions Rate assumed for each housing type is as follows:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Dwelling Emissions Rate(^{11})</th>
<th>Energy Performance Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Retrofit</td>
<td>11.1 kgCO(_2)/m(^2).yr</td>
<td>Described in Section 2.1.</td>
</tr>
<tr>
<td>New Build Building Regulations 2010</td>
<td>18.9 kgCO(_2)/m(^2).yr</td>
<td>As for Advanced Retrofit but reduced PV from 2.1kW(_p) to 0.2kW(_p)(^{12})</td>
</tr>
<tr>
<td>New Build Code Level 4</td>
<td>14.2 kgCO(_2)/m(^2).yr</td>
<td>As for Advanced Retrofit but reduced PV from 2.1kW(_p) to 1.15kW(_p)</td>
</tr>
<tr>
<td>New Build ZCH Carbon Compliance 2016(^{13})</td>
<td>11.0 kgCO(_2)/m(^2).yr</td>
<td>As for Advanced Retrofit</td>
</tr>
</tbody>
</table>

Table A1: Dwelling Emissions Rate for Each Scenario

Due to the high uncertainty surrounding the Government’s likely policy on Allowable Solutions, embodied emissions associated with offsite energy generation in the ‘New Build ZCH Carbon Compliance’ scenario have been excluded from the analysis. It is unlikely that the offsite ‘Allowable Solutions’ requirement under this scenario would be 100% additional anyway due to the complexities of additionality (such as the EU Emissions Trading Scheme overlap - see the Zero Carbon Hub’s report on the subject\(^{14}\)).

\(^{11}\) Based on floor area 84.4m\(^2\) and same built form and layout as Borough Grove

\(^{12}\) In practice it is highly unlikely that such a small PV scheme would be installed, and enhanced insulation would be a preferable option

\(^{13}\) For an attached house. NB figure relates to built performance, which the ZCH report acknowledges cannot be directly compared with designed performance. For the purposes of this report however they are assumed to be the same.

Appendix 2: Tables showing lifetime emissions and cost

The following tables provide the source data for the charts shown in Sections 3 and 4.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tCO₂e</td>
<td>tCO₂e</td>
<td>tCO₂e</td>
<td>tCO₂e</td>
<td>tCO₂e</td>
<td>tCO₂e</td>
<td>tCO₂e</td>
</tr>
<tr>
<td>Deliveries by third parties - LGV</td>
<td>2.33</td>
<td>2.33</td>
<td>2.33</td>
<td>2.22</td>
<td>2.22</td>
<td>2.22</td>
<td>1.74</td>
</tr>
<tr>
<td>Deliveries by third parties - HGV</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
<td>0.03</td>
</tr>
<tr>
<td>Materials - Superstructures</td>
<td>29.7</td>
<td>28.8</td>
<td>27.9</td>
<td>21.6</td>
<td>20.6</td>
<td>19.7</td>
<td>21.5</td>
</tr>
<tr>
<td>Removal of waste from site - LGV/HGV</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
<td>0.21</td>
</tr>
<tr>
<td>Site energy consumption - gas oil</td>
<td>3.52</td>
<td>3.52</td>
<td>3.52</td>
<td>3.52</td>
<td>3.52</td>
<td>3.52</td>
<td></td>
</tr>
<tr>
<td>Site energy consumption - electricity</td>
<td>3.04</td>
<td>3.04</td>
<td>3.04</td>
<td>3.04</td>
<td>3.04</td>
<td>3.04</td>
<td>1.52</td>
</tr>
<tr>
<td>Site energy consumption - natural gas</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.27</td>
<td>0.54</td>
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<tr>
<td>Landfilled waste</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-use regulated energy sources</td>
<td>46.42</td>
<td>59.97</td>
<td>79.93</td>
<td>46.42</td>
<td>59.97</td>
<td>79.93</td>
<td>46.76</td>
</tr>
<tr>
<td>In-use appliances &amp; cooking</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
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<tr>
<td>Total</td>
<td>159.9</td>
<td>172.5</td>
<td>191.6</td>
<td>151.2</td>
<td>163.9</td>
<td>182.9</td>
<td>140.8</td>
</tr>
</tbody>
</table>

Table A2: Total Lifetime Carbon Emissions for different properties considered

<table>
<thead>
<tr>
<th></th>
<th>B&amp;B BRregs 2010</th>
<th>Timber BRregs 2010</th>
<th>B&amp;B ZCH 2016</th>
<th>Timber ZCH 2016</th>
<th>Advanced Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>£137,700</td>
<td>£137,700</td>
<td>£141,200</td>
<td>£144,700</td>
<td>£91,900</td>
</tr>
<tr>
<td>Lifetime emissions saving*</td>
<td>168</td>
<td>177</td>
<td>187</td>
<td>196</td>
<td>209</td>
</tr>
<tr>
<td>Cost per t lifetime emissions saving</td>
<td>£818</td>
<td>£778</td>
<td>£754</td>
<td>£720</td>
<td>£693</td>
</tr>
</tbody>
</table>

Table A3: Cost per tonne of lifetime CO₂ emissions saving

* Compared to pre-refurbishment case at Borough Grove

Assumptions used in the calculation of cost figures:

- The cost of the Building regulations 2010 homes is the ‘like for like’ demolition and replacement cost quoted in Section 4.1, without the 2.1kWp PV.
- The cost of the CSH Level 4 homes is equal to the ‘like for like’ demolition and replacement cost quoted in Section 4.1, with 1.1kWp less PV.
- The cost of the Zero Carbon Hub 2016 Carbon Compliance Standard homes is equal to the ‘like for like’ demolition and replacement cost quoted in Section 4.1
- The cost of a brick and block construction is broadly the same as timber frame construction.
Appendix 3: Comparison with previous studies on lifetime emissions

This section includes a brief comparison between the findings of this report and those of a number of previous reports on the lifetime emissions of advanced retrofit projects.

Empty Homes Agency report

The Empty Homes Agency published a report in 2008 called ‘New Tricks with Old Bricks’\(^{15}\), which compared the lifetime emissions of a number of both refurbished and new build homes.

The approach taken in the report varied from this study in the following ways:

- Both the new build homes and the retrofitted homes were built to a lower energy performance standard than the homes considered in this study (2002 Building Regulations for the new build homes, and no defined standard for the retrofitted homes).
- It did not take into account the energy used on site during construction or the emissions associated with site clearance and disposal of demolition waste.
- It examined embodied CO\(_2\) only, not greenhouse gas emissions
- The carbon storage effect of timber was not taken into account.

The absence of any defined performance standards for the refurbished properties made it difficult to compare directly between the different refurbished homes considered, as well as with the new homes. As with this study, the Empty Homes Agency report found that in-use emissions tend to dominate over a 50 year horizon, highlighting that energy performance of household appliances is critical to overall lifetime emissions.

Overall the range of total lifetime emissions (150-270 tCO\(_2\)) found by the EHA research is slightly higher than the range in this study (139-191 tCO\(_2\)), largely due to the difference in energy performance standards assumed. The embodied emissions of the new build properties in the EHA report are generally similar (per m\(^2\) floor area) to those in this report, with any discrepancies due to the differing assumptions described in the bullet points above. The embodied emissions for the refurbished homes in the EHA report are lower, due to the less advanced refurbishment package specified in each case.

College of Estate Management & BRE Trust report

The College of Estate Management and BRE Trust also published a report in 2008, ‘Knock it down or do it up? Sustainable house building: New build and refurbishment in the Sustainable Communities Plan’\(^{16}\). The aim of this research was to assess the sustainability of refurbishing existing housing in comparison with demolishing it and building new housing, in the context of the previous government’s Sustainable Communities Plan. The research examined attitudes within the construction sector to the sustainability of refurbishing older housing versus demolition and new build, and looked at the range of methodologies (including whole life cycle costing) available to the house builder to assess the relative sustainability of housing construction and refurbishment.

However, the report does not include a comparison of the actual lifetime emissions of new build versus refurbishment projects. While there is an attempt at a cost comparison between new build and refurbishment, no common energy performance standards are established for either category which makes it difficult to draw a meaningful comparison. For instance ‘refurbishment’ of some homes is simply taken to mean replacement of a kitchen or bathroom, sufficient to


\(^{16}\) College of Estate Management & BRE Trust, ‘Knock it down or do it up? Sustainable house building: New build and refurbishment in the Sustainable Communities Plan’, Frances Plimmer, Gaye Pottinger, Sarah Harris, Michael Waters and Yasmin Pocock, 2008
achieve the Decent Homes Standard, which contains no minimum energy standard (beyond a requirement for some basic energy efficiency measures in certain housing types) and generally equates to a performance level below current Building Regulations for new build.
Radian has recently refurbished a small estate of so-called ‘hard-to-treat’ properties at Borough Grove, Petersfield, to an advanced energy performance standard. The best of these homes have lower CO₂ emissions than those allowed under the Code for Sustainable Homes Level 4 standard for new build, having reduced regulated CO₂ emissions by 88% and total emissions including electrical appliances by 71%. The homes were refurbished as part of an ERDF-funded project ‘Retrofit South East’ led by Radian, with project team Camco, GESB & Parity Projects.

This study compares the lifetime emissions projected for these homes over a 50 year period with an alternative scenario, where the homes are demolished and rebuilt to a range of modern new build standards and construction types. Fifty years is the period over which we might expect a home to be inhabited before a major refurbishment takes place. The ‘lifetime emissions’ of a project include the embodied emissions associated with the construction and refurbishment phase, as well as the ‘in-use’ emissions arising annually from heating, lighting and powering the home over the property’s lifetime.

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This report was launched on 22 February 2012 at the joint Radian and Ashden retrofit event, Westminster.