# Net-zero buildings
## Where do we stand?

ARUP

## Contents

# Foreword

**The built environment is a critical sector to tackle if we are to reach the climate mitigation targets set out in the Paris Agreement,[1] as it represents close to 40% of global energy-related carbon emissions. In 2020, the World Business Council for Sustainable Development (WBCSD) published the Building System Carbon Framework to provide a common language to companies and other stakeholders involved in the built environment on how they can collaborate to achieve decarbonization across the full life cycle of buildings.**

The Framework provides a clear overview of all the carbon emissions in the building system over a full life cycle, and it enables reflections and opportunities for dialogue between all stakeholders.

This report presents and discusses the results of six case studies developed from Arup projects using whole life carbon assessment of buildings based on the WBCSD Framework. The work shows that it remains difficult to collect all the necessary data from across the full life cycle of building projects. Despite this, it is critical that we start using this information to inform the earliest phase of the decision-making process when the opportunity to reduce whole life carbon emissions is greatest.

**The case studies, all of which focus on some degree of low carbon design, indicate a potential for clear targets to emerge, and the halving of global buildings related emissions within the next decade to be a possibility.**

The high-level milestones being proposed by 2030 globally on the path to net-zero, are not out of reach, but to achieve them, whole life carbon assessment is critical and needs to inform widespread decision making.

The case studies also help us to better understand the key levers that will drive the built environment decarbonization, for example, in new building projects more than 50% of emissions may be from the embodied carbon associated with the construction, and 70% of this comes from six materials. As much as 20% of life-cycle emissions come from the maintenance and refurbishment of installations during the lifetime of a building. Hence it is paramount that we tackle these emissions alongside a continued focus on driving down emissions from the energy used to operate buildings. The report discusses some approaches and potential targets to accelerate action.

**Based on this work we call on companies from across the built environment and around the globe to conduct whole life carbon assessments of their projects as a matter of course, openly publishing the results so we can create and build a body of evidence and shared learning.**

By doing so, we can help inform and educate all stakeholders and provide greater opportunities to reduce emissions, driving more immediate action.

For WBCSD and Arup, this report represents an important collaboration toward better understanding how we can reduce all emissions from the construction and use of buildings to achieve net zero. Going forward, we will explore together with a wider group of WBCSD members the key levers, strategies and actions that will help us reach net-zero emissions across the full life cycle of buildings.

We look forward to engaging many stakeholders in this work and to sharing and further developing the learning widely so that the buildings and construction sector can decisively accelerate collaboration and action toward net-zero buildings in the critical next few years.

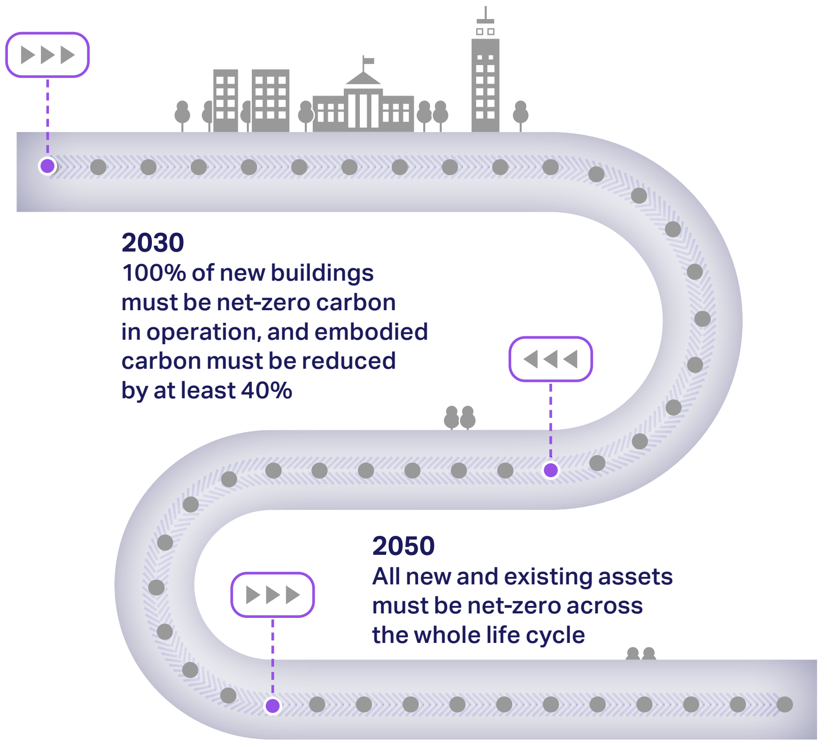
**Roland Hunziker**
Director, Sustainable Buildings & Cities, WBCSD

**Chris Carroll**
Building Engineering Director, Arup

With willingness and a holistic look at all emissions occurring over the lifetime of buildings we can achieve significant emissions reductions immediately. For this to happen, collaboration and a whole life carbon approach from the very start of any project are critical.

**Roland Hunziker**

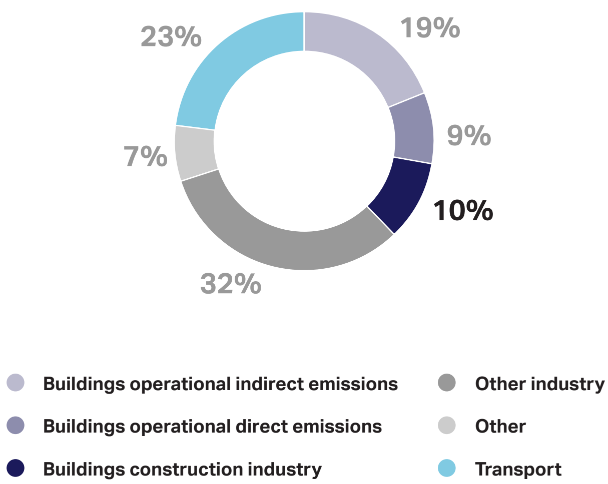
**Figure 1:** Route to net-zero buildings, UNFCCC (2021)[2]




To achieve the required decarbonization of our buildings we have to rapidly gain wider understanding of the whole life cycle impact. From this informed position we can then collaborate intelligently to make deep and meaningful reductions toward net zero.

**Chris Carroll**

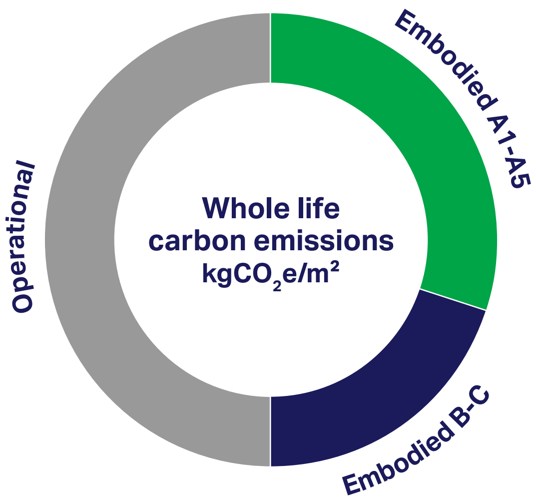
**Figure 2:** Buildings share of global energy emissions, Global ABC/IEA/UNEP (2020)[3]




**Notes:** Direct emissions are those emitted from buildings, while indirect emissions are emissions from power generation for electricity and commercial heat. Land use change is not included in the global energy emissions.

# Executive summary

**This report looks in detail at the results of six whole life cycle carbon assessments (WLCA) case studies to illustrate some of the current challenges, barriers, and opportunities relating to the buildings industry's carbon footprint. It aims to provide an insight into the industry's current performance in relation to possible net-zero trajectories and identify some potential next steps to aid the sector's journey toward total decarbonization.**




We ask the reader to consider the question posed by the report "Where do we stand?" with respect to the immediate demands on the global building industry to decarbonize as a key part of tackling the climate emergency we all face.

## KEY OUTCOMES

The six projects represent a small sample, and likely the more advanced end of the industry. However, they provide a good insight into a building's whole life carbon footprint and how it is broken down into key constituent parts, further described in section 1 of this report. The case studies point to outcomes regarding current achievable performance and alignment against the developing net-zero pathway.

### Upfront embodied A1-A5

Looking across the six case studies, the upfront embodied carbon averages between 500-600 $kgCO_2e/m^2$, and it would seem a global target in this vicinity could be established immediately, representing an achievable level of universal improvement. Should this target be committed to universally as a starting point we would make good immediate in-roads into significant global emissions reduction.

### In-use and end-of-life embodied B-C

The case studies point to a current lack of clear understanding regarding the in-use embodied carbon which averages above 300 $kgCO_2e/m^2$ using currently established accounting methods. Greater focus is required to design out this impact through the adoption of circular economy principles as opposed to wholesale replacement of key components as currently assumed. We also need more transparent and accurate understanding across the industry in relation to the decarbonization of materials over time to make the right decisions to minimize whole life impacts. The case studies also show that end of life embodied carbon has generally little impact on overall figures, except when considering organic material such as timber where more clarity on possible end of life scenarios is still needed.

### Operational

The operational energy use varies significantly across the case studies from around 75 to 220 $kWh/m^2$/year. The units here are provided in total energy consumption rather than in GHG emissions owing to regional variability in the carbon intensity of the grid. Most of the case studies estimate energy consumption based on calculations. Moving forward, we need to collect better in-use energy data to verify these assumed values. In addition, an improved understanding of the decarbonization of the supply grid over the building's life is required to clearly determine whether we are on track to achieve the necessary overall emissions reductions.

## KEY CHALLENGES AND OPPORTUNITIES

One important observation has been the difficulty and time taken to develop the case studies. Significant effort was required to collect consistent levels of WLCA data across all projects. We must rapidly improve the process of creating and sharing transparent WLCA data. The current availability and consistency of the carbon intensity data associated with building components and materials in different parts of the world is of particular concern. The case studies indicate that around 70% of all upfront embodied emissions are associated with only six materials. It would seem plausible that, through industry focus and collaboration, we can drive reduction of embodied carbon emissions through research, development and knowledge sharing.

## KEY MESSAGES

### Commit to WLCA on all projects

- Measure everything, at all stages, on all projects.
- Consistent methodology and approach.
- Process of open source sharing of data.

### Develop consistent and transparent carbon intensity and benchmark data

- All components, systems and materials to have a carbon intensity certification.
- Collect and share in-use energy consumption data.
- Better understanding of supply chain and national energy grid decarbonization trajectories.

### Define explicit targets

- Clear, simple global targets adopted across the buildings industry.
- A valid approach to residual carbon emissions.
- Supportive international and country-specific policy and legislation.

### Define net-zero buildings

- Clear and precise definition of net-zero buildings aligned with overall global decarbonization, emerging net-zero definition and the Paris Agreement.

### Establish wider collaboration

- Individual organizations taking action is not enough.
- Rapid industry-wide systems change is required.
- All stakeholders across the value chain must play their part.

## KEY TERMINOLOGY

- **Carbon dioxide equivalent emissions ($CO_2e$)** represents an equal GHG emissions quantum. It is commonly use since it is the major component of GHG emissions (burning of fossil fuels, waste, biological materials, emissions from chemical reactions).
- **Embodied carbon** refers to a quantity of $CO_2e$ associated with the materials used to construct and maintain the building throughout its lifespan (material extraction, manufacture, construction, demolition and end of life).
- **Operational carbon** refers to the emissions associated with the heating, cooling, and energy use of the building.
- **Whole Life Cycle Assessment (WLCA)** is a method to quantify both embodied and operational carbon emissions of an asset over its life cycle.

# 1 Introduction

# ① Introduction

**To meet the ambitions of the Paris Climate Agreement and limit global warming to +1.5°C above pre-industrial levels, we need to manage and mitigate greenhouse gas (GHG) emissions to a credible version of zero by adopting a systems thinking approach to our anthropogenic activities and impacts.**[4]

Approximately 38% of energy related GHG emissions are attributed to the building industry, 28% derive from building operation and 10% from the materials used in their construction and maintenance.[3] It is estimated that approximately 255 billion $m^2$ of buildings currently exist in the world. With an addition of roughly 5.5 billion $m^2$ every year, a city the size of Paris is constructed every single week.[5]

Clearly, we must significantly and rapidly address the GHG emissions associated with the building industry to be on track with our overarching decarbonization emissions.

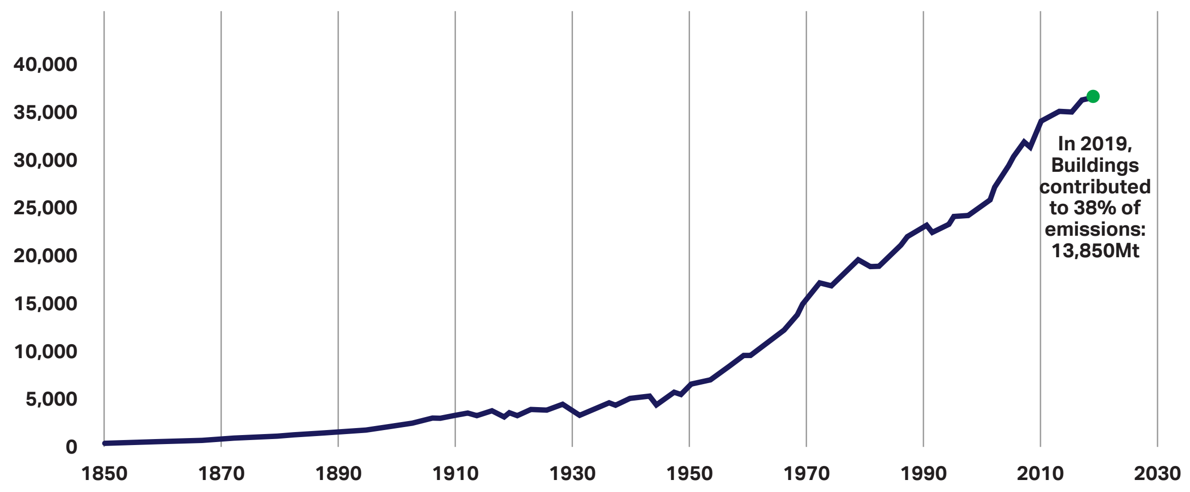
Currently the industry lacks a well-established and universal understanding of the detailed challenges associated with the decarbonization of the built environment. The approach toward achieving GHG reductions across the whole industry, design, construction, delivery and operation needs to be much better informed by knowledge sharing, data transparency, research and innovation. This also relates to property developers, financiers and policy makers who influence the value chain.

Understanding the whole life carbon emissions of buildings is a key step towards meaningfully creating reductions and credible pathways towards net zero. We need to more accurately understand where we are, where we want to get to, and importantly, how we get there.

**The purpose of this report is to put a spotlight on the carbon footprint range of existing buildings' projects; show where and when the emissions occur during the building's lifetime and discuss the results in relation to net-zero trajectories.**
It is important when assessing the carbon impact of a building to understand the constituent parts as they build up over time (fig. 4 and fig. 5). The WLCA includes all the building's life stages, often referred as "from cradle to grave". Over the past decade, the focus has been mainly on reducing the operational carbon emissions associated with buildings. As a result, embodied carbon of new buildings now represents a significant contributor to total emissions, often as much as 50% of the total life cycle emissions as illustrated by this study.

This study is only part of a beginning to the process of measuring and importantly reducing whole life carbon emissions. Currently very few projects globally have rigorous carbon assessments and we need to change this situation quickly. This is not yet a trivial exercise as the WLCA requires assumptions to be made regarding current and future $CO_2e$ intensities of both the energy and materials supply.

**Figure 3:** Global Annual $CO_2$ Emissions (Mt), Our World in Data and Global ABC/IEA/UNEP (2020)[3, 6]



We explore these assumptions in more detail and we point to the current limitations in relation to assessing and reporting whole life carbon and to the need for consistency and rigor in the methods adopted with a particular focus on; the life cycle stages, the building elements scope, the general assumptions made and the decarbonization scenario adopted for energy use.

Collecting and sharing data relative to the carbon footprint of individual projects will help to build up a better understanding of where we are currently and where we need to get to as global industry in relation to the high-level vision to decarbonize all buildings by the middle of this century. The case studies address the need for transparent data by sharing the information such as the building general description and systems, the highest contributing materials and components, the energy consumption and the carbon factors chosen. It is important to note that WLCA is still a field in development and it is not a precise science. The assumptions are based on best available information. The importance here is to understand the main drivers, what the biggest contributors are and what needs to be done to reduce our carbon impact.

## OUR APPROACH

1. **Framework.** The first section of this report describes the methodology adopted for the WLCA case studies. We integrate the global 2030 and 2050 decarbonization vision for the building industry proposed by WorldGBC, which is now widely supported by key organizations such as WBCSD, GlobalABC, WMB and the UNFCCC Marrakesh Partnership Climate Action Pathways. To relate this high-level vision to our case studies, we discuss WLCA benchmarks and potential targets.
2. **Case studies.** The second section summarizes the six case studies providing an introductory overview of the buildings and outlining the results of the WLCAs using the Building System Carbon Framework published by WBCSD in 2020 as the principal reporting structure.
3. **Analysis.** The third section analyzes the results highlighting common synergies, challenges and limitations. The results are discussed in line with the targets proposed in the first section. This seeks to present an indicative outline of current achievable performance against a potential net-zero trajectory.
4. **Supporting data.** The fourth section acts as an appendix giving detailed information on each of the six case studies WLCAs. This fulfills one of the key objectives of this study which is to report transparently the data used in the case studies.

**Figure 4:** Estimated distribution of carbon emissions per life cycle stage

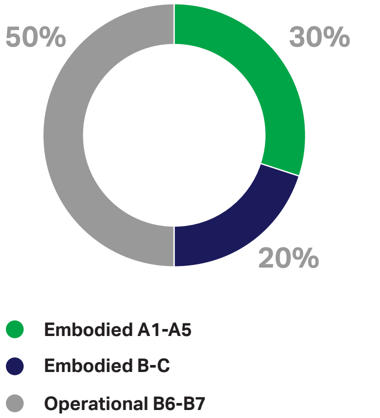
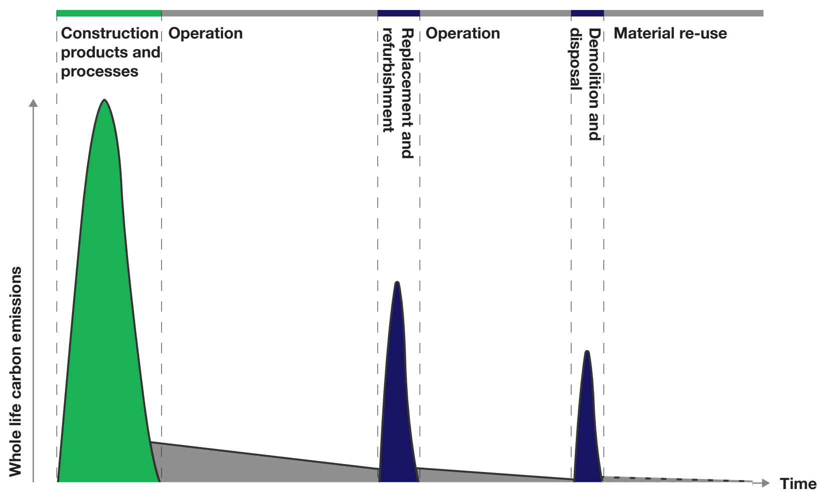



**Figure 5:** Whole life carbon emissions, Arup (2020)[7]



# 1. 1 Whole life cycle assessment methodology

### GENERAL APPROACH

A key aspect of a WLCA is to adopt some form of recognized and standardized methodology so that benchmarks and targets can be established in a consistent way. Currently a number of methodologies are emerging with consistent principles across each. For example:

- International Organization for Standardization (2006), ISO 14040: 2006 Environmental Management - Life cycle Assessment - Principles and Framework[8]
- European Standard EN15978 (2011), Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method[9]
- Royal Institution of Chartered Surveyors (RICS) (2017), Whole Life Carbon Assessment for the Built Environment[10]
- WBCSD (2020), The Building System Carbon Framework[11]

As this study is intended to be internationally representative, we have built upon the work of WBCSD and adopted the Building System Carbon Framework (BSCF, fig. 6) to present our results.

In addition, we have integrated the RICS building elements classification in the section 4 of this report, as this is the most used reporting format so far owing to its advanced stage of maturity. This approach will help when comparing available industry benchmarks.

The differences between the BSCF table used to report the case study summaries and the extended version presented in section 4 are:

- The structure is divided between substructure and superstructure
- The space plan is divided between internal walls and internal finishes
- The site emissions are reported in a distinct cell

In both cases, the carbon compensation row figuring in the BSCF was removed as it was out of scope for this work.

### SYSTEM BOUNDARIES

- The building's life cycle is split into different life cycle stages A to D, themselves divided in modules. These are described in the EN 15978:2011[6] and summarized below:

### Stage A: Product and construction

The end of this stage marks the practical completion of the building. This stage only relates to embodied carbon.

**A1-A3:** Product stage and manufacturing – accounting for the carbon emissions associated with the "cradle to gate" processes: raw material supply, transportation and manufacturing processes.

**Figure 6:** Building System Carbon Framework, WBCSD (2020)[11]

| | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | $kgCO_2/m^2$ | D |
| BUILDING LAYERS | **Structure**<br>Foundation, load-bearing | | | | | | | |
| | **Skin**<br>Windows, roof, insulations | | | | | | | |
| | **Space plan**<br>Interior finishes | | | | | | | |
| | **Services**<br>Mechanical, electrical, plumbing | | | | | | | |
| | **Stuff** *(optional)*<br>Furniture and appliances | | | | | | | |
| | **Building carbon emissions** | | | | | | | |
| | **Carbon compensation**<br>Removals and offset | | | | | | | |

Embodied carbon · Operational carbon · Partial and total sums

**A4-A5:** Construction stage process – accounting for the carbon emissions associated with the transportation of the materials to site and the construction itself (material wastes, construction plant and machineries).

**Stage B: In use**
Throughout this stage, the building is in function. It is divided in five modules relating to embodied carbon and two relating to operational carbon.

**B1-B5:** In use embodied – accounting for the carbon emissions associated with the maintenance, repair, replacement and refurbishment of the built asset over its lifetime. For buildings, embodied emissions generally only concern B4 – owing to the availability of data at the time of reporting.

**B6-B7:** In use operational – accounting for the carbon emitted throughout the utilization of the building (energy and water). Operational energy may be calculated using the current grid energy carbon factor and accounts for decarbonization scenarios in line with national assumptions.

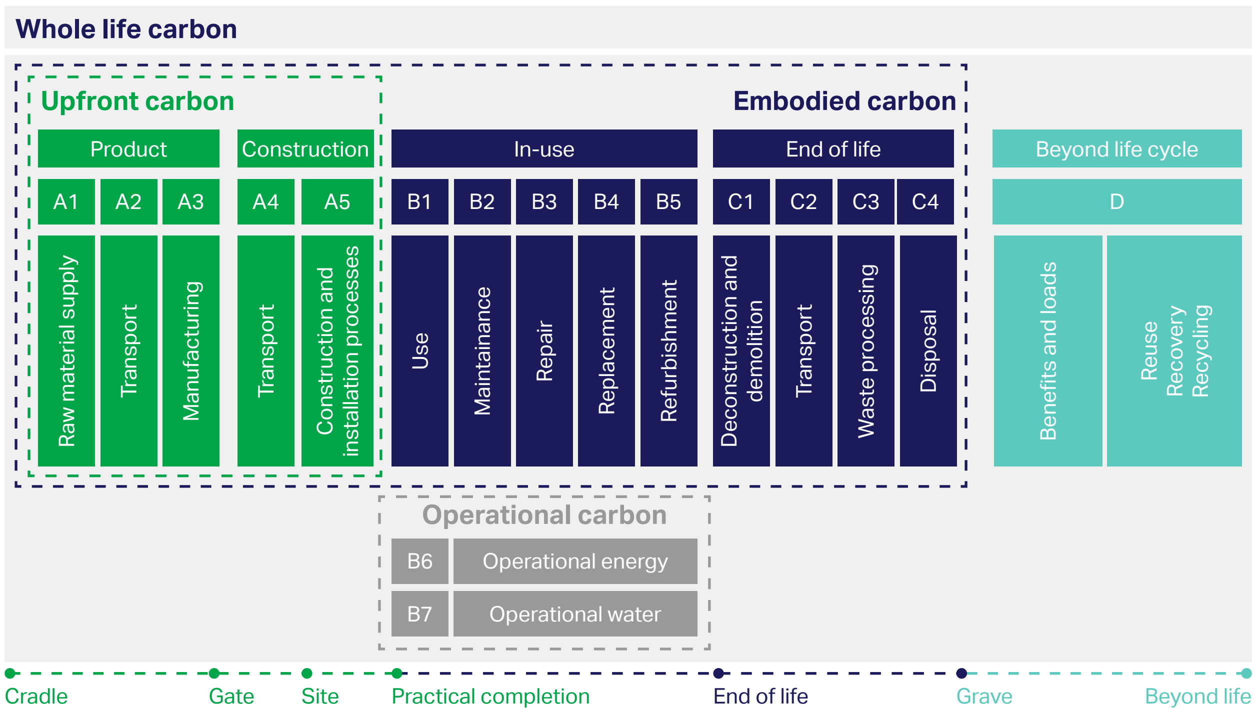
**Stage C: End of life**
This stage is associated with the demolition and waste processing of construction materials. It generally has a low impact however when using biogenic material, the disposal will release a part or all of the sequestered carbon to the atmosphere depending of the end of life scenario considered.

**Stage D: Beyond life benefits**
This module accounts for benefits or burdens associated with repurposing building elements e.g. discarded materials from the built asset or energy recovered from beyond the project's life cycle. This seeks to present a wider picture of the environmental impacts of the project and accounts for the future potential of the products and the circular economy.
The carbon emissions associated with Module D are generally not included within the whole life carbon emission as they are outside the building system. The values are however interesting in the context of circular economy.

Further information on WLCA methodology and calculating embodied carbon can be found in RICS and IStructE guidance referenced at this end of this report.[10, 12]

In this study, the scope considers modules A, B and C and reports module D separately.

**Figure 7: Whole life cycle stages, EN15978 (2011)**[10]



## BUILDING ELEMENTS SCOPE

The scope of an WLCA also needs to specify which parts and elements of the building are to be assessed. This is essential to be able to create benchmarks and is often not clearly defined.

In this study, the scope encompasses the elements from the table below which uses the WBCSD BSCF reporting structure linked back to the RICS categories.

Each building element category refers to a particular color used consistently throughout the report as per the table below.

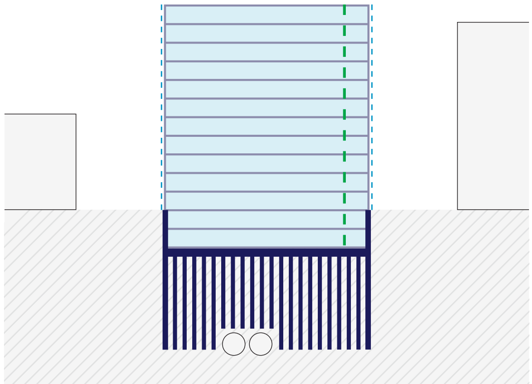


**Table 1:** WBCSD (2020) and RICS (2017) building elements categories[10, 11]

| WBCSD | RICS | | | |
|---|---|---|---|---|
| **BSCF** | **Level 1** | **Element Group** | **Level 2** | **Element Group** |
| Structure | 1 | Substructure | 1.1 | Substructure |
| | 2 | Superstructure | 2.1 | Frame |
| | | | 2.2 | Upper floors |
| | | | 2.3 | Roofs |
| | | | 2.4 | Stairs and ramps |
| Skin | 2 | Façade | 2.5 | External walls |
| | | | 2.6 | Windows and external doors |
| Space Plan | 2 | Internal walls and partitions | 2.7 | Internal walls and partitions |
| | | | 2.8 | Internal doors |
| | 3 | Internal finishes | 3.1 | Wall finishes |
| | | | 3.2 | Floor finishes |
| | | | 3.3 | Ceiling finishes |
| Stuff | 4 | FF&E | 4.1 | Fittings, furnishings and equipment |
| Services | 5 | Building services | 5.1 – 5.14 | Building services |

## GENERAL ASSUMPTIONS

While creating these case studies, we realized that it is not yet trivial to gather data on all parameters influencing the results (material quantities, specifications, carbon factors, etc.). Therefore, we need to make assumptions based on the best available data. Ultimately it will be important as we grow the database of WLCA for projects globally that there is a general level of transparency and consistency allowing us to make good comparisons. To this end we have for this particular study used the following key assumptions which can be developed and adapted in the future.

**Table 2: Whole life cycle WLCA case studies – general assumptions**

| | |
|---|---|
| General | **Best guesses** are made on build-ups, thicknesses and material selection at the time of the project assessment.<br><br>**Allowances** are made for categories where material quantities are unknown (typically building services) based on past projects. |
| Transportation scenarios[10] | 50km – Locally manufactured<br>300km – Nationally manufactured<br>1,500km – European manufactured |
| Element lifespan[10] | Structural frame and foundations – 60 years<br>Roof coverings – 30 years<br>Partitions – 30 years<br>Finishes – 30/20/10 years<br>Façade elements – 35/30 years<br>FF&E – 10 years<br>Services – 20 years |
| Building life | 60 years |
| Services | Factor assumed of 120 $kgCO_2e/m^2$ for services within office buildings; and 70 $kgCO_2e/m^2$ for services within residential buildings. CIBSE (2013).[10] |
| Construction site impacts (A5w + A5a)[13] | OneClick LCA Europe factor of 30.34 $kgCO_2e/m^2$ GIA which assumes an average production of construction waste of 5 kg/$m^2$, an electricity use of 37 $kWh/m^2$ and a total use of diesel 4.5 $l/m^2$. |
| Carbon factors data sources[15] | Environmental Product Declarations (EPD) from manufacturers<br>Databases: Inventory of Carbon and Energy (ICE), Ecoinvent, Okobaudat, Inies<br>OneClick LCA carbon factors<br>Material carbon factors assumed constant throughout the WLCA (not accounting for material decarbonization) |

## ENERGY USE – DECARBONIZATION SCENARIOS

The energy use intensity (EUI) of a building over its life span is typically calculated in kWh/m$^2$ – most regulations relate to this energy use intensity and not specifically to carbon emissions.

It can be challenging to convert the EUI into $CO_2$e as it involves both a clear understanding of the current production intensities as well as a clear understanding of how the production (i.e. the grid) will decarbonize over time. Current predictions on grid decarbonization rely heavily on having a clear understanding of specific long-term national strategies and the outcomes in terms of available clean energy mixes over time. There is a lot of uncertainty globally in relation to real and verified grid decarbonization trajectories.

Since it is hard to gauge, especially in a country-specific way, we have been forced for this particular set of case studies to make a series of assumptions.

The electricity operator for the UK issued a series of Future Energy Scenarios (FES).[16] The projections show how governments decisions – currently in place to reach 2030 and 2050 targets – affect the grid carbon factor.

The different scenarios relate to the development of technologies in renewable energies and the strategies in place to reduce demand such as consumer engagement, improved home insulation and growth in electric vehicles usage.

For the purpose of this work, the FES scenario "steady progression" projection is applied to each country's or region's currently available data, unless specified otherwise. For example, in the UK, the data set has been adjusted such that the 2020 figure matches with the latest measured value while the 2050 targets would still be reached.[17]

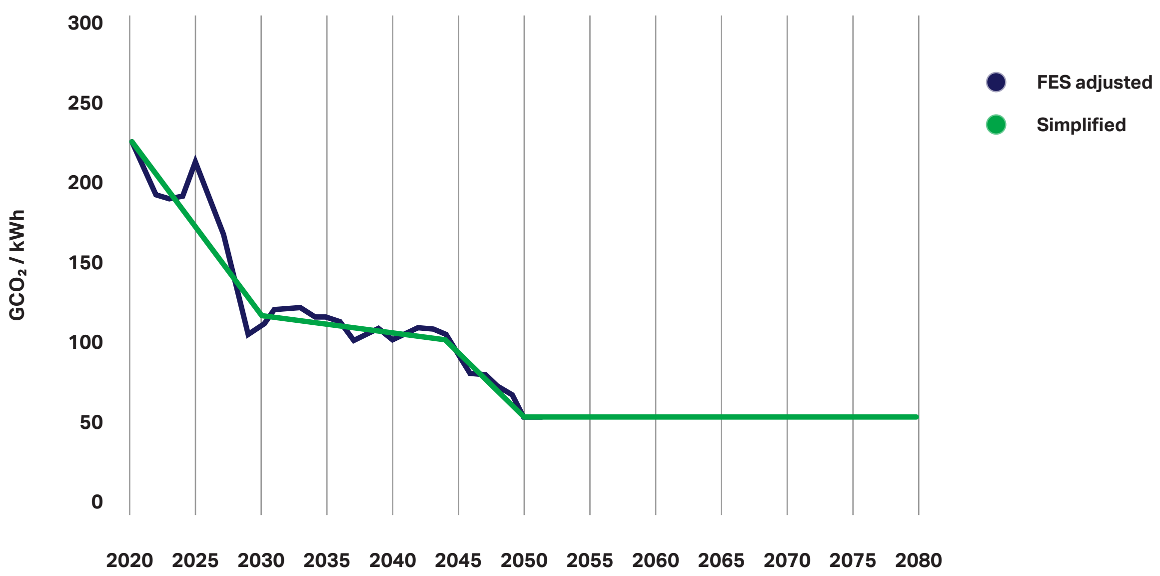
This is viewed as a conservative approach as the "steady progression" scenario paints a rather carbon heavy progression compared to others that rely on the grid to decarbonize completely by 2050.

This means that this approach also pushes for optimization of energy strategies and for a reduction of the global demand.

Decarbonization scenarios have not been applied to the building materials/components replaced through stage B. This is owing to a lack of data availability for the context of the case studies.

Each country needs to develop a better understanding of their national grid decarbonization trajectories and clear and simple process should be agreed to undertake operational carbon calculations.

**Figure 8:** $CO_2$ intensity of electricity generation – estimated progression



# 1.2 Net-zero buildings, benchmarks and targets

In the context of the building industry, the definition from the IPCC means that the demand for construction materials and the demand for energy to operate buildings need to be reduced to a point where it can all be sourced without emitting additional GHG emissions (figure 10). This needs to be considered at systems level but also accounted for at the level of individual building assets by applying the following principles:

1. Designing more efficient buildings – reduce material and energy demand
2. Using circular economy principles – reuse existing material and design new buildings to be dismantlable and reusable
3. Using renewable energies and low carbon materials
4. Neutralizing residual carbon emissions.

Although consensus is still building, certain types of offset are possibly an option to balance the minimised residual emissions and pursue a global net-zero built environment.

> Net-zero carbon dioxide ($CO_2$) emissions are achieved when anthropogenic $CO_2$ emissions are balanced globally by anthropogenic $CO_2$ removals over a specified period.[4]
>
> **Intergovernmental Panel on Climate Change**

**Figure 9:** Embodied carbon reduction strategy

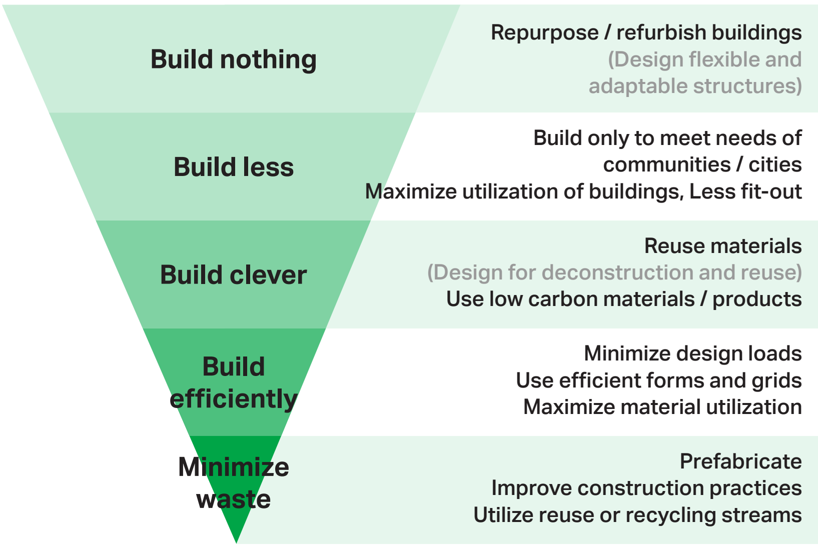
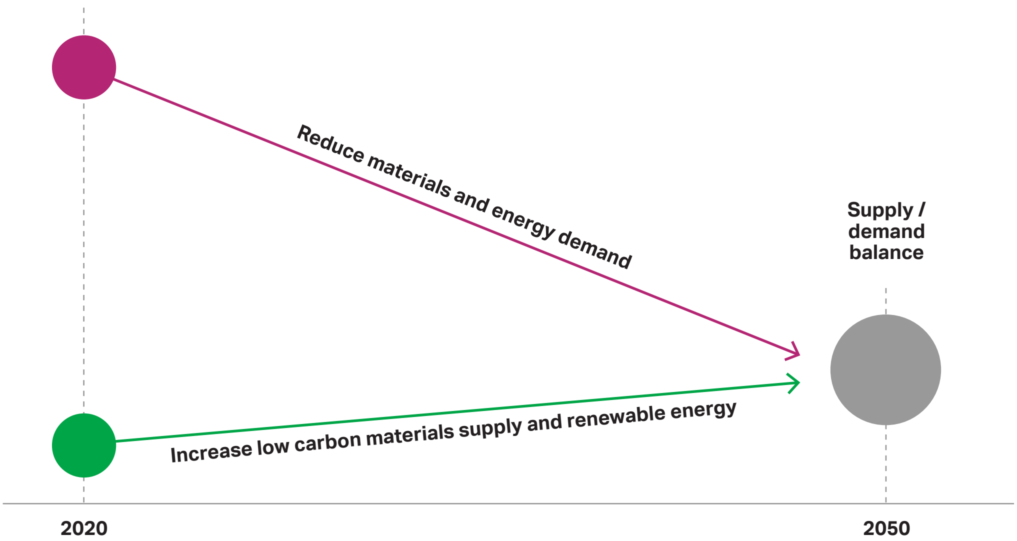



**Figure 10:** Net-zero strategy for the built environemnt, Arup (2020)[7]



## EMERGING BENCHMARKS AND TARGETS TOWARD NET-ZERO

To meet the targets outlined within the Paris Agreement, scientists have estimated that the building industry needs to reach net zero by 2050.[1]

The World Green Building Council broke down the net-zero objective between embodied carbon and operational carbon, implementing a major milestone in 2030.[18]

This high level vision is becoming a recognized objective by influential organizations such as WBCSD, GlobalABC and UNEP and is being adopted more widely as awareness builds.

The definition of net-zero carbon and the short period of time allowed to reach it unveils a massive challenge for the construction industry which needs to adopt immediately new ways of designing much more efficient buildings with sustainable resources.

In order to react in time, the construction industry needs to set clearer and more explicit targets. This will encourage universal measurement of carbon emissions, set short and long term priorities on how to reduce them and accelerate the transition toward a net-zero carbon built environment.

## EMBODIED CARBON TARGETS

The list below outlines some examples where more defined targets are beginning to emerge. The representative sample further showcases where different parts of the building industry can collaborate towards a single goal. This section also attempts to understand what business as usual carbon impact might look like – to be able to assess and frame the 40% reduction on embodied carbon aimed at by 2030.[15]

### Royal Institute of British Architects (RIBA) – Institution

RIBA is the main professional body representing architects in the United Kingdom and well recognized internationally. RIBA sets the following targets:

- Embodied: 1,100 $kgCO_2e/m^2$ as a business as usual benchmark over the whole life with best practice representing 500 $kgCO_2e/m^2$ by 2030 for non-domestic buildings.

### London Energy Transformation Initiative (LETI) – Initiative

LETI regroups professionals from the built environment dedicated to put London on an exemplary path to reduce carbon emissions. They recommend the following:

- Embodied: Baseline of 1,000 $kgCO_2e/m^2$ and a best practice 2020 target of <600 $kgCO_2e/m^2$ for office buildings.

### Greater London Authority (GLA) – Policy

The GLA is the official governance body of London which notably regulates the built environment and provides construction permits.

- Embodied: For office buildings, GLA estimated the business as usual embodied carbon at practical completion to be 950 $kgCO_2e/m^2$ and 1,400 $kgCO_2e/m^2$ over the whole life. They recommend aspirational targets at respectively 500 $kgCO_2e/m^2$ and 850 $kgCO_2e/m^2$.[21]

### Carbon Leadership Forum (CLF) – Initiative

The CLF (based in the United States) unites professionals from the built environment to accelerate the transition to net-zero with a focus on embodied carbon.

- Embodied: CLF estimates the Stage A carbon impact of the structure, substructure and façades to be less than 1,000 $kgCO_2e/m^2$. In addition, their studies show that the substructure and superstructure (for offices) is typically responsible for 500 $kgCO_2e/m^2$. As these generally represent 50-60% of the total upfront carbon emissions, we deducted from the CLF studies, a benchmark figure of 950 $kgCO_2e/m^2$ for BAU.[22]

### One Click LCA Ltd –

One Click LCA Ltd. is the developer of the LCA and LCC Software, One Click.

- Embodied: Based on an extensive dataset of office buildings in twelve Western European countries, they estimate the current benchmark (2021) for embodied carbon at practical completion as 600 $kgCO_2e/m^2$. This number corresponds to a minimum scope of substructure, structure and façade, which are generally responsible for approximately 70% of the upfront carbon. Therefore, the full scope should approximate 900 $kgCO_2e/m^2$.[23]

## By 2030,
## new buildings, infrastructure and renovations will have at least 40% less embodied carbon with significant upfront carbon reduction, and all new buildings must be net-zero operational carbon.[18]

**Whole life carbon vision (WorldGBC)**

**Figure 11:** Upfront embodied carbon targets

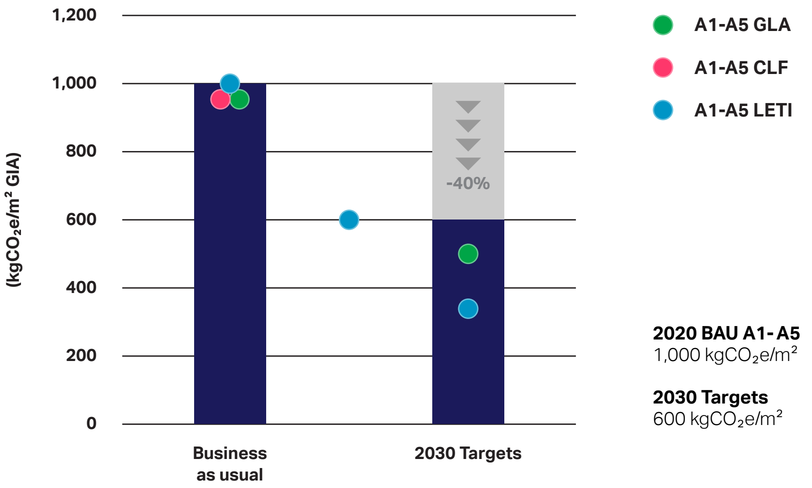



Figure 11 presents current business as usual (BAU) figures in comparison to indicative 2030 targets for upfront embodied carbon and whole life embodied carbon within the industry context.

**Although by no means a rigorous process, a number of the key organizations referenced within this report point to a value of circa 1,000 $kgCO_2e/m^2$ as a credible value to capture global BAU upfront embodied carbon benchmarks (A1-A5).**

If this was accepted, the 2030 target of a minimum 40% reduction would establish a future target for all projects of a maximum of 600 $kgCO_2e/m^2$.

Although this would represent a progressive target if achieved on a global scale, consideration should be given based on these, albeit advanced, case studies as to whether this is ambitious enough.

Further to proposing a construction (A1-A5) BAU value we have subsequently estimated an extra 30% for the whole life embodied benchmark (based on RIBA, GLA and Arup past projects). This would give a WLCA (A-C) embodied carbon BAU reference value in the region of 1,300 $kgCO_2e/m^2$ against which we can compare our case study results.

Should this be the agreed baseline for comparison, the case study selection would suggest already progressive whole life embodied carbon results. Clearly, much more global data is required in this field to establish clear BAU benchmarks and from there set clearer and fixed targets.

Where targets are not aspirational enough, the industry should revisit these in line with emerging research, innovation and collected data to better establish, assess and ultimately reduce the in-use embodied carbon emissions associated with our building projects.

## OPERATIONAL CARBON TARGETS

Similarly, the organizations referenced below are beginning to propose targets on buildings Energy Use Intensity (EUI) and their respective carbon impact aligned with a view of achieving a credible reduction in EUI demand by 2030 to guide the industry toward decarbonization.

**Royal Institute of British Architects (RIBA)** – Institution

- Operational: The energy use intensity should progressively regress from 225 kWh/m² (usual benchmark) to 55 kWh/m² for non-domestic buildings.[19]

**London Energy Transformation Initiative (LETI)** – Initiative

- Operational: LETI also targets 55 kWh/m² for office buildings with 15 kWh/m² attributed to heating.[20]

**The Real Estate Environmental Benchmark (REEB)** – Initiative

Set by the Buildings Better Partnership, the REEB benchmark is a publicly available operational benchmark for commercial buildings in the UK. The benchmark is based on the buildings 'in-use' data adopting a 3-year rolling average.

- Operational: For office buildings, REEB presents a 2019 benchmark for operational energy threshold of 233 kWh/m² for air-conditioned offices.[24]

**Climate Risk Real Estate Monitor (CRREM)** – Tool

Climate Risk Real Estate Monitor is a tool developed with funds from the European Commission Horizons 2020 program by a consortium of 5 partners including academic institutions and SMEs. CRREM defines the decarbonization pathway for buildings in alignment with the commitments of the Paris Agreement.

- Operational: CRREM developed building use specific decarbonization pathways for all EU countries and the largest international real estate markets. The pathways are bespoke to the buildings' country of origin and the sectoral market. The pathways are expressed in both $kgCO_2e/m^2$ and kWh/m². For the purpose of this report, we are expressing the CRREM pathways as decarbonization targets. Refer to Figures 12 and 13.[25]

**Swiss Engineers and Architects Association (SIA)** – Association

- Operational: The SIA 2000-Watt Society Energy Efficiency Path sets an operational energy 2050 target for new and refurbished office buildings at 80kWh/m² and 100kWh/m² respectively. By 2050, this would correspond to 4 and 6 $kgCO_2e/m^2$/year respectively in Switzerland.[26]

Typically, the energy use intensity (EUI) of a building over its life span is calculated and reported in kWh/m², as opposed to $kgCO_2e/m^2$, to reduce the level of assumptions needed to account for particular national energy grid carbon intensity and decarbonization trajectories. If a project is to be zero carbon in operation by 2030, the EUI needs to reduce to a point where it can be fully provided by renewable energy supply.

The data shown in the diagram opposite corresponds to office buildings as an example. Clearly, each country should establish and clarify specific target data in line with their own national energy system decarbonization trajectory as a key next step.

The second graphic translates the EUI in carbon emissions of UK initiatives (LETI/RIBA/UKGBC) using the UK grid carbon factors (as available at the time) and applying the decarbonization trajectory scenario described previously in the report. It shows that to meet the suggested UK demand target by 2030, 10kg/$CO_2e/m^2$/year will need to be provided via clean energy. As a mean of comparison, the CREEM pathways for UK, DK and ND are also plotted on the graphic.

Clearly, there is a great need for better, clearer data and more transparency from a wider number of individual countries in relation to setting targets aligned with credible national energy system decarbonization scenarios.

**Figure 12:** Energy use targets

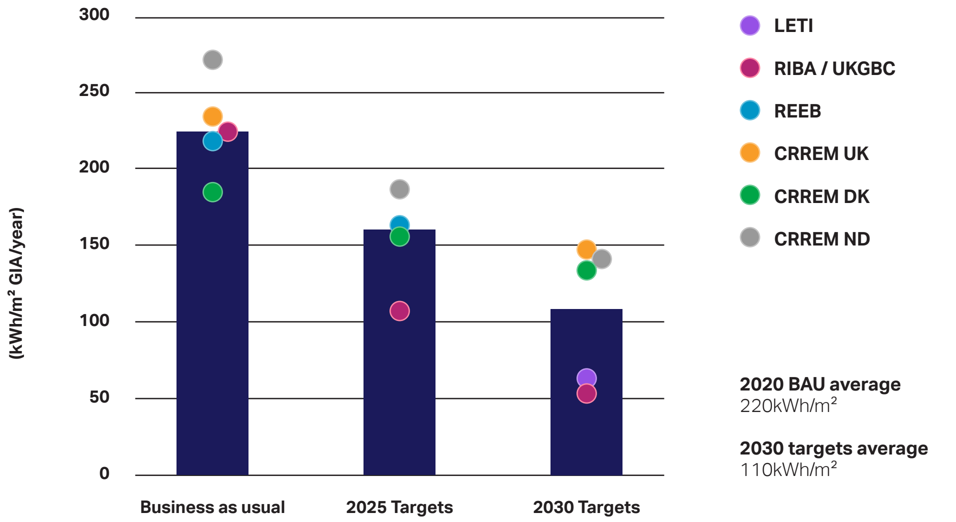
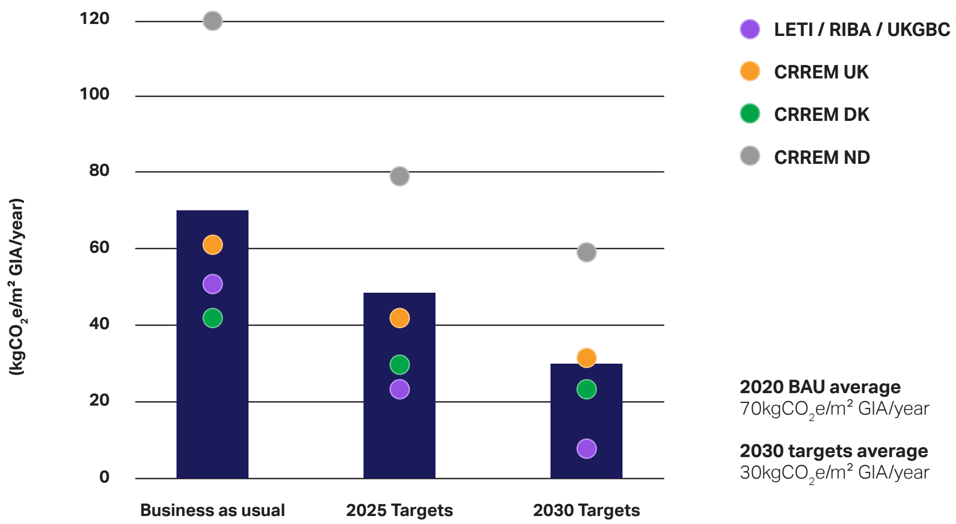



**Figure 13:** Operational carbon targets

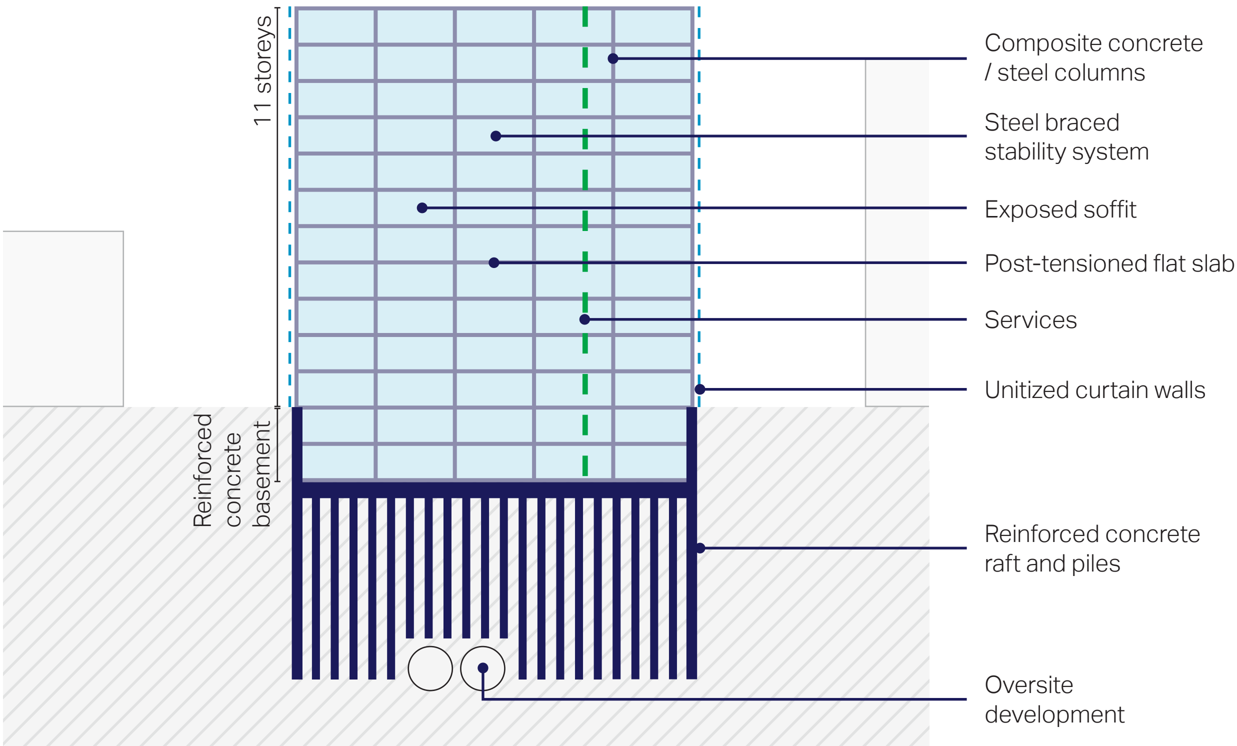


# 2 Case studies summary



This section gives summary data only.
For more detailed information on the case studies including key factors related to their design development the reader should reference section 4 - additional data on case studies.

# 01. Office building, London, UK




**TYPE**
Office, New build

**LOCATION**
London, UK

**DEVELOPMENT STAGE**
Manufacturing and construction

**GIA**
29,819 m²

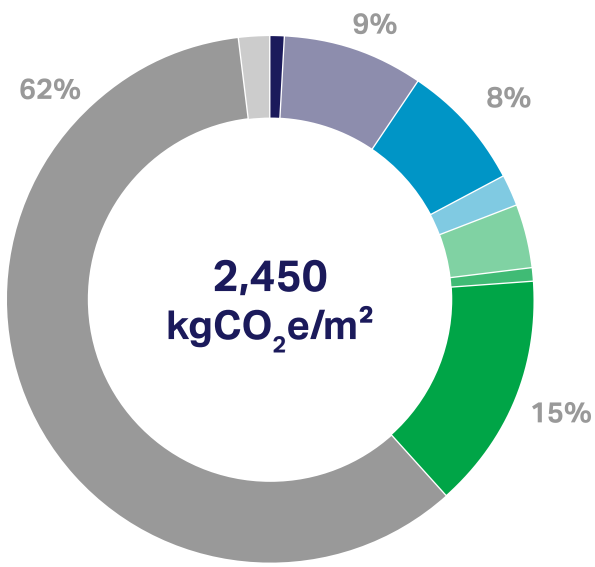
**RATING SCHEME**
LEED V4 Gold
BREEAM 2014 Outstanding

**TOOL**
OneClick LCA

**PROJECT DATA**
Late design stage information: cost plan, drawings and specifications. Structural material quantities issued directly by contractor. Allowance made for services embodied carbon.

**ANNUAL ENERGY CONSUMPTION**
222 kWh/m²/year

**Figure 14:** Whole life carbon (A-C)



## Main results

**Figure 15:** Embodied carbon at practical completion (A1-A5)

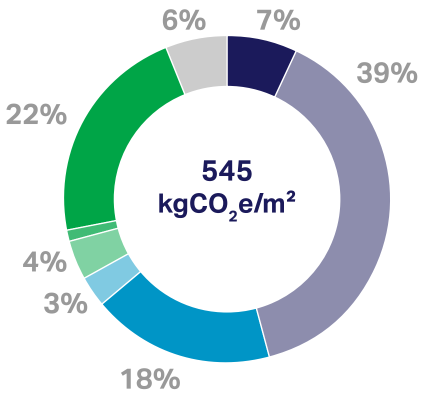
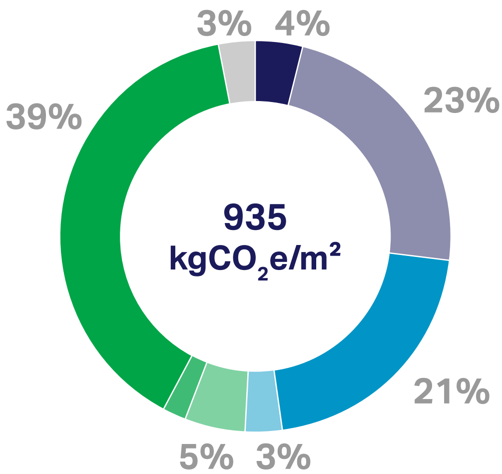



**Figure 16:** Embodied carbon over the life cycle (A-C)



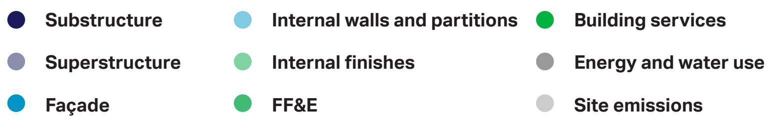
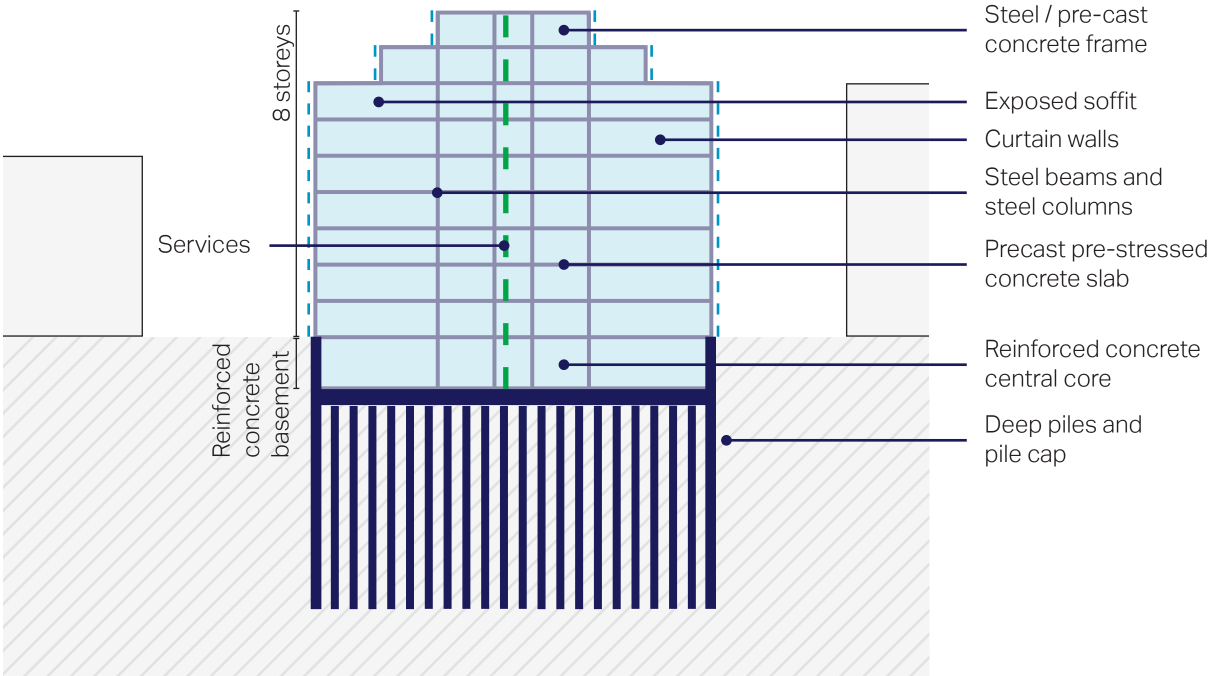




**Table 3:** Building system carbon framework

| BUILDING LAYERS | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | $kgCO_2e/m^2$ | D |
| BUILDING LAYERS | **Structure** Substructure and superstructure | 240 | 9 | 6 | | 4.1 | 258 | -53 |
| | **Skin** Façade | 100 | 1 | 94 | | 0.2 | 195 | 111 |
| | **Space plan** Partitions and internal finishes | 39 | 0 | 39 | | 0.2 | 78 | -2 |
| | **Services** Building services, energy and water use | 120 | 1 | 240 | 1512 | 1.4 | 1873 | -56 |
| | **Stuff** Fittings, furnishings and equipment (FF&E) | 5 | | 10 | | | 15 | -5 |
| | **Site emissions** Waste, electricity and fuel | | 30 | | | | 30 | |
| | **Building carbon emissions** Embodied and operational | **503** | **40** | **388** | **1,512** | **6** | **2,449** | **-227** |

# 02. All electric office building, London, UK




**TYPE**
Office, New build

**LOCATION**
London, UK

**DEVELOPMENT STAGE**
Building's handover

**GIA**
40,065 $m^2$

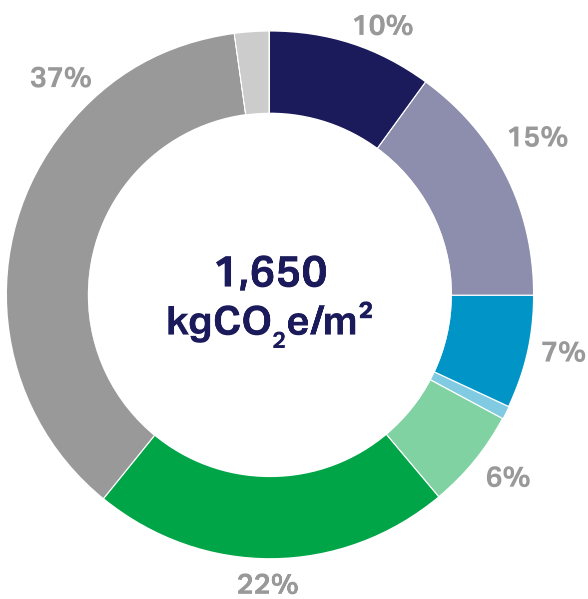
**RATING SCHEME**
LEED 2014 Gold
BREEAM 2014 Excellent
Ecohomes Excellent

**TOOL**
OneClick LCA and Arup PECC tool

**PROJECT DATA**
Late design stage information: engineers' quantities from calculations and models and cost plan. Allowance made for services embodied carbon.

**ANNUAL ENERGY CONSUMPTION**
109 kWh/$m^2$/year

**Figure 17:** Whole life carbon (A-C)



## Main results

**Figure 18:** Embodied carbon at practical completion (A1-A5)

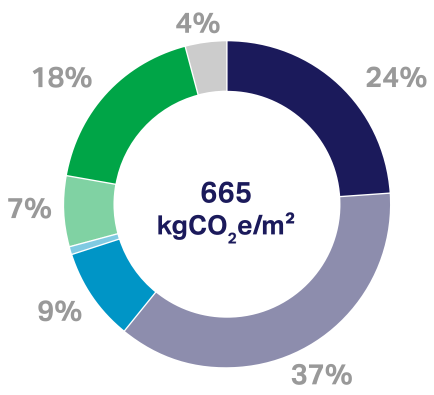
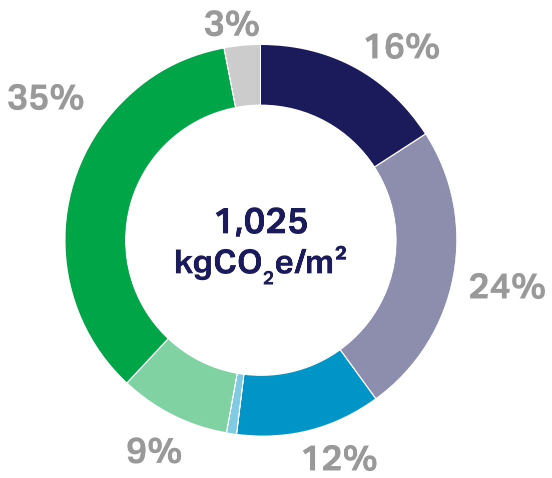



**Figure 19:** Embodied carbon over the life cycle (A-C)

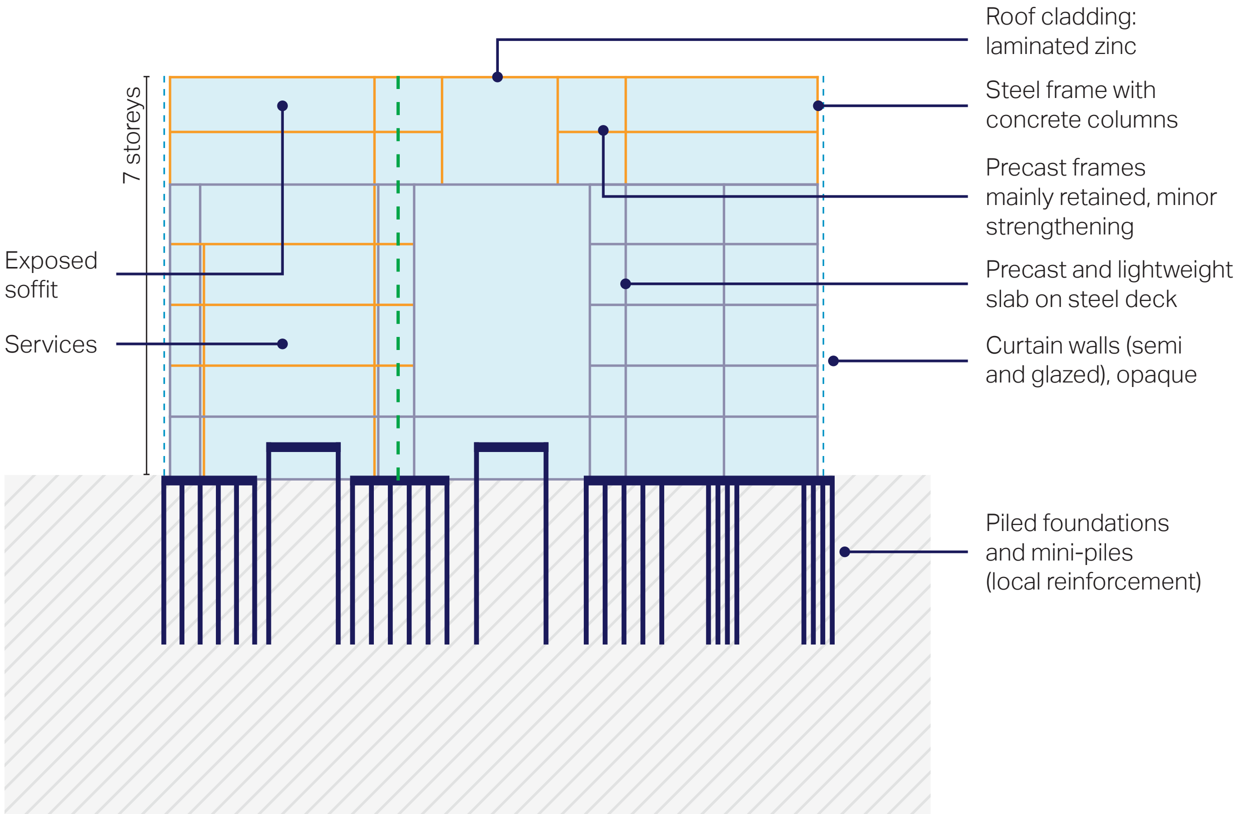



- Substructure
- Superstructure
- Façade
- Internal walls and partitions
- Internal finishes
- FF&E
- Building services
- Energy and water use
- Site emissions

**Table 4:** Building system carbon framework

| | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | kgCO$_2$e/m$^2$ | D |
| BUILDING LAYERS | **Structure** Substructure and superstructure | 392 | 11 | 0 | | 5.0 | 408 | -107 |
| | **Skin** Façade | 59 | 1 | 59 | | 0.6 | 120 | -33 |
| | **Space plan** Partitions and internal finishes | 51 | 2 | 53 | | 0.9 | 107 | -7 |
| | **Services** Building services, energy and water use | 120 | 1 | 240 | 620 | 1.3 | 981 | -60 |
| | **Stuff** Fittings, furnishings and equipment (FF&E) | 0 | | 0 | | | 0 | 0 |
| | **Site emissions** Waste, electricity and fuel | | 30 | | | | 30 | |
| | **Building carbon emissions** Embodied and operational | **623** | **44** | **352** | **620** | **8** | **1,647** | **-208** |

# 03. Complete transformation office building, London, UK




**TYPE**
Office, Complete transformation

**LOCATION**
London, UK

**DEVELOPMENT STAGE**
Concept design

**GIA**
42,776 m$^2$

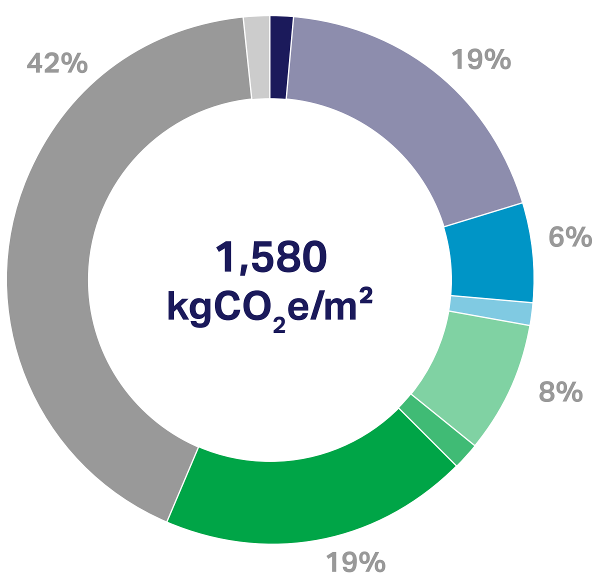
**RATING SCHEME**
Aiming for BREEAM 2018 Outstanding

**TOOL**
OneClick LCA

**PROJECT DATA**
Concept design information: cost plan and drawings. Industry averages as material specifications. Energy consumption predicted through building energy modelling.

**ANNUAL ENERGY CONSUMPTION**
118 kWh/m$^2$/year

**Figure 20:** Whole life carbon (A-C)



## Main results

**Figure 21:** Embodied carbon at practical completion (A1-A5)

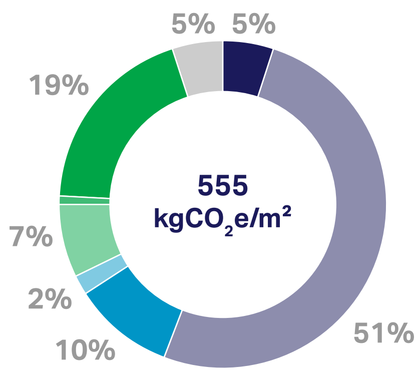
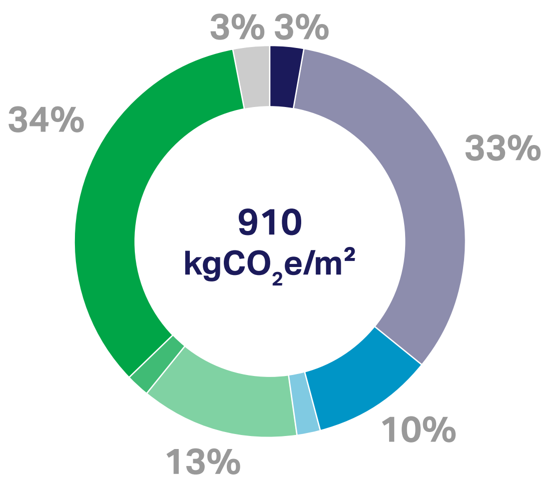



**Figure 22:** Embodied carbon over the life cycle (A-C)

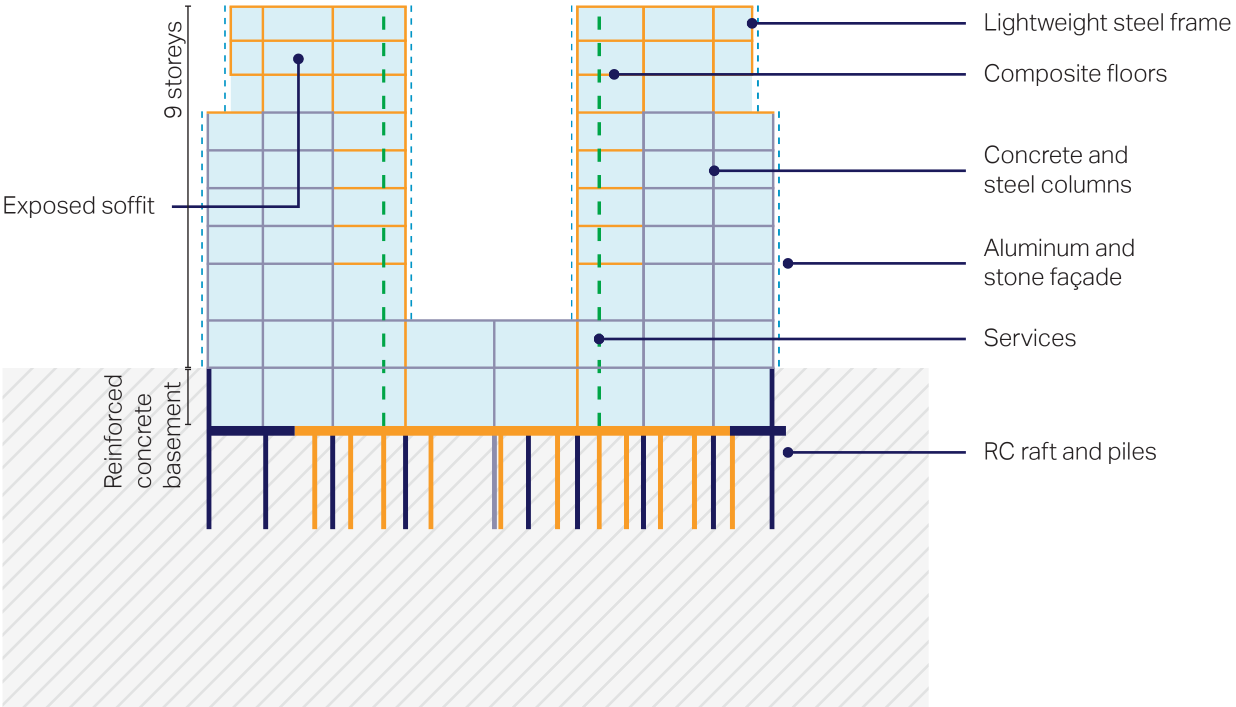



- Substructure
- Superstructure
- Façade
- Internal walls and partitions
- Internal finishes
- FF&E
- Building services
- Energy and water use
- Site emissions

**Table 5:** Building system carbon framework

| | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | kgCO$_2$e/m$^2$ | D |
| BUILDING LAYERS | **Structure** Substructure and superstructure | 303 | 5 | 14 | | 2.7 | 326 | -108 |
| | **Skin** Façade | 54 | 0 | 38 | | 0.1 | 93 | -21 |
| | **Space plan** Partitions and internal finishes | 51 | 0 | 84 | | 0.5 | 136 | -3 |
| | **Services** Building services, energy and water use | 104 | 1 | 200 | 670 | 1.0 | 976 | -51 |
| | **Stuff** Fittings, furnishings and equipment (FF&E) | 4 | | 18 | | | 21 | -8 |
| | **Site emissions** Waste, electricity and fuel | | 30 | | | | 30 | |
| | **Building carbon emissions** Embodied and operational | **516** | **37** | **354** | **670** | **4** | **1,582** | **-145** |

# 04. Refurbishment office building, London, UK




**TYPE**
Office, Refurbishment

**LOCATION**
London, UK

**DEVELOPMENT STAGE**
Refurbishment completed

**GIA**
47,264 m²

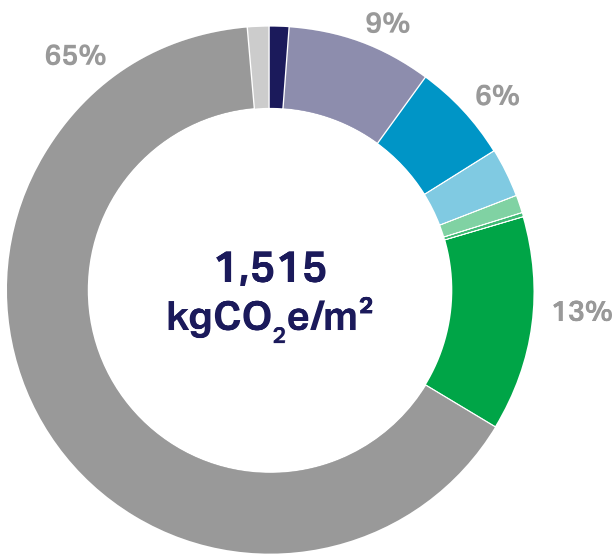
**RATING SCHEME**
LEED V4 Gold
BREEAM 2014 Outstanding

**TOOL**
OneClick LCA

**PROJECT DATA**
Late design stage information – cost plan, drawings and specifications. Structural material quantities issued by contractor as well as emissions due to site activity. Services embodied carbon calculated from quantities issued by the engineers.

**ANNUAL ENERGY CONSUMPTION**
149 kWh/m²/year

**Figure 23:** Whole life carbon (A-C)



## Main results

**Figure 24:** Embodied carbon at practical completion (A1-A5)

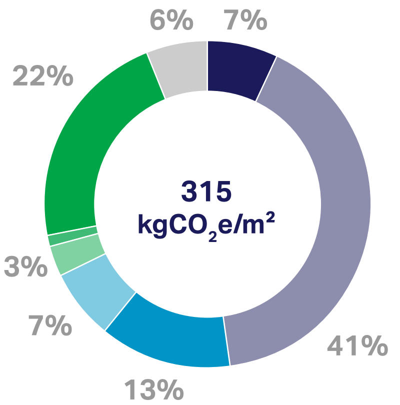
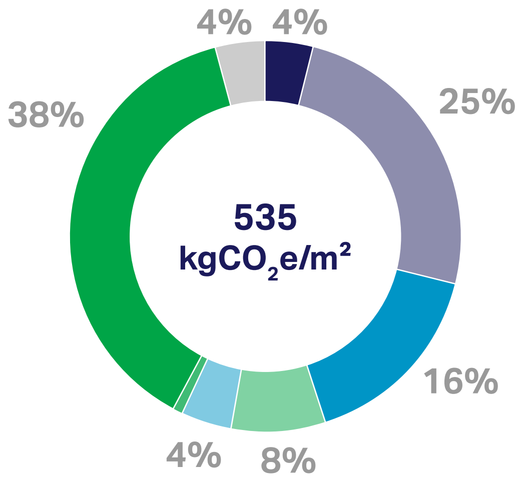



**Figure 25:** Embodied carbon over the life cycle (A-C)



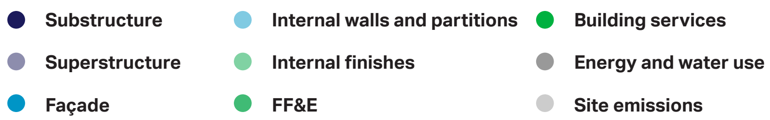
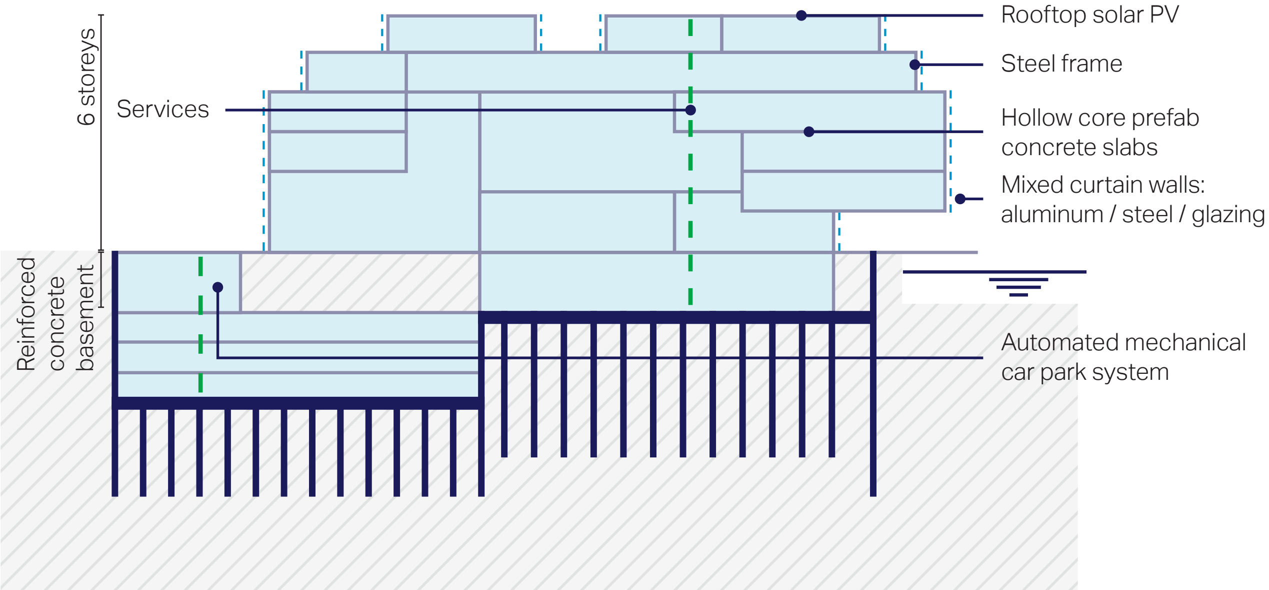




**Table 6:** Building system carbon framework

| | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | $kgCO_2e/m^2$ | D |
| BUILDING LAYERS | **Structure** Substructure and superstructure | 146 | 3 | 2 | | 3.2 | 155 | -62 |
| | **Skin** Façade | 41 | 0 | 41 | | 0.1 | 83 | 50 |
| | **Space plan** Partitions and internal finishes | 31 | 1 | 33 | | 1.0 | 66 | -18 |
| | **Services** Building services, energy and water use | 67 | 0 | 134 | 983 | 0.8 | 1,185 | -21 |
| | **Stuff** Fittings, furnishings and equipment (FF&E) | 3 | | 3 | | | 6 | -6 |
| | **Site emissions** Waste, electricity and fuel | | 20 | | | | 20 | |
| | **Building carbon emissions** Embodied and operational | **289** | **24** | **214** | **983** | **5** | **1,515** | **-155** |

# 05. Mixed-use building, Copenhagen, DK




**TYPE**
Mixed-use, New build

**LOCATION**
Copenhagen, Denmark

**DEVELOPMENT STAGE**
Building in use

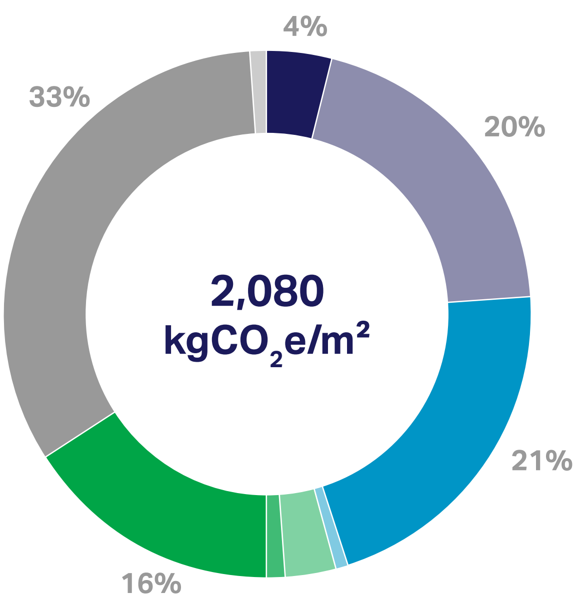
**GIA**
26,366 m²

**TOOL**
OneClick LCA

**PROJECT DATA**
Material quantities, transportation distances, construction drawings and specifications issued by contractor and design team.

**ANNUAL ENERGY CONSUMPTION**
117 kWh/m²/year

**Figure 26:** Whole life carbon (A-C)



## Main results

**Figure 27:** Embodied carbon at practical completion (A1-A5)

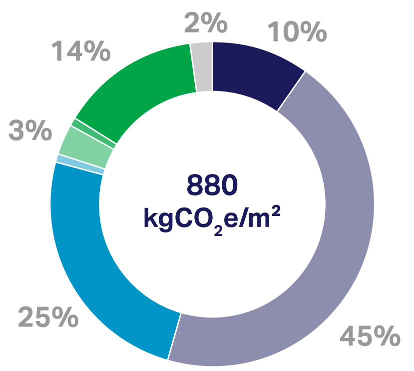
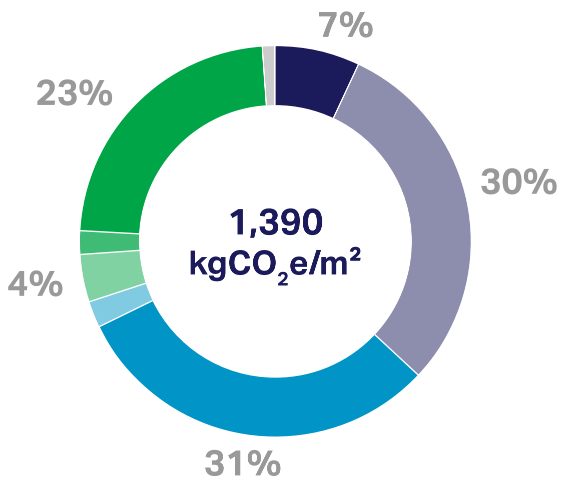



**Figure 28:** Embodied carbon over the life cycle (A-C)

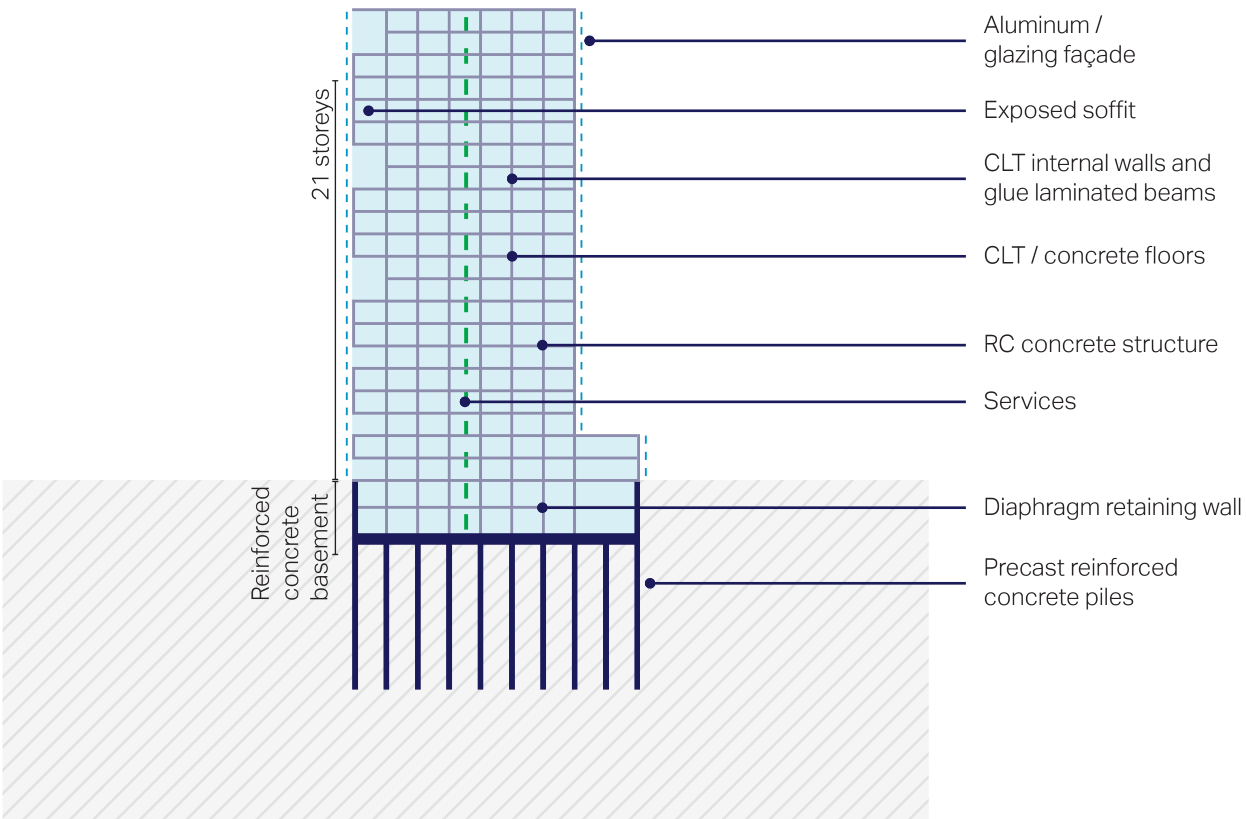



- Substructure
- Superstructure
- Façade
- Internal walls and partitions
- Internal finishes
- FF&E
- Building services
- Energy and water use
- Site emissions

**Table 7:** Building system carbon framework

| | | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | kgCO$_2$e/m$^2$ | D |
| BUILDING LAYERS | **Structure**<br>Substructure and superstructure | 466 | 13 | 2 | | 22.4 | 504 | -69 |
| | **Skin**<br>Façade | 215 | 3 | 215 | | 0.6 | 434 | -197 |
| | **Space plan**<br>Partitions and internal finishes | 34 | 1 | 34 | | 8.2 | 78 | -12 |
| | **Services**<br>Building services, energy and water use | 120 | 1 | 201 | 692 | 1.7 | 1,009 | -46 |
| | **Stuff**<br>Fittings, furnishings and equipment (FF&E) | 5 | | 24 | | | 29 | -11 |
| | **Site emissions**<br>Waste, electricity and fuel | | 19 | | | | 19 | |
| | **Building carbon emissions**<br>Embodied and operational | **842** | **36** | **476** | **692** | **33** | **2,079** | **-336** |

# 06. Residential timber tower, Amsterdam, NL




**TYPE**
Residential, New build

**LOCATION**
Amsterdarm, Netherlands

**DEVELOPMENT STAGE**
End of construction

**GIA**
14,544 m²

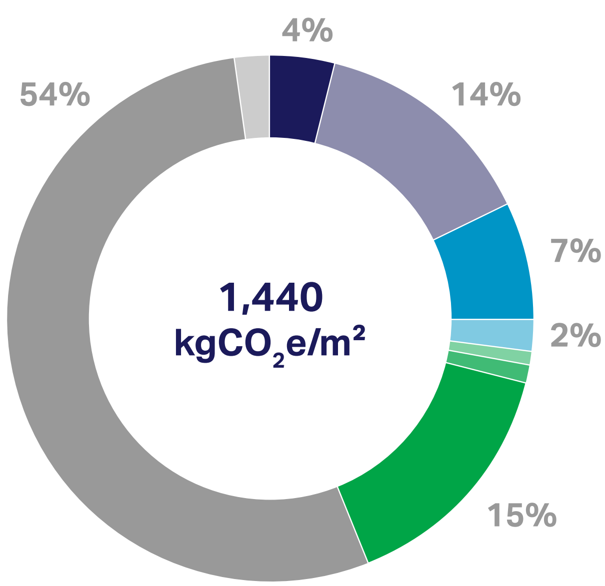
**RATING SCHEME**
BREEAM 2014 Outstanding

**TOOL**
OneClick LCA

**PROJECT DATA**
Design information from tender documents, material quantities from 3D models. Assumptions taken for services embodied carbon (lower than for office buildings).

**ANNUAL ENERGY CONSUMPTION**
74 kWh/m²/year

**Figure 29:** Whole life carbon (A-C)



## Main results

**Figure 30:** Embodied carbon at practical completion (A1-A5)

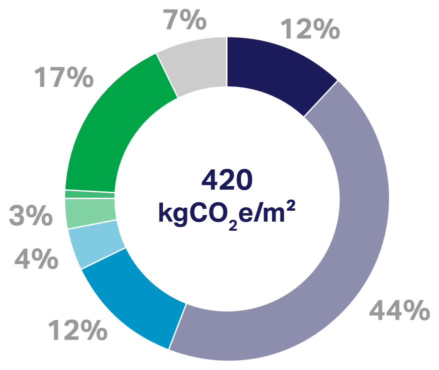
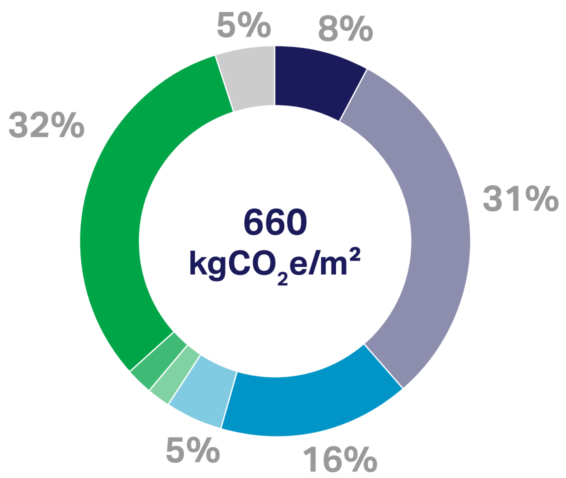



**Figure 31:** Embodied carbon over the life cycle (A-C)




- Substructure
- Superstructure
- Façade
- Internal walls and partitions
- Internal finishes
- FF&E
- Building services
- Energy and water use
- Site emissions

**Table 8:** Building system carbon framework

| BUILDING LAYERS | BUILDING STAGES | | | | | | |
|---|---|---|---|---|---|---|---|
| | PRODUCTS | CONSTRUCTION | USE | | END OF LIFE | EMISSIONS | BEYOND LIFE |
| | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | $kgCO_2e/m^2$ | D |
| **Structure**<br>Substructure and superstructure | 225 | 9 | 9 | | 14.4 | 257 | -105 |
| **Skin**<br>Façade | 51 | 1 | 51 | | 1.4 | 104 | -37 |
| **Space plan**<br>Partitions and internal finishes | 28 | 1 | 16 | | 0.7 | 47 | -4 |
| **Services**<br>Building services, energy and water use | 70 | 0 | 140 | 781 | 0.8 | 993 | -11 |
| **Stuff**<br>Fittings, furnishings and equipment (FF&E) | 3 | | 7 | | | 10 | -2 |
| **Site emissions**<br>Waste, electricity and fuel | | 30 | | | | 30 | |
| **Building carbon emissions**<br>Embodied and operational | **377** | **41** | **224** | **781** | **17** | **1,440** | **-158** |

Biogenic carbon storage: **$-146kgCO_2e/m^2$ (2116t $CO_2e$)** PV Offset: **$-61\ kgCO_2e/m^2$**

# ③ Results and discussion

# 3.1 Whole life carbon analysis

**UPFRONT EMBODIED CARBON (A1-A5)**

Figures 32 and 33 display the embodied carbon impact at "practical completion" (modules A1-A5) – the end of the initial construction phase – looking at an average value taken across all six case studies.

As a reminder, this corresponds to all the carbon emissions associated with the manufacturing of materials and the construction process. The doughnut chart represents the average distribution per building element.

At this stage, the substructure and the superstructure are consistently responsible for the largest impact across all case studies. Together, they represent 54% of the average emissions whereas 15% and 18% are attributed respectively to the façade and to the building services.

The distribution per building element also highlights the respective impact of each part of the value chain. Over the first life cycle stage (A1-A5), a focus on the sub and superstructure have the greatest potential to reduce the upfront embodied carbon emissions. This is not to say other elements, such as façade and building services, are not important contributors and deserve attention at this stage.

The results also highlight that the geography is a non-negligible parameter. The energy invested in the extraction of raw materials and the manufacturing of products has a different carbon impact depending on where it takes place. Case study 05 – in addition to being material intensive – is located in a region which has a higher energy grid carbon factor than the other case studies. The material sourced locally have therefore a higher embodied carbon impact or are transported from a further location.

Case study 04 (refurbishment) is a key example where the design team collaborated with the client to reduce the extent of the structural works to an absolute minimum by undertaking in-depth design studies which allowed for the re-use of most of the existing structural frame. The impact of case study 04 at practical completion is 44% less than the average over the six case studies.

The first chapter looked at the industry's current averages and proposed a 2020 business as usual (BAU) figure at practical completion of 1,000 $kgCO_2e/m^2$. Looking at values across the six projects, it can be seen that the BAU figure could be challenged and potentially lowered, suggesting that with an increased focus on low carbon design, the industry could aim at significantly more challenging targets for 2030. This also raises the question of what actually is the baseline in the WorldGBC definition for embodied carbon targets. In other words what are we proposing to reduce by 40% by 2030? Perhaps this target should be made more explicit and refined on a region by region basis?

From the case studies, we are able to identify a range of results for A1-A5 which spread from 310 $kgCO_2e/m^2$ for an efficient refurbishment to 880 $kgCO_2e/m^2$ for a more typical building, with an average at 560 $kgCO_2e/m^2$. This demonstrates that a 40% reduction on average compare to a BAU of 1000 $kgCO_2/m^2$ is already achievable.

**Challenge: could a 2030 target of 400 $kgCO_2e/m^2$ (A1–A5) be set for all projects?**

Overall, there is a need for better clarification and transparency of specific targets related to the overall decarbonization ambitions. As exemplified in case study 04, a more collaborative approach between project stakeholders will support decarbonization through better understanding of the building design and opportunity areas and technical challenges. Research and development should focus on the areas with the largest impact to drive decarbonization although smaller contributors should not be ignored.

**A1-A5 IN NUMBERS**

- Case study results range 310-880 $kgCO_2e/m^2$
- 54% substructure and superstucture (average)
- Business as usual assumed benchmark (2020) 1,000 $kgCO_2e/m^2$
- Case studies average 560 $kgCO_2e/m^2$ (44% reduction)

Figure 32: A1-A5 Average Distribution across all six case Studies

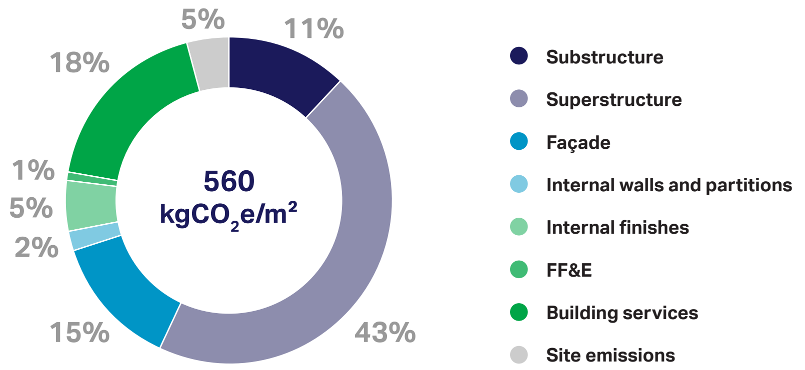
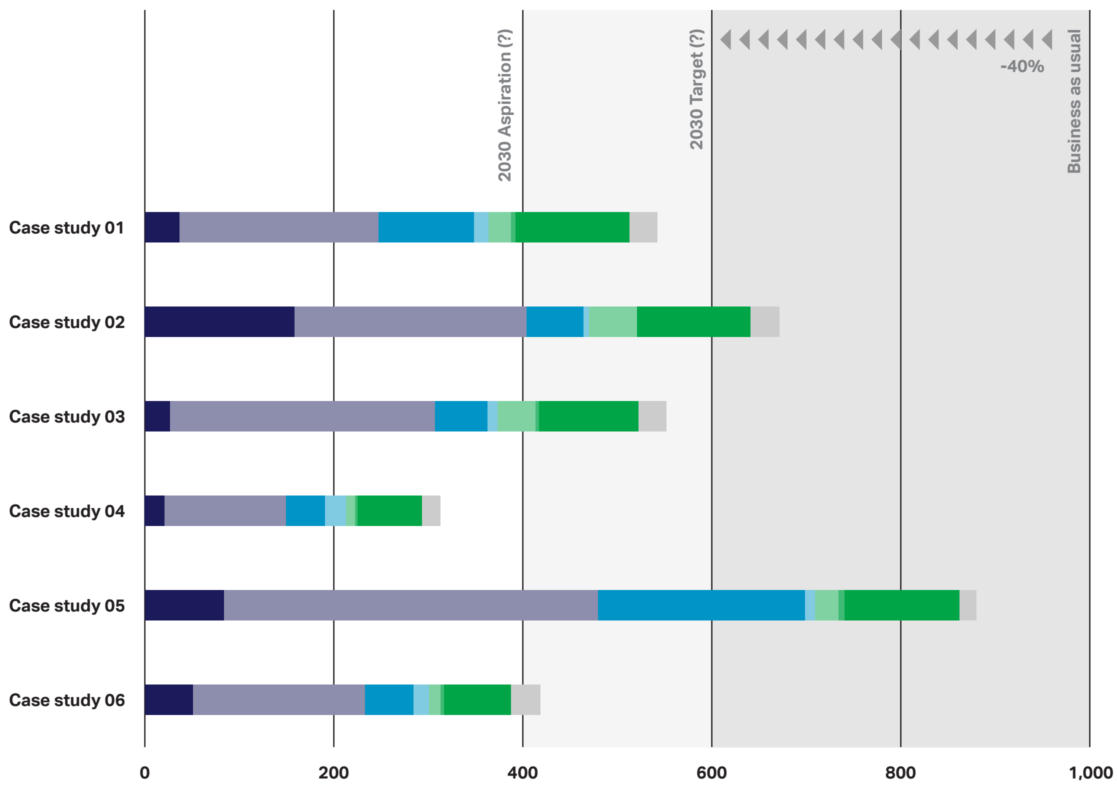



Figure 33: A1-A5 per case study (kgCO$_2$e/m$^2$)



## IN-USE AND END-OF-LIFE EMBODIED CARBON (B-C)

Figures 34 to 37 display the embodied carbon impact "in use" and "end of life" (Modules B1-B5 and C1-C4) across all six case studies. For buildings, this corresponds to all the carbon emissions associated with the building elements that will be replaced as their lifespan is shorter than the building lifespan.

The doughnut chart represents the average distribution across all six case sudies per building element. Through the in-use stage, the building services equipment is responsible for the largest impact. Building services equipment represents 57% of the emissions, and 25% is attributed to the façade whereas the primary structural elements are designed to last the whole building life.

This also highlights the impact of each part of the value chain over the in-use stage. A focus on the building services and the façade design has the greatest potential to reduce the in use embodied carbon emissions.

Following the RICS methodology – which is the clearest WLCA guidance published at the moment – where no specific information is given, the life span of the building services and of the façade are taken as 20 years and 30 years respectively. WLCA is still an emerging field, and a great deal of work is being undertaken to increase the amount of data available on building services to develop a better understanding of their carbon impact over their life span such as the TM65 CIBSE guidance.[14]

There is a lot of potential to improve this part of the WLCA; the big equipment pieces may be designed to last longer and the façade can partially be dismantled or reused to avoid full replacement of the entire system.

The BAU figures for embodied carbon over life cycle stages B and C are currently estimated to be around 300 $kgCO_2e/m^2$ (see chapter 01). More thought and rigor needs to be considered in terms of this stage of the life cycle assessment. The initial design process must better assess the future impact of the elements that will need to be replaced and evaluate this against better established criteria and targets.

However, for buildings designed today, the average first major replacement cycle would occur around 2050. By this stage, further supply chain decarbonization will likely have occurred across all materials use. It is unclear at the moment how to account for this, and targets should therefore be reviewed as new knowledge, research, and guidance emerges. A better methodology to deal with the supply chain decarbonization is needed which will allow the in-use embodied carbon to be estimated in a consistent way. The methodology should seek to define an industry-wide and unified approach to supply chain decarbonization including a verified data source for carbon factors; a defined scope of assessment; and key enablers and interventions.

Meanwhile, the IEA outlines a trajectory for the global $CO_2e$ emissions emanating from the energy sector and industrial processes which suggest that emissions will have reduced by two-thirds by 2050.[33] This could be used to estimate material carbon factors in 30 years. Generally, if we are to decarbonize this portion of the WLCA, we need to optimize the systems to have fewer elements to replace, use products with longer life span and apply circular economy principles, to reduce the in-use embodied emissions to a minimum.

**Challenge: could a 2030 target of 0 $kgCO_2e/m^2$ (B1-C4) be set for all projects to drive innovation, better practice and circular principles?**

### EMBODIED B AND C IN NUMBERS

- Case study results range 220-510 $kgCO_2e/m^2$
- 56% building services
- Business as usual assumed benchmark (2020) 300 $kgCO_2e/m^2$
- Case studies average 347 $kgCO_2e/m^2$ (12% higher)

### EMBODIED A-C IN NUMBERS

- Case study results range 530 – 1390 $kgCO_2e/m^2$
- Business as usual assumed benchmark (2020) 1300 $kgCO_2e/m^2$
- Case studies average 910 $kgCO_2e/m^2$

**Figure 34:** B1-B5 – Average distribution

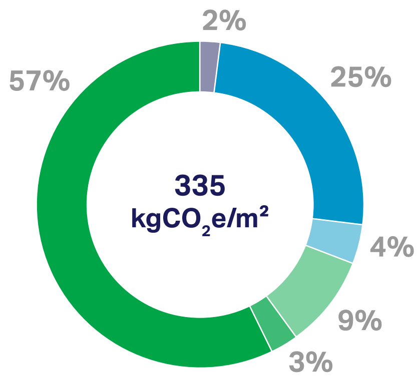



**Figure 35:** C1-C4 – Average distribution

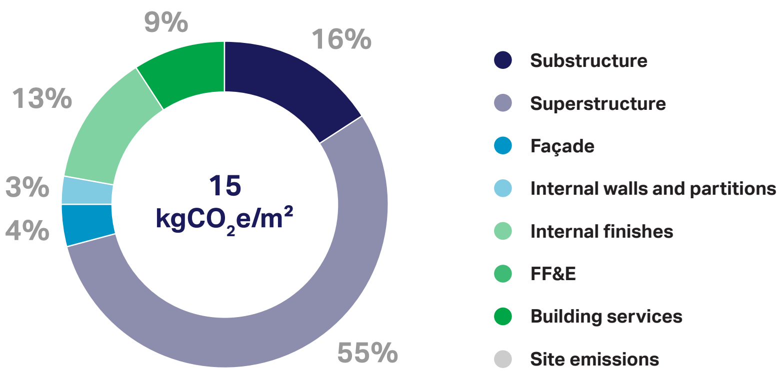



**Figure 36:** A-C – Average distribution per building element

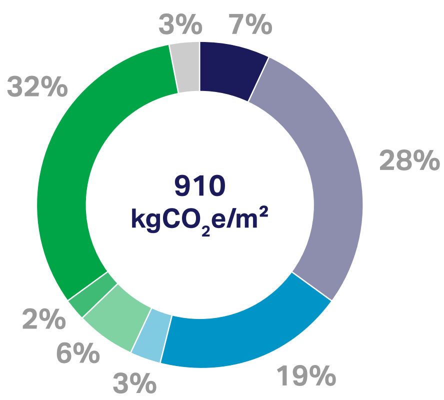
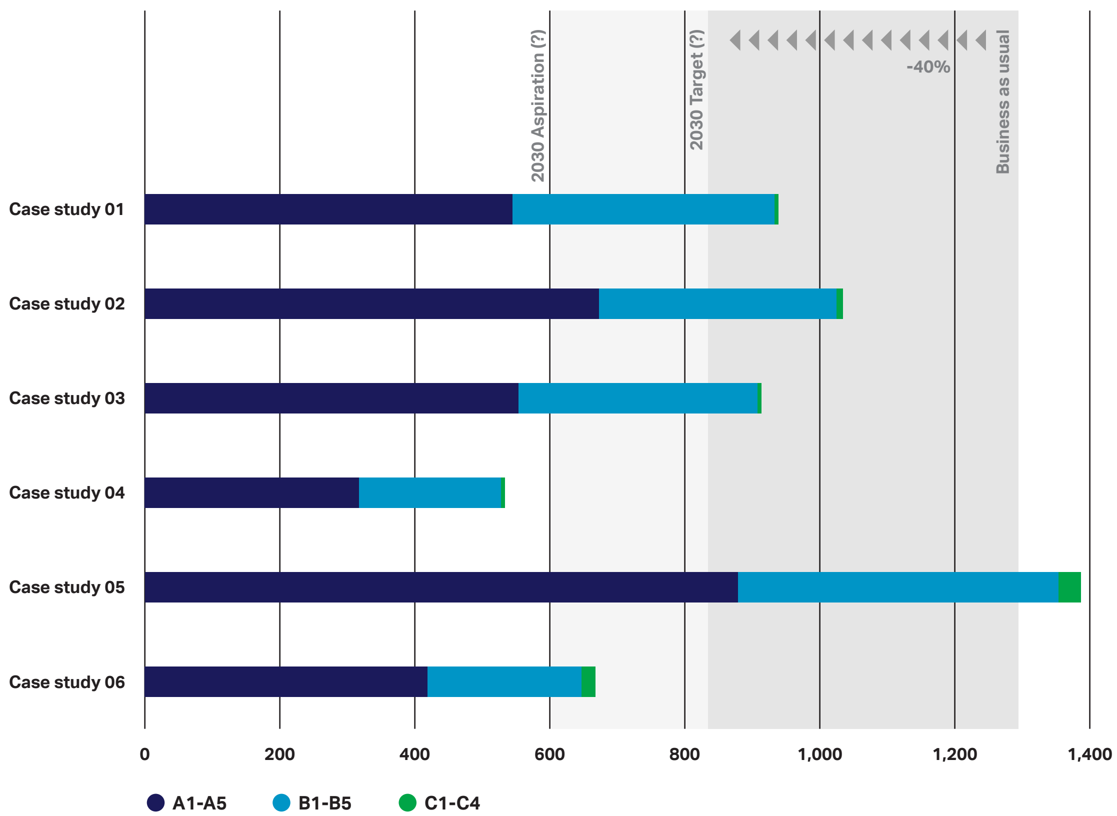



**Figure 37:** A-C per case study ($kgCO_2e/m^2$)



## OPERATIONAL CARBON (B6-B7)

The graphics display the operational carbon impact in-use across all six case studies. As a reminder, this corresponds to the carbon emissions associated with all the energy and water needed to operate the building over its 60 years lifespan (module B6, B7).

The first bar chart illustrates the annual energy consumption of each project accounting for regulated and unregulated loads in kWh/m². This is easier to assess as it removes a layer of assumptions taken on the grid's carbon factor.

It can be seen that the case studies typically perform better than the current BAU for office buildings, estimated at 220 kWh/m² (REEB/RIBA benchmarks described in chapter 01). Note that case study six is a residential building and belongs to a different benchmark (150kWh/m² REEB/RIBA benchmarks).

The enregy use intensity is typically estimated using advanced energy modelling tools and benchmarks. The energy consumption of case study 05 was measured via the use of actual energy bills since the building has been in use for two years. In this particular case, it is interesting to observe that the actual demand was actually 50% lower than originally estimated. This highlights the difficulties to accurately foresee the operational carbon emissions and the need to measure continually the energy consumption of our buildings to gather better data.

Based on the targets described in chapter 01, the industry is pushing to lower office buildings' energy use to 75kWh/m². This represents a 65% reduction compared to 2020 BAU. It can be seen that the case study estimated EUI are in some cases getting closer to the 2030 targets but much progress is still needed. All these case studies are close to practical completion or already completed, except case study 03, which might reach practical completion in 2025. This is reinforcing that we need to be able to design for the 2030 targets by 2025 the latest.

To achieve the required levels of decarbonization we will need to design buildings to be much more energy efficient than we are currently to provide the energy that is required via clean, zero-carbon supplies. It may also be necessary in terms of achieving the required demand levels to change the expectations of the occupants as to the level of environmental conditioning they can always assume.

More work is required to validate the setting of energy use (demand) targets that are aligned with regional supply grid decarbonization in order that we better understand where we sit in terms of genuine net-zero carbon operation trajectories.

Figure 39 estimates the equivalent operational carbon (kg$CO_2$e/m²/year) in three key scenarios: 2020 grid factor; 2030 grid factor projection; and as an estimated average over the next 60 years. To set the benchmark for comparison (e.g. the BAU baseline and the aspirational target levels), the benchmark converts the EUI in carbon equivalent emissions based on the current UK grid BEIS factor.[13, 16]
The case study results adopt national grid carbon factors amended to the geographical context of the case study.
On average, it appears operational emissions are responsible for 1,860 kg$CO_2$e/m², not accounting for decarbonization and 870 kg$CO_2$e/m², accounting for decarbonization over a 60 year building life.

Are maximum EUI targets being established regionally for all countries? Are they aligned with national grid decarbonization trajectories? Do they represent sufficient demand reduction to match clean supply potential?[33]

These questions need to be addressed collaboratively by the industry to help shaping realist targets aligned with the remaining carbon budget.

### OPERATIONAL B IN NUMBERS

- **Case study results range**
  110-220 kWh/m² for offices 75kWh/m² for residential
- **Business as usual benchmark (offices)**
  220kWh/m²
- **Target 2030**
  75 kWh/m²
- **Case studies average**
  140kWh/m² (offices only): +87%

**Figure 38:** Energy use intensity (kWh / m² / year)

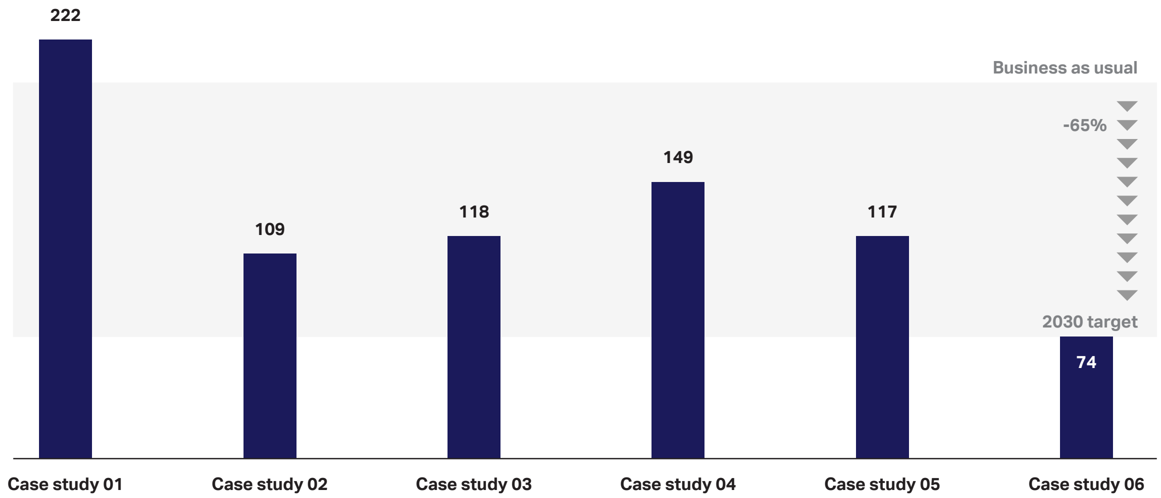
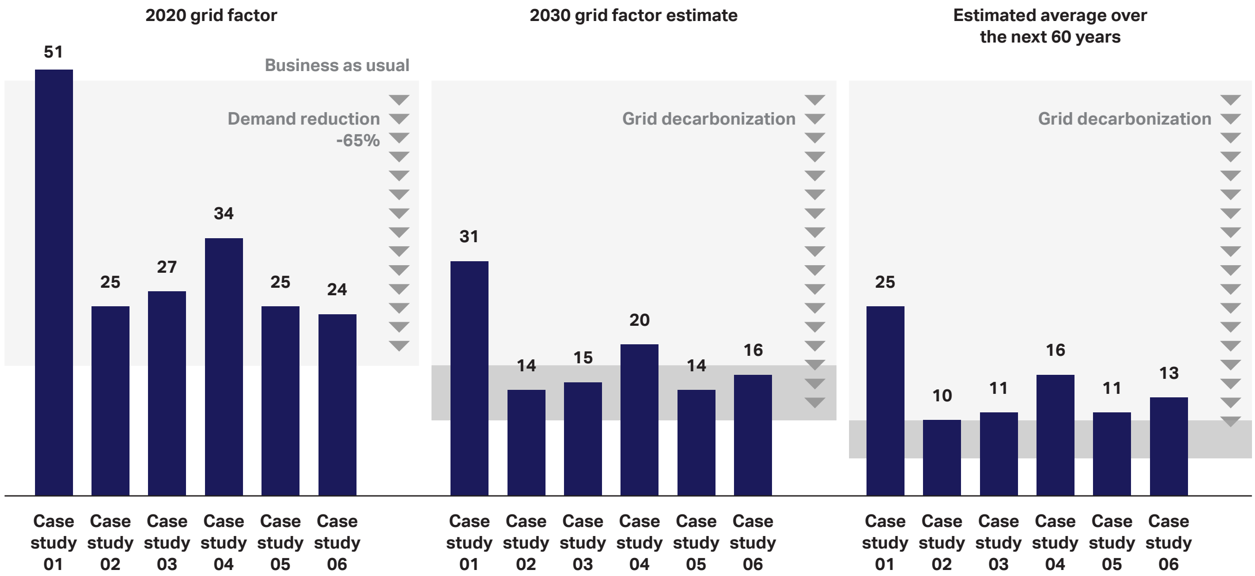



**Figure 39:** Operational carbon – $kgCO_2e / m^2$ / year



## WHOLE LIFE CARBON (A-C)

Figure 39 and 40 display the whole life carbon impact looking at all six case studies.

As reminder this accounts for both embodied and operational carbon from stages A to C over a 60 year building life span. Some of the projects presented here are innovative and represent a growing focus on low carbon designs.

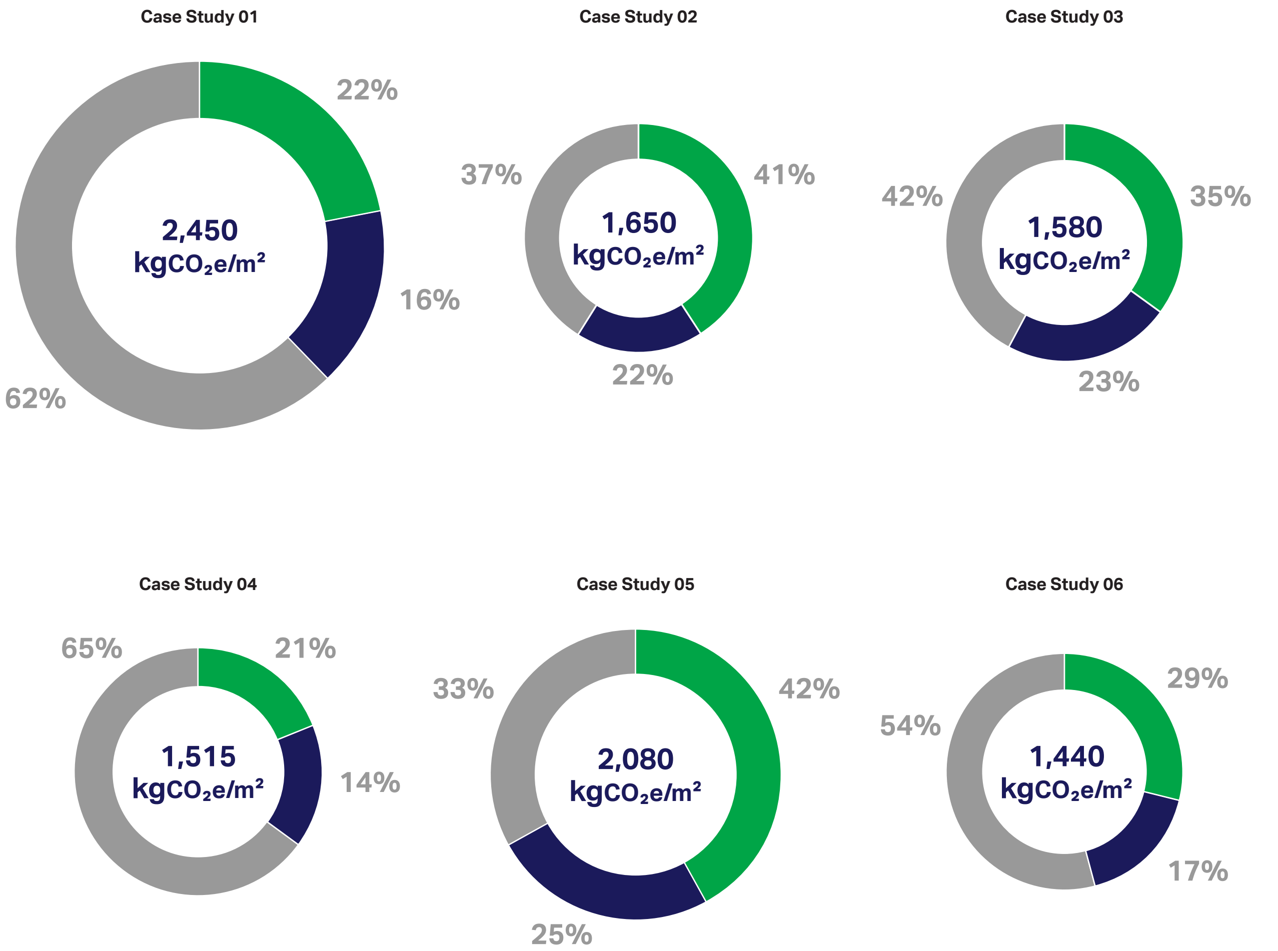
A wider, easily-accessible data set is required is required in order to establish clear targets in terms of demand reduction both from and embodied and operational carbon perspective. However these few studies perhaps point to possibilities in terms of raising our immediate sights and establishing clearer and more widely ambitious targets going forwards.

**Challenge: could a maximum 2030 target of less than 1,000 $kgCO_2e/m^2$ (A-C) be set for all projects?**

### A-C IN NUMBERS

- **Case study results range**
  1,440 to 2,450 $kgCO_2e/m^2$
- **Average breakdown across all six case studies**
  32% A1-A5
  19% B1-B5 and C
  49% B6-B7
- **Case studies average**
  1,790 $kgCO_2e/m^2$
  (30% reduction)

**Figure 40:** Case studies results



Setting up explicit targets will contribute to drive the required immediate decarbonization of all future building projects towards much more ambitious outcomes.

Based on growing a better understanding and focus on whole-life decarbonization could we imagine figure 42, representing an aspirational maximum carbon footprint target for all buildings being delivered in 2030? Is this too much of a stretch and if so why?

Can we design all future projects to avoid any further carbon emissions are required during their life span (B1-B5) via adopting genuine circular economy principles?

Clearly the whole industry must come together and work collaboratively to achieve the desired ultimate outcome of decarbonising all elements of the built environment and to do this we need clear and unambiguous objectives and targets.

**Figure 41:** Whole life carbon (A-C) average across all six case studies

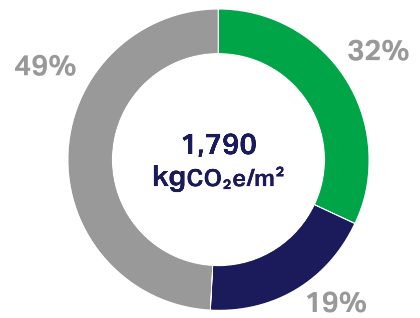



**Figure 42:** Whole life carbon (A-C) aspirational performance by 2030

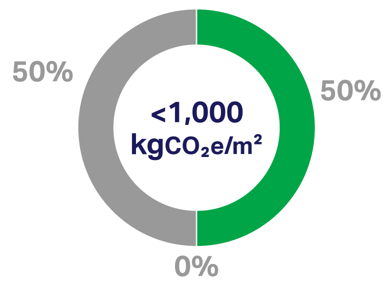
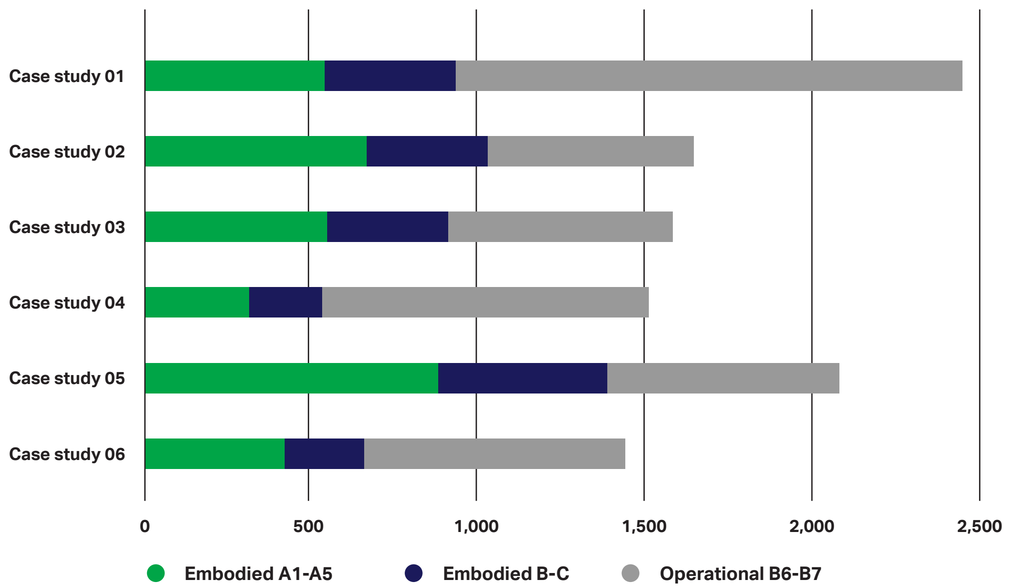



**Figure 43:** A-C per case study ($kgCO_2e/m^2$)



## BEYOND BUILDING LIFE (D)

Figure 44 and 45 display the stage D emissions looking at all six case studies. As a reminder this represents the potential benefits (or loads) associated with the material to serve a purpose beyond the 60 years life cycle.

It is not included in the scope of WLCA, often owing to the difficulty in drawing assumptions post the end of the building's life. However, it is potentially non-negligible and the impacts and benefits can appear significant especially in regard to metals and biogenic materials.

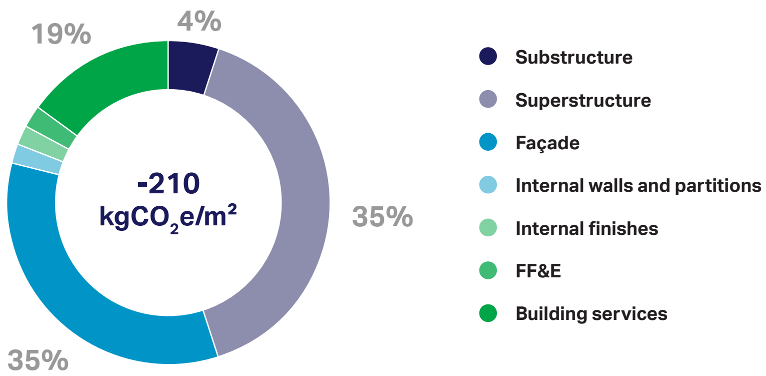
Steel can be 100% recycled and represents a benefit for future projects which can be procured with recycled steel, lowering their upfront carbon impact. This valuable as currently the demand for steel far outstrips the availability of scrap.

Timber different end of life scenarios need to be considered carefully at the outset of a project. Timber placed in landfill to decompose emits methane, this has a further detrimental carbon emission impact. On the other hand, timber can be reused as a product, incinerated or used as biomass to create energy in which cases the carbon initially sequestered in the trees is stored longer or serve a new purpose beyond the buildings life. Figure 44 illustrates the reduction – averaged across the six case studies – in WLCA emissions that would appear if stage D was theoretically accounted for. This number represents about 38% of the upfront embodied carbon emissions. Figure 45 show the A-D total carbon impact for each case study. Although stage D reduction is not negligeable, it doesn't by itself provide carbon return on our investment. As circular economy principles are starting to emerge for the building industry, Module D will have increasing importance in the WLCA process and materials will have a growing potential for reuse without being downcycled.

### STAGE D IN NUMBERS

- Case study results range -150 to -340 $kgCO_2e/m^2$
- Case studies average -210 $kgCO_2e/m^2$
- 35% superstructure and 35% façade

**Figure 44:** Stage D – Average distribution




## RESULTS SUMMARY

Figure 46 demonstrates the total distribution of carbon emissions over the six case studies throughout the building's life cycle.

Over the past decade, design teams have focused mainly on reducing the operational carbon emissions associated with the building sector. On average, the case studies demonstrate that the embodied carbon is now estimated to be approximatively 50% of the life cycle emissions of a building which clearly further emphasises the importance of addressing embodied carbon now.

The WLCA graphic presented in time domain highlights the significance of the A1-A5 emissions. These immediate embodied carbon (construction) emissions represent on average 30% of the WLCA and in the context of the climate emergency - we are all faced with - are released in the short term with currently little focus on real global abatement. Without question, we must reduce these emissions.

However, the case studies also show on average 70% of the average WLCA, using current assumptions and methodologies, will be emitted during the life time of the buildings.

**Figure 45:** Whole life carbon – A-D ($kgCO_2e$ / $m^2$)

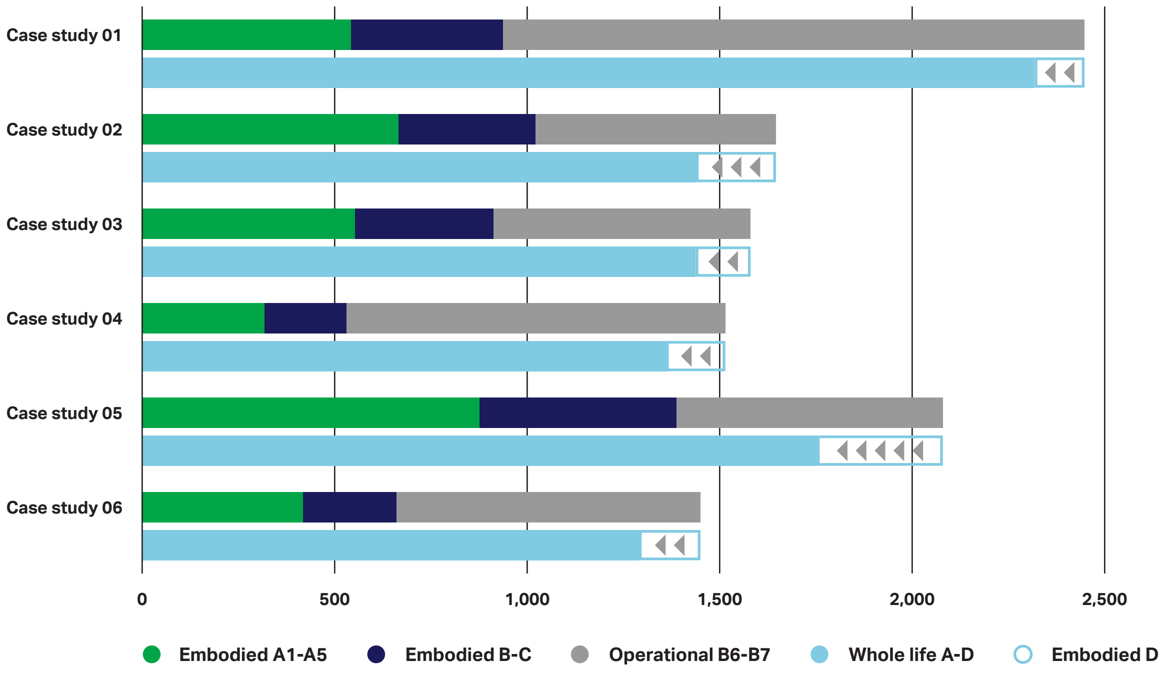
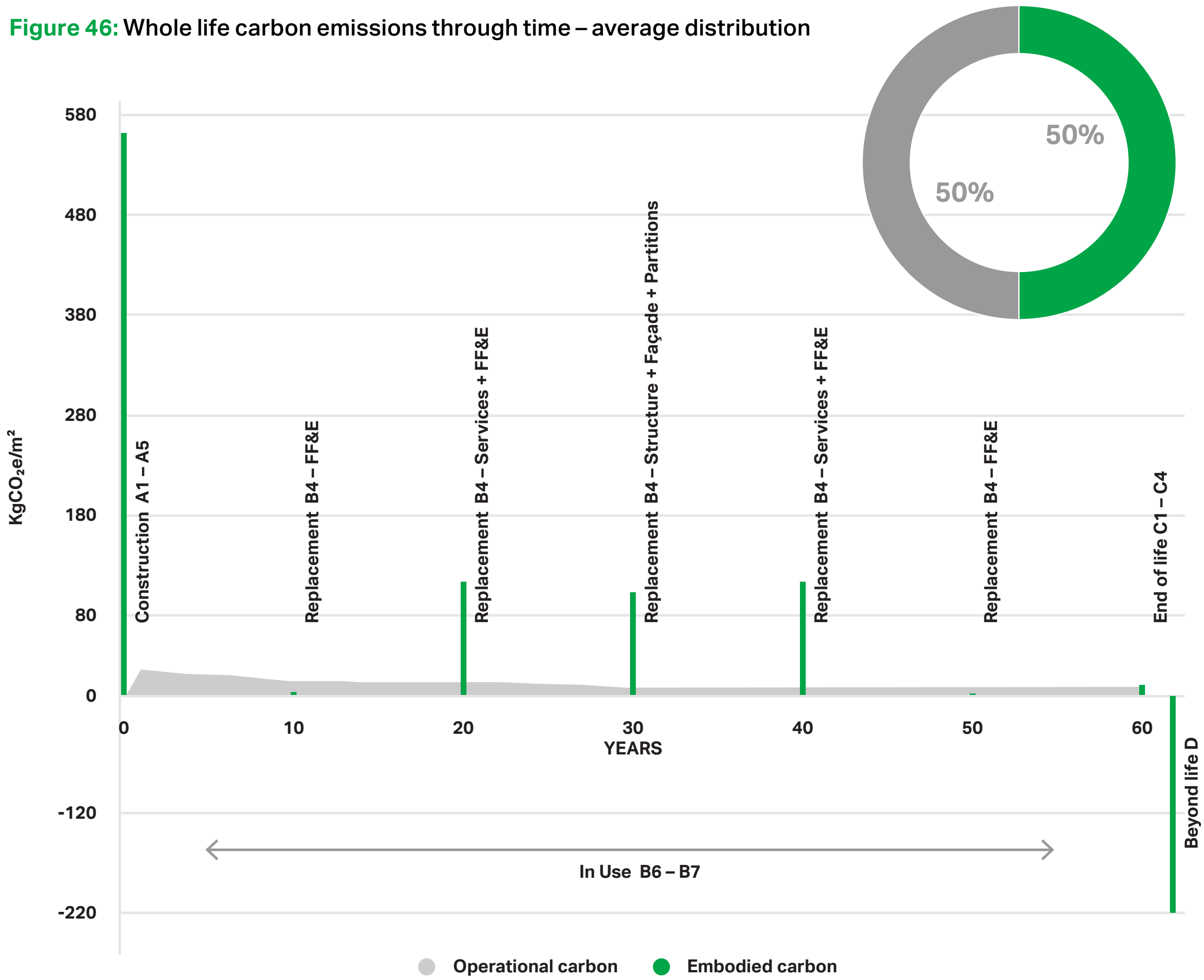



**Figure 46:** Whole life carbon emissions through time – average distribution



## BIGGEST CONTRIBUTING MATERIALS

The first graphic summarizes the highest contributing materials to the overall embodied carbon footprint across the first five case studies. Together, steel, concrete, aluminum, steel reinforcement, glass, and raised floor account for approximately 75% of the overall A1-A3 emissions. The contribution of services to embodied carbon accounts for approximately 20% with all other residual emissions comprising 6% of the footprint. The second graphic highlights the average most contributing materials to the overall embodied carbon of case study six – a residential timber building. The average material contribution deviates from the other case studies owing to the timber frame rather than the mixed concrete and steel frame. Together, steel, concrete, aluminum, steel reinforcement, and glass account for approximately 60% of overall A1-A3 emissions. The timber within the building accounts for approximately 10% of the embodied carbon total. The contribution of services to embodied carbon accounts for approximately 20% with all other residual materials comprising 10% of the footprint.

**Figure 47:** Total $tCO_2e$ per material across the first five case studies

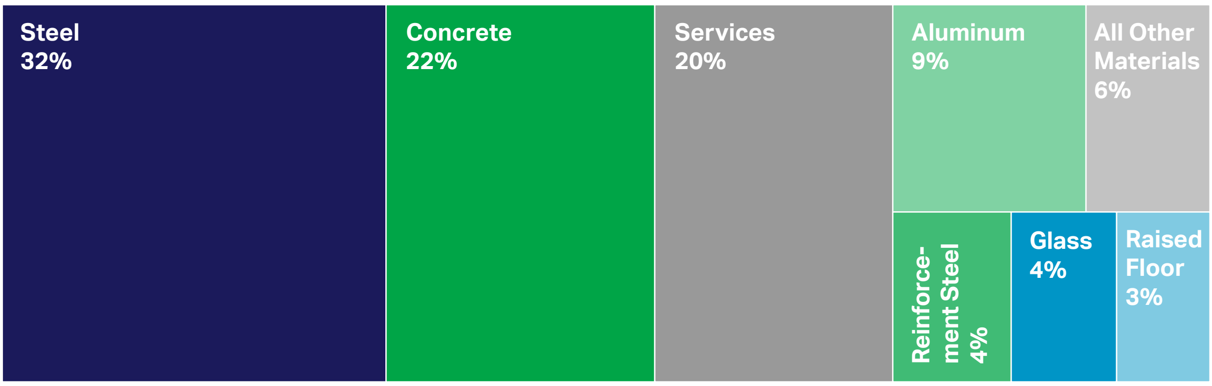
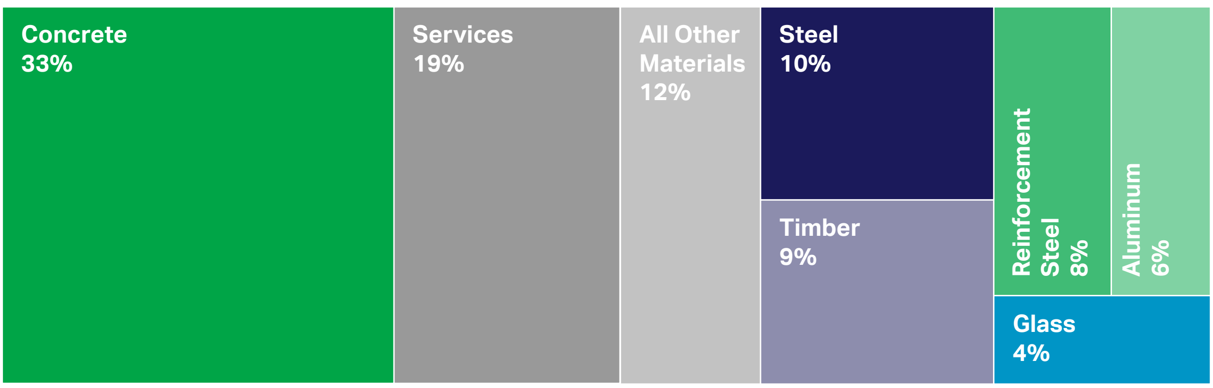



**Figure 48:** Total $tCO_2e$ per material for case study 06 – Residential timber building



# 3.2 The role of offsetting

Currently carbon offsetting plays a role in the achievement of most global carbon-neutral and net-zero commitments. At present there is a lack of a unified and precise definition and accountability in relation to valid offsetting for both terminologies.

In fact, when it comes to net zero, the prefix "net" implies some form of balancing of the emitted carbon. Various organizations and institutions, such as the Science Based Target Initiative (SBTi) and the University of Oxford on behalf of the Race To Zero, are working toward creating clarity of the net zero definitions, terminologies and its application toward net zero claims.

Agreement is mounting toward a firm emphasis of mitigation first, followed by how much and when carbon can be compensated (residual emissions) and what type of "offsets" are allowed to be used.

The six case studies presented here demonstrate an average upfront embodied carbon of 560 $kgCO_2e/m^2$ and a whole life cycle carbon footprint of around 1800 $kgCO_2e/m^2$, hence for any of these buildings to hypothetically claim to be net-zero now, some offsetting would need to be employed.

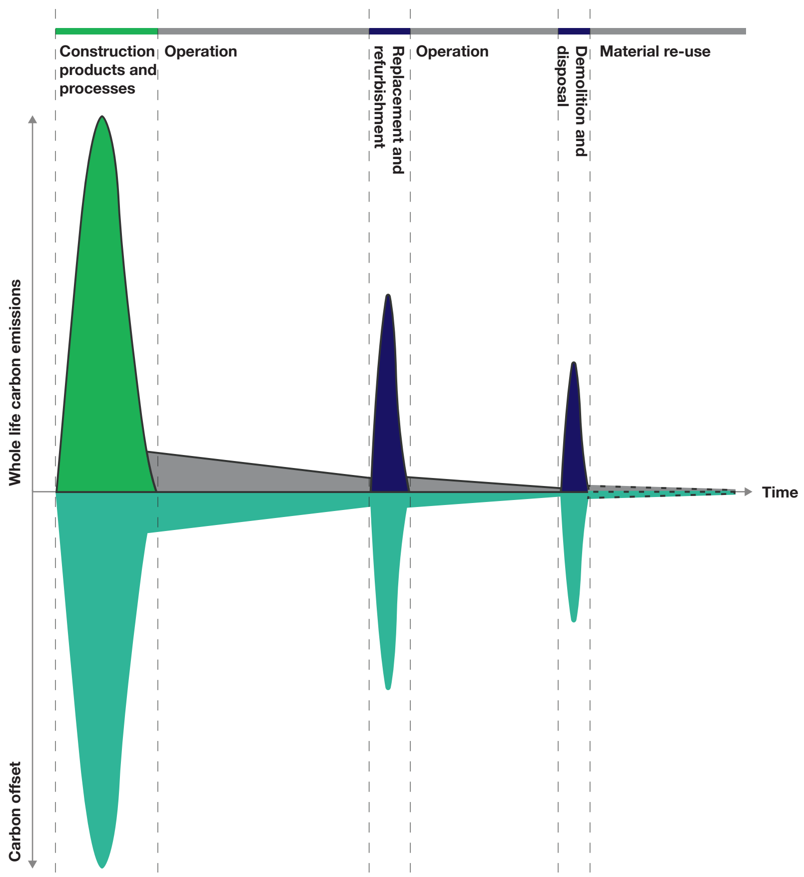
Currently building projects make use of offsetting by either direct procurement (using energy from clean, renewable sources) or by purchasing equivalent carbon credits from a recognized emissions reduction scheme.[27] Several internationally recognized and certifiable schemes exist, including the Gold Standard,[29] and those recognized schemes within the International Carbon Reduction and Offset Alliance.[30] Types of investment projects include afforestation, direct air capture with carbon storage, renewable energy, and community initiatives. In the current offsetting market (e.g. Gold Standard) credits could be purchased to offset business as usual carbon outcomes for as little as 1% of the total construction cost.

The primary aim of the industry needs to be to focus on widescale, systematic reduction as a priority if we are to achieve the global emissions reductions needed. Hence the strategic hierarchy discussed early in the introduction needs for all reasonable approaches towards reducing embodied and operational carbon to have been rigorously exhausted before offsets are considered.

The diagram below provides an indicative outline of the whole-life carbon emissions associated with a typical buildings' projects in line with a timeline for the hypothetical corresponding offsets.

It seems clear that more rigor is urgently needed in verifying acceptable levels and processes for adopting offsets before making any claims, especially for net zero.

**Figure 49:** Whole life carbon emissions, Arup (2020)[16]



## CARBON SEQUESTRATION – CASE STUDY 06 EXAMPLE

To explore the practical implications of sequestration (locking carbon into a system) as a form of offsetting, case study six presents a useful example.

Figure 50 outlines case study six's embodied carbon (A1-A5) at practical completion. Where carbon sequestration is accounted for, the embodied carbon is approximately 35% lower than excluding sequestration. Whilst widely neglected from many international life cycle assessments, 'climate-friendly' timber construction may prove a useful incentive for improved carbon sequestration in forests through regenerative forest management practices that exceed best practice.[32] Could the inclusion of biogenic carbon steer the industry towards regenerative and natural cycles as a means of investment?

## END OF LIFE PAYBACK – CASE STUDY 06 EXAMPLE

By considering the benefits associated with the Beyond Building Life (module D), a carbon "payback" of 24% is calculated for this case study (figure 51).

Incorporating the potential of re-use/ repurposing of the building's systems and materials within WLCA should be explored and verified more thoroughly. If not included in the WLCA scope, should it be seen as a sort of offset? Can the industry as a whole set the direction for a circular economy of components whereby genuine whole scale payback is achieved, and would this ultimately benefit the overall road to net-zero?

## ON SITE RENEWABLE ENERGY – CASE STUDY 06 EXAMPLE

In figure 52, operational carbon (B6) over the building life cycle is compared against operational carbon accounting for on-site renewable energy generation.

Renewable energy presents a widely recognized approach to carbon neutralization through clean energy generation and procurement. For case study six, on-site renewable energy generation accounts for an 11% carbon saving. As the global energy mix transitions towards a decarbonized future, carbon offsetting should consider changes in the energy mix and priority/ viable energy sources as a means of offsetting. Contributions should consider wider parameters needed for a renewable transition including research and technologies, emerging energy sources.

**Figure 50:** Embodied carbon at practical completion ($kgCO_2e/m^2$)

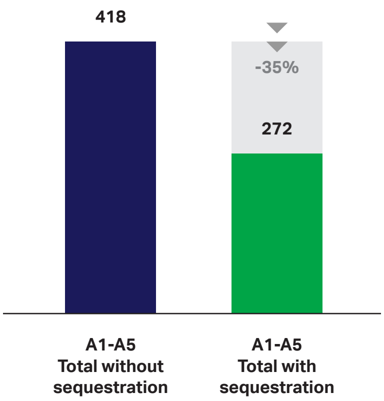



**Figure 51:** Whole life embodied carbon results ($kgCO_2e/m^2$)

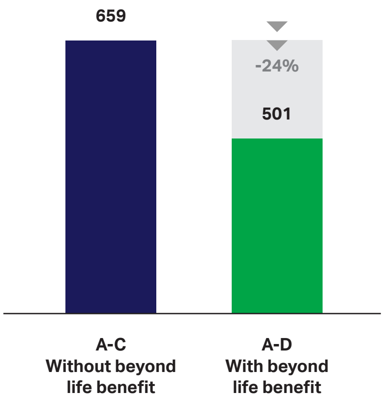
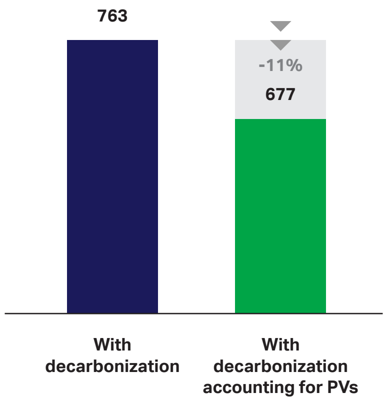



**Figure 52:** Operational carbon ($kgCO_2e/m^2$)




The three graphs highlight the lack of clear and consistent approach to direct offsetting related to buildings. In the short term, the industry must focus on accelerating and sharing knowledge on the benefits of emissions reductions and emissions removals via the methods above.

A clear methodological approach and appropriately determined Module boundary must be set for these types of carbon compensation to ensure that valid reductions are accounted for at the appropriate project stage, and the right decisions are made to drive lowest carbon design.

Offsetting approaches must be regularly reviewed to support the development of the market for carbon neutrality, account for technological developments, and climate mitigation goals.

# 3.3 Challenges and opportunities

| Challenges | | Opportunities |
|---|---|---|
| • Small number of completed WLCA – all projects should commit to WLCA with performance measurements<br>• Incentives for client/developer to drive reductions and how to encourage end user behavioral change within buildings<br>• Aligning international strategies, policies and legislative guidance<br>• Commitment to reduce buildings carbon footprint | **Incentive** | • Growing awareness and industry engagement, collaboration and partnerships<br>• Increased importance within sustainability certifications and rating schemes<br>• Regulatory and financial trends for buildings decarbonization in line with sustainable finance mechanisms<br>• Challenging brief, need and design criteria at early stage |
| • Definition of net-zero for the building asset still unclear<br>• Clarity if current buildings impact for different typologies and in different regions<br>• Clarity on targets relative to a baseline or absolute<br>• Role of carbon offsetting: what type, when, how much | **Net-zero for the building asset** | • Organizations such as SBTi, WorldGBC and WBCSD collaborating toward answers<br>• Emerging benchmarks – need for transparent assumptions for the data to be valid<br>• Emerging industry accepted targets<br>• Industry working together to ensure the validity and transparency of offsetting schemes |
| • Common scope and methodology<br>• Plethora of WLCA tools exist with differing methodological assumptions<br>• Transparency on assumptions | **Approach** | • Adopting and embedding common methodologies<br>• Development of efficient tools and technologies including digital innovation<br>• Industry is challenged to share openly data |
| • Efficiently gathering all relevant project data: material quantities and specifications of all building elements<br>• Availability and transparency of embodied carbon factor data per region<br>• Understanding of material decarbonization for the main material contributors<br>• Clear measures to be identified on how to drive reduction needed at all project life cycles | **Embodied carbon** | • Digitalization of data collection and work-flow optimization<br>• Manufacturers producing and sharing EPDs<br>• Low carbon materials progress through research and innovation<br>• Circular economy implementation and business models within the supply chain, prioritizing reused and recycled materials<br>• Dematerialization and designing efficient and long-lasting systems |
| • Accurately assessing operational carbon<br>• Estimating energy grid decarbonization<br>• How to reduce the demand in energy of multi-storey buildings | **Operational carbon** | • Growing initiatives to measure and compare environmental performances (e.g. Nabers)<br>• New technologies, research, and development |
| • Lack of knowledge sharing<br>• Accounting for geographical and jurisdictional variations in approach, limitations, and technical constraints<br>• Clearly understanding the synergies and challenges between decarbonization and other key sustainability disciplines | **Industry collaboration** | • Growing acknowledgement of importance of WLCA and further research needed<br>• Behavioral change and effectively communicated systems thinking approach to allow flexibility to change<br>• International engagement at events such as the COP26 |

## 3.4 Where do we stand?

### CONCLUSION

The decarbonization of the built environment is integral towards the attainment of the IPCC 1.5°C scenario. Representing nearly 40% of all global energy-related carbon emissions, the building sector needs to be a significant part of a clear and absolute pathway towards overall decarbonization.

Although the six case studies represent a small sample from Northern Europe, the findings provide an indicative picture of the industry's current performance and challenges, identifying opportunities for the sector's journey toward net zero.

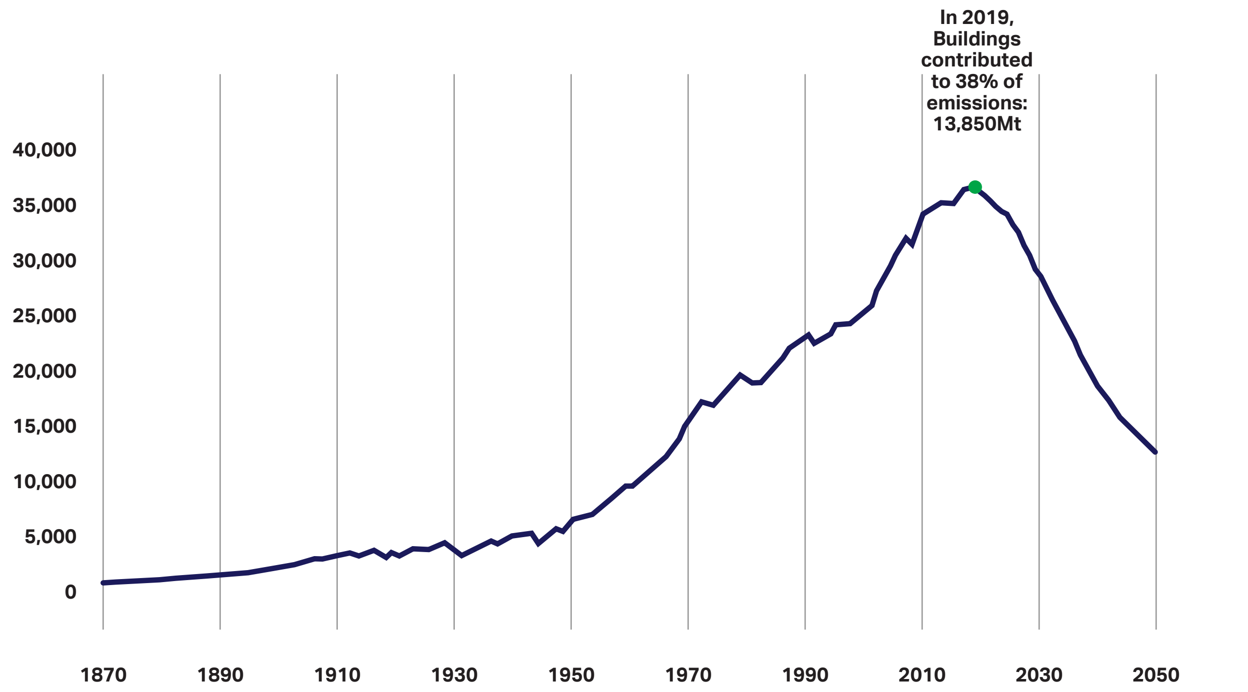
The projects chosen could arguably be representative of the better end of the spectrum in terms of overall building WLCA as all have had some form of sustainability or low carbon agenda from their outset as detailed in the individual case studies. However, we would also argue these projects could do better with even more focus on achieving the absolute minimum carbon footprint possible.

Recent GlobalABC status reports for the building and construction industry have pointed to there being a current global cumulative building floor area of circa 250 billion $m^2$ and that this number is forecast at current population growth estimates to rise to circa 415 billion $m^2$ by 2050.[3,5]
This is an average annual growth of over 5 billion $m^2$/year.

Considering this quantum of building construction in the context of the case results of this report we gain insight into the urgency associated with challenging ourselves all together as an industry to rapidly and significantly reduce both embodied and operational carbon emissions. As a facilitator of this reduction we need to collaborate more widely to gain widespread, data-informed, WLCA understanding, and from this informed position develop credible and impactful reduction strategies.

At present there are clearly barriers to accurately and consistently assessing carbon intensity data both from an embodied (construction) and operational (energy use) perspective in all building projects.

**Figure 53:** **Past and future global annual carbon emissions (Mt) from the energy sector and industrial processes. Our World in Data, Global ABC/IEA/UNEP and IEA (2020)** [3, 6, 33]



There is a current lack of available carbon intensity and WLCA data as well as a general lack of wide scale resource, collaboration and knowledge sharing in this field.

There is also a lack of global consensus on methodological assumptions and definitions of net-zero proportionate to required GHG emissions reductions, removals, offsetting and established explicit targets to support this. These barriers need to be addressed rapidly at scale if we are to have the impact we need.

The case studies highlight key opportunity areas for decarbonization through growing partnerships and industry collaboration; an industry-wide call for accepted targets and methodologies; and emergent regulatory and financial trends for incentivizing the low carbon transition.

Properly focused collaborative research, technology, and innovation will drive decarbonization. The report points to the main material and systems contributors to building whole life carbon and highlights the benefits of consumption reduction and the development of lower carbon materials, improved reusability and recyclability.

Additionally, we need to explore the opportunity to simplify the comparison between new built vs retrofit. Adopting the same embodied carbon target will create a strong incentive towards renovation as this starts with a clear advantage in terms of upfront carbon (A1-A5) (see case study 04).

By using more case studies as a lens for interrogation, we can gain insight into current and future challenges and opportunities within the buildings sector. By sharing our case study work we hope we are contributing to wider knowledge sharing on the route to net-zero buildings. By working collaboratively as an industry toward the same goal we can drive our projects to achieve the required level of decarbonization that the planet needs. To do this we must consider the whole life cycle and value chain in an open and honest way and share generously our knowledge, insight, and success stories to promote industry-wide learning and rapid advancement.

From this point forward we must aim to drive transformation across every project we undertake. Based on this work we call on companies from across the built environment and around the globe to conduct whole life carbon assessments of their projects as a matter of course, openly publishing the results in view of building a body of evidence and shared learning.

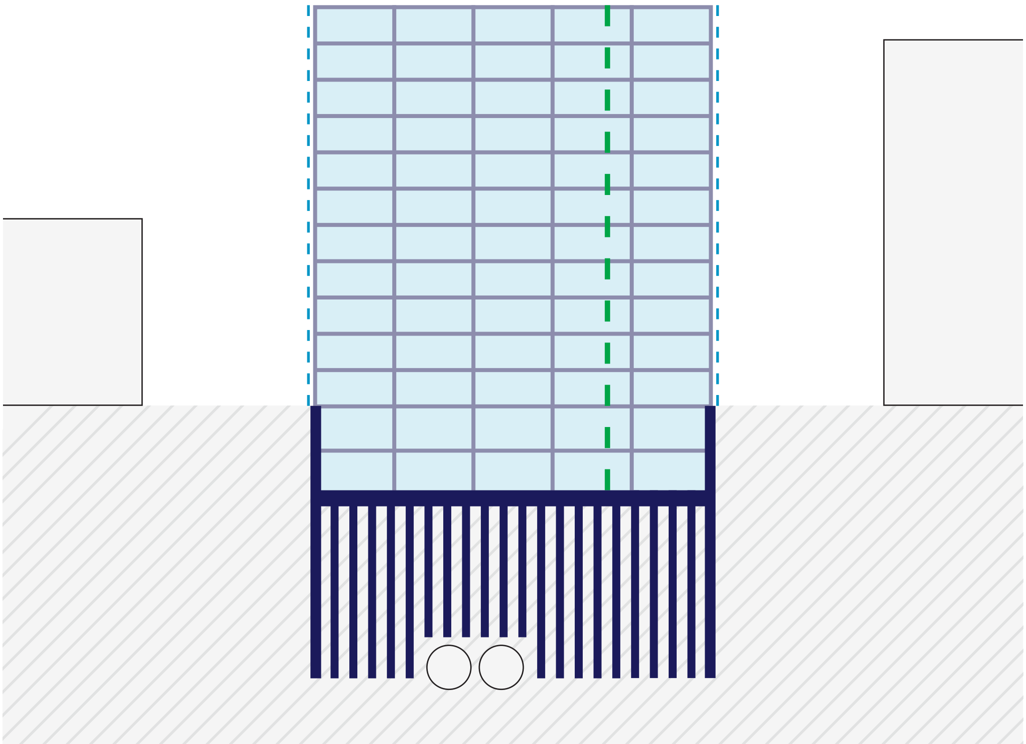
The building industry must now come together and commit to measuring the whole life carbon emissions associated with all future projects in a clear and transparent way demonstrated here. If we start to systematically collect and use this information at the beginning of each project, then we can achieve an immediate cut in the 14 gigatonnes of carbon this industry is responsible for globally each year. By setting clear targets as discussed in this report we can halve both the embodied and operational carbon in buildings. The numbers in this report show that this goal can be within our reach. This would in turn make it possible to halve our emissions in the next decade, an act that will genuinely put us on track towards a net-zero built environment.

**KEY ACTIONS FOR DECARBONIZATION**

- Commit to WLCA on all projects
- Develop consistent and transparent carbon intensity and benchmark data
- Adopt explicit targets
- Define net-zero buildings
- Establish wider collaboration

# 4 Additional data on case studies

# 01. Office building, London, UK



## Type
Office, New build

## Location
London, UK

## Development stage
Manufacturing and construction

## GIA
29,819 m$^2$

## Rating scheme
LEED V4 Gold
BREEAM 2014 Outstanding

## Tool
OneClick LCA

## Project data
Late design stage information: cost plan, drawings and specifications. Structural material quantities issued directly by contractor. Allowance made for services embodied carbon.

## Description
- 11 storeys office building (retail at ground floor)
- Oversite development – highly constrained environment
- Composite steel/concrete superstructure
  - Post tensioned flat slab 9x9m grid and 6m perimeter grid
  - Composite columns – fabricated steel hollow sections filled with concrete
  - Steel braced stability system
- Reinforced concrete basement – 2 levels
  - 2m raft foundation slab
  - Secant pile walls + lining wall
- Main façade systems
  - Unitized curtain walling systems – glazing and stone/metal partial cladding
  - Shop front – glazed stick system, aluminum/steel frame
- Exposed soffit and services – no false ceiling
- Fully serviced with lift (cooling, heating, ventilation, electricity, water, lighting, sprinkler)
  - Cooling provided by water cooled chillers and distribution by fan coil systems
  - Heating and hot water by natural gas boiler and distribution by fan coil systems
  - LED lighting system with daylight dimming City center
  - Server rooms (data center)

## Key embodied $CO_2e$

### Material quantities and carbon factors

| | |
|---|---|
| Ready-mix **concrete**<br>(16,710m³) | • Ready-mix concrete, RC 35/45 (32/40 MPa), 50% average cement replacement with blast furnace slag (GGBS)<br>• ICE database V3<br>• Carbon factor: **0.095 kg$CO_2$e/kg** |
| **Structural steel** sections and plates<br>(890 t) | • Structural steel profiles, generic, 20% recycled content, I, H, U, L, and T sections<br>• OneClick LCA database<br>• Carbon factor: **2.51 kg$CO_2$e/kg** (This is close to British steel value for open sections of 2.45 kg$CO_2$e/kg) |
| **Aluminum** sheets and profiles<br>(247 t) | • Aluminum sheet, 2700.0 kg/m³ and Aluminum linear profiles for ceiling decoration/ cladding<br>• Database: OKOBAUDAT 2017 and EPD SAS System 740<br>• Carbon factor: **10.62 kg$CO_2$e/kg** and **8.46 kg$CO_2$e/kg** |
| Steel **reinforcement**<br>(1,700 t) | • Reinforcement steel (rebar), generic – 97% recycled content (typical for UK)<br>• Database: OneClick LCA<br>• Carbon factor: **0.5 kg$CO_2$e/kg** |
| **Raised access floors**<br>(15,350m²) | • Raised access flooring system, 60 – 380mm variable height, 26 kg/m²<br>• Database: EPD Kingspan RG3 Europe<br>• Carbon factor: **43.4 kg$CO_2$e/m²** |
| **Services**: Heating, cooling, ventilation, electricity, lighting, distribution systems, lifts and others. | • Average impact per m² GIA of the different systems based on past studies<br>• Database: OneClick LCA<br>• Carbon factor: 10 – 30 kg$CO_2$e/m²/system<br>• Total services: **120 kg$CO_2$e/m²** |

## 01. Office building, London, UK

### Key operational $CO_2e$

### Energy and water consumption

**TM54** assessment: In depth operational energy performance evaluation taking in account regulated and unregulated emissions.

Annual energy consumption:
**222kWh$_{equivalent}$/m²(GIA)**

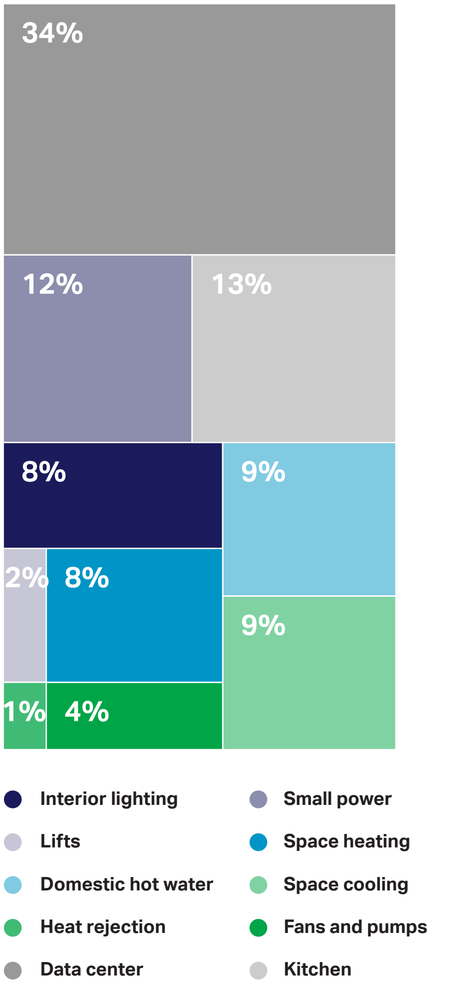
**This includes a reduction of approximatively 0.5% of the electricity needs provided by 250m² of PV panels.*

84% electricity / 16% natural gas

Grid carbon factor (SAP 10)
- Electricity: **0.233 kg$CO_2$e/kWh** (SAP10) and decarbonization progressions based on FES "steady progression" scenario
- Natural gas: **0.21 kg$CO_2$e/kWh**

Annual water consumption
**0.35m³/m²**
Carbon factor:
- Tap water, clean – Thames Water Utilities Ltd: **0.001 kg$CO_2$e/m³**

**Figure 54:** Energy consumption by activity




** Data center accounts for potential server rooms*

## Breakdown of carbon emissions per building element

**Figure 55:** Embodied carbon at practical completion (A1-A5)

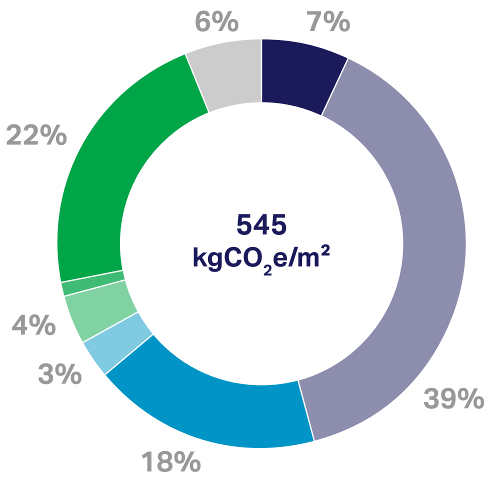



**Figure 56:** Embodied carbon over the life cycle (A-C)

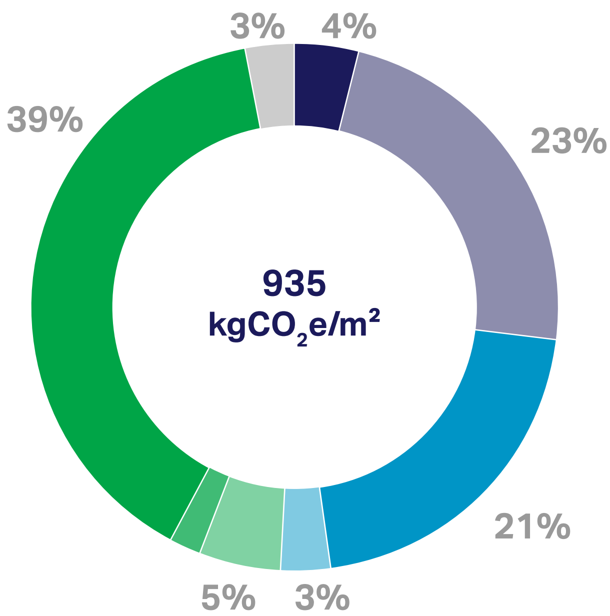
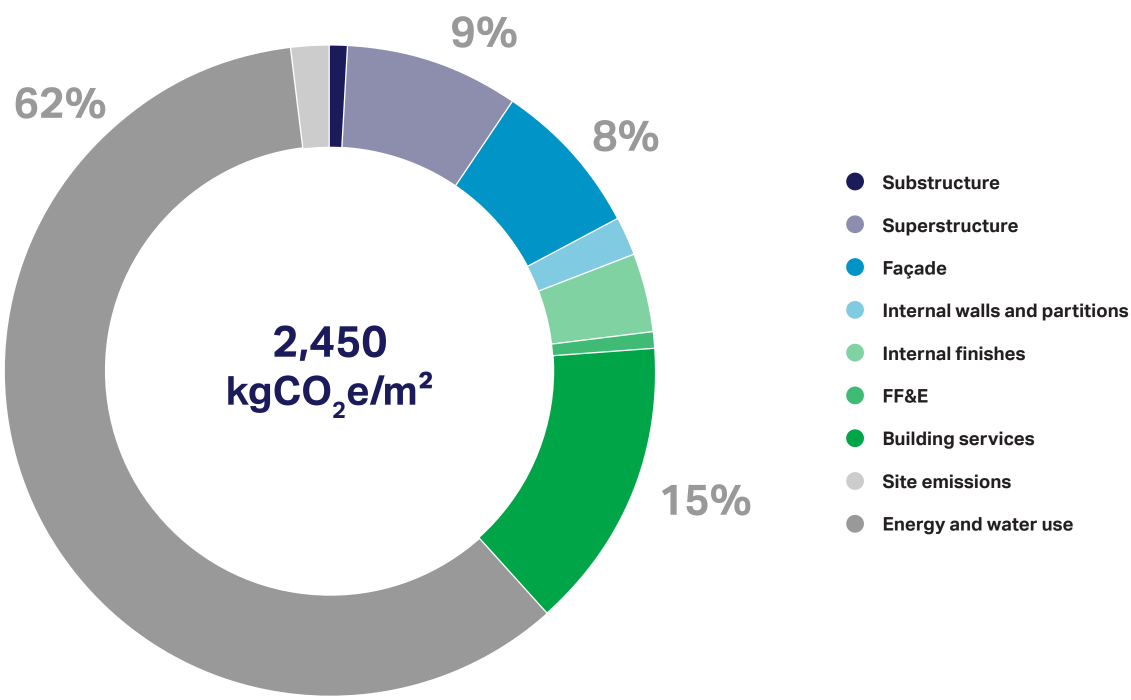



**Figure 57:** Whole life carbon (A-C)



## 01. Office building, London, UK

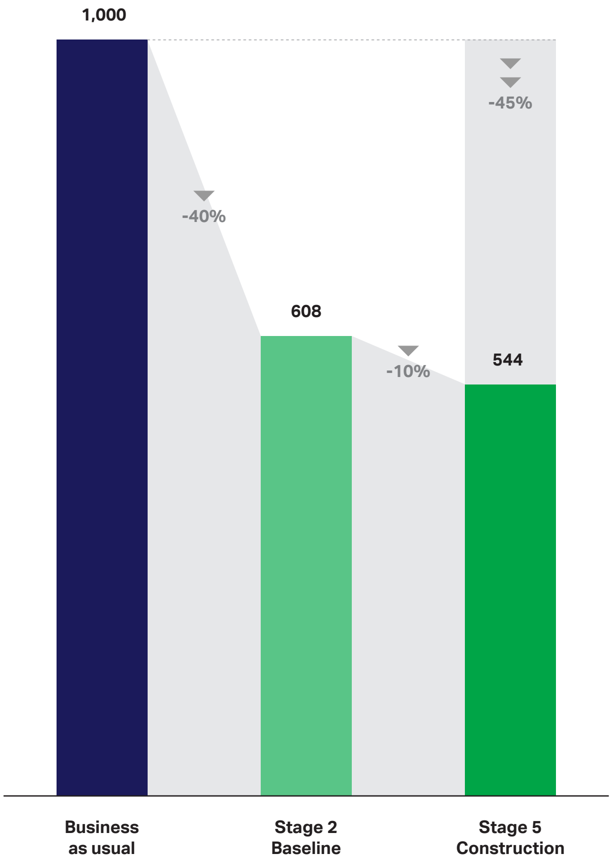
## WBCSD Building System Carbon Framework

| Case Study 01 | | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Whole life carbon emissions kgCO$_2$e/m$^2$ | | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1 *Foundations, lowest floor construction, retaining walls* | 36 | 3 | 0 | | 1.1 | 39 | -5 |
| | **Structure** – RICS Level 2.1 – 2.4 *Frame, floors, roofs and stairs* | 204 | 6 | 6 | | 3.0 | 219 | -48 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6 *External walls, windows and doors* | 100 | 1 | 94 | | 0.2 | 195 | -111 |
| | **Space Plan** – RICS Level 2.7 – 2.8 *Internal walls, partitions and doors* | 16 | 0 | 16 | | 0.1 | 32 | -2 |
| | **Space Plan** – RICS Level 3 *Internal finishes* | 23 | 0 | 23 | | 0.0 | 46 | 0 |
| | **Stuff** – RICS Level 4 *Fittings, furnishings and equipment* | 5 | 0 | 10 | | 0.0 | 15 | -5 |
| | **Services** – RICS Level 5 *Building services* | 120 | 1 | 240 | 1,512 | 1.4 | 1,873 | -56 |
| | **Site emissions** (A5) *Waste, electricity and fuel* | | 30 | | | | 30 | |
| **Embodied carbon emissions** | | **503** | **40** | **388** | | **6** | **937** | **-227** |
| **Operational carbon emissions** Energy and water use | | | | | **1,512** | | **1,512** | |
| **Building carbon emissions** | | **503** | **40** | **388** | **1,512** | **6** | **2,449** | **-227** |

## Project strengths

- Embodied carbon tracking from stage 2 to construction stage
- System optimization: maximum efficiency of structural/façade systems
- Ex: Post-tensioned slab minimized use of reinforced concrete, pile diameter reduced and simplified façade systems (change in panel sizes – decrease in framing)
- Cement replacement: High percentage of GGBS
- Dematerialisation: no false ceilings
- (exposed structural slab soffit), removing external blinds
- Coordination between disciplines: holistic carbon approach
- Selection of products and materials based on their carbon footprint
  - Ex: Rock fibre insulation chosen versus glass fibre and laminated glass partition walls instead if steel reduced material use
- Polyester powder coating versus anodized aluminum everywhere possible
- 250m² PV panels (operational carbon)

**Figure 58:** Carbon emissions at practical completion ($kgCO_2e/m^2$ GIA)

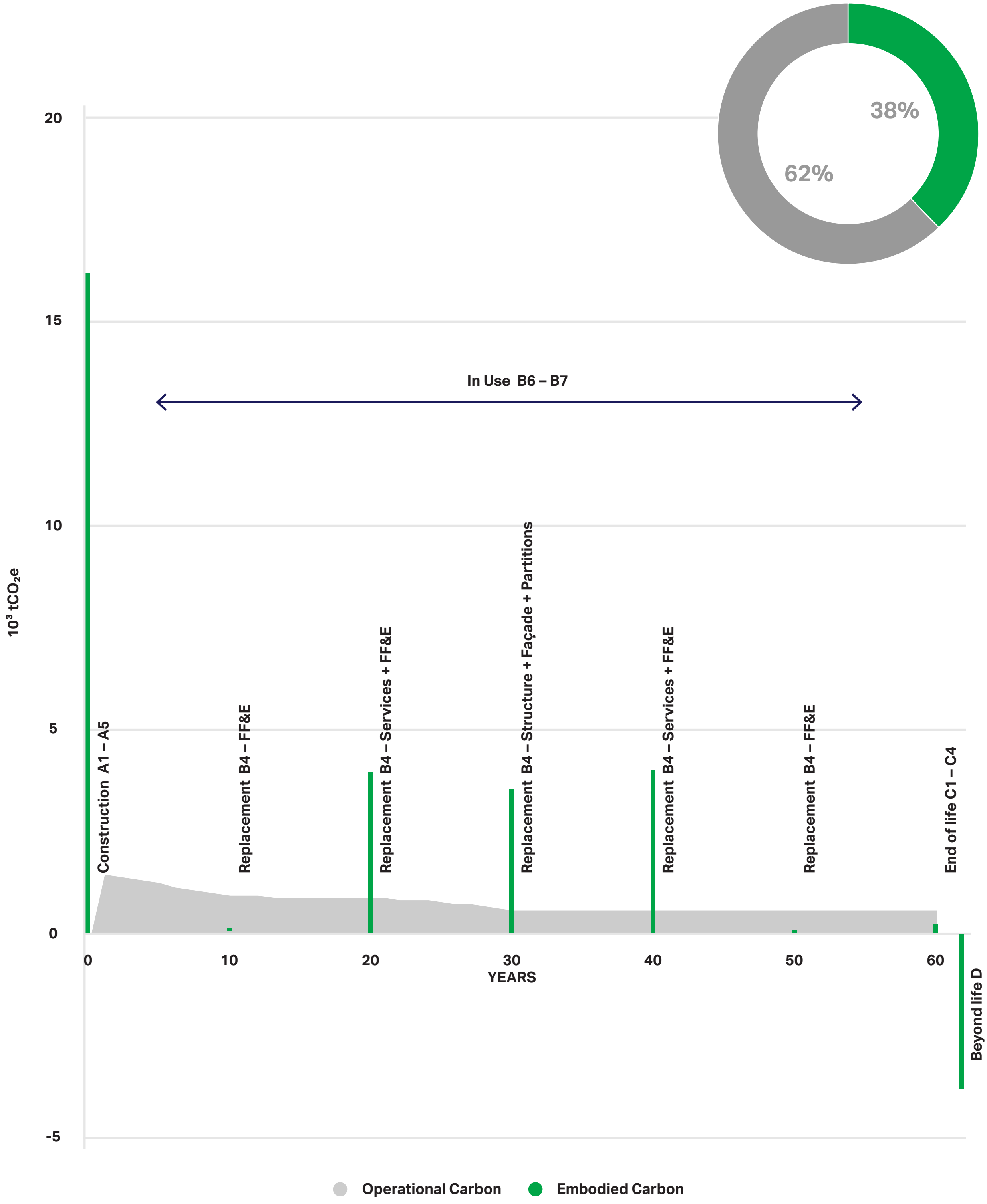



This project demonstrated advanced consideration of embodied carbon from the earliest stage onwards. The total embodied carbon at practical completion is 544 $kgCO_2e/m^2$, this represents a 10% saving in comparison with the stage 2 baseline.

This is good but does not align with the 40% reduction target presented in the first section of this report. However, in comparison with the “business as usual” benchmark for an office building (~1,000 $kgCO_2e/m^2$), it does represent a 40% saving.

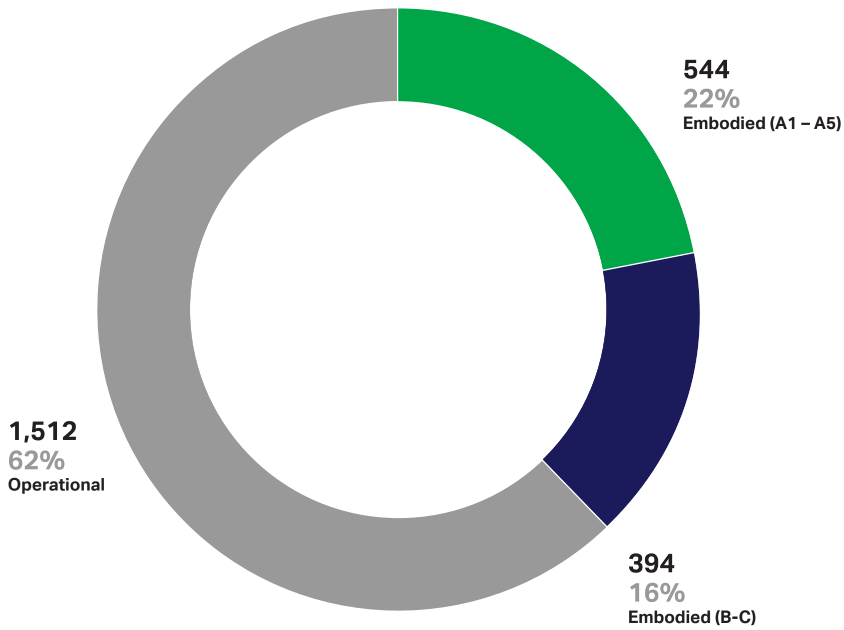
## 01. Office building, London, UK

**Figure 59:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

**Figure 60:** WLCA summary ($kgCO_2e/m^2$)

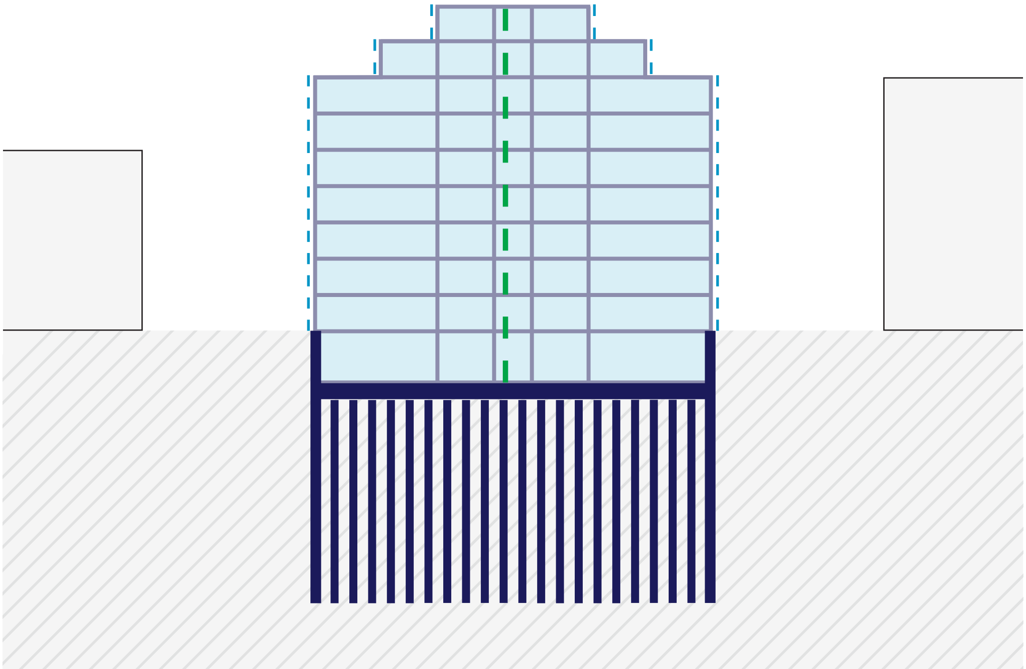



**Embodied carbon**
At practical completion – **16’210 $tCO_2e$**
Over the life cycle – **27’950 $tCO_2e$**

**Operational energy**
Over the life cycle – 45’100 $tCO_2e$

**WLCA** – 73’050 $tCO_2e$

# 02. All electric office building, London, UK



### Type
Office, New build

### Location
London, UK

### Development stage
Building's handover

### GIA
40,065 $m^2$

### Rating scheme
LEED 2014 Gold
BREEAM 2014 Excellent
Ecohomes Excellent

### Tool
OneClick LCA and Arup PECC tool

### Project data
Late design stage information: engineers' quantities from calculations and models and cost plan. Allowance made for services embodied carbon.

### Description
- 8 storeys office building
- Reinforced concrete and steel structure
  - One way spanning precast prestress concrete slab (100mm + 50mm topping) on steel beams and steel columns – grid 6m x 9m (perimeter 4.5m)
  - Stability: Reinforced Concrete central core (250-300mm thick walls) cantilevering from the piled foundations
- Foundations and reinforced concrete basement – 1 level
  - Retaining wall
  - Suspended RC basement slab (~300mm)
  - Deep piles and pile cap (~2m)
- Façade
  - Some retrained façade elements (conservation principles)
  - Existing steel and concrete – locally reinforced – framed fixed to new steel frame
  - New façade: precast concrete frame
  - New curtain walling and brick work at base level
- Exposed soffit and services
- Fully serviced with lift (cooling, heating, ventilation, electricity, water, lighting, sprinkler) and server rooms (data center)
- City center – highly constrained environment

## Key embodied $CO_2e$

### Material quantities and carbon factors

| | |
|---|---|
| Ready-mix **concrete**<br>(25,710$m^3$) | • Ready-mix concrete, RC 35/45 (32/40 MPa), 30% Cement replacement with fly ash<br>• ICE Database V3<br>• Carbon factor: **0.13 kg$CO_2$e/kg** |
| **Structural steel** sections and plates<br>(2,920t) | • Structural steel profiles, generic, 20% recycled content, I, H, U, L, and T sections<br>• OneClick LCA database<br>• Carbon factor: **2.51 kg$CO_2$e/kg** (This is close to British steel value for open sections of 2.45 kg$CO_2$e/kg) |
| Laminated raised **access floor**<br>(29,160$m^2$) | • Raised access flooring system – RG2 Europed (Kingspan)<br>• OneClick LCA database<br>• Carbon factor: **40.3 kg$CO_2$e/$m^2$** |
| Steel **reinforcement**<br>(180$m^3$ – 1405t) | • Steel reinforcement (generic – 97% recycled)<br>• One Click LCA database<br>• Carbon factor: **0.5 kg$CO_2$e/kg** |
| **Aluminum / glass** curtain walls<br>(13,420$m^2$) | • Aluminum mullion-transom system and insulating double-glazed units<br>• Database: Okobaudat and Vetrotech EPD<br>• Carbon factor: **9.9 kg$CO_2$e/$m^2$ and 87.5 kg$CO_2$e/$m^2$** |
| **Services**: Heating, cooling, ventilation, electricity, lighting, distribution systems, lifts and others. | • Average impact per $m^2$ GIA of the different systems based on past studies<br>• Database: OneClick LCA<br>• Carbon factor: 10 – 30 kg$CO_2$e/$m^2$/system<br>• Total services: **120 kg$CO_2$e/$m^2$** |

## 02. All electric office building, London, UK

### Key operational $CO_2$e

### Energy and water consumption

**TM54** assessment: In depth operational energy performance evaluation taking in account regulated and unregulated emissions.

Annual energy consumption:
**109kWh/m²(GIA)**

100% electricity

Grid carbon factors:

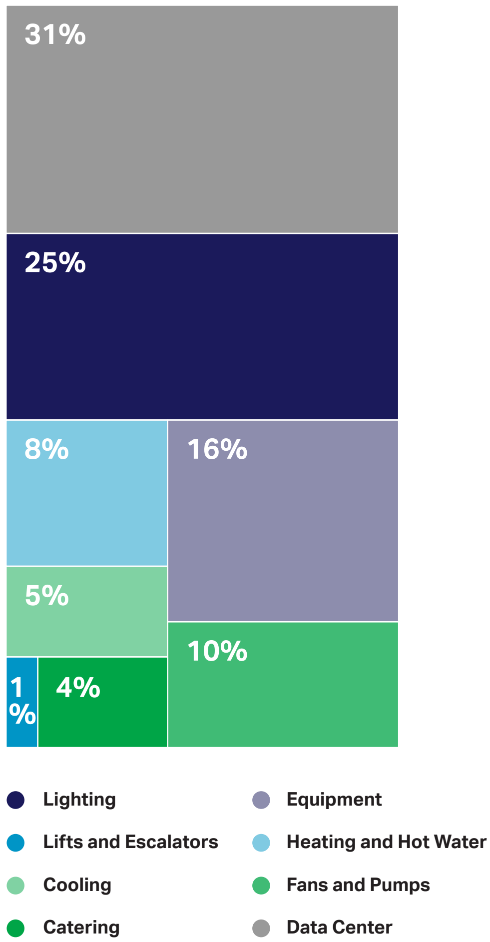
- Electricity: **0.233 kg$CO_2$e/ kWh** (SAP10) and decarbonization progressions based on FES "steady progression" scenario

Annual water consumption
**0.40m³/m²**

Carbon factor:

- Tap water, clean – Thames Water Utilities Ltd: **0.001 kg$CO_2$e/m³**

**Figure 61:** Energy consumption by activity




** Data center accounts for potential server rooms*

Results

## Breakdown of carbon emissions per building element

Figure 62: Embodied carbon at practical completion (A1-A5)

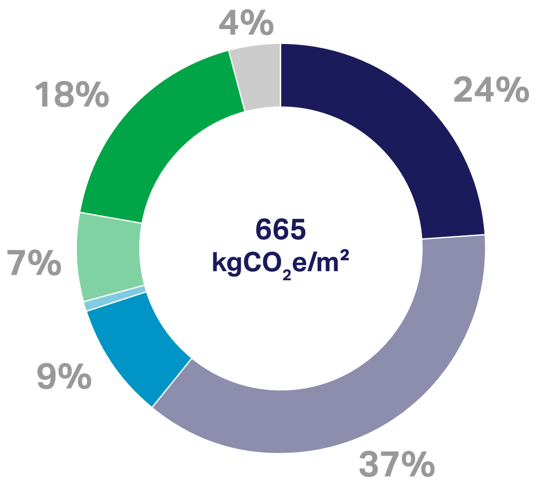



Figure 63: Embodied carbon over the life cycle (A-C)

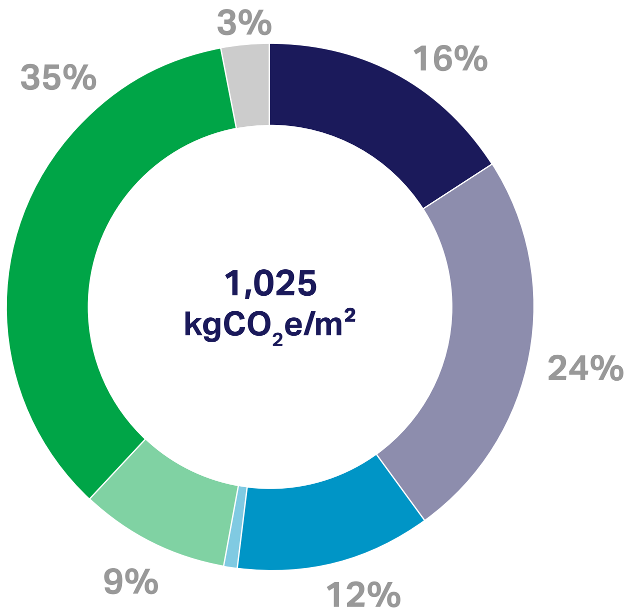
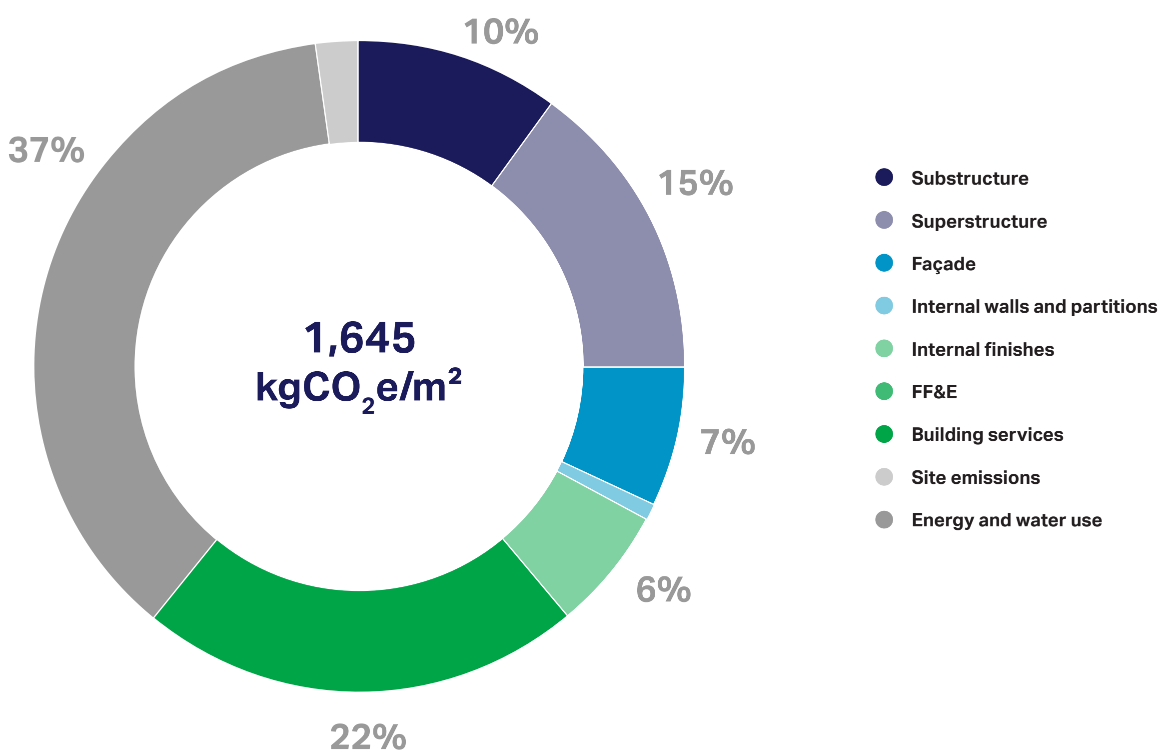



Figure 64: Whole life carbon (A-C)



## 02. All electric office building, London, UK

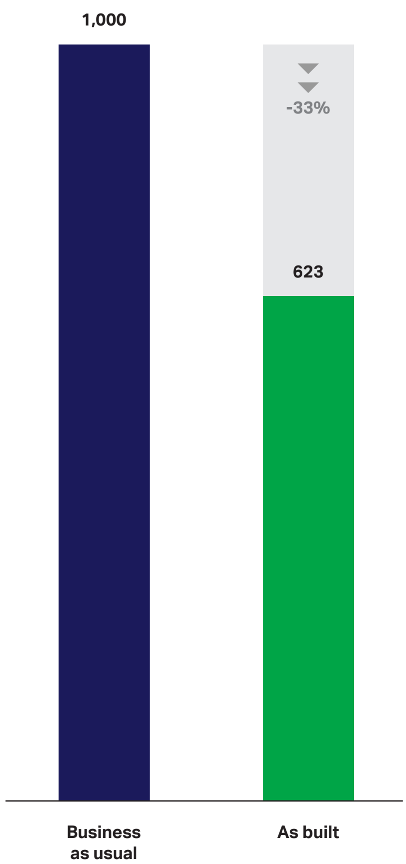
### WBCSD Building System Carbon Framework

| Case Study 02 | | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Whole life carbon emissions $kgCO_2e/m^2$ | | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1 *Foundations, lowest floor construction, retaining walls* | 152 | 7 | 0 | | 3.2 | 162 | -14.9 |
| | **Structure** – RICS Level 2.1 – 2.4 *Frame, floors, roofs and stairs* | 240 | 4 | 0 | | 1.8 | 246 | -92.2 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6 *External walls, windows and doors* | 59 | 1 | 59 | | 0.6 | 120 | -33.1 |
| | **Space Plan** – RICS Level 2.7 – 2.8 *Internal walls, partitions and doors* | 6 | 0 | 6 | | 0.2 | 13 | -1.7 |
| | **Space Plan** – RICS Level 3 *Internal finishes* | 45 | 1 | 46 | | 0.7 | 94 | -5.7 |
| | **Stuff** – RICS Level 4 *Fittings, furnishings and equipment* | 0 | 0 | 0 | | 0.0 | 0 | 0 |
| | **Services** – RICS Level 5 *Building services* | 120 | 1 | 240 | 619 | 1.3 | 981 | -60 |
| | **Site emissions** (A5) *Waste, electricity and fuel* | | 30 | | | | 30 | |
| **Embodied carbon emissions** | | **623** | **44** | **352** | | **8** | **1,027** | **-208** |
| **Operational carbon emissions** Energy and water use | | | | | **619** | | **619** | |
| **Building carbon emissions** | | **623** | **44** | **352** | **619** | **8** | **1,647** | **-208** |

## Project strengths

- Operational energy performance
  - Low energy consumption
- 100% electric building: carbon emissions associated with operational energy – 619 $kgCO_2e$ / $m^2$
- Material selection
  - Low embodied carbon for concrete with fly ash replacement – 40%
  - Low embodied carbon product selection for finishes: gypsum plasterboard, paint, ceramic tiles
  - Low embodied carbon blockwork
  - Prioritisation of timber framing against steel for internal walls
- Dematerialization
  - Less dense blockwork heavy partitions with design development (-4,000$m^2$)
  - No false ceiling

**Figure 65:** Carbon emissions at practical completion ($kgCO_2e/m^2$ GIA)

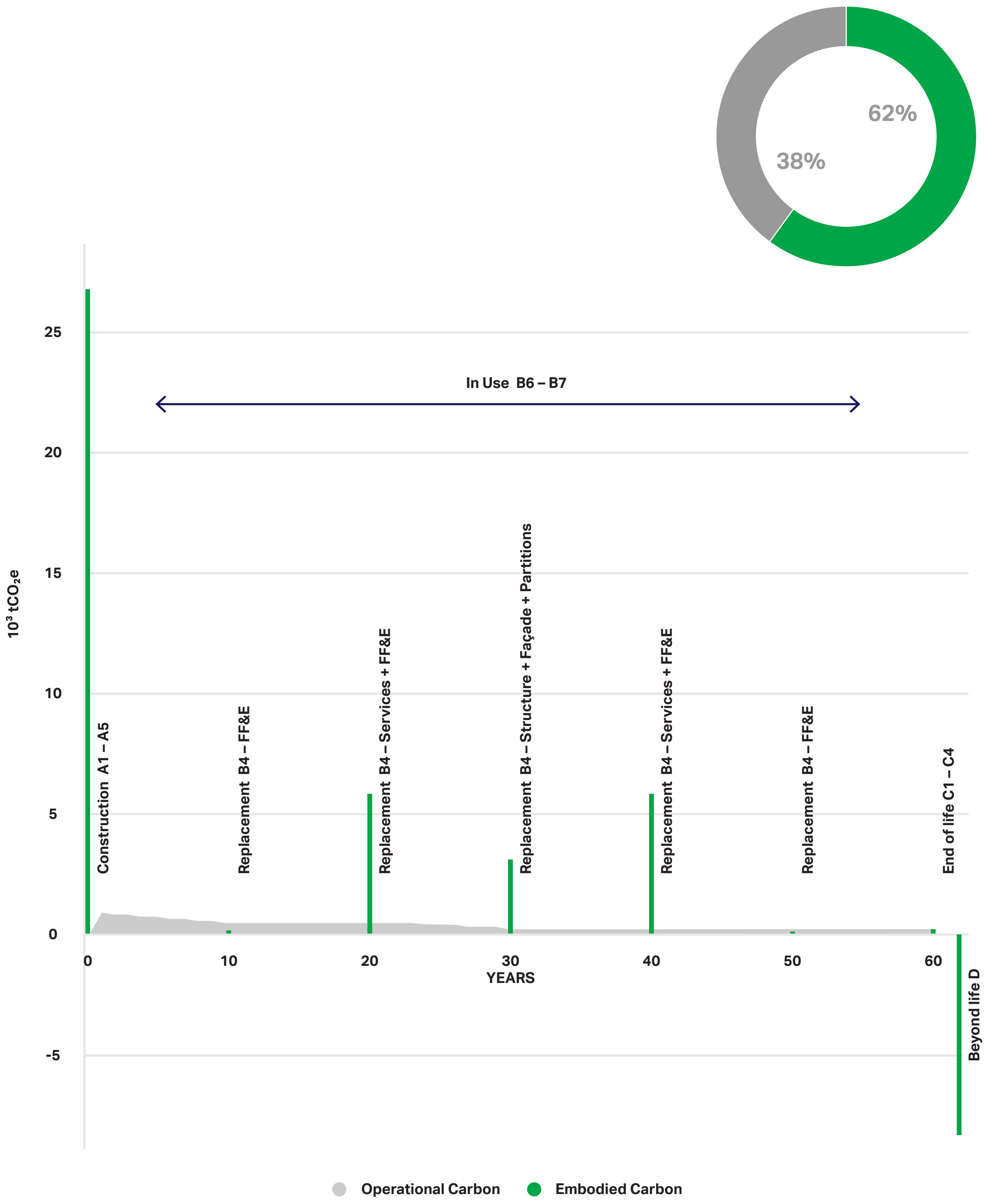



This project demonstrated advanced consideration of operational carbon as it was designed in 2015 to be powered by electricity only. The annual operational carbon emissions will reduce proportionally to the grid decarbonization. The whole life operational carbon was estimated around 620$kgCO_2e/m^2$ which is less than 50% of the building's emissions.

This highlights the needs to focus efforts on reducing the embodied carbon as well. The total embodied carbon at practical completion is equivalent ~ 620 $kgCO_2e/m^2$. This represents a 38% reduction in comparison with the stage the "business as usual" benchmark for an office building (~1,000 $kgCO_2e/m^2$).

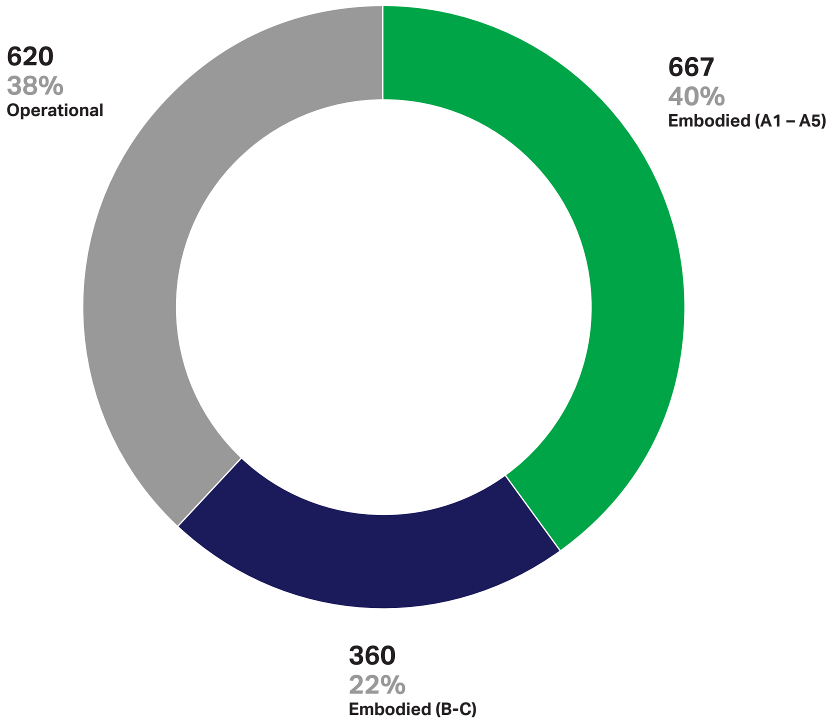
## 02. All electric office building, London, UK

**Figure 66:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

**Figure 67:** WLCA summary ($kgCO_2e/m^2$)

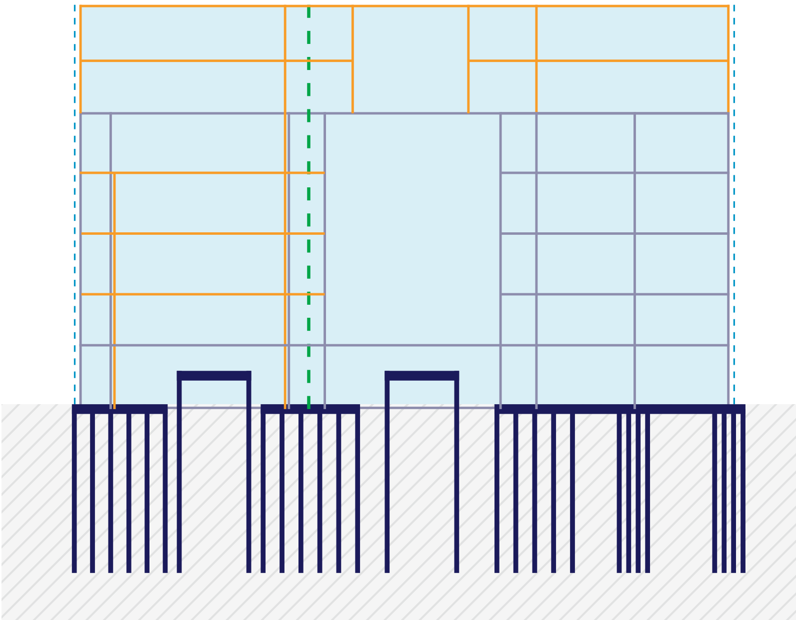



**Embodied carbon**
At practical completion – **26’719 $tCO_2e$**
Over the life cycle – **41’155 $tCO_2e$**

**Operational energy**
Over the life cycle – **24’820 $tCO_2e$**

**WLCA – 65’975 $tCO_2e$**

# 03. Complete transformation office building, London, UK



**Type**
Office, Complete transformation

**Location**
London, UK

**Development stage**
Concept design

**GIA**
42,776 $m^2$

**Rating scheme**
Aiming for BREEAM 2018 Outstanding

**Tool**
OneClick LCA

**Project data**
Concept design information: cost plan and drawings. Industry averages as material specifications. Energy consumption predicted through building energy modelling.

**Description**

- 7 storeys office building (retail at ground floor)
- Reinforced concrete and composite structure (existing and new)
  - Part A – Existing steel frame with concrete encapsulated columns, bracings and Vierendeel frames. Precast concrete planks or slab on steel deck on steel beams. New floors created to fill existing hall : lightweight composite slabs and new set of columns adjacent to existing ones
  - Part B – Existing precast concrete portal frames and shear walls with precast slabs and beams. Mainly retained – openings, infills and minor strengthening
- New extension (in plan) and 2 additional storeys – steel framing and composite slabs
- Ground floor and Foundations
  - Thick RC ground slab, piles and pile caps – retained
  - New piled foundations for extension
  - Local reinforcement with mini-piles
- Façade – entirely replaced
  - Semi-curtain walling systems with ribbon windows
  - Glazed curtain walling system
  - Opaque cladding system
  - Roof cladding – laminated zinc standing seam system
- Little partitions, exposed soffit and raised floors.
- Fully serviced with lift (cooling, healing, ventilation, electricity, water, lighting, sprinkler)

Key embodied $CO_2e$

## Material quantities and carbon factors

| | |
|---|---|
| **Structural steel** sections and plates (3,030t) | • Structural steel profiles, generic, 20% recycled content, I, H, U, L, and T sections<br>• OneClick LCA database<br>• Carbon factor: **2.51 kg$CO_2$e/kg** (This is close to British steel value for open sections of 2.45 kg$CO_2$e/kg) |
| Ready-mix **concrete** (8,990$m^3$) | • Ready-mix concrete, RC 32/40 (32/40 MPa), 25% Cement replacement with blast furnace slag (GGBS)<br>• ICE Database V3<br>• Carbon factor: **0.12 kg$CO_2$e/kg** |
| **Raised access floors** (24,670$m^2$) | • Raised access flooring system, 60-640 mm Variable height, 30 kg/$m^2$<br>• Database: EPD Kingspan TLM26 Alpha V<br>• Carbon factor: **51.8 kg$CO_2$e/$m^2$** |
| Profiled **steel decking** for composite floor (315t) | • Profiled steel decking for composite floor slabs / decking, 0.9mm sheet thickness, 13.01kg/$m^2$, ComFlor 51+ 0.9mm<br>• Database: EPD TATA Steel<br>• Carbon factor: **2.72 kg$CO_2$e/kg** |
| Steel **reinforcement** (1,140t) | • Reinforcement steel (rebar), generic, 97% recycled content (typical for UK)<br>• Database: OneClick LCA<br>• Carbon factor: **0.5 kg$CO_2$e/kg** |
| **Services**: Heating, cooling, electricity, ventilation, lighting distribution systems and lifts. | • Average impact per $m^2$ GIA of the different systems based on past studies<br>• Database: OneClick LCA<br>• Carbon factor: **10-30 kg$CO_2$e/$m^2$/system total: approx. 105kg$CO_2$e/$m^2$** |

## 03. Complete transformation office building, London, UK

### Key operational $CO_2e$

### Energy and water consumption

Enhanced Building Energy Modelling (similar to Nabers)

Annual energy consumption (Averaged between plot H1 and H2)
**118kWh$_{equivalent}$/m$^2$(GIA)**

**This includes a reduction of approximatively 2% of the electricity needs provided by 250 PV panels.*

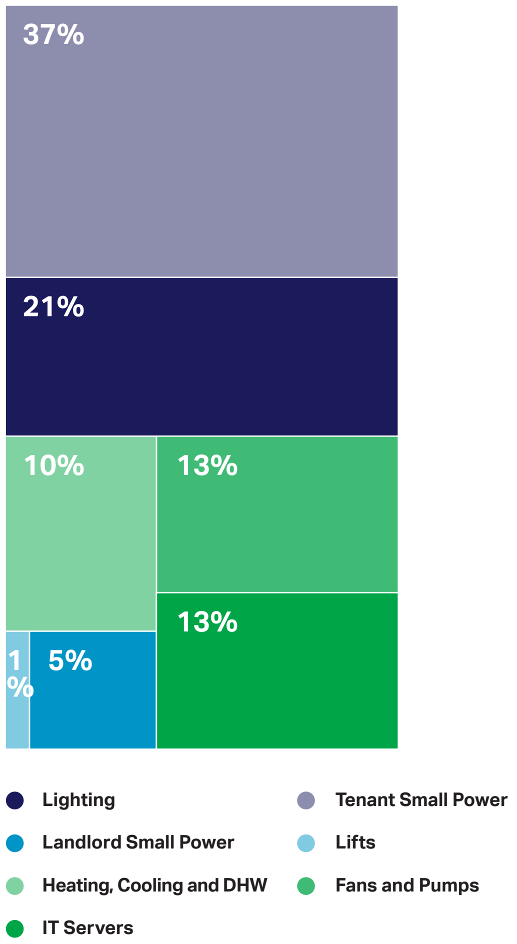
100% electricity

Grid carbon factor (SAP 10)
- Electricity: Decarbonization progressions based on FES "steady progression" scenario applied to the current factor of **0.233 kg$CO_2$e/kWh** (SAP10)
- Natural gas: **0.21 kg$CO_2$e/kWh**

Annual water consumption
**0.45m$^3$/m$^2$**

Carbon factor:
- Tap water, clean – Thames Water Utilities Ltd: **0.001 kg$CO_2$e/m$^3$**

**Figure 68:** Energy consumption by activity



Results

## Breakdown of carbon emissions per building element

**Figure 69:** Embodied carbon at practical completion (A1-A5)

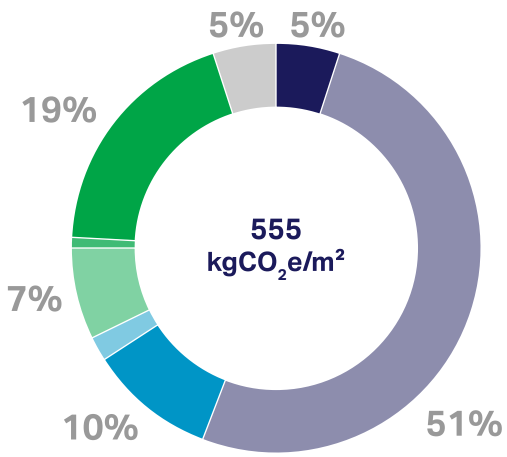



**Figure 70:** Embodied carbon over the life cycle (A-C)

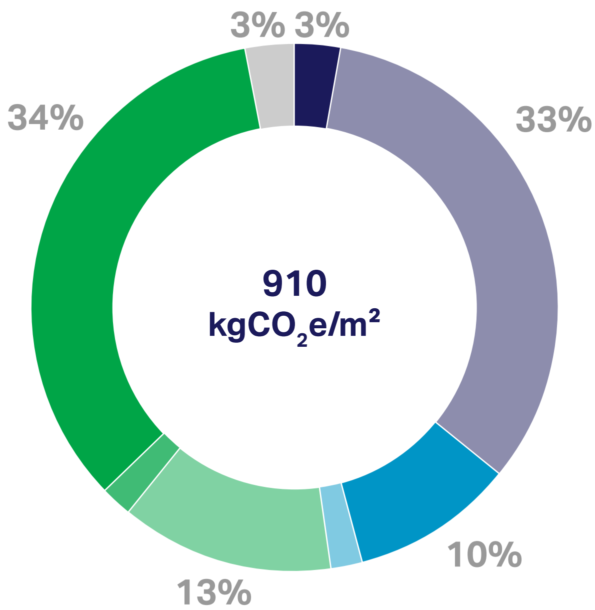
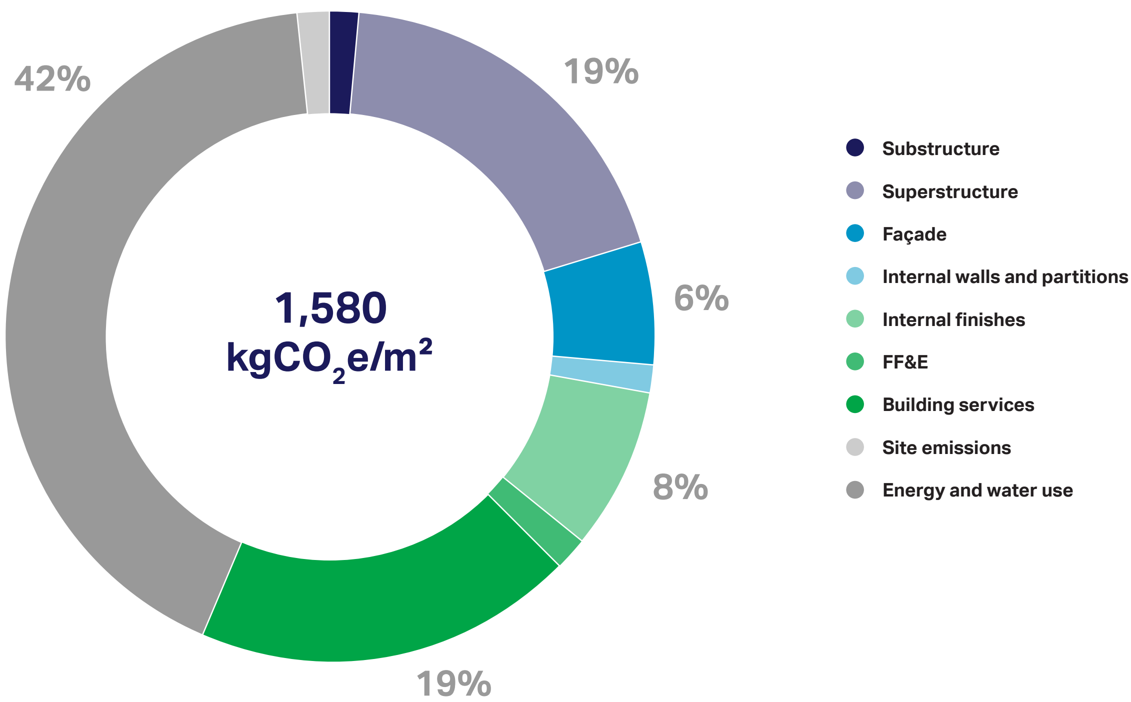



**Figure 71:** Whole life carbon (A-C)



## 03. Complete transformation office building, London, UK

### WBCSD Building System Carbon Framework

| Case Study 03 | | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Whole life carbon emissions $kgCO_2e/m^2$ | | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1 *Foundations, lowest floor construction, retaining walls* | 25 | 1 | 0 | | 0.6 | 27 | -3 |
| | **Structure** – RICS Level 2.1 – 2.4 *Frame, floors, roofs and stairs* | 278 | 4 | 14 | | 2.1 | 298 | -105 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6 *External walls, windows and doors* | 54 | 0 | 38 | | 0.1 | 93 | -21 |
| | **Space Plan** – RICS Level 2.7 – 2.8 *Internal walls, partitions and doors* | 11 | 0 | 7 | | 0.4 | 18 | -2 |
| | **Space Plan** – RICS Level 3 *Internal finishes* | 40 | 0 | 77 | | 0.1 | 118 | -1 |
| | **Stuff** – RICS Level 4 *Fittings, furnishings and equipment* | 4 | 0 | 18 | | 0.0 | 21 | -8 |
| | **Services** – RICS Level 5 *Building services* | 104 | 1 | 200 | 670 | 1.0 | 976 | -51 |
| | **Site emissions** (A5) *Waste, electricity and fuel* | | 30 | | | | 30 | |
| **Embodied carbon emissions** | | **516** | **37** | **354** | | **4** | **912** | **-191** |
| **Operational carbon emissions** Energy and water use | | | | | **670** | | **670** | |
| **Building carbon emissions** | | **516** | **37** | **354** | **670** | **4** | **1,582** | **-191** |

## Project strengths

- Embodied carbon calculations to support decision making
- Existing substructure reused
- Some existing framing reused
- Low predicted energy consumptions next to current standards
- 100% electric building
- No false ceilings
- PVs??

## Project opportunities

The design team have been studying options to further reduce the embodied carbon impact of the future project.

Amended baseline

- Reduce steel weight by adding a line of supports (more efficient system)
- Enhancing the GGBS ratios of all concrete

CLT alternative

- Using the same steel ratio as amended baseline
- Replace composite deck with CLT slabs (new areas)

**Figure 72:** Embodied carbon emissions at practical completion – A1-A5 ($kgCO_2e/m^2$ GIA)

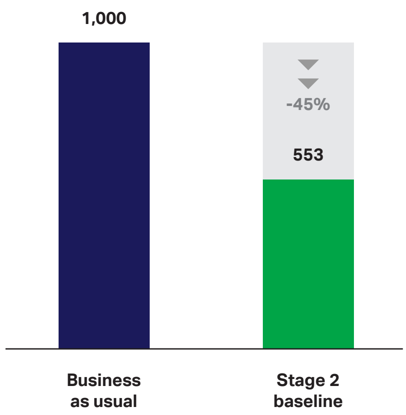
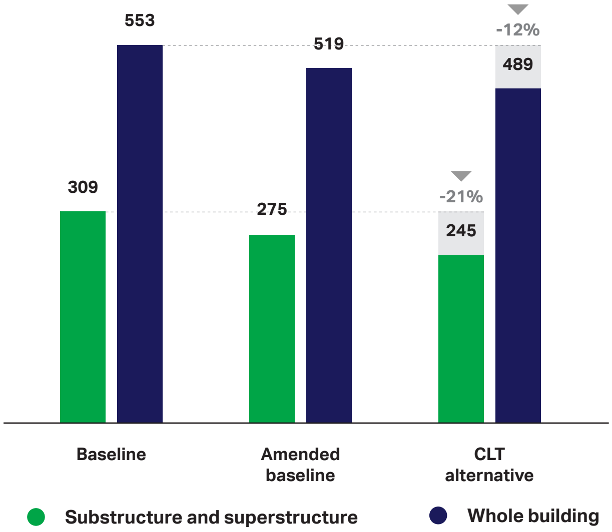


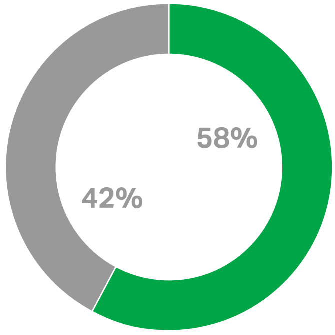

**Figure 73:** Potential embodied carbon reductions A1-A4 ($kgCO_2e/m^2$ GIA)

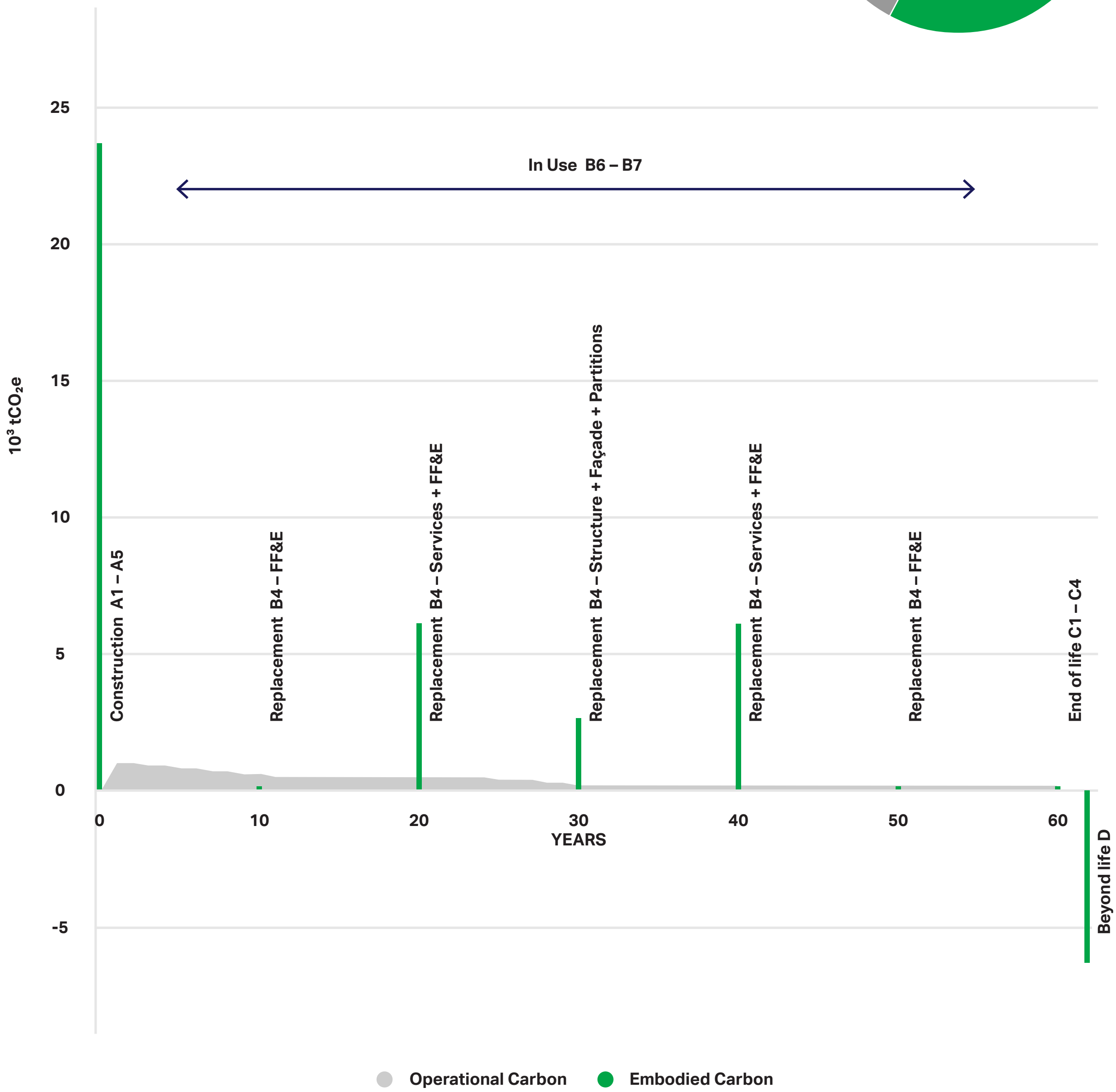



This project is demonstrating advanced consideration of whole life carbon from the earliest stage. A whole life cycle assessment of the stage 2 design approximated the total carbon emissions over the whole life at approximatively 1,700 $kgCO_2e/m^2$. The embodied carbon at practical completion is 544 $kgCO_2e/m^2$. Further studies demonstrated that the building could save an extra 12% of embodied carbon at practical completion, bringing the upfront embodied carbon down to 489$kgCO_2e/m^2$, which will be reassessed at the next stage. This is good but does not align with the 40% reduction target discussed in the first section of this report. However, in comparison with the "business as usual" benchmark for an office building (~1,000 $kgCO_2e/m^2$), the stage 2 design already exceeds that 40% saving.

## 03. Complete transformation office building, London, UK

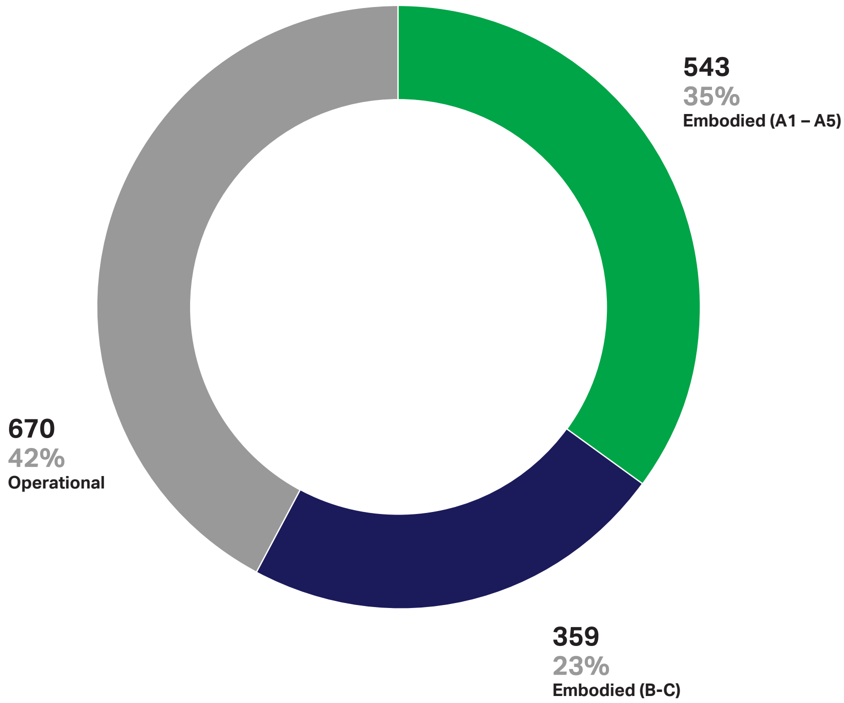
**Figure 74:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

**Figure 75:** WLCA summary ($kgCO_2e/m^2$)

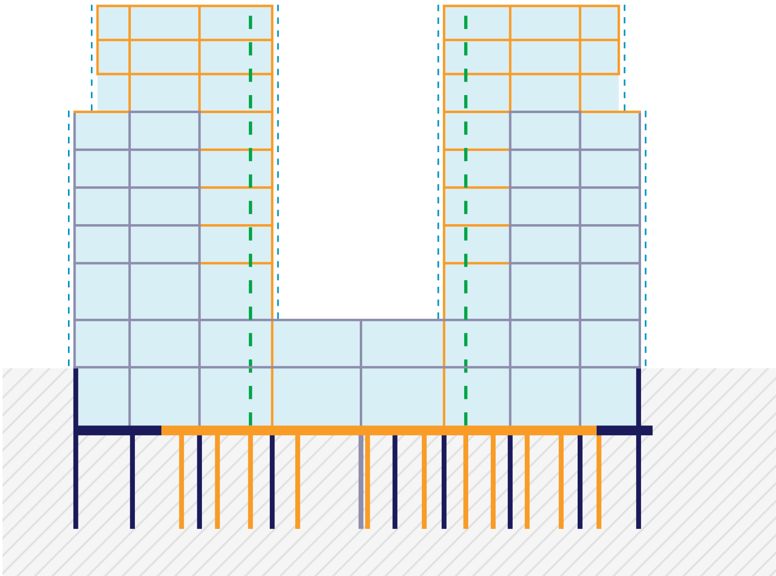



**Embodied carbon**
At practical completion – **23’700 $tCO_2e$**
Over the life cycle – **39’000 $tCO_2e$**

**Operational energy**
Over the life cycle – **28’700 $tCO_2e$**

**WLCA – 67’700 $tCO_2e$**

# 04. Refurbishment office building, London, UK



**Type**
Office, Refurbishment

**Location**
London, UK

**Development stage**
Refurbishment completed

**GIA**
47,264 $m^2$

**Rating scheme**
LEED V4 Gold
BREEAM 2014 Outstanding

**Tool**
OneClick LCA

**Project data**
Late design stage information – cost plan, drawings and specifications. Project Sustainability Report. Structural material quantities issued directly by contractor as well as emissions due to site activity. Services embodied carbon calculated from quantities issued by the engineers.

**Description**

- 6 storey office building (+1 level of basement)
- Refurbishment to the existing 6 floors with the partial infill of the atrium, infill of the reception, strengthening of existing vertical structure
- Substructure: New piled raft, retaining walls and sundry lift pits / slab infills, all formed in reinforced concrete
- Composite steel/concrete superstructure
  - New structure: lightweight steel frame supporting composite floors
  - Existing concrete and steel columns strengthening and existing floor-imposed load reduced to free up capacity
- 1 deep level reinforced concrete basement
- Main façade systems: aluminum and stone
  - Retain 40% of original stone façade
  - New unitized stone façade panels and
  - Aluminum Façade with rock wool insulation and glazing
- Exposed soffit and services – no false ceiling
- Fully serviced with lift (cooling, heating, ventilation, electricity, water, lighting)
  - Full optimization of services to reduce operation carbon such as innovative heat recovery system

## Key embodied $CO_2e$

### Material quantities and carbon factors

| | |
|---|---|
| Ready-mix **concrete** (6,750m$^3$) | • Average ready-mix concrete, RC 35/45 (32/40 MPa), 65% Cement replacement with blast furnace slag (GGBS)<br>• ICE Database V3<br>• Carbon factor: **0.1 kg$CO_2$e/kg** |
| **Structural steel** sections and plates (2,390t) | • Structural steel profiles, generic, 20% recycled content, I, H, U, L, and T sections<br>• OneClick LCA database<br>• Carbon factor: **2.51 kg$CO_2$e/kg** (This is close to British steel value for open sections of 2.45 kg$CO_2$e/kg) |
| **Aluminum** profile and sheets (200t) | • Aluminum extruded profile, European Mix, Inc Imports and European Aluminum profiled sheets<br>• ICE database V3 and IBU EPD Database<br>• Carbon factor: **6.83 kg$CO_2$e/kg and 9.32 kg$CO_2$e/kg** |
| **Glass** (420t) | • Coated flat glass, 1 mm, max 3,210x6,000 mm, 2,500 kg/m$^3$ (Guardian Europe) and Toughened Glass<br>• Database: IFT Rosenheim (EPD-GFEV-GB-19.0) and ICE V3.0<br>• Carbon factor: **1.11 kg$CO_2$e/kg and 1.67 kg$CO_2$e/kg** |
| Steel **reinforcement** (710t) | • Reinforcement steel (rebar), generic, 97% recycled content (typical for UK)<br>• Database: OneClick LCA<br>• Carbon factor: **0.5 kg$CO_2$e/kg** |
| **Services**: Heating, cooling, ventilation, electricity, lighting, distribution systems, lifts and others | • Quantities based on data received from project services engineers<br>• Highest contributing material: Air handling unit<br>• Database: OneClick LCA<br>• Carbon factor: **8.11 kg$CO_2$e/kg**<br>• **Total services: 67 kg$CO_2$e/m$^2$** |

**04. Refurbishment office building, London, UK**

**Key operational $CO_2e$**

## Energy and water consumption

TM54 assessment: In depth operational energy performance evaluation taking in account regulated and unregulated emissions.

Annual energy consumption
**149kWh$_{equivalent}$/m$^2$(GIA)**

**This includes a reduction of approximatively 1% of the electricity needs provided by PV panels.*

87% electricity / 13% natural gas

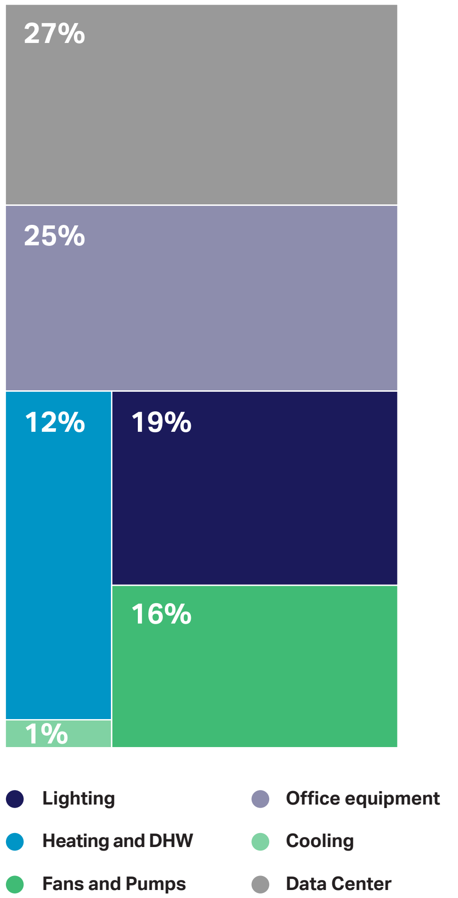
Grid carbon factor (SAP 10)

- Electricity: Decarbonization progressions based on FES "steady progression" scenario applied to the current factor of **0.233 kg$CO_2$e/kWh** (SAP10)
- Natural gas: **0.21 kg$CO_2$e/kWh**
- Annual water consumption **0.45m$^3$/m$^2$**

Carbon factor:

- Tap water, clean – Thames Water Utilities Ltd: **0.001 kg$CO_2$e/m$^3$**

**Figure 76:** Energy consumption by activity




** Data center accounts for potential server rooms*

Results

## Breakdown of carbon emissions per building element

**Figure 77:** Embodied carbon at practical completion (A1-A5)

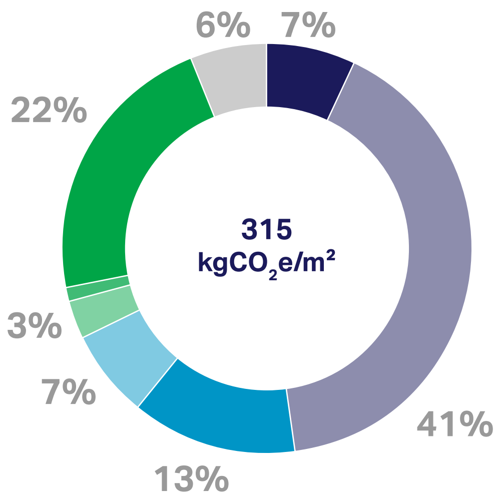



**Figure 78:** Embodied carbon over the life cycle (A-C)

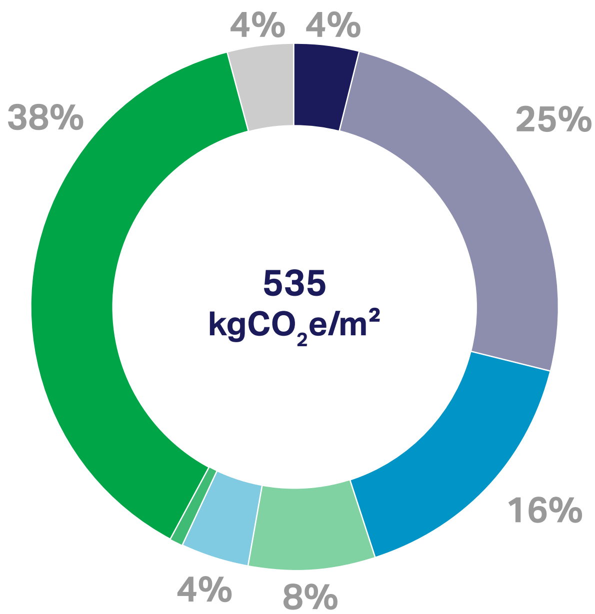
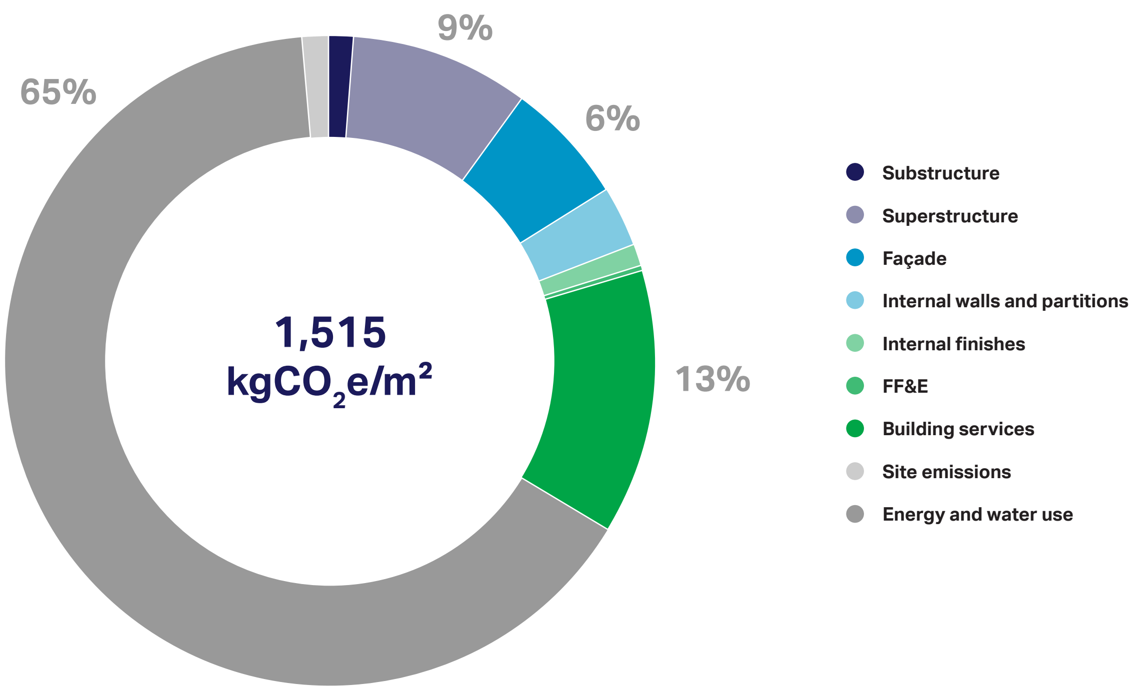



**Figure 79:** Whole life carbon (A-C)



## 04. Refurbishment office building, London, UK

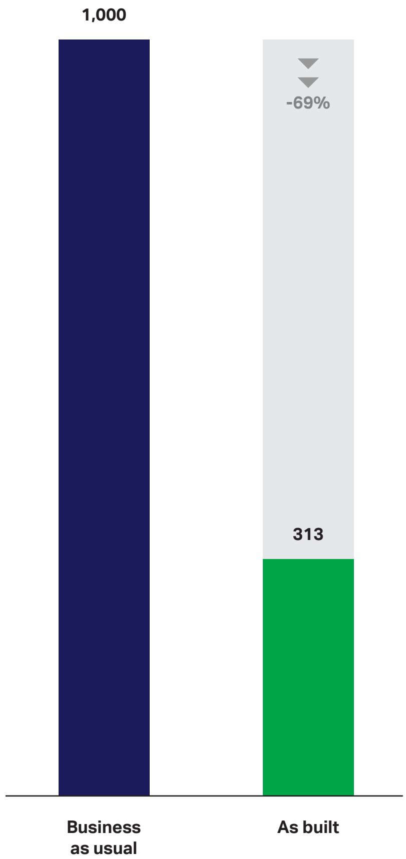
### WBCSD Building System Carbon Framework

| Case Study 04 | | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Whole life carbon emissions $kgCO_2e/m^2$ | | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1<br>*Foundations, lowest floor construction, retaining walls* | 19 | 1 | | | 0.6 | 21 | -3 |
| | **Structure** – RICS Level 2.1 – 2.4<br>*Frame, floors, roofs and stairs* | 127 | 2 | 2 | | 2.6 | 134 | -59 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6<br>*External walls, windows and doors* | 41 | 0 | 41 | | 0.1 | 83 | 50 |
| | **Space Plan** – RICS Level 2.7 – 2.8<br>*Internal walls, partitions and doors* | 21 | 0 | 21 | | 0.6 | 43 | -16 |
| | **Space Plan** – RICS Level 3<br>*Internal finishes* | 10 | 0 | 12 | | 0.5 | 23 | -2 |
| | **Stuff** – RICS Level 4<br>*Fittings, furnishings and equipment* | 3 | 0 | 3 | | 0.0 | 6 | -6 |
| | **Services** – RICS Level 5<br>*Building services* | 67 | 0 | 134 | 983 | 0.8 | 1,185 | -21 |
| | **Site emissions** (A5)<br>*Waste, electricity and fuel* | | 20 | | | | 20 | |
| **Embodied carbon emissions** | | **289** | **24** | **214** | | **5** | **533** | **-155** |
| **Operational carbon emissions**<br>Energy and water use | | | | | **983** | | **983** | |
| **Building carbon emissions** | | **289** | **24** | **214** | **893** | **5** | **1,515** | **-155** |

## Project strengths

- Retention of significant areas of the existing raft, and significant alteration works minimized
- Retention and upgrade of existing significant parts of the façade
- Two thirds of the final floor area from existing structure – reduce floors impact by ap. 50% compare to new built
- Cement replacement : High percentage of GGBS – up to 70%
- Local procurement of concrete and screed
- Adoption of lower concrete grades for low stress elements
- Low embodied carbon materials including plasterboard, steel, natural stone, aluminum, and glass
- Select of mineral based wool (rather than oil based insulation) to lower the embodied impact of the building envelope
- Engagement with partners / supply chain to establish circular business models for leasing and renting materials schemes – particularly for internal finishes e.g. raised floor, carpet, partitions
- Coordination between disciplines: holistic carbon approach
- Early adoption of green building certification schemes to lower embodied carbon impacts across the project life cycle e.g. BREEAM / LEED

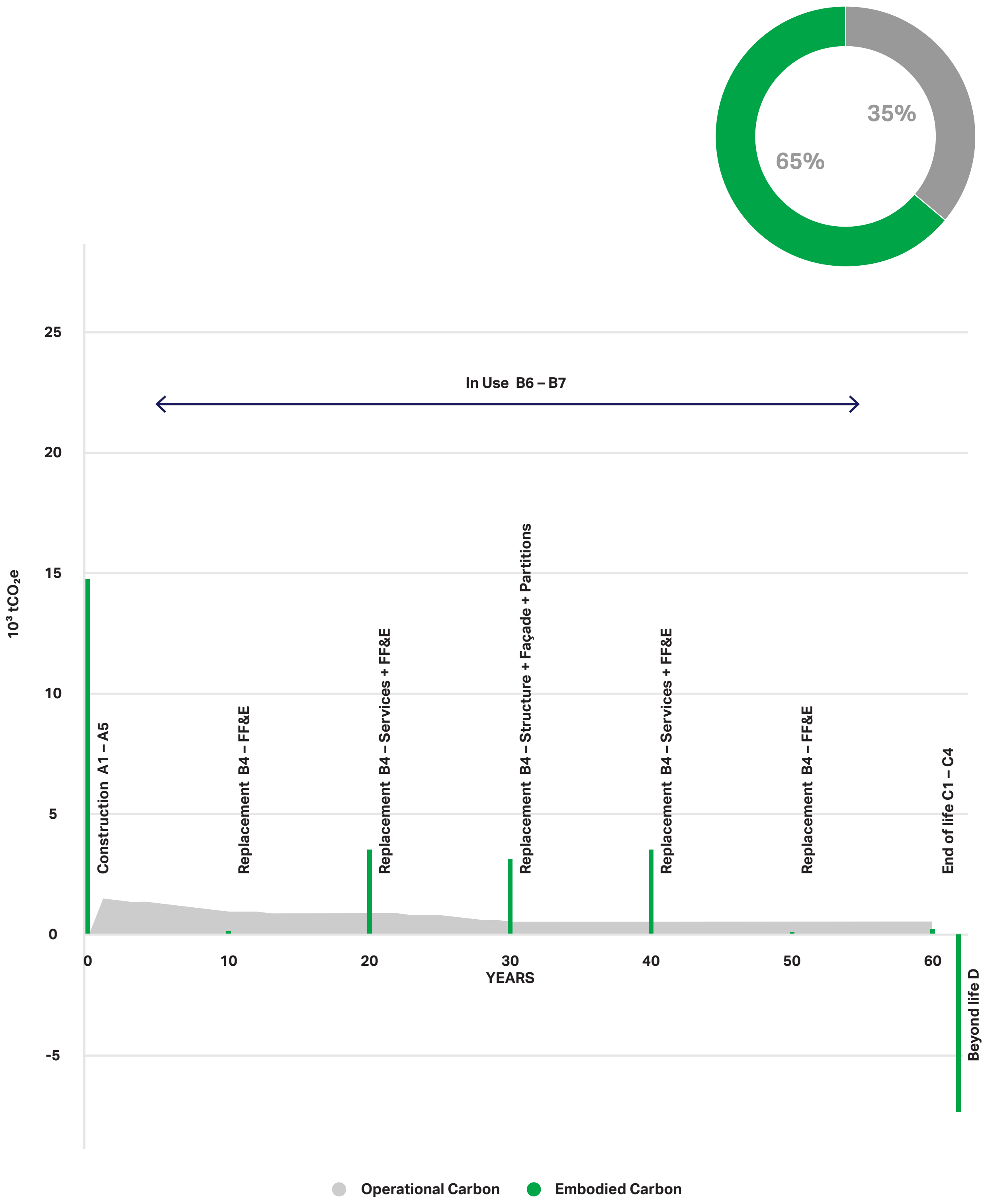
**Figure 80:** Carbon emissions at practical completion (kg$CO_2$e/m$^2$ GIA)




This project is a successful example of how building less and reusing existing structure can lead to significant carbon savings. The total embodied carbon at practical completion is 313 kg$CO_2$e/m$^2$, this represents a 68% saving in comparison with the "business as usual" benchmark for an office building (~1,000 kg$CO_2$e/m$^2$).

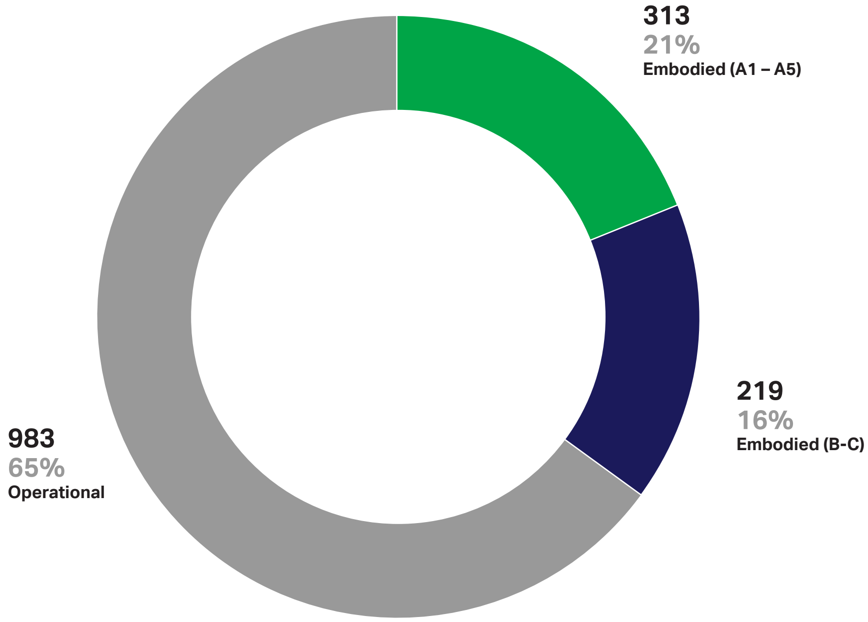
## 04. Refurbishment office building, London, UK

**Figure 81:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

Figure 82: WLCA summary ($kgCO_2e/m^2$)

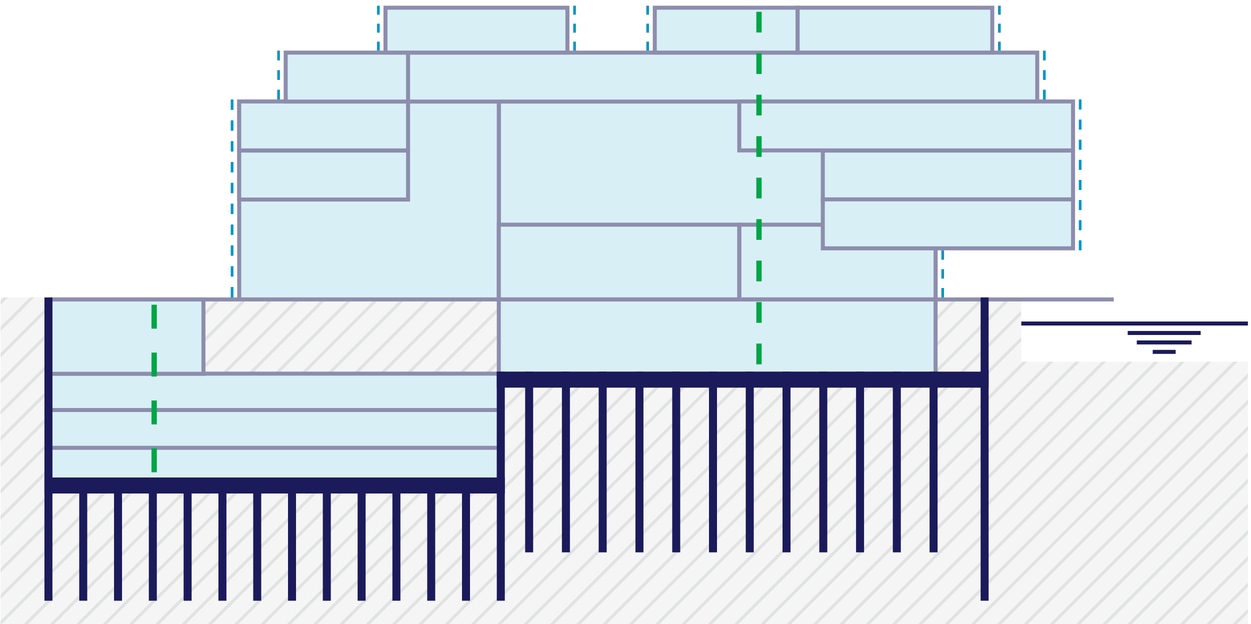



**Embodied carbon**
At practical completion – **14’813 $tCO_2e$**
Over the life cycle – **25’171 $tCO_2e$**

**Operational energy**
Over the life cycle – **46’441 $tCO_2e$**

**WLCA – 71’612 $tCO_2e$**

# 05. Mixed-use building, Copenhagen, DK



## Type
Mixed-use, New build

## Location
Copenhagen, Denmark

## Development stage
Building in use

## GIA
26,366 m$^2$

## Tool
OneClick LCA

## Project data
Material quantities, transportation distances, construction drawings and specifications issued by contractor and design team.

## Description
- 6 storey mixed-use building – hosting exhibition spaces, offices, an auditorium, restaurant and cafe, a fitness center, residential apartments and an automated mechanical car park within the basement of the building
- Composite steel/concrete superstructure
  - Steel frame with storey height trusses acting as bridges, cantilevers or transfer structures
  - Hollow core prefabricated concrete slabs
  - Concrete stability cores
- Basement and foundations
  - Reinforced concrete basement (1 level) and piled foundations
  - Secant pile walls and lining wall
  - Automated mechanical car park system on 3 levels
- Façade systems – mixed curtain walling: aluminum, steel, glazing and rockwool insulation panels
- Fully serviced with lift – cooling, heating, ventilation, electricity, water, lighting, sprinkler and PV roof – connected to the local heating and cooling system
- Very constraint environment – harbour front and building crossed by a road

### Key embodied $CO_2e$

## Assumptions specific to project

| | |
|---|---|
| Transportation scenarios | • Concrete, locally manufactured – 13km<br>• Steel reinforcement – 70km<br>• European manufactured products – 300km<br>• Seagoing ship transported steel – 940km<br>• Truck transported steel – 2,090km |
| Element lifespan | • Services – 25 years (suggested by contractor) |

## Material quantities and carbon factors

| | |
|---|---|
| **Structural steel** sections and plates<br>(1,890t) | • Structural steel sections and plates, S235-S960 (bauforumstahl)<br>• Data bas: PD structural steel: sections and plates bauforumstahl e.V.<br>• Carbon factor: **1.13 $kgCO_2e/kg$** |
| Ready-mix **concrete**<br>(21,390$m^3$) | • Most common concrete: ready-mix concrete, normal-strength, generic, C40/50, 30% recycled binders in cement<br>• One Click Database v3<br>• Carbon factor for most common concrete: **0.12 $kgCO_2e/kg$** |
| **Aluminum** sheets<br>(360t) | • Aluminum sheet, 2700 $kg/m^3$<br>• Database: OKOBAUDAT 2017<br>• Carbon factor: **10.62 $kgCO_2e/kg$** |
| Steel **reinforcement**<br>(250t) | • Reinforcement steel (rebar), generic, 90% recycled<br>• Database: OneClick LCA v3<br>• Carbon factor: **0.67 $kgCO_2e/kg$** |
| Fire-resistant **glazing**<br>(840t) | • Fire-resistant glazing, 22 mm, 49 $kg/m^2$<br>• EPD CONTRAFLAM<br>• Carbon factor: **1.95 $kgCO_2e/kg$** |
| **Services**: Heating, cooling, ventilation, electricity, lighting, distribution systems, lifts and others. | • Average impact per $m^2$ GIA of the different systems<br>• Database: OneClick LCA<br>• Carbon factor: **10-30 $kgCO_2e/m^2$/system**<br>• Total services: **120$kgCO_2e/m^2$** |

## 05. Mixed-use building, Copenhagen, DK

### Key operational $CO_2e$

### Energy and water consumption

The Building has been operational for 2 years. The data presented was measured during the second year (2019) of the building's life.

Annual energy consumption
**117kWh$_{equivalent}$/m$^2$(GIA)**

- 46% electricity
- 32% district heating
- 22% district cooling

**In addition, 444 PV panels provide 5kWh/m$^2$(GIA)*

Carbon factors

- Electricity: Decarbonization progressions based on FES "steady progression" scenario applied to the current grid factor – Orsted 2018: **0.39 kg$CO_2$e/kWh**
- District heating – Hofor 2019: **0.064 kg$CO_2$e/kWh**
- District cooling – Hofor 2019: **0.039 kg$CO_2$e/kWh**

Annual water consumption
**0.37m$^3$/m$^2$**

Carbon factor:

- Tap water, clean (taken from One Click LCA) – Denmark average:
- Global Warming Potential: **0.3 kg$CO_2$e/m$^3$**

**Figure 83:** Measured energy demand

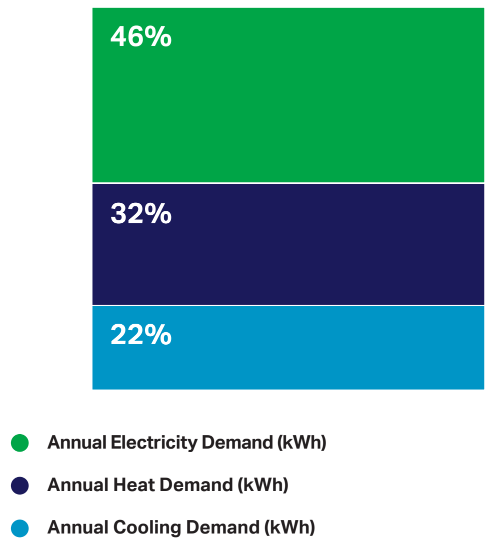
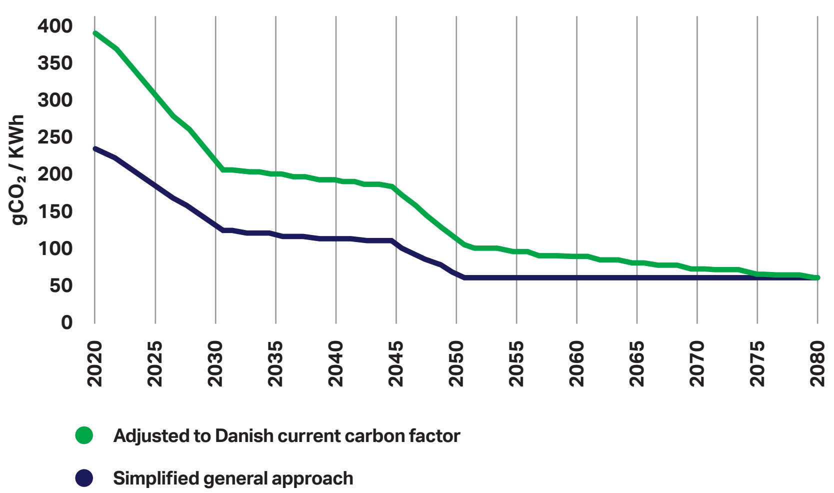



**Figure 84:** $CO_2$ intensity of electricity generation –estimated progression



Results

## Breakdown of carbon emissions per building element

Figure 85: Embodied carbon at practical completion (A1-A5)

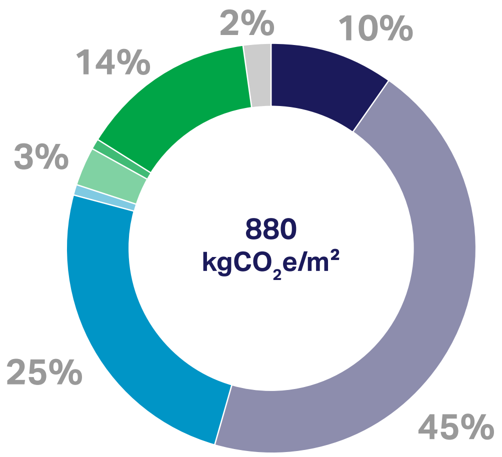



Figure 86: Embodied carbon over the life cycle (A-C)

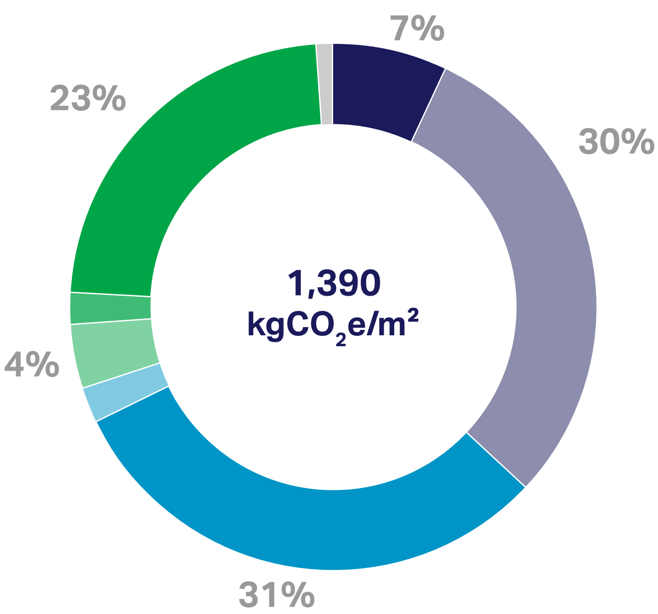
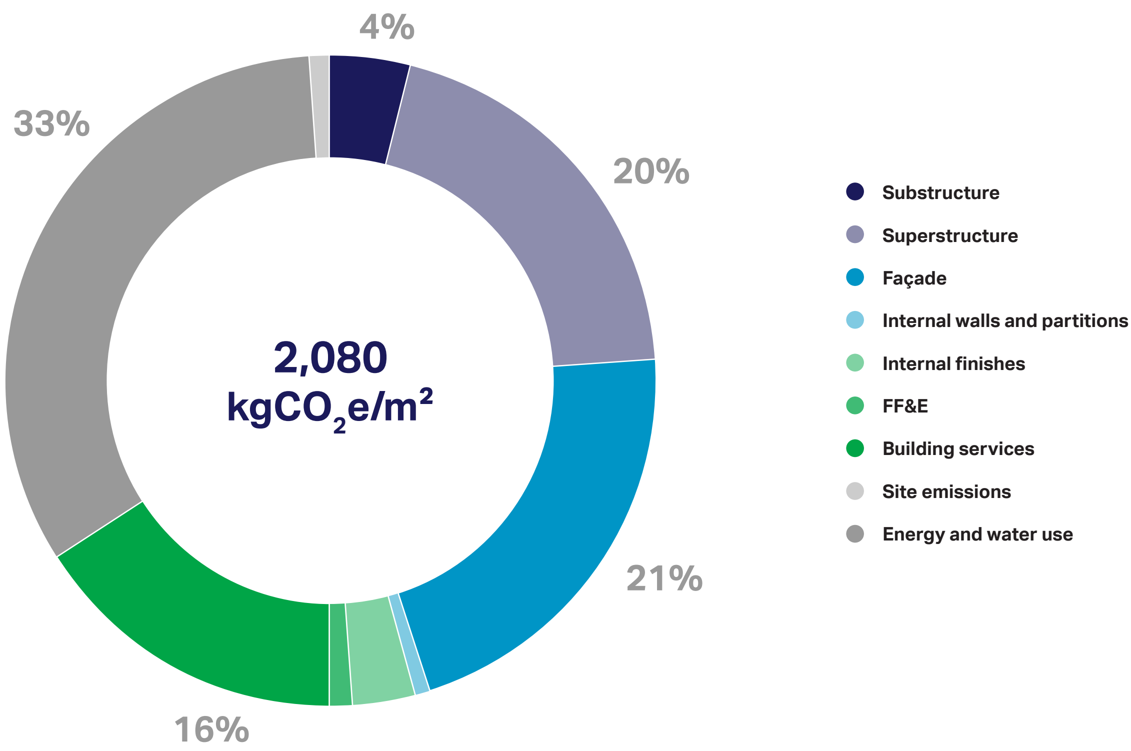



Figure 87: Whole life carbon (A-C)



## 05. Mixed-use building, Copenhagen, DK

### WBCSD Building System Carbon Framework

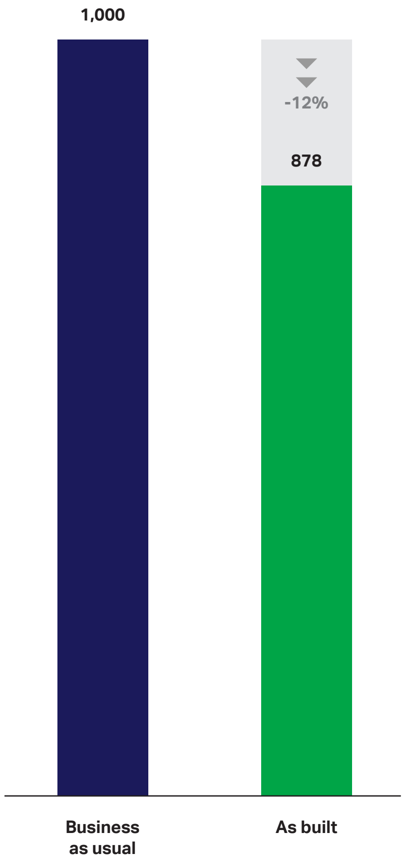
| | Case Study 05 | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole life carbon emissions<br>$kgCO_2e/m^2$ | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1<br>*Foundations, lowest floor construction, retaining walls* | 84 | 1 | 0 | | 7 | 91 | -20 |
| | **Structure** – RICS Level 2.1 – 2.4<br>*Frame, floors, roofs and stairs* | 383 | 12 | 2 | | 16 | 413 | -50 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6<br>*External walls, windows and doors* | 215 | 3 | 215 | | 1 | 434 | -197 |
| | **Space Plan** – RICS Level 2.7 – 2.8<br>*Internal walls, partitions and doors* | 11 | 0 | 11 | | 0 | 22 | -2 |
| | **Space Plan** – RICS Level 3<br>*Internal finishes* | 24 | 1 | 24 | | 8 | 56 | -11 |
| | **Stuff** – RICS Level 4<br>*Fittings, furnishings and equipment* | 5 | 0 | 24 | | 0 | 29 | -11 |
| | **Services** – RICS Level 5<br>*Building services* | 120 | 1 | 201 | 692 | 2 | 1,009 | -46 |
| | **Site emissions** (A5)<br>*Waste, electricity and fuel* | | 19 | | | | 19 | |
| **Embodied carbon emissions** | | **842** | **36** | **476** | | **33** | **1,388** | **-336** |
| **Operational carbon emissions**<br>Energy and water use | | | | | **692** | | **692** | |
| **Building carbon emissions** | | **842** | **36** | **476** | **692** | **33** | **2,079** | **-336** |

PV Offset: **-91 $kgCO_2e/m^2$**

## Project strengths

- Operational Energy Performance
  - 50% lower demand than industry building average from Arup Benchmark
- On-site renewable energy generation
  - Solar PV generates just under 10% of the annual electricity demand: 444 PV panels, generating 136,847 kWh per annum
- Recycling at decommissioning
  - 96% materials recyclable at decommissioning
- Materials Selection
  - Prioritisation of products with Danish Climate Labels
- Materials Transportation
  - Short transportation distances for earthworks and in-situ concrete
  - Use of seagoing ships for steel transportation

**Figure 88:** Carbon emissions at practical completion ($kgCO_2e/m^2$ GIA)

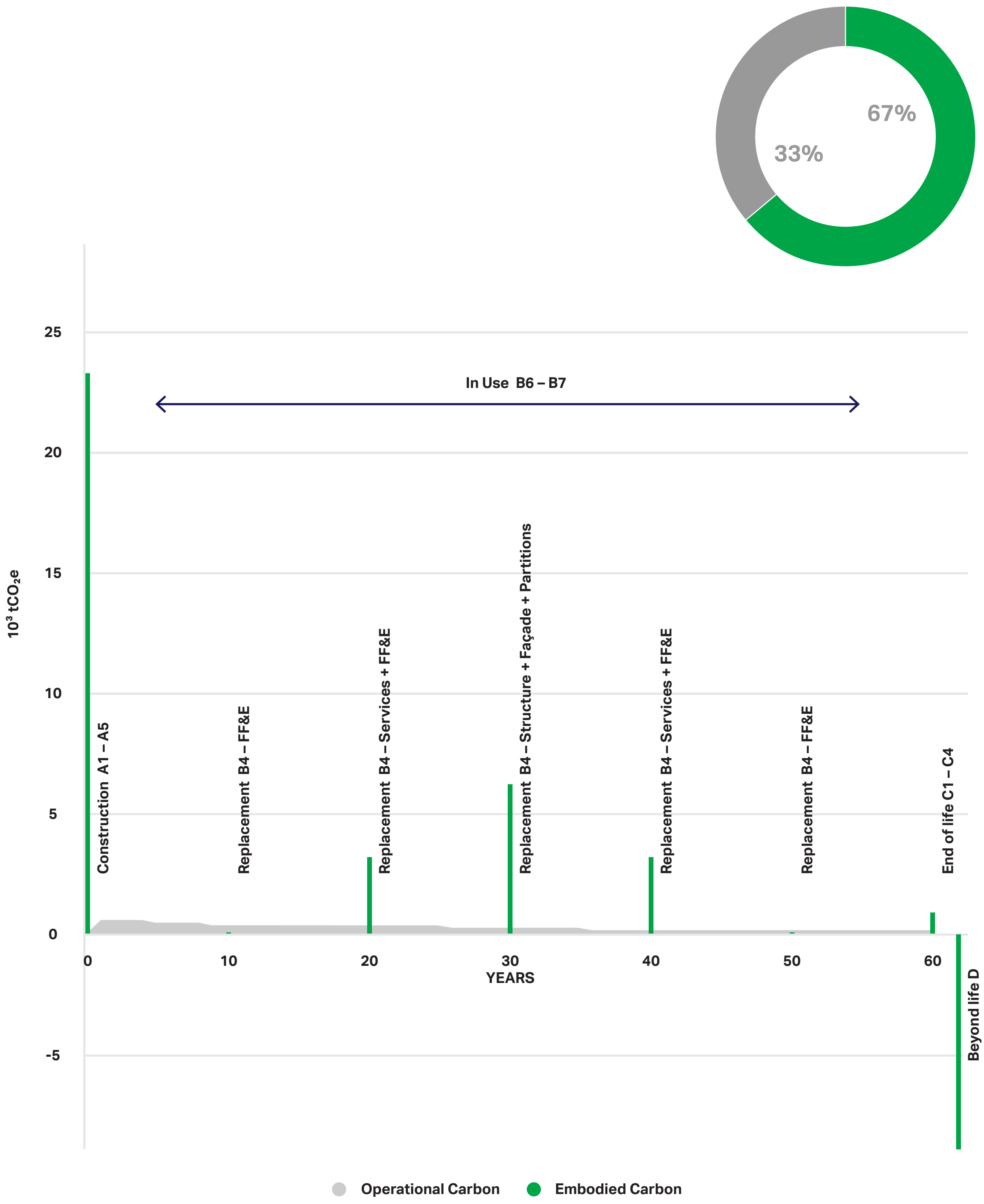



The total embodied carbon at practical completion is 807 $kgCO_2e/m^2$. In comparison with the "business as usual" benchmark for an office building (~1,000 $kgCO_2e/m^2$), discussed in the first section of this report.

It is worth noting that the project embodied carbon impact which is mainly driven by the structure is link to the very constrained environment of the site. In addition, the building is a new landmark for the city which will probably last for more than 60 years.

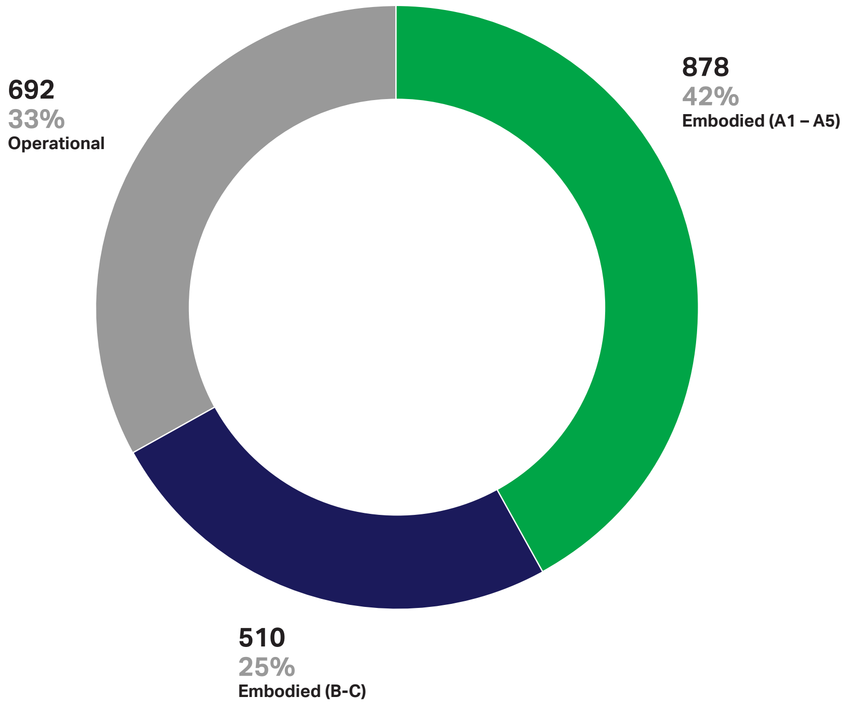
### 05. Mixed-use building, Copenhagen, DK

**Figure 89:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

**Figure 90:** WLCA summary ($kgCO_2e/m^2$)

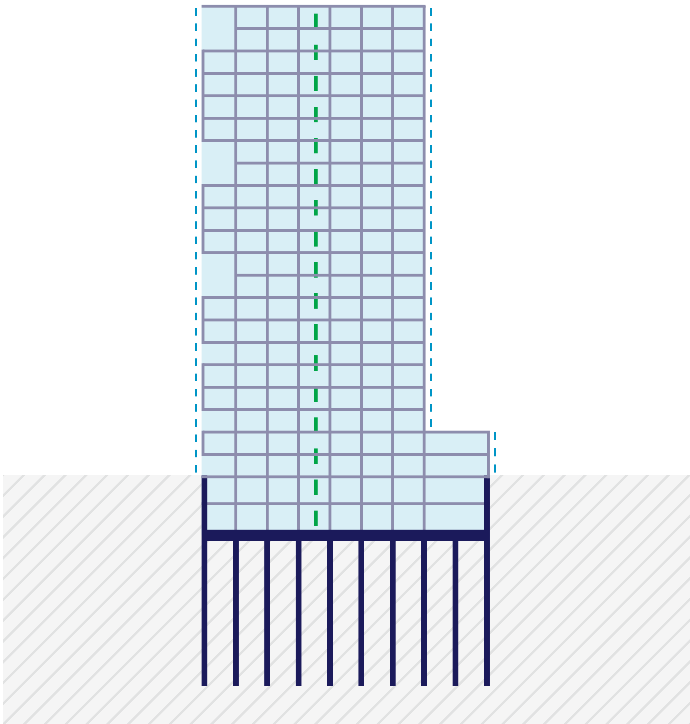



**Embodied carbon**
At practical completion – **21’270 $tCO_2e$**
Over the life cycle – **32’750 $tCO_2e$**

**Operational energy**
Over the life cycle – **18’240 $tCO_2e$**

**WLCA – 50’980 $tCO_2e$**

# 06. Residential timber tower, Amsterdam, NL



### Type
Residential, New build

### Location
Amsterdarm, Netherlands

### Development stage
End of construction

### GIA
14,544 m$^2$

### Rating scheme
BREEAM 2014 Outstanding

### Tool
OneClick LCA

### Project data
Design information from tender documents, material quantities from 3D models. Assumptions taken for services embodied carbon (lower than for office buildings).

### Description
- 21 storey office building (+2 level of basement) – 73m high
- Reinforced concrete/timber hybrid superstructure
  - Load bearing internal CLT walls
  - Glue laminated beams
  - Floors CLT/concrete hybrid panels
  - Cantilevering corners supported by steel framing
  - Stability : concrete core + single CLT wall
  - Reinforced concrete structure for first 2 levels
- Substructure: 2 levels reinforced concrete basement
- Foundations:
  - Precast reinforced concrete piles
  - Diaphragm retaining wall
- Main façade system
  - Prefabricated timber frames with Rockwool insulation, aluminum window frames and triple glazing
- Finishes
  - No false ceiling and no raised floor
  - Top screed (floor heating)
  - Floor insulation and additional screed for fire protection
- Fully serviced with lift (cooling, heating, ventilation, electricity, water, lighting)

### Key embodied $CO_2e$

## Material quantities and carbon factors

| | |
|---|---|
| Engineered **timber**<br>(1,215 $m^3$) | • Cross-laminated timber (CLT), 480 kg/$m^3$ (KLH Massivholz), Wooden frameworks from softwood (480kg/$m^3$), and Plywood, generic, 4-50 mm (620kg/$m^3$)<br>• Database: EPD KLH cross-laminated timber panels, INIES (2019) and One Click LCA Database<br>• Carbon factor: **0.4 kg$CO_2$e/kg, 0.17 kg$CO_2$e/kg, and 0.53kg$CO_2$e/kg**<br>• Average Biogenic Carbon: **794.7kg/$m^2$** (Biogenic carbon not subtracted from A1-A3 totals)<br>• End of life scenario: Incineration assumed |
| Ready-mix **concrete**<br>(6,240$m^3$) | • Average ready-mix concrete, C32/40 (4,600/5,800 PSI) with CEM III/A, 40% GGBS content (320 kg/$m^3$)<br>• ICE database v3<br>• Carbon factor: **0.088 kg$CO_2$e/kg** |
| **Structural steel** sections and plates<br>(215t) | • Structural steel profiles, generic, 20% recycled content, I, H, U, L and T sections<br>• OneClick LCA database<br>• Carbon factor: **2.51 kg$CO_2$e/kg** |
| Anodized **aluminum**<br>(27t) | • Anodized aluminum, Netherlands<br>• NMD v2.0 database<br>• Carbon factor: **12.4 kg$CO_2$e/kg** |
| **Glass**<br>(4,510$m^2$) | • Flat glass, single to triple glass (6 to 16mm)<br>• Database: One Click LCA (2018)<br>• Carbon factor: **12.25 kg$CO_2$e/$m^2$** |
| Steel **reinforcement**<br>(770t) | • Reinforcement steel (rebar), generic, 97% recycled content (typical for UK)<br>• Database: OneClick LCA<br>• Carbon factor: **0.5 kg$CO_2$e/kg** |
| **Services**: Heating, cooling, ventilation, electricity, lighting, distribution systems, lifts and others. | • Assumption taken from industry benchmarks<br>• Total services: **70kg$CO_2$e/$m^2$** |

## 06. Residential timber tower, Amsterdam, NL

### Key operational $CO_2e$

### Energy and water consumption

An assessment was carried out to estimate the regulated energy consumption.

- Annual regulated energy consumption 44kWh/m²
- The unregulated energy consumption was assumed at 30kWh/m²
- Total annual energy consumption **74kWh$_{equivalent}$/m²(GIA)**

65% electricity / 35% district heating

**In addition, 727m² of PV panels located on the façades and the roof provide 10kWh/m²*

Grid carbon factors
- Electricity: Decarbonization progressions based on FES "steady progression" scenario applied to the current grid factor of **0.61 $kgCO_2e/kWh$** (2019, Netherlands)
- District heating: **0.23 $kgCO_2e/kWh$** (taken from OneClick LCA for Netherlands)
- Annual water consumption estimated at **1.1m³/m²**

Carbon factor:
- Tap water, clean – Netherlands (One Click LCA): **0.3 $kgCO_2e/m^3$**

**Figure 91:** Energy consumption by activity

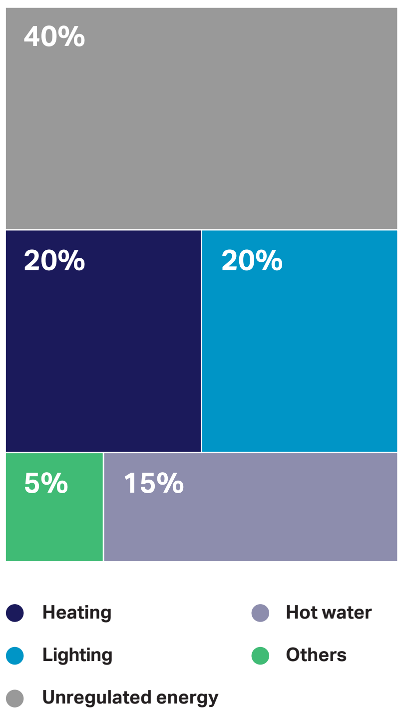
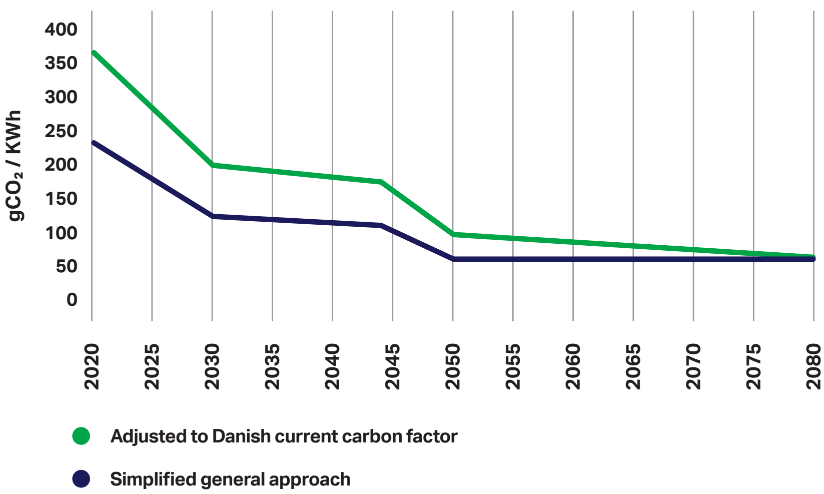



**Figure 92:** $CO_2$ intensity of electricity generation estimated progression



## Results

### Breakdown of carbon emissions per building element

**Figure 93:** Embodied carbon at practical completion (A1-A5)

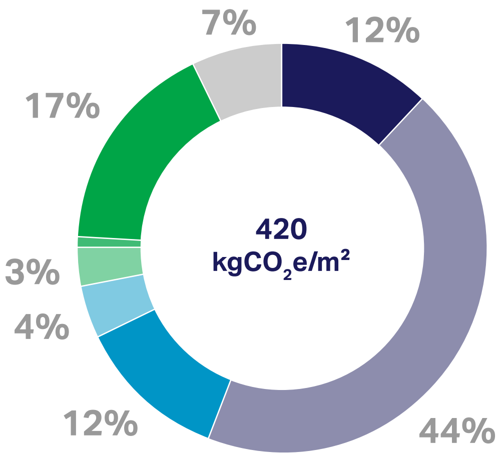



**Figure 94:** Embodied carbon over the life cycle (A-C)

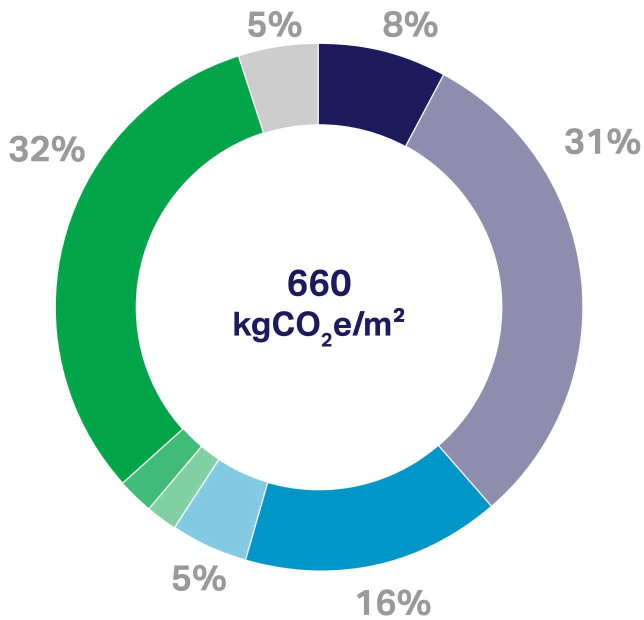
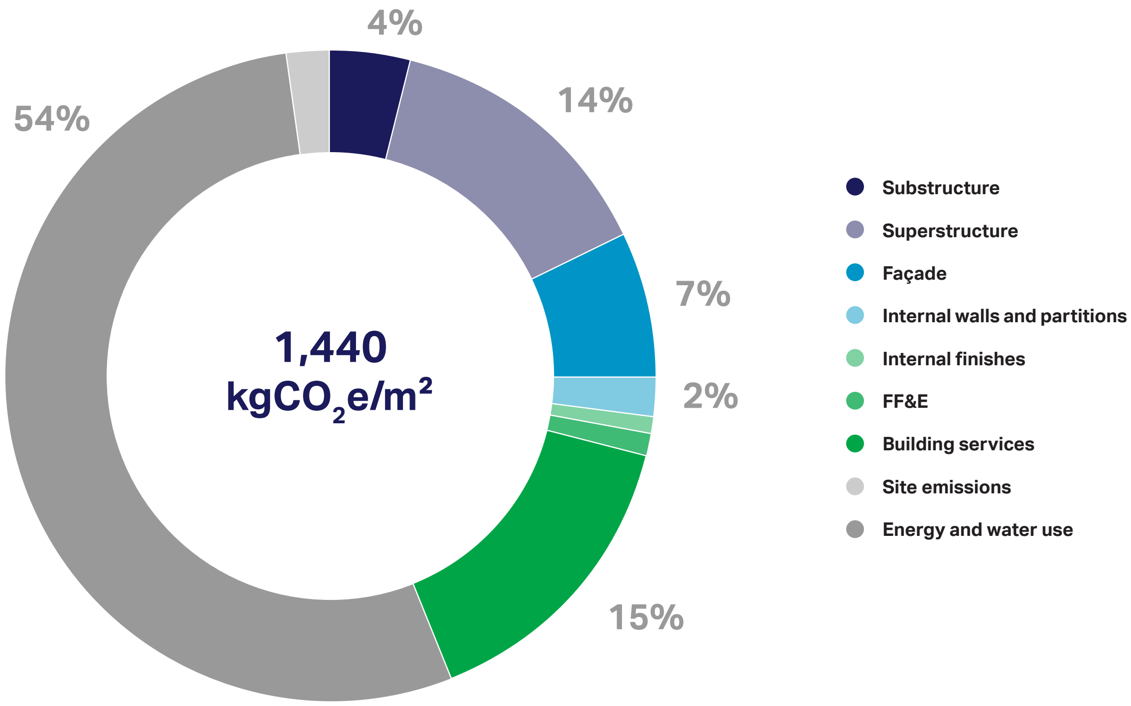



**Figure 95:** Whole life carbon (A-C)



## 06. Residential timber tower, Amsterdam, NL

### WBCSD Building System Carbon Framework

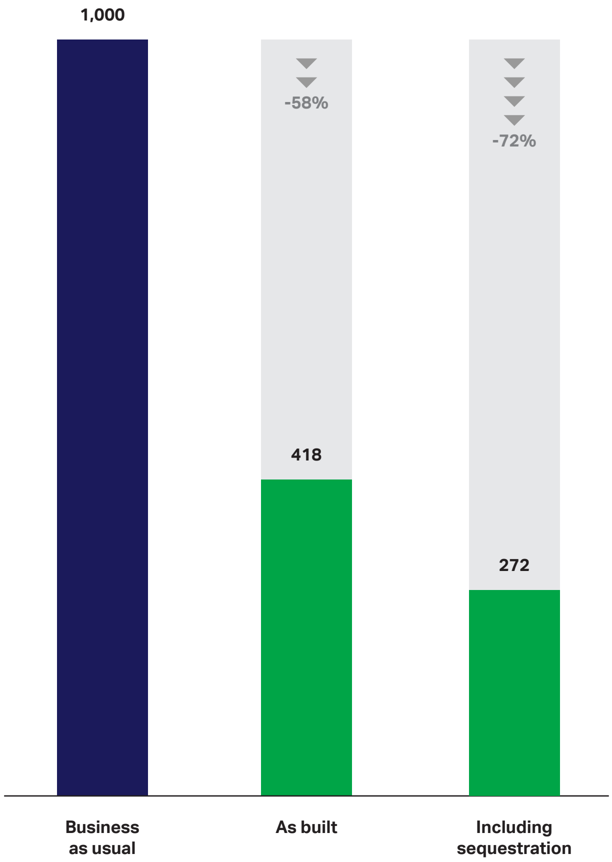
| Case Study 06 | | Building Stages | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Whole life carbon emissions $kgCO_2e/m^2$ | | Product | Construction | Use | | End of life | A-C Emissions | Beyond Life |
| | | A1-A3 | A4-A5 | B1-B5 | B6-B7 | C | | D |
| Building layers | **Substructure** – RICS Level 1 *Foundations, lowest floor construction, retaining walls* | 51 | 1 | 0 | | 0.9 | 53 | -8 |
| | **Structure** – RICS Level 2.1 – 2.4 *Frame, floors, roofs and stairs* | 174 | 7 | 9 | | 13.6 | 205 | -96 |
| | **Skin/Façade** – RICS Level 2.5 – 2.6 *External walls, windows and doors* | 51 | 1 | 51 | | 1.4 | 104 | -37 |
| | **Space Plan** – RICS Level 2.7 – 2.8 *Internal walls, partitions and doors* | 16 | 0 | 16 | | 0.5 | 33 | -2 |
| | **Space Plan** – RICS Level 3 *Internal finishes* | 12 | 1 | 0 | | 0.3 | 13 | -1 |
| | **Stuff** – RICS Level 4 *Fittings, furnishings and equipment* | 3 | 0 | 7 | | 0.1 | 10 | -2 |
| | **Services** – RICS Level 5 *Building services* | 70 | 0 | 140 | 781 | 0.8 | 993 | -11 |
| | **Site emissions** (A5) *Waste, electricity and fuel* | | 30 | | | | 30 | |
| **Embodied carbon emissions** | | **377** | **41** | **224** | | **17** | **659** | **-158** |
| **Operational carbon emissions** Energy and water use | | | | | **781** | | **781** | |
| **Building carbon emissions** | | **377** | **41** | **224** | **781** | **17** | **1,440** | **-158** |

Biogenic carbon storage: **$-146kgCO_2e/m^2$**
PV Offset: **$-61\ kgCO_2e/m^2$**

## Project strengths

- Timber primary structural material – lowest carbon structural material and benefit from sequestration
- Relatively small spans
- No raised floor
- PV panels – on site renewable energy
- Efficient energy strategy leads to low regulated energy use
- CEM III with 40% of GGBS
- Timber façade frame
- Coordination between disciplines: holistic carbon approach
- Early adoption of green building certification schemes to lower embodied carbon impacts across the project life cycle – BRREAM outstanding

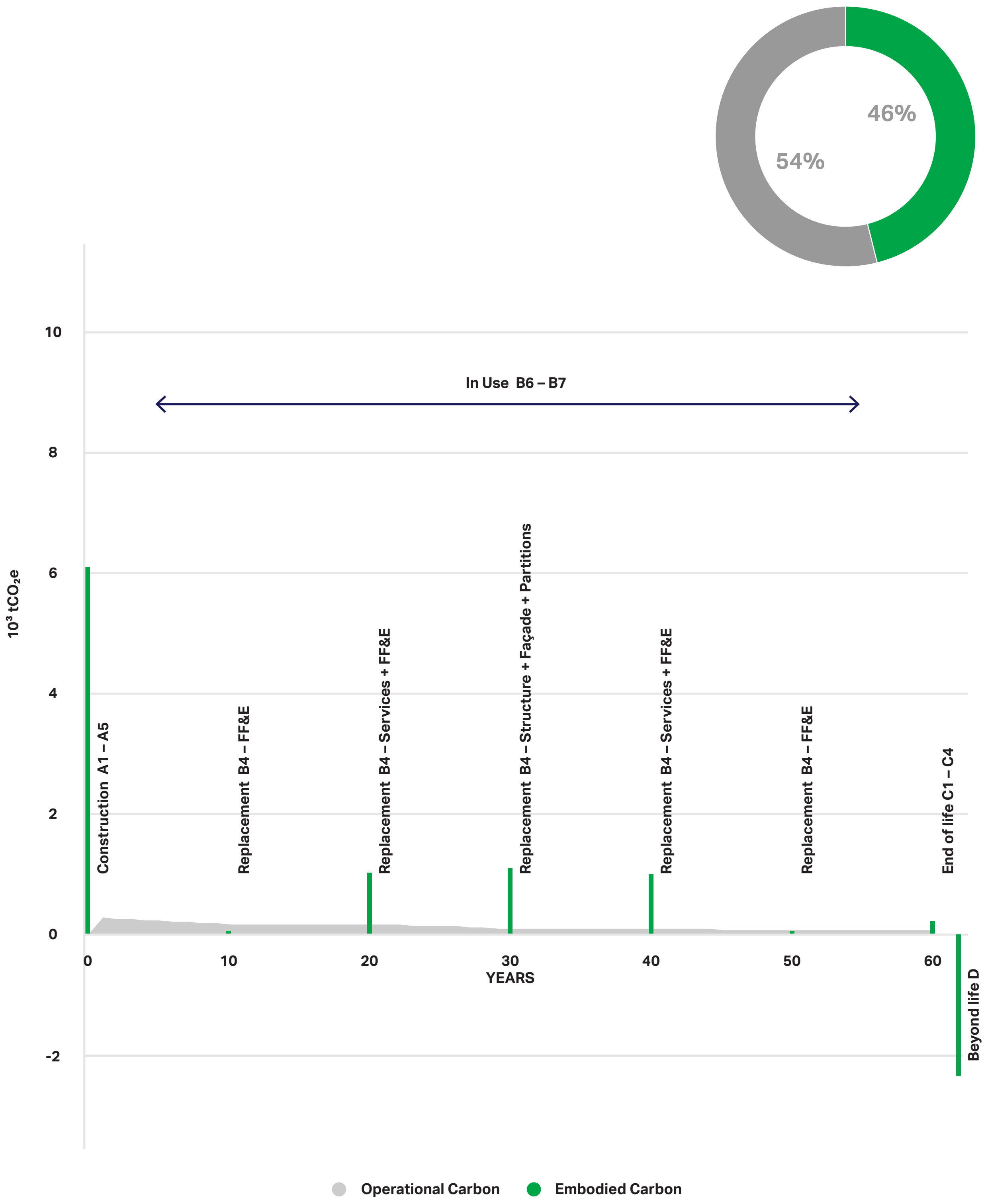
**Figure 96:** Carbon emissions at practical completion ($kgCO_2e/m^2$ GIA)




This project is a successful example of how using timber as primary structural material can reduce the embodied carbon impact. Although a significant amount of concrete and steel were required to achieved the desired geometry and deal with the ground conditions, the total embodied carbon at practical completion is 418 $kgCO_2e/m^2$, this represents a 58% saving in comparison with the business as usual benchmark for an office building (~1,000 $kgCO_2e/m^2$). The benchmark for a middle/high rise would be higher than that.

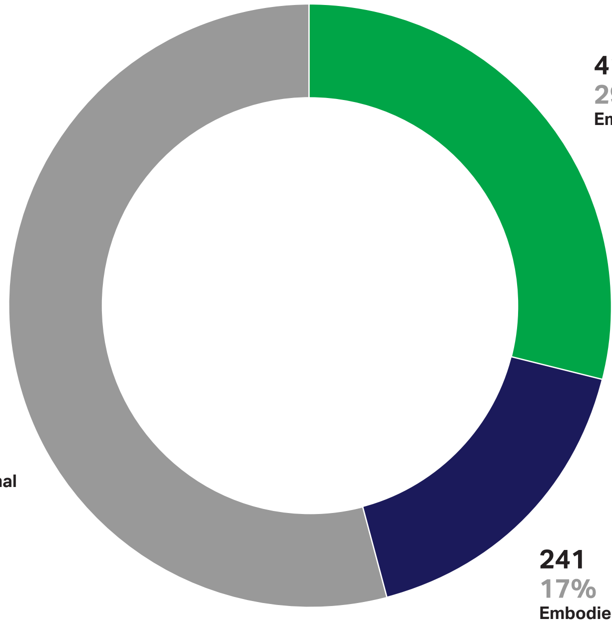
## 06. Residential timber tower, Amsterdam, NL

**Figure 97:** Whole life carbon emissions



## WLCA summary ($kgCO_2e/m^2$)

**Figure 98:** WLCA summary ($kgCO_2e/m^2$)




**Embodied carbon**
At practical completion – **6’079 $tCO_2e$**
Over the life cycle – **9’584 $tCO_2e$**

**Operational energy**
Over the life cycle – **11’365 $tCO_2e$**

**WLCA – 20’950 $tCO_2e$**

# Endnotes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# Abbreviations, acronyms and units of measurement

| | |
|---|---|
| BAU | Business as usual |
| COP21 | Conference of Parties 21 |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| CRREM | Carbon Risk Real Estate Monitor |
| EPD | Environmental Product Declaration |
| EUI | Energy use intensity |
| FES | Future energy scenarios |
| FF&E | Fittings, furnishings and equipment |
| GHG | Greenhouse gases |
| GLA | Greater London Authority |
| ICE | Institute of Civil Engineers |
| IEA | International Energy Agency |
| ISO | International Organization for Standardization |
| Kg | Kilogram |
| kWh | Kilowatt hour |
| LCA | Life cycle carbon assessment |
| LETI | London Energy Transformation Initiative |
| $m^2$ | Meters squared |
| REEB | Real Estate Environmental Benchmark |
| RIBA | Royal Institute of British Architects |
| RICS | Royal Institute of Chartered Surveyors |
| SIA | Swiss Engineers and Architects Association |
| t | Tonne |
| UKGBC | UK Green Building Council |
| WBCSD | World Business Council for Sustainable Development |
| WLCA | Whole life carbon assessment |

## ACKNOWLEDGMENTS

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## DISCLAIMER



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Our work is shaped by our mission statement, to Shape a Better World, and in 2020 we revised our Global Strategy to put sustainable development at the heart of everything we do. Arup has committed to achieving net-zero emissions across its entire operations by 2030, covering everything from the energy used in offices to goods and services purchased. To achieve this the firm has set a target to reduce its scope 1, 2 and 3 global greenhouse gas (GHG) emissions by 30% within the next five years from a 2018 baseline.

We were founding signatories of UK Architects Declare Climate and Biodiversity Emergency and UK Engineeers Declare Climate and Biodiversity Emergency.

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## ABOUT WBCSD

WBCSD is a global, CEO-led organization of over 200 leading businesses working together to accelerate the transition to a sustainable world. We help make our member companies more successful and sustainable by focusing on the maximum positive impact for shareholders, the environment and societies.

Our member companies come from all business sectors and all major economies, representing a combined revenue of more than USD $8.5 trillion and 19 million employees.
Our global network of almost 70 national business councils gives our members unparalleled reach across the globe. Since 1995, WBCSD has been uniquely positioned to work with member companies along and across value chains to deliver impactful business solutions to the most challenging sustainability issues.

Together, we are the leading voice of business for sustainability: united by our vision of a world where more than 9 billion people are all living well and within the boundaries of our planet, by 2050.

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