Operational and embodied carbon in new build housing

A reappraisal

NHBC Foundation

Housing research in partnership with BRE Trust

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October 2011

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FOREWORD

The energy performance of new homes has improved significantly in recent years, with a rapid acceleration in the past decade as we approach the zero carbon target date of 2016. The 2016 edition of the Building Regulations Part L will require excellence in energy performance as the house-building industry delivers homes to the zero carbon standard. As a result of these improvements, the carbon emissions resulting from the use of homes for space heating, hot water and lighting, etc. will be minimal, but to achieve that performance, more materials will have been used in the construction process.

Until now our focus has been almost entirely on the carbon emissions resulting from using homes, but clearly the balance between those operational carbon emissions and emissions from producing and installing the materials – the embodied carbon – needs to be considered. This is the subject of this latest report from the NHBC Foundation which explores a subject which has to date lacked a strong and accessible evidence base.

By looking at a range of carbon reduction scenarios as delivered through typical house types, this report estimates the likely impact both in terms of operational and embodied carbon. By doing so it provides insights into the contribution of different technical responses to the low carbon agenda, including the balance between operational and embodied carbon.

I hope that you find this report useful in getting to grips with some of the key issues involved in measuring carbon and that it stimulates further discussion in this important area.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation

ABOUT THE NHBC FOUNDATION

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

The NHBC Foundation is also involved in a programme of positive engagement with government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

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Professor Steve Wilcox, Centre for Housing Policy, University of York

CONTENTS

GLOSSARY

Building Regulations	Within this report, Building Regulations refers to Part L1A 2010 (England and Wales).
Carbon compliance	Measured in kg CO_2/m^2y, carbon compliance is designed to ensure that new dwellings are built with effective CO_2-reduction measures directly installed on site. Measures such as low-carbon heating systems, microgeneration (photovoltaic panels or solar water heating), or a connection to low-carbon heat sources such as combined heat and power (CHP) all fall under the carbon compliance heading.
Code for Sustainable Homes	Environmental assessment method for rating and certifying the performance of new homes. A national standard for use in the design and construction of new homes with a view to encouraging continuous improvement in sustainable homebuilding, and includes categories such as Energy and CO_2 emissions, Water, Materials, and several others. See www.planningportal.gov.uk/buildingregulations/greenerbuildings/sustainablehomes.
Embodied CO_{2eq} emissions	These are emissions resulting from extraction and manufacture of construction materials, transport to site and assembly of building elements to create a finished dwelling, and subsequent refurbishment and demolition.
Equivalent CO_2 (CO_{2eq})	The activities associated with the life cycle of a dwelling (sourcing materials, construction on site, occupation, demolition, etc) are responsible for releasing a variety of greenhouse gases of varying potency, including CO_2, methane and others. To aid simplicity, equivalent CO_2 allows the cumulative effect of all these gases to be added together and expressed as an equivalent quantity of CO_2.
Grid decarbonisation	This term describes the gradual reduction in CO_2 emissions associated with electricity provided by the National Grid, which is expected to occur over the coming decades. The reduction is expected due to the gradual introduction of renewable generation and carbon-capture technology.
Life cycle assessment	This accounts for and evaluates the environmental impacts of products, from the extraction of raw materials through manufacturing, distribution and use to recycling or disposal.
Operational CO_2 emissions	These are emissions resulting from space and water heating, ventilation, lighting, appliances and cooking within a living space.
Standard Assessment Procedure (SAP) 2009	The Government's Standard Assessment Procedure (SAP), which is used to determine whether a given housing design complies with the requirements of Building Regulations. SAP software is typically used, which provides information on expected CO_2 emissions from heating, cooling, lighting and other impacts.

Executive summary

This report was commissioned by the NHBC Foundation to investigate the percentage split between operational and embodied CO_{2eq} in new build housing, in the context of the progressively more demanding Building Regulations the industry is expecting in 2016 and beyond.

Twenty-four scenarios were appraised, using SAP software to determine operational CO_2 emissions and BRE Global's Environmental Profile methodology to analyse embodied CO_{2eq} emissions.

The research considered the following variables:

- two built forms (detached and mid-terraced)
- two construction weights (masonry and timber frame)
- three operational CO_2 performance levels (25, 31 and 40% reductions over Part L1A 2010)
- two dwelling lifespans (60- and 120-year study periods)
- varying grid electricity CO_2 intensity (to account for the expected impacts of grid decarbonisation).

The research was carried out by BRE, with assistance from several leading housing developers. Stewart Milne Group and Barratt Developments plc provided house designs for modelling (selected as typical of expected new build development in the coming years). Crest Nicholson plc and Stewart Milne Group led development of commercially minded specifications to meet the three CO_2 performance levels.

The key results of this research are as follows:

- The modelling showed a typical percentage split between operational and embodied CO_{2eq} of 62/38% for masonry construction, and 65/35% for timber-frame construction. These are averaged figures – for individual percentage splits, see Tables 3 to 14.

- No significant differences emerged between masonry and timber construction in terms of overall CO_2 impact over the 60- and 120-year study periods. The largest difference observed between comparable masonry and timber constructions was 4%.
- The modelling showed that space and water heating, along with foundations, ground floors, windows/doors and floor coverings, were the largest contributors to overall lifetime CO_2 impact. Appliances were also a significant contributor, but building designers have limited opportunity to reduce these emissions via their designs.
- No significant difference in heating or cooling load between the two construction weights was identified by the modelling.
- The impact of grid electricity decarbonisation was more pronounced in the 120-year study, and indicated that electric heating may be a lower CO_2 option in the long term.

It was necessary to make a number of assumptions in order to carry out this research:

- certain services components – such as thermostats and other heating controls – were omitted
- potential climate-change impacts from a warming/cooling climate were not included
- emissions from mains gas were assumed to remain constant
- the potential impact of future developments in technology (eg new types of boiler) was not included
- dwelling performance was assumed to remain constant over the study period, and all components were assumed to be replaced like-for-like.

The reasoning behind these assumptions and their potential influence on the results are discussed within the main report.

The report concludes with recommendations for further research to develop greater knowledge in this area.

1 Introduction

The influence of successively more demanding Building Regulations means that new dwellings are now more energy efficient than ever before. Consumers living in new properties enjoy lower bills and better comfort levels, as well as lower CO_2 emissions.

The expected path of the Building Regulations means that these positive effects should continue into the future. However, the Building Regulations deal with only one part of the picture – operational CO_2 emissions which include:

- CO_2 emissions created by heating the home, water heating, lighting and ventilation (included within Building Regulations compliance assessments)
- CO_2 emissions from cooking and using electrical appliances (not currently included within the Building Regulations, but included within the Code for Sustainable Homes).

Alongside these operational CO_2 emissions, the life cycle of a dwelling also includes a number of other stages in which CO_2 emissions are generated, including materials extraction, dwelling construction and ultimate demolition. These other stages are collectively known as embodied CO_{2eq} emissions, and they are not currently accounted for within Building Regulations.

Figure 1 shows the total CO_2 emissions arising from the life cycle of a dwelling, with operational CO_2 (purple), and embodied CO_{2eq} (blue).

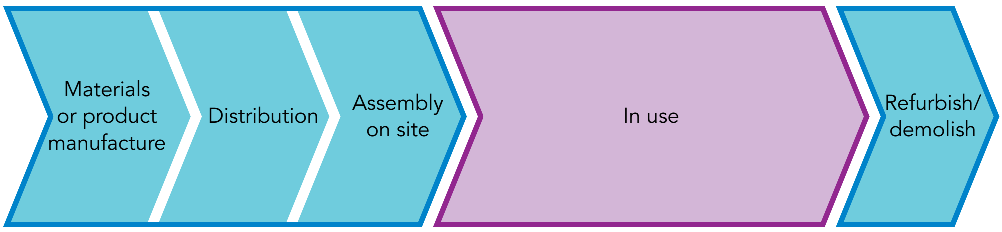


Figure 1 Total CO_2 emissions arising from the life cycle of a dwelling

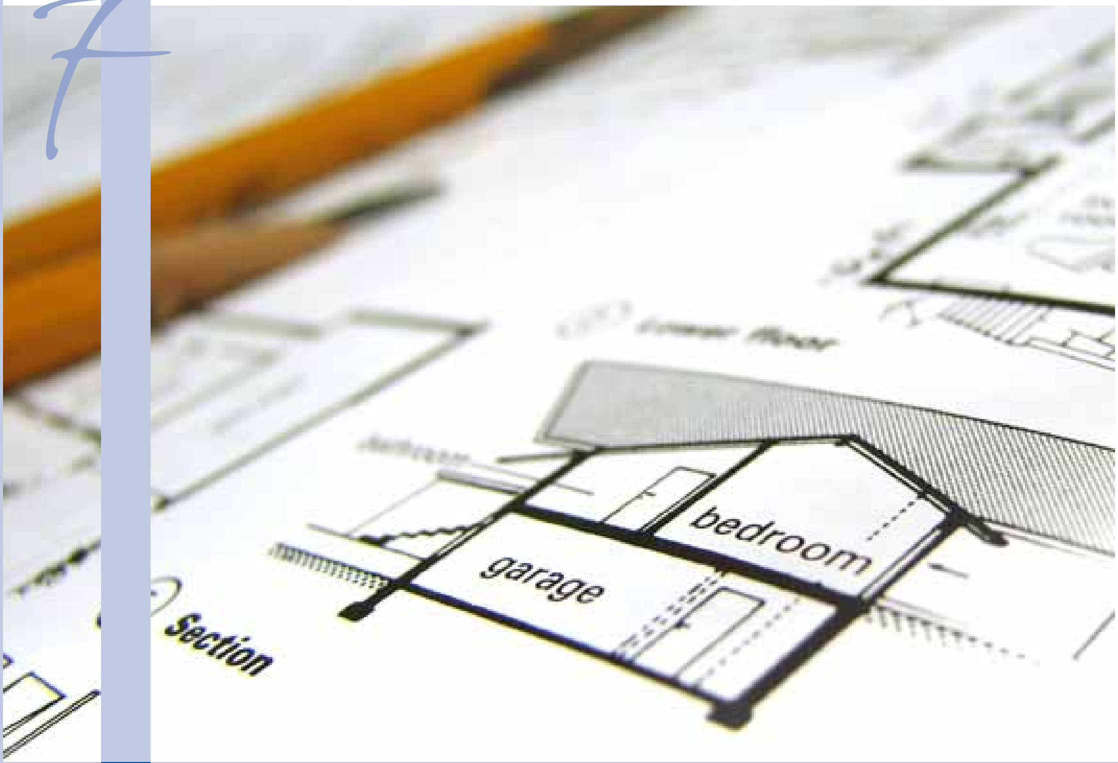
A quick guide to terminology

- **Dwelling life cycle** describes the complete cycle of building, occupying and maintaining, and then demolishing a dwelling; each stage leads to CO_2 emissions. These emissions are split into two categories, operational and embodied.
- **Operational CO_2** describes emissions resulting from space and water heating, ventilation, lighting, appliances and cooking within a living space.
- **Embodied CO_{2eq}** describes emissions resulting from extraction and manufacture of construction materials, transport to site and assembly of building elements to create a finished dwelling, and subsequent refurbishment and demolition.

Embodied CO_{2eq} has historically been a niche area of investigation, due to both the difficulty in analysing it, and its perceived lack of importance when compared with operational CO_2. Anecdotally, the typical split between operational and embodied CO_{2eq} in new build housing has been taken as 80% operational, 20% embodied, a position largely confirmed by recent studies[1]. However, within the context of future Building Regulations requirements – which are expected to tighten to the point that new homes will be significantly lower in CO_2 from 2016[2] – operational CO_2 emissions are set to fall radically. This means that embodied CO_{2eq} emissions will become increasingly significant in terms of the percentage they contribute to the overall CO_2 impact of new build dwellings. In addition, typically the more energy efficient a given house type becomes, the greater the quantity of additional materials required to construct it (eg additional insulation, more services). There is also potential that such additional materials (eg renewable generation installations) may have particularly high embodied CO_{2eq} levels. Both these considerations suggest that, as operational CO_2 emissions reduce, embodied CO_{2eq} emissions will increase.

Currently, the only mainstream assessment of embodied CO_{2eq} in buildings is BRE's *Green Guide to Specification*[3], as used within Code for Sustainable Homes assessments to rate material choices. However, with European legislation now expected to address this issue there is a need for home builders to gain a deeper understanding of the area. This will allow the industry to respond in an informed way to any forthcoming legislation, as well as ensure that new homes are constructed in the most sustainable way possible.

Taking these considerations into account, the NHBC Foundation commissioned a research project into the likely split between embodied and operational CO_2 in new build housing. The research was carried out by BRE, with assistance from several leading housing developers. Stewart Milne Group and Barratt Developments plc provided house designs for modelling (selected as typical of expected new build development in the coming years). Crest Nicholson plc and Stewart Milne Group led development of commercially minded specifications to meet the three CO_2 performance levels.



2 Project objectives and variables

The overall project aim was to analyse the proportional split between operational and embodied CO_{2eq} in new dwellings. Twenty-four scenarios were modelled in total, based on the variables listed in Table 1.

Table 1

Project variables
Two contrasting house types (mid-terraced and detached)
▪ These house types were chosen as 'typical' following input from Stewart Milne Group, Crest Nicholson plc and Barratt Developments plc regarding the type of housing expected to predominate in the coming years. ▪ They feature widely differing external surface area to volume (A/V) ratios. The A/V ratio is a key determinant of fundamental energy efficiency, and differs for each built form. ▪ Both designs have the same floor area, providing a useful basis for comparison. ▪ Having chosen the generic house types to investigate, real house designs (see section 4) representative of typical build practice were provided by Stewart Milne Group and Barratt Developments plc.
Two contrasting construction weights (medium and light)
▪ Two contrasting construction weights were chosen to provide a broader spread of data. ▪ This allowed us to investigate whether the medium-weight construction had a significantly larger embodied CO_{2eq} when both construction and services were taken into account. ▪ We also wanted to understand whether the varying levels of mass between the medium- and light-weight constructions had a significant impact on summer cooling load, thus resulting in additional CO_2 emissions. ▪ The medium-weight build was modelled using brick and block construction; the light-weight build used timber frame.

Three CO_2 performance levels (25, 31 and 40% CO_2 reductions over Part L1A 2010)
■ These performance levels were chosen to reflect possible future Building Regulations' CO_2 compliance levels. ■ At the time this research was being carried out, the Zero Carbon Hub's document on future levels of carbon compliance[4] was out to consultation; had the results been available they would have provided a useful indication of the future level of CO_2 performance likely to be required by forthcoming Building Regulations. ■ As a result, the authors were required to estimate future CO_2 performance levels, with a range of carbon compliance levels being selected to model: 25, 31 and 40% reductions over Part L1A 2010. ■ To ensure that the dwelling specifications chosen for each performance level were realistic and commercially minded, Stewart Milne Group and Crest Nicholson plc provided specifications for the timber and masonry designs, respectively.
60- and 120-year analyses
■ Operational and embodied CO_{2eq} was analysed for each house type over both 60- and 120-year periods. ■ The 60-year study length was chosen to correspond with the NHBC Foundation's requirements and industry-standard documents such as BRE's *Green Guide to Specification*[3]. ■ The 120-year study length was chosen to represent the long service life typical of UK housing.
Potential future impacts of fuel CO_2 intensity
■ The CO_2 intensity of fuels is measured in kg CO_2 per kWh of energy. ■ Grid electricity CO_2 intensity is expected to drop over the 120-year study period due to the gradual introduction of renewable generation and carbon-capture technology. Expected impacts have been reflected in this research. ■ The CO_2 intensity of mains gas is expected to rise in the short term due to additional imports, and subsequently to fall due to the introduction of biogas; however, these impacts have not been quantified in academic research. In the absence of a definitive study, CO_2 emissions from mains gas were assumed to remain constant over the 120-year study period.

3 Methodology

3.1 Operational CO_2 modelling methodology

- SAP 2009 software was used to model each scenario, and energy-demand figures noted by end use, and fuel type.
- The cooking and appliances equation within SAP 2009 was reverse-engineered to derive energy-demand figures for each end use.
- Fuel emissions factors from *Validation of Energy Use and Greenhouse Gas Emissions for Appraisal and Evaluation*[5] were then used to calculate CO_2 emissions over the 60- and 120-year study periods.
- The average figure was used up to, and including, 2050; thereafter the marginal figure (0.0226 kg CO_2/kWh) was used.
- Future warming/cooling scenarios were not included in the study due to the difficulty of sourcing the detailed monthly data (solar insolation, wind speed and air temperature) required to analyse impacts over a 120-year period. Had these data been readily available, a bespoke version of SAP software would also have been required to enter the data into the calculation.
- Had it been possible to include these impacts in the study, they would potentially have had a significant impact on both dwelling cooling and heating energy demand.

3.2 Life cycle assessment and embodied CO_{2eq} modelling

3.2.1 Background

BRE Global's Environmental Profile methodology[6] (the cradle-to-grave life cycle assessment methodology which underpins the BRE *Green Guide to Specification*[3]) was used to analyse the embodied CO_{2eq} impact of the dwellings. The analysis includes impacts arising from:

- the production phase – raw material extraction, transport, manufacturing of products, and all upstream processes
- the assembly process phase – transport to the assembly site and housing development
- the use phase – maintenance, repair and replacement, refurbishment
- the end-of-life phase – recycling and disposal; all including transport.

The methodology refers to 13 impact categories, but the CO_{2eq} values can be extracted from the Global Warming Potential impact, measured in kg CO_{2eq}. For the purpose of this project, the only impact reported was the Global Warming Potential for a 100-year timescale or CO_{2eq} figures.

3.2.2 Embodied CO_{2eq} modelling methodology

The embodied carbon of the houses was measured using the approach described below.

1) The drawings and information provided by Stewart Milne Group, Crest Nicholson plc and Barratt Developments plc were reviewed, and the building broken down into the following building elements, based on the *Green Guide to Specification*[3]:

    a) substructure and foundations
    b) external walls
    c) internal walls
    d) ground floor
    e) upper floor
    f) floor coverings
    g) windows
    h) roof
    i) building services.

2) The quantities of materials were measured using the drawings as follows.

    a) For the main building elements, where this element type is covered in the *Green Guide to Specification*[3]: the surface area of the building element was measured in m^2 (eg external walls, windows or roof).
    b) For foundations and building services, the volume of materials was calculated. The volume of materials was then multiplied by the kg CO_{2eq} per tonne of materials (as published in the BRE *Green Guide* or Ecoinvent[7] databases).

3) The impact of the building elements was calculated using the *Green Guide to Specification* tool, which provides a kg of CO_{2eq}/m^2 of building elements for generic materials.

4) The total amount of embodied CO_{2eq} of each of the building elements was found by using the following formula: surface area of building element in $m^2 \times$ (kg CO_{2eq}/m^2).

5) The calculations for building services were based on manufacturers' information using the references provided by Stewart Milne Group and Crest Nicholson plc. The volume of materials was then used to calculate the total amount of CO_{2eq} for which each building service was responsible.

   a) Due to unavailability of reliable data, all electrical components are excluded from calculations – pumps, control boxes, electrical cables, electronic components (circuit boards, etc).
   b) No transport impacts were included for any of the services/renewable units to site.
   c) While the above impacts may be assumed to have limited significance, firm conclusions cannot be drawn without reliable data, which are currently not available, hence they have been omitted from this study.

6) The surface area of building elements was calculated from the drawings.

7) The embodied carbon of the building was calculated following the BRE Global methodology and was therefore predicted over a 60- or 120-year study period.

3.3 Assumptions regarding service life and replacement of components

- The replacement of services and other building components has a direct bearing on both operational and embodied CO_{2eq} emissions across the 60- and 120-year study periods.
- A simple like-for-like replacement regime for all key components was assumed, due to the unreliability of predicting future technology types.
- Based on Energy Saving Trust and trade body data, estimated service lives for key components were derived.
- Certain technologies (eg waste water heat recovery) are new to the UK marketplace, and in such cases likely service lives were estimated based on the best knowledge currently available.

The assumed service lives are listed in Table 2.

Table 2

Construction element lifespan

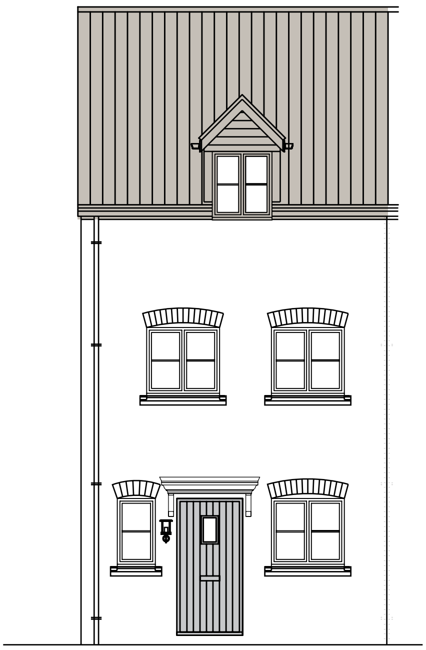
	Lifespan (years)
Building envelope, superstructure and substructure	120
Windows and doors	40
Boiler	12
Hot water cylinder	30
Mechanical ventilation heat recovery	15
Solar water heating panels	30
Waste water heat recovery system	60
Flooring products (linoleum, laminate and carpet)	10

- In addition to the replacements listed above, the additional impacts of a basic dwelling refurbishment at 60 years were included. The assumptions made were as follows:
  - All service components, windows and floor finishes were assumed to have undergone cyclical replacement, so additional replacements were not included in the refurbishment.
  - Because all dwelling specifications are very thermally efficient, it was assumed additional insulation would not be added during refurbishment.
  - It was assumed that all internal dry lining would be replaced during refurbishment.

4 Dwelling designs

Stewart Milne Group and Barratt Developments plc provided house designs for modelling; these two designs are shown in this section of the report. Crest Nicholson plc did not provide a house design, but were actively involved along with the other developers in selecting the chosen designs as typical of expected new build development in the coming years.

4.1 Stewart Milne Group HC10 dwelling design



– Three bedroom mid-terraced dwelling
– Three storeys
– Total floor area 103 m^2

Figure 2 HC10 dwelling front elevation

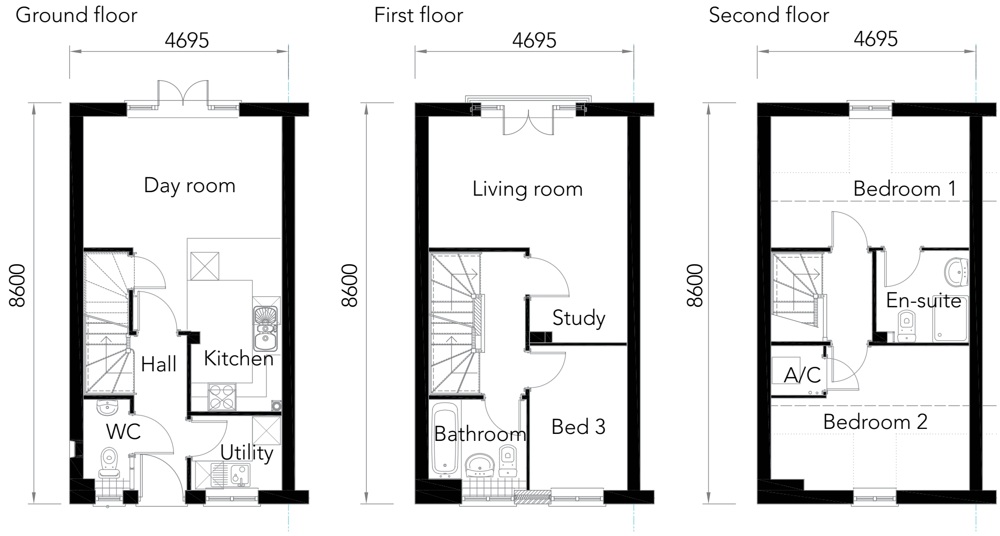


Figure 3 HC10 dwelling floor plans

4.2 Barratt Developments plc Ripon dwelling design

– Four bedroom detached dwelling
– Two storeys
– Total floor area 103 m²

Figure 4 Ripon dwelling front elevation

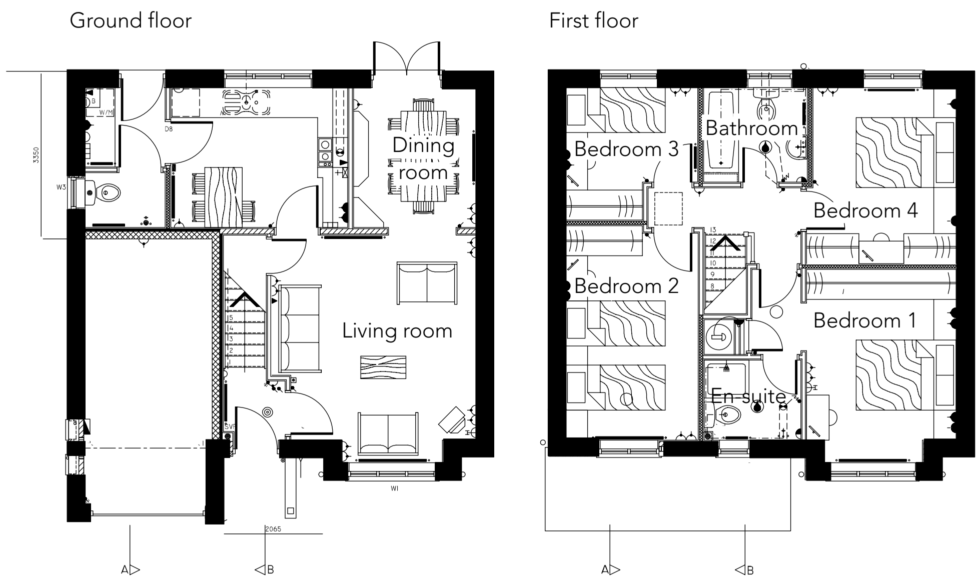


Figure 5 Ripon dwelling floor plans

5 Results

5.1 Interpreting the results data

Figure 6 provides data on operational and embodied CO_{2eq} emissions for each scenario.

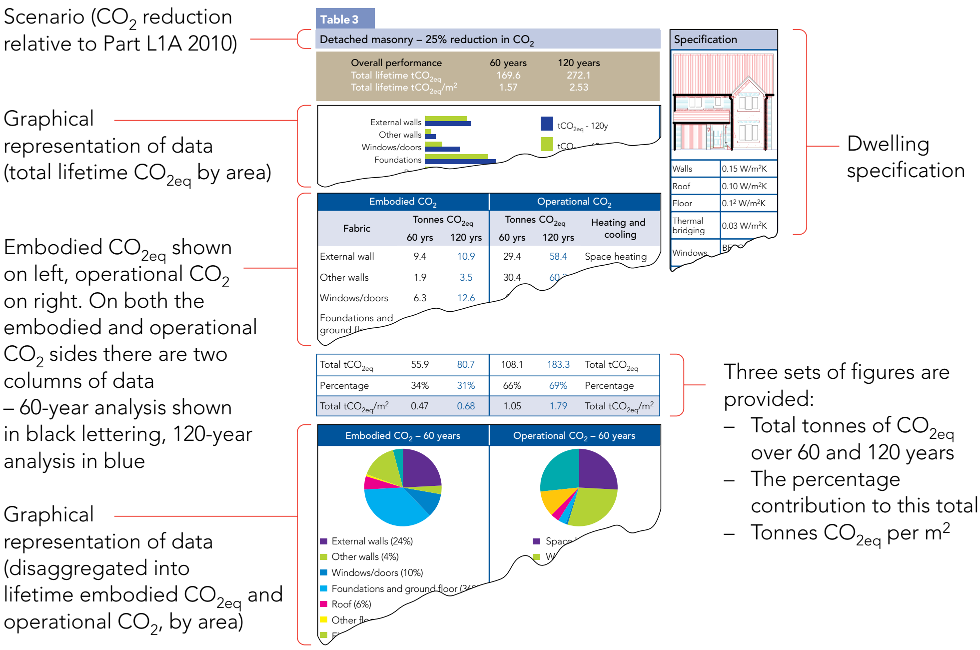


Figure 6 Explanation of results data

5.2 Results data

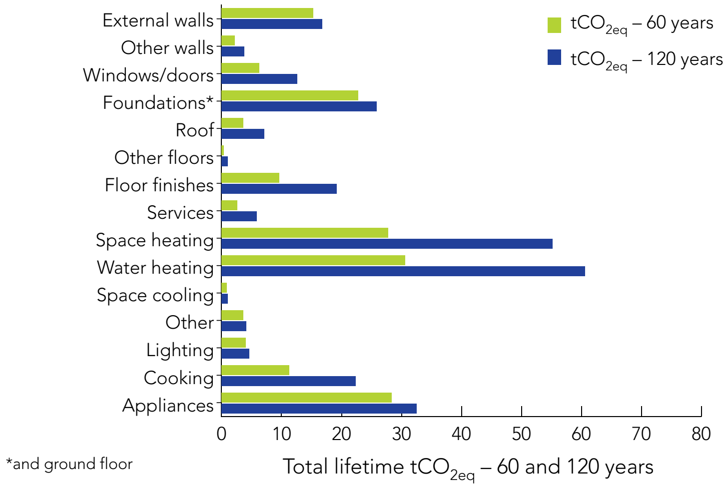
Tables 3 to 14 give results data for reductions in CO_2 for different types of dwelling: Tables 3 to 6 show results for a 25% CO_2 reduction; Tables 7 to 10 for a 31% CO_2 reduction; Tables 11 to 14 for a 40% CO_2 reduction.

Table 3

Detached masonry – 25% reduction in CO_2

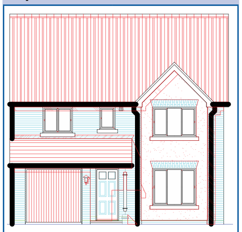
25%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**169.4**	**272.8**
Total lifetime CO_{2eq}/m^2	**1.57**	**2.53**



*and ground floor

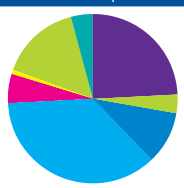
Crest Nicholson plc Specification



Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.12 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	4.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, time and temp zone control
Water cylinder	100 mm PU insulation
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery

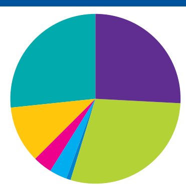
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_2		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	15.3	16.8	27.8	55.2	Space heating
Other walls	2.2	3.8	30.6	60.6	Water heating
Windows/doors	6.3	12.6	0.9	1.0	Space cooling
Foundations and ground floor	22.8	25.9	3.6	4.1	Other
Roof	3.6	7.1	4.0	4.6	Lighting
Other floors	0.4	1.0	11.3	22.4	Cooking
Floor finishes	9.6	19.2	28.4	32.5	Appliances
Services	2.6	5.9			
Total tCO_{2eq}	62.8	92.3	106.6	180.5	Total tCO_2
Percentage	37%	34%	63%	66%	Percentage
Total tCO_{2eq}/m^2	0.53	0.77	1.04	1.76	Total tCO_2/m^2

Embodied CO_{2eq} – 60 years



- External walls (24%)
- Other walls (4%)
- Windows/doors (10%)
- Foundations and ground floor (36%)
- Roof (6%)
- Other floors (1%)
- Floor finishes (15%)
- Services (4%)

Operational CO_2 – 60 years



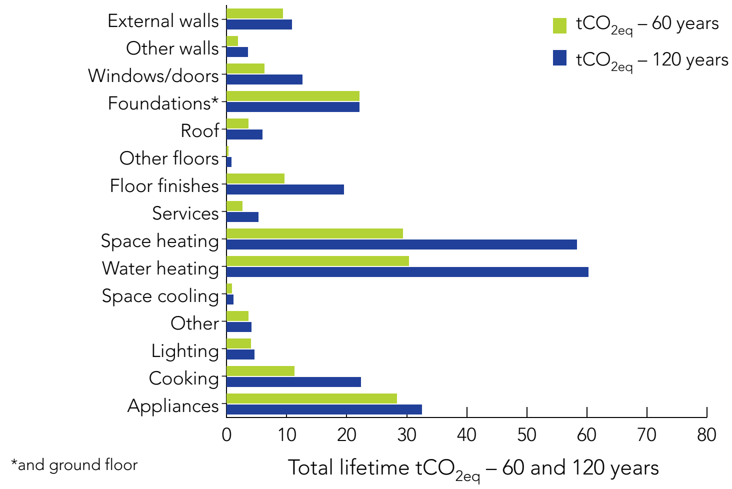
- Space heating (26%)
- Water heating (29%)
- Space cooling (1%)
- Other (3%)
- Lighting (4%)
- Cooking (10%)
- Appliances (27%)

Table 4

Detached timber – 25% reduction in CO_2

25%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**164.0**	**264.0**
Total lifetime CO_{2eq}/m^2	**1.52**	**2.47**



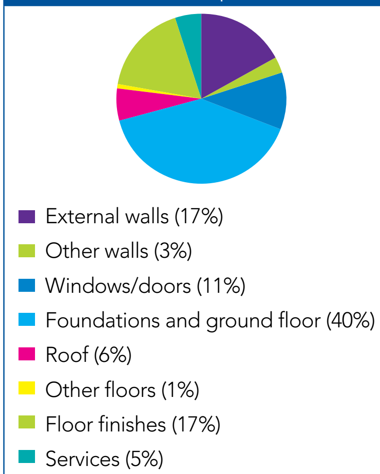
*and ground floor

Barratt Developments Specification

Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.12 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	4.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, time and temp zone control
Water cylinder	100 mm PU insulation
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery

Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_2		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	9.4	10.9	29.4	58.4	Space heating
Other walls	1.9	3.5	30.4	60.3	Water heating
Windows/doors	6.3	12.6	0.9	1.1	Space cooling
Foundations and ground floor	22.1	22.1	3.6	4.1	Other
Roof	3.6	6.0	4.0	4.6	Lighting
Other floors	0.3	0.8	11.3	22.4	Cooking
Floor finishes	9.6	19.5	28.4	32.5	Appliances
Services	2.6	5.3			
Total tCO_{2eq}	55.9	80.7	108.1	183.3	Total tCO_2
Percentage	34%	31%	66%	69%	Percentage
Total tCO_{2eq}/m^2	0.47	0.68	1.05	1.79	Total tCO_2/m^2

Embodied CO_{2eq} – 60 years



Operational CO_2 – 60 years

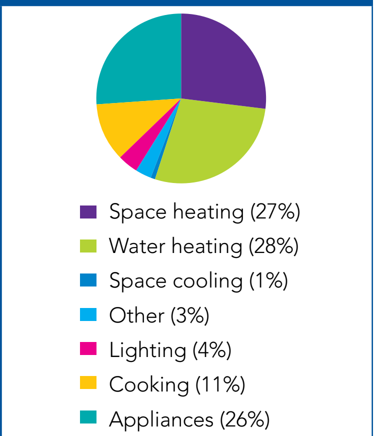
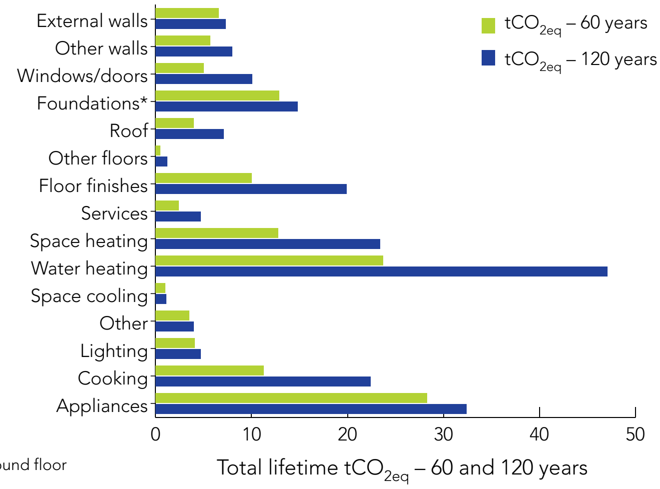


Table 5

Mid-terraced masonry – 25% reduction in CO_2

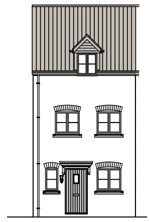
25%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	131.9	208.2
Total lifetime CO_{2eq}/m^2	1.31	2.08



*and ground floor

Crest Nicholson plc Specification



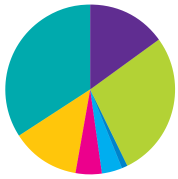
Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.10 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	3.0 m³/hr.m²
Space heating	Gas combi boiler 90.3%, thermostat, timer and TRVs
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Waste water

Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq} 60 yrs	Tonnes CO_{2eq} 120 yrs	Tonnes CO_2 60 yrs	Tonnes CO_2 120 yrs	Heating and cooling
External wall	6.6	7.3	12.8	23.4	Space heating
Other walls	5.7	8.0	23.7	47.1	Water heating
Windows/doors	5.0	10.1	1.0	1.1	Space cooling
Foundations and ground floor	12.9	14.8	3.5	4.0	Other
Roof	4.0	7.1	4.1	4.7	Lighting
Other floors	0.5	1.2	11.3	22.4	Cooking
Floor finishes	10.0	19.9	28.3	32.4	Appliances
Services	2.4	4.7			
Total tCO_{2eq}	47.2	73.1	84.7	135.1	Total tCO_2
Percentage	36%	35%	64%	65%	Percentage
Total tCO_{2eq}/m^2	0.48	0.74	0.83	1.34	Total tCO_2/m^2

Embodied CO_{2eq} – 60 years

- External walls (14%)
- Other walls (12%)
- Windows/doors (11%)
- Foundations and ground floor (27%)
- Roof (9%)
- Other floors (1%)
- Floor finishes (21%)
- Services (5%)

Operational CO_2 – 60 years



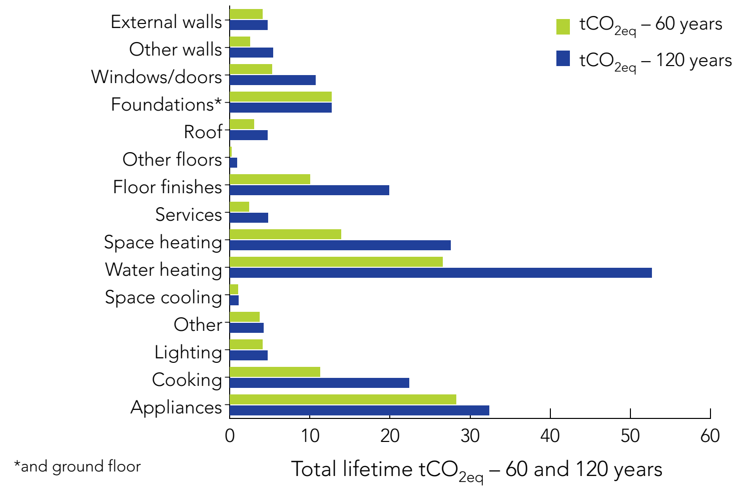
- Space heating (15%)
- Water heating (28%)
- Space cooling (1%)
- Other (4%)
- Lighting (5%)
- Cooking (13%)
- Appliances (34%)

Table 6

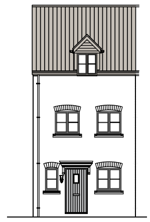
Mid-terraced timber – 25% reduction in CO_2

25%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**129.0**	**209.0**
Total lifetime CO_{2eq}/m^2	**1.28**	**2.07**



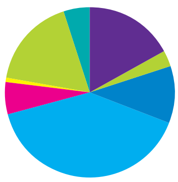
Stewart Milne Group Specification



Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.10 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	3.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, thermostat, timer and TRVs
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery

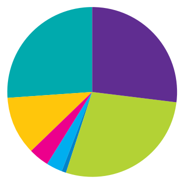
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_2		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	4.1	4.7	13.9	27.6	Space heating
Other walls	2.5	5.4	26.6	52.7	Water heating
Windows/doors	5.3	10.7	1.0	1.1	Space cooling
Foundations and ground floor	12.7	12.7	3.7	4.2	Other
Roof	3.0	4.7	4.1	4.7	Lighting
Other floors	0.2	0.9	11.3	22.4	Cooking
Floor finishes	10	19.9	28.3	32.4	Appliances
Services	2.4	4.8			
Total tCO_{2eq}	40.1	63.9	88.9	145.1	Total tCO_2
Percentage	31%	31%	69%	69%	Percentage
Total tCO_{2eq}/m^2	0.41	0.65	0.87	1.42	Total tCO_2/m^2

Embodied CO_{2eq} – 60 years



- External walls (17%)
- Other walls (3%)
- Windows/doors (11%)
- Foundations and ground floor (40%)
- Roof (6%)
- Other floors (1%)
- Floor finishes (17%)
- Services (5%)

Operational CO_2 – 60 years



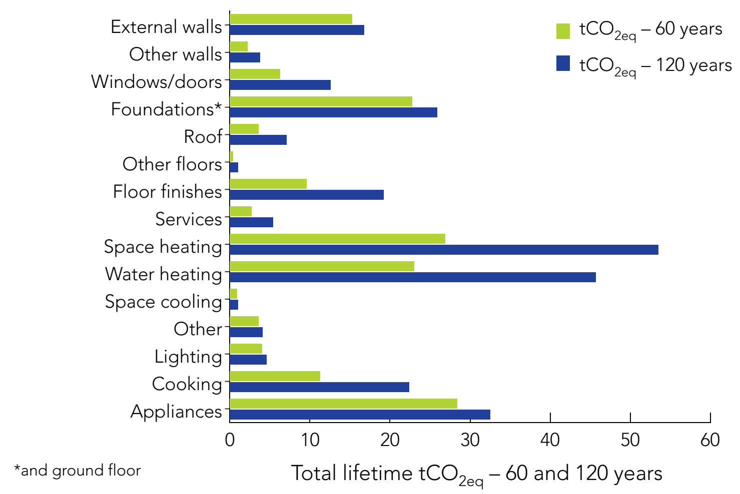
- Space heating (27%)
- Water heating (28%)
- Space cooling (1%)
- Other (3%)
- Lighting (4%)
- Cooking (11%)
- Appliances (26%)

Table 7

Detached masonry – 31% reduction in CO_2

31%↓

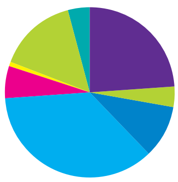
Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**161.2**	**255.5**
Total lifetime CO_{2eq}/m^2	**1.51**	**2.37**



*and ground floor

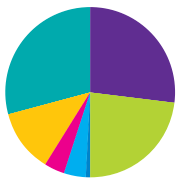
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_2		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	15.3	16.8	26.9	53.5	Space heating
Other walls	2.2	3.8	23.0	45.7	Water heating
Windows/doors	6.3	12.6	0.9	1.0	Space cooling
Foundations and ground floor	22.8	25.9	3.6	4.1	Other
Roof	3.6	7.1	4.0	4.6	Lighting
Other floors	0.4	1.0	11.3	22.4	Cooking
Floor finishes	9.6	19.2	28.4	32.5	Appliances
Services	2.7	5.4			
Total tCO_{2eq}	63.0	91.7	98.2	163.8	Total tCO_2
Percentage	39%	36%	61%	64%	Percentage
Total tCO_{2eq}/m^2	0.53	0.77	0.98	1.60	Total tCO_2/m^2

Embodied CO_{2eq} – 60 years



- External walls (24%)
- Other walls (4%)
- Windows/doors (10%)
- Foundations and ground floor (36%)
- Roof (6%)
- Other floors (1%)
- Floor finishes (15%)
- Services (4%)

Operational CO_2 – 60 years



- Space heating (27%)
- Water heating (23%)
- Space cooling (1%)
- Other (4%)
- Lighting (4%)
- Cooking (12%)
- Appliances (29%)

Crest Nicholson plc Specification

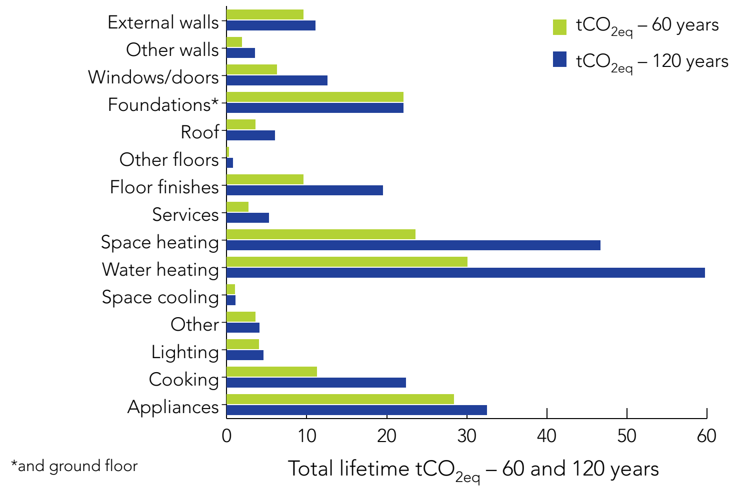
Walls	0.15 W/m^2K
Roof	0.10 W/m^2K
Floor	0.12 W/m^2K
Thermal bridging	0.03 W/m^2K
Windows	BFRC band A double
Doors	1.0 W/m^2K
Airtightness	4.0 $m^3/hr.m^2$
Space heating	Gas conventional boiler 90.3%, time and temp zone control
Water cylinder	Heat loss 1.57 kWh/day
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas and waste water heat recovery

Table 8

Detached timber – 31% reduction in CO_2

31%↓

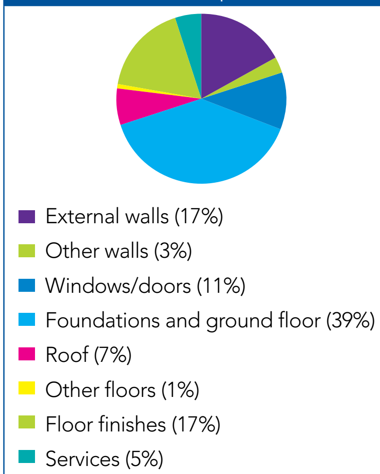
Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**158.1**	**252.1**
Total lifetime CO_{2eq}/m^2	**1.46**	**2.35**



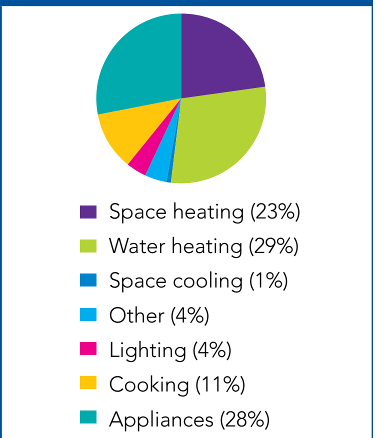
*and ground floor

Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	9.6	11.1	23.6	46.7	Space heating
Other walls	1.9	3.5	30.1	59.8	Water heating
Windows/doors	6.3	12.6	1.0	1.1	Space cooling
Foundations and ground floor	22.1	22.1	3.6	4.1	Other
Roof	3.6	6.0	4.0	4.6	Lighting
Other floors	0.3	0.8	11.3	22.4	Cooking
Floor finishes	9.6	19.5	28.4	32.5	Appliances
Services	2.7	5.3			
Total tCO_{2eq}	56.1	80.9	102.0	171.2	Total tCO_{2eq}
Percentage	35%	32%	65%	68%	Percentage
Total tCO_{2eq}/m^2	0.47	0.68	0.99	1.67	Total tCO_{2eq}/m^2

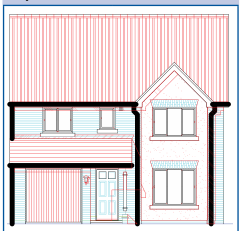
Embodied CO_{2eq} – 60 years



Operational CO_2 – 60 years



Barratt Developments Specification



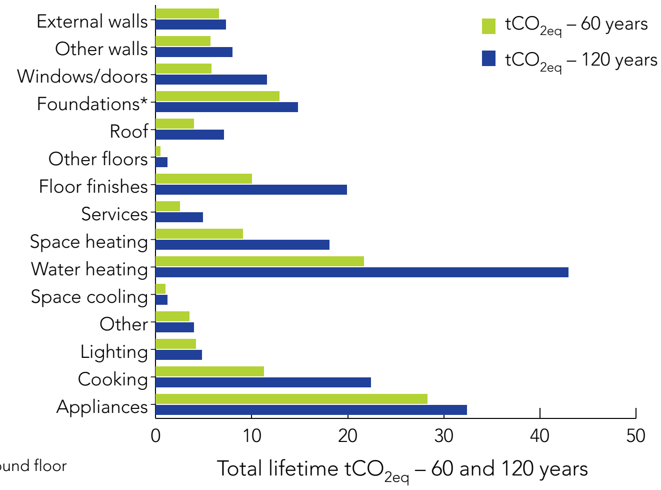
Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.12 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	4.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, time and temp zone control
Water cylinder	100 mm PU insulation
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery

Table 9

Mid-terraced masonry – 31% reduction in CO_2

31%↓

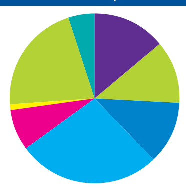
Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	127.3	200.6
Total lifetime CO_{2eq}/m^2	1.26	1.99



*and ground floor

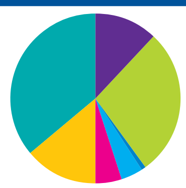
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	6.6	7.3	9.1	18.1	Space heating
Other walls	5.7	8.0	21.7	43.0	Water heating
Windows/doors	5.8	11.6	1.0	1.2	Space cooling
Foundations and ground floor	12.9	14.8	3.5	4.0	Other
Roof	4.0	7.1	4.2	4.8	Lighting
Other floors	0.5	1.2	11.3	22.4	Cooking
Floor finishes	10.0	19.9	28.3	32.4	Appliances
Services	2.5	4.9			
Total tCO_{2eq}	48.1	74.8	79.2	125.8	Total tCO_{2eq}
Percentage	38%	37%	62%	63%	Percentage
Total tCO_{2eq}/m^2	0.49	0.76	0.77	1.23	Total tCO_{2eq}/m^2

Embodied CO_{2eq} – 60 years



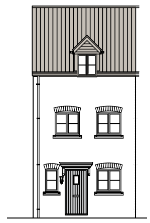
- External walls (14%)
- Other walls (12%)
- Windows/doors (12%)
- Foundations and ground floor (27%)
- Roof (8%)
- Other floors (1%)
- Floor finishes (21%)
- Services (5%)

Operational CO_2 – 60 years



- Space heating (12%)
- Water heating (28%)
- Space cooling (1%)
- Other (4%)
- Lighting (5%)
- Cooking (14%)
- Appliances (36%)

Crest Nicholson plc Specification



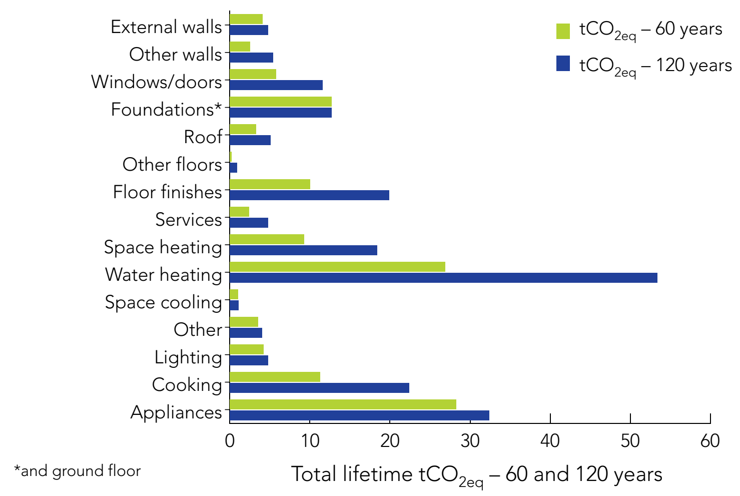
Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.10 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A triple
Doors	1.0 W/m²K
Airtightness	3.0 m³/hr.m²
Space heating	Gas combi boiler 90.3%, thermostat, timer and TRVs
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas and waste water heat recovery

Table 10

Mid-terraced timber – 31% reduction in CO_2

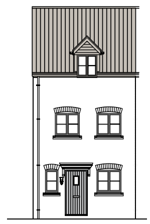
31%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	125.5	201.7
Total lifetime CO_{2eq}/m^2	1.23	1.99



*and ground floor

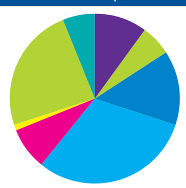
Stewart Milne Group Specification



Walls	0.12 W/m²K
Roof	0.08 W/m²K
Floor	0.10 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A triple
Doors	0.8 W/m²K
Airtightness	2.5 m³/hr.m²
Space heating	Gas combi boiler 90.3%, thermostat, timer and TRVs
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery

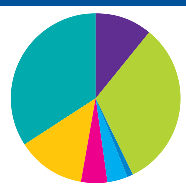
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	4.1	4.8	9.3	18.4	Space heating
Other walls	2.5	5.4	26.9	53.4	Water heating
Windows/doors	5.8	11.6	1.0	1.1	Space cooling
Foundations and ground floor	12.7	12.7	3.5	4.0	Other
Roof	3.3	5.1	4.2	4.8	Lighting
Other floors	0.2	0.9	11.3	22.4	Cooking
Floor finishes	10.0	19.9	28.3	32.4	Appliances
Services	2.4	4.8			
Total tCO_{2eq}	41.0	65.2	84.5	136.5	Total tCO_{2eq}
Percentage	33%	32%	67%	68%	Percentage
Total tCO_{2eq}/m^2	0.41	0.66	0.82	1.33	Total tCO_{2eq}/m^2

Embodied CO_{2eq} – 60 years



- External walls (10%)
- Other walls (6%)
- Windows/doors (14%)
- Foundations and ground floor (31%)
- Roof (8%)
- Other floors (1%)
- Floor finishes (24%)
- Services (6%)

Operational CO_2 – 60 years



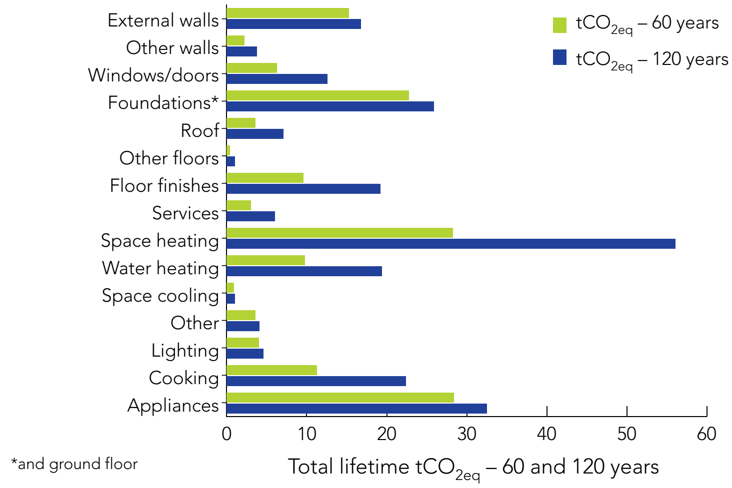
- Space heating (11%)
- Water heating (32%)
- Space cooling (1%)
- Other (4%)
- Lighting (5%)
- Cooking (13%)
- Appliances (34%)

Table 11

Detached masonry – 40% reduction in CO_2

40% ↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**149.5**	**232.3**
Total lifetime CO_{2eq}/m^2	**1.37**	**2.15**



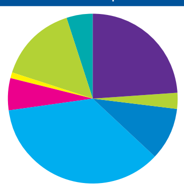
*and ground floor

Crest Nicholson plc Specification

Walls	0.15 W/m^2K
Roof	0.10 W/m^2K
Floor	0.12 W/m^2K
Thermal bridging	0.03 W/m^2K
Windows	BFRC band A double
Doors	1.0 W/m^2K
Airtightness	4.0 $m^3/hr.m^2$
Space heating	Gas conventional boiler 90.3%, time and temp zone control
Water cylinder	Heat loss 1.57 kWh/day
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas and waste water heat recovery, 4 m^2 solar water heating

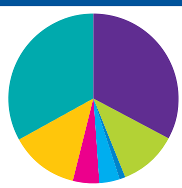
Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	15.3	16.8	28.3	56.1	Space heating
Other walls	2.2	3.8	9.8	19.4	Water heating
Windows/doors	6.3	12.6	0.9	1.0	Space cooling
Foundations and ground floor	22.8	25.9	3.6	4.1	Other
Roof	3.6	7.1	4.0	4.6	Lighting
Other floors	0.4	1.0	11.3	22.4	Cooking
Floor finishes	9.6	19.2	28.4	32.5	Appliances
Services	3.0	6.0			
Total tCO_{2eq}	63.3	92.3	86.2	140.0	Total tCO_{2eq}
Percentage	42%	40%	58%	60%	Percentage
Total tCO_{2eq}/m^2	0.53	0.78	0.84	1.37	Total tCO_{2eq}/m^2

Embodied CO_{2eq} – 60 years



- External walls (24%)
- Other walls (3%)
- Windows/doors (10%)
- Foundations and ground floor (36%)
- Roof (6%)
- Other floors (1%)
- Floor finishes (15%)
- Services (5%)

Operational CO_2 – 60 years

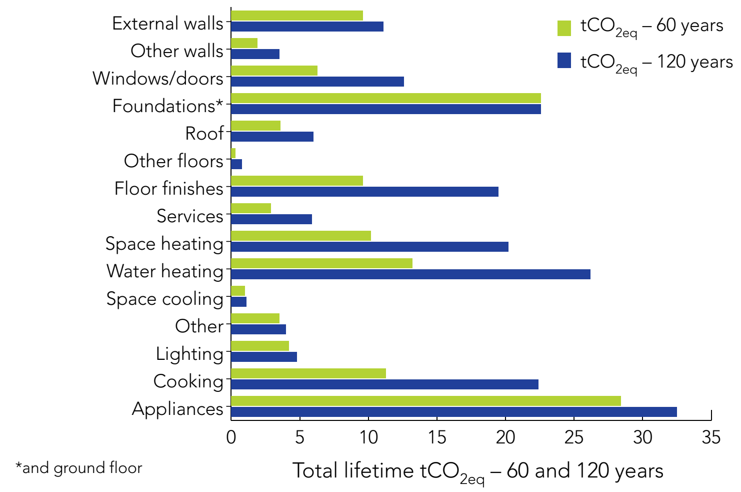


- Space heating (30%)
- Water heating (11%)
- Space cooling (1%)
- Other (4%)
- Lighting (5%)
- Cooking (13%)
- Appliances (33%)

Table 12

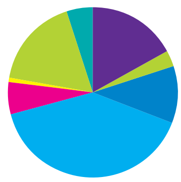
Detached timber – 40% reduction in CO_2 **40%↓**

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**128.6**	**193.3**
Total lifetime CO_{2eq}/m^2	**1.18**	**1.77**



Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq} 60 yrs	Tonnes CO_{2eq} 120 yrs	Tonnes CO_{2eq} 60 yrs	Tonnes CO_{2eq} 120 yrs	Heating and cooling
External wall	9.6	11.1	10.2	20.2	Space heating
Other walls	1.9	3.5	13.2	26.2	Water heating
Windows/doors	6.3	12.6	1.0	1.1	Space cooling
Foundations and ground floor	22.6	22.6	3.5	4.0	Other
Roof	3.6	6.0	4.2	4.8	Lighting
Other floors	0.3	0.8	11.3	22.4	Cooking
Floor finishes	9.6	19.5	28.4	32.5	Appliances
Services	2.9	5.9			
Total tCO_{2eq}	56.8	82.0	71.8	111.3	Total tCO_{2eq}
Percentage	44%	42%	56%	58%	Percentage
Total tCO_{2eq}/m^2	0.48	0.69	0.70	1.08	Total tCO_{2eq}/m^2

Embodied CO_{2eq} – 60 years



- External walls (17%)
- Other walls (3%)
- Windows/doors (11%)
- Foundations and ground floor (40%)
- Roof (6%)
- Other floors (1%)
- Floor finishes (17%)
- Services (5%)

Operational CO_2 – 60 years

- Space heating (14%)
- Water heating (18%)
- Space cooling (1%)
- Other (5%)
- Lighting (6%)
- Cooking (16%)
- Appliances (40%)

Barratt Developments Specification

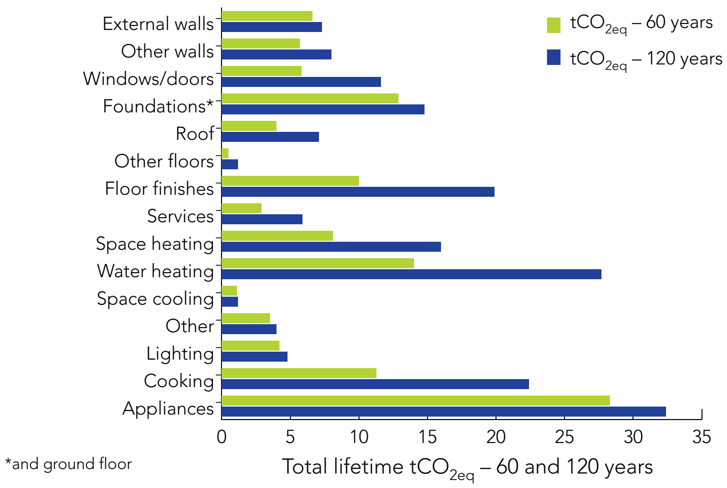
Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.12 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A double
Doors	1.0 W/m²K
Airtightness	4.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, programmer, room thermostat and TRVs
Water cylinder	100 mm PU insulation
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery. 4 m² solar water heating

Table 13

Mid-terraced masonry – 40% reduction in CO_2

40%↓

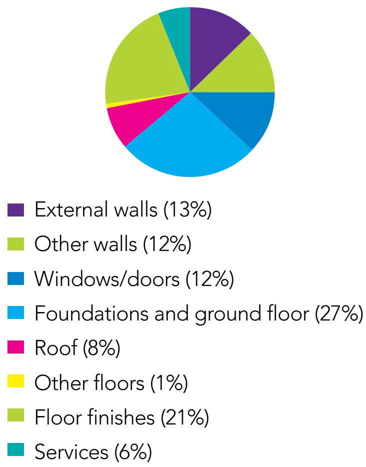
Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	**119.0**	**184.3**
Total lifetime CO_{2eq}/m^2	**1.18**	**1.83**



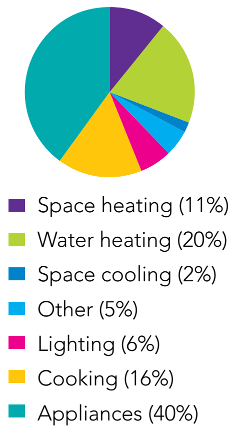
*and ground floor

Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	6.6	7.3	8.1	16.0	Space heating
Other walls	5.7	8.0	14.0	27.7	Water heating
Windows/doors	5.8	11.6	1.1	1.2	Space cooling
Foundations and ground floor	12.9	14.8	3.5	4.0	Other
Roof	4.0	7.1	4.2	4.8	Lighting
Other floors	0.5	1.2	11.3	22.4	Cooking
Floor finishes	10.0	19.9	28.3	32.4	Appliances
Services	2.9	5.9			
Total tCO_{2eq}	48.5	75.8	70.5	108.5	Total tCO_{2eq}
Percentage	41%	41%	59%	59%	Percentage
Total tCO_{2eq}/m^2	0.49	0.77	0.69	1.06	Total tCO_{2eq}/m^2

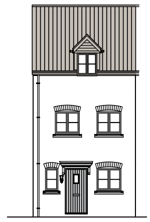
Embodied CO_{2eq} – 60 years



Operational CO_2 – 60 years



Crest Nicholson plc Specification

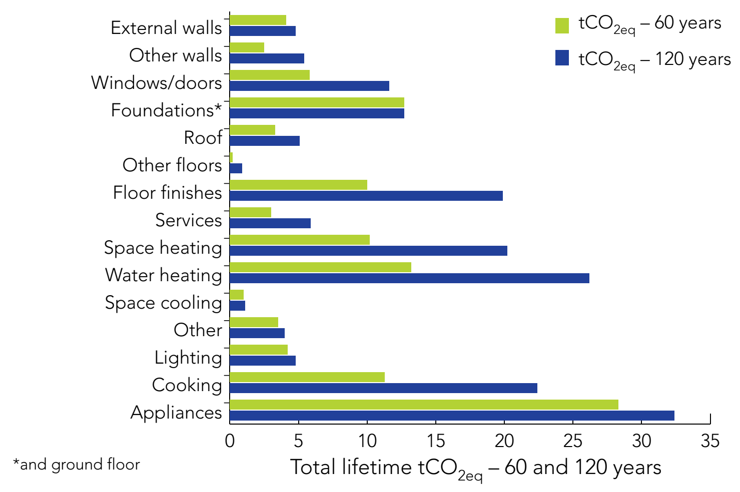


Walls	0.15 W/m²K
Roof	0.10 W/m²K
Floor	0.10 W/m²K
Thermal bridging	0.03 W/m²K
Windows	BFRC band A triple
Doors	1.0 W/m²K
Airtightness	3.0 m³/hr.m²
Space heating	Gas conventional boiler 90.3%, thermostat, timer, TRVs
Water cylinder	Heat loss 1.57 kWh/day
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas and waste water heat recovery, 4 m² solar water heating

Table 14

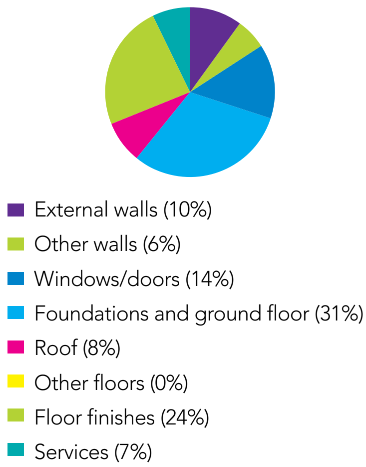
Mid-terraced timber – 40% reduction in CO_2 40%↓

Overall performance	60 years	120 years
Total lifetime tCO_{2eq}	113.2	177.4
Total lifetime CO_{2eq}/m^2	1.12	1.75

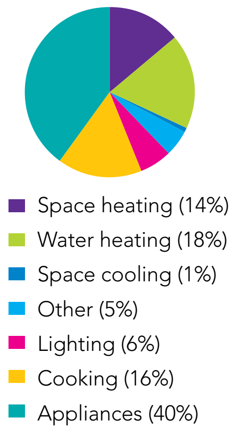


Embodied CO_{2eq}			Operational CO_2		
Fabric	Tonnes CO_{2eq}		Tonnes CO_{2eq}		Heating and cooling
	60 yrs	120 yrs	60 yrs	120 yrs	
External wall	4.1	4.8	10.2	20.2	Space heating
Other walls	2.5	5.4	13.2	26.2	Water heating
Windows/doors	5.8	11.6	1.0	1.1	Space cooling
Foundations and ground floor	12.7	12.7	3.5	4.0	Other
Roof	3.3	5.1	4.2	4.8	Lighting
Other floors	0.2	0.9	11.3	22.4	Cooking
Floor finishes	10.0	19.9	28.3	32.4	Appliances
Services	3.0	5.9			
Total tCO_{2eq}	41.5	66.3	71.7	111.1	Total tCO_2
Percentage	37%	37%	63%	63%	Percentage
Total tCO_{2eq}/m^2	0.42	0.67	0.70	1.08	Total tCO_2/m^2

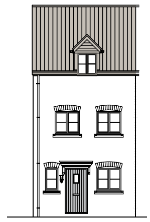
Embodied CO_{2eq} – 60 years



Operational CO_2 – 60 years



Stewart Milne Group Specification



Walls	0.12 W/m^2K
Roof	0.10 W/m^2K
Floor	0.10 W/m^2K
Thermal bridging	0.03 W/m^2K
Windows	BFRC band A triple
Doors	1.0 W/m^2K
Airtightness	3.0 $m^3/hr.m^2$
Space heating	Gas conventional boiler 91.5%, thermostat, timer and TRVs
Water cylinder	100 mm PU insulation
Ventilation	Mechanical ventilation with heat recovery 90% (SAP Appendix Q)
Other	Flue gas heat recovery, 4 m^2 solar water heating

5.3 Summary of results data

Figures 7 to 9 show the results data in summary format.

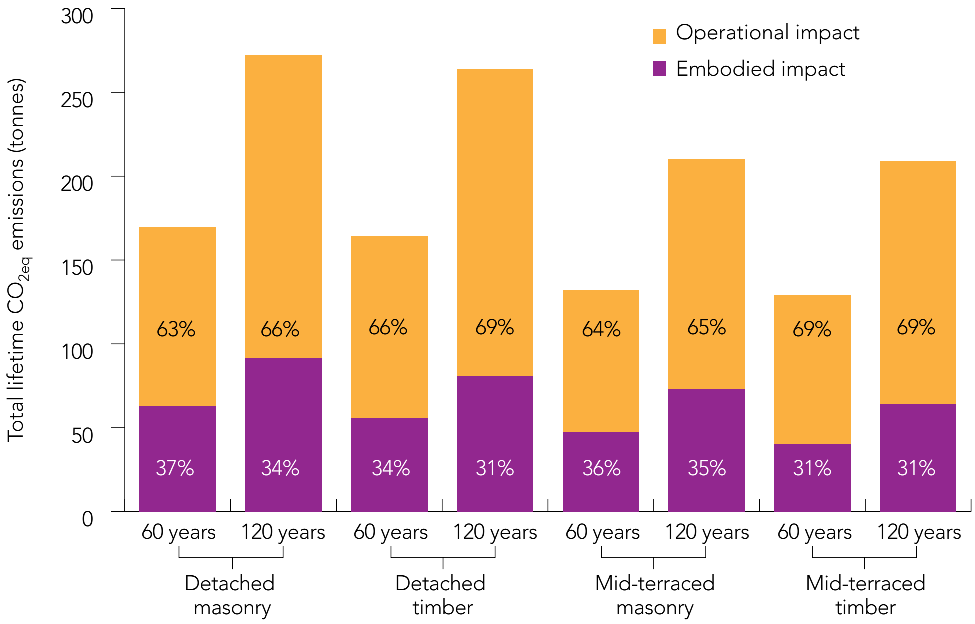


Figure 7 Overall comparison of all 25% CO_2 reduction scenarios (includes both built forms and both construction weights)

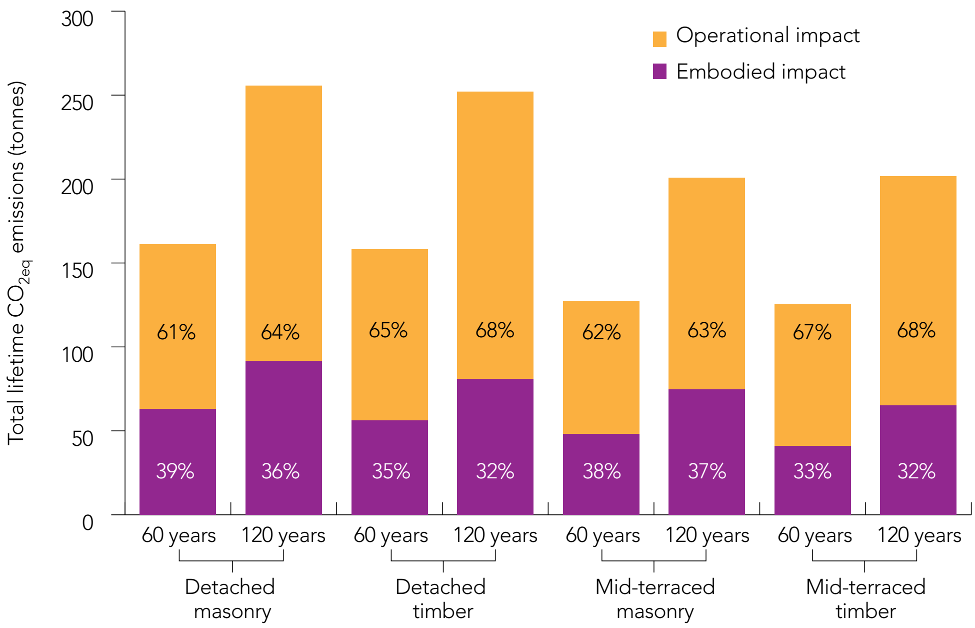


Figure 8 Overall comparison of all 31% CO_2 reduction scenarios (includes both built forms and both construction weights)

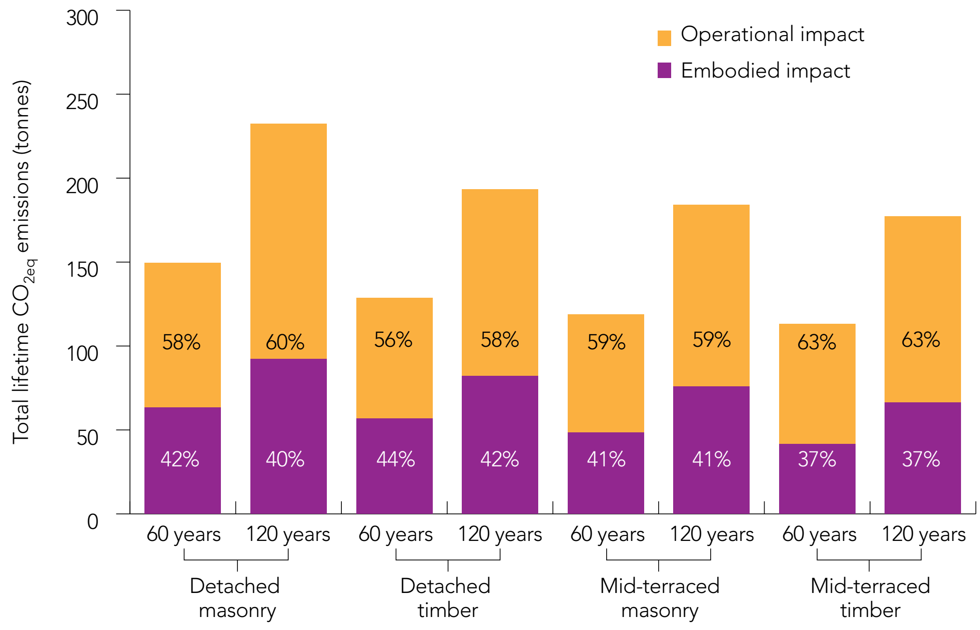


Figure 9 Overall comparison of all 40% CO_2 reduction scenarios (includes both built forms and both construction weights)

6 Analysis and conclusions

6.1 What is the typical percentage split between operational and embodied CO_{2eq}?

The figures in Table 15 show typical percentage splits between operational and embodied CO_{2eq} emissions over both 60- and 120-year study periods. They include both detached and mid-terraced built forms.

Table 15

Typical overall split between operational and embodied CO_{2eq}

	CO_2 reduction (%)	Masonry		Timber	
		Operational CO_2 (%)	Embodied CO_{2eq} (%)	Operational CO_2 (%)	Embodied CO_{2eq} (%)
60 years	25	64	36	68	32
	31	62	38	66	34
	40	59	41	60	40
120 years	25	66	34	69	31
	31	64	36	68	32
	40	60	40	61	39

6.2 Did any significant differences emerge between masonry and timber construction?

As indicated by Table 15, the proportion of embodied CO_{2eq} in masonry construction was found to be higher than that in timber construction. However, this difference was relatively marginal, the maximum difference being 4%. This is because, other than the walls, the majority of building elements were similar in both the masonry and timber constructions modelled.

6.3 Which aspects of the dwelling are responsible for the largest CO_2 impact?

- Space and water heating have the largest CO_2 impact in dwellings; this remains significant in all scenarios despite diminishing slightly as designs move from 25 to 40% CO_2 reduction.
- Appliances also have a large operational CO_2 impact, although dwelling designers have limited ability to help achieve reductions in this area.
- In both masonry and timber constructions, the impact of foundations and ground floors dominates the embodied CO_{2eq} impact.
- In masonry construction, the external walls also have a major impact.
- Because both of these areas will last the lifetime of the dwelling, they should be considered at the design stage when seeking to reduce the overall dwelling CO_2 impact.
- Other elements, such as windows/doors and floor finishes, have a relatively large impact because they are repeatedly replaced throughout the life of the dwelling.
- The embodied impact of services was found to be approximately 5% of impact at 60 years and 7% at 120 years. However, these results should be treated with caution as some aspects, such as controls, had to be omitted due to lack of available data, and the services were not studied in depth during this project.

6.4 Did the varying thermal mass levels have a significant impact on cooling?

No clear trend was identified from the modelling carried out, with minimal impact from space cooling in both masonry and timber designs. It is important to note that the potential climate-change impacts of either a warming or a cooling climate were not included in this study; these would be likely to fundamentally alter heating and cooling demand. For this reason, further more detailed analysis is recommended before drawing any firm conclusions.

6.5 What was the impact of grid decarbonisation?

The anticipated progressive reduction in grid electricity over the study period meant that electrically driven processes such as cooling and lighting were less significant when analysed over 120 as opposed to 60 years.

It should be noted that there is uncertainty inherent in all projections of grid decarbonisation, particularly over longer time scales.

All the scenarios were modelled using gas heating. As an illustration of the impact that grid decarbonisation could have on an electrically heated property, an analysis was carried out to compare 60- and 120-year operational CO_2 emissions for the two fuel sources, using standard (non-heat pump) electrical heating technology (see Table 16).

Table 16

Analysis of the impact of electrical heating

	Masonry mid-terraced dwelling, 40% CO_2 reduction	
Study period (years)	Gas space/water heating	Electric space/water heating
60 (tCO_{2eq})	70.5	64.0
120 (tCO_{2eq})	108.5	82.7

This suggests that, should projected grid CO_2 intensity fall as predicted, electrical heating may be a lower-CO_2 option when considered long term.

6.6 Impact of carbon compliance consultation recommendations

As noted in Table 1, the three CO_2 performance levels chosen for this report were intended to provide a broad range of data, as the level of carbon compliance recommended by the Zero Carbon Hub Task Group was not available at the start of this project[4].

The final consultation recommendations were as follows[8] (note that these relate to operational CO_2 only):

- detached dwellings: maximum 10 kg $CO_{2eq}/m^2/y$
- terraced dwellings: maximum 11 kg $CO_{2eq}/m^2/y$.

These final recommendations were slightly more demanding than the standards modelled in this report, and therefore not all modelled scenarios comply.

Of those modelled, the compliant scenarios are presented in Table 17. The compliant scenarios should be of particular interest to designers.

Table 17

Carbon compliance and the scenarios modelled for this research

Construction	Reduction (%)	Detached	Mid-terraced
Masonry	25	N	Y
	31	N	Y
	40	N	Y
Timber	25	N	N
	31	N	Y
	40	N	Y

6.7 Further research

This research provides a clearer picture of the likely split between operational and embodied CO_{2eq} emissions in the types of housing expected to predominate between now and 2016. Nevertheless, it is a relatively small study and readers should beware of drawing firm conclusions from its content. A number of assumptions were necessary in order to project likely emissions across the 120-year study period.

To develop knowledge in this area further, more detailed information on the embodied CO_{2eq} of building services is required. A current BRE Trust project, *Extending LCA Methodology to the Evaluation of Building Services*, is analysing the embodied CO_{2eq} of services, including domestic boilers; further such studies are required to allow building designers to make more informed choices.

In addition, climate-change impacts need to be analysed in more detail in order to understand the impact on dwelling heating and cooling loads. This is likely to have a significant impact on overall CO_2 emissions.

To obtain greater insight into total dwelling CO_2 emissions, a follow-up study focusing on specific material substitutions to reduce embodied CO_{2eq} would be beneficial. Readers may be interested in an existing report which provides guidance in this area[9].

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NF31 October 2011

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NF33 October 2011

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NHBC Foundation
Housing research in partnership with BRE Trust

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Operational and embodied carbon in new build housing

A study was commissioned to investigate the percentage split between operational and embodied CO_{2eq} in new build housing, in the context of the progressively more demanding Building Regulations the industry is expecting to 2016 and beyond. This report, supported by Stewart Milne Group, Crest Nicholson plc and Barratt Developments plc, provides detailed results across multiple dwelling types, build weights and compliance levels, and includes a full account of the methodology used.

Increased awareness of the balance between operational and embodied CO_{2eq} will help to drive further progress in making our homes more sustainable.

NHBC Foundation

Housing research in partnership with BRE Trust

The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports housebuilders in developing strong relationships with their customers.

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