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Life Cycle Carbon Analysis

Extensions and Subterranean Developments in RBKC

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Executive Summary

Executive Summary

This report aims to provide a discussion about the carbon footprint of subterranean extensions. Analysing 16 different case studies, including above ground extensions, single storey basements and multi storey basements the goal is to compare the carbon footprint of the different typologies of projects.

The report was commissioned by The Royal Borough of Kensington & Chelsea to inform the revision of Policy CE1: 'Climate Change', with a special focus on the environmental impacts of subterranean extensions.

The key findings are:

Projects which include subterranean extensions in dwellings are generally characterised by a more carbon intense building life cycle.

When considering the building life cycle carbon emissions of projects with subterranean extensions vs. projects with above ground extensions, the present report findings show the following:

Embodied carbon:

- Single storey basements are likely to be 55% more carbon intense than above ground extensions and multi-storey basements are likely to be 61% more carbon intense than above ground extensions.
- Multi storey basements are likely to have carbon intensity for the materials used around 12% higher than single storey basements.

Construction Carbon:

- Single storey basements are likely to have 57% more carbon emissions during this stage than above ground extensions.
- In multi storey basements the carbon emissions can be 70% higher than the carbon emissions of construction works for above ground extensions.
- The works to build a multi storey basement are generally longer and ask for more and more heavy machinery, which results in multi storey basements having carbon emissions 28% higher than single storey basements at this stage.

Executive Summary

Operational Carbon:

- Extensions mostly have negative operational carbon emissions i.e. they reduce the carbon emissions of the existing dwelling on a metre square basis. The multi-storey basements have the highest operational carbon emissions, 9% higher than single storey basements.

- Basements that are exclusively in the garden perform worse as they have more heat loss area relative to basements under or attached to the existing dwelling.

Sensitivity Analysis :

- If 50% GGBS and 20% recycled coarse aggregate was used in the concrete the embodied carbon results over 60 years are likely to be reduced by approximately 19% for single storey basements and by approximately 23.5% for multi storey basements.

- However, with the use of concrete with recycled content, single storey basements are still likely to be 46% more carbon intense than above ground extensions and multi-storey basements are still likely to be 49% more carbon intense than above ground extensions.

- Upgrades to the existing dwelling can achieve significant reductions in carbon emissions; up to 45 to 52% for the advanced package. Above ground extensions can achieve a carbon payback in less than 7 years with the Intermediate refurbishment. However, even if multi storey basements were to utilise advanced retrofit measures, the carbon saving would not be enough to compensate for the embodied and construction carbon over 60 years.

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Context

Context

The Royal Borough of Kensington & Chelsea (RBKC) are revising their planning policy relating to subterranean developments, to ensure these types of developments meet environmental standards and carbon emission reduction targets.

The environmental performance of an extension to an existing building can be assessed against a range of environmental issues; this report focuses on the carbon emissions of subterranean extensions.

When additional carbon emissions (CO_2) are released into the atmosphere, the 'greenhouse effect' is intensified, leading to increased global warming and ultimately climate change. On a local scale this often leads to a change in weather patterns, an increase in extreme weather events and other alterations to the local environment.

The World Green Building Council (2012) stated:

- Energy from fossil fuels consumed in the construction and operation of buildings accounts for approximately half of the UK's emissions of CO^2
- Around 10% of UK emissions are associated with the manufacture and transport of construction materials, and the construction process.
- Housing alone generates 27% of UK emissions, of which 73% is used for space and water heating.

From this understanding of the UK's current position on carbon emissions, there is a strong emphasis on carbon emissions being a measure for the environmental performance of subterranean developments.

By focusing on carbon emissions as a proxy for environmental performance of buildings, RBKC will incorporate the aims of the UK Climate Change Act 2008 which sets out the reduction of UK's Greenhouse Gas emissions by at least 80% by 2050, and 34% by 2020, based on 1990 levels (UK Government 2009). The UK's first commitment was a 12.5% reduction and has been achieved, with emissions being reduced by 27% by 2011. Further changes and additional measures are required to ensure future targets are met.

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Introduction

Introduction

Eight Associates has been appointed to provide an evidence base for the Royal Borough of Kensington & Chelsea (RBKC) policy related to meeting environmental standards and carbon emission reductions for subterranean development in the Borough.

Following the public consultation in July/September 2013 it was considered that a more detailed analysis of the carbon footprint of basements was needed than that presented in the previous 2010 report. This report aims to provide evidence through the analysis of 16 case studies.

This report focuses on carbon emissions from extensions and basements.

Section 1 of the report presents the key findings of the analysis performed. It discusses how basements are likely to have higher embodied carbon emissions from materials and construction works and presents the results for the energy performance forecast for the case studies in a 60-year scenario.

Section 2 briefly discusses policy aspects and the potential mitigation of environmental impacts, based on the modelling of different sensitivity analysis scenarios and outlines how BREEAM Domestic Refurbishment requirements might be used as a tool for the mitigation of the environmental impact.

Full details regarding the methodology used and details of each case study are included within the appendices.

Key Considerations

Key Considerations

The methodology used in this report has been clearly defined and the data used has been attributed to the source (please see Appendix 1).

'Carbon footprint' is a term used to describe the amount of greenhouse gas (GHG) emissions caused by a particular activity or product. For this analysis CO_{2eq} emissions are considered and all the carbon factors used are based on standardised and recognised methodologies.

There are several ways to determine the embodied carbon of products, services or buildings, one being the methodology chosen herein.

This report has updated the methodology used in Eight Associates first report (2010). The methodology used in this report follows the guidelines of the following international standards, in line with current best practice:

- BS EN 15643[5];
- ISO 14040;
- BS ISO 21931-1[4].

This report compares very different buildings in terms of materials used, construction method and size, however, the functional purpose of the buildings is not taken into account.

The assumptions made are discussed in Appendix 1 of this report, and a brief explanation for each assumption is provided.

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Scope of Works and Background: Policy Overview

Policy overview

RBKC has experienced an unprecedented number of planning applications for Subterranean Extensions over the last decade. Since 2001 the council has seen a rise of 85% in subterranean planning applications, from 46 basement applications in 2001 to 307 basement applications in 2012.

Based on this, the feasibility of subterranean developments has come under increased scrutiny. The environmental impact of such developments has started to be reviewed and in 2010, Eight Associates were commissioned to analyse the carbon footprint of subterranean extensions to support the Council's planning policy for subterranean extensions.

The current RBKC policy (Core Strategy, Policy CE 1) relating to subterranean developments is detailed below.

" The Council will require an assessment to demonstrate that subterranean developments achieve the following relevant BREEAM standards: i. Residential Development: EcoHomes Very Good (at Design and Post Construction) with 40% of credits achieved under the Energy, Water and Materials sections, or comparable when BREEAM for Refurbishments is published."

This policy is being revised and this report, commissioned by the RBKC, aims to provide more detailed evidence about the environmental impact of subterranean extension.

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Scope of Works and Background: Aim of Report

Aim

The initial impact assessment of subterranean developments, undertaken in 2010 by Eight Associates, was based on the relatively limited data that was available at the time.

This report has a wider scope than the 2010 report and analyses 16 different case studies, between above ground extensions, single storey basements and double storey basements.

Although the main purpose of this report is to provide a detailed analysis of the real environmental impact of subterranean extensions when compared with above ground extensions it is necessary to highlight that the available data for this analysis was also limited and somewhat inaccurate. This is particularly relevant for the data used for the embodied carbon of materials and the construction works. The data used for the calculations in these sections was based on the (limited) information provided for the projects in the planning submissions.

Eight Associates have analysed the available data from the Construction Method Statements for each project, and when available, Traffic Management Plans as well as the drawings submitted for planning. Generally, more detailed data would be needed to analyse in detail the environmental impact of subterranean extensions. When data was not available assumptions had to be made. Appendix 1 provides more insights about the assumptions made for the calculations. Bearing this in mind, the approach in this report is conservative and the best case scenarios were assumed when data was not available. This is likely to be relevant to the environmental performance of basements, which are likely to perform better under these circumstances.

The report has been divided in 2 different parts.

The main section of this report has 2 key sections as follows:

- Section 1: Life Cycle Carbon analysis of subterranean extensions. The scope of work of this chapter was enlarged when compared with the 2010 report, and now aims to compare the embodied carbon of 16 different case studies. The sample of case studies include:
  - Above ground extensions;
  - Single storey basements;
  - Multi storey basements.

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Scope of Works and Background: Aim of Report

Aim

For each of the case studies the relative environmental impact of subterranean extension is determined and compared with standard above ground extensions.

- Section 2: Sensitivity analysis and analysis of the BREEAM Domestic Refurbishment methodology for each of the case studies, which will include the incorporation/synthesis of the Eight Associates 'Evidence Base for Basement and Policy CE1: Climate Change' report.

This will assess what each of the case studies would achieve under the BREEAM Domestic Refurbishment assessment method. This section includes a sensitivity analysis for the case studies and analyses strategies to mitigate the environmental impact of subterranean extensions.

Appendices

The appendices of the report provides the results and calculations for each of the case studies and has 3 key sections as follows:

- 1) Methodological report with information about the carbon factors used and assumptions made,
- 2) Results and information about each of the case studies analysed,
- 3) Full list of references used within this report.

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Section 1: Life Cycle Carbon Analysis

Introduction

This section of the report provides the calculations for the whole life carbon emissions and details the embodied carbon of the case studies, carbon relating to the associated construction works and the operational carbon emissions for each development.

The same methodology has been used for all case studies.

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1.1 Methodology: Life Cycle Carbon Analysis

Methodology

The section below provides a step-by-step description of the project methodology.

Brief

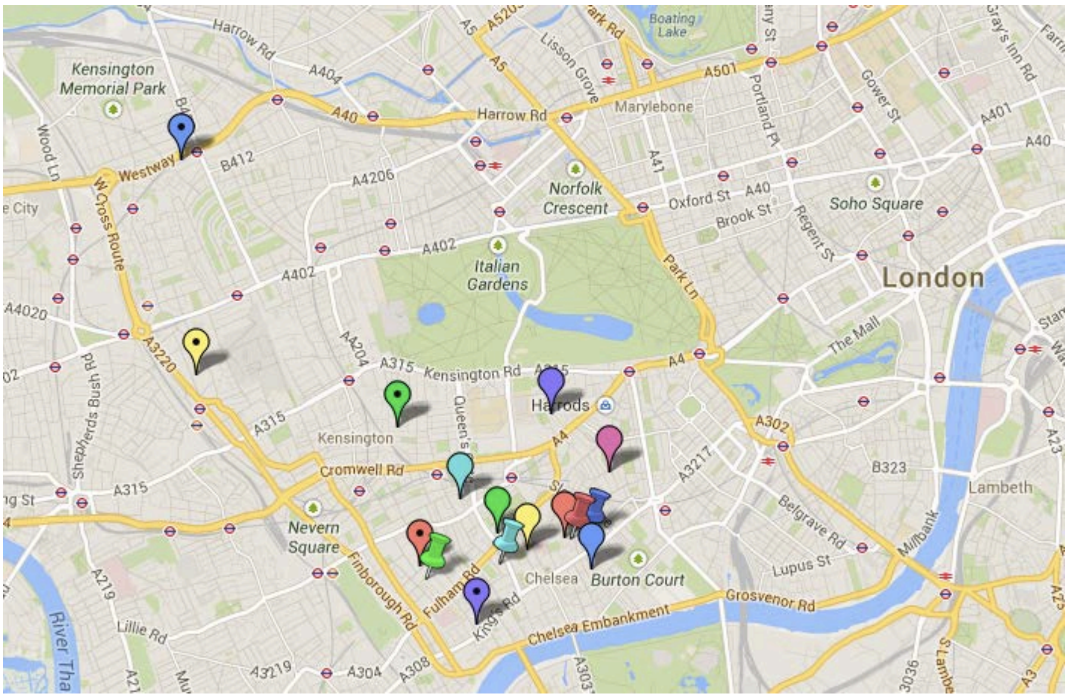
The brief was to analyse and then compare the carbon intensity of different types of development, typical to RBKC: extensions and subterranean extension (single and double basements).

A particular focus was placed on a whole life cycle analysis, which encompasses all stages of development from the sourcing of the materials, the activity during construction works and the operations of the building.

1 – Case Studies

This reports analyses 16 case studies, which aim to cover all the typical subterranean extensions and typical extensions submitted for planning application in the last 12 years. The case studies have information relating to the development such as drawings and other consultant reports. Further information is provided in the appendices.

- 19 Clareville Grove
- 24 Chelsea Square
- 30 Brompton Square
- 30 Milner Street
- 36 Markham Square
- 37 Jubilee Place
- 49 Redcliffe Road
- 149-151 Old Church Street
- 2 Ruston Mews
- 2 Tregunter Road
- 5 Eldon Road
- 8 Holland Villas Road
- 8 Lamont Road
- 16 Radnor Walk
- 16A St Luke's Street
- 17 Neville Street



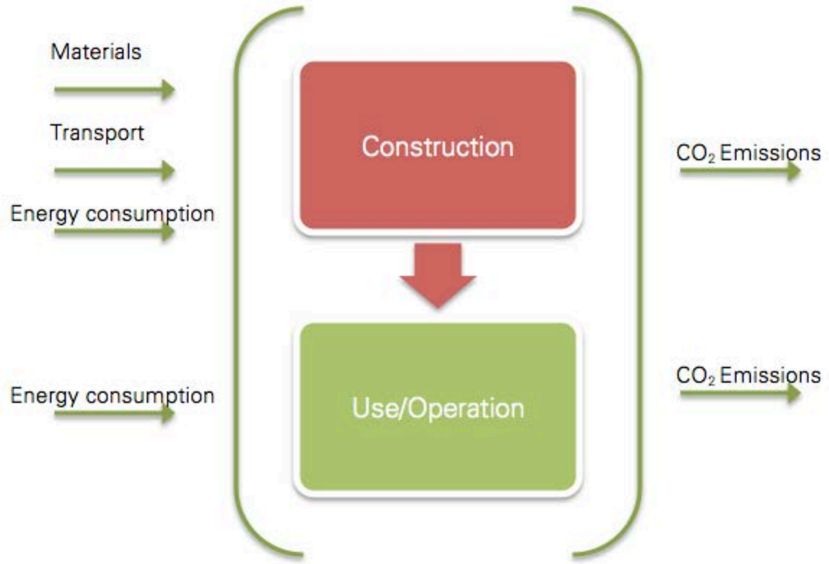
1.1 Methodology: Life Cycle Carbon Analysis

2 – Building Life-Cycle – System boundaries

According to ISO standardisation guidelines, a Life Cycle Analysis (LCA) study can be divided into 4 steps:

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation.

The following image synthetises the system boundaries defined for the current project, the scope of works and the environmental impacts assessment.



Eight Associates has broken down the whole life carbon emissions for each case study and provided the embodied carbon from the materials, carbon relating to construction works and the operational carbon. The same methodology has been applied to all case studies.

The deconstruction phase of the building was excluded from this assessment due the myriad variables that it presented, although in the embodied calculations of the materials the end of life of materials is considered as explained in the BRE methodology for this tool[3].

The life cycle of the building has been assessed over a 60-year period.

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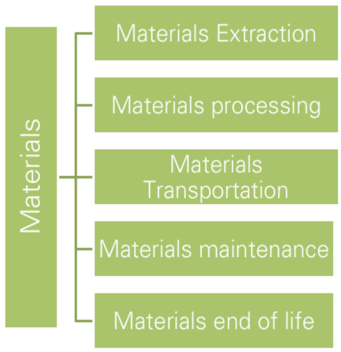
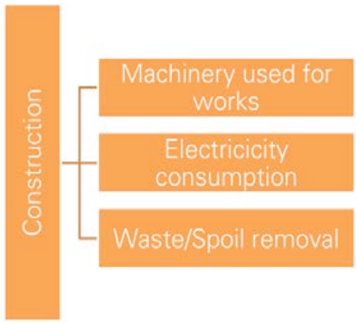
1.1 Methodology: Life Cycle Carbon Analysis

3 – Embodied Carbon Methodology



At this stage the inventory included all the carbon emissions related to the building's material processes, from raw materials acquisition to the materials' processing impacts, deliveries on site and refurbishment and end of life data for the 60 years, all provided in an aggregate CO_2eq from the BRE Green Guide tool[3].

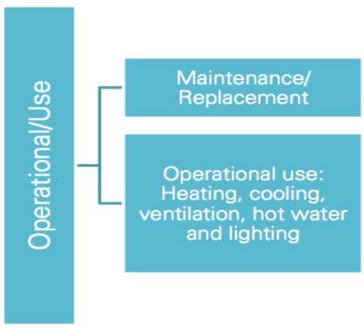
4 – Construction Works Embodied Carbon Methodology



During this stage, estimates of the quantity of electricity and fuels used on the project site are used, as well as the removal of spoil and demolition waste from the site. The fuel consumption of the machinery and vehicles used and the electricity consumed at the site during the constructions works are accounted for[14,15,16,11].

The transportation for workers to and from site is excluded.

5 – Operational Carbon Analysis Methodology



For this stage the regulated carbon emissions from the dwelling's operation have been calculated. This includes space and water heating, ventilation and lighting (appliances are excluded in-keeping with Building Regulations[8,9]). The calculation of operational emissions was based on 'net increase' i.e. the increase or decrease in emissions that results as a result of the refurbishment and new works.

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1.2 Overview and Modelling: Life Cycle Carbon Analysis

Background

The system considered for this report is broken down into two phases:

1. Construction Phase
   The carbon emissions embodied in the construction phase of a project were divided into two parts:
   - a) 'cradle to grave' emissions for the materials used, including their transport to site and maintenance along the 60 years of the building life cycle
   - b) emissions of site operations, including the transport of spoil and demolition waste to landfill.

2. Operational Phase
   Operational emissions i.e. in-use emissions from space and water heating, pumps and fans and lighting.

To ensure that the methodology is as robust and comparable as possible, the guidelines of the ISO 14040 – "Life cycle assessment – Principles and framework" and the BS ISO 21931-1: "Sustainability in Building Construction – Framework"4 for methods of assessment of the environmental performance of construction works were followed in the development of the current methodology.

The model data collection was based on the sources listed below.

Modelling

Building data input

- Construction plans, drawings, elevations and measurements;
- Construction method statements;
- Transportation statements;
- Energy strategies submitted for planning.

Benchmark data

- BRE Green Guide for materials specifications – Embodied carbon values and build ups;
- DEFRA carbon factors for CO_2 eq factors– Operational and construction works analysis;
- Literature review of previous case studies.

Model

- Combined building data and benchmark data

Please see the appendices of this report for more details about the model data and calculations.

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1.3 Carbon Analysis Results & Comparison: Embodied Carbon

Introduction

The following section summarises the results and key findings of the embodied carbon of materials assessment for the 16 case studies.

Vital Characteristics

The input data for the embodied carbon is based on the BRE Green Guide tool. For each case study the following elements were considered:

- External walls;
- Ground and upper floors;
- Glazing (windows, rooflights);
- Roofs.

For each element, the corresponding build-up was selected from the Green Guide tool (*www.bre.co.uk/greenguide)*, based on the drawings provided for each case study in the planning stage. The following table provides a list of the considered case studies.

	BRE Green Guide code	kg CO_2eq/kg
External wall, roofs and ground floors basements	1212540075[36]	240
External wall small extensions	806170615[31]	74
External wall big extensions	806170033[30]	72
Pitched roof s	812410026[39]	49
Flat roofs	1212540069[35]	58
Glazed walls	1206510006	200
Timber windows	813100013[26]	220
Aluminium windows	1213100004[28]	250
Basements rooflights	813100011[25]	310
Flat asphalt roofs	1212540031[34]	47
Upper floor basements concrete	807280063[42]	96
Upper floors timber	807280023[40]	-8.2
Zinc roof	1212540083[38]	17
Concrete layer additional basement reinforcement	79889450	118.12
Metal decking	79889685[43]	61

For detailed information for each of the above build-ups please see Appendix 1 of this report.

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1.3 Carbon Analysis Results & Comparison: Embodied Carbon

Results

The comparison of the embodied carbon for the case studies analysed shows that single storey basements are likely to be 55% more carbon intense than above ground extensions and multi-storey basements are likely to be 61% more carbon intense than above ground extensions.

When comparing single storey basements with multi storey basements, multi storey basements are likely to have a carbon intensity for the materials used of approximately 12% higher.

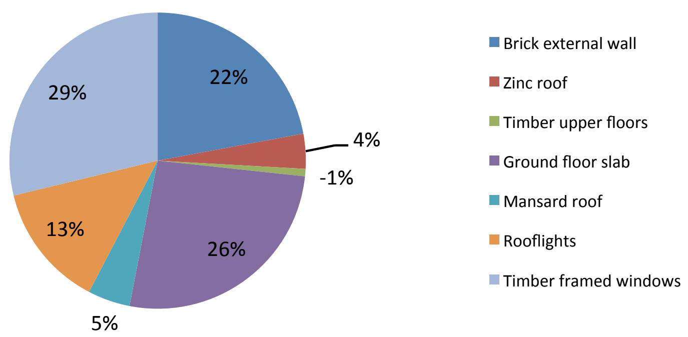
Extensions:

Case Study	Increase in Gross Internal Area (m^2)	Total Embodied Carbon ($kgCO_2$)	Embodied Carbon per Square Metre ($kgCO_2/m^2$)	Average Embodied Carbon per Square Metre ($kgCO_2/m^2$)
2 Ruston Mews	40	5,506	138	372
8 Lamont Road	8.5	4,298	503	
17 Neville Street	15.5	7,108	459	
36 Markham Square	36.4	20,406	562	

Analysis

The above table shows an average embodied carbon of 372 $kgCO^2$ eq/m^2 for extensions.

36 Markham Sq - Embodied carbon by building element



As an example, the above graph shows the relative impact of each building element in the total embodied carbon for the 36 Markham Square extension.

The details of the embodied carbon for each case study are detailed in Appendix 2 of this report. For all the extensions it is possible to conclude that the most relevant impacts originate from the glazing areas derived from the high embodied carbon of glass manufacturing processes[23,24]. For 36 Markham Square the glazing alone represents 43% of the total embodied impact, almost as much as the external walls and ground floors summed (49%), although the glazing area is only 34% of the total area of these two building elements.

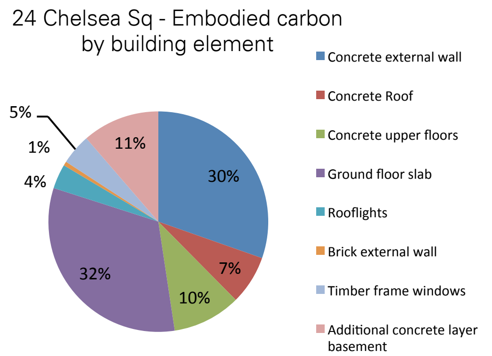
1.3 Carbon Analysis Results & Comparison: Embodied Carbon

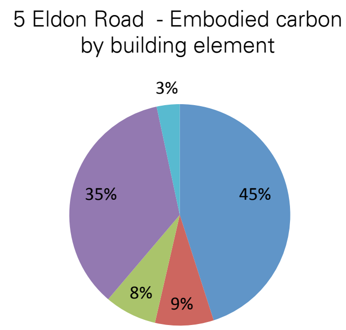
Single storey basements:

Case Study	Increase in Gross Internal Area (m^2)	Total Embodied Carbon ($kgCO_2$)	Embodied Carbon per Square Metre ($kgCO_2/m^2$)	Average Embodied Carbon per Square Metre ($kgCO_2/m^2$)
5 Eldon Road	82	70,620	861	838
16 Radnor walk	62	56,101	900	
37 Jubilee Place	72	62,149	879	
49 Redcliffe Road	116	87,795	832	
19 Clareville Grove	185	155,712	842	
8 Holland Villas	275	244,031	889	
24 Chelsea Square	222	173,471	773	

Analysis

The above table shows an average embodied carbon of 838 kg CO^2eq/m^2 for single storey basements.





As an example, the above graphs show the relative impact of each building element in the total embodied carbon for a smaller subterranean extension, 5 Eldon Road, and a medium subterranean extension, 24 Chelsea Square.

The details of the embodied carbon for each case study are detailed in Appendix 2 of this report. For all single storey basements it is possible to conclude that the most relevant impacts originate from the concrete areas derived from the relatively high embodied carbon of concrete manufacturing processes[48] and the amount of concrete used to build these structures.

For 5 Eldon Road, the concrete alone represents 97% of the total embodied impact, and for 24 Chelsea Square represents 91%.

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1.3 Carbon Analysis Results & Comparison: Embodied Carbon

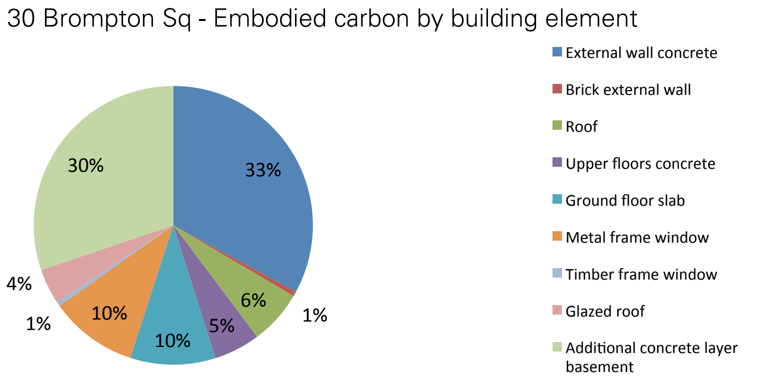
Multi storey basements:

Case Study	Increase in Gross Internal Area (m^2)	Total Embodied Carbon ($kgCO_2$)	Embodied Carbon per Square Metre ($kgCO_2/m^2$)	Average Embodied Carbon per Square Metre ($kgCO_2/m^2$)
2 Tregunter Road	466	421,511	905	947
30 Milner Street	152	133,652	878	
16A St. Lukes Street	171	143,557	841	
30 Brompton Square	287	320,772	1,118	
149-151 Old Church Street *	1,278	1,228,042	961	

* Excluded from the average of the case studies because the area of the project would distort the average results.

Analysis

The above table shows an average embodied carbon of 947 per m^2 for multi storey basements.



As an example, the above graph shows the relative impact of each building element in the total embodied carbon for the 30 Brompton Square subterranean extension.

The details of the embodied carbon for each case study are detailed in Appendix 2 of this report. For all the extensions it is possible to conclude that the most relevant impacts originate from the concrete areas as well.

For 30 Brompton Square the concrete alone represents 85% of the total embodied impact. The amount of concrete used to reinforce the basement walls and ground floors due to its high depth is 36% of the 92% of total concrete. This specific case study also provides some information about how the increase of glazed areas in basements is likely to increase the total embodied carbon. The glazed area of this subterranean extension represents 7% of the total area of new materials and around 15% of the total embodied carbon.

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1.4 Carbon Analysis Results & Comparison: Construction Works

Introduction

The following section summarises the results and key findings of the carbon emissions assessment of the construction works for the case studies under the scope of the present report.

Vital Characteristics

The carbon emissions from construction works calculations exposed some difficulties because of the lack of precision in the information available for the project planning applications. The calculations were based on the details provided in the traffic management plans for each project, these appear to include unrealistic timeframes for the projects and some unexplained volumes.

As an example, below is a table with the volume of the basements, measured by Eight Associates vs. the amount of spoil described in the planning application documents for the particular projects.

Project	Basement volume m^3	Planning application spoil removal m^3	Projection of spoil based on real basement volume with 35% bulk volume for stiff clay soils m^3
30 Brompton Square	1145	1250	1545
140-151 Old Church Street	4238	2700	5721

The 30 Brompton Square subterranean extension volume reported in the planning application is very close of the real volume of the basement. However, for 140-151 Old Church Street, if a bulk factor of 35%[17,18,19] is considered (based on the data provided in Baxter's 2014 report), the total volume of spoil can be approximately 2.2 times higher than the projected volume in the planning application.

These numbers can substantially influence the timeframe of the project as well as the machinery needed and therefore all the associated results in the embodied carbon of the construction works.

It should also be noted that because of the lack of detail regarding the machinery used and that the real timeframe for each project was unavailable for many of the case studies, assumptions have had to be made. Please refer to Appendix 2 for more information.

Results

When analysing the carbon emissions from construction works, single storey basements are likely to have 57% more carbon emissions during this stage than above ground extensions. If extensions are compared with multi storey basements the carbon emissions can be 70% higher for multi storey basements.

The works to build a multi storey basement are generally longer and require more heavy machinery, which results in multi storey basements having carbon emissions 28% higher than single storey basements.

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1.4 Carbon Analysis Results & Comparison: Construction Works

Extensions:

Case Study	Increase in Gross Internal Area (m^2)	Total Carbon emissions ($kgCO_2$)	Carbon emissions per Square Metre ($kgCO_2/m^2$)	Average Carbon emissions per Square Metre ($kgCO_2/m^2$)
Small extensions	10	878	88	71
Big Extensions	30	1,954	65	

Analysis

The table above shows average carbon emissions of 71 kg of CO_2 per m^2 during construction works. The embodied carbon of construction works for small extensions is higher than the embodied carbon of construction works for larger extensions. This is because all other things being equal (materials and construction methods), a larger refurbishment should have a lower embodied carbon factor on a square metre basis. This is because of the surface area to volume relationship i.e. larger shapes have less surface area to volume relative to smaller shapes of the same form.

Single storey basements

Case Study	Increase in Gross Internal Area (m^2)	Total Carbon emissions ($kgCO_2$)	Carbon emissions per Square Metre ($kgCO_2/m^2$)	Average Carbon emissions per Square Metre ($kgCO_2/m^2$)
5 Eldon Road	82	13,384	163	163
16 Radnor walk	62	10,488	168	
37 Jubilee Place	72	10,806	151	
49 Redcliffe Road	116	22,152	193	
19 Clareville Grove	185	30,072	163	
8 Holland Villas	275	36,027	132	
24 Chelsea Square	222	42,002	189	

Analysis

The table above shows an average embodied carbon of 163 kg of CO_2 per m^2 during construction works for single storey basements. The results show that if basements are outside the building footprint and the access to site is good, the carbon emissions of the construction works can decrease significantly. The 8 Holland Villas case study is a subterranean extension exclusively under the garden and presents a carbon footprint for the construction works 19% smaller than the average of single storey basements.

1.4 Carbon Analysis Results & Comparison: Construction Works

Multi storey basements

Case Study	Increase in Gross Internal Area (m^2)	Total Embodied Carbon ($kgCO_2$)	Embodied Carbon per Square Metre ($kgCO_2/m^2$)	Average Embodied Carbon per Square Metre ($kgCO_2/m^2$)
2 Tregunter Road	466	93,646	201	228
30 Milner Street	152	35,487	233	
16A St. Lukes Street	171	40,531	237	
30 Brompton Square	287	76,141	265	
149-151 Old Church Street *	1,278	268,131	210	

* Excluded from the average of the case studies because the area of the project would distort the average results.

Analysis

The table above shows average carbon emissions for construction works of 228 kg of CO_2 per m^2 during construction works. Multi basements carbon emissions during construction works are likely to be 28% higher than single storey basements.

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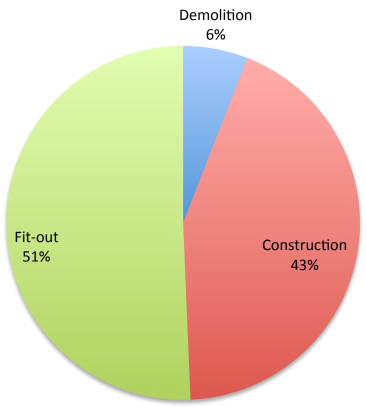
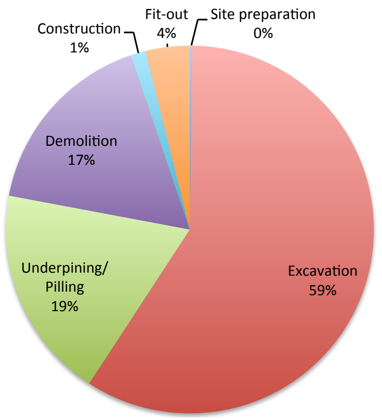
1.4 Carbon Analysis Results & Comparison: Construction Works

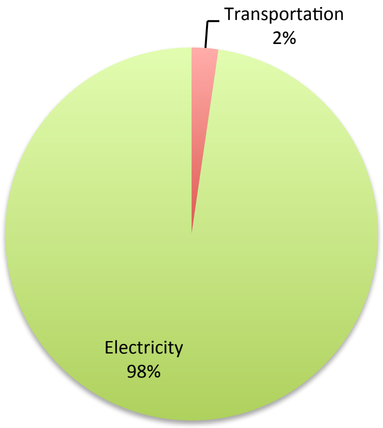
Breakdown of average carbon emissions during construction works for extensions by project phase



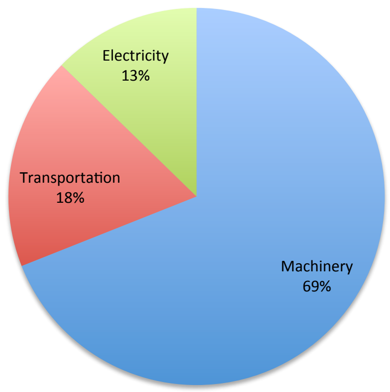
Breakdown of average carbon emissions during construction works for subterranean extensions by project phase



Breakdown of average carbon emissions during construction works for extensions by energy source



Breakdown of average carbon emissions during construction works for subterranean extensions by energy source



Analysis

The charts above provide information about the amount of carbon emissions per phase of the project and by type of energy source - both for extensions and basements. The results show that for subterranean extensions, the highest amount of carbon emissions are derived from the excavation phase (59%) and for above ground extensions from the fit-out works (51%).

Looking at the breakdown of the carbon emissions by energy source, for subterranean extensions the highest energy consumption is the machinery used, mainly for the excavation phase. For the extensions the main source of energy consumption is electricity.

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1.5 Carbon Analysis Results & Comparison: Operational Carbon

Introduction	This section summarises the results and key findings of the carbon emitted during the buildings' operational phase, under the scope of the present report.
Vital Characteristics	The operational carbon was calculated using SAP software[13]. The dwellings were modelled before the works to establish the baseline performance, then they were modelled as a whole after the extension and basement. This established the 'net carbon increase' of the works.
Results	The results demonstrate that the above ground extensions have a negative impact; the performance of the dwelling as a whole is better after the works have been carried out. The larger basements result in a net increase in operational carbon, and the multi-storey basements have a larger increase in carbon during their operation as a result of the works.

Extensions:

Case Study	Total Existing Operational Carbon ($kgCO_2$/year)	Total Post Operational Carbon ($kgCO_2$/year)	Increase in Gross Internal Area (m^2)	Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)	Average Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)
2 Ruston Mews	5,216	5,650	40	10.9	-16
8 Lamont Road	6,211	6,136	8.5	-8.7	
17 Neville Street	8,969	8,123	15.5	-54.6	
36 Markham Square	7,021	6,633	36.4	-10.7	

The averaged above ground extension is carbon negative on a per metre square basis. This means that the operational carbon of the building reduces. Rustow Mews is carbon positive, this scheme added a new mansard roof and windows, this created a new floor that effectively increased the dwelling's existing volume by approximately 25%. Because the extensions do not add large volumes of space that require conditioning, and they replace existing thermally poor elements with new Building Regulations compliant [8,9] thermal elements they effectively reduce total carbon.

Single Basements:

Case Study	Total Existing Operational Carbon ($kgCO_2$/year)	Total Post Operational Carbon ($kgCO_2$/year)	Increase in Gross Internal Area (m^2)	Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)	Average Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)
5 Eldon Road	9,324	12,106	82.1	33.9	31
16 Radnor walk	5,235	7,040	62.2	29.0	
37 Jubilee Place	6,278	8,000	72.6	23.7	
49 Redcliffe Road	10,068	14,559	116.1	38.7	
19 Clareville Grove	7,206	12,369	169.2	30.5	
8 Holland Villas	27,746	37,354	274.5	35.1	
24 Chelsea Square	10,729	15,939	222.7	23.4	

The averaged single basement on a per metre square basis increases the operational carbon as more usable floor area is added to the building. Although an existing non-insulated floor may be replaced with a new floor (as with extensions), there is a much larger increase in dwelling volume which requires conditioning, so this increases the total carbon emissions of basements.

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1.5 Carbon Analysis Results & Comparison: Operational Carbon

Large Basements:

Case Study	Total Existing Operational Carbon ($kgCO_2$/year)	Total Post Operational Carbon ($kgCO_2$/year)	Increase in Gross Internal Area (m^2)	Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)	Average Carbon Impact for Increase in Gross Internal Area ($kgCO_2/m^2$/year)
2 Tregunter Road	17,166	28,232	466	29.3	34
30 Milner Street	8,709	14,094	152	35.4	
16A St. Lukes Street	6,571	11,415	171	28.3	
30 Brompton Square	16,376	28,232	287	41.3	
149-151 Old Church Street *	45,569	89,374	1,278	30.8	

* Excluded from the average of the case studies because the area of the project would distort the average results.

Similarly to single storey basements, multi storey basements increase the total carbon emissions in operation. The averaged multi-storey basement on a per metre square basis increases the operational carbon as more usable floor area is added to the building, the average is 9% more carbon intense than single storey basements.

Analysis

A key feature in the operational carbon is the building form and resulting energy efficiency. For example, schemes that have a higher proportion of external area will have higher carbon emissions because they have more heat loss. This principle means that basements exclusively under the garden have relatively higher carbon emissions, 30 Brompton Square is an example of this as it has 3 new storeys which are installed adjacent to the existing dwelling.

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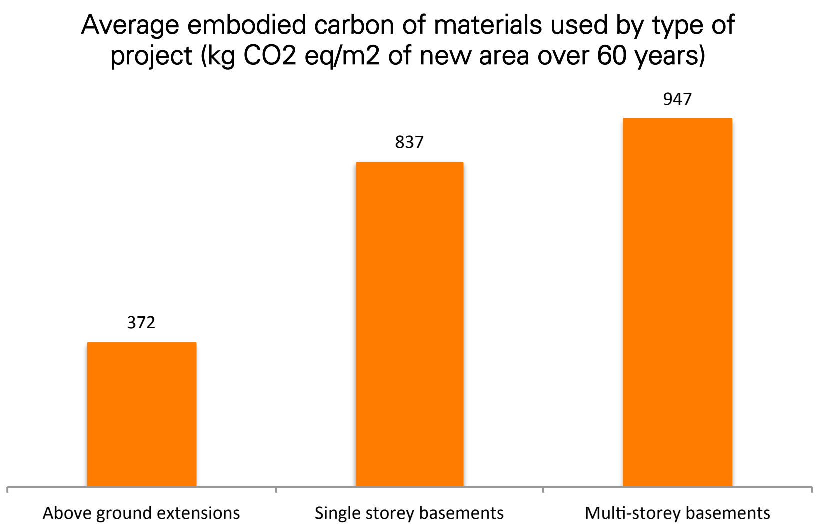
1.5 Carbon Analysis Results & Comparison: Analysis of results

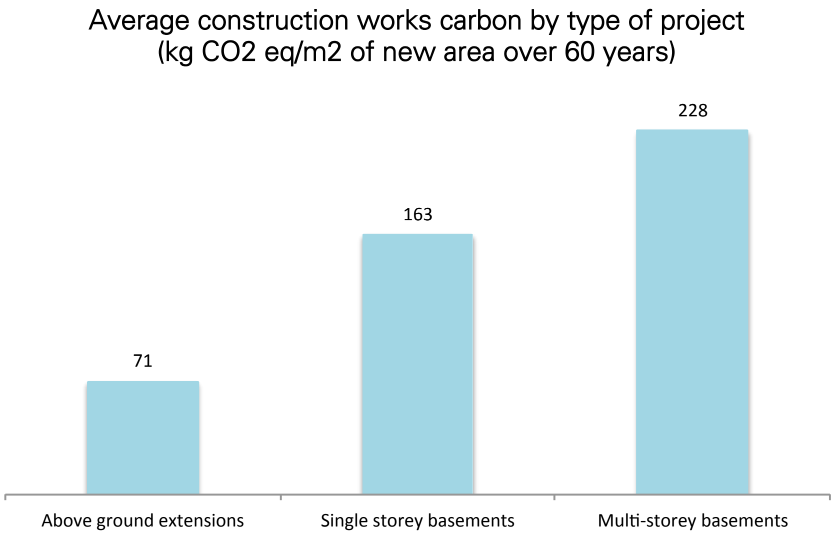
Introduction

The carbon footprint for each of the stages has now been calculated. The results for each of the life cycle stages are compared below; the charts show the average performance of all the dwellings (by type of works) over a 60-year time period.

1) Embodied Carbon



2) Construction Works



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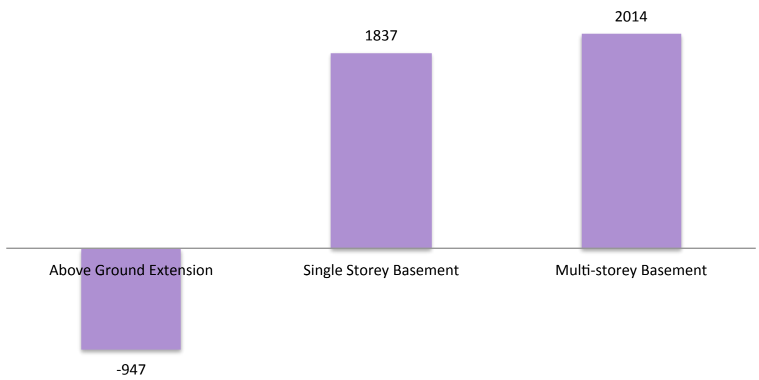
1.5 Carbon Analysis Results & Comparison: Analysis of results

3) Operational Carbon

Average operational carbon by type of project
(kg CO2 eq/m2 of new area over 60 years)



Summary

The results for each of the stages can be are summarised as follows:

1) Embodied Carbon:
The comparison of the embodied carbon of the case studies analysed shows that single storey basements are likely to be 55% more carbon intense than above ground extensions and multi-storey basements are likely to be 61% more carbon intense than above ground extensions.

When comparing single storey basements with multi storey basements, multi storey basements are likely to be 12% more carbon intense in the materials used.

2) Construction Carbon:
When analysing the carbon emissions from construction works, single storey basements are likely to have 57% more carbon emissions during this stage than above ground extensions.

If extensions are compared with multi storey basements, the carbon emissions can be 70% higher for multi storey basements.

The works to build a multi storey basement are generally longer and require more heavy machinery, which results in multi storey basements having carbon emissions that are 28% higher than single storey basements.

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1.5 Carbon Analysis Results & Comparison: Analysis of results

3) **Operational Carbon**: The extensions mostly have negative operational carbon emissions i.e. they reduce the carbon emissions of the existing dwelling on a metre square basis. The multi-storey basements have the highest operational carbon emissions, 9% higher than single storey basements.

   Basements that are exclusively in the garden perform worse as they have more heat loss area relative to basements under or attached to the existing dwelling.

Overall, the multi-storey basements have the highest carbon emissions, and the extensions have the lowest on a square metre basis. The next chapter will analyse these findings in more depth and assess the impact of a change in variables. This will aim to establish where improvements in carbon emissions can be made and how effective they would be.

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2.0 Sensitivity Analysis of Results: Overview

Overview

Having established the key findings it is necessary to test some potential variables that may occur in real life. This section of the report will examine ways in which the associated carbon from extensions and basement developments could vary when particular parameters are changed.

Sensitivity Analysis

Sensitivity analysis is used to determine how "sensitive" a model or a set of results are to changes in the values of the parameters and changes in the basic structure of the model. By demonstrating how a set of results respond to changes in parameters the analysis helps to build confidence and studying the uncertainties that are often associated with models.

A sensitivity analysis will determine what level of accuracy is necessary for a parameter to make the modelling sufficiently useful and valid. If the tests reveal that the model is relatively insensitive, then it may be acceptable to use an estimate rather than a value calculated with greater precision. Sensitivity analysis can also indicate which parameter values are reasonable to use in the model. If the model behaves as expected from real world observations, it gives some indication that the parameter values reflect, at least in part, the "real world".

Some of the key parameters used in calculating the result will be subject to sensitivity analysis, this will essentially involve 'What if?" questions, there are:

1) What if concrete with a lower carbon impact was to be used in the construction of extensions and basements?
2) To what extent could retrofitting of the existing dwelling offset the carbon generate in new construction?

Note. The temporary works i.e. temporary supports and structures, associated with basement construction could potentially result in a non-trivial increase in the construction works carbon. However, the data available for each of the case studies was not adequate to accurately quantify this component so it was excluded from the sensitivity analysis. A real life case study analysis would provide an interesting and very relevant insight into the carbon impact of temporary works.

The two scenarios above will be assessed in turn.

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2.1 Sensitivity Analysis of Results
1) Embodied Carbon of Concrete

Overview

There are several ways to mitigate the environmental impacts of the embodied carbon of a building. This can be done by defining standards for the choice of more sustainable materials at the design stage of the project. Theses standards can include, among others, the following aspects:

- reuse of materials;
- recycled content of materials (pre and post consumer);
- the use of rapidly renewable materials;
- the use of local or regionally manufactured materials;

The embodied carbon in a building life cycle can typically represent around a quarter of the total carbon footprint of a building [23,24].

UK environmental policies are heavily targeting the reduction of carbon emissions from buildings. However, the focus remains on the operational phase of the building's life cycle and little attention is usually given to the embodied carbon of materials.

The embodied carbon of materials represents around a quarter of the total carbon footprint of a building and these figures are likely to change if the new low carbon targets for the UK are achieved and the energy consumption of dwellings is substantially reduced. Where buildings have low carbon emissions in their operation the proportion of the embodied carbon of the materials used in the building is likely to increase as a measure of the overall lifecycle carbon.

Buildings are major consumers of natural resources. An aspect that is especially relevant for the present analysis is the energy intensity needed for the production of materials such as glass, metals and cement. Cement manufacturing alone accounts for, approximately, 7-8 % of carbon dioxide emissions globally [48].

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2.1 Sensitivity Analysis of Results
1) Embodied Carbon of Concrete

Build-ups

For the following analysis, the concrete used for basements in the previous embodied carbon calculations was replaced by a concrete with recycled content as described in the table below (BRE environmental profiles – Green Guide):

Build-up	Green Guide code	Kg of CO_2eq/kg
In situ reinforced concrete slab, vapour control layer, insulation, and Polyester cold applied liquid waterproofing membrane system.	1212540075	240
Replaced by:		
In situ reinforced concrete with 50% GGBS and 20% recycled coarse aggregate, vapour control layer, insulation, Polyester cold applied liquid waterproofing membrane system	1212540080	190

Build-up	Green Guide code	Kg of CO_2eq/kg
In situ concrete, reinforced	Bespoke profile	118
Replaced by:		
In situ reinforced concrete with 50% GGBS and 20% recycled coarse aggregate	Bespoke profile	75

The reduced embodied carbon values have been incorporated into the calculations and the results for each case study are shown in the following graph (please see overleaf).

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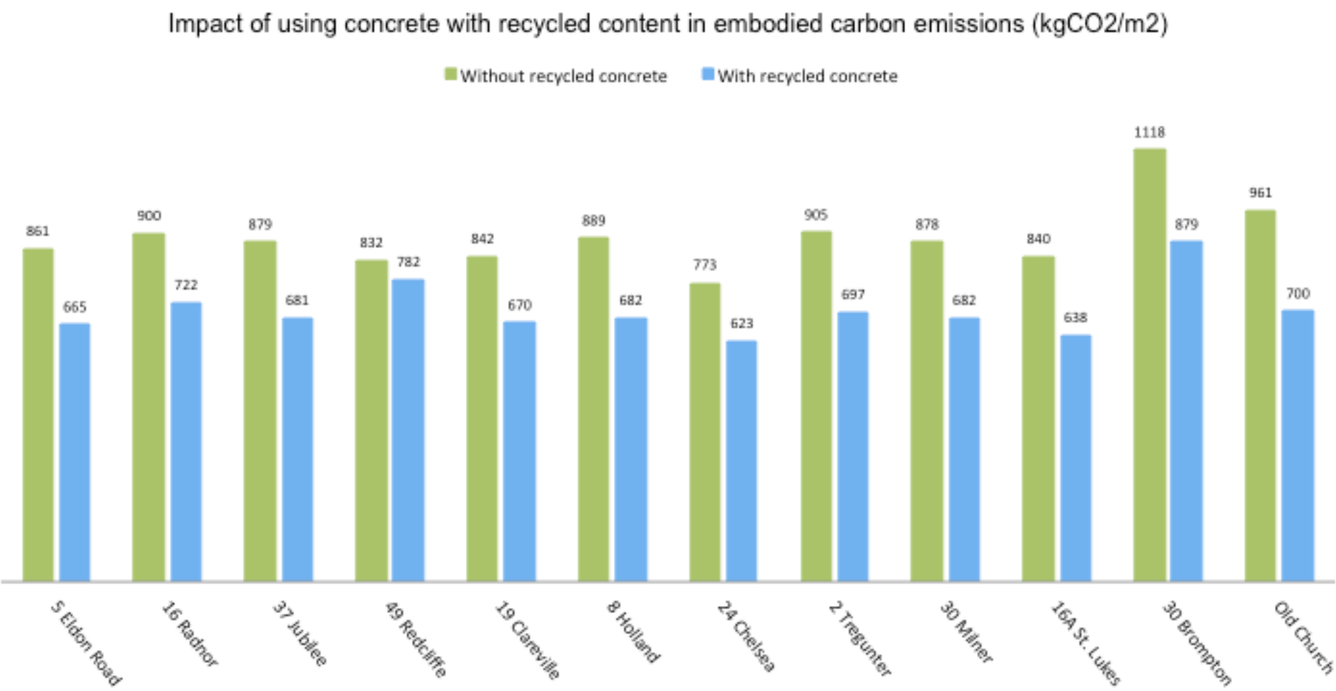
2.1 Sensitivity Analysis of Results
1) Embodied Carbon of Concrete

Sensitivity Analysis



The graph above shows that if concrete with recycled content is used, the embodied carbon results over 60 years are likely to be reduced by approximately 19% for single storey basements and by approximately 23.5% for multi storey basements.

Although the analysis is limited to these specific case studies and, therefore, dependent on the characteristics of each project, the results show a consistent reduction in the embodied carbon of subterranean extensions if more sustainable materials are used.

However, even with the use of concrete with recycled content, the analysed single storey basements were still likely to be 46% more carbon intense than the above ground extensions case studies and multi-storey basements case studies were still likely to be 49% more carbon intense than the above ground extensions case studies.

Other aspects

The results of the embodied carbon also provide evidence that subterranean extensions entirely/partially outside of the building footprint (i.e. in the gardens) will have a higher embodied carbon per square meter than similar basements built entirely under the building footprint (i.e. 8 Holland Villas vs. 24 Chelsea Square), this relationship is particularly pronounced for multi storey basements (30 Brompton Square vs. 16A St Lukes or 30 Milner Street).

2.1 Sensitivity Analysis of Results
1) Embodied Carbon of Concrete

If carbon emissions related with the change of land use are accounted for these results are likely to be even more relevant, as subterranean extensions under gardens can result in significant changes in terms of land use, modifying the functions of the soil to act as a carbon sink if the land was previously undeveloped land (greenfield).

However, to better understand the tangible impacts of the statements above, a more detailed analysis, outside of the scope of this report, would have to be undertaken.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
BREEAM

Overview

This chapter will consider how the developments compare from an energy and carbon perspective. This will be based within the context of current and proposed policy requirements. The current Core Strategy Policy, CE1 of the RBKC Local Development Framework (LDF) is detailed below.

" The Council will require an assessment to demonstrate that subterranean developments achieve the following relevant BREEAM standards: i. Residential Development: EcoHomes Very Good (at Design and Post Construction) with 40% of credits achieved under the Energy, Water and Materials sections, or comparable when BREEAM for Refurbishments is published."
Furthermore; *" requires that carbon dioxide and other greenhouse gas emissions are reduced to meet the Code for Sustainable Homes, EcoHomes and BREEAM standards"*

The carbon emission reductions are to be in accordance with the Greater London Plan Energy Hierarchy of Lean, Clean and Green[46]. Moreover, Policy 5.2 (E) also states; *" The carbon dioxide reduction targets should be met on-site. Where it is clearly demonstrated that the specific targets cannot be fully achieved on-site, any shortfall may be provided off-site or through a cash in lieu contribution to the relevant borough to be ring fenced to secure delivery of carbon dioxide savings elsewhere".*

RBKC's draft policy for the Implementation of BREEAM Domestic Refurbishment[1] states that a 'Very Good' rating and the 'Excellent' minimum standard of a SAP/EER rating of 70 should be achieved. The performance of each of the case studies in relation to this standard will be considered.

BREEAM Energy and Carbon

Energy contributes 43% of the total score within the BREEAM assessment. The first three credits are related to result from the SAP modelling, and within the energy section offer 58% of the total energy credits:

Issue	Issue name	Credits available	Credit summary
Ene 01	Improvement in Energy Efficiency Rating	6	Up to 6 credits for the improvement to the dwelling's Energy Efficiency Rating. Credit allocation is based on exceeding EER improvement benchmarks, from the baseline EER.
Ene 02	Energy Efficiency Rating post Refurbishment	4	Up to 4 credits available for the Energy Efficiency Rating post refurbishment. ***RBKC Draft Policy requires a minimum EER of 70 in this credit.***
Ene 03	Primary Energy Demand	7	Up to 7 credits available for the primary energy demand. Credit allocation is based on exceeding refurbishment benchmarks.

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2.2 Sensitivity Analysis of Results 2) Retrofitting and Offsetting Carbon

BREEAM

BREEAM Energy and Carbon (Continued)

The remaining energy credits relate to renewable technology contributions and additional measures that save energy that are not covered under SAP, or measures that provide occupants with opportunities to reduce their energy use such as; energy efficient white goods, energy efficient lighting, monitoring of energy use and providing cyclist facilities.

The BREEAM credit performance of the case studies is shown below.

	SAP Outputs			BREEAM Credits			
	EER Pre-Development	EER Post-Development	EER Improvement	Ene 01	Ene 02	Ene 03	RBKC Draft Policy BREEAM Requirements Achieved?
Above Ground Extensions							
2 Ruston Mews	61	67	6	0.5	2	5.0	No
8 Lamont Road	68	69	1	0	2	5.5	No
17 Neville Street	69	73	4	0	2.5	6.0	Yes
36 Markham Square	68	74	6	0.5	2.5	6.5	Yes
Single Storey Basements							
5 Eldon Road	69	68	-1	0	2	5.5	No
16 Radnor walk	64	66	2	0	2	5.0	No
37 Jubilee Place	68	70	2	0	2.5	6.0	Yes
49 Redcliffe Road	71	68	-3	0	2	5.5	No
19 Clareville Grove	67	68	1	0	2	5.5	No
8 Holland Villas	65	64	-1	0	2	5.5	No
24 Chelsea Square	69	72	3	0	2.5	6.0	Yes
Multi Storey Basements							
2 Tregunter Road	63	66	3	0	2	5.5	No
30 Milner Street	68	66	-2	0	2	5.5	No
16A St. Lukes Street	58	65	7	0.5	2	5.0	No
30 Brompton Square	70	66	-4	0	2	5.5	No
149-151 Old Church Street	66	67	1	0	2	5.5	No

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
BREEAM

The table on the previous page shows that two of the above ground extensions achieved the EER target of 70, as did two of the single storey basements, none of the multi-storey basements achieved 70.

The differences in the energy performance of the case studies and as a result, compliance with policy requirements, are directly related with the different geometries and specifications of the dwelling's fabric, as each dwelling has its own vital characteristics. However, it became clear that with more complex projects, like multi-storey subterranean extensions, it becomes more difficult to achieve the minimum BREEAM DR requirements needed for planning without fabric improvements.

In order to establish what measures would be required to achieve the EER of 70, and to assess the potential of the case studies to achieve carbon emission savings, the following refurbishment scenarios were modelled:

Basic Upgrade:
- Roof insulation to existing structure to achieve 0.18 W/m^{2}K (Building Regulations Compliance)
- Draught proofing to achieve an air permeability of 10 m^3/(hr.m^2)

Intermediate Upgrade:
- Basic Upgrade and;
- 75% low energy light fittings (by number)
- Secondary glazing to existing windows to achieve u value of 1.8 W/m^{2}K
- Draught proofing to achieve an air permeability of 8 m^3/(hr.m^2)

Advanced Upgrade:
- Intermediate Upgrade and;
- Floor insulation to achieve 0.25 W/m^{2}K (Building Regulations Compliance)
- Internal insulation to achieve 0.30 W/m^{2}K (Building Regulations Compliance)
- Draught proofing to achieve an air permeability of 5 m^3/(hr.m^2)
- Mechanical ventilation with heat recovery (compliance with the Domestic Building Services Compliance Guide 2010)
- Weather compensator added to the boiler system

The table of the following page shows the results of the Basic Upgrade.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
BREEAM

Basic Upgrade

The BREEAM credit performance of the case studies when the dwellings are upgraded with the Basic Upgrade refurbishment package is shown below.

	SAP Outputs			BREEAM Credits			
	EER Pre-Development	EER Post-Development	EER Improvement	Ene 01	Ene 02	Ene 03	RBKC Draft Policy BREEAM Requirements Achieved?
Above Ground Extensions							
2 Ruston Mews	61	70	9	1.0	2.5	5.5	Yes
8 Lamont Road	68	72	4	0	2.5	6.0	Yes
17 Neville Street	69	76	7	0.5	3.0	6.5	Yes
36 Markham Square	68	77	9	1.0	3.0	7.0	Yes
Single Storey Basements							
5 Eldon Road	69	73	4	0	2.5	6.5	Yes
16 Radnor walk	64	68	4	0	2.0	5.5	No
37 Jubilee Place	68	74	6	0.5	2.5	6.5	Yes
49 Redcliffe Road	71	74	3	0	2.5	6.5	Yes
19 Clareville Grove	67	72	5	0.5	2.5	6.0	Yes
8 Holland Villas	65	69	4	0	2.0	6.0	No
24 Chelsea Square	69	76	7	0.5	3.0	7.0	Yes
Multi Storey Basements							
2 Tregunter Road	63	72	9	1.0	2.5	6.5	Yes
30 Milner Street	68	72	4	0	2.5	6.5	Yes
16A St. Lukes Street	58	68	10	1.0	2.0	5.5	No
30 Brompton Square	70	73	3	0	2.5	6.5	Yes
149-151 Old Church Street	66	74	8	0.5	2.5	6.5	Yes

The table shows that all of the above ground extensions achieved the EER target of 70, two single storey basements, and one multi-storey basement did not achieve the EER of 70. The Intermediate Upgrade package results are shown on the following page.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
BREEAM

Intermediate Upgrade

The BREEAM credit performance of the case studies when the dwellings are upgraded with the Intermediate Upgrade refurbishment package is shown below.

	SAP Outputs			BREEAM Credits			
	EER Pre-Development	EER Post-Development	EER Improvement	Ene 01	Ene 02	Ene 03	RBKC Draft Policy BREEAM Requirements Achieved?
Above Ground Extensions							
2 Ruston Mews	61	72	11	1.0	2.5	6.0	Yes
8 Lamont Road	68	75	7	0.5	3.0	6.5	Yes
17 Neville Street	69	78	9	1.0	3.0	7.0	Yes
36 Markham Square	68	79	11	1.0	3.0	7.0	Yes
Single Storey Basements							
5 Eldon Road	69	77	8	0.5	3.0	7.0	Yes
16 Radnor walk	64	72	8	0.5	2.5	6.0	Yes
37 Jubilee Place	68	77	9	1.0	3.0	7.0	Yes
49 Redcliffe Road	71	78	7	0.5	3.0	7.0	Yes
19 Clareville Grove	67	72	5	0.5	2.5	6.5	Yes
8 Holland Villas	65	72	7	0.5	2.5	6.5	Yes
24 Chelsea Square	69	79	10	1.0	3.0	7.0	Yes
Multi Storey Basements							
2 Tregunter Road	63	75	12	1.0	3.0	6.5	Yes
30 Milner Street	68	76	8	0.5	3.0	6.5	Yes
16A St. Lukes Street	58	72	14	1.5	2.5	6.0	Yes
30 Brompton Square	70	75	5	0.5	3.0	6.5	Yes
149-151 Old Church Street	66	76	10	1.0	3.0	7.0	Yes

The table shows that all of the above ground extensions and all of the basements achieve the EER of 70 with the Intermediate Upgrade. RBKC's policy requirements can be achieved by; roof insulation, draught proofing, low energy lights and secondary glazing if required, or a combination of all of these measures.

2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
BREEAM

Note that a boiler upgrade is also included in each scenario, including the existing energy model.

Methodological note and review of results	Please note that the analysis undertaken is based on policy requirements and not on the "real" increase in carbon emissions for each case study. It is therefore not a measure of the real environmental impact of extensions (above ground and subterranean) over the buildings' life cycles. The analysis is based on the scenarios and methodology defined in the Greater London Plan, Policy 5.2 and BREEAM Domestic Refurbishment (DR) compliance. For more information please see the following link as well as the BREEAM DR manual: *(http://www.london.gov.uk/priorities/planning/strategic-planning-applications/preplanning-application-meeting-service/energy-planning-gla-guidance-on-preparing-energy-assessments).* Consequently, the analysis in this section is based exclusively on the parameters of the above policy and assessment compliance perspective. The next section of this report does not follow the above policy methodology, and has modelled the dwellings based on the "real" before and after scenarios (i.e. total net operational carbon emissions over 60 years for each of the proposed projects) to assess the environmental impact of the projects. The analysis shows that if these scenarios are used, it becomes very challenging to mitigate and offset the associated environmental impacts, especially for subterranean extensions, during the buildings' life cycle. Offsetting the carbon emissions at the site is particularly challenging in RBKC because of restrictions related with the historical character of buildings.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
Carbon Payback

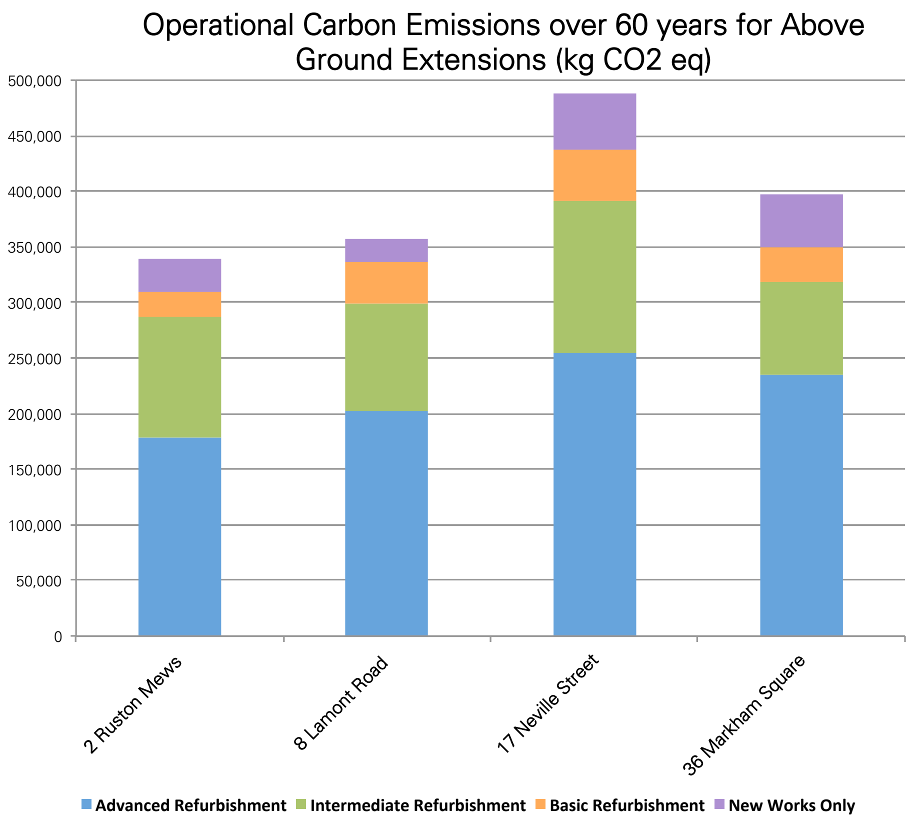
Carbon Payback

The modelling of the Basic and Intermediate Upgrade (see page 35) has demonstrated that all of the case studies can achieve compliance with RBKC's EER target of 70. Having established the policy context, the potential operational carbon savings as the result of more advanced upgrades will be analysed. The aim is to determine the ability of the extensions and basements to recoup the carbon produced in the manufacture and construction of extensions and basements.

The Operational Carbon Analysis in Chapter 1.5 demonstrated that the basements modelled were carbon positive in operational terms i.e. the addition of a basement increased the total emissions of the building as a whole. The following analysis models the inclusion of refurbishment measures to the existing dwelling in addition to the proposed extension or basement works.

Above Ground Extensions

The graph below shows that the Basic, Intermediate and Advanced Upgrade reduce the average total operational carbon of the case studies by 9%, 18% and 45% respectively for above ground extensions.



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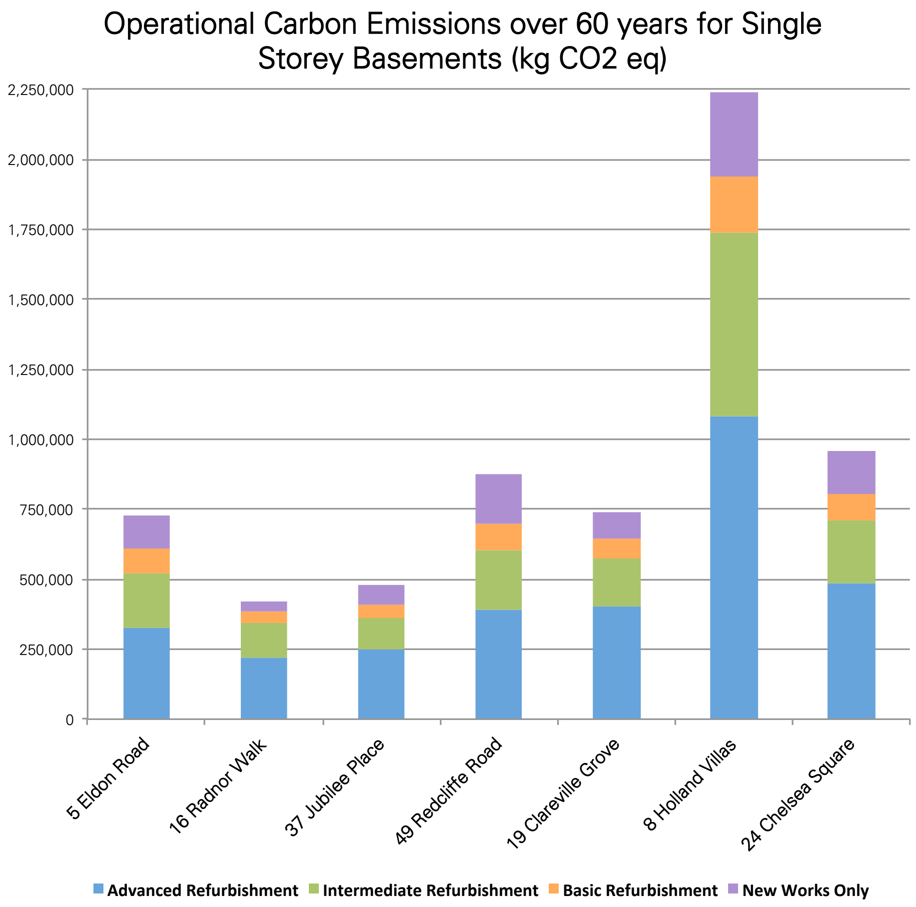
2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
Carbon Payback

Single Storey Basements

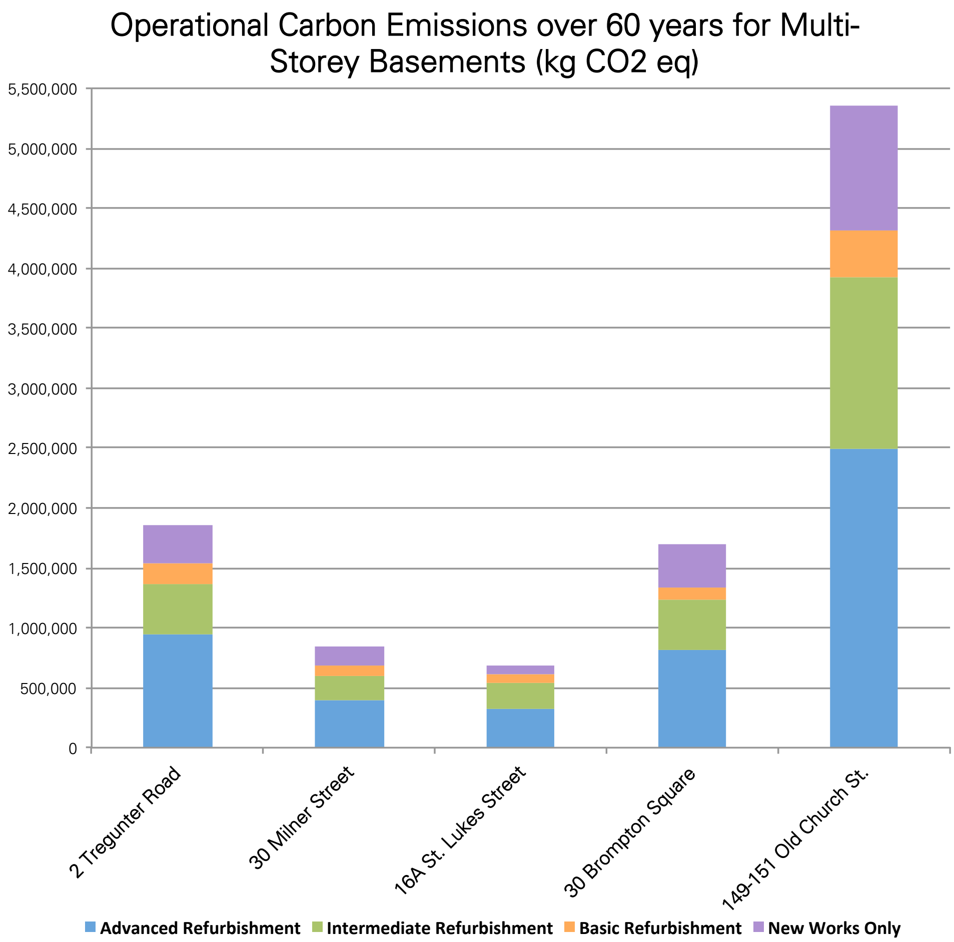
The graph below shows that the Basic, Intermediate and Advanced Upgrade reduce the average total operational carbon of the case studies by 15%, 25% and 51% respectively for single storey basements.



2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
Carbon Payback

Multi Storey Basements

The graph below shows that the Basic, Intermediate and Advanced Upgrade reduce the average total operational carbon of the case studies by 19%, 26% and 52% respectively for multi storey basements.



Summary of Upgrades

The modelling of the upgrade packages has demonstrated the potential for reducing the operational carbon emissions by refurbishments to the existing dwelling in addition to the extension or basement. Significant reductions can potentially be made in the operational emissions with retrofit actions, however, these would be subject to conservation restraints within the Borough and consequently they may not be feasible in reality.

The following section will ask the question "Could the new works be carbon negative?" I.e. could the total carbon emissions from the scheme be less following the extension or basement works if the existing dwelling was retrofitted.

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2.2 Sensitivity Analysis of Results 2) Retrofitting and Offsetting Carbon

Carbon Payback

Carbon Payback in Years

The total carbon generated as a result of the works over 60 years is shown on the following page. The 'Net Operational Carbon' column is the net increase or decrease in operational carbon emissions following the works without any retrofit measures to the existing parts of the dwelling.

The 'Basic, Intermediate and Advanced Upgrade Payback' columns show the number of years that would be required to pass before the carbon emitted for the new extension or basement works would be recouped by the operational savings. Where the term 'Increase' is used, the proposed extension or basement and the retrofit package results in a net increase in the total emissions of the scheme. Therefore it will never payback and is 'adding' carbon.

The 'Photovoltaic Panels…' column is the number of PV panels that would be required to be installed to recoup the carbon emitted for the works over the life expectancy of the panels. This scenario assumes, a standard 250W panel, orientated south at 30 degrees for optimal performance and a life expectancy of 25 years.

Note. The embodied carbon related to the upgrade scenarios ***has not been included*** in the calculation, so these figures can be regarded as the payback that would be required if the upgrade materials could be gained essentially 'carbon free'. Consequently, in reality the payback would be longer once the embodied carbon of the upgrade is included. This is particularly relevant for PV, which has very high-embodied carbon relative to other engineered materials. Although this 'carbon-free' scenario is purely theoretical, the exercise will demonstrate if the extension or basement has any potential to payback its embodied carbon.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
Carbon Payback

	Carbon Generated (60 years)			Payback in Years Relative to Existing			
	Embodied Carbon	Construction Carbon	Net Operational Carbon	Basic Upgrade Payback	Intermediate Upgrade Payback	Advanced Upgrade Payback	Photovoltaic Panels Required for Payback
Above Ground Extensions							
2 Ruston Mews	5,506	1,954	26,042	112	18	3	2
8 Lamont Road	4,298	878	-4,475	9	4	2	1
17 Neville Street	7,108	878	-50,758	5	3	2	2
36 Markham Square	20,406	1,954	-23,273	337	13	7	6
Single Storey Basements							
5 Eldon Road	70,602	13,384	166,901	Increase	131	21	24
16 Radnor walk	56,101	10,488	108,296	Increase	Increase	41	19
37 Jubilee Place	62,149	10,806	103,314	Increase	289	34	21
49 Redcliffe Road	87,795	22,152	269,448	Increase	Increase	31	31
19 Clareville Grove	155,712	30,072	309,789	Increase	Increase	395	52
8 Holland Villas	244,031	36,027	576,505	Increase	Increase	29	79
24 Chelsea Square	173,471	42,002	312,626	Increase	Increase	82	61
Multi Storey Basements							
2 Tregunter Road	421,511	93,646	819,560	Increase	Increase	372	145
30 Milner Street	133,652	35,487	323,130	Increase	Increase	77	48
16A St. Lukes Street	143,557	40,531	290,662	Increase	Increase	172	52
30 Brompton Square	320,772	76,141	711,348	Increase	Increase	139	112
149-151 Old Church Street	1,228,042	268,131	2,628,304	Increase	Increase	381	421

The results above show that extensions will all have a negative carbon impact over a period of time, although the time frame varies greatly depending on the upgrade. Two of the single storey basements require the Intermediate upgrade before any payback is achieved. None of the multi storey basements are carbon negative under the Intermediate package. The Advanced upgrade achieves a payback of between 2 and 7 years for the extensions, between 21 and 395 years for the single storey basements and between 77 and 381 for the multi storey basements. Note that multi storey basements will not recoup the carbon emitted within the 60-year lifecycle used for the embodied and operational timeframe. The PV requirements in line with the payback periods.

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2.2 Sensitivity Analysis of Results
2) Retrofitting and Offsetting Carbon
Carbon Payback

Sensitivity Analysis Key Findings

The findings from the What-if? scenarios can be summarised as follows:

1) What if concrete with a lower carbon impact was to be used in the construction of extensions and basements?

   If 50% GGBS and 20% recycled coarse aggregate was used in the concrete the embodied carbon results over 60 years are likely to be reduced by approximately 19% for single storey basements and by approximately 23.5% for multi storey basements.

   However, even with the use of concrete with recycled content, single storey basements are still likely to be 46% more carbon intense than above ground extensions and multi-storey basements are still likely to be 49% more carbon intense than above ground extensions.

2) To what extent could retrofitting of the existing dwelling offset the carbon generate in new construction?

   Upgrades to the existing dwelling can achieve significant reductions in carbon emissions; up to 45 to 52% for the advanced package. Above ground extensions can achieve a carbon payback in less than 7 years with the Intermediate refurbishment. However, even if multi storey basements were to utilise advanced retrofit measures, the carbon saving would not be enough to compensate for the embodied and construction carbon over 60 years.

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Section 3: Conclusions and Recommendations

Key Findings

Projects which include subterranean extensions in dwellings are generally characterised by a more carbon intense building life cycle.
When considering the building life cycle carbon emissions of projects with subterranean extensions vs. projects with above ground extensions, the present report findings show the following:

Embodied carbon:

- Single storey basements are likely to be 55% more carbon intense than above ground extensions and multi-storey basements are likely to be 61% more carbon intense than above ground extensions.
- Multi storey basements are likely to have carbon intensity for the materials used around 12% higher than single storey basements.
- If more sustainable materials are used for subterranean extensions, the embodied carbon of single storey basements is likely to decrease 19% and 23.5% for multi storey basements. However, even with the use of more sustainable materials (concrete with recycled content), single storey basements are still likely to be 46% more carbon intense than above ground extensions and multi-storey basements are still likely to be 49% more carbon intense than above ground extensions.

Construction Carbon:

- Single storey basements are likely to have 57% more carbon emissions during this stage than above ground extensions.
- Multi storey basements the carbon emissions can be 70% higher than the carbon emissions of construction works for above ground extensions.
- The works to build a multi storey basement are generally longer and ask for more and more heavy machinery, which results in multi storey basements to have carbon emissions 28% higher than single storey basements at this stage.

Operational Carbon:

- Extensions mostly have negative operational carbon emissions i.e. they reduce the carbon emissions of the existing dwelling on a metre square basis. The multi-storey basements have the highest operational carbon emissions, 9% higher than single storey basements.
- Basements that are exclusively in the garden perform worse as they have more heat loss area relative to basements under or attached to the existing dwelling.
- If refurbishments to the existing dwelling were undertaken, the embodied carbon could be recouped by lower operational carbon emissions. However, multi storey basements are not able to be recouped by existing dwelling refurbishments, because of the scale of the associated embodied carbon.

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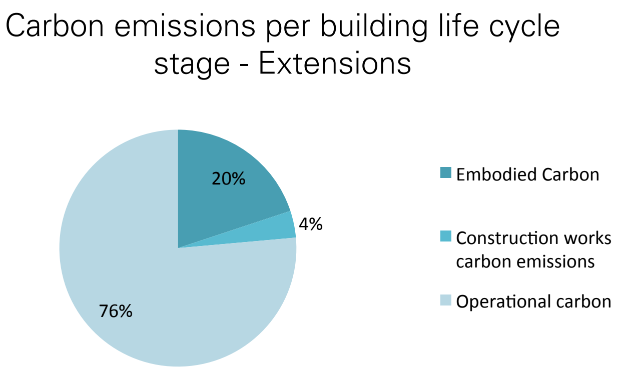
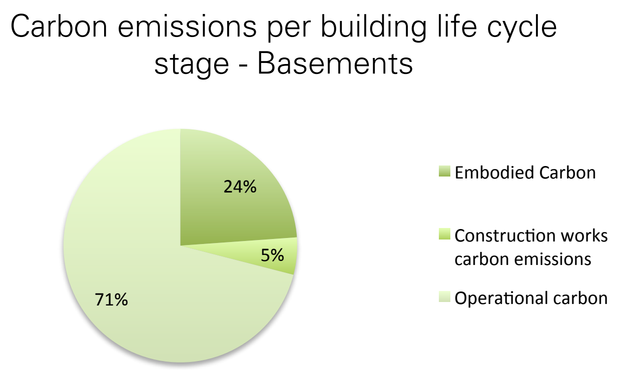
Section 3: Conclusions and Recommendations

Benchmark studies[23,24] show that the embodied carbon impact of a building life cycle is generally around 15 - 20% of the total carbon footprint of the building.

The results of this report show that, for extensions, the sum of the embodied carbon of materials and the carbon emissions of the construction works are approximately 24% of the building's life cycle. For basements these figures increase to 29%. When comparing these results with the benchmark[23,24] it is possible to conclude that the results follow the trend and the higher contribution of the embodied carbon in the results can be attributed to the end of life of materials and associated operations is included in the carbon factors used, while for other stages was excluded.





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Appendix 1
Methodological Considerations and Assumptions: Embodied carbon

Key Considerations

The calculations for the embodied carbon of the case studies analysed were based on the following equation:

$$\mathit{Area\ of\ building\ element}\ (m^2) \times \mathit{Carbon\ factor\ from\ BRE\ environmental\ profiles}\left(kg\ of\ \frac{CO_2}{kg}\right)$$

The BRE environmental profiles are ISO14025:2006 compliant[24,44,45,3] and are based on CEN/TC 350 standards. The Environmental Profiles database (Green Guide) includes information on all stages of the life cycle, for a 60 year period, including disposal.

The following functional units were considered for each building element[44,45]:

Pitched and flat roofs, basements roofs, basement walls and basement floors: 1m² area (measured horizontally), to satisfy England & Wales Building Regulations, particularly a U value of 0.16 W/m²K (pitched) or 0.25 W/m²K (flat). Span of 8m to include a plasterboard ceiling and emulsion paint finish.

Upper floors: 1m² of upper floor construction, to satisfy England & Wales Building Regulations, based on a 4m span between loadbearing walls, a live loading of 1.5 kN/m² and a surface ready for the addition of a sheet carpet and underlay. Upper floors also include a painted plasterboard ceiling.

Windows: Double glazed window based on the BFRC domestic window model, to satisfy Building Regulations and a U value of 1.8 W/m2K.

Ground floors: 1m² ground floor based on a dwelling with a ground floor area of 40m² and exposed perimeter of 18m to satisfy England & Wales Building Regulations and a U value of 0.22 W/m²K. To include any repair, refurbishment or replacement over the 60-year study period.

External walls: 1m² of external wall construction, to satisfy current Building Regulations, and a U value of 0.3 W/m²K. Where relevant, the specification will also include an internal wall finish.

Methodological note: The BRE Green Guide presents several methodological restrictions for its use, particularly if there is a need of case specific build-ups to calculate the effective embodied carbon of a building. However, as the report's main goal is the comparison between different case studies it was considered that this was the best and more standardised tool available for this purpose.

The embodied carbon for materials excluded the materials for finishes and decorations, building services and external works. Only the quantities for the forming of structural and thermal envelope were included. This is because these materials can vary significantly between case study; consequently the clarity of study would be undermined.

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Appendix 1
Methodological Considerations and Assumptions: Embodied carbon

Key Considerations

The following table shows the BRE profiles used in this study.

BRE profile	Green Guide code	Kg CO2/kg
Basements external wall, floor and ground floor - In situ reinforced concrete slab, vapour control layer, insulation, Polyester cold applied liquid waterproofing membrane system.	1212540075	240
External wall extensions build up - Brickwork, blockwork outer leaf, insulation, aircrete blockwork inner leaf, cement mortar, plasterboard on battens, paint	806170615	74
Pitched roof - Timber trussed rafters and joists with insulation, roofing underlay, counterbattens, battens and UK produced slates	812410026	49
Flat roof - Timber joists, plywood (temperate EN636-2) decking, vapour control layer, insulation, Polyurethane cold applied liquid water proofing membrane system	1212540069	58
Windows timber - Durable hardwood window, double glazed, solvent borne gloss paint (non-TWAS)	813100013	220
Aluminium windows - Powder coated aluminium window (profile < 1.08 kg/m) double glazed	1213100004	250
Basement steel rooflights - Powder coated galvanised hot rolled steel window, double glazed	813100011	310
Flat asphalt roof - Timber joists, plywood (temperate EN 636-2) decking, vapour control layer, insulation, felt isolating layer, mastic asphalt roof	1212540031	47
Upper floor concrete - Screeded in situ 30% PFA concrete (20% RCA) slab	807280063	96
Upper floor timber - T&G floorboards on timber joists	807280023	- 8.2
Ground floors- Screeded in situ 30% PFA concrete slab, over insulation on polyethylene dpm laid on blinded virgin aggregate sub-base	820100040	79
Lead roofs - timber joists, plywood(temperate EN636-2) decking, vapour control layer, insulation, plywood(temperate EN636-2), building paper, Code 5 100% recycled lead sheet	1212540083	17
Concrete additional layer - in situ concrete, reinforced	79889450	118.12
Metal decking floor - Power floated in situ reinforced concrete slab on "shallow" profiled metal decking	807280074	61

Assumptions:

- All the areas used for the modelling of the embodied carbon are based on the planning application drawings.
- Multi storey basements typically show an additional layer of concrete between 450 to 600 mm, if they have a depth of +/- 5.5 meters. To account for this additional thickness, an additional concrete layer, using a calculated ratio (based on the above 79889450 build up embodied carbon) of carbon per mm was multiplied by the thickness of the concrete layer.
- For the zinc roofs in the case studies, in the absence of an identical profile, a lead roof profile was used for calculations.
- For more information about the BRE profiles methodology please consult the following link: http://www.bre.co.uk/greenguide/page.jsp?id=2106

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Appendix 1

Methodological Considerations and Assumptions: Construction works carbon emissions

Key Considerations

The calculations of the carbon emissions for construction works of each case study were based on the following planning documents, when they were available:

- **Construction Method Statements (CMS):** Used to define the different phases of the construction works;
- **Traffic Management Plans (TMP):** Used to define the frequencies of vehicle movements for each project and the amount of spoil to be removed as well as the timeframe for each phase of the construction process.

Only a few case studies had the above documents available for consultation. Based on this, several assumptions had to be made to calculate the potential carbon emissions of the construction works of each project. For each stage of the construction phase the machinery needed to complete that stage was assumed.

The following assumptions were made for the calculations:

- The timeframes for each project, especially for the excavation phase, were based on the volume of each basement and a bulk factor of 35% was added to that volume[17].
- It was considered that any demolition waste and spoil removal would go directly to landfill - It is likely that spoil can be reused as well as the waste from demolition, however, in the absence of evidence this was not considered;
- References 11,14,15, and 16 have the fuel consumption of the excavators and trucks used for the calculations.
- The machinery used for calculations was based on the project volumes and type of works needed.
- The rate of spoil removal by conveyor was based on the report from Baxter's (2014)17: 4 m^3 was considered for projects with a spoil removal of less than 350 m^3 and 6 m^3 for projects of more than 350 m^3. Higher amounts of spoil removal per conveyor were not considered due to restrictions in the weight of the lorries needed to remove higher amounts of spoil.
- The electricity factor (kWh) considered was based on the benchmark of previous case studies from Eight Associates projects – 4,33 kWh. This factor is likely to be lower for extensions, due to the low intensity nature of the works involved. However, in the absence of better available data this factor was applied to all case studies.
- When data was not available in the planning documents the assumptions were made based on the volumes and areas of projects and the reference values used for the calculations were the based on similar projects where there was data available (CMS and TMP).
- In the absence of project specific data, similar assumptions were made for small extensions (around 10 m^2) - 42 days of project
- In the absence of project specific data, similar assumptions were made for large extensions (around 30 m^2) - 93 days of project

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Appendix 1 Methodological Considerations and Assumptions: Construction works carbon emissions

Key Considerations

The following equations were used for the calculations:

$$Hours\ of\ use \times Carbon\ factor\ from\ Defra(kg\ of\ CO_{2\ eq})$$

The following carbon factors were used:

Element	DEFRA Carbon factor[49]
Lorries for waste removal empty	0.67 kg of CO_2eq/km
Lorries for waste removal full	0.78 kg of CO_2eq/km
Machinery (diesel motor)	2.57 kg of CO_2eq/litre
Electricity consumed	0.58 kg of CO_2eq/kWh

Methodological note: The assumptions made in this section were always based on benchmarks from previous studies, mainly Baxter's reports[17,18,19], submitted for RBKC. If data was available, the timeframes from the Traffic Management Plans and the projects areas and volumes were used.

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Appendix 1 Methodological Considerations and Assumptions: Operational Carbon

Key Considerations

The operational component of the case studies was modelled using SAP software. The existing dwellings and proposed works were modelled based on the plans available from RBKC's Planning Portal. Any new thermal elements were assumed to be fully complaint with Part L of the 2010 Building Regulations. U-values for new external walls in the basement were aligned with the BRE Green Guide so that the operational benefit of the build-up was realised. Any new services were assumed to be fully compliant with the Domestic Building Services Compliance Guide[9].

The net carbon increase was calculated in the following way:

Proposed scheme – Existing scheme = net increase in operational carbon

Where u-value or services details were not known inputs were taken from RdSAP. With the exception of the external wall u-value which was modelled as 1.7 W/m^{2}K to account for the increased wall thickness of dwellings of this nature. The existing dwelling was modelled with a minimum 2010 Building Regulations compliant gas boiler upgrade and hot water cylinder[9,10]. The proposed dwelling was modelled with exactly the same system; this allowed the impact of the works to be assessed independently without being distorted by a non-compliant heat and hot water system that would typically exist in an existing dwelling.

Where new wet rooms were included in the extension works, exhaust fans were added for Compliance with Part F of the Building Regulations. Where basements formed part of the works mechanical ventilation was incorporated, the specification was in compliance with the minimum requirements of the Domestic Building Services Compliance Guide.

The upgrade packages in the sensitivity analysis were all modelled to be in compliance with Part L1B 2010 Building Regulations. The upgrades did not make any exceptions for conservation issues.

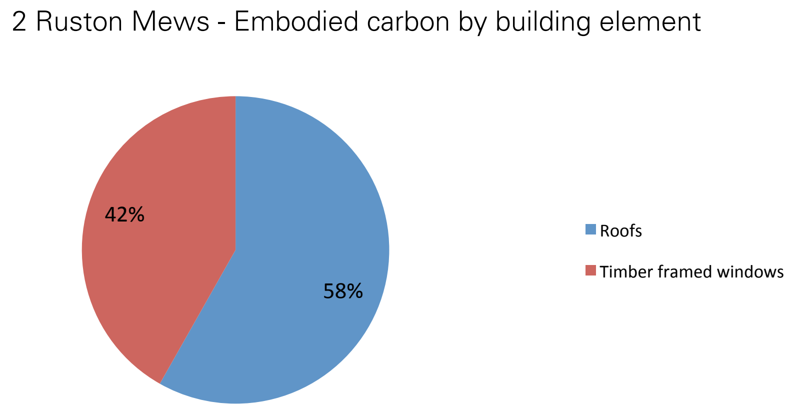
Exclusions: Pumps/sumps for basement drainage and services for swimming pools.

All carbon figures for the operational phase were converted into carbon dioxide equivalent figures; CO_2 eq.

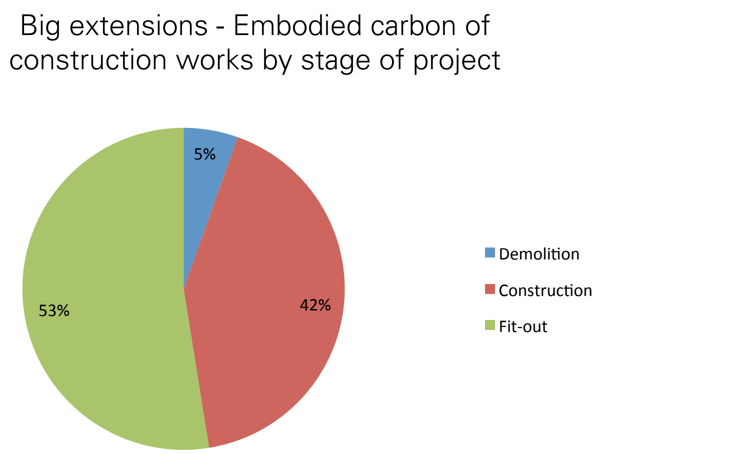
Appendix 2
Case Studies
2 Ruston Mews

Address:	2 Ruston Mews, London, W11 1RB.
Development:	Erection of new mansard roof extension to main building with two dormer windows to front and rear.
Total Area pre-development:	107.10 m^2
Total Area post-development:	147.10 m^2
Net increase in floor area:	40 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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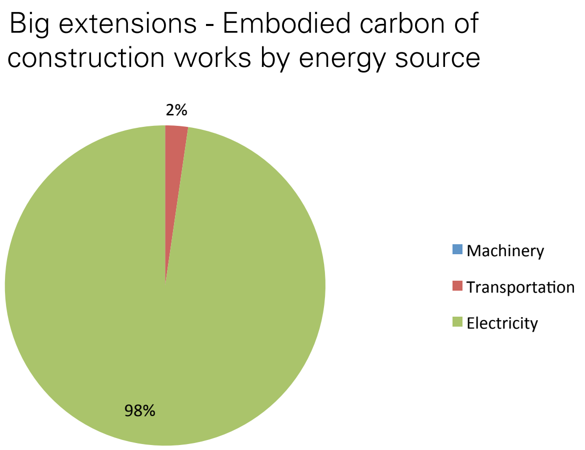
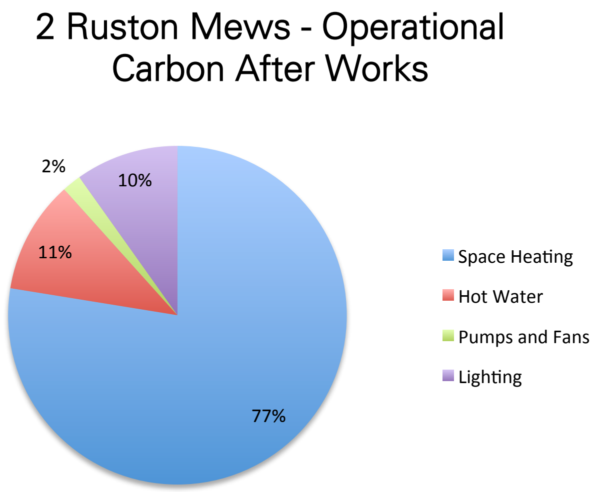
Appendix 2
Case Studies
2 Ruston Mews

Embodied Carbon per energy source



Operational carbon



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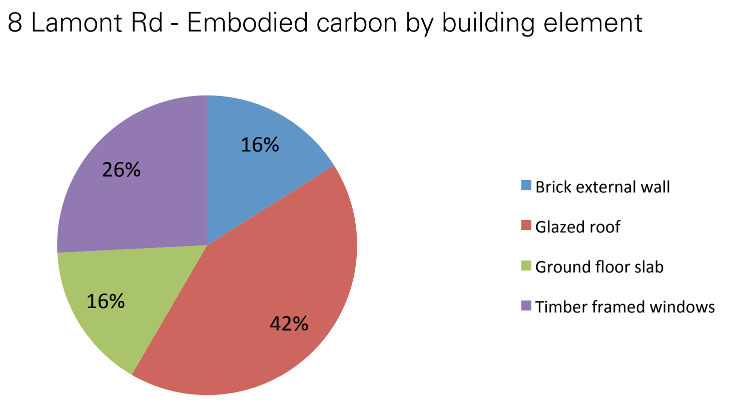
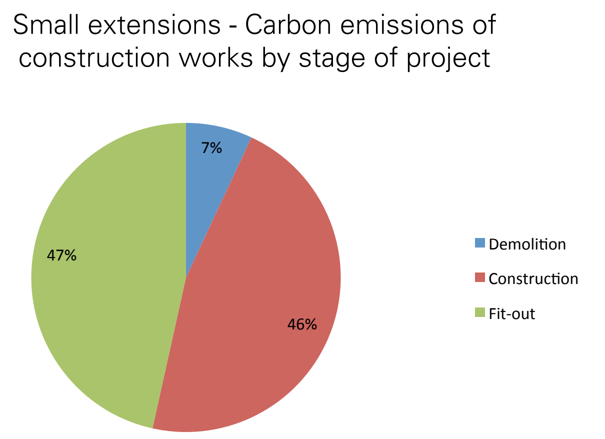
Appendix 2
Case Studies
8 Lamont Road

Address:	8 Lamont Road, London, SW10 0HL.
Development:	Erection of lower ground floor rear extension.
Total Area pre-development:	167 m^2
Total Area post-development:	175.54 m^2
Net increase in floor area:	8.54 m^2

Embodied carbon per building element



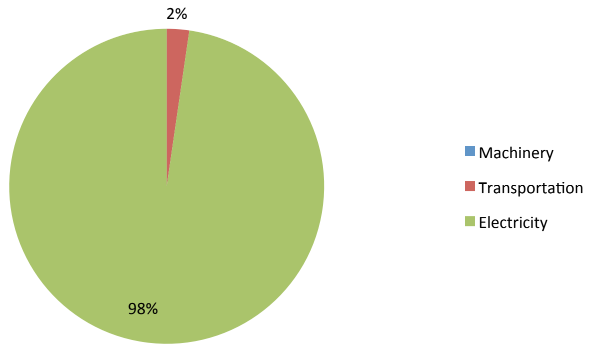
Embodied Carbon per stage of project



Appendix 2
Case Studies
8 Lamont Road

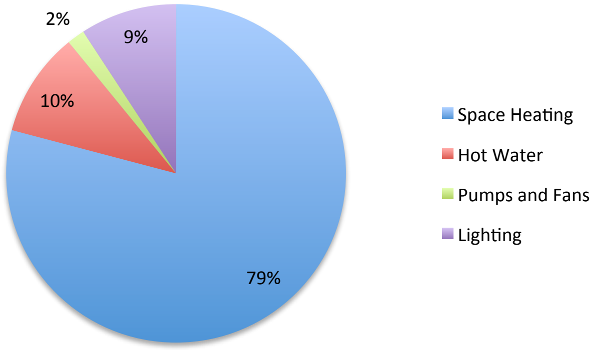
Embodied Carbon per energy source

Small extensions - Embodied carbon of construction works by energy source



Operational carbon

8 Lamont Road - Operational Carbon After Works



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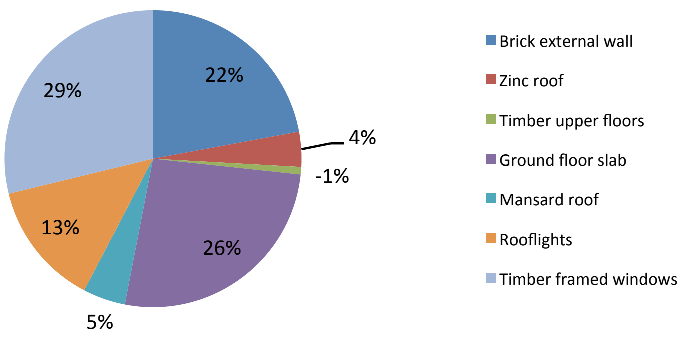
Appendix 2
Case Studies
36 Markham Square

Address:	36 Markham Square, London, SW3 4XA.
Development:	Demolition and replacement of rear extensions and top storey.
Total Area pre-development:	197.80 m^2
Total Area post-development:	234.20 m^2
Net increase in floor area:	36.40 m^2

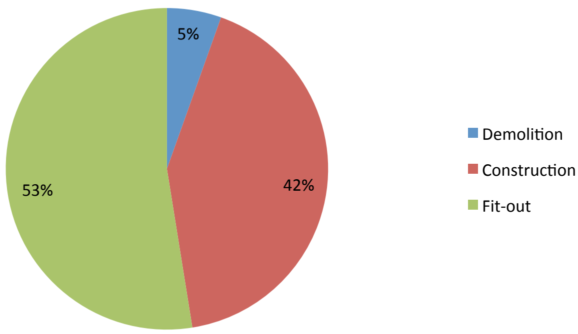
Embodied carbon per building element

36 Markham Sq - Embodied carbon by building element



Embodied Carbon per stage of project

Big extensions - Embodied carbon of construction works by stage of project



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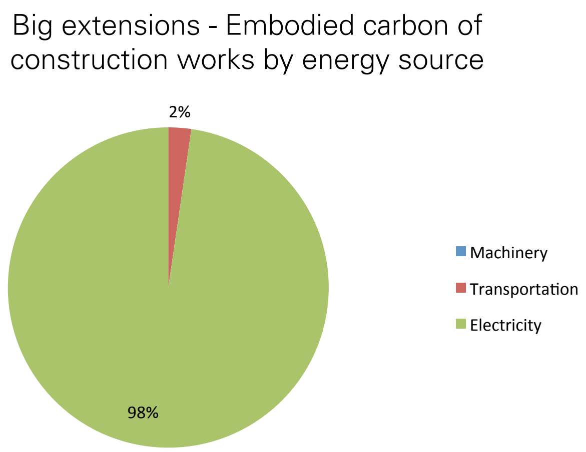
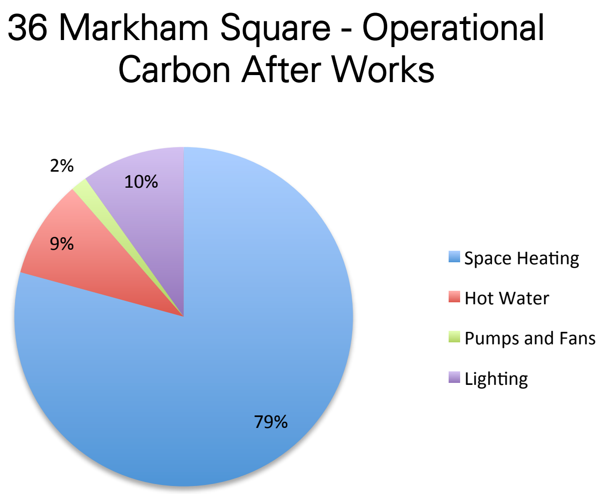
Appendix 2
Case Studies
36 Markham Square

Embodied Carbon per energy source



Operational carbon



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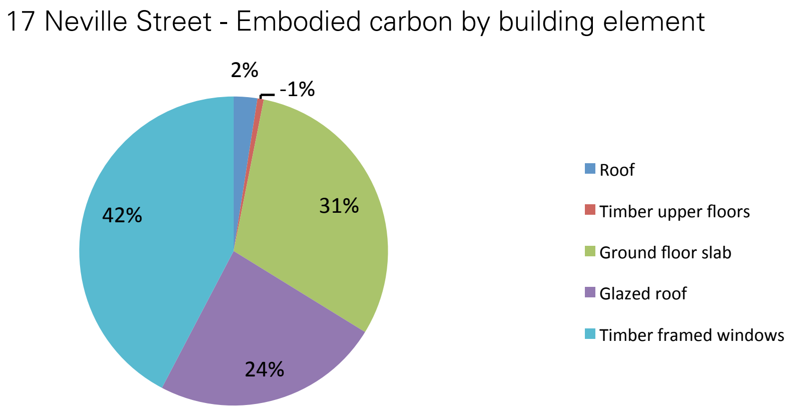
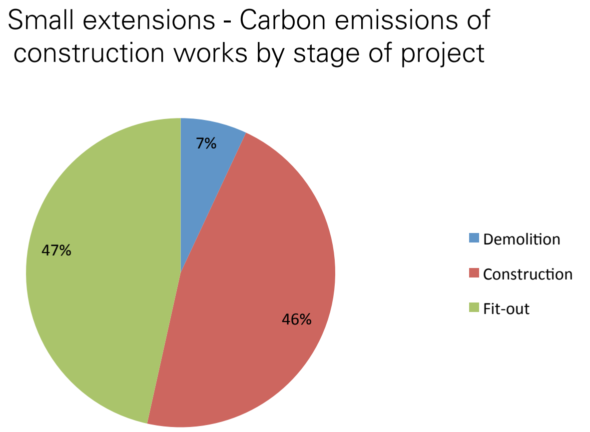
Appendix 2
Case Studies
17 Neville Street

Address:	17 Neville Street, London, SW7 3AS.
Development:	Erection of a two storey rear extension at lower ground and ground floor levels and internal alterations throughout
Total Area pre-development:	261.70 m^2
Total Area post-development:	277.20 m^2
Net increase in floor area:	15.50 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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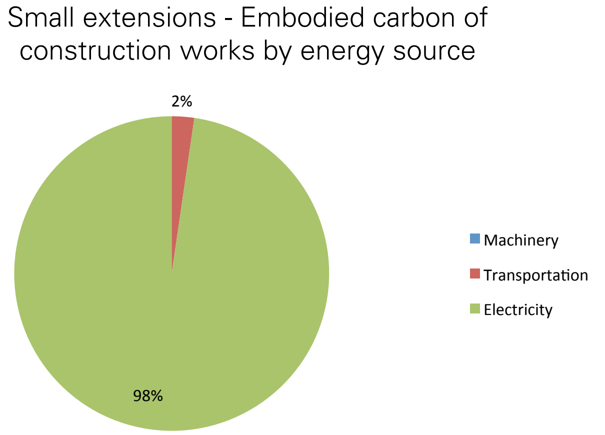
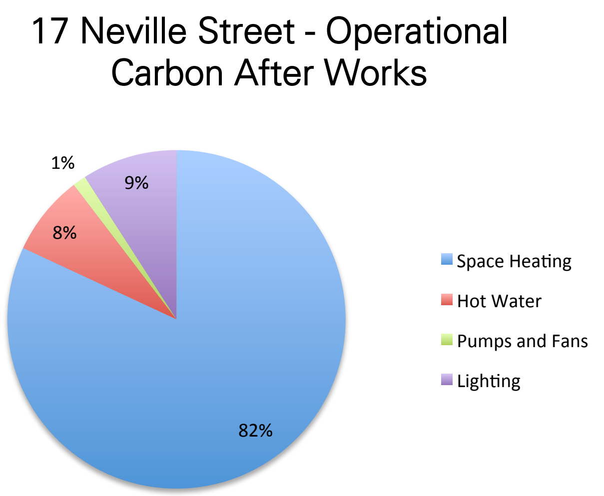
Appendix 2
Case Studies
17 Neville Street

Embodied Carbon per energy source



Operational carbon



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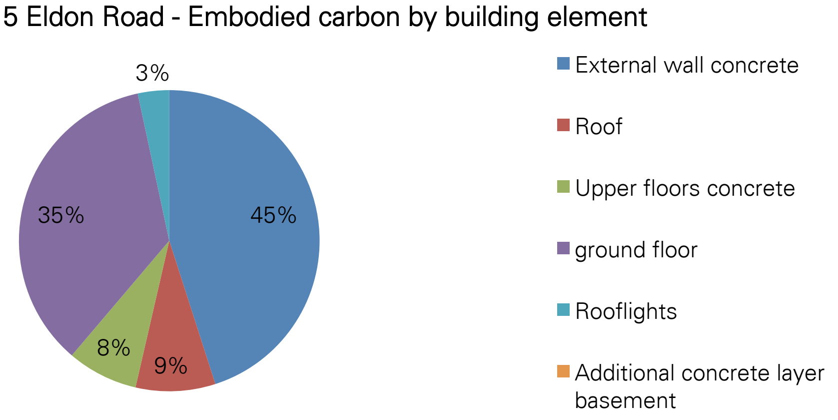
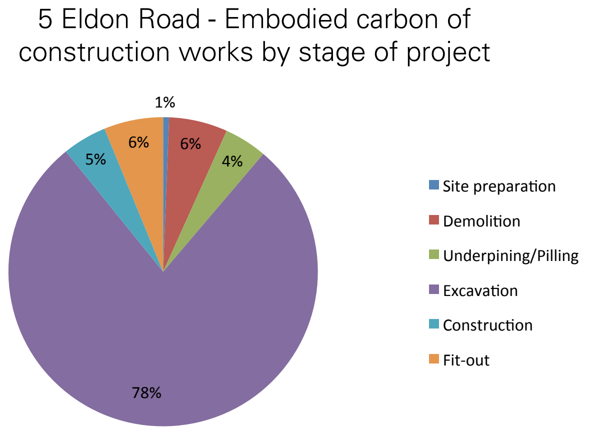
Appendix 2
Case Studies
5 Eldon Road

Address:	5 Eldon Road, London, W8 5PU.
Development:	Creation of basement extension to footprint of dwelling, front and rear garden. Installation of skylights to front and rear of property.
Total Area pre-development:	276.30 m^2
Total Area post-development:	358.40 m^2
Net increase in floor area:	82.10 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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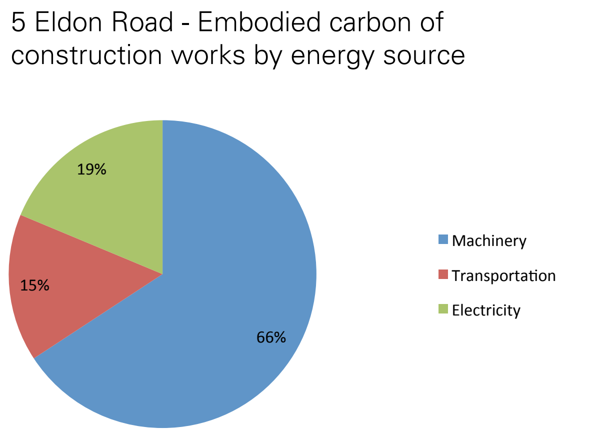
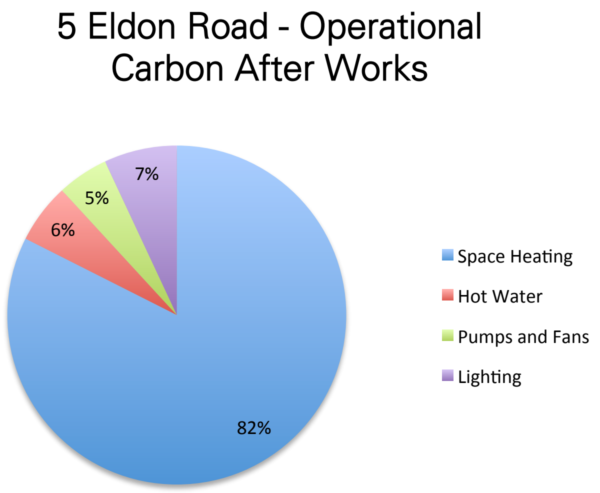
Appendix 2
Case Studies
5 Eldon Road

Embodied Carbon per energy source



Operational carbon



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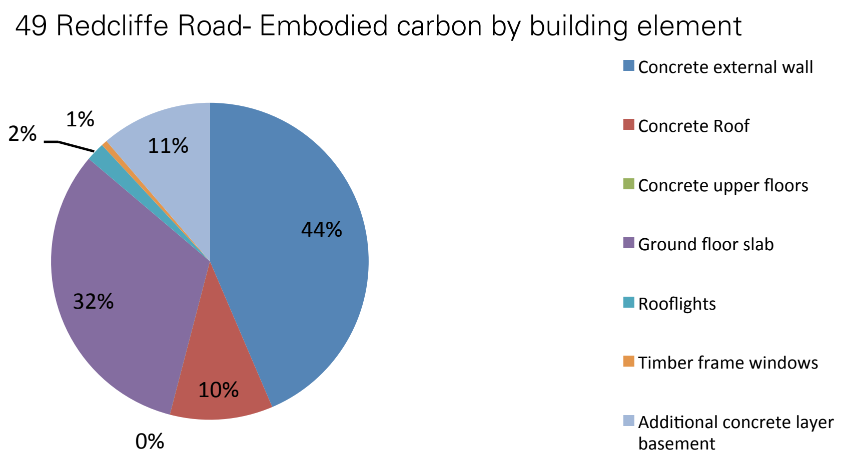
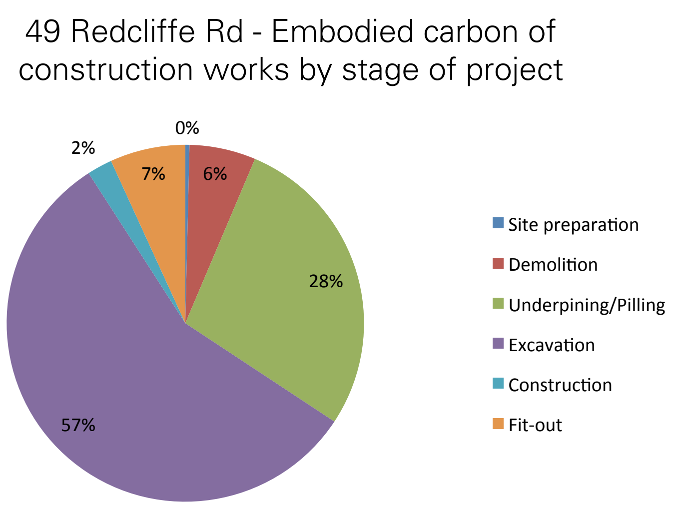
Appendix 2
Case Studies
49 Redcliffe Road

Address:	49 Redcliffe Road, London, SW10 9NJ.
Development:	Single storey basement partially under the garden
Total Area pre-development:	312.40 m^2
Total Area post-development:	428.50 m^2
Net increase in floor area:	116.10 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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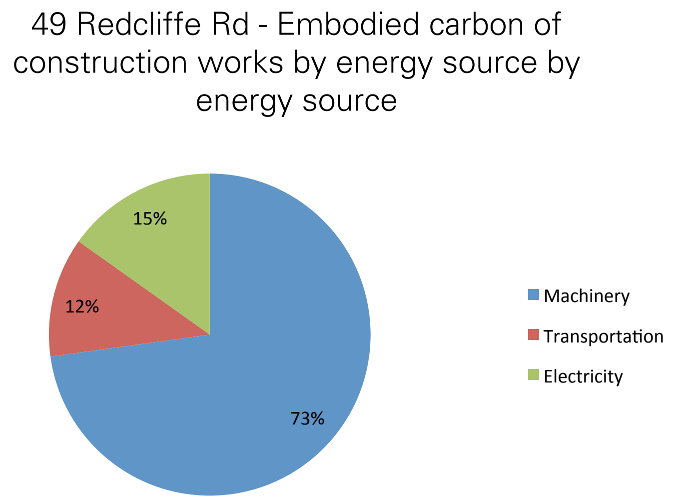
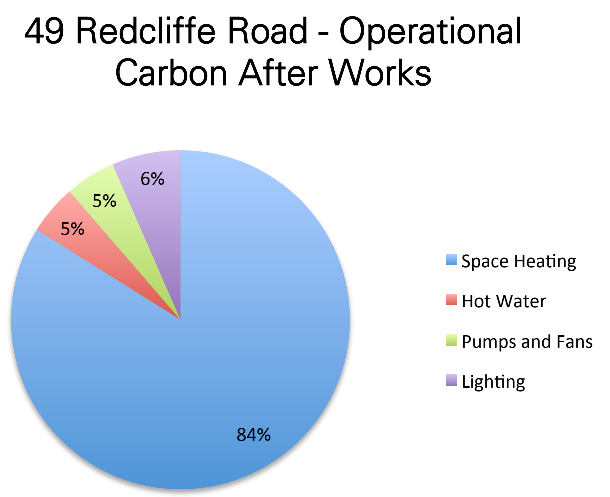
Appendix 2
Case Studies
49 Redcliffe Road

Embodied Carbon per energy source



Operational carbon



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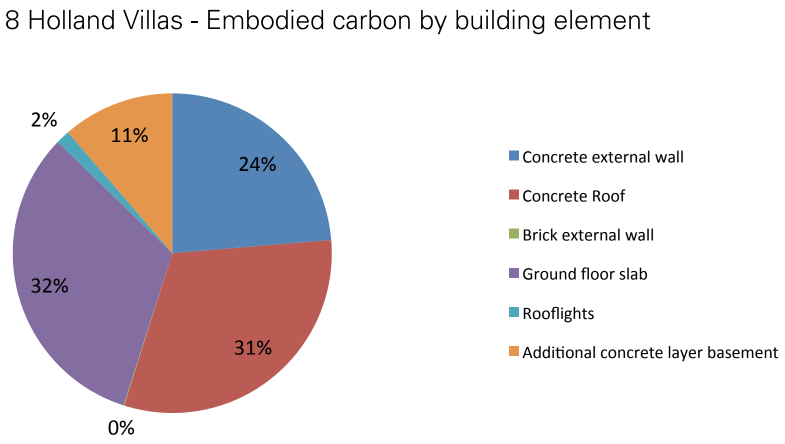
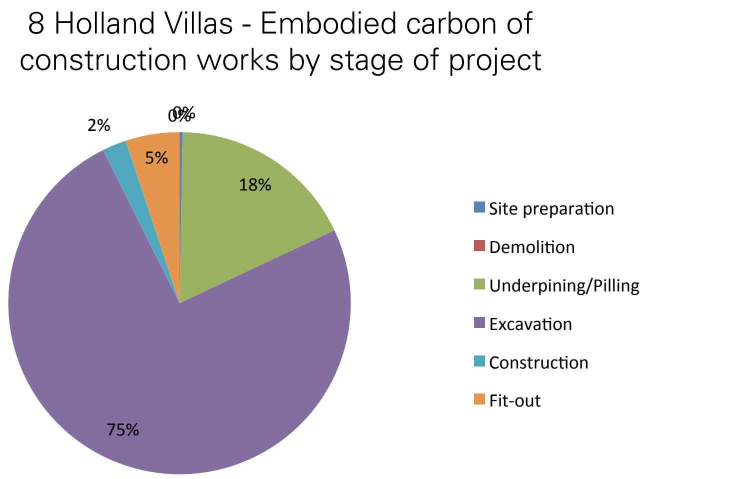
Appendix 2
Case Studies
8 Holland Villas Road

Address:	8 Holland Villas Road, London, W14 8BP.
Development:	Excavation and construction of subterranean extension under rear garden with associated roof lights and new and replacement windows to main property.
Total Area pre-development:	760.50 m^2
Total Area post-development:	1034.00 m^2
Net increase in floor area:	275 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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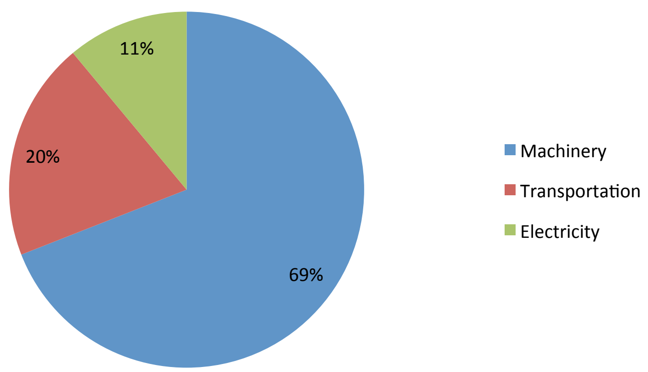
Appendix 2
Case Studies
8 Holland Villas Road

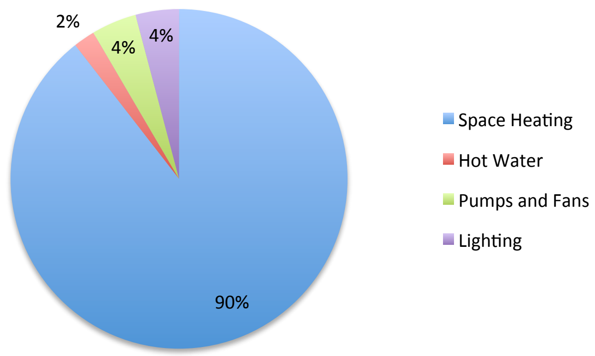
Embodied Carbon per energy source

8 Holland Villas - Embodied carbon of construction works by energy source



Operational carbon

8 Holland Villas - Operational Carbon After Works



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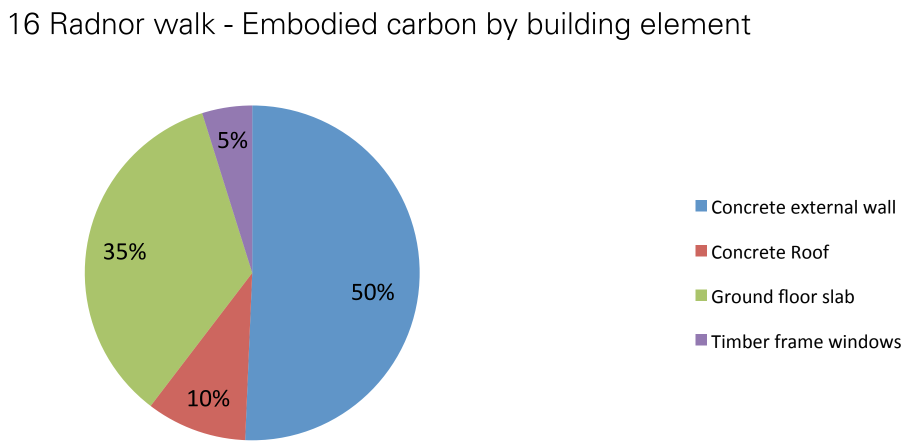
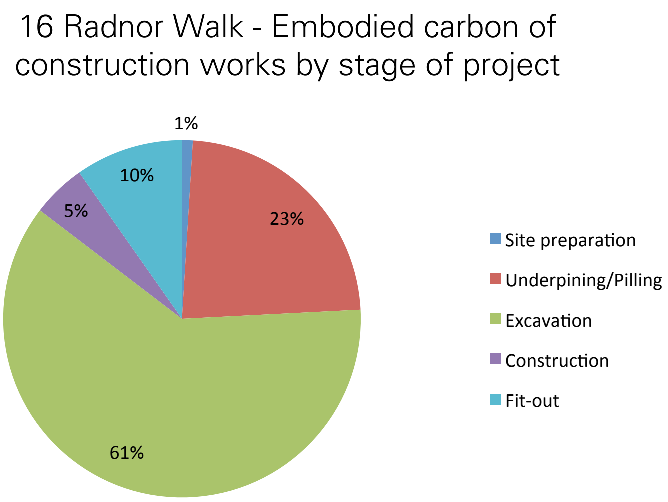
Appendix 2
Case Studies
16 Radnor Walk

Address:	16 Radnor Walk, London, SW3 4BN.
Development:	Construction of basement and rear lightwell.
Total Area pre-development:	116.50 m^2
Total Area post-development:	178.70 m^2
Net increase in floor area:	62.3 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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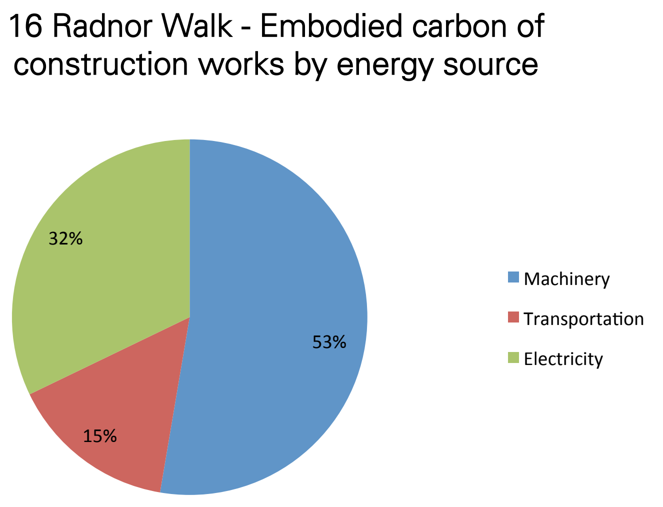
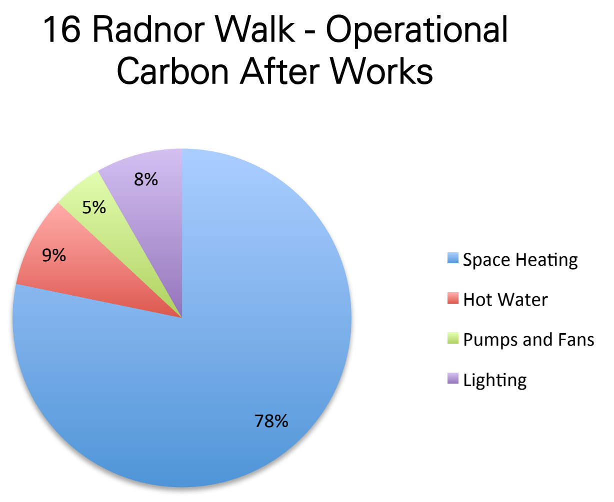
Appendix 2
Case Studies
16 Radnor Walk

Embodied Carbon per energy source



Operational carbon



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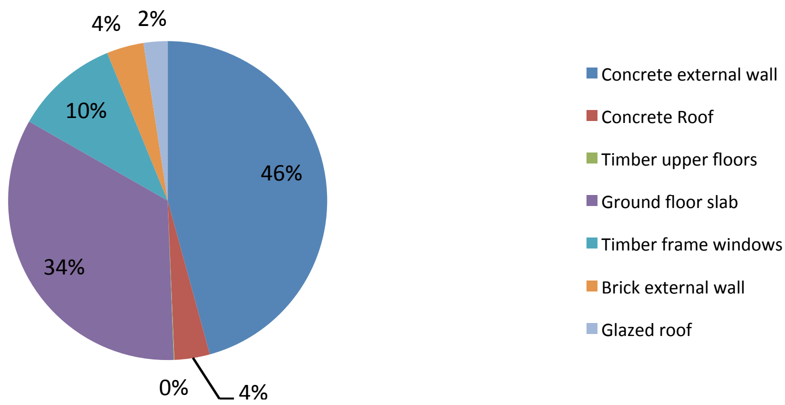
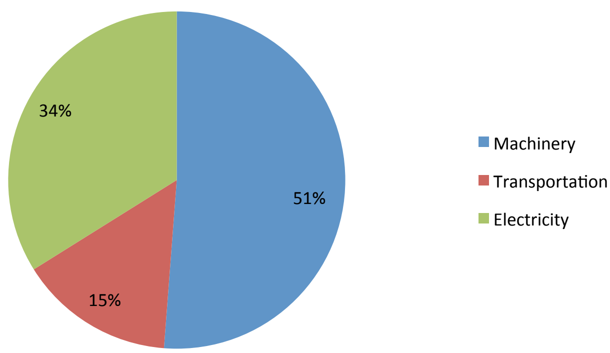
Appendix 2
Case Studies
37 Jubilee Place

Address:	37 Jubilee Place, London. SW3 3TD.
Development:	Creation of basement and lightwell including amendments to front door design and the erection of a side extension at ground floor with associated external alterations.
Total Area pre-development:	173.40 m^2
Total Area post-development:	246.00 m^2
Net increase in floor area:	72 m^2
Embodied Carbon per stage of project	

37 Jubilee Place - Embodied carbon by building element



37 Jubilee Place - Embodied carbon of construction works by energy source



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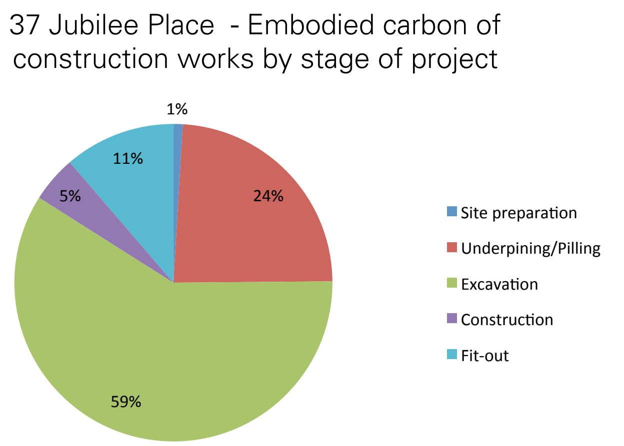
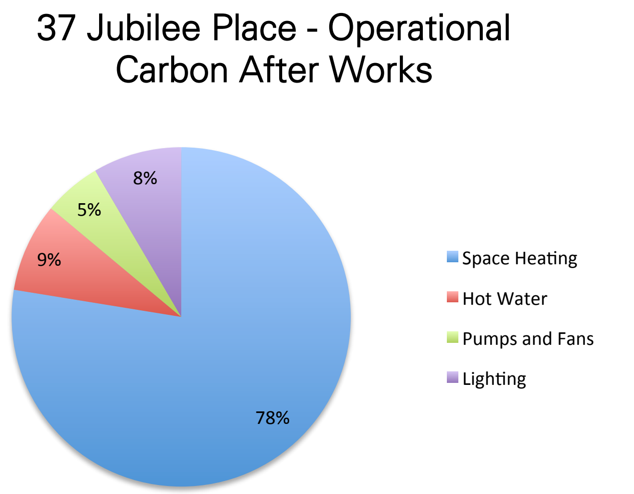
Appendix 2
Case Studies
37 Jubilee Place

Embodied Carbon per energy source



Operational carbon



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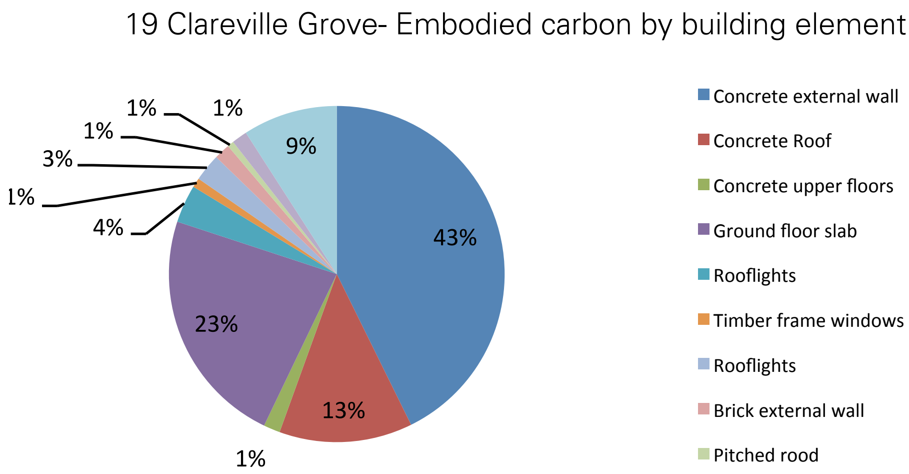
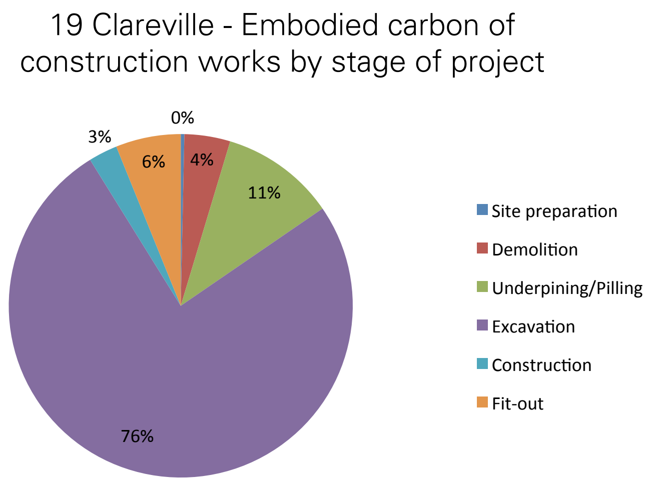
Appendix 2
Case Studies
19 Clareville Grove

Address:	19 Clareville Grove, London, SW7 5AU.
Development:	Excavation of a single storey sub-basement, formation of lightwells and associated works.
Total Area pre-development:	180.30 m^2
Total Area post-development:	364.50 m^2
Net increase in floor area:	185 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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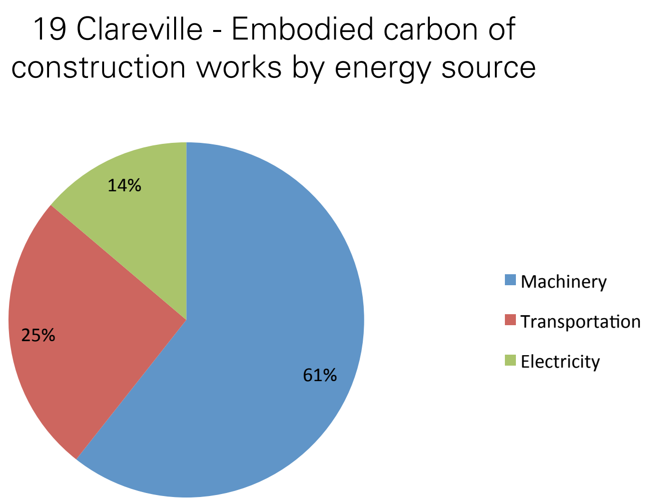
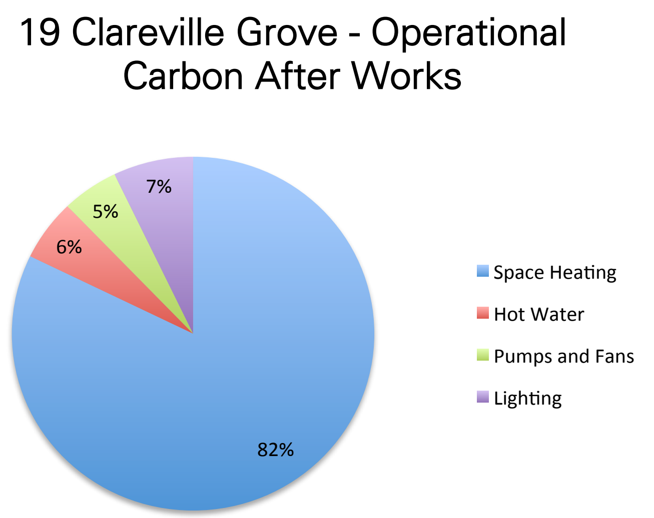
Appendix 2
Case Studies
19 Clareville Grove

Embodied Carbon per energy source



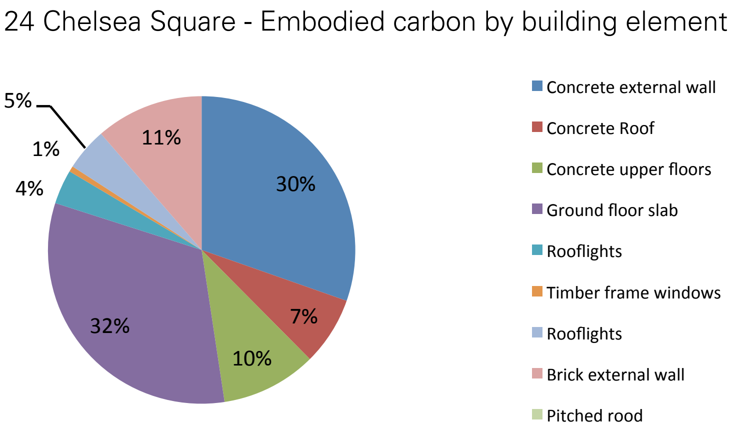
Operational carbon



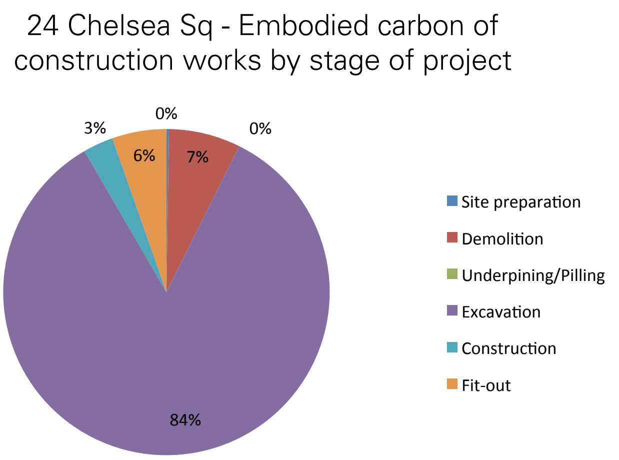
Appendix 2
Case Studies
24 Chelsea Square

Address:	24 Chelsea Square, London, SW3 6LF.
Development:	Development of extension to basement, with a light well window to the rear, alteration to the rear roof dormer window, replacement and additional roof lights at ground floor, altered fenestration to courtyard and alterations to rear garage elevation.
Total Area pre-development:	327.00 m^2
Total Area post-development:	549.70 m^2
Net increase in floor area:	222.70 m^2

Embodied carbon per building element

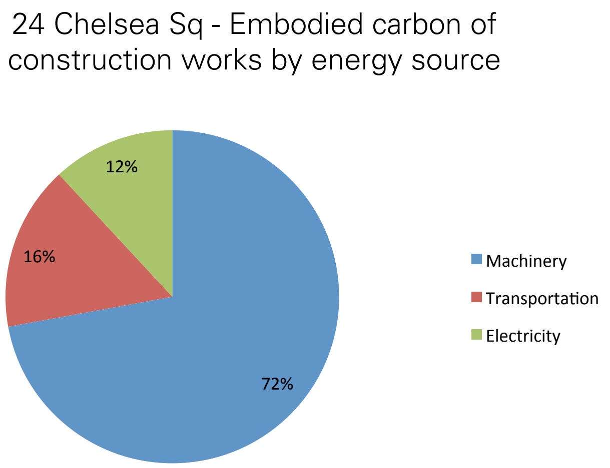


Embodied Carbon per stage of project

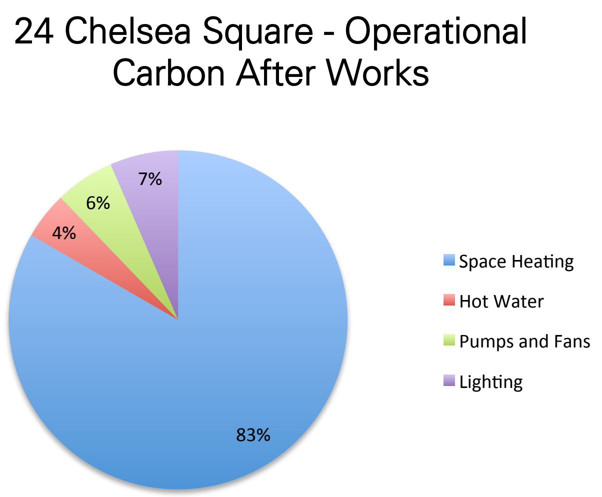


Appendix 2
Case Studies
24 Chelsea Square

Embodied Carbon per energy source



Operational carbon



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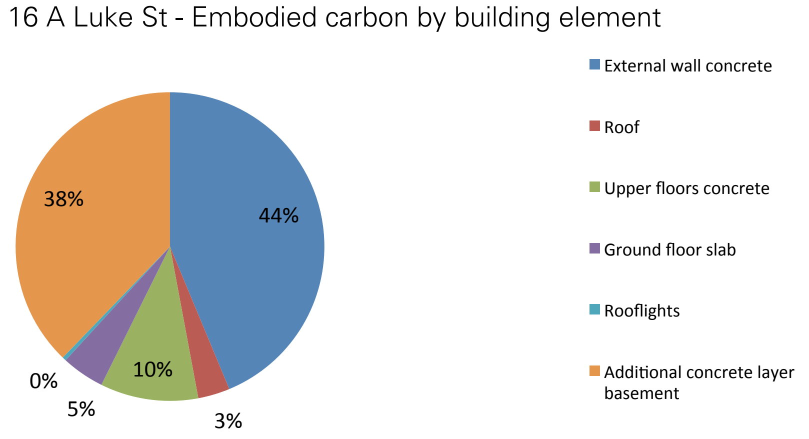
Appendix 2
Case Studies
16A St Luke's Street

Address:	16A St Luke's Street, London, SW3 3RS.
Development:	Excavation of two storey basement.
Total Area pre-development:	127.64 m^2
Total Area post-development:	298.64 m^2
Net increase in floor area:	171.00 m^2

Embodied carbon per building element



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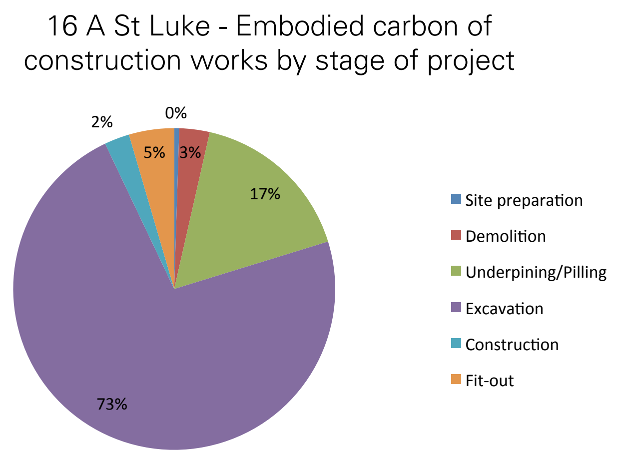

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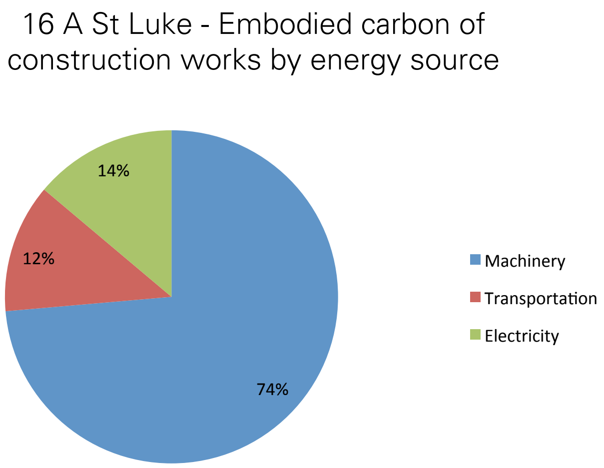
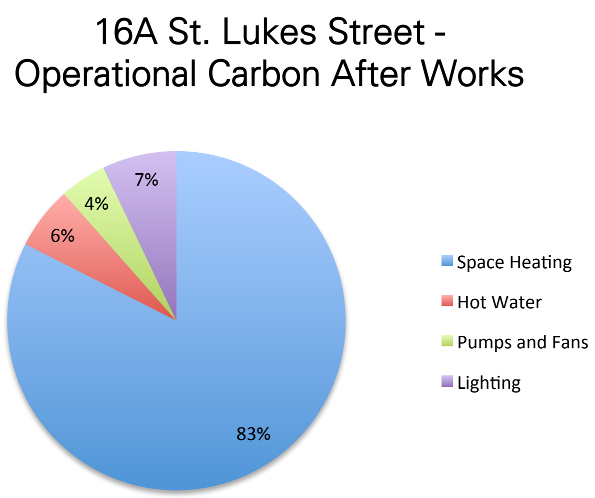
Appendix 2
Case Studies
16A St Luke's Street

Embodied Carbon per energy source



Operational carbon



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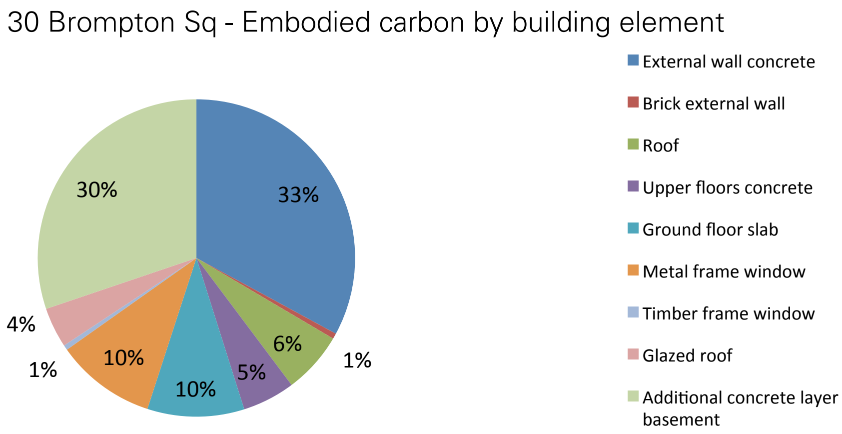
Appendix 2
Case Studies
30 Brompton Square

Address:	30 Brompton Square, London, SW3 2AE.
Development:	Redevelopment of lower ground floor in garden, excavation of three basement levels, replacement of glass pavilion, extension of windows at ground floor level and internal alterations.
Total Area pre-development:	519.80 m^2
Total Area post-development:	807.00 m^2
Net increase in floor area:	287.20 m^2

Embodied carbon per building element



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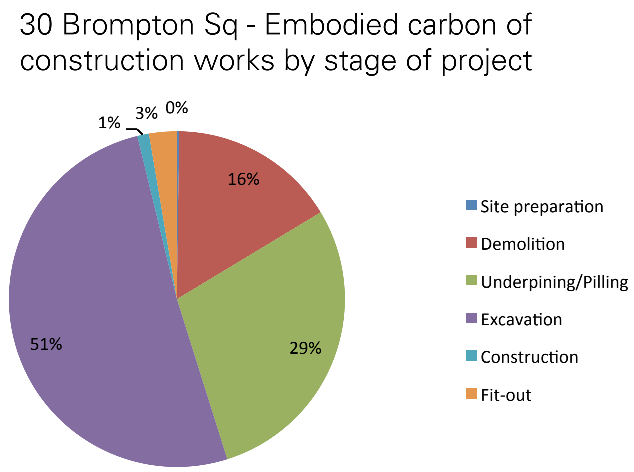

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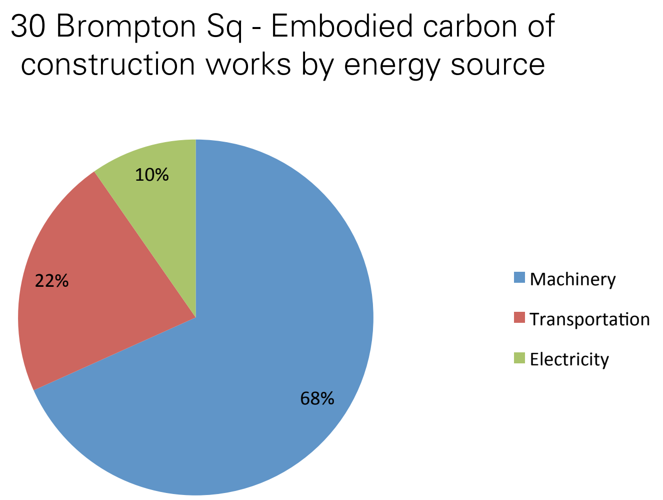
Appendix 2
Case Studies
30 Brompton Square

Embodied Carbon per energy source



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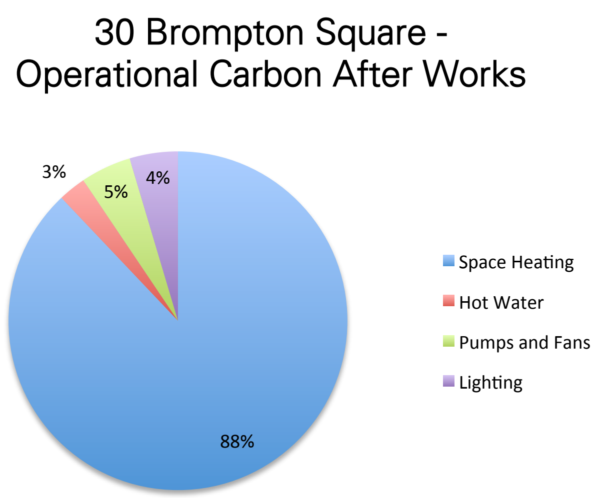

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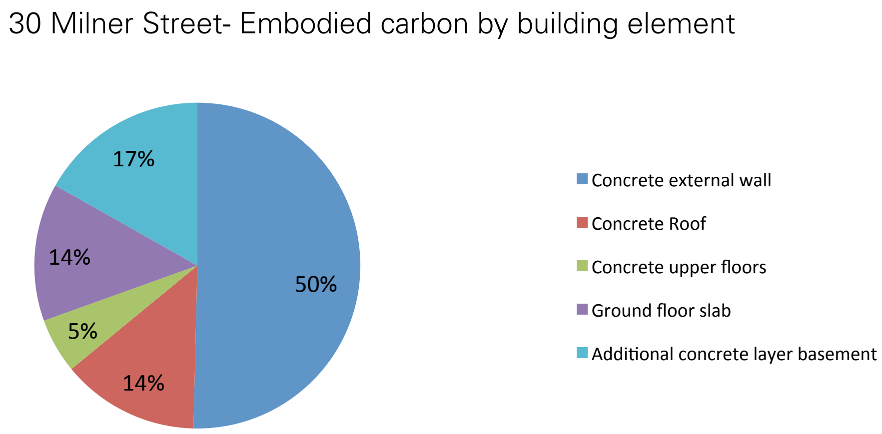
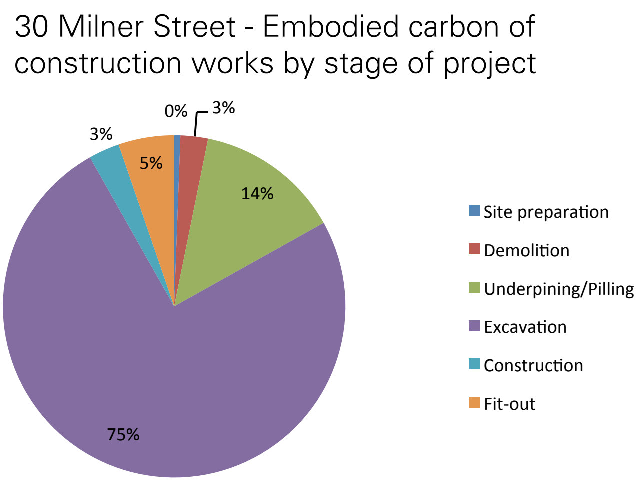
Appendix 2
Case Studies
30 Milner Street

Address:	30 Milner Street, London, SW3 2QF.
Development:	Excavation of two storey basement extension.
Total Area pre-development:	244.20 m^2
Total Area post-development:	396.48 m^2
Net increase in floor area:	152.28 m^2

Embodied carbon per building element

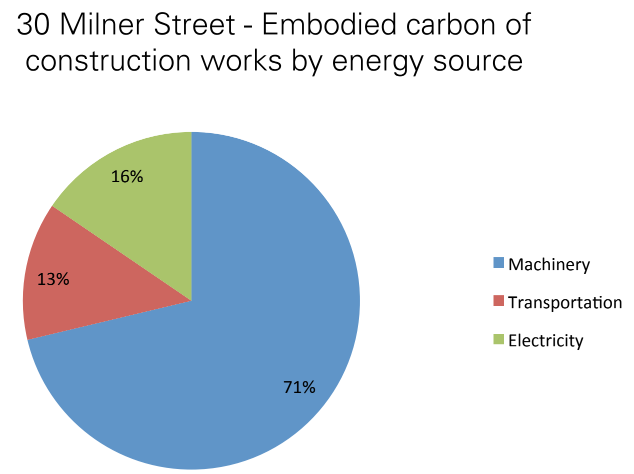


Embodied Carbon per stage of project

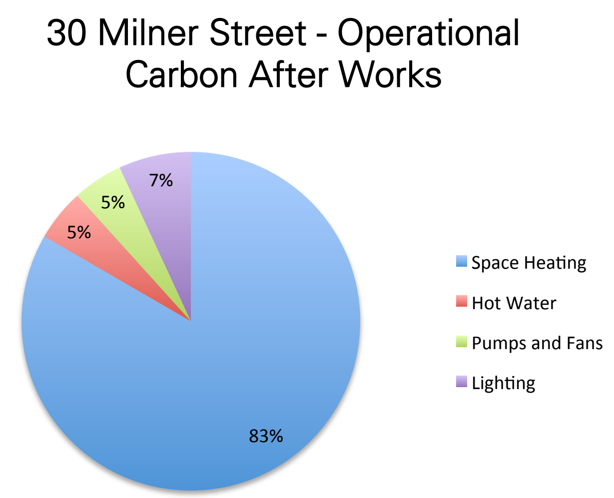


Appendix 2
Case Studies
30 Milner Street

Embodied Carbon per energy source



Operational carbon



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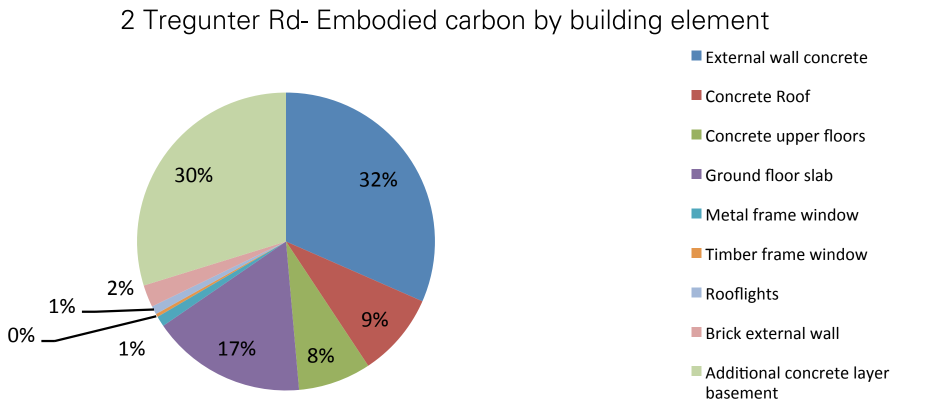
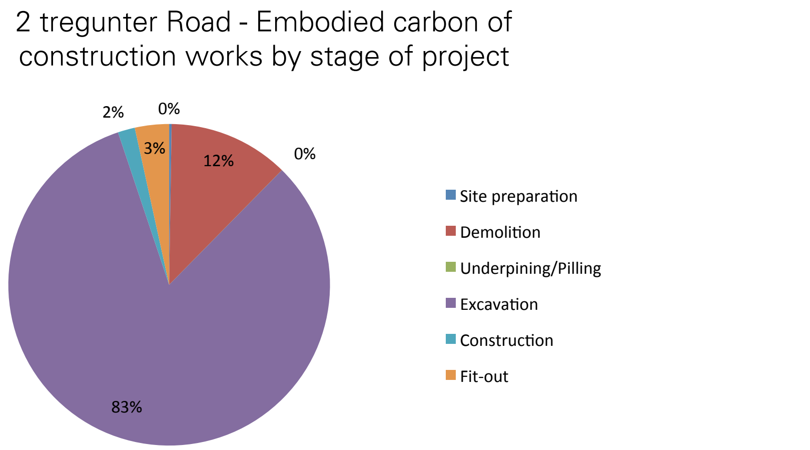
Appendix 2
Case Studies
2 Tregunter Road

Address:	2 Tregunter Road, London. SW10 9LR.
Development:	Construction of two basement levels, installation of lightwell in front of front elevation, rooflight along rear elevation, 2no rooflights along side elevation and terrace and patio area to rear.
Total Area pre-development:	424.00 m^2
Total Area post-development:	889.90 m^2
Net increase in floor area:	465.90 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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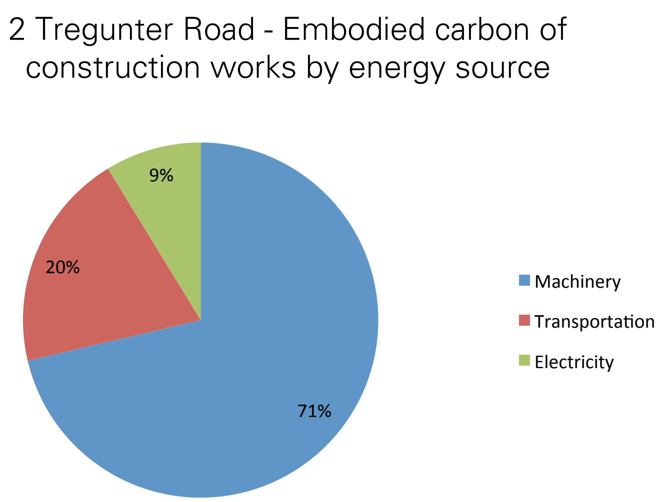
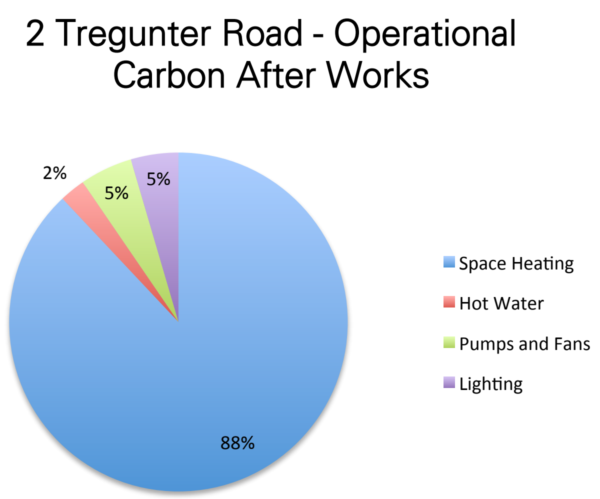
Appendix 2
Case Studies
2 Tregunter Road

Embodied Carbon per energy source



Operational carbon



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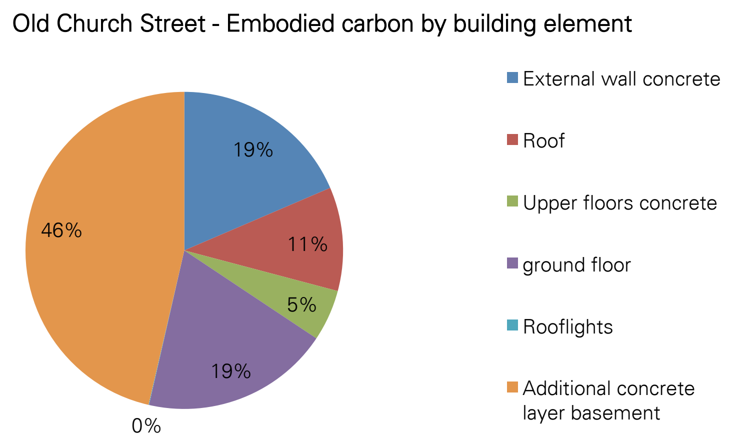
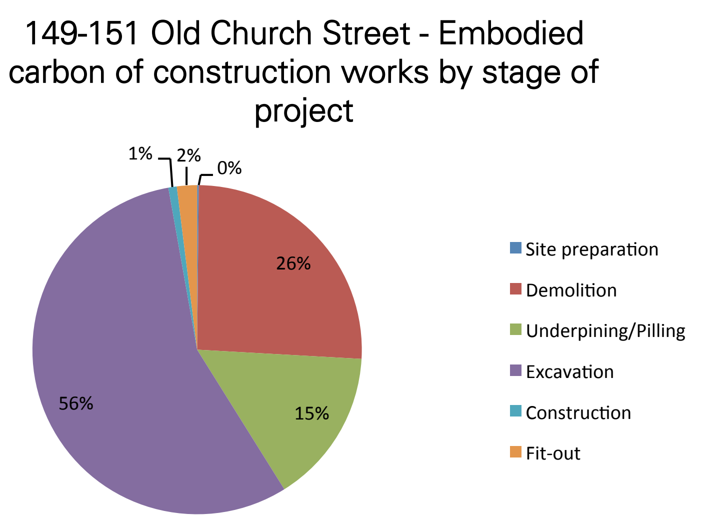
Appendix 2
Case Studies
149-151 Old Church Street

Address:	149-151 Old Church Street, London. SW3 6EB.
Development:	Remodeling of Sloane Lodge behind a retained façade including the creation of a swimming pool complex at basement level and sub basement level within the garden and alternation to the boundary walls to both properties.
Total Area pre-development:	1232.40 m^2
Total Area post-development:	2710.90 m^2
Net increase in floor area:	1278 m^2

Embodied carbon per building element



Embodied Carbon per stage of project



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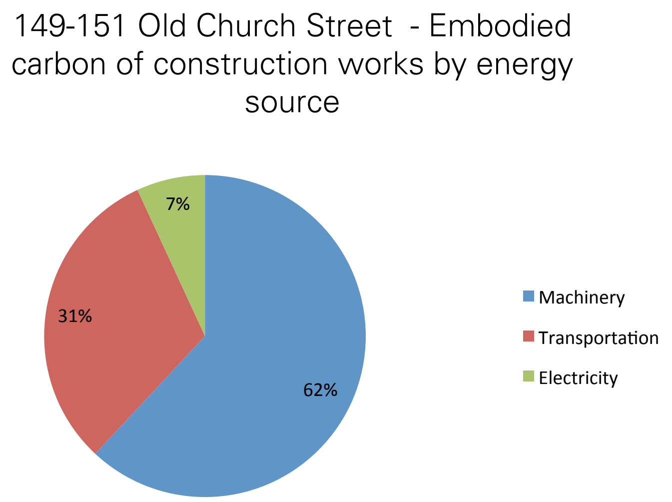
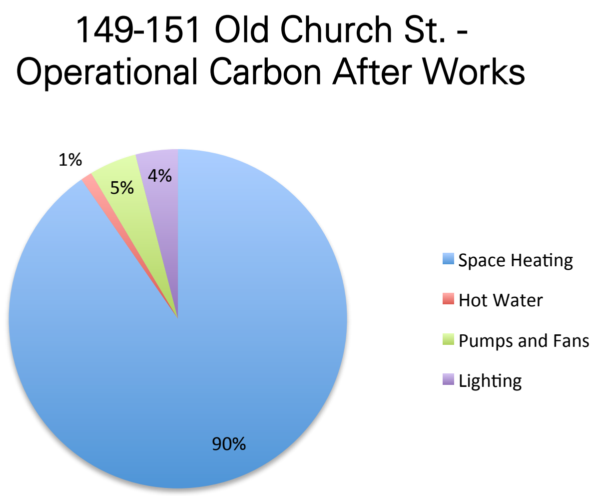
Appendix 2
Case Studies 149-151 Old Church Street

Embodied Carbon per energy source



Operational carbon



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Appendix 3
References

Documents

Source		Title	Published	Reference number
BREEAM DR	Manual	BREEAM DR Manual		1
BRE	2009 edition incorporating RdSAP 2009	The Government's Standard Assessment Procedure for Energy Ratings of Dwellings	On behalf of DECC by: BRE, Crown Copyright (2011)	2
BRE Trust	BRE Global Environmental Profiles methodology 2008	BRE Global Methodology for Environmental Profiles of Construction Products.		3
BSI	Business Standards Publication	Sustainability in building construction - Framework for methods of assessment of the environmental performance of construction works. Part 1: Buildings	-	4
BSI	Business Standards Publication	Sustainability of construction works - Sustainability assessment of buildings. Part 1: General framework	-	5
BSI	Business Standards Publication	Sustainability of construction works - Assessment of buildings. Part 2: Framework for the assessment of environmental performance	-	6
Construction Production Association		A Guide to Understanding the Embodies Impacts of Construction Products	2012	7
HM Government	The Building Regulations 2010 - 2010 version (with 2010 and 2011 amendents)	L1 Conservation of fuel and power in existing dwellings	Online version, Crown Copyright (2010)	8
HM Government	Domestic Building Services Compliance Guide 2010 - 2010 version (with 2011 amendments)	Domestic Building Services Compliance Guide 2010 Edition	Online version, Crown Copyright (2010)	9
Joint CIB W080 / RILEM TC 140 – Prediction of Service Life of Building Materials and Components	Guide and Bibliography to Service Life and Durability Research for Buildings and Components	PART I – Service Life and Durability Research		10
KUBOTA Europe S.A.S.		Kubota Mini Excavator - KX121-3a	Printed in Japan 05-3D	11
Ofgem	Promoting choice and value for all gas and electricity customers	Typical domestic energy consumption figures	18-Nov-11	12
SAP Conventions			01-Sep-13	13
VOLVO	Volvo Truck Corporation	Emissions from Volvo's trucks (standard diesel fuel)	03-Nov-00	14
VOLVO	Volvo Construction Equipment North America, Inc.	Volve Compact Excavators ECR58, ECR88	Printed in USA 02/05	15
VOLVO	Volvo Construction Equipment.	Volve Excavators EC140D, EC160D, EC220D	Printed in USA 03/12	16

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Appendix 3
References

Reports

Author	Year of Publication	Title	Name of Organisation	Reference
Gardiner, J.	2014	Case Studies of basement excavation in relation to programme and vehicle movements.	Alan Baxter & Associates LLP for RBKC 2014	17
Baxter, A.	2012	Royal Borough of Kensington and Chelsea Residential Basement Study Report	Alan Baxter & Associates LLP for RBKC 2012	18
Coombs, M.	2013	Royal Borough of Kensington and ChelseaResidential Basement Study Report	Alan Baxter & Associates LLP for RBKC 2013	19
Hed, G.	2005	Service Life Estimations in the Design of a PCM Based Night Cooling System.	KTH Research School Centre for Built Environment, Department of Technology and Built Environment University of Gävle. 2005	20
J.H.M. Tah, W.Zhou, F.H. Abanda & F.K.T. Cheung		Towards a holistic modeling framework for embodied carbon and waste in the building lifecyle.	School of the Built Environment, Oxford Brookes University, UK. Nottingham University Press - Proceedings of the International Conference on Computing in Civil and Building Engineering W Tizani (Editor)	21
Pout, C.	2011	Proposed Carbon Emission Factors and Primary Energy Factors for SAP 2012.	BRE for Technical Papers Supporting SAP 2012	22
Sweetnam, T., Croxford B.	2011	A carbon, energy and cost assessment of whether refurbish or rebuild aging UK residential blocks.	CIBSE Technical Symposium, DeMontfort University, Leicester, 2011	23
Anderson, J.	2013	Carbon Leaders Briefings - Materials, products and carbon	PE International/CIRIA	24

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Appendix 3
References

Screen Shots

Source	Version	Building Type	Category	Element Type	Element Number	Reference
Green Guide	2008 ratings	Domestic	Domestic Windows	Windows	813100011	25
Green Guide	2008 ratings	Domestic	Domestic Windows	Windows	813100013	26
Green Guide	2008 ratings	Domestic	Domestic Windows	Windows	813100016	27
Green Guide	2008 ratings	Domestic	Domestic Windows	Windows	1213100004	28
Green Guide	2008 ratings	Domestic	External Wall Construction	Aluminium Curtainwalling Systems	1206510006	29
Green Guide	2008 ratings	Domestic	External Wall Construction	Brick, Stone & Block Cavity Wall	806170033	30
Green Guide	2008 ratings	Domestic	External Wall Construction	Brick, Stone & Block Cavity Wall	806170615	31
Green Guide	2008 ratings	Domestic	Ground Floor Construction	Solid Concrete	820100040	32
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540001	33
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540031	34
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540069	35
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540075	36
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540080	37
Green Guide	2008 ratings	Domestic	Roof Construction	Flat Roof: Warm Deck	1212540083	38
Green Guide	2008 ratings	Domestic	Roof Construction	Pitched Roof Timber Construction	812410026	39
Green Guide	2008 ratings	Domestic	Upper Floor Construction	Upper Floor Construction	807280023	40
Green Guide	2008 ratings	Domestic	Upper Floor Construction	Upper Floor Construction	807280060	41
Green Guide	2008 ratings	Domestic	Upper Floor Construction	Upper Floor Construction	807280063	42
Green Guide	2009 ratings	Domestic	Roofing : Flat Roof: Warm Deck	Upper Floor Construction	79889685	43

Website

	Title	Address	Reference
BRE	Green Guide for Specification	Available at: http://www.bre.co.uk/greenguide/podpage.jsp?id=2126	44
BRE	Green Guide for Specification	Available at: http://www.iso.org/iso/catalogue_detail?csnumber=37456	45
Greater London Plan	Policy 5.2	http://www.london.gov.uk/priorities/environment/consultations/climate-change-mitigation-and-energy-strategy	46
Greater London Plan	Policy 5.4	http://www.london.gov.uk/priorities/environment/consultations/climate-change-mitigation-and-energy-strategy	47
Ecosmart Foundation	-	http://www.ecosmart.org	48