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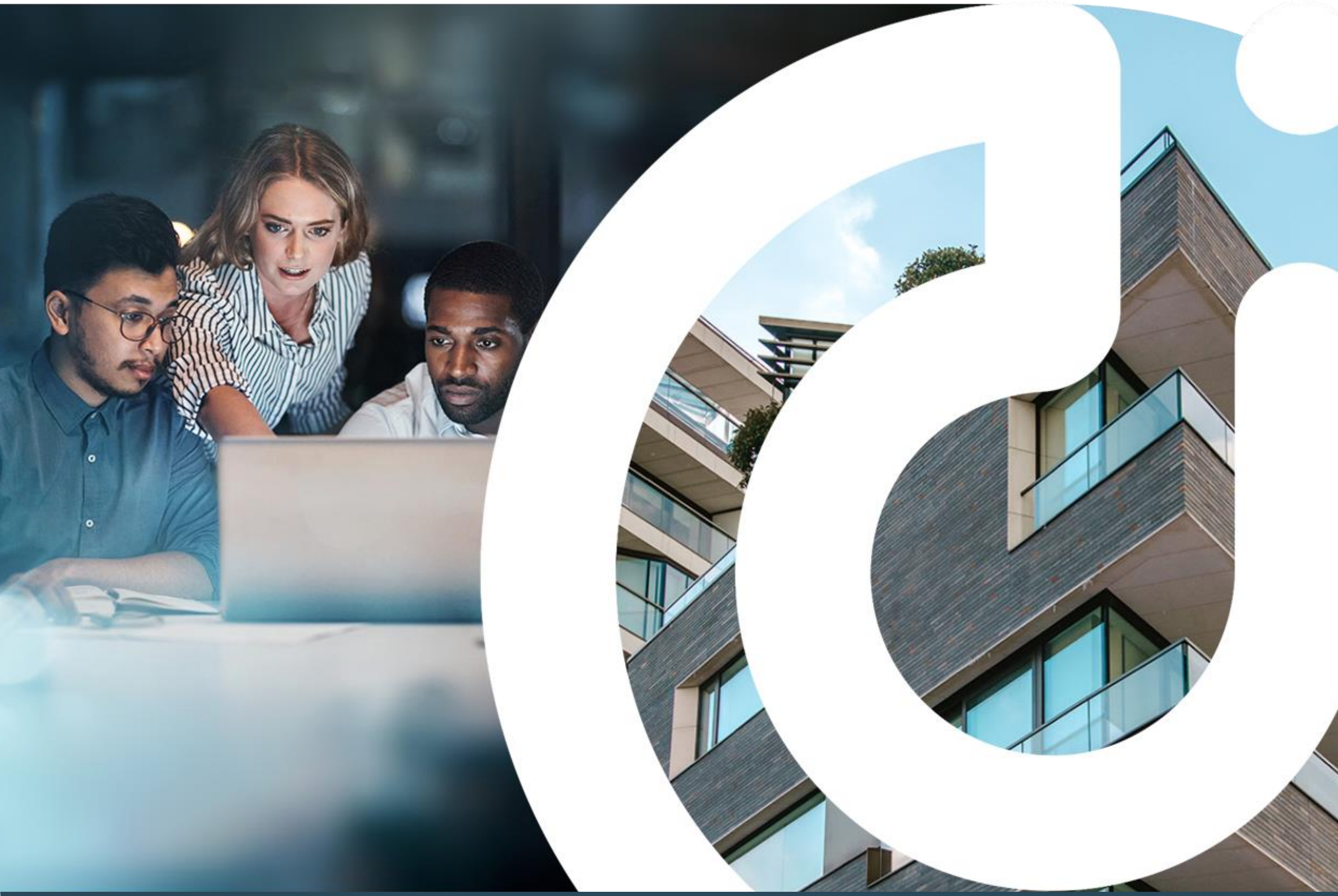

Benchmarking Embodied Carbon Baselines for Building in Ireland (updated)

March 2025

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Abbreviations

BOQ: Bill of Quantities

EC: Embodied Carbon

EPD: Environmental Product Declaration

EU: European Union

FF&E: Furniture, fixtures and equipment

FU: Functional Unit

GHG: Greenhouse Gas

GIA: Gross internal area

GWP: Global Warming Potential

IGBC: Irish Green Building Council

LCA: Life Cycle Assessment

LCI: Life cycle inventory

MEP: Mechanical, Electrical, and Plumbing

UFA: Usable Floor Area

UK: United Kingdom

WLC: Whole-Life Carbon

WLEC: Whole-Life Embodied Carbon

Executive Summary

"Embodied carbon" refers to the greenhouse gas (GHG) emissions associated with the materials and construction processes used across the whole life cycle of a building. While past efforts have mostly focused on increasing energy efficiency in building operation, recent research highlights the increasing importance of embodied carbon.

The INDICATE project is sponsored by the Laudes Foundation. It builds on the UpfrontCO$_2$ project completed earlier this year with the support of the SEAI. The objective is to broaden the sample size of case studies of Whole Life Embodied Carbon assessment from 20 to 50 to increase confidence in the results of the methodology designed as part of the UpfrontCO$_2$ project and create baseline results as a starting point for introducing reduction strategies. In particular, the focus is on upfront embodied emissions which represent the largest share of embodied carbon and can be shaped at the design stage.

This report describes the experience of designing a methodology for collecting data, the collection process undertaken, and the resulting findings.

The objective of this part of the project was to compile consistent LCA assessments of Irish projects which represent different building typologies. This would allow relatively robust and consistent conclusions to be made regarding the baseline levels of different typologies. Each typology is discussed and a bar chart of the EC for an average building provided.

It was found that the average carbon cost per m^2 varies depending on the typology from 623kgCO$_2$e/m^2 for larger, one-off housing to around1,000 for offices and schools and over 2,000 for a manufacturing plant (although this is a sample of one plant with a specific pharmaceutical manufacturing purpose). In general, sample sizes remain very small however, so we would expect these averages to change with each new assessment added to our sample database.

The report concludes with the recommendation that a single method for carrying out assessments in the State is

developed and made available. This will require consultation with industry on surrounding data, the establishment of a central database to hold both assessment results and background data and the integration of this methodology into software already available in the market so that assessments can be performed more easily.

1. Introduction

1.1 Report Structure

The report begins by outlining its purpose and context as part of the INDICATE project. Section 2 presents the developed methodology and the process for its testing and application. Section 3 presents the embodied carbon results of the assessed case study buildings. Section 4 provides overall conclusions and next steps.

1.2 Background

In Ireland, approximately 37% of all greenhouse gas (GHG) emissions come from the built environment. Around a third of these are embodied emissions in the form of material production, the transport of materials and the construction and demolition of buildings [1]. Given that the Irish Governments Housing for All plan aims to construct around 300,000 new homes and the necessary supporting infrastructure buildings in the period up to 2030, having accurate data around the embodied impact of this construction activity is vital in ensuring Ireland meets its climate targets.

There is currently a lack of attention placed on EC in buildings at both the EU and national level. Multiple bodies are working to improve this situation, with the World Green Building Council publishing a roadmap for EU whole life carbon (WLC) policy implementation [2] and a policy brief for governments tasked with complying with the revised EPBD [3]. According to the roadmap, a key tool for achieving EU WLC policy is the development of freely available LCA databases at national and EU level to allow the harmonisation of WLC benchmarks and legislation across Europe. The Nordic countries are working together to establish a common approach to measurement [4], and the RICS in the UK is working to promote its methodology and accompanying database globally [5].

The Ramboll Report "Towards Embodied Carbon Benchmarks for buildings in Europe" [6] outlines the current EC data available in Europe, what is needed to benchmark EC and how to attain adequate data to align the construction industry with emissions reduction goals. Figure 1 shows data availability in the EU and the UK. The report finds only five EU Member States (MS) with 50 or more accessible LCA studies based on a consistent methodology, with the bulk of EU Member States having little or no LCA data available for generating bottom-up EC benchmarks. There remains a lack of guidance or legislation on EC across EU member states, although with the update to the EPBD there will be a need for each MS to develop a consistent methodology for assessing buildings in its jurisdiction.

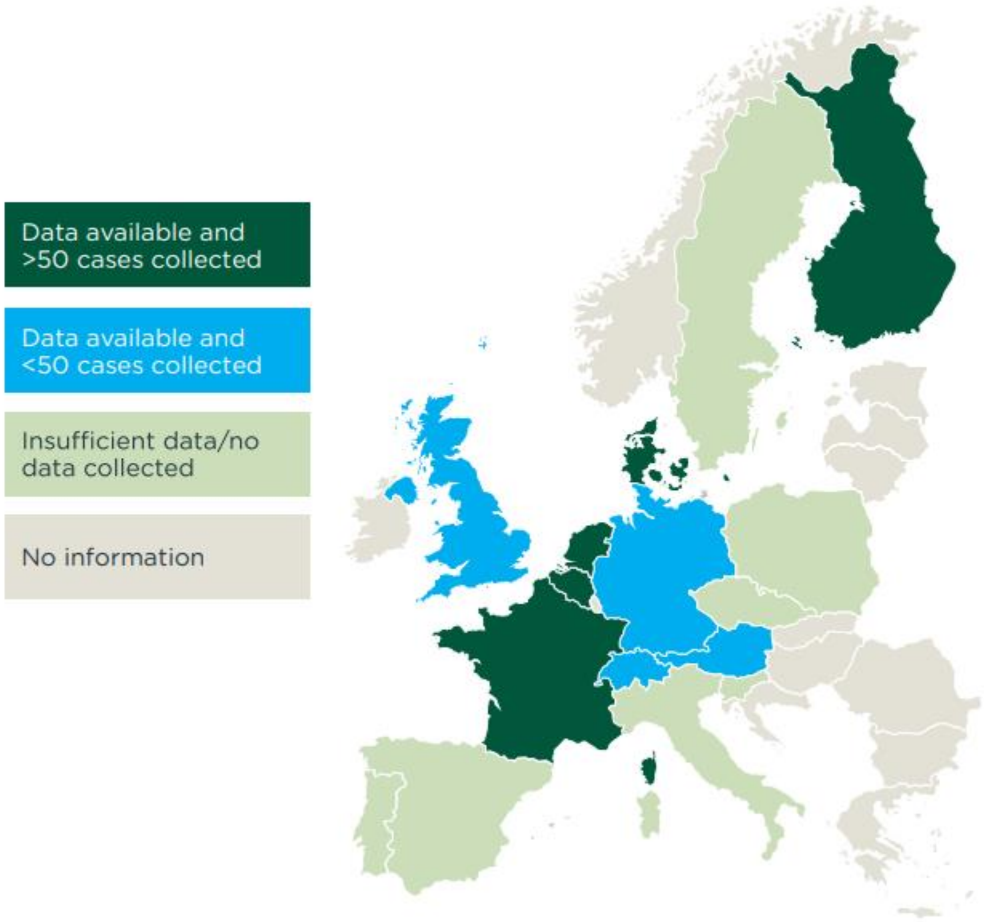

Figure 1: Overview of data available in Europe (taken from Ramboll "Towards embodied carbon benchmarks for buildings in Europe #1 Facing the data challenge”

There is currently no regulation in Ireland governing EC in construction. Ireland’s national certification scheme for residential buildings, the Home Performance Index, along with the international certification schemes LEED and BREEAM all award credits for LCA and EC calculation based on differing requirements and methodologies. The Royal Institute of Architects of Ireland (RIAI) has published targets for EC for various building types as show in **Error! Reference source not found.** but does not stipulate how buildings should be assessed.

According to the Ramboll study, on average a building of 1,000m^2 will have an EC footprint of around 600 tonnes of CO2 equivalent (or 600 kgCO$_2$e/m^2), and two thirds of this will be emitted ‘upfront’ – during the materials production and building construction.

In response to the missing data for Ireland, the main objective of this study was to begin the development of EC baselines for Irish buildings and their elements through the use of a standardised methodology. LCA studies were carried out on fifty-one case study buildings of differing typologies, analysing embodied carbon across the life cycle modules A1-A5, B4 and C1-4.

1.1.1 Current Benchmarks

Table 1: RIAI Climate Challenge 2030 target EC per m^2 GFA, based on LETI research

Building Type	Current Benchmarks	2025 Targets	2030 Targets	LCA stages
Domestic	1200 $kgCO_2eq./m^2$	< 800 $kgCO_2eq./m^2$	< 625 $kgCO_2eq./m^2$ (< 450 if over $133m^2$ in total)	A1-A5, B1-B5, C1-C4
Non- Domestic Buildings	< 1400 $kgCO_2eq./m^2$	< 970 $kgCO_2eq./m^2$	< 750 $kgCO_2eq./m^2$ (A1-A5 < 475 $kgCO_2eq./m^2$)	A1-A5, B1-B5, C1-C4
Schools (New Build)	<1000 $kgCO_2eq./m^2$	< 675 $kgCO_2eq./m^2$	< 540 $kgCO_2eq./m^2$ (A1-A5 < 400 $kgCO_2eq./m^2$)	A1-A5, B1-B5, C1-C4

The above table shows the current benchmarks and targets set by the RIAI and derived from the Low Energy Transition Initiative (LETI) benchmarks and targets published in 2021. They are subject to revision as more data from actual buildings emerges and we understand more about our current EC sources.

2. Methodology

2.1 Creating an LCA methodology

Life cycle analysis (LCA) considers a whole system or process in order to provide a complete picture of its inputs and outputs including environmental pollution (an output). For man-made processes such as manufacture, use and disposal, this usually begins with raw materials harvesting or mining and ends with the product being sent to landfill or incinerated for energy recovery after its useful life. There are a set of international standards for LCAs; the general principles are set out in ISO 14040 and the more specific principles for buildings are set out in the standard IS EN 15978[1].

The assessment methodology uses the EU standard EN 15978 and the EU Level(s) indicator 1.2 - Life cycle Global Warming Potential (GWP) as a framework. Using Level(s) indicator 1.2 is critical as Level(s) underpins much current and future legislation with regards to buildings, and indicator 1.2 specifically is the indicator that provides the framework for the updated EPBD and a Technical Screening Criteria (TSC) for the EU Taxonomy.

Although EN 15978 explains the principles, there are still more specific questions that should be addressed such as the exact inventory of what constitutes a building, the assumed lifetime of the building, the assumed lifetime of building components and what happens to those components at the end of the building's useful lifetime. The EU sustainable buildings framework Level(s)[2] indicator 1.2[3] provides guidance to do this. It specifies the inventory of the building, the assumed lifetime of the building and the lifetimes of its components. It was used to answer some of the above questions. Following Level(s) guidance provides assurance that the methodology will align with EU requirements in the Green Deal Taxonomy, EPBD, and CSRD. It should also allow for comparison with other member states' results.

Table 2 shows the modules required by the EN 15978 standard, the assumptions that have been made and the source of any supporting data required. The assumptions were programmed into an excel calculation[4] to allow end users to simply provide estimates of materials quantities, MEP quantities, energy, water and refrigerant demand in order to produce a detailed forecast of the likely emissions of the building over its entire lifetime. Those marked 'Out of scope' are not considered to have a significant impact and/or are subject to individual circumstance, making them difficult to assess while adding little insight to the overall result. Module D, which considers the re-use or

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[1] https://shop.standards.ie/en-ie/standards/i-s-en-15978-2011-875896_saig_nsai_nsai_2082014/

[2] https://environment.ec.europa.eu/topics/circular-economy/levels_en

[3] https://susproc.jrc.ec.europa.eu/product-bureau/sites/default/files/2020-10/20201013%20New%20Level(s)%20documentation_Indicator%201.2_Publication%20v1.0.pdf

[4] The Excel spreadsheet can be downloaded here

recycling potential of materials is outside the scope of the assessment as its benefits are realised after the buildings lifetime, usually some 50+ years from now.

Table 2: Assumptions and sources applied to life cycle modules in EN15978.

Module	Name	Assumptions	Data Source
A1	Extraction of raw materials	Database of generic average carbon emissions for common materials was provided so all assessments use consistent assumptions on material provenance.	National Generic Dataset: igbc.ie/generic-data
A2	Transportation to plant		
A3	Manufacturing		
A4	Transportation to site	100km road journey for bulk materials and 200km for others. Imported materials also assumed 1,000km sea journey.	EPD Ireland
A5	Construction	Wastage rates on site	Level(s) manual
B1	In-use refrigerant leakage	Assumed annual leakage rate of 2%	CIBSE TM65
B2	Maintenance	Out of scope	n/a
B3	Repair	Out of scope	n/a
B4	Replacement	Reference Service Life of elements	Level(s) manual
B5	Refurbishment	Out of scope	n/a
B6	Operational Energy	Emissions factors of fuels and forecast of grid emissions factors	SEAI
B7	Operational Water	Emissions factor for pumping water to and from buildings	Irish Water
C1	Deconstruction	Per m^2 estimate of demolition emissions	RICS
C2	Removal from site	% of waste recycled, energy recovered or landfilled / distance to disposal facility	EPA / EPD Ireland
C3	Waste Processing	2022 Waste Disposal Carbon Factors (kgCO$_2$e/kg)	DEFRA
C4	Disposal	2022 Waste Disposal Carbon Factors (kgCO$_2$e/kg)	DEFRA

D	Re-use/recycle potential	Out of scope	n/a

Fundamentally, the methodology is quite simple – quantify the inventory and multiply each input in the inventory by its relevant carbon factor and assumed replacement cycles and disposal pathway , using credible sources to determine these carbon factors and assumptions. Figure 2 shows the relationships between the inventory, carbon factor sources and the modules in which each result is recorded. The authors used the most credible assumption sources for each carbon factor (discussed individually below) but would advise scrutiny and consultation before launching any national requirement, particularly with regards to materials and MEP carbon factors.

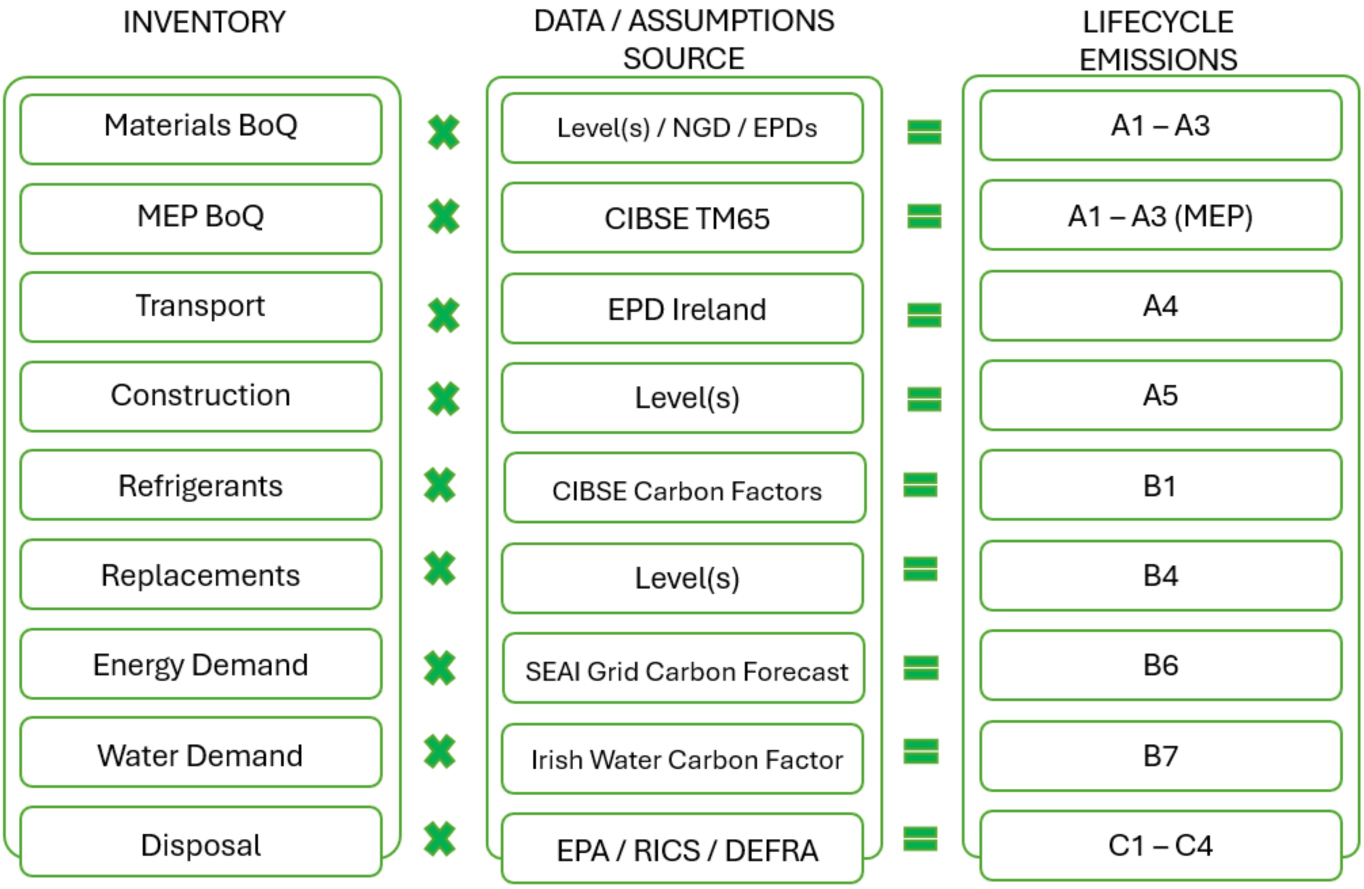

Figure 2: Relationship between the inventory of input quantities, background data sources and life cycle modules in an EN15978 compliant assessment. Inventory quantity multiplied by carbon factor data and assumptions equals total emissions in each Module.

Note: The following sections concern specific modules of the EN 15978 standard that require further data and assumptions about the lifecycle, known as background data. The best way to understand the following sections is to read them with reference to the Materials Data and Stage Assumptions tabs in the methodology spreadsheet available for download here. As a design develops, generic assumptions can be replaced with actual workplans or measurements for a more accurate assessment.

2.1.1 A1 Raw Material Supply, A2 Transport, A3 Manufacturing: Materials

Producing life cycle carbon estimates of buildings at the early stages of design, before suppliers of materials are identified, requires a set of generic materials carbon profiles. In order to carry out consistent assessments in line with Ireland's Climate Action Plan and the Climate Action and Low Carbon Development Act 2021[5], it is important to provide a consistent set of background data based on materials used in the state to reflect the overall emissions, and it should be used for *all* assessments in the state to ensure consistency.

In 2020, IGBC commissioned Cambridge Architectural Research in the UK to carry out a study of the emissions involved in producing high-volume materials (aggregate, brick, cement, glass, steel, aluminium, timber) being used in Irish construction, and provide an estimate of the average carbon footprint of production for each (A1-A3). In 2022, IGBC commissioned Circular Ecology, another UK-based consultancy, to carry out similar studies on further high-volume materials in the Irish market (concrete blocks, various insulation materials, slate, stone, windows and doors, plasterboard, and various floor types). Both studies were in line with the method used in Finland and Sweden, which is to review the market share of suppliers, assess what environmental data is available on their products, and determine a weighted average for the country based on the available data [7].

The A1-A3 carbon data the Cambridge Architectural Research and Circular Ecology studies produced was then supplemented with EPDs from Cement Manufacturers Ireland and data from the UK Inventory of Carbon and Energy (ICE) database for other materials to provide one database of consistent carbon emission production figures for many materials used in Ireland's construction sector today. Also included was the type of material the product will be categorised as at other stages of its life cycle – transportation (A4), construction (A5) and end of life (C2-4). This aids estimation of associated emissions at those stages. The figures were published and a call for public consultation was made. Response was limited but small further adjustments were made as a result. The dataset is published on the IGBC website as the 'National Generic Dataset' (NGD) [8].

The NGD of consistent carbon emission production figures for many materials used in Ireland's construction sector was used as a set of generic data for the assessment methodology. One set of generic data should provide consistent results for all building level whole life carbon assessments. More accurate assessments can be done by using EPD data where available, and should be encouraged.

2.1.2 A1 Raw Material Supply, A2 Transport, A3 Manufacturing: MEP

Mechanical, electrical, and plumbing (MEP) building services are thought to have a significant impact on total embodied carbon because they are predominantly made from metals and plastics, and have a shorter service life than a building, so they are likely to undergo one or more replacement cycles during the operational phase of a building's life cycle. Currently there is not a large amount of data available from equipment suppliers in this area. CIBSE TM65 was created with the aim of encouraging suppliers to provide more data and in the meantime to provide estimates on the likely carbon impact of MEP equipment based on the total mass of equipment and assumptions about its composition and durability. The methodology adopted CIBSE TM65 MEP carbon intensity estimates.

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[5] https://www.irishstatutebook.ie/eli/2021/act/32/section/15/enacted/en/html

As research data emerges, the project team plans to update the methodology with more accurate figures. The benefit of following TM65 is that the methodology will be aligned with best practice in this area.

2.1.3 A4: Transport to site

Transportation of materials from manufacturing plants to building sites is virtually impossible to calculate as most materials do not take the shortest possible route and are transported via some form of storage and distribution network. It is also usually not a significant contributor to emissions in the context of the *whole life* of a building. For these two reasons, it is more effective to apply default assumptions for journeys, saving the LCA practitioner much time and effort for a part of the result that will have a negligible effect on the overall result. For the methodology, it is assumed that all materials manufactured in Ireland will travel 200km by road to site, except for bulk materials such as concrete, which will travel 100km by road. All imported materials are assumed to also travel a further 1,000km by sea. These assumptions are as per the EPD Ireland Product Category Rules (PCR) for developing EPDs of specific materials [9]. When a user selects a material the assumptions on travel for that material are also included in the calculation.

2.1.4 A5: Construction Installation Process: On-site wastage

Similar to transport, it is more effectual to apply assumptions of wastage rates for different materials as a percentage of each material when assessment occurs before construction. Level(s) provides a set of percentage assumptions which are added to the materials bill of quantities. In this way the embodied carbon of the manufacturing and delivery of materials that are wasted in the construction process is also captured.

A5 should also consider the emissions from any demolition in preparation for construction, and construction process energy usage. This has not been considered in this methodology owing to the limits of data and resource available. Similar to transport, it is thought to be less significant than other modules in the context of a whole lifecycle, nevertheless we would recommend updating the methodology as the research grows. There are ongoing research projects developing more data on stages A4 and A5 and the results could be applied at a later stage.

2.1.5 B1: Use stage, Refrigerants

The global warming impact of refrigerant fugitive emissions can represent a significant proportion of a development’s WLC emissions. To reduce emissions, the industry must focus on minimising the volume of refrigerants, specifying refrigerants with a low GWP, and reducing leakage rate through inspections and maintenance.[6]

The methodology captures the type and amount (the charge) of refrigerants being used in the building and applies an assumption of 2% leakage per year. This assumption, compounded over the 50-year lifetime assumption, can be significant where high GWP refrigerants are in use.

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[6] https://www.cibsejournal.com/technical/calculating-whole-life-carbon-in-heating-and-cooling-systems/

2.1.6 B2: Maintenance

The maintenance boundary is currently outside the scope of the methodology.

2.1.7 B3: Repair

The repair boundary is currently outside the scope of the methodology.

2.1.8 B4: Replacements

Many elements of a building, such as finishes and fixtures, will need replacing over its lifetime. Others, mostly structural, will be in place as long as the building is in use without causing any further environmental impact. In order to account for these replacement cycles, the methodology has a set of assumptions on the Reference Service Life (RSL) of building elements as laid out in the Level(s) manual for indicator 1.2. The RSLs are used to calculate the number of particular elements that will be needed over the building's lifetime and include the associated manufacture, transport, and disposal emissions associated with each.

There is a question mark here which is, will elements be manufactured, transported, and disposed of in the future at a lower carbon cost? For now the simple assumption is that they are assumed to be the same as the latest carbon intensity factors, but when finalising a methodology for use, a percentage reduction may be introduced to reflect manufacturing using a cleaner energy source in the future. The important aspect of this module is consistency – all assessments will have the same assumptions, thereby not improving the result by taking an over optimistic view of likely replacement needs in the future.

2.1.9 B5: Refurbishment

The refurbishment module is outside the scope of this methodology. Modules B4 refers to direct replacements but B5 is often considered a deeper re-designing or re-purposing of a building which is often not known or foreseen at the initial stage of the first building design.

2.1.10 B6: Operational Energy Use

Carbon factors (CF) of fossil fuels expressed in grams of CO_2e per kWh were provided by the SEAI along with Primary Factors (PF) to account for energy losses in energy conversion and transmission. The SEAI Energy Modelling team also provided a forecast of the CF of the electricity grid for each year in the future as the grid decarbonises.

This has been used to allow the assessment to simply require only the annual energy demand and fuel source(s) of the building. The energy demand is multiplied by the PF and the CF to calculate the total CO_2e for that year. As many buildings currently in development have electricity based heating systems, the forecast CF will reduce as the grid decarbonises, a significant influence on the WLC result.

2.1.11 B7: Operational Water Use

Irish Water provided an emissions factor for the pumping and treatment of water to and from buildings. This does not include the energy for heating water, which is captured in the B6 module above. The methodology requires an estimate of the total number of litres per annum based on the occupancy pattern of the building. The carbon factor is then applied to give an annual carbon cost of water supplied to the building.

2.1.12 C1: Deconstruction/Demolition

In the 2017 Professional Statement, the RICS provides an estimate of the carbon cost of demolition per m^2 of useful floor area as $3.4kgCO_2e/m^2$. This factor is applied to the building to represent the carbon required as part of the deconstruction/demolition stage of the building life cycle.

2.1.13 C2: Disposal Transport

The EPA provides estimates of the percentage of different waste types that are recycled, landfilled and incinerated. When a material is selected in the Materials BoQ, its waste type is used to calculate the proportions of this stage. Similar to stage A4, the distance to final disposal plants is assumed and the same carbon factors per kg per km are applied, ensuring a consistent carbon estimate for transport specific to Ireland for building end of life scenarios. This is calculated when the user selects the material.

2.1.14 C3: Waste processing for reuse, recovery or recycling

The UK Dept. for Environment, Food & Rural Affairs (DEFRA) publishes carbon factors for the recycling processes of various material waste types. These carbon factors are applied to the proportions as generated by the EPA guidance in Module C2 to calculate emissions from these processes in proportion to the building’s mass.

2.1.15 C4: Disposal

The UK Dept. for Environment, Food & Rural Affairs (DEFRA) publishes carbon factors for incinerating and landfilling processes of various material waste types. These carbon factors are applied to the proportions as generated by the EPA guidance in module C2 to calculate emissions from these processes in proportion to the building’s mass.

2.1.16 Building Element Completeness

Assessments carried out today can be inconsistent. Often an LCA study report will have a caveat explaining that a significant element was not included in the scope. These caveats are often buried in the small print and can easily be overlooked, making it difficult to compare two buildings without a forensic analysis of each scope. The ‘completeness’ of an assessment has a large bearing on the result. This methodology tracks which elements of the building have data supplied against them and requires the assessor to signal which elements do not exist in the building. A 100% complete assessment should contain data on every element in the scope or record that the element does not exist in the building. The physical scope is defined in the Level(s) Indicator 1.2 manual as per Table 3. As of March 2024, The EU JRC is updating Level(s) with a further level of detail in this scope and aligning the scope with ICMS3 codes. The methodology can be updated to accommodate this. It will be useful to add granularity and consistency to LCA and LCC assessments.

Table 3: Physical scope of assessment as described in Level(s) Indicator 1.2 manual.

Scope Tier 1 Building Element	Scope Tier 2 Building Element
Foundations (substructure)	Piles
	Basements
	Retaining walls
Load bearing structural frame	Frame (beams, columns and slabs)
	Upper floors
	External walls
	Balconies
Non-load bearing elements	Ground floor slab
	Internal walls, partitions and doors
	Stairs and ramps
Facades	External wall systems, cladding and shading devices
	Façade openings (including windows and external doors)
	External render
Roof	Roof Structure
	Weatherproofing
Parking facilities	Above ground and underground (within the curtilage of the building and servicing the building occupiers)
Fittings and furnishings	Sanitary fittings
	Cupboards, wardrobes and worktops (where provided in residential property)
	Ceilings finish
	Wall finish
	Floor coverings and finishes
Drainage systems	Drainage system
Utilities	Connections and diversions
	Substations and equipment
Landscaping	Paving and other hard surfacing
	Fencing, railings and walls
In-built lighting system	Light fittings
	Control systems and sensors
Energy system	Heating plant and distribution

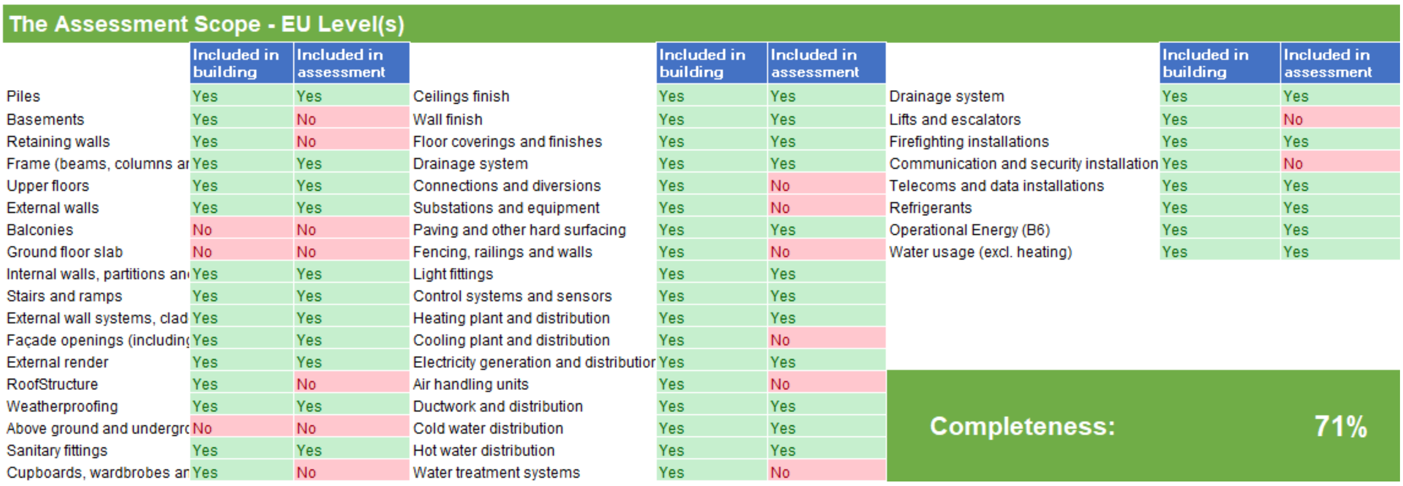
	Cooling plant and distribution
	Electricity generation and distribution
Ventilation system	Air handling units
	Ductwork and distribution
Sanitary systems	Cold water distribution
	Hot water distribution
	Water treatment systems
	Drainage system
Other systems	Lifts and escalators
	Firefighting installations
	Communication and security installations
	Telecoms and data installations

The three operational stage sources of emissions are also tracked, giving a full life cycle perspective on the emissions associated with the project (N.B. refrigerants are classed as embodied as they are locked in with the materials at the design stage):

Table 4: Operational stage sources of emissions

B1 Refrigerants	Refrigerants
B6 Operational Energy	Operational Energy (B6)
B7 Operational Water	Water usage (excl. heating)

In reality, all of this data will usually not be available until the design is nearing completion, so a completeness tracker provides an overview of the assessment as it develops. The completeness tracker can be seen on the Report Template tab in the excel assessment. We believe that completing a greater volume of assessments will help identify the key contributors to EC and would recommend that any future assessment procedure stipulate these elements as mandatory.



The Assessment Scope - EU Level(s)

	Included in building	Included in assessment		Included in building	Included in assessment		Included in building	Included in assessment
Piles	Yes	Yes	Ceilings finish	Yes	Yes	Drainage system	Yes	Yes
Basements	Yes	No	Wall finish	Yes	Yes	Lifts and escalators	Yes	No
Retaining walls	Yes	No	Floor coverings and finishes	Yes	Yes	Firefighting installations	Yes	Yes
Frame (beams, columns ar	Yes	Yes	Drainage system	Yes	Yes	Communication and security installation	Yes	No
Upper floors	Yes	Yes	Connections and diversions	Yes	No	Telecoms and data installations	Yes	Yes
External walls	Yes	Yes	Substations and equipment	Yes	No	Refrigerants	Yes	Yes
Balconies	No	No	Paving and other hard surfacing	Yes	Yes	Operational Energy (B6)	Yes	Yes
Ground floor slab	No	No	Fencing, railings and walls	Yes	No	Water usage (excl. heating)	Yes	Yes
Internal walls, partitions an	Yes	Yes	Light fittings	Yes	Yes			
Stairs and ramps	Yes	Yes	Control systems and sensors	Yes	Yes			
External wall systems, clad	Yes	Yes	Heating plant and distribution	Yes	Yes			
Façade openings (includin	Yes	Yes	Cooling plant and distribution	Yes	No			
External render	Yes	Yes	Electricity generation and distributior	Yes	Yes			
RoofStructure	Yes	No	Air handling units	Yes	No			
Weatherproofing	Yes	Yes	Ductwork and distribution	Yes	Yes	**Completeness:**		**71%**
Above ground and undergrc	No	No	Cold water distribution	Yes	Yes			
Sanitary fittings	Yes	Yes	Hot water distribution	Yes	Yes			
Cupboards, wardbrobes ar	Yes	No	Water treatment systems	Yes	No			

Figure 3: Example of completeness checker in the Report Template gives an overview of what should be included as it exists in the building, and what has been included so far in the assessment.

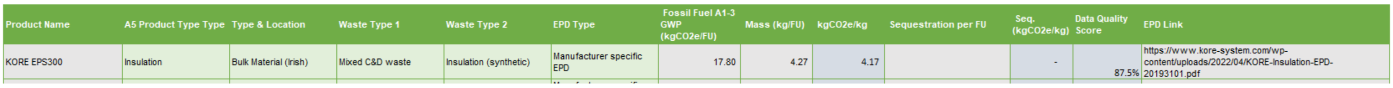
2.1.17 Data Quality and the use of EPDs

The Data Quality (DQ) refers to the reliability and accuracy of the carbon factors applied to the production of each material. The assessment methodology is programmed with a set of generic carbon factors (from the NGD), but in reality the carbon factor of a material can vary widely depending on the manufacturing process and the energy sources involved. At early stages the suppliers of materials may not be known, so a generic estimate can be used. As a design develops and materials (or their properties) are specified, then the background data on carbon factors can be sourced more accurately from Environmental Product Declarations (EPD). An EPD will offer a more accurate carbon factor for the A1-A3 stages of a material as it is a report of an LCA carried out on that specific material.

Table 5: Data sources and confidence scores as indicated in the RICS WLCA Professional Statement 2023

Data Source	Confidence Score (%)
Product & manufacturer specific EPD	100%
Manufacturer specific EPD	87.5%
National average EPD	80%
EU average EPD	65%
NGD - Irish National Generic Dataset	35 – 55% depending on material

Carbon factors are labelled ‘GWP’ in the results table of an EPD. This GWP data can be used in the methodology, but it can be difficult to incorporate. The GWP is expressed as $kgCO_2e$ per Functional Unit (FU) rather than per kg mass, which is what the methodology uses. An FU may be a cubic metre of concrete or a square meter of plasterboard for example. To convert the result in the EPD to $kgCO_2e$ per kg a conversion factor must be applied - essentially the mass weight of the FU expressed in kg. Dividing the GWP score by the number of kg will give the $kgCO_2e$/kg figure that can then be added into the EPD page of the assessment.



Product Name	A5 Product Type Type	Type & Location	Waste Type 1	Waste Type 2	EPD Type	Fossil Fuel A1-3 GWP (kgCO2e/FU)	Mass (kg/FU)	kgCO2e/kg	Sequestration per FU	Seq. (kgCO2e/kg)	Data Quality Score	EPD Link
KORE EPS300	Insulation	Bulk Material (Irish)	Mixed C&D waste	Insulation (synthetic)	Manufacturer specific EPD	17.80	4.27	4.17		-	87.5%	https://www.kore-system.com/wp-content/uploads/2022/04/KORE-Insulation-EPD-20193101.pdf

Figure 4: An example of EPD data added into the methodology under the EPD tab

The generic data, used when EPDs are not available, has to be consistent across assessments in order to avoid practitioners selecting data from EPDs of optimum products which may not actually be used in reality. Generic data provides a level playing field from the outset. It is also the case that currently EPDs are not mandatory and are not available for many products, so a consistent estimate has to be provided. Generic data does this, but the confidence level for its accuracy is low. We would recommend that for cases where generic data is used, a safety margin is also added to the result to ensure the reality is no worse than calculated in the assessment. This will also encourage building designers to specify products where EPD data is available. In turn, this will encourage manufacturers to provide EPD data alongside their products.

2.2 Testing Methodology

The methodology went through a number of development stages throughout the project. These stages, discussed in more detail in the following sections, included comparing the resulting output against another market-leading LCA tool, sharing of methodology with LCA experts, and implementation of the methodology by 12 design teams to conduct LCA studies. This has resulted in continuous feedback with the tool constantly being improved throughout the project. Areas of the tool the project team will continue to develop moving forward are also discussed below.

2.2.1 Comparison against other LCA tool

A bill of quantities for a school was used to test the methodology against an assessment already completed using the market leading One Click LCA software. The two methodologies produced differing results owing to the differing assumptions as discussed above. The largest difference was in the replacement emissions (B4). We were able to understand that this is owing to the EU Level(s) guidance on replacement rates for materials/products being quite high and applicable to many elements. Neither methodology is ‘correct’ as both are estimates of the future but it underlines the need to apply one methodology across all projects in order to produce consistent, comparable results.

Table 6: Comparison of LCA embodied carbon (kgCO2) results of a school using UPFRONT and One Click LCA.

	A1 - A3	A4	B4	C2	C3	C4	TOTAL
CLAP	3,385,961	204,561	2,033,632	30,617	6,779	-	5,678,772
One Click LCA	2,564,979	71,771	454,555	52,596	75,797	340	3,481,675
DIFFERENCE	**820,982**	**132,790**	**1,579,077**	**-21,979**	**-69,018**	**-340**	**2,197,097**
DIFFERENCE AS %	**32%**	**185%**	**347%**	**-42%**	**-91%**		**63%**

The CLAP methodology produced a plausible result and was considered suitable for sharing and implementation on live projects in order to create a set of consistent, comparable assessments of actual buildings or building designs.

2.3 Implementation on case study buildings

Real world design teams were invited to use the spreadsheet to develop whole life carbon assessments of their buildings. Meetings were arranged with as many interested parties as possible, this included major developers, architects, building owners, an AHB, the Department of Education, the HSE, the LDA, the OPW and the OGP. The methodology was universally accepted as useful as all participants recognised a need for a single standard approach to WLC assessment and the simplicity and open-source nature of this approach was appreciated.

Completing an assessment to the level of detail required by Level(s) is challenging. Quantities data on all elements of the building must be found, verified, and converted into a mass figure [kg] in order to apply a carbon factor for each material. Although all participants were enthusiastic and welcoming of the methodology, it was difficult for many to provide the time and resource required to gather all this information. Many of the buildings in the sample are complete and so the assessments were applied retrospectively – this was found to add to the complexity of data gathering as information had not been gathered and stored systematically. In some cases the Bill of Quantities was taken from previous LCAs performed in OneclickLCA software and processed using the INDICATE methodology so results remained consistent. It was found that the best way to ensure completion was to offer a payment for assessments completed to a standard by a set date. The payment incentive has resulted in the completion of 18 newbuild assessments and 2 renovation project assessments.

Table 7: Participants who submitted assessments to the project.

Company/Institution
Arup Engineering (Ireland)
BDP (Dublin)
Cluid AHB (Dublin)
Coady Architects (Dublin)
EC Reduction Ltd (Cork)
Grangegorman Developent Agency (Dublin) / MMC QS (Cork)
Henry J. Lyon Architects (Dublin)
Kosmos Ireland Building Consultants (Dublin/Copenhagen)
Meehan Green Building Consultants (Dublin)
McElmeel Architects (Galway)

MMP QS (Dublin)
PM Group (Cork)
Scott Tallon Walker Architects (Dublin)
UCD – University College Dublin (Dublin)
University of Galway (Galway)
Wain Morehead Architects (Cork)
Walls Construction (Dublin)

3. Case Studies Results

52 case studies across seven typologies including four refurbishments and two hybrid newbuild/refurbishment projects have been included in this analysis as summarised in Table 8. The aim was to carry out assessments on buildings that were being designed today, mostly without the carbon impact being considered[7] - regular buildings with no deliberate carbon mitigation strategies employed. In this way, a baseline could be established for building in Ireland today. Future designs should be assessed using the same methodology so that comparison is consistent and improvements can be fairly quantified.

Sample sizes are small for each typology, ranging from one to four, so should be considered early indicators that will change, possibly significantly, as more studies are added.

Table 8: List of assessments and their associated typologies

No.	Case Study	Typology	No.	Case Study	Typology
1	APARTMENTS 1	Apartment	29	OFFICE 1	Offices
2	APARTMENTS 2		30	OFFICE 2	
3	APARTMENTS 3		31	OFFICE 3	
4	APARTMENTS 4		32	OFFICE 4	
5	APARTMENTS 5		33	OFFICE 5	
6	APARTMENTS 6		34	OFFICE 6	
7	APARTMENTS 7		35	OFFICE 7	
8	APARTMENTS 8		36	OFFICE 8	
9	APARTMENTS 9		37	OFFICE 9	

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[7] There is one CLT building and the velodrome which have been designed with carbon emissions addressed as part of the brief.

10	APARTMENTS 10	
11	APARTMENTS 11	
12	APARTMENTS 12	
13	APARTMENTS 13	
14	APARTMENTS 14	
15	HOSPITALITY 1	Apartment/Hospitality
16	HOSPITALITY 2	
17	HOSPITALITY 3	
18	DETACHED 1	Detached - Resi
19	DETACHED 2	
20	DETACHED 3	
21	DETACHED 4	
22	SEMI 1	Semi - Resi
23	SEMI 2	
24	SEMI 3	
25	SEMI 4	
26	TERRACE 1	Terrace - Resi
27	TERRACE 2	
28	TERRACE 3	
38	OFFICE 10	
39	SCHOOL 1	Education
40	SCHOOL 2	
41	SPORT 1	Sports Facility
42	SPORT 2	
43	WAREHOUSE 1	Warehouse
44	WAREHOUSE 2	
45	WAREHOUSE 3	
46	MANU 1	Manufacturing
47	EDU REN 1	School Renovation
48	APPT REN 1	Apartment Renovation
49	OFF REN 1	Office Renovation
50	OFF REN 2	
51	HYBRID 1	Office Deep Reno + NewBuild
52	HYBRID 2	

3.1 Mass and Carbon for verification

By understanding average mass and carbon figures we can spot what is ‘normal’ when verifying an assessment and so focus on outliers to understand why a building deviates in either a positive or negative way. As the sample size grows we can also look at individual typologies to understand them more specifically. Deviation should come from either an unusual quantity of material per m^2 of floor area, a deviating carbon factor from an EPD, or a deviation in the assumptions made around Reference Service Life (RSL) and replacement rates or end-of-life disposal. The RSL may require closer scrutiny – in one of our case studies the concrete boundary wall is stipulated as having an RSL of 20 years, resulting in 3 walls over a 50 year period, which may not be representative.

For newbuild projects, the average mass intensity of all our building designs is **2,057kg of materials, (including estimates for MEP) per m^2 UFA**. MEP, where estimated, was found to range between 1 and 12 kg per m^2, excluding the manufacturing plant which contained a high volume of specialist equipment. It must be noted that in most cases the MEP data was not available as MEP design was often carried out by a separate design team so estimates should be treated with caution. Estimates were made by each design team where possible, often following the method as recommended in the updated RICS guidance on WLC assessment [10].

Table 9: Average mass and MEP per m^2 of each new-build typology

Typology	Average mass per m^2 (kg/m^2)	Average MEP per m^2 (kg/m^2)
Apartment/Hospitality	1,897.66	3.51
Apartments	2,288.71	3.82
Detached-Resi	1,685.11	3.19
Education	2,027.47	12.43
Offices	2,383.95	5.55
Manufacturing	1,957.91	34.48
Semi-Resi	2,032.38	2.64
Sports Facility	1,099.95	1.69
Terrace-Resi	1,655.19	2.75
Warehouse	1,669.29	4.74
ALL Newbuild Average	**2,057.18**	**5.10 (exc. Manufacturing)**

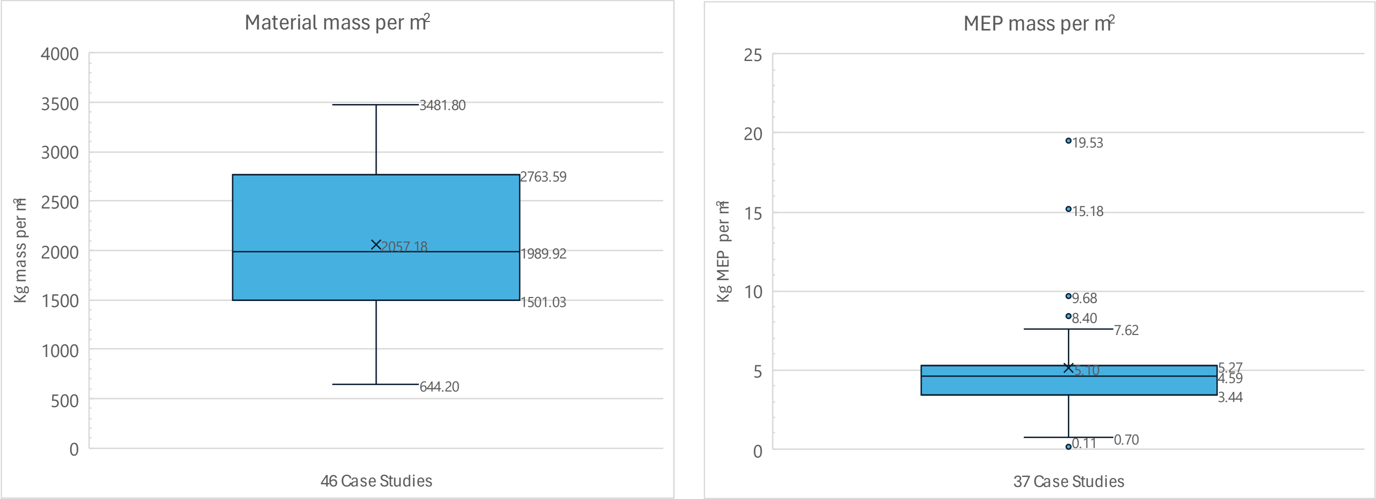

Figure 5: Box and Whiskers charts showing range of material mass and MEP mass per m² of buildings in our newbuild sample

For renovations, the four assessments are shown in Table 10 below. The average additional material going into a renovation was found to be 322kg per m² but the variation is large, with a span from 65.8 to 689 kg. MEP estimates were found to be similar to newbuild, both rounding to 5kg per m².

Table 10 Average mass and MEP per m² of renovation case studies

Typology	Average mass per m² (kg/m²)	Average MEP per m² (kg/m²)
OFFICE REN	336.02	4.91
SCHOOL REN	65.84	6.19
APPT REN	689.48	4.93
OFFICE REN	197.37	3.73
ALL REN	**322.18**	**4.94**

Of the two hybrid projects, one was in line with newbuild, the other slightly lower but with greater MEP per m²:

Table 11 Average mass and MEP per m² of two hybrid case studies

Typology	Average mass per m² (kg/m²)	Average MEP per m² (kg/m²)
HYBRID 1	852.83	11.37
HYBRID 2	1,943.84	4.91

ALL Hybrid Average	**1,398.33**	**8.14**

3.2 Typology Results Overview

Table 12: Average upfront (A1-A5) EC per m2 and average WLEC (A1-5, B4, C1-C4) over an assumed 50-year operational lifetime of different typologies.

Typology	Sample size	Average Upfront EC (A1-A5) (kgCO$_2$e/m^2)	Average WLEC (A1-C4) (kgCO$_2$e/m^2)
Apartment/Hospitality (3)	3	518.54	742.19
Apartments (14)	14	584.21	862.51
Detached-Resi (4)	4	367.54	624.46
Semi-Resi (4)	4	410.99	642.51
Terrace-Resi (3)	3	472.48	747.25
Offices (10)	10	636.42	931.16
Education (2)	2	659.75	1,063.00
Warehouse (3)	3	437.16	604.17
Sports Facility (2)	2	418.57	546.09
Manufacturing (1)	1	1,038.72	2,042.05
MEAN AVERAGE NEW (46)	**46**	**546.46**	**825.80**
Apartment Renovation (1)	1	306.50	554.92
Office Renovation (2)	2	208.31	350.84
Education Renovation (1)	1	112.44	288.22
MEAN AVERAGE RENO (4)	4	**209.08**	**397.99**
Office Deep Reno&Newbuild (2)	2	614.22	839.18[8]

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[8] Two case studies were included as renovation and new-build hybrid. It was not known what proportion of the building was new. The average for these two turned out to be higher than for new-build alone, suggesting much of the buildings was indeed now. It is a small sample and should be treated with caution

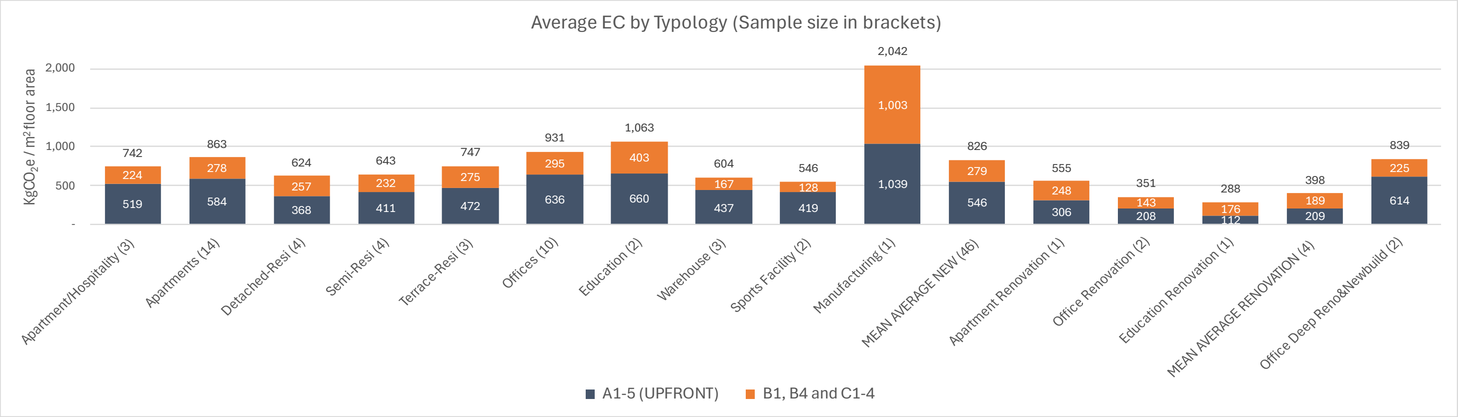
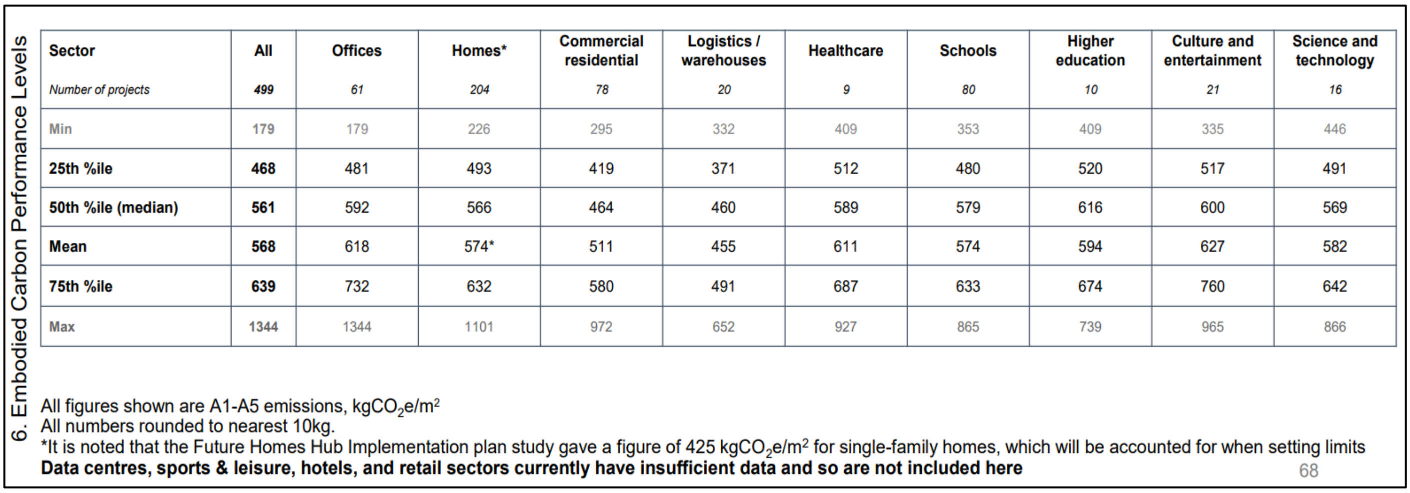


Figure 6: Average whole-life embodied carbon intensity of different typologies.

It can be seen in the assessments of 46 new buildings that **the mean average whole-life embodied carbon intensity of different typologies in new build in Ireland today is an estimated 826kgCO₂e per square meter of useful floor area** with a range from 546 for sports facilities (sample size = 2) to 2042 for a manufacturing plant (sample size = 1), only apartments and offices have a sample size of 10 or more that may be considered more reliable. Th embodied carbon includes emissions from the manufacture of materials, construction, refrigerant leakage, replacement estimates over a 50-year use period, and final demolition and disposal. **For retrofitting, based on a smaller sample of four case studies, the value is 398kgCO₂e/m^2**.

The mean average up to practical completion **(A1 – A5) was 546kgCO₂e per m^2**. In many ways this is the more useful figure as it is based on measurement of material manufacture and installation, and not assumptions about the future life of the building. Our result was found to be very closely aligned with the 568kgCO₂e/m^2 mean average taken from a larger sample of 499 case studies reported in the UK Net Zero Carbon Buildings Standard research of June 2023 and reproduced below [11].



6. Embodied Carbon Performance Levels

Sector	**All**	**Offices**	**Homes***	**Commercial residential**	**Logistics / warehouses**	**Healthcare**	**Schools**	**Higher education**	**Culture and entertainment**	**Science and technology**
Number of projects	*499*	*61*	*204*	*78*	*20*	*9*	*80*	*10*	*21*	*16*
Min	179	179	226	295	332	409	353	409	335	446
25th %ile	**468**	481	493	419	371	512	480	520	517	491
50th %ile (median)	**561**	592	566	464	460	589	579	616	600	569
Mean	**568**	618	574*	511	455	611	574	594	627	582
75th %ile	**639**	732	632	580	491	687	633	674	760	642
Max	1344	1344	1101	972	652	927	865	739	965	866

All figures shown are A1-A5 emissions, kgCO$_2$e/m^2
All numbers rounded to nearest 10kg.
*It is noted that the Future Homes Hub Implementation plan study gave a figure of 425 kgCO$_2$e/m^2 for single-family homes, which will be accounted for when setting limits
Data centres, sports & leisure, hotels, and retail sectors currently have insufficient data and so are not included here

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Figure 7 Reproduction of the findings of the UK Net Zero Carbon Building Standard result of 499 case studies measuring A1 – A5 emissions

3.3 Aggregate of Reported Materials

Figure 8 shows two charts – the total mass of all materials across all case studies on the left and their share of manufacturing emissions (A1-3) on the right. In total, 82% of the mass, and 77% of manufacturing emissions were attributable to concrete and metals (primarily steel). A further 6% of manufacturing emissions was attributable to insulation, despite insulation only making up 1% of the mass, which underlines the high GWP of some insulation materials – primarily PIR and EPS.

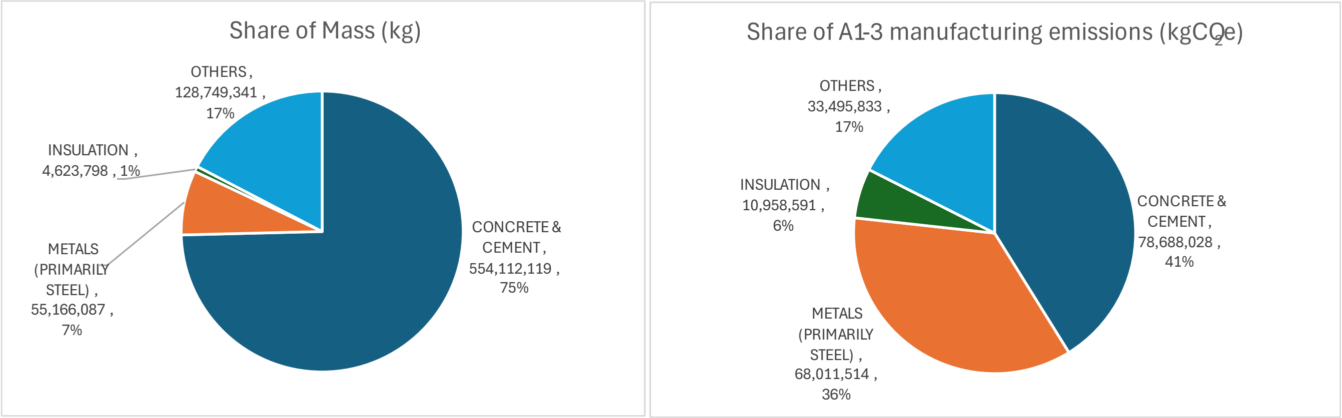


Figure 8 Share of Mass and Emissions - aggregate of all materials input across all assessments

Data Sources

In order for assessments to be consistent, the data they are built upon must be consistent also. In most cases, studies are difficult to compare as the background data is taken from sources that are either obscured or are not comparable. In our case studies we provided a set of generic carbon factors for common materials known as the National Generic Dataset and available at https://www.igbc.ie/generic-data/. Assessors were told to use EPD data if it was available for the products they used and, if no EPD was available, to use this generic dataset. In this way all assessments used the same carbon factors for each material type when EPDs were unavailable. Figure 9 shows the proportion of mass that was measured using EPD and generic data. The A1-3 emissions of over 90% of the mass of case studies was calculated using the generic data provided, demonstrating the current difficulty in obtaining EPD data when assessment is not considered from the outset.

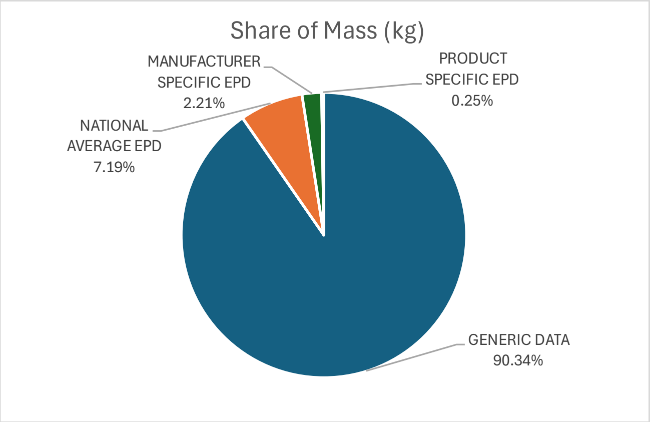


Figure 9 Proportion of manufacturing emissions measured using generic data and EPDs

For the remaining stages after manufacture, the consistent set of assumptions ensure all assessments are assumed to follow the same replacement schedules and that all deconstruction scenarios are the same.

3.4 Average carbon intensity by element

Another goal of this study was to understand the ratio of the emissions associated with different elements of a building. The following two figures show the aggregate results of all elements in the assessments (excluding retrofits) divided by the aggregate floor area (in total 305,700m^2 of new UFA was assessed by our participants) to give the average carbon intensity of each element per square metre of building. So, for example, if the WLEC of the load bearing structural frame is 285kgCO$_2$e per m^2 of UFA, a building of 10m^2 will have on average 2,850kgCO$_2$e attributable to the load bearing structural frame (10 x 285). This could be a useful metric to allow assumptions to be made where data is missing or not available in order to provide indicative numbers at early stages. It can be broken down by typology when the sample sizes are large enough.

The two figures also contrast the upfront EC (A1-5) and the WLEC (A1-C4). It can be seen that on average, the load bearing structure is the most carbon intensive element of a building both up to completion (281kgCO$_2$e/m^2) and over its whole life (285kgCO$_2$e/m^2). There are no replacement cycles for this element, so only the small amount of emissions involved in deconstruction (C1-4) is added to the upfront CO$_2$e at the end-of-life stage. Energy systems on the other hand, have an A1-5 score of 36kgCO$_2$e/m^2, but by the time the building is assumed to be decommissioned 50 years later this figure has increased to 109kgCO$_2$e/m^2 as a result of replacement cycles during the lifetime of the building and the C1-4 at end-of-life.

This is useful for thinking long term at the design stage – designing with reduced energy systems in mind initially will not only mean a better result in the short term but it also means that in the long term, when the building is probably no longer under the control of the original designer, there should be no need to add more carbon intensive systems. Designers may not control a building throughout its lifetime but they can set the direction of its use and maintenance requirements.

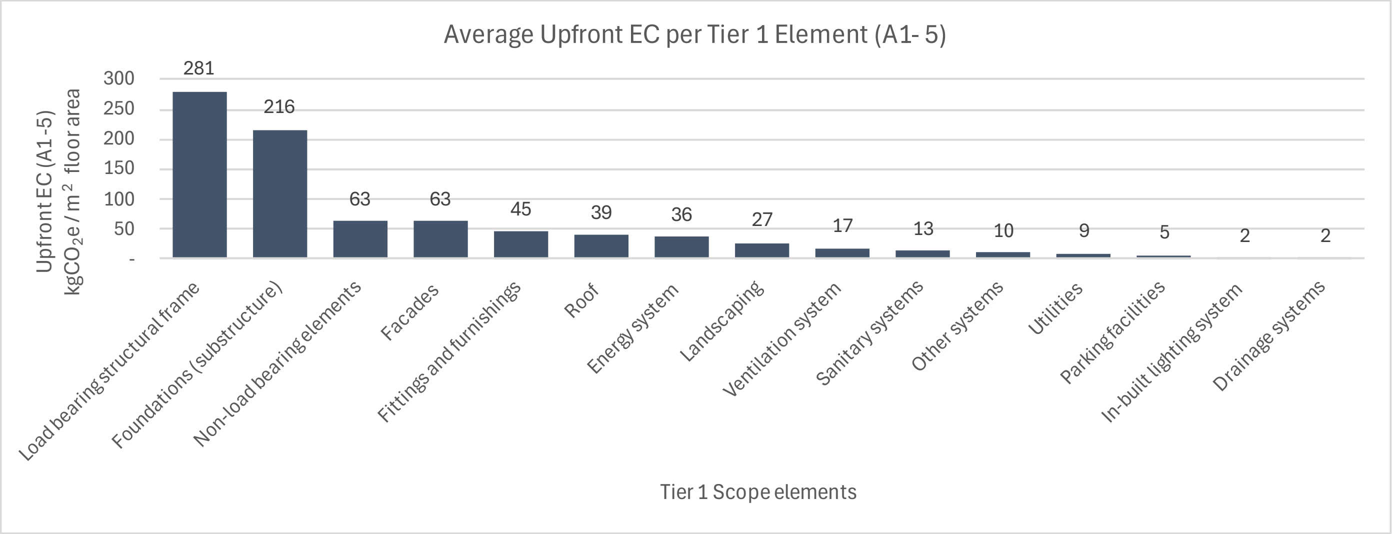


Figure 10: Average carbon intensity of Tier 1 building elements per m² of UFA (kgCO₂e/m²) up to completion of building.

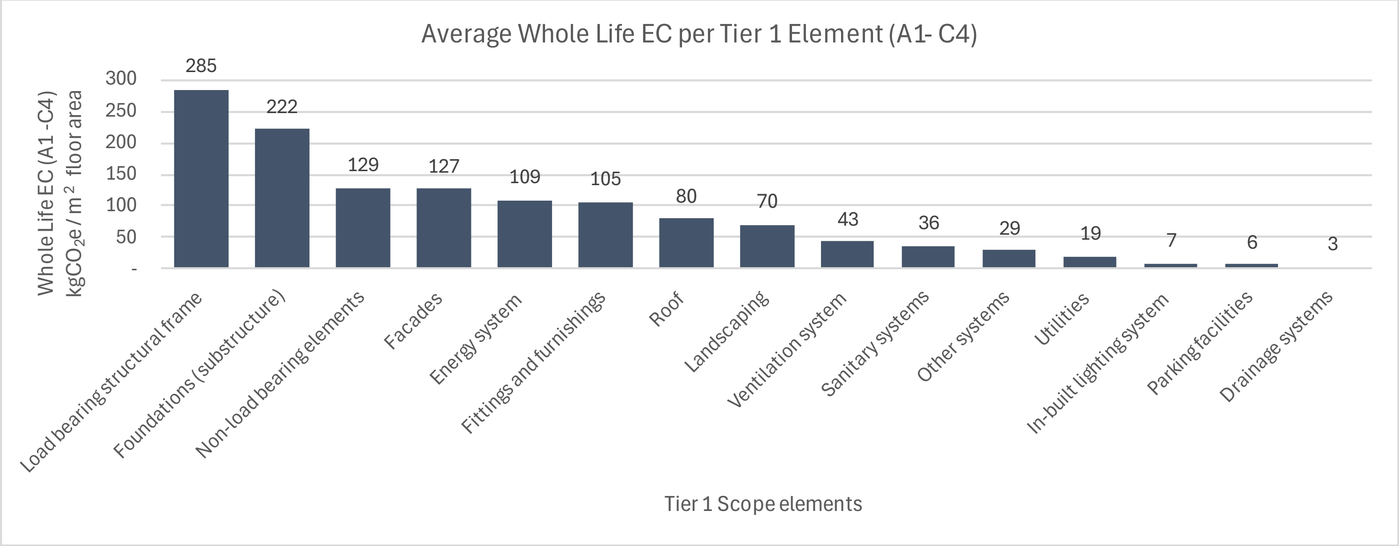


Figure 11: Average carbon intensity of Tier 1 building elements per m² of UFA (kgCO₂e/m²) over the whole life cycle including replacement cycles and deconstruction.

The four refurbishments in the sample show the most carbon intensive element of a refurbishment is also the load bearing frame up to completion of the refurbishment. For a specific refurbishment where no additional load bearing frame is planned this element could be discounted in an early-stage estimate. Based on our assumptions, after 50 years replacement cycles of facades and non-load bearing elements may overtake the total for the frame.

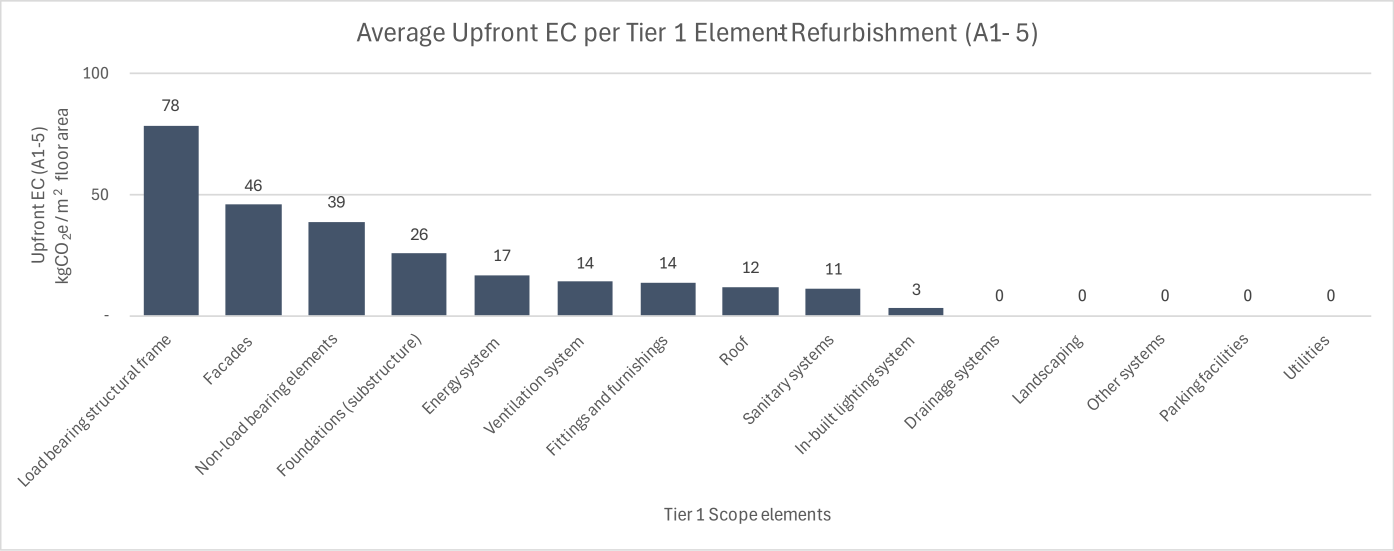


Figure 12: Average carbon intensity of Tier 1 building elements per m² of UFA (kgCO$_2$e/m²) up to completion of refurbishment

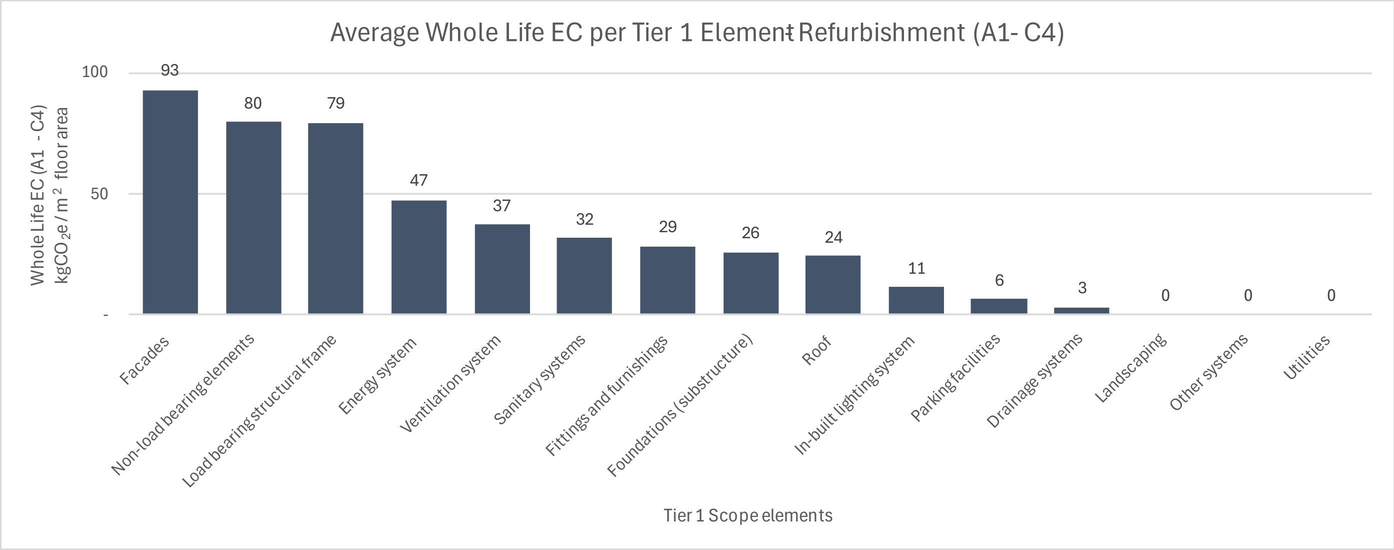


Figure 13: Average carbon intensity of Tier 1 building elements per m² of UFA (kgCO$_2$e/m²) over the whole life cycle including replacement cycles and deconstruction

3.5 Residential and non-residential baselines

Breaking down the new-build total into residential (apartments, terraces, semis and detached) and non-residential (everything else) reveals a difference. The **residential buildings had an average WLEC per m^2 of 775kgCO$_2$e**. The figure for **non-residential was 886kgCO$_2$e**. The sample sizes were 25 cases studies (77,352m^2) and 21 case studies (228,348m^2) respectively. The **A1-5 results were 508kgCO$_2$e/m^2 for residential**, and **592kgCO$_2$e/m^2 for non-residential.**

An elemental breakdown up to completion (A1-A5) and WLEC (A1-C4) is given in Figure 14 to Figure 17 for residential and non-residential below. Note, these figures should be viewed as an average for each element rather than a total for residential or non-residential; the sum of the elements here is higher than any one typology because some elements may not be present in all of the case studies.

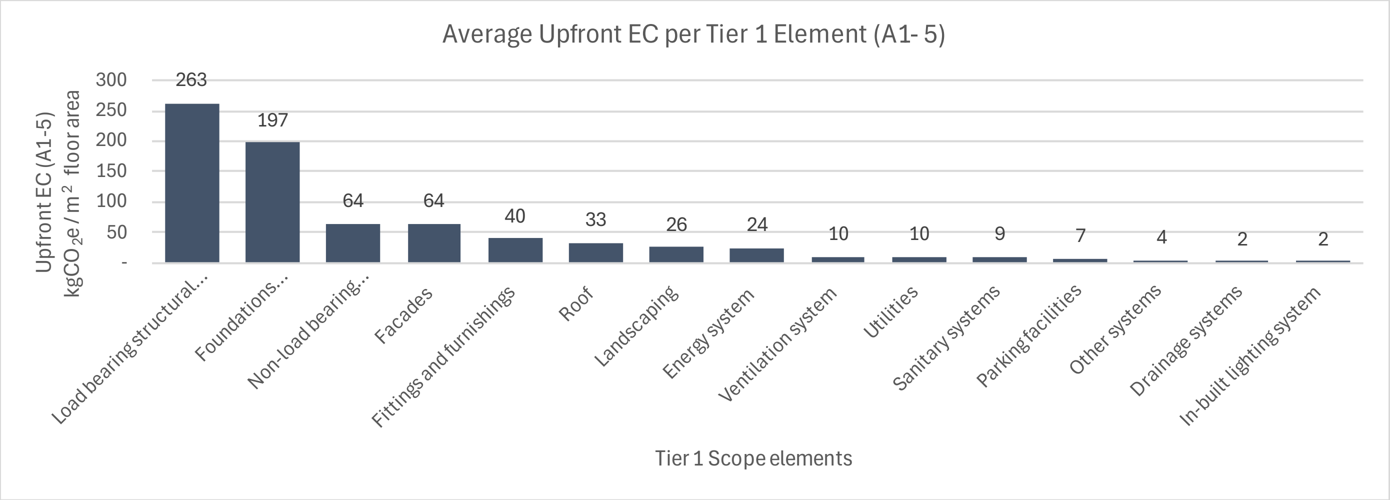


Figure 14: Average Upfront A1-5 expressed as kgCO2e per m^2 for 25 residential case studies

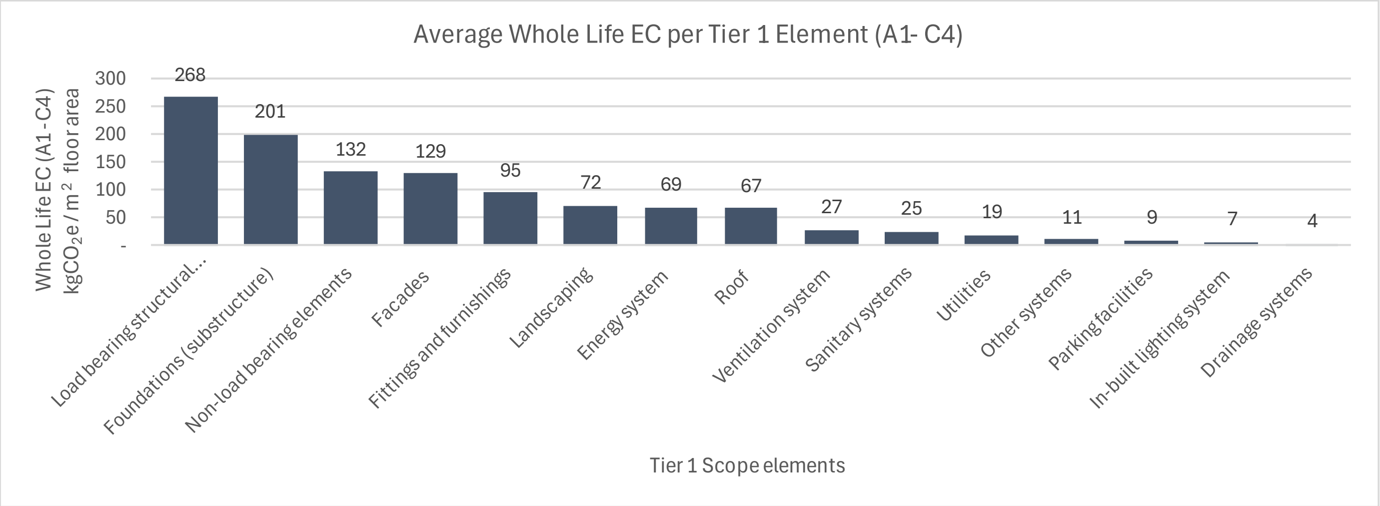


Figure 15: Average WLEC expressed as kgCO$_2$e per m^2 for 25 residential case studies

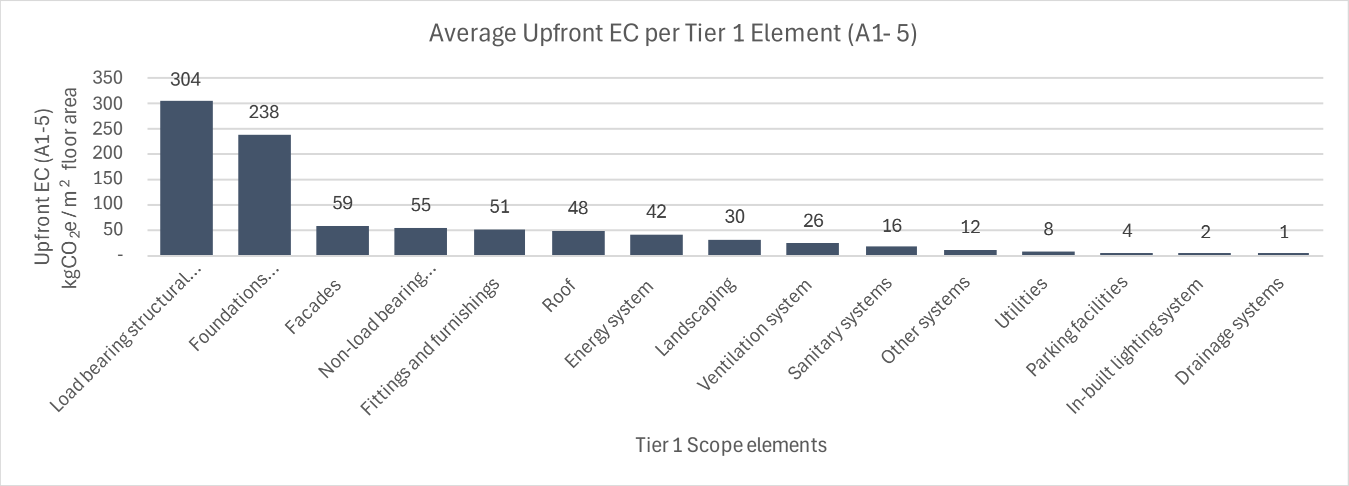


Figure 16: Average A1-5 expressed as kgCO2e per m² for 21 non-residential case studies

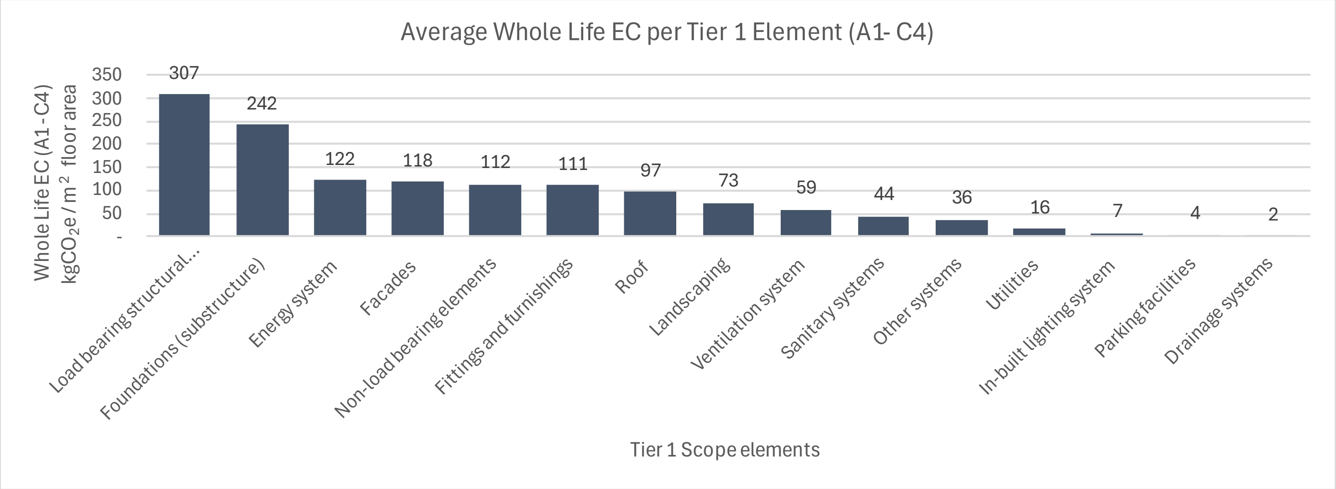


Figure 17: Average WLEC expressed as kgCO2e per m2 for 21 non- residential case studies

3.6 Typical Residential Typology - Totals

The residential typologies are worth exploring in further detail to understand the total impact of each unit rather than each square meter. The table below shows the average size of each typology in square meters multiplied by the average impact per square meter to display the total impact per dwelling. Size data was taken from CSO statistics on averages for 2020-2024, sample size is in brackets. This sample is within curtilage only and does not include supporting infrastructure, roads etc. which would typically be higher for single detached than terrace, semi or apartment typologies.

Table 13 Dwelling type average size multiplied by carbon factors to determine average EC of each typology

				TOTALS PER DWELLING		
DWELLING TYPE	**FLOOR AREA**	**A1 - 5**	**B-C**	**A1 - A5**	**B - C**	**TOTAL**
APARTMENT, 74.3m^2 (14)	74	584	278	43,424	20,686	64,111
TERRACE, 108.5m^2 (3)	109	472	275	51,264	29,813	81,077
SEMI DETACHED, 118m^2 (4)	118	411	232	48,497	27,320	75,817
DETACHED, 201m^2 (4)	201	368	257	73,876	51,640	125,516

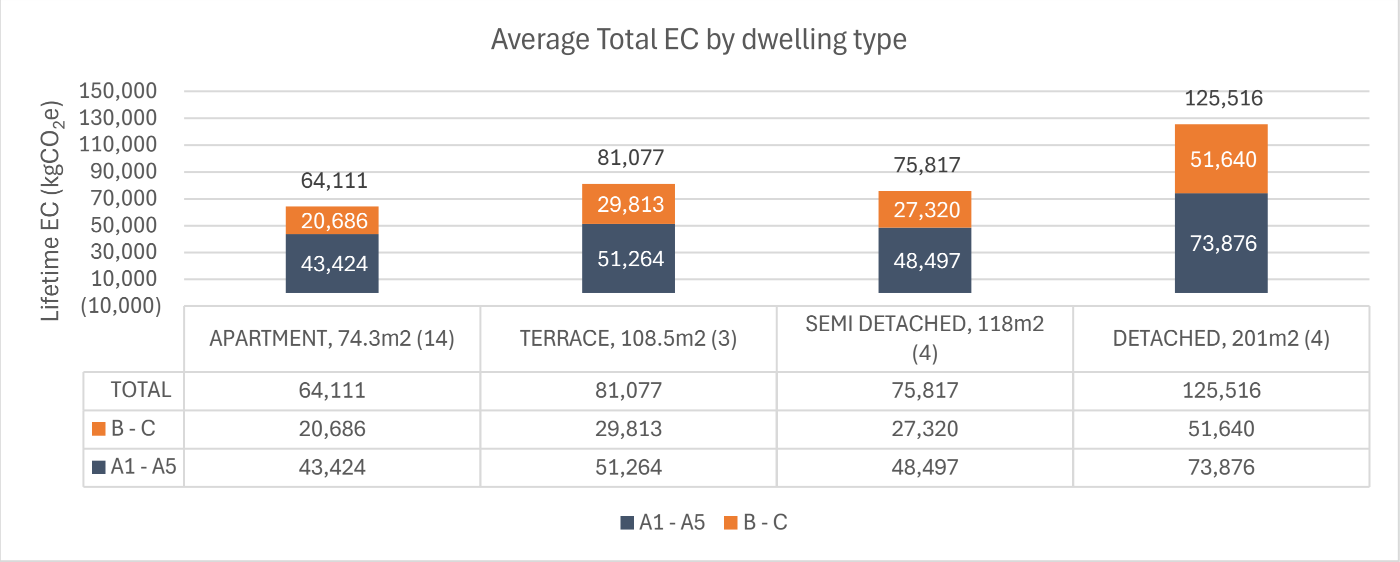


Figure 18 Resulting total for each typology

It can be seen that although detached homes have the lowest embodied carbon on a per square meter basis, the typical detached home is almost twice as large as a terrace or semi-detached home, meaning that at 125.5 tonnes, the total EC per dwelling is double that of an apartment and 40% higher than a semi-detached home. This suggests that although per square meter is a good measure for comparison, other measures, such as per bed space may be more appropriate in the residential and healthcare sectors, and per desk space or user may be more appropriate in offices or public buildings for example.

3.7 Typology Analysis

The embodied carbon of the case studies were analysed and results are presented below. Each set of charts refers to a mean average for the case studies of that particular typology. It must be noted that the sample sizes are still quite small when broken down by typology, in some cases still only one case study, so the addition of further case studies could change the averages significantly in the future. What this sample represents is the start of a database of consistently measured buildings – as more case studies emerge, they should be added to the database to adjust the mean average to a representation of the average in Ireland today.

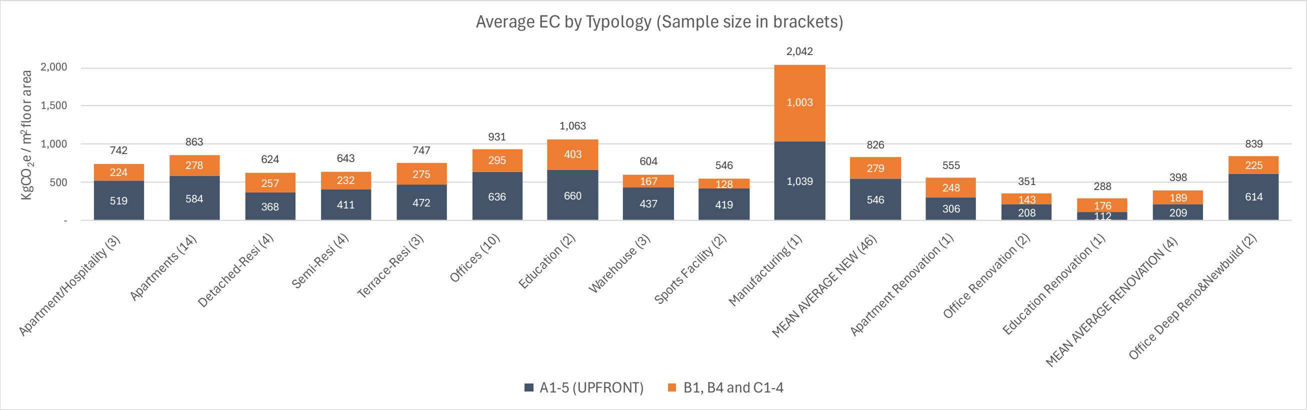


Figure 19: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.1 Semi detached

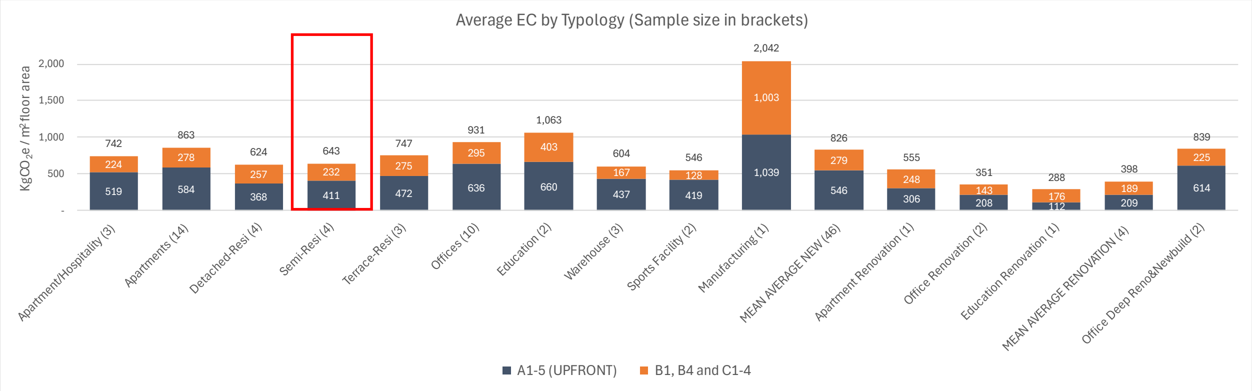


Figure 20: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.1.1 Variation

The four semi-detached assessments consisted of three concrete block and one timber frame with block and brick external walls. Floor area ranges from 100 to 130m^2. SEMI 1 contained no data on building services, which is reflected in the smaller B4 result of this assessment. Where a case study is missing data on a particular element like this, it is taken into account when calculating mean averages for each element so does not affect the overall results, although it does reduce the sample size for the element.

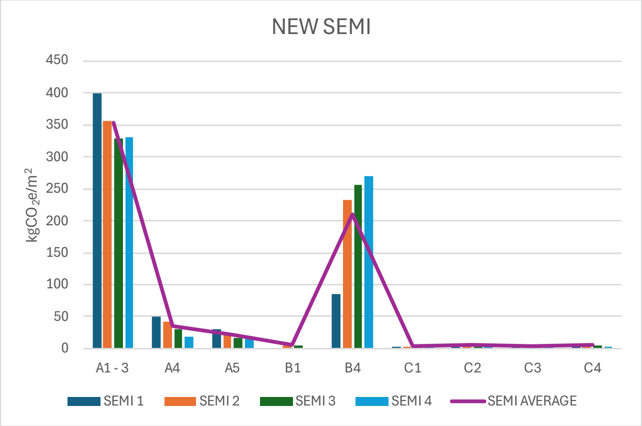


Figure 21: Carbon profile of the SEMI case studies as described in EN 15978, and the mean average.

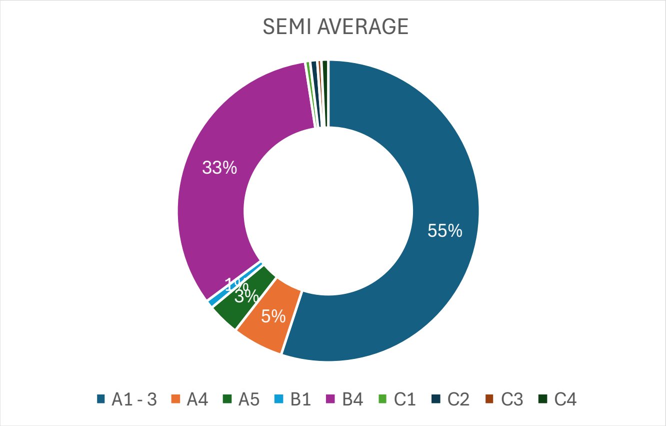


Figure 22: Distribution of EC across the life cycle (SEMI)

5.5.1.2 Results

Overall the average WLEC for a semi detached house was 643kgCO₂e per m^2, which equates to 75.8 tonnes for an average semi of 118m^2. Results were broadly similar, reflecting the similarity in material choices. The main deviation was in the replacement results for SEMI 1 which were much lower owing to the missing building services data. It can be seen in Figure 21 and 22 that the manufacturing (A1-3) and replacement (B4) stages account for the great majority of the embodied carbon – 55% and 33% respectively. While A1-3 is a calculation of the actual quantities multiplied by generic material carbon factors, the B4 is an estimate of the likely replacement requirements over 50 years as stipulated by Level(s). It is therefore one estimate of the future scenario. This pattern emerges across all assessments as assessments are based on consistent future scenarios.

5.5.1.3 Tier 1 and Tier 2 scope elements

The following charts show the average of EC apportioned to the elements as defined in Level(s). Figure 23 shows the Tier 1 scope elements, and then Figure 24 shows the Tier 2, more specific components. Looking at these two charts together, Figure 23 tells us that the load bearing structural frame was the largest contributor, followed by non-load bearing elements, the substructure, fittings and energy systems. Figure 24 highlights the specific components within each element. So here we see it is the external walls (in the load bearing structure), the heating plant and distribution (of energy systems), the retaining walls (of the substructure) and the internal walls (of the non-load bearing elements) and facade openings (of the facades) that are the hotspots.

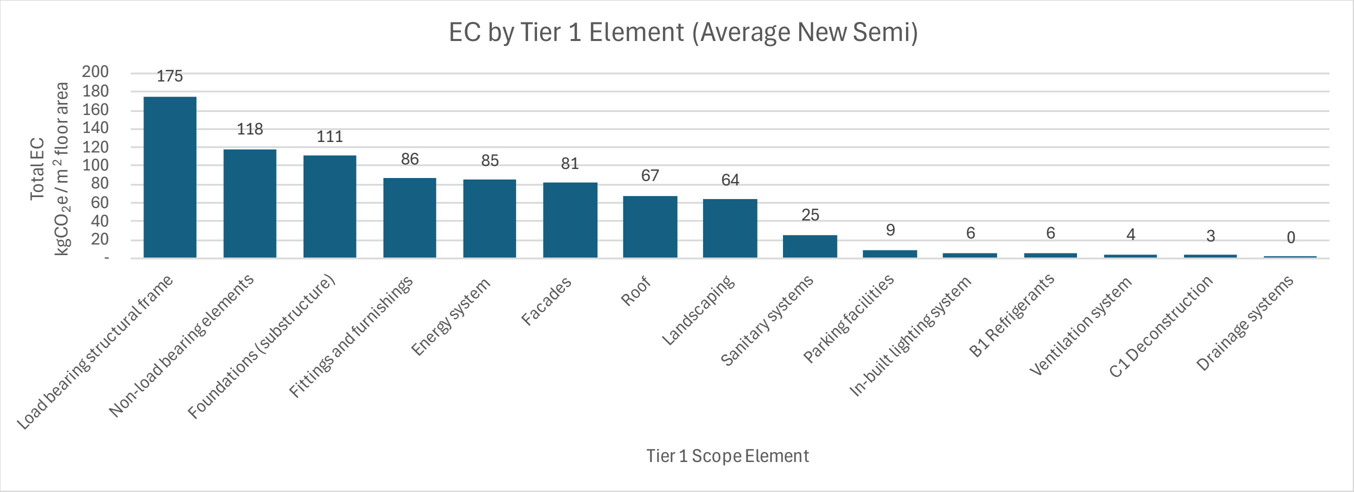


Figure 23: Breakdown of embodied carbon of average SEMI by TIER 1 building element as defined by Level(s) (manual 2, Table 11)

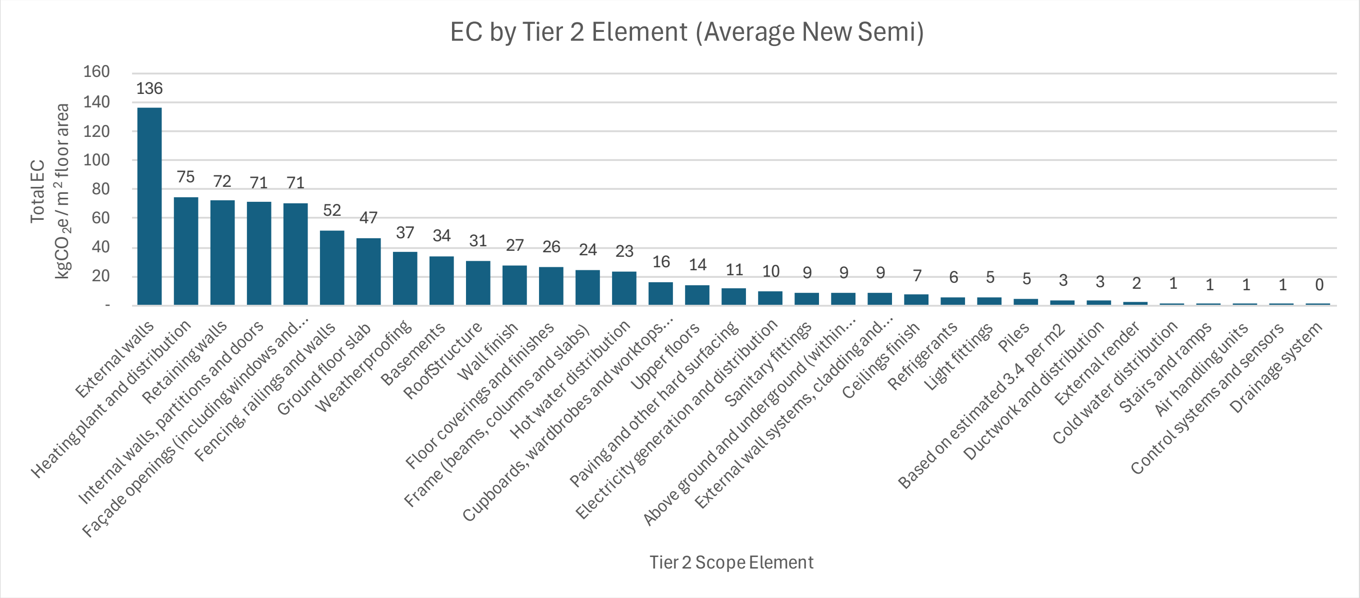


Figure 24: Breakdown of embodied carbon of average SEMI by TIER 2 building elements as defined by Level(s) (manual 2, Table 11)

Although the average of the reported assessments was 643kgCO_2e/m^2, owing to data availability no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 840kgCO_2e/m^2, an uplift of 23%.

5.5.2 Detached

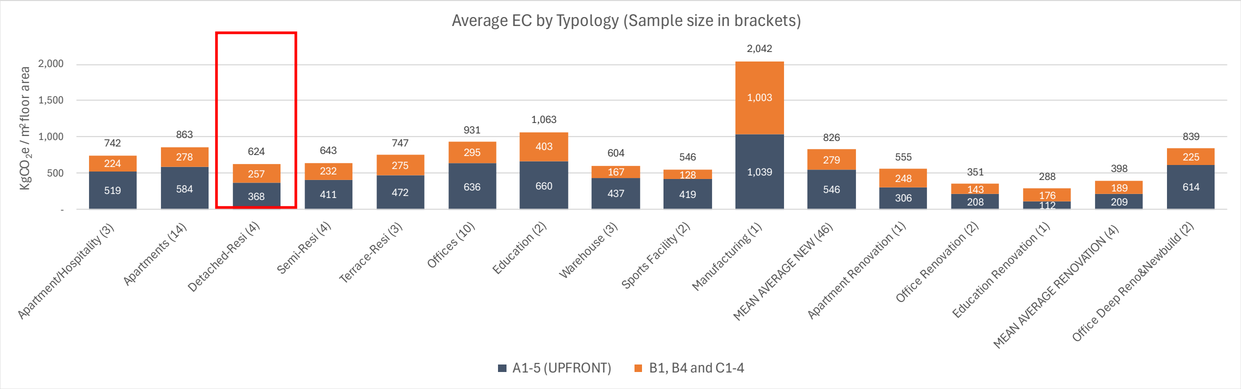


Figure 25: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.2.1 Variation

The four case studies were all new detached houses with floor areas ranging from 206 to 382m². The material mass score of DETACHED 4 appeared to be much lower than the others, and this was supported in the verification process that revealed the overall mass of DETACHED 4 was 644kg per m², compared to a typical range of 1000 to 3,000kg for all buildings. Nevertheless it was included pending a review owing to already small sample sizes but this does underline the need for a larger sample size so outliers can be further investigated.

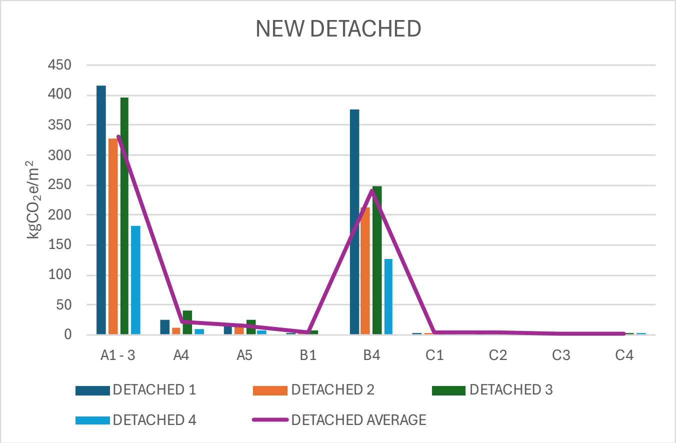


Figure 26 Carbon profile of the DETACHED case studies and the mean

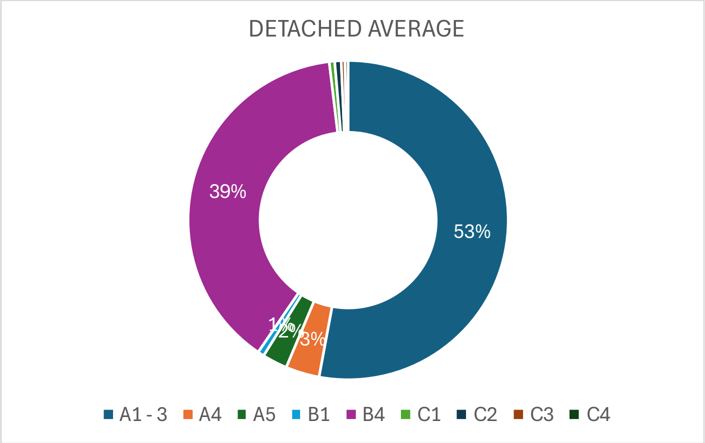


Figure 27 Distribution of EC across the life cycle (DETACHED)

5.5.2.2 Results

Overall the average WLC for a detached house of 201m² was 125.5 tonnes of CO₂e, or 624kgCO₂e per m². This is lower than SEMI on a per square meter basis but considerably higher per dwelling owing to the much larger typical size. The division across the life cycle stages is similar, with a slight increase in the B4 proportion.

5.5.2.3 Level 1 and Level 2 scope elements

As with the SEMI analysis, the following charts show the average carbon intensity of each element per square meter of UFA. The superstructure, facade and energy system make up the greatest proportions of the WLEC, but this time it can be seen that the greatest single component is facade openings. The four samples are one-off bespoke homes which may have significantly more glazing than the basic semi-detached samples. Glazing typically has an associated replacement cycle over its lifetime, unlike opaque elements, which would account for the higher replacement embodied carbon in B4 also.

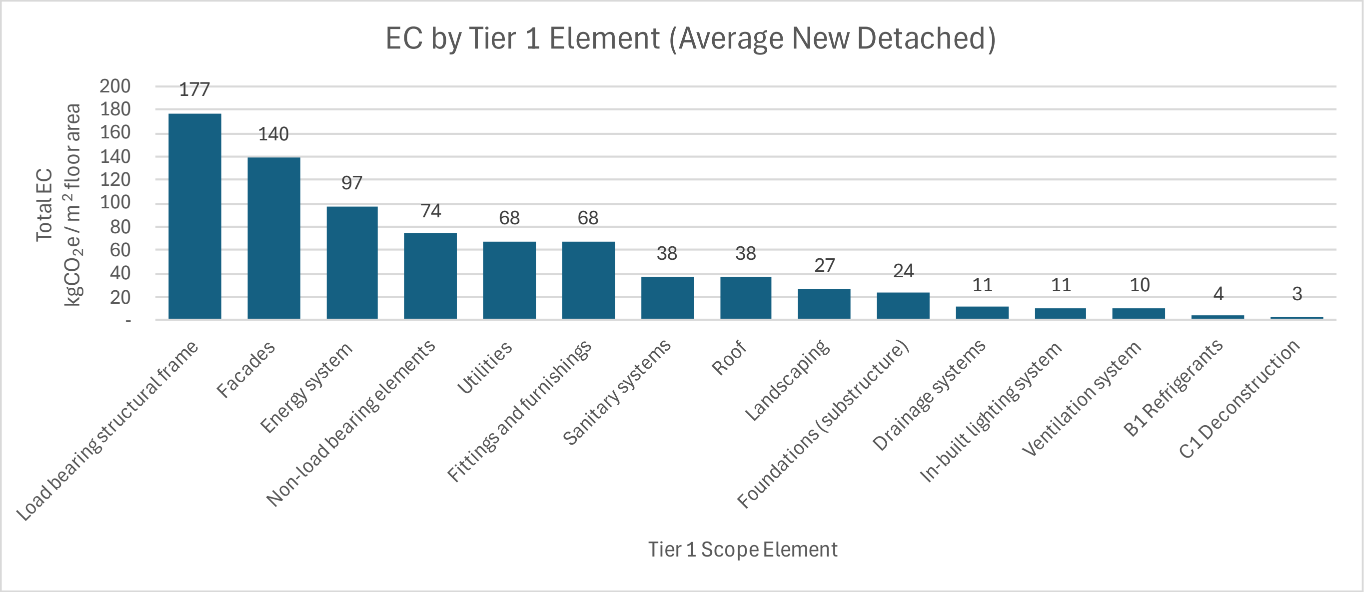


Figure 28: Breakdown of embodied carbon of average DETACHED by building part as defined by Level(s) (manual 2, Table 11)

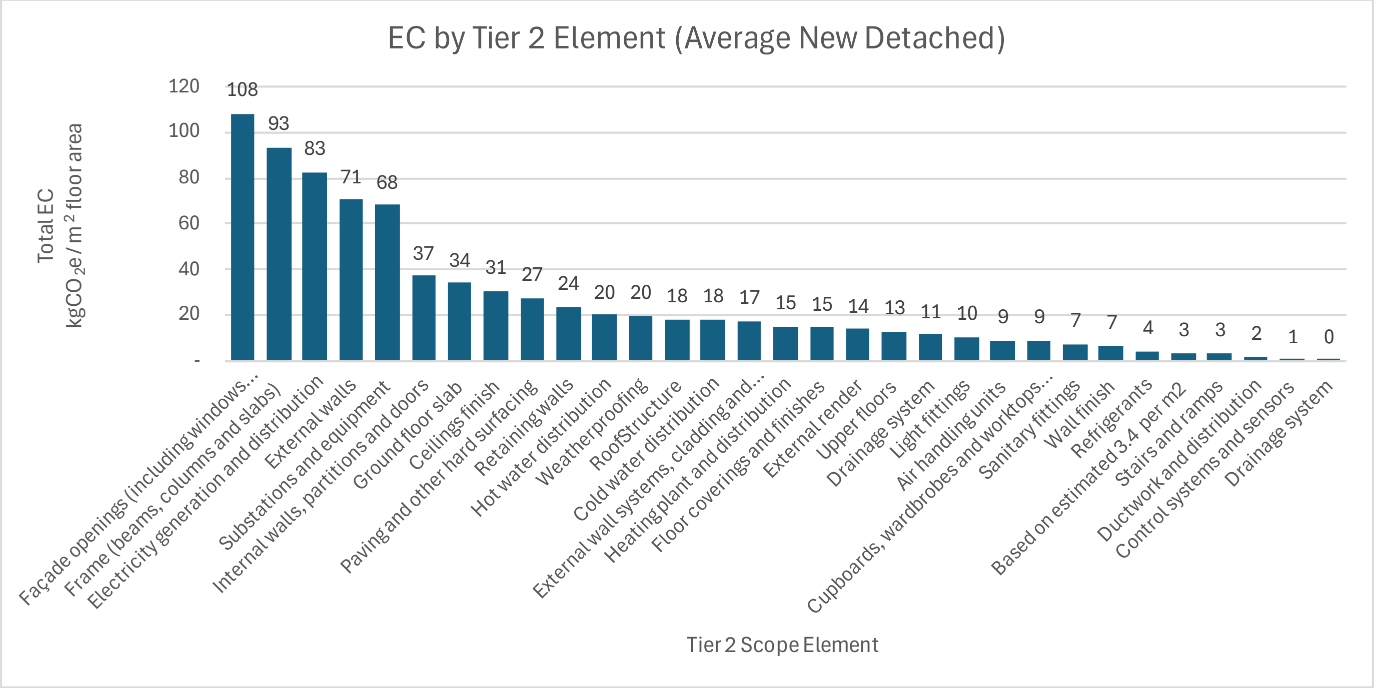


Figure 29: Breakdown of embodied carbon of average DETACHED by specific building elements as defined by Level(s) (manual 2, Table 11)

Although the average of the reported assessments was 624kgCO₂e/m^2, owing to data availability no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 791kgCO₂e/m^2, an uplift of 21%.

5.5.3 Terraced Housing

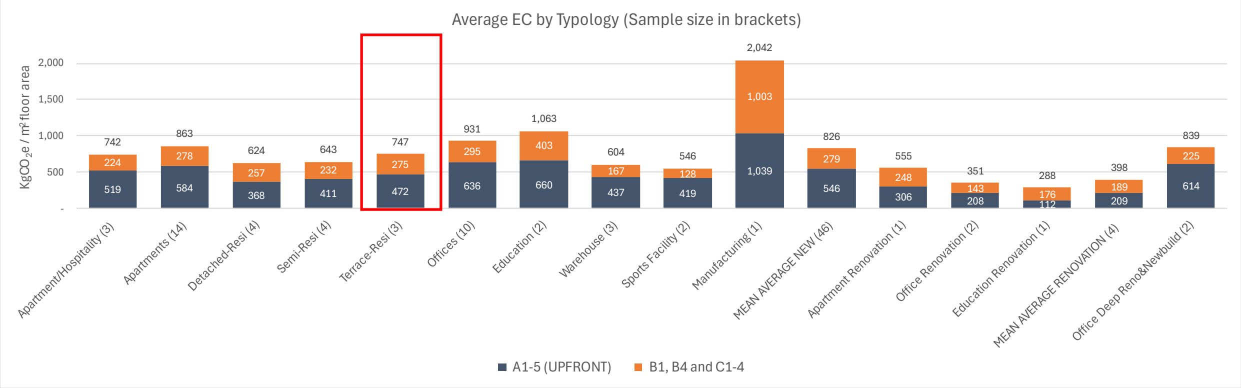


Figure 30: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.3.1 Variation

The terraced sample consists of two mid terrace homes and an end of terrace, more in line with a semi-detached as only one wall is shared with a neighbouring home. It is not clear from the quantities of the mid-terrace assessments if shared party walls are taken into account and further investigation is recommended.

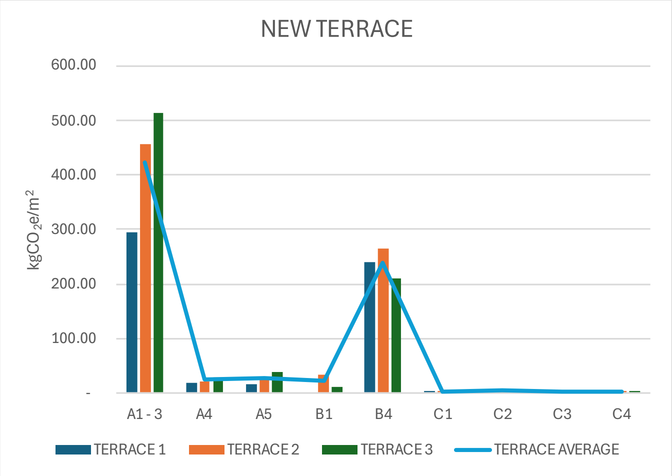


Figure 31 Carbon profile of the TERRACED case studies and the mean

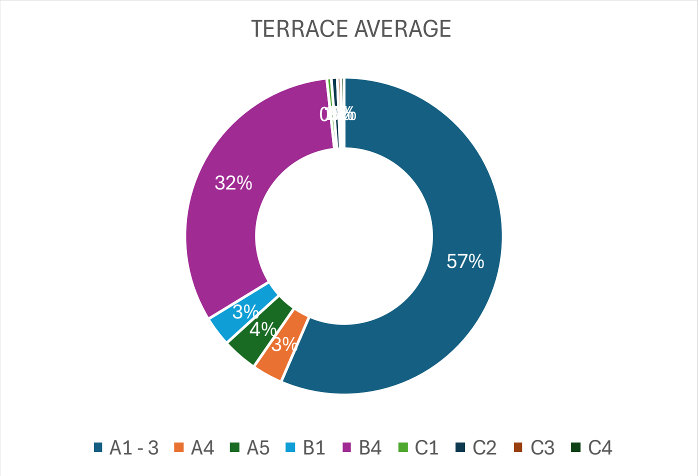


Figure 32 Distribution of EC across the life cycle (TERRACED)

5.5.3.2 Results

Overall the average WLC for a terrace house of 108.5m^2 was 81 tonnes of CO$_2$e, or 747kgCO$_2$e per m^2. Slightly higher than the semi-detached sample on both a per square meter and total basis but considerably lower per dwelling than detached housing.

5.5.3.3 Level 1 and Level 2 scope elements

The following charts show the average carbon intensity of each element per square meter of UFA. The external walls and structural frame make up the greatest proportions of the WLEC.

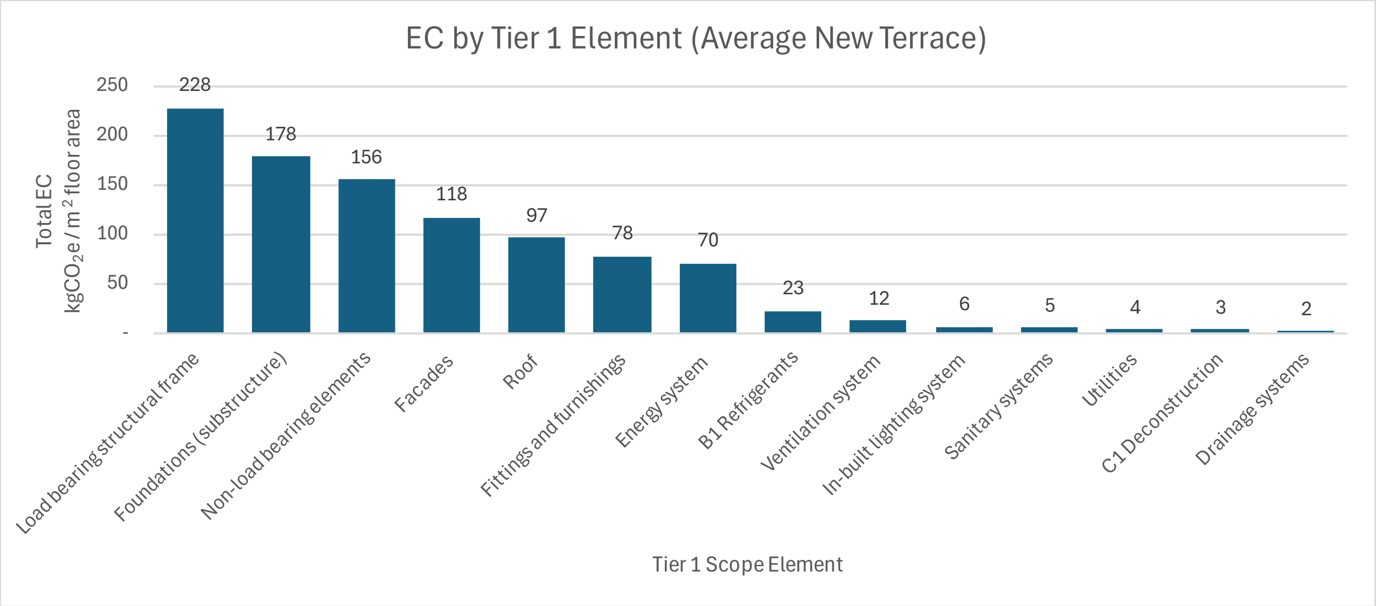


Figure 33: Breakdown of embodied carbon of average TERRACED by building part as defined by Level(s) (manual 2, Table 11)

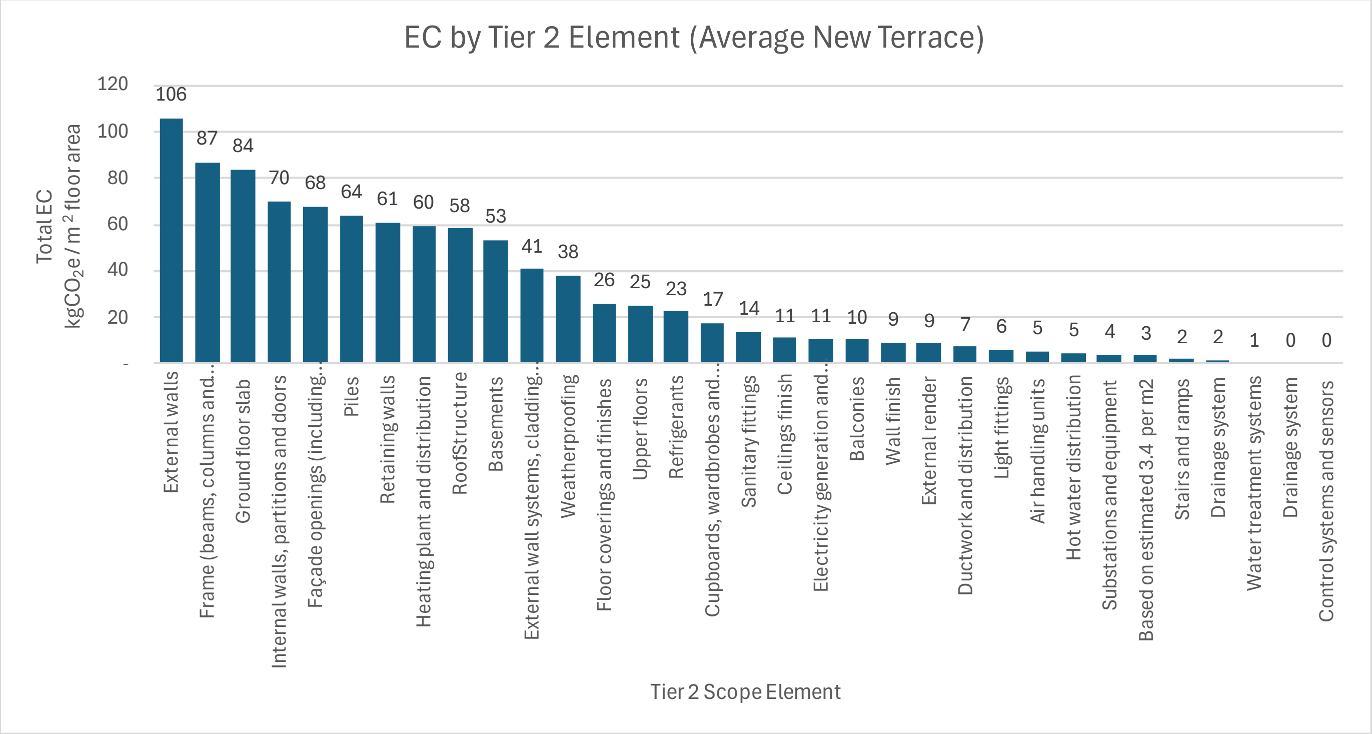


Figure 34: Breakdown of embodied carbon of average TERRACED by specific building elements as defined by Level(s) (manual 2, Table 11)

Although the average of the reported assessments was 747kgCO_2e/m^2, owing to data availability no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 980kgCO_2e/m^2, an uplift of 24%.

5.5.4 Apartments / multi-occupant

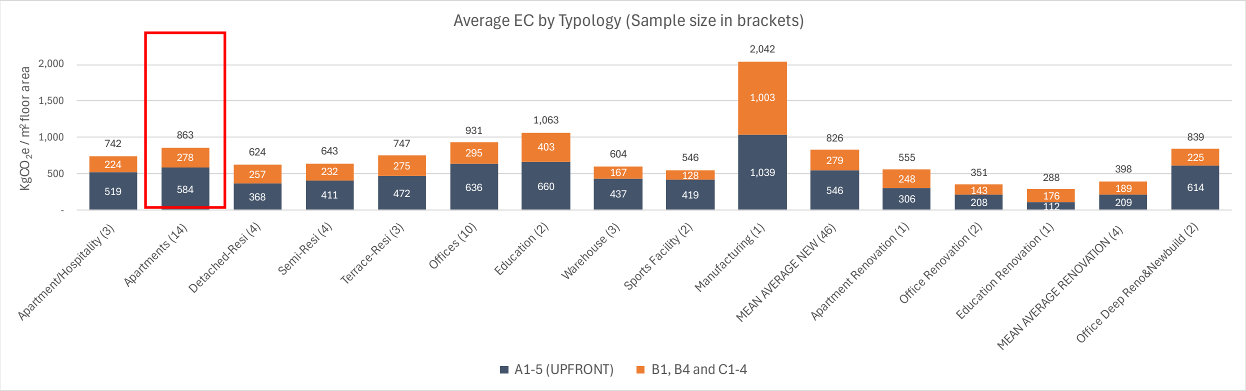


Figure 35: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.4.1 Variation

At fourteen case studies, apartment blocks was our largest sample, allowing for greater confidence in the result. The range of results was from 682 to 984kgCO$_2$e/m^2.

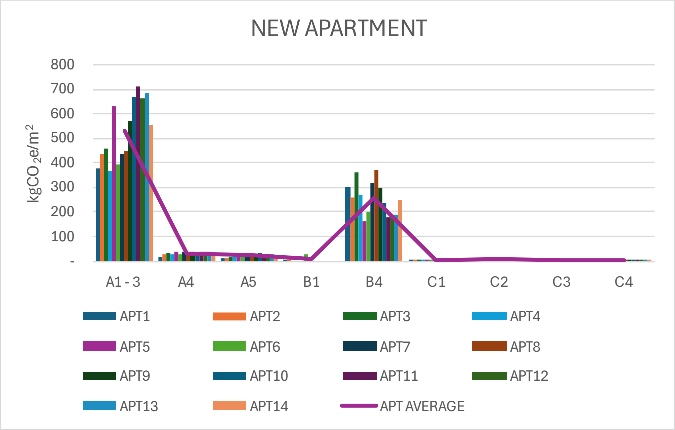


Figure 36 APARTMENT case studies and the mean average

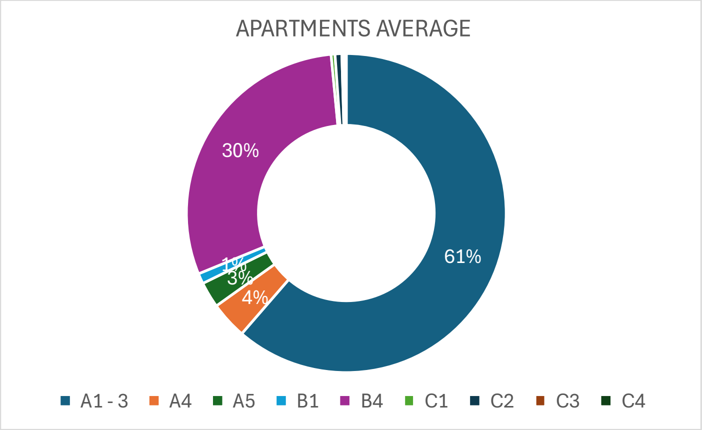


Figure 37 Distribution of EC across the life cycle (APARTMENTS)

5.5.4.2 Results

Overall average WLEC was 863kgCO$_2$e/m^2. An overall average for an apartment block cannot be calculated as the size of a block can vary greatly. A calculation per residential unit or per bed space may be more useful.

5.5.4.3 Level 1 and Level 2 scope elements

Looking at Tier 1 elements, unsurprisingly the superstructure and foundations account for the largest hotspots in an average apartment block. Within these elements it is the structural frame and the basements that typically have the highest embodied carbon and should therefore be the focus of reduction strategies.

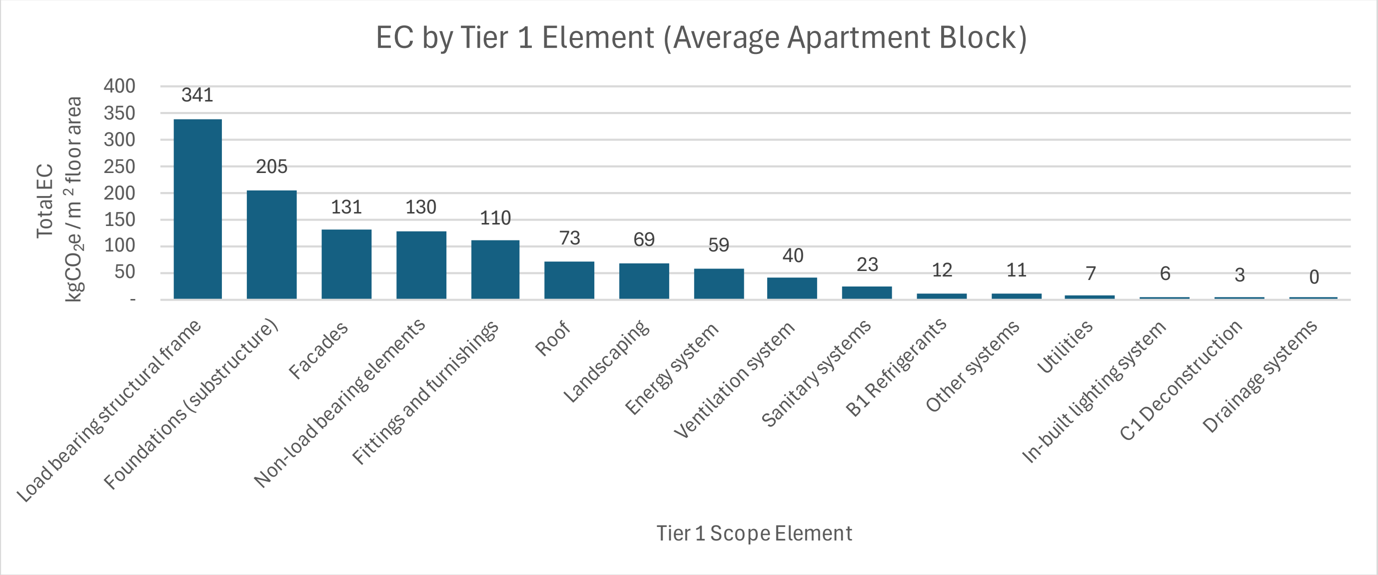


Figure 38: Breakdown of embodied carbon of average APARTMENT by building part as defined by Level(s) (manual 2, Table 11)

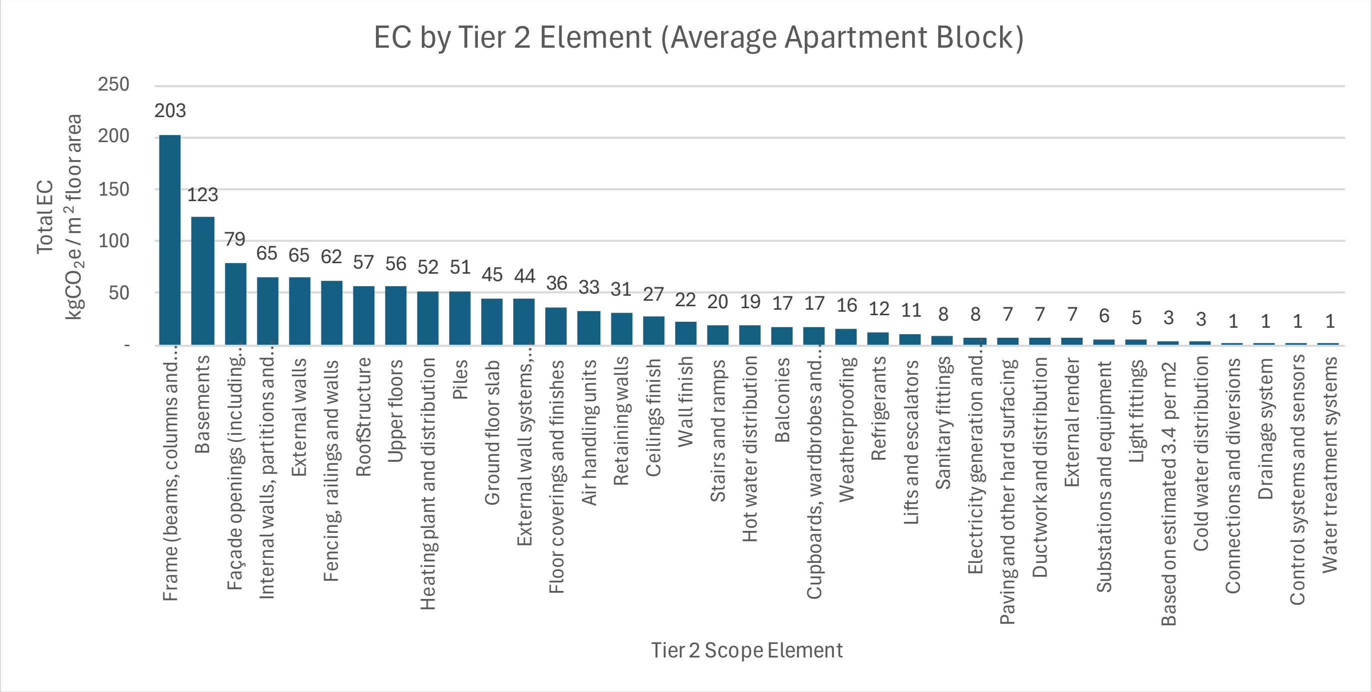


Figure 39: Breakdown of embodied carbon of average APARTMENT by specific building elements as defined by Level(s) (manual 2, Table 11)

Although the average of the reported assessments was 863kgCO$_2$e/m^2, owing to data availability no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 1,222kgCO$_2$e/m^2, an uplift of 29%.

5.5.5 Office

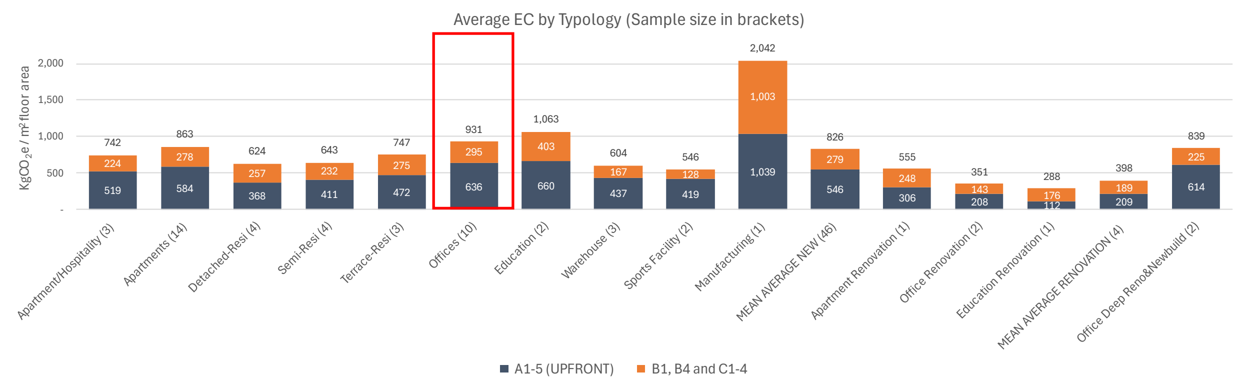


Figure 40: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.5.1 Variation

The ten office case studies comprise our second largest sample, with a spread of results from 540 to 1,178kg CO_2e/m^2 . Floor area varied widely from 3,556 to 51,000m^2.

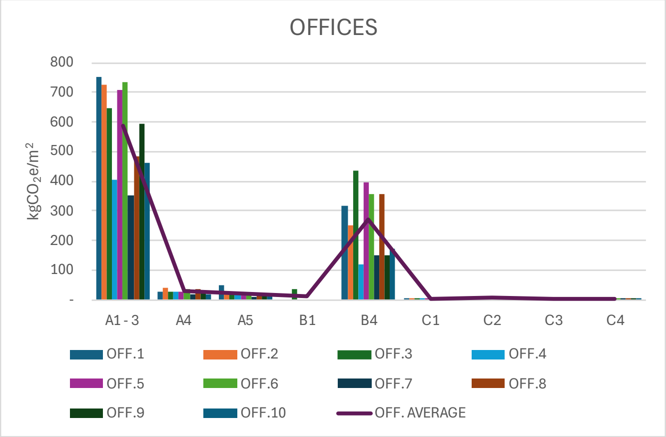


Figure 41: OFFICE case studies and the mean average

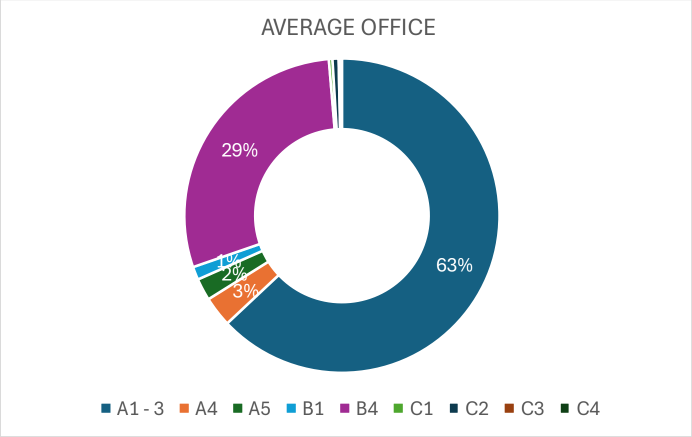


Figure 42: Distribution of EC across the life cycle (OFFICE)

5.5.5.2 Results

Overall average WLEC was 931kgCO_2e/m^2. 68% of the EC was 'upfront' in stages A1 to A5.

5.5.5.3 Level 1 and Level 2 scope elements

The superstructure, substructure and energy systems were the greatest EC hotspots. For the superstructure and substructure, all of these emissions will occur before the practical completion, primarily in the production of the materials, mainly concrete and steel (A1-3). Basements were the single largest contributor, even higher than the structural frame. Other architectural elements and energy systems also contribute a large proportion although this is spread across the initial production (A1-3) and replacement cycles during the building's lifetime (B4). Internal walls are also assumed to undergo one replacement in the 50-year period.

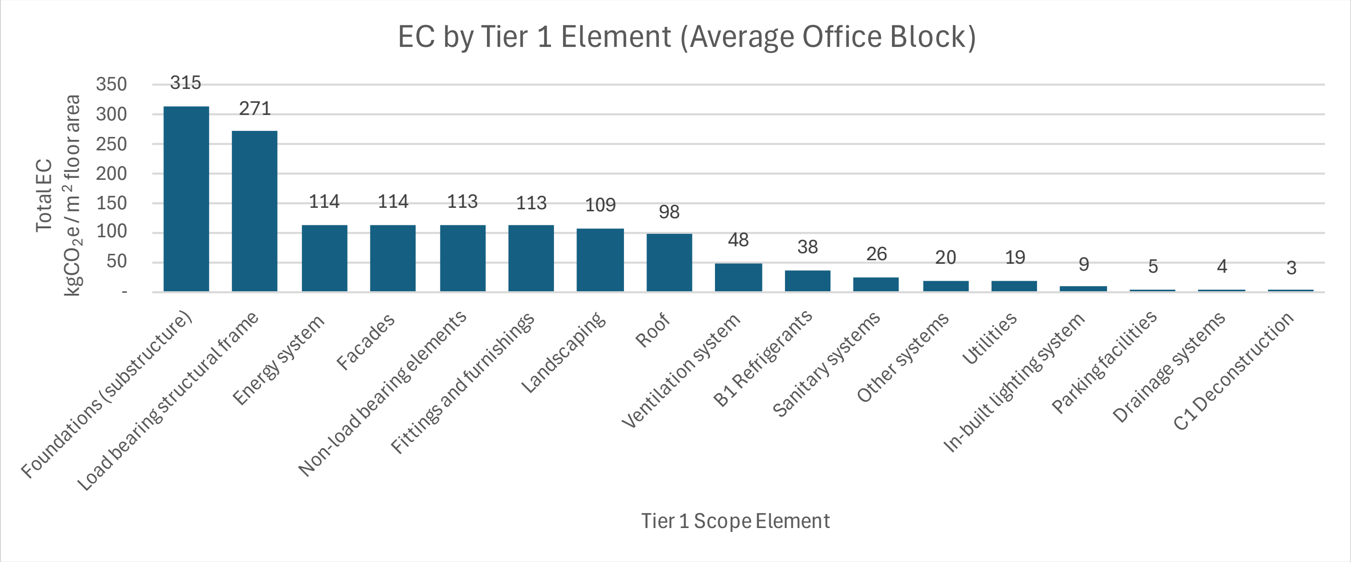


Figure 43: Breakdown of embodied carbon of average OFFICE by building part as defined by Level(s) (manual 2, Table 11)

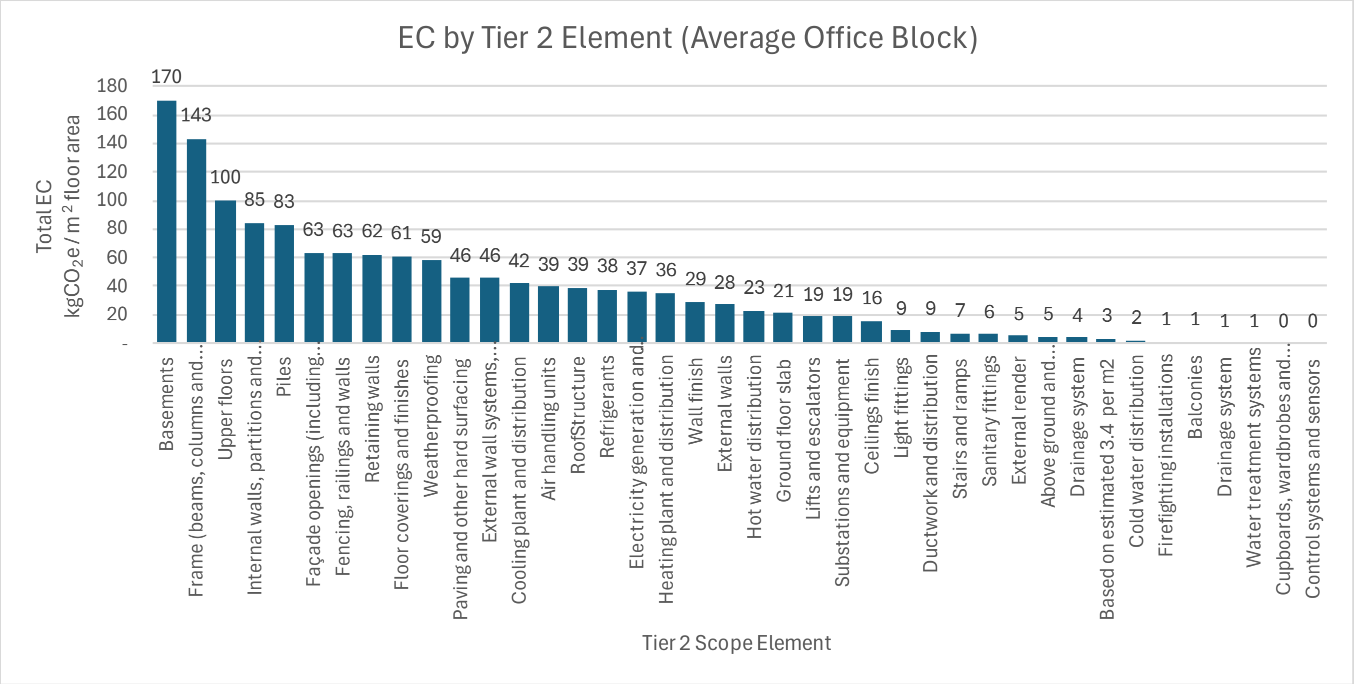


Figure 44: Breakdown of embodied carbon of average OFFICE by specific building elements as defined by Level(s) (manual 2, Table 11

Although the average of the reported assessments was 931kgCO$_2$e/m^2, owing to data availability no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 1,418kgCO$_2$e/m^2, an uplift of 34%.

5.5.6 Warehouse

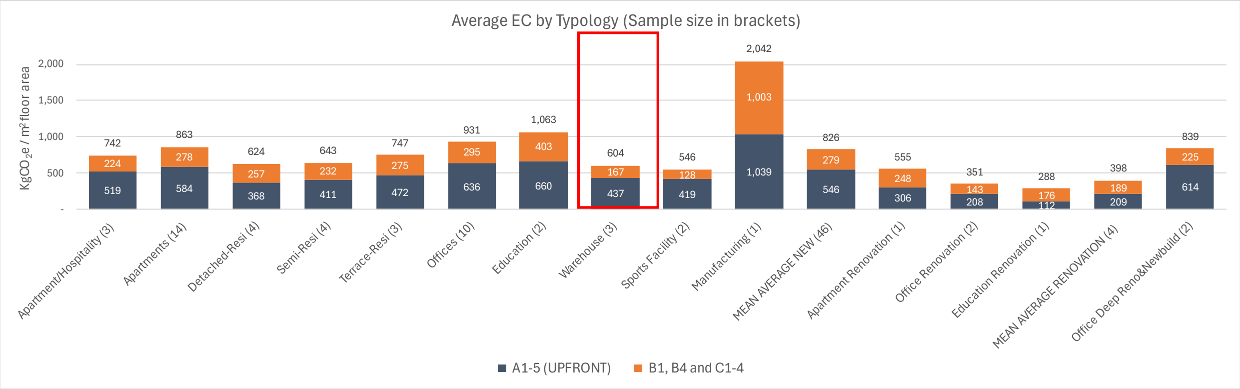


Figure 45: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.6.1 Variation

The warehouse assessments included a single storey steel frame and blockwork building with no heating systems and a 2 storey in-situ RC concrete and steel structure including heating system.

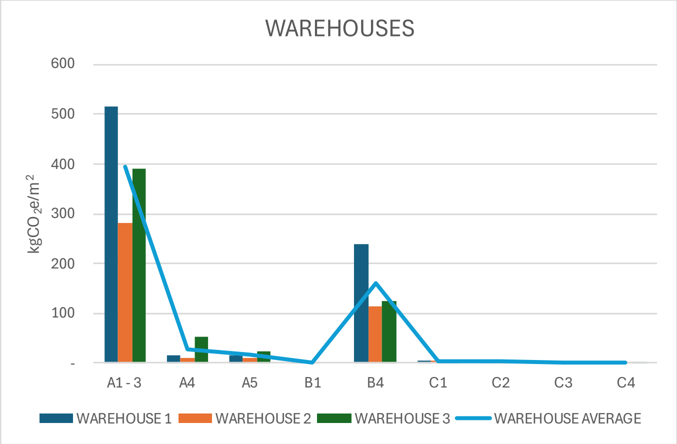


Figure 46: WAREHOUSE case studies and the mean average

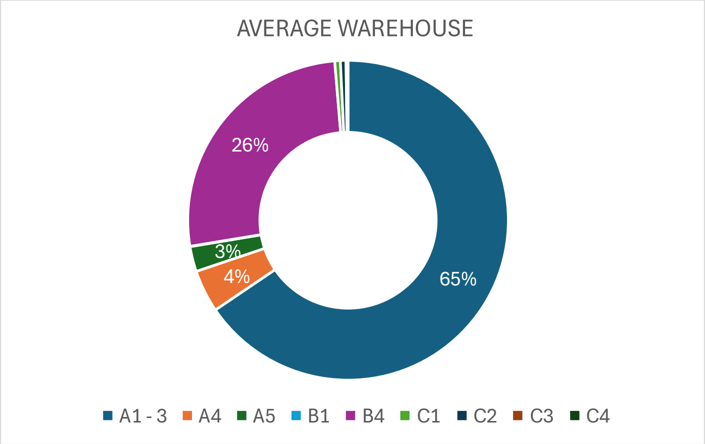


Figure 47: Distribution of EC across the life cycle (WAREHOUSES)

5.5.6.2 Results

Overall average WLEC was $604kgCO_2e/m^2$. Because of the simpler designs with fewer components likely to need replacement, more of the EC is contained in the upfront stage. 72% of all material related emissions occur in stages A1-5. This is the highest of any of our average models so far, owing to the simplicity of designs and fewer elements requiring replacement during the useful phase of the lifecycle.

5.5.6.3 Level 1 and Level 2 scope elements

Figure 48 tells us that the superstructure is typically the largest contributor, followed by the facade and fittings. The structure breaks down in Figure 49 to $233kgCO_2e/m^2$ in the frame and a further 72 in the external wall itself. External wall cladding systems (facades) add a further 146 but it should be noted that facade calculation is based on a sample size of 1 since WAREHOUSES 1 and 2 contained all of the external wall in the structure (i.e. no facade was present). This emphasizes a need for a clearer classification system of elements – the current system relies on descriptions of elements which can often serve more than one function in the building so attributing materials can be subjective.

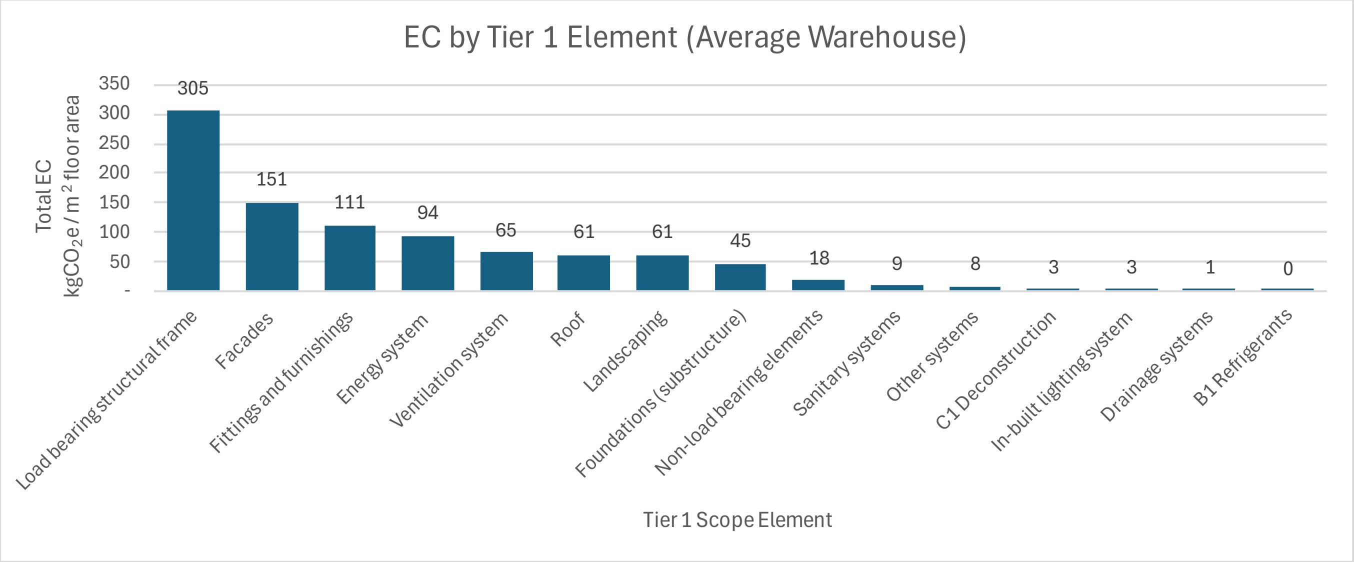


Figure 48: Breakdown of embodied carbon of average WAREHOUSE by building part as defined by Level(s) (manual 2, Table 11)

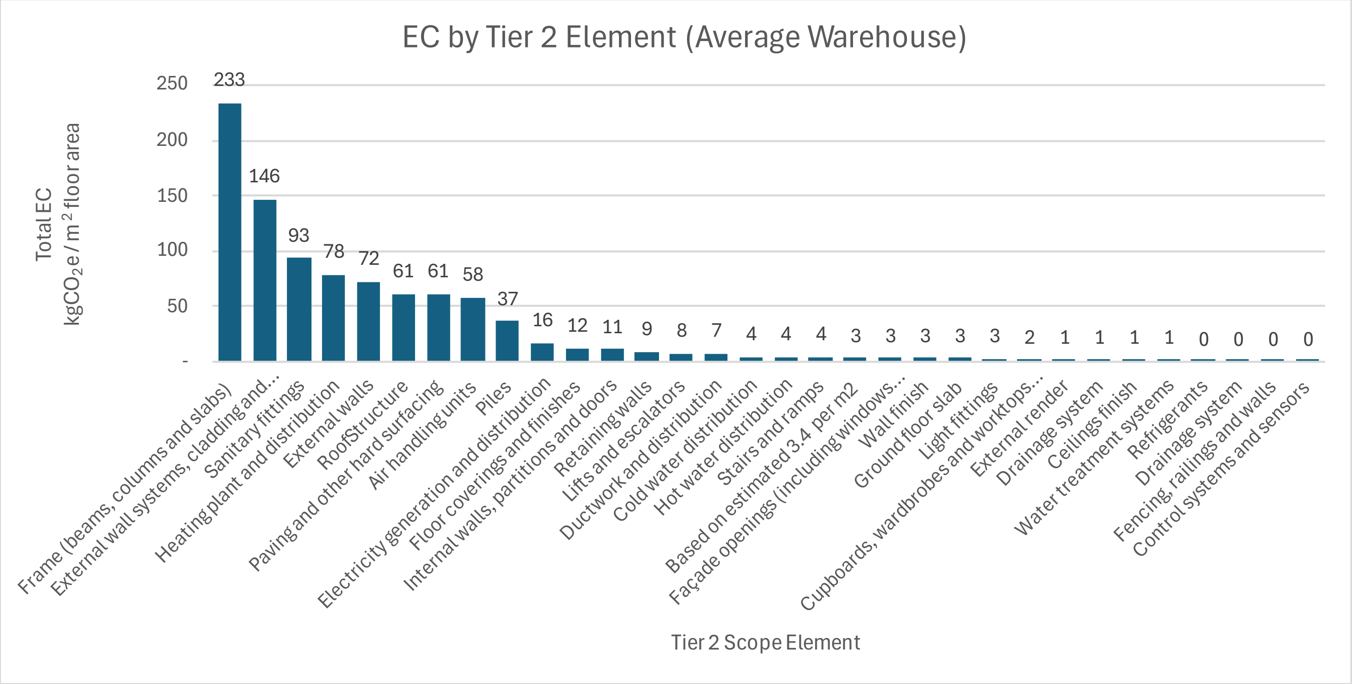


Figure 49: Breakdown of embodied carbon of average WAREHOUSE by specific building elements as defined by Level(s) manual 2, Table 11

Although the average of the reported assessments was 604kgCO$_2$e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 936kgCO$_2$e/m^2, an uplift of 35%.

5.5.7 Education (Schools)

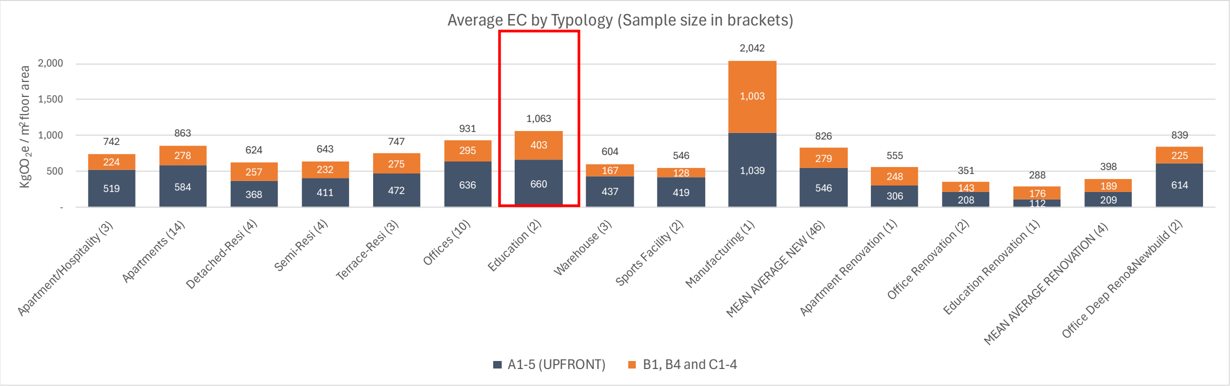
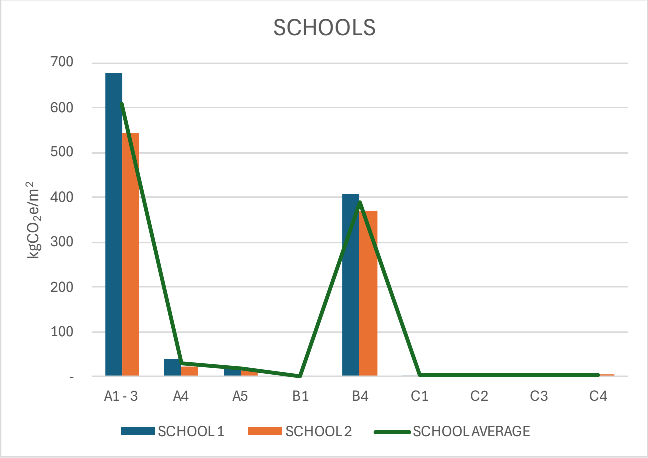


Figure 50: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.7.1 Variation

The assessment has been applied to two schools – an in-situ RC frame with precast slabs and a steel frame with a mixture of hollowcore precast and in-situ slabs.



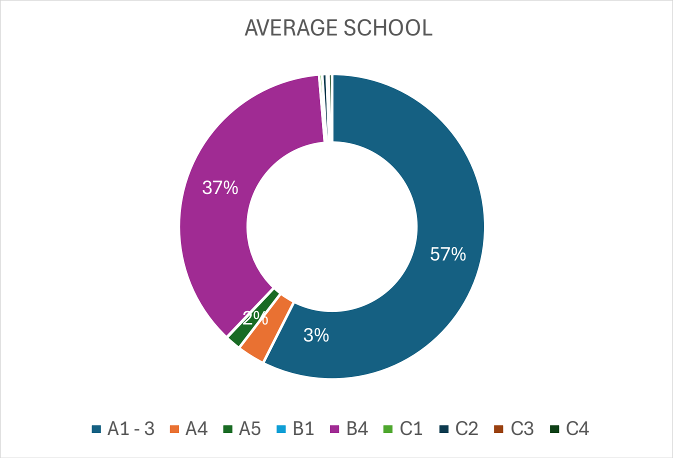


Figure 51: Carbon profile of the SCHOOL case study

Figure 52: Distribution of EC across the life cycle (SCHOOL)

5.5.7.2 Results

Overall average WLEC was 1,063kgCO₂e/m^2. 62% of this was upfront in material manufacture, transportation and construction (A1-5).

5.5.7.3 Level 1 and Level 2 scope elements

As in most cases, the substructure and superstructures are the largest contributor to the embodied carbon. In one of these cases the building also required a significant amount of piling, resulting in a significant EC hotspot below ground, emphasizing the importance of site selection to minimise support materials need. The Tier 2 analysis shows the EC in the piling was the largest single hotspot, greater than the structural frame in the case where it was required.

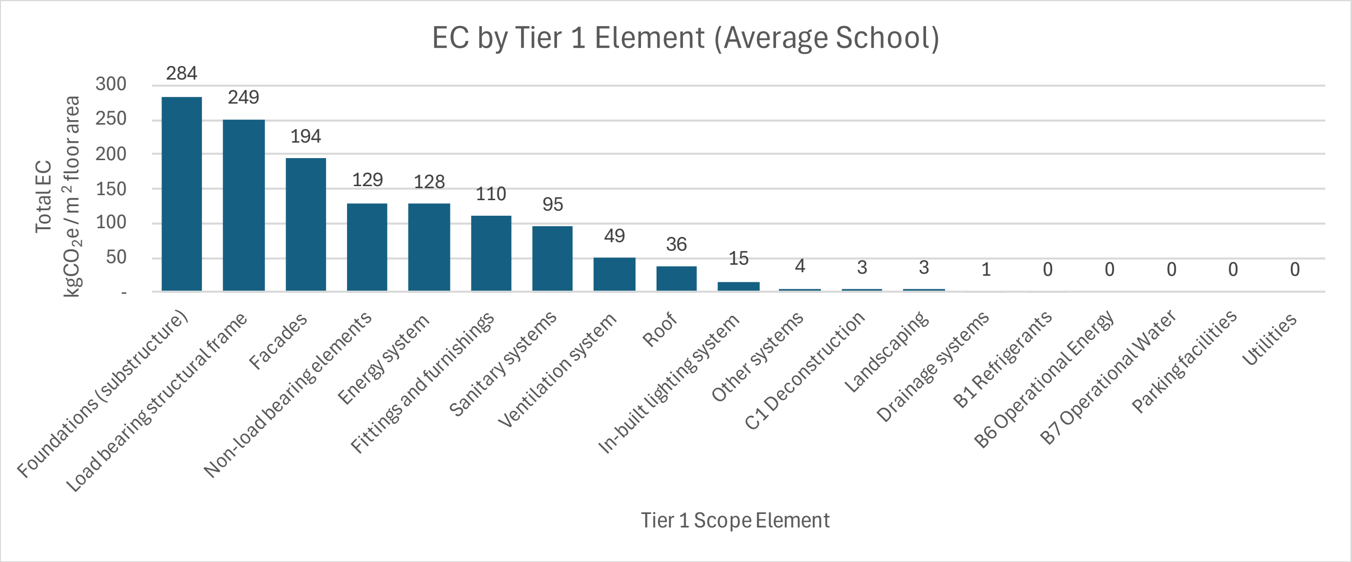


Figure 53: Breakdown of embodied carbon of the SCHOOL assessment by building part as defined by Level(s) (manual 2, Table 11)

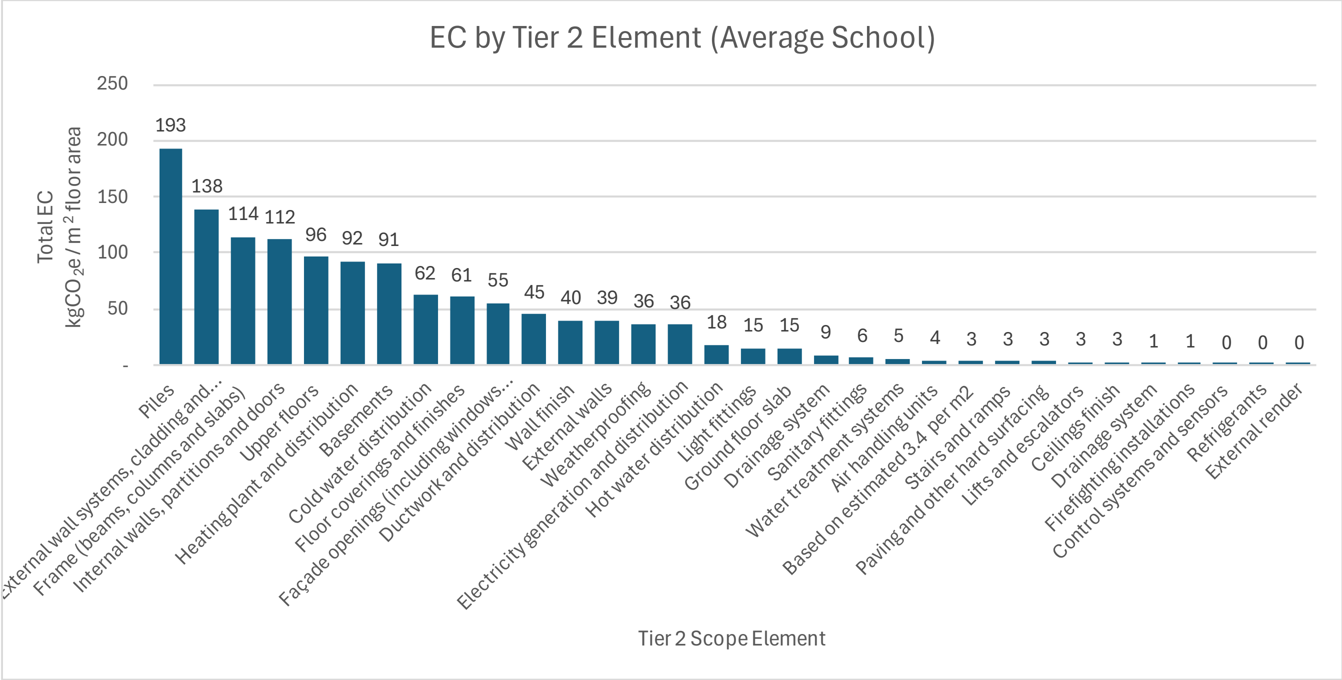


Figure 54: Breakdown of embodied carbon of the SCHOOL assessment by specific building elements as defined by Level(s) manual 2, Table

Although the average of the reported assessments was 1,063kgCO_2e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 1,302kgCO_2e/m^2, an uplift of 18%.

5.5.8 Manufacturing Plant

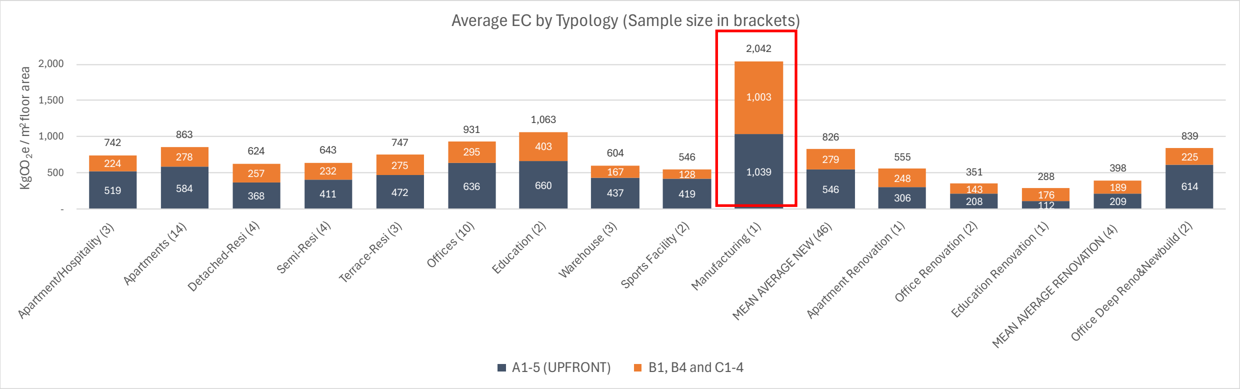


Figure 55: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.8.1 Variation

The single manufacturing plant assessment is a steel framed 5 storey building on concrete piling with concrete slabs. There is extensive pipe racks, platforms and secondary support structures.

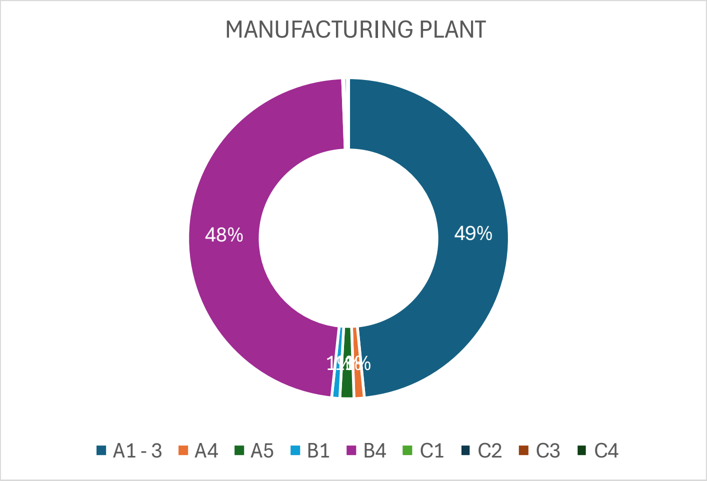


Figure 56: Carbon profile of the PLANT case study

Figure 57: Distribution of EC across the life cycle (PLANT)

5.5.8.2 Results

Overall WLEC was 2,042kgCO$_2$e/m^2. This was the highest result of any of our case studies. The result is divided evenly between the upfront A1-5 and the replacement cycles of B4. Extensive energy and ventilation services have increased both the upfront and replacement carbon.

5.5.8.3 Level 1 and Level 2 scope elements

Owing to the assumption that there will be two replacement cycles of many MEP elements over a 50 year period, the heating and distribution systems are large contributors. These inputs account for a third of the upfront carbon but more than half of the B4 replacement cycles carbon (the roof and stairs/ramps are assumed to have one replacement cycle in the building's lifetime.

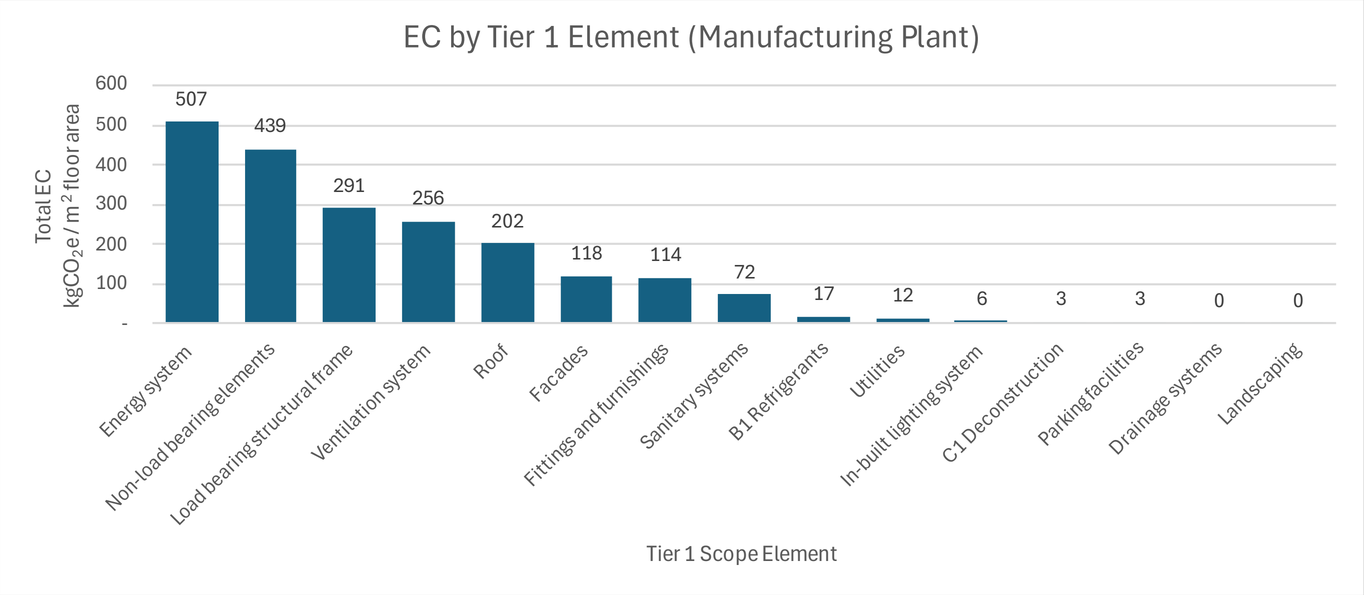


Figure 58: Breakdown of embodied carbon of the PLANT assessment by building part as defined by Level(s) (manual 2, Table 11)

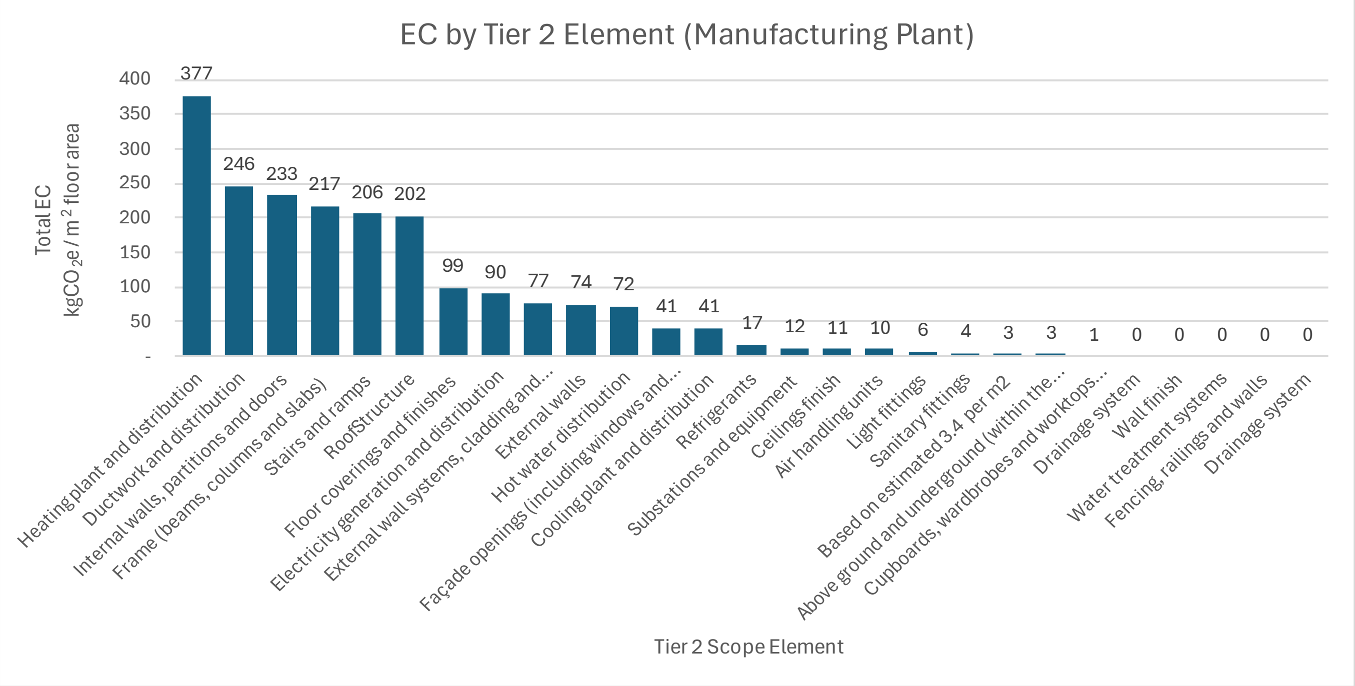


Figure 59: Breakdown of embodied carbon of the PLANT assessment by specific building elements as defined by Level(s) manual 2, Table 11

More case studies are required to determine averages per element for manufacturing plants.

5.5.9 Hospitality / Apartment hotel

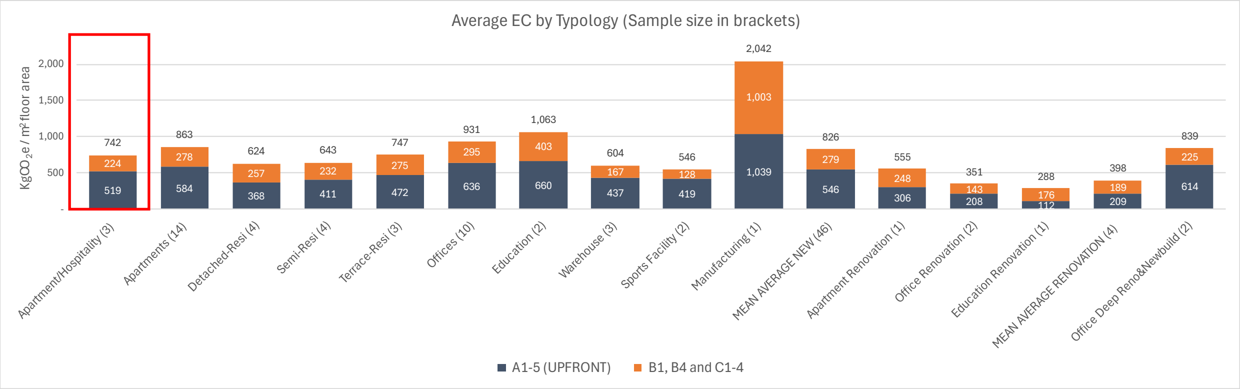


Figure 60: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.9.1 Variation

The three case studies included a halls of residence, a short term serviced studios block and a care home.

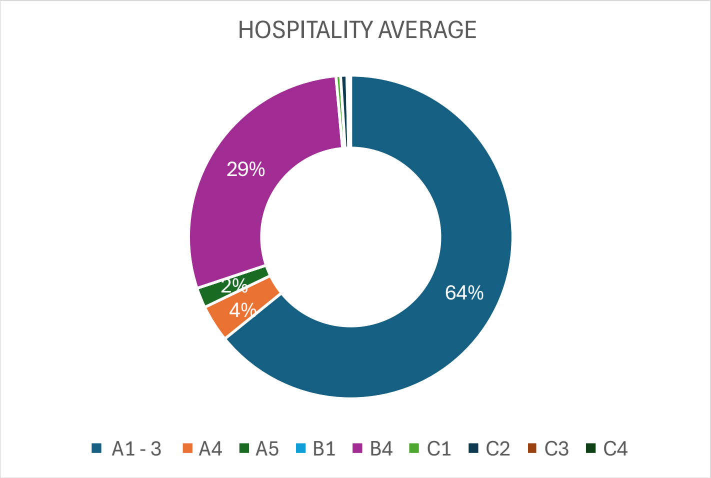


Figure 61: Carbon profile of the PLANT case study

Figure 62: Distribution of EC across the life cycle (PLANT)

5.5.9.2 Results

Overall WLEC was 742 kgCO$_2$e/m^2. This was lower than the apartment blocks but the sample size is considerably smaller. The upfront proportion of emissions was found to be very similar at 70%.

5.5.9.3 Level 1 and Level 2 scope elements

Interestingly, one of the assessments includes a significant mass for lifts – 59 tonnes. As the MEP calculation is based on CIBSE TM65 estimates and Level(s) guidance on replacement cycles, this has resulted in the lift system being the most carbon intensive element of the building over its lifetime, as it is assumed there will be two replacement cycles over the 50 years. Over the course of the project we have found MEP data to be the most difficult to obtain as building design and MEP design are usually carried out by separate teams and there is no single data repository.

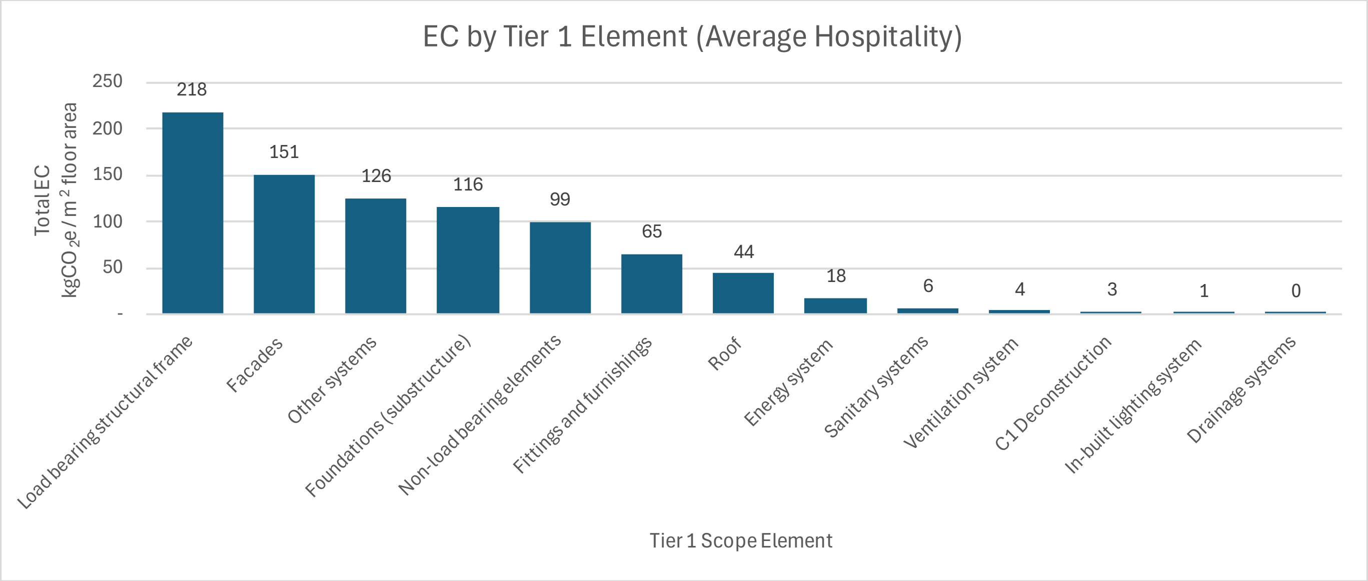


Figure 63: Breakdown of embodied carbon of the HOSPITALITY assessment by building part as defined by Level(s) (manual 2, Table 11)

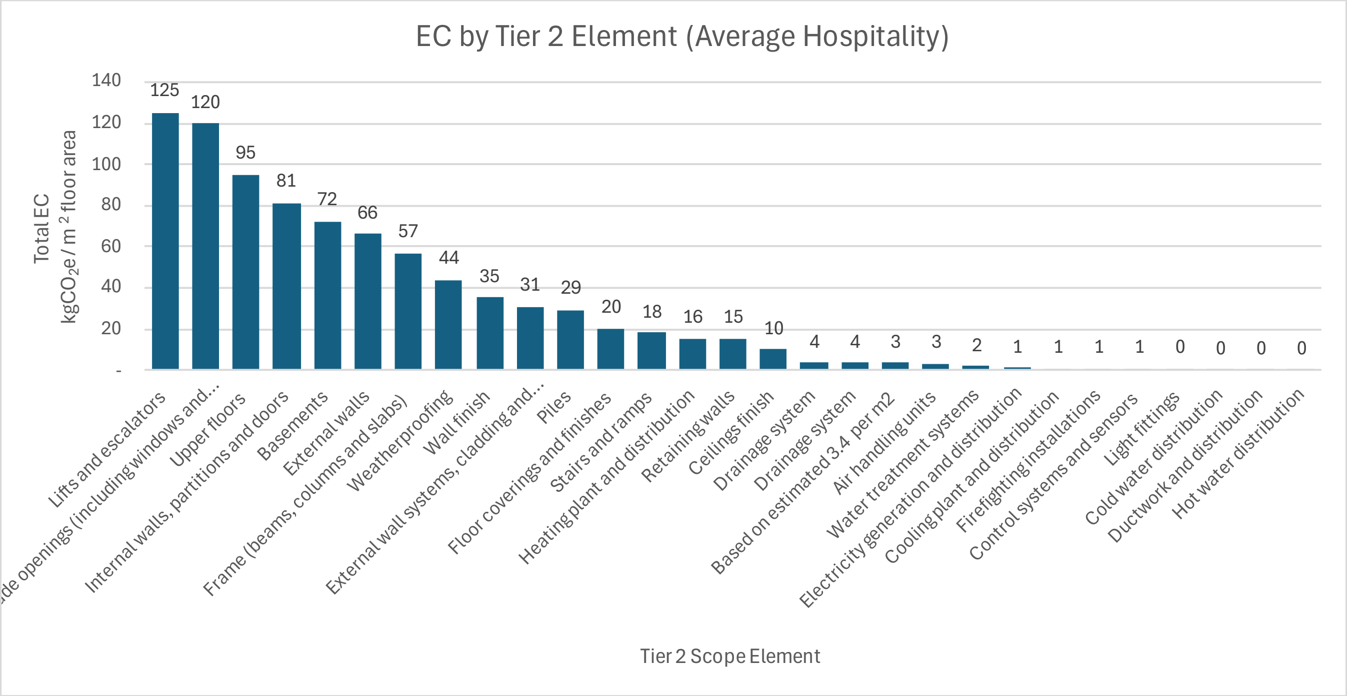


Figure 64: Breakdown of embodied carbon of the HOSPITALITY assessment by specific building elements defined by Level(s) manual 2, Table 11

Although the average of the reported assessments was 742kgCO$_2$e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that was reported across the assessments is summed the total is 852kgCO$_2$e/m^2, an uplift of 13%.

5.5.10 Sports facilities

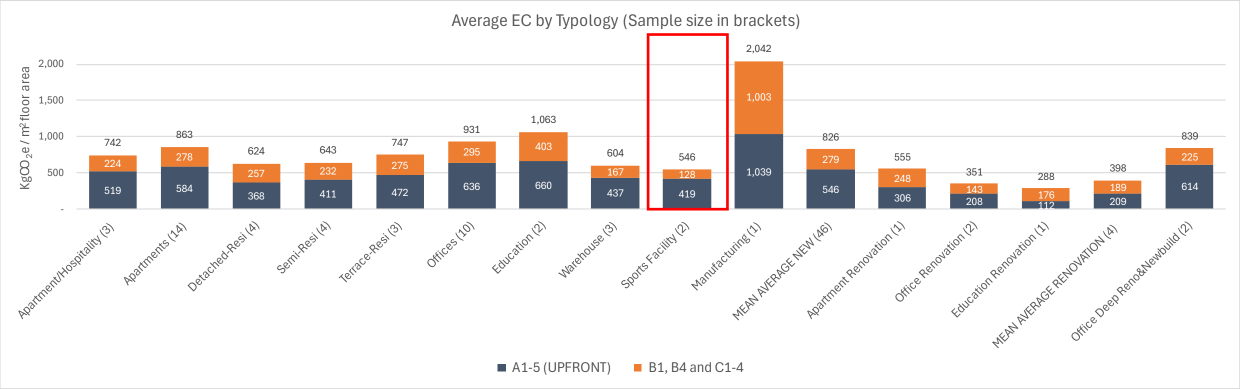


Figure 65: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.10.1 Variation

Unlike the rest of the case studies, the two sports facilities that were offered to the project were designed with EC as a consideration, including a CLT structure in one of the case studies, the other being optimised concrete and steel.

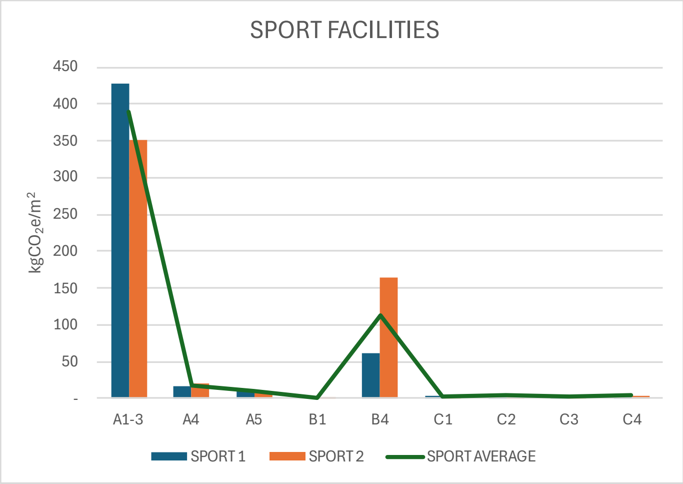


Figure 66: Carbon profile of the SPORT FACILITY case studies

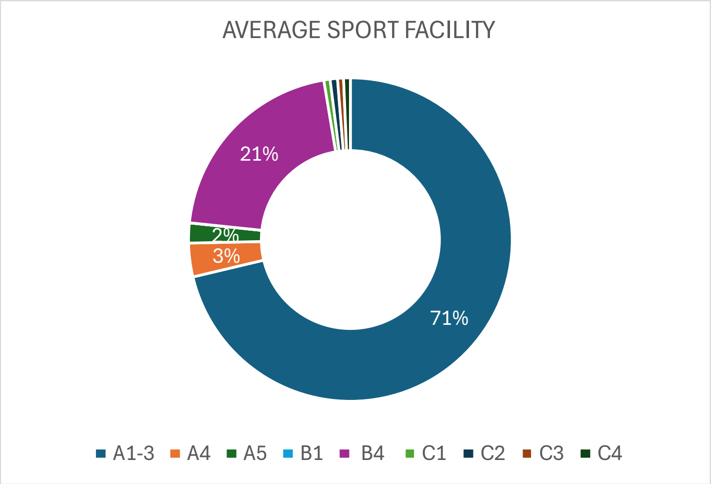


Figure 67: Distribution of EC across the life cycle (AVERAGE SPORT)

5.5.10.2 Results

Overall WLEC was 546kgCO$_2$e/m^2. This was the lowest result of any of our case studies. The result is weighted towards upfront emissions as few materials were allocated to elements that would require replacement in the CLT building.

5.5.10.3 Level 1 and Level 2 scope elements

One element that would need replacing in the concrete and steel building was the flooring. As this is a specialist building with a complex floor build up that may need replacements over the lifetime of the building this has resulted in it being the highest contributing element when considered over a fifty year period.

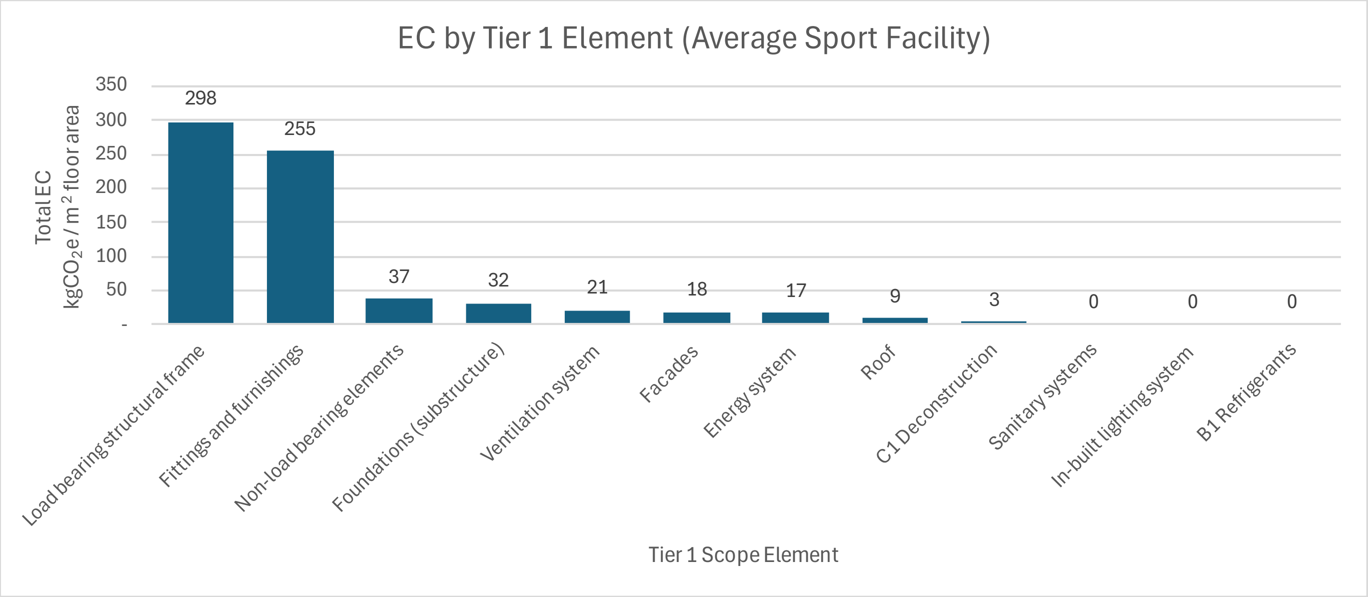


Figure 68: Breakdown of embodied carbon of the average SPORT assessments by building part as defined by Level(s) (manual 2, Table 11)

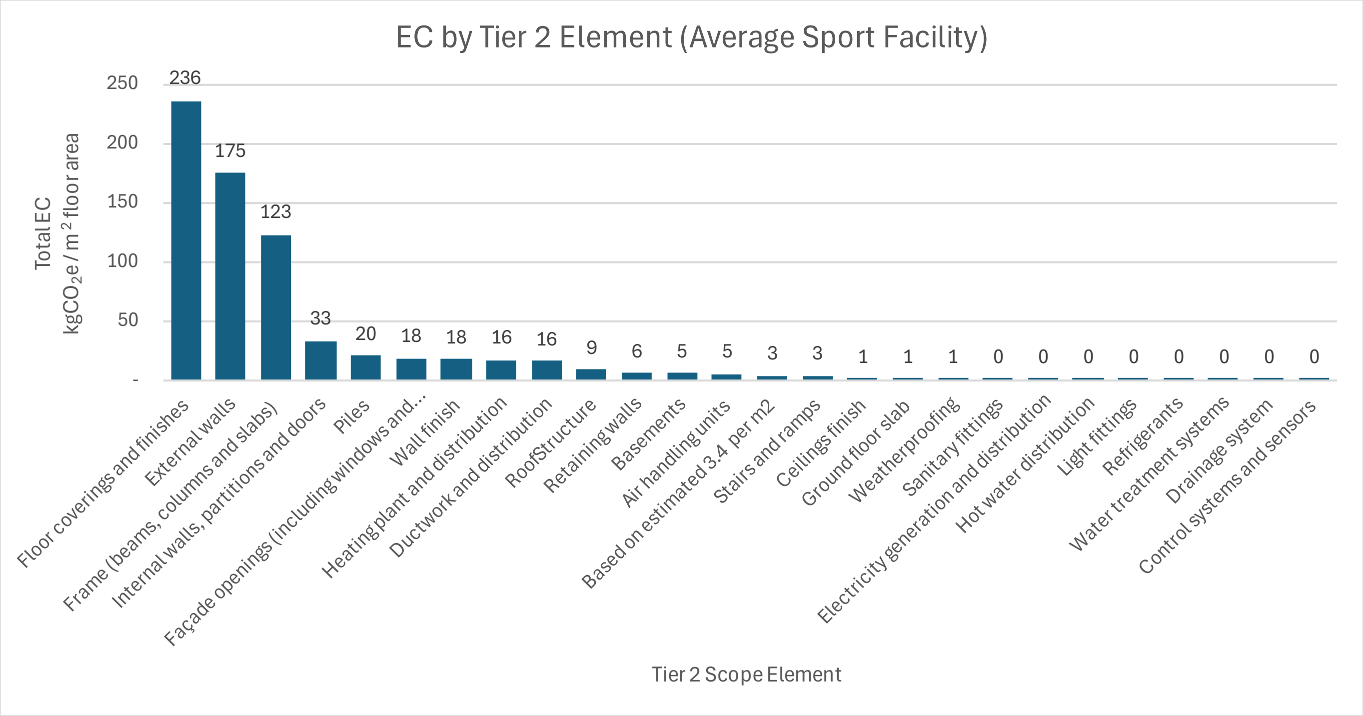


Figure 69: Breakdown of embodied carbon of the SPORT assessments by specific building elements as defined by Level(s) manual 2, Table 11

Although the average of the reported assessments was 546kgCO_2e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that was reported across the assessments is summed the total is 689kgCO_2e/m^2, an uplift of 20%. This very small sample size includes specialist buildings however, so should be treated with considerable caution.

5.5.11 Refurbishment

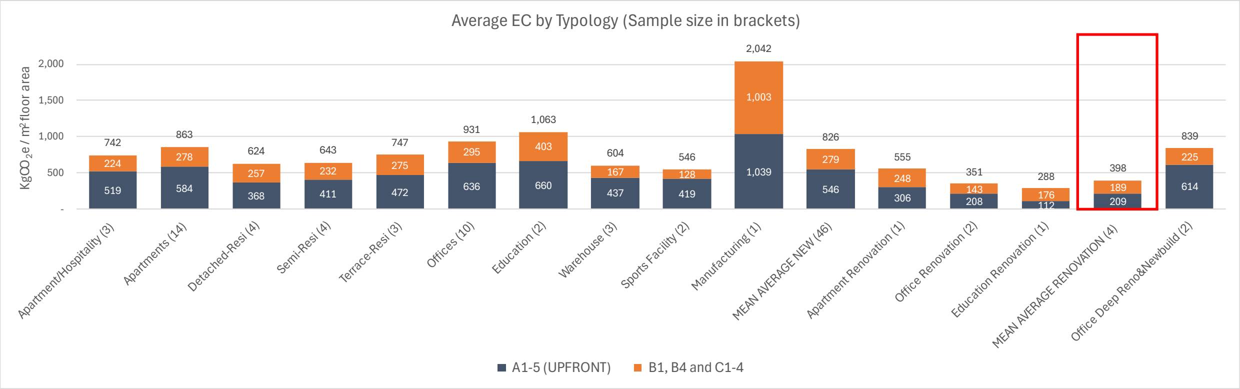


Figure 70: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.11.1 Variation

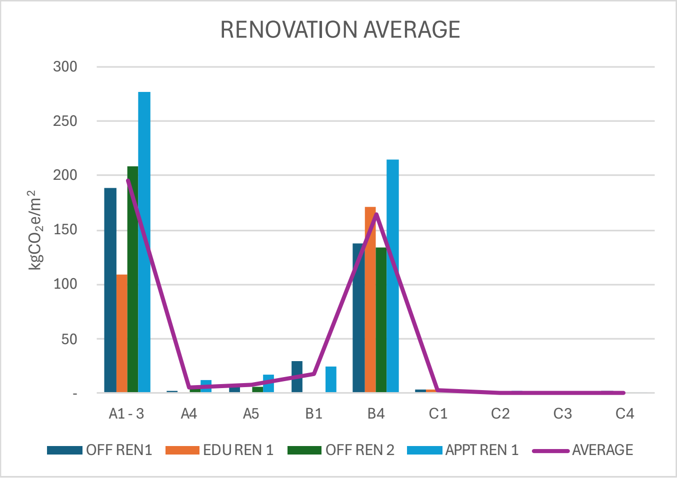
Four refurbishment projects were also assessed – a two-storey concrete and steel school and a fabric first approach to improving energy management in a warehouse office.

5.5.11.2 Results

Overall average WLEC was 398kgCO$_2$e/m^2. This was made up of an average of 209kg in the first refurbishment (A1 to 5) and almost the same again in the future as virtually all refurb elements are assumed to need updating at least once in a 50 year period. The remainder is primarily due to refrigerant leakage over the building lifetime(B1) – in newbuild this figure is usually overlooked as it is obscured by the larger elements. Overall, the average is around one third of the WLEC of newbuild schools and offices. Table 14 shows the reductions in CO2 emissions and material demand (in kg) compared to new-build apartments, offices and schools. The A1-5 is the greatest saving as the assumed future replacement rates would be similar for newbuild and renovation.

Table 14 Difference in renovation and newbuild of the typologies assessed so far (sample size of newbuilds in brackets)

	A1-5	WLC	Mass
Apartments (14)	64%	54%	85%
Offices (10)	67%	57%	86%
Education (2)	68%	63%	83%



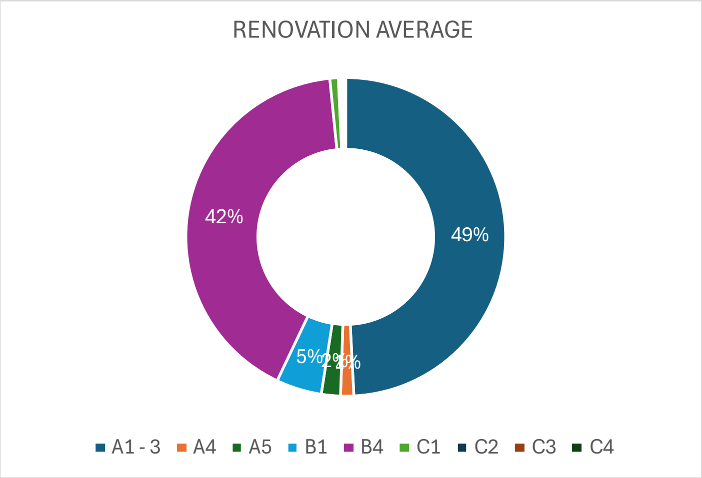


Figure 71: REFURB case studies and the mean average

Figure 72: Distribution of EC across the life cycle (REFURB) stages

5.5.11.3 Level 1 and Level 2 scope elements

No substructure and only small superstructure changes were present. The removal and reduction of these two hotspots means there is significantly less CO$_2$e associated with the manufacturing of materials and therefore the projects as a whole when compared with newbuild. The internal remodelling of walls, external walls and the installation of heating systems are the primary contributors.

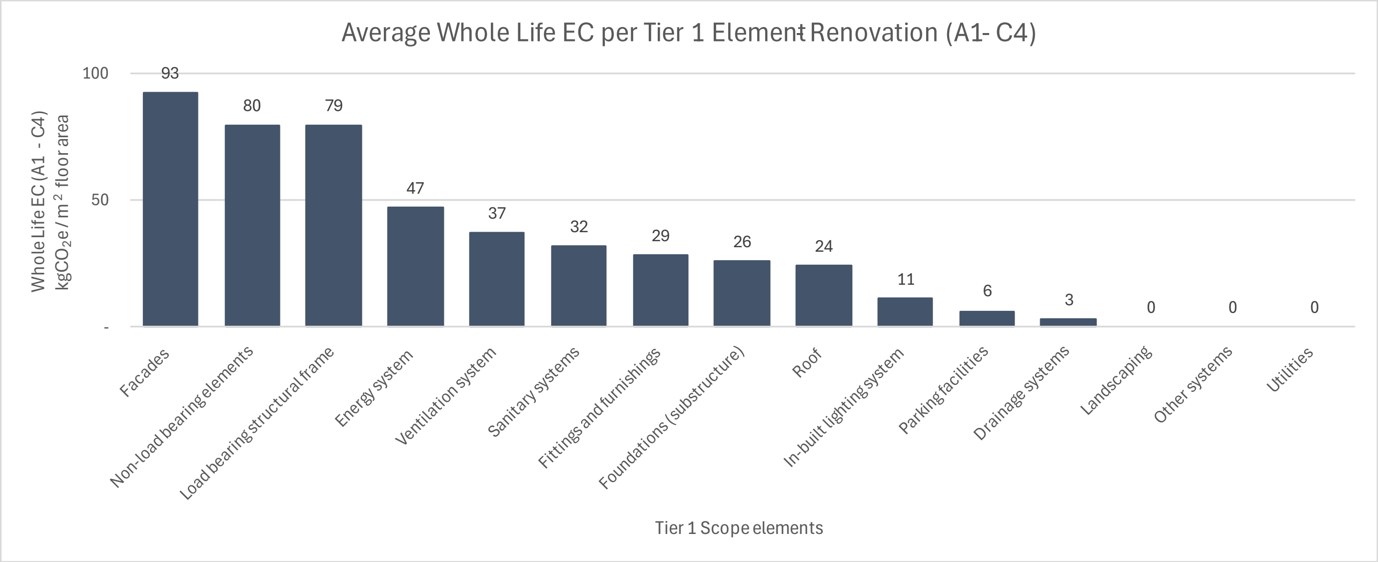


Figure 73: Breakdown of embodied carbon of the REFURBISHMENT assessment by building part as defined by Level(s) (manual 2, Table 11)

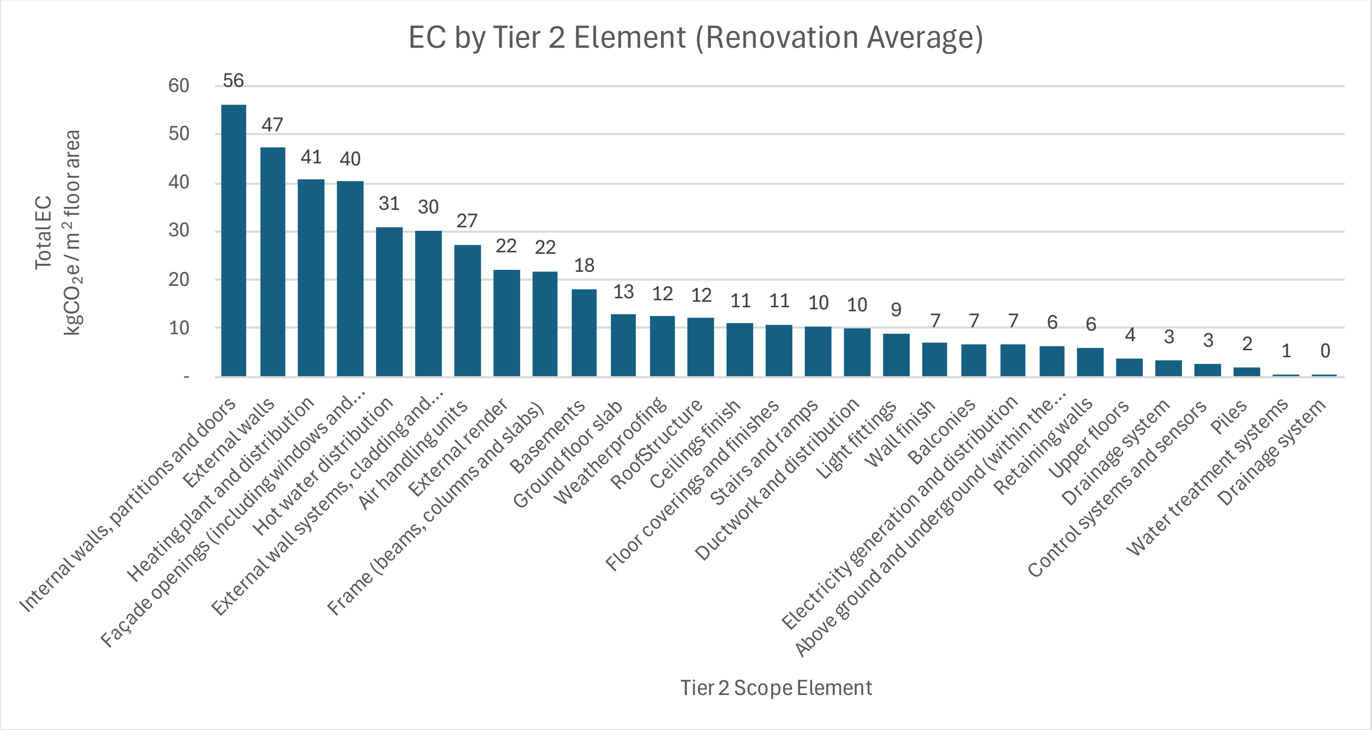


Figure 74: Breakdown of embodied carbon of the REFURBISHMENT assessment by specific building elements as defined by Level(s) manual 2, Table 11

Although the average of the reported assessments was 398kgCO_2e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 499kgCO_2e/m^2, an uplift of 20%.

5.5.12 Renovation/Newbuild Hybrid

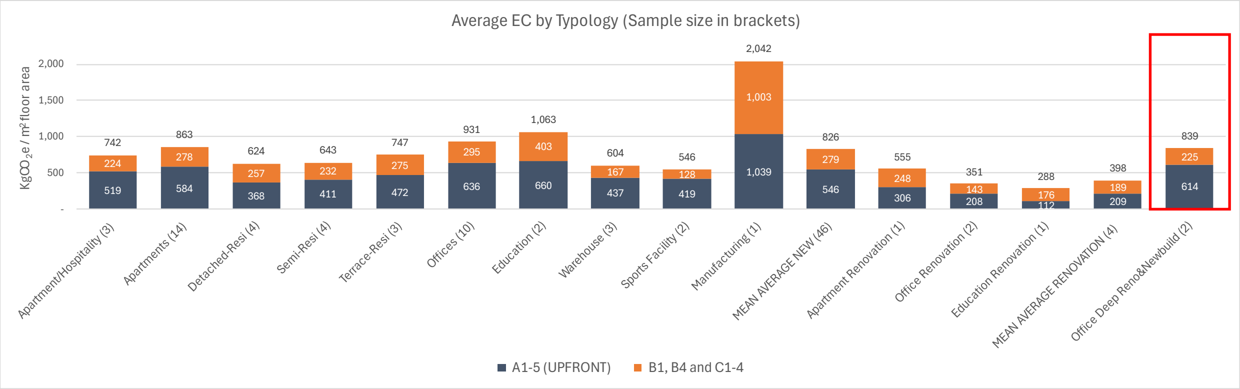


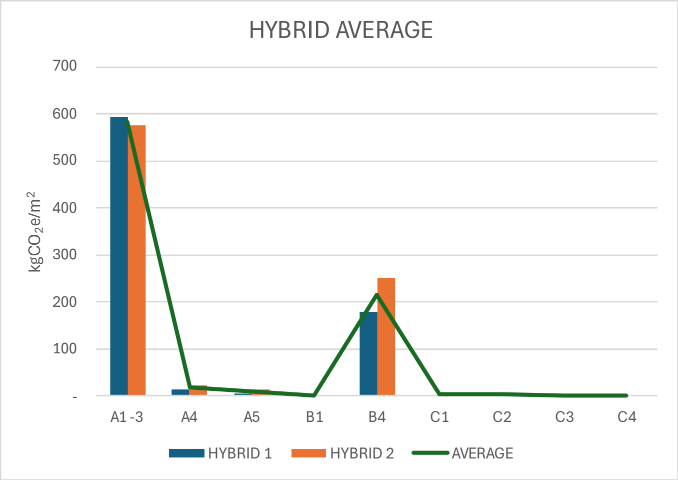
Figure 75: Average upfront and whole life embodied carbon of buildings by typology as assessed using the methodology (n=sample size).

5.5.12.1 Variation

Two refurbishment / newbuild hybrids projects were also assessed – both were office buildings in Dublin.

5.5.12.2 Results

Overall average WLEC was 839kgCO₂e/m². 73% of this was ‘upfront’ (A1-5).



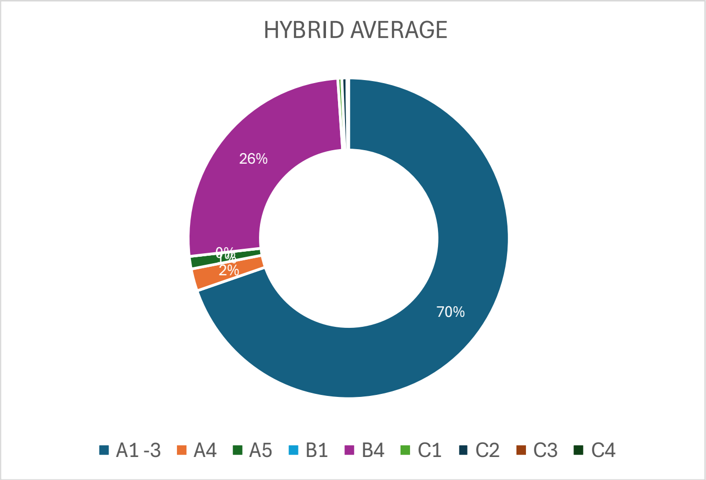


Figure 76: REFURB case studies and the mean average

Figure 77: Distribution of EC across the life cycle (REFURB) stages

5.5.12.3 Level 1 and Level 2 scope elements

There was a significant steel structure addition in one of the assessments, causing the uplift in the result by element below. Excluding this, the hotspots are similar to renovation;

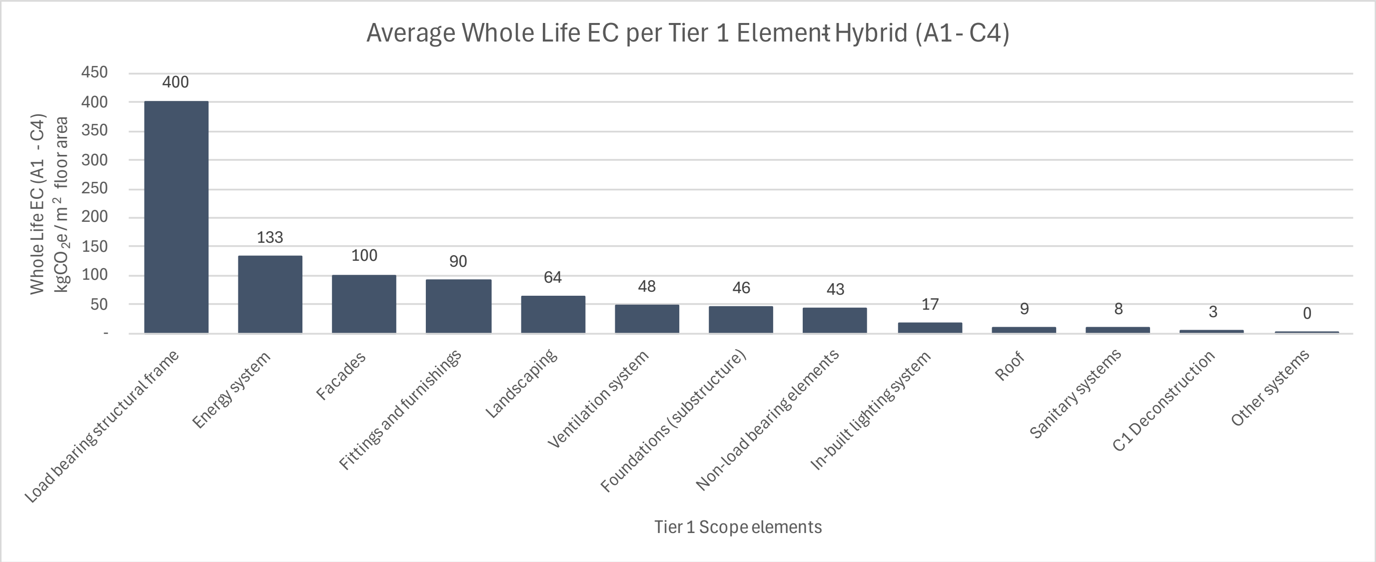


Figure 78: Breakdown of embodied carbon of the REFURBISHMENT assessment by building part as defined by Level(s) (manual 2, Table 11)

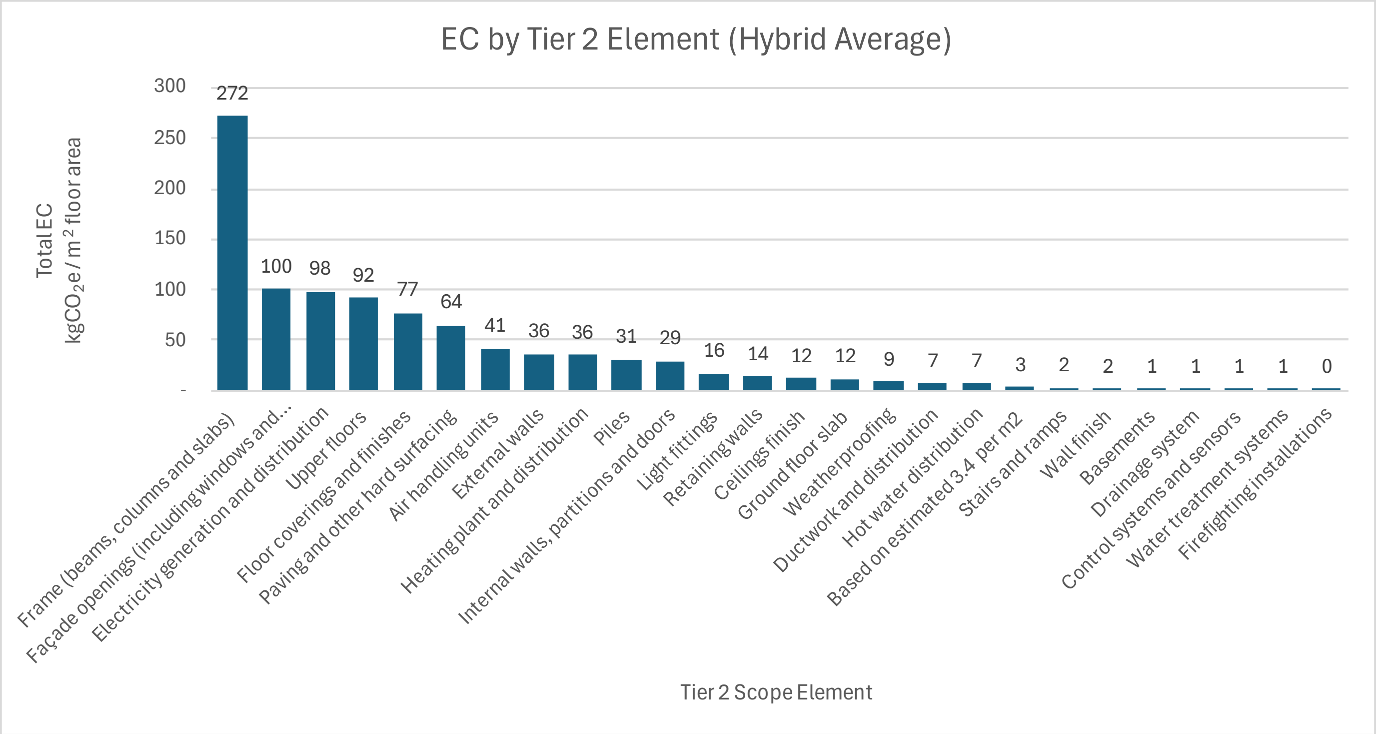


Figure 79: Breakdown of embodied carbon of the REFURBISHMENT assessment by specific building elements as defined by Level(s) manual 2, Table 11

Two buildings involved renovation and new-build. Although the average of the reported assessments was 839 kgCO$_2$e/m^2, owing to data availability, no one assessment reported on the full scope as defined by Level(s). If the average for each element that *was* reported across the assessments is summed the total is 963kgCO$_2$e/m^2, an uplift of 13%.

3.8 Limitations

This report presented the results of the first set of buildings evaluated using a known and consistent method for assessing the lifecycle carbon of buildings in Ireland today. The buildings were selected because they were standard, not particularly ‘green’. A sample of 52 new-build, renovation and hybrid buildings have been considered. This sample size is reasonable when considered as a whole but still very small when broken down by typology. A building assessed using the same methodology could be compared and contrasted to these results (when the sample size is increased) to understand how it performs compared to the mean average in Ireland today. Although as much guidance as possible was provided, the above assessments have been carried out unsupervised by a variety of volunteer participants, some were paid to cover the time required to gather data on all elements, others did so because they recognise the importance of the topic.

The resulting assessments were screened for plausibility and completeness without reference to original drawings, invoices etc. making the completeness difficult to judge. Plausibility was considered by dividing the total mass of materials by the floor area, and any ‘lightweight’ buildings were questioned and if necessary, rejected as probably/possibly incomplete. None of the assessments was judged to have provided data on every element as stipulated in the scope for three reasons: not every element in the scope is present in every building, in some cases a material performs more than one role in a building and thirdly there was a question of data availability – some elements were just unknown. Whole Life Carbon Assessment is much easier to perform when it is known to be a requirement at the beginning of a project so that data can be provided and organised as the project develops. Trying to gather data ex-post is a harder exercise than in parallel with a project’s development. In reality it is likely that scores may increase as more data becomes available and the method of tracking evolves.

The relatively small sample size is also a problem; although together there was a sample of fifty-two, none of the typologies numbered more than fourteen in sample size. Adding this limitation to the fact that there may be missing data for some elements in some assessments reduces the reliability of the result; the results should be viewed as indicative until the sample sizes increase to build confidence. Adding more assessments to the database of results should allow for more reliable averages for each element to be calculated.

4. Conclusions

From the analysis presented above, the following conclusions can be drawn:

Whole life embodied carbon baseline: For residential buildings the baseline for whole lifecycle embodied carbon emissions ranges from around 620 to 860 kg CO_2e/m^2. For non-residential the figure can range from around 550 to over 2,000 kg CO_2e/m^2 – the result can vary greatly depending on the building type. The mean average value of 826 kg CO_2e/m^2 was established for all the building types assessed so far.

Owing to the pre-existence of structural frames and substructures, refurbishment will usually result in lower EC than new-build. Our assessments taken as a whole indicate that emissions are reduced by around 60-70%**.**

An average of 65% of the EC associated with a new-build is emitted before the building is complete, the great majority of this occurring at the materials manufacturing stage (A1-3). This shows that the next area to look at after operational energy emissions is product manufacturing emissions – this will result in a greater impact on overall emissions than focussing on material transport, site construction or deconstruction.

In all newbuild cases except the specialist manufacturing plant and a specific sports facility, the largest contributor to upfront emissions was the manufacture of the structural frame, which was either concrete or steel in all but one case. This element offers the greatest scope for reducing emissions by considering reductions in mass and/or switching to lower carbon intensity materials.

Embodied carbon per m^2 may not always be the best metric. Our case studies have found that one off housing can produce a lower score per m^2 but the total for a detached house was more than double that of a semi-detached owing to the less efficient use of space. In residential measurements measuring per occupant or per bed space would be more useful. Similarly in offices or hospitality settings, per user or occupant may be more relevant. In all cases, the most important figure is the total, and not the per m^2 figure.

Following the analysis, recommendations are as follows:

- Raise the profile of embodied carbon among building designers. WLC Assessments will be mandatory for buildings over 1,000m^2 in 2028 so learning today will ensure preparedness.
- Encourage manufacturing emissions data from manufacturers – 97% of the mass in these assessments has been linked to generic carbon factors rather than specific EPD data. This is mainly because these studies were carried out ex-post and so EPD data was not considered during the design, but also because manufacturers usually do not supply EPD data with materials anyway, and designers do not ask. Recent updates to the EU CPR mean EPD data will be mandatory soon and this should be highlighted to both the supply and demand sides of industry in order to stimulate interest as soon as possible.
- Set ambitious targets based on the above findings and demonstrate how they can be achieved by addressing the largest hotspots first.

- Create transparency at every level, driving down emissions in manufacturing processes.
- Review the current Agrément system which can be slow and costly for bringing new products to market, particularly for smaller manufacturers and MMC products entering the market.

5. Next Steps and Future Development

Following the research presented in this report, future work required is detailed in Table 15 across five themes

Table 15: Future Work Recommendations

Theme	Future work
Consult with industry on addressing surrounding data including data availability, data quality, data comparability and data representativeness.	More studies are needed to build confidence in results. The background generic carbon footprint of production of materials (A1-3) should be verified and figures agreed in consultation with industry. A safety margin should also be considered to ensure that products being used in reality are not actually poorer in performance than the generic average backstop. It could be considered that the poorest performing materials are used as the backstop to encourage the issuance of EPD data by manufacturers and use of better performing materials by the market. The methodology relies heavily on assumptions for many modules. Although numerous studies have concluded that the A1-3 and B6 modules are the largest contributors to emissions, all modules make some contribution, and when scaled up to a national level they can be significant, therefore further research into transport, on-site activities and deconstruction should help improve accuracy for A4, A5, B4 and C1-4. Mechanical, Electrical and Plumbing systems are thought to be significant contributors owing to their material composition (metals and plastics), their energy intensive assembly and their complex supply chains. Their relatively short service life means multiple replacement cycles also. Further research and data from manufacturers would be welcome. A verification system needs to be introduced. Owing to the limited resource of this project, verifying assessments has been cursory. The database above should provide mean averages and trends – outliers can be examined in more detail via a checklist. Such a checklist has been developed but it was not implemented on this project due to resource constraints and the voluntary nature of participation.
Develop database for WLC assessments and background data.	A database to store information is needed. This should provide hosting for both background data and assumptions used in the methodology, and results from live projects. In this way assessments can be analysed and monitored for hotspots and trends, and updated in bulk as research evolves – for example, the current estimate of MEP EC is an estimate as

	guided by CIBSE TM65 but new, more accurate measurement should emerge over the next few years – a bulk update to all assessments would then improve accuracy and maintain a level playing field. The new Building Embodied Carbon Database (BECD) hosted by the RICS in the UK is a good example (https://carbon.becd.co.uk/)
Harmonise reporting to improve comparability and consistency.	As ICMS3 is becoming a requirement in the CWMF, its role should be considered. Level(s) is currently being updated to provide a mapping of building elements to ICMS, which should mean WLC assessment can be linked to costing, ensuring better completeness tracking and possibly promoting the cost savings that can be achieved by reducing material and energy demand over time.
Make CLAP methodology interoperable with digital tools/software.	The methodology would benefit from BIM integration. Performing assessments as early as possible will mean interventions can be made when they will have the greatest impact. There is little point assessing a building after it is built as very little can then be done to improve the result. Adding data to IFC properties in BIM models and extracting data to a PowerBI dashboard looks like the most promising way to go. It could automate results, making them available as a design evolves and therefore being of greater influence on design decisions. Integration into tools, particularly early stage tools such as OneclickLCA CarbonDesigner, Preoptima and Eccolab is essential to communicate benefits of particular design approaches at early stages. An open-source free integration of the methodology into BlenderBIM is also recommended as an area to explore and develop.
Increase awareness of LCA and embodied carbon throughout construction industry.	A general upskilling and roll out plan is needed. Awareness of the embodied carbon concept in Ireland is now reasonably high as the IGBC has been running courses for the last three years but detailed knowledge remains relatively low while there is no imperative to consider it in design. A single clear methodology and manual would help ensure practitioners are all aligned in their work. The RICS in the UK recently updated their WLC Assessment guidance – it is more comprehensive than Level(s) and could form a starting point for answering many of the questions WLC Assessment poses. Alternatively, Nordic Sustainable Construction, set up by the Nordic Council of Ministers, is working to ensure WLC Assessments are consistent across the Nordic region. Aligning with this organisation could mean access to research and development that Ireland alone is not currently doing.

Acknowledgements

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[12]