Sustainability Guide 01

An Introduction to Sustainability in Façades

CENTRE FOR WINDOW AND CLADDING TECHNOLOGY

1.0 Introduction

The Brundtland Commission[1] defined sustainable development as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*'.

Sustainability is a broad topic encompassing environmental issues such as greenhouse gas emissions, the use of water and other resources, the treatment of waste and many other social and economic factors.

This document is the first in a series of Sustainability Guides outlining the issue of sustainability within the façade industry with a focus on greenhouse gas (GHG) emissions.

A selection of key definitions has been provided at the end of the document to aid the reader.

1.1 Climate Emergency

Many countries and organisations have now recognised that we are in a climate emergency and have made public declarations to that effect. Earth's climate is undergoing a period of intense change, and that humankind is at least in part driving this change through environmental engineering, intentional or otherwise.

Moreover, humankind will have to learn to deal with the consequences of climate change, and there is growing scientific evidence that if we moderate certain aspects of our behaviour we can at least slow the pace of climate change, halting and perhaps even reversing some of the less pleasant consequences.

The background to the global climate emergency is well documented in other publications, and we would recommend interested readers to visit:

- https://www.istructe.org/resources/guidance/how-to-calculate-embodied-carbon/ (IStructE)
- https://www.leti.london/ (LETI)
- https://www.architecture.com/about/policy/climate-action/2030-climate-challenge (RIBA)
- https://www.ukgbc.org/ (UKGBC)
- https://www.worldgbc.org/ (World Green Building Council)
- https://www.ipcc.ch/report/ar6/wg1/ (IPCC Sixth Assessment Report)

Responding to the climate emergency is now seen as an urgent global issue. Governments around the world have now set target dates to achieve a net zero carbon (NZC) position. At the time of publication the UK Government have set a deadline of 2050[2].

Clients, both public and private, are similarly setting their own target dates for NZC which typically lie within a range from 2030 to 2050. The construction sector is reported to account for close to 40% of global greenhouse gas emissions, and for occupied buildings the façade accounts for a significant proportion of those emissions.

1.2 Construction and the Facade

The façade industry therefore has a key role to play in reducing global GHG emissions and contributing to the overall imperative of achieving net zero carbon targets. Global emissions continued to rise in 2019 and 2020 and our challenge is not only to arrest that rise but then rapidly reduce our emissions.

Facades can be incredibly complex with regards to their architecture/design, procurement, performance requirements and the variety of materials used. A building's façade is the filter between the internal and external environments and may dominate the operational energy requirements and GHG emissions of a building through its thermal transmittance, solar gains, daylighting requirements and air leakage. A well-performing façade, and one that is well-matched to the use of the building, will help prolong the sustainable life of a building.

Due to the range of highly processed materials that are used, the façade also accounts for a significant part of the embodied carbon of the building. Depending on the building typology, figures published by LETI[3] suggest the façade may account for between 13% and 17% of the overall embodied carbon of the building. It is important to note that this is an approximation based on a small number of case studies to date and will become more accurate over time as the dataset is expanded. If other contributors (e.g. the primary structural frame) significantly improve the carbon footprint of their products then the façade could well become an even more significant contributor to the overall embodied carbon of the building.

The task of understanding the contribution of the facade, assessing and improving work practices, the innovations in design and delivery, and the changes that will be required is not without some significant uncertainty. The size of the challenge ahead should not be underestimated, but it should not be left for others to deal with either.

We must also remember that most of the buildings we construct now will still be standing at the point where the UK is committed to be NZC. It must also be highlighted that 80% of buildings in 2050 have already been built[4]. This puts a priority on decarbonising the current stock of buildings to achieve UK commitment to NZC. Given the time lag between design and realisation of our projects and the critical importance of reducing emissions in the next decade we must now act with considerable foresight for the changing landscape. We should be designing for the expectations of 2050 and beyond, and not just looking back to those targets that were set by Building Regulations in 2010 to 2020.

We all have a responsibility to share best practice, increase knowledge, stay informed and act now in order to reduce the impact our buildings and their facades have on the environment.

New building structures inherently have a high embodied carbon and there are many energy inefficient existing buildings in the UK and elsewhere. It is therefore it is expected that progress towards NZC can be accelerated by prioritising the recladding of existing structures in lieu of new build. Government legislation and subsidies may be used to stimulate improvements in the performance of the existing building stock. Such prioritisation is likely to promote a demand for façade replacement/remediation. Current concerns regarding fire safety are also driving significant demand for expertise in this area.

The procurement of facades should also be reviewed in the ever-changing context of energy demand. With efforts at decarbonisation of the electric supply the embodied and operational carbon of buildings and their facades that will be manufactured over the next 10 years are of even greater importance.

1.3 Scope of this Guide

The purpose of this Guide (and those which will follow) is to educate and position the façade industry so that it is briefed to meet the challenges that lie ahead in achieving NZC. It is also intended to energise and stimulate open debate and sharing of relevant information.

Whilst every effort has been made to ensure the accuracy of this document there will inevitably be errors and omissions. We have taken the view that it is more important to start to tackle this issue now rather than wait until every aspect of this Guide is fully scrutinised.

This Guide aims to discuss key definitions and concepts in the area of sustainability with a focus on carbon and point towards further reading. We shall also discuss some of the background to the current climate emergency.

This remainder of this Guide contains the following sections:

- **Greenhouse Gases and Carbon Accounting** set out the wider context within which facade fabrication and building operation must respond;
- **Embodied Carbon** explains the concept of embodied carbon in the context of the façade and the factors that can be considered to minimise the embodied carbon;
- **Operational Carbon** explains how the façade can be designed to improve the operational performance of a building through intelligent selection of performance attributes and design;
- **Environmental Product Declarations (EPDs)** explains how environmental product declarations are assembled and considers how their use and specification may change the selection process of appropriate cladding solutions for the built environment;
- **Façade Materials** reviews the carbon credentials of typically available cladding materials, to consider what other materials might increase in terms of their use in façades;
- **Definitions** sets out a common language to be used.

2.0 Greenhouse Gases and Carbon Accounting

2.1 Introduction

This section briefly introduces the concept of greenhouse gases, why they are important and how they are measured/accounted for.

2.2 What are greenhouse gases?

A greenhouse gas (GHG) is a gas which is relatively transparent to the wavelengths of electromagnetic energy which predominate in solar radiation (ultraviolet (UV), visible light and shortwave infrared (IR)), but not to those wavelengths emitted by surfaces at normal ambient temperatures (longwave IR).

Around 70% of the solar radiation which reaches the Earth's atmosphere passes through and is absorbed by the ground, buildings and other surfaces. This energy is then re-emitted at longer wavelengths, of which around 90% is blocked from leaving by GHGs in the Earth's atmosphere.

This leads to the so-called 'greenhouse effect'. Without this effect the Earth's surface would be too cold to sustain life as we know it, but if the effect is increased it leads to an increase in global average temperatures (global warming) which can also be detrimental to life.

There are six main GHGs recognized in the Kyoto Protocol[5]: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). All of these are generated by human activity, although some are also produced through natural causes.

Atmospheric water vapour (H_2O) and clouds are the biggest contributors to the greenhouse effect but are outside of the direct control of human intervention. However, the effect of increasing the concentration of other GHGs in the atmosphere has the effect of increasing global average temperatures, which thereby raises the amount of water vapour in the atmosphere and further increases global temperatures. There is thus a feedback loop between GHGs, water vapour and climate change.

2.3 Why are they measured?

GHG emissions due to human activity are called anthropogenic emissions to distinguish them from the natural biological cycle. The vast majority come from the combustion of fossil fuels (coal, oil and natural gas) with additional contributions associated with deforestation, changes in land use and some manufacturing activity, for example the production of cement.

The United Nations' Intergovernmental Panel on Climate Change (IPCC) has established that there is a direct and broadly linear correlation between the atmospheric concentration of GHGs and the average global surface temperature on land and in the oceans[6]. There is a consensus of opinion amongst climate scientists that limiting the global average temperature rise to 1.5°C above pre-industrial levels offers the best chance of minimising the severity of consequent climate change and severe weather events. This limit was agreed internationally and written into the 2015 Paris Agreement[8].

According to the World Meteorological Organization[7] (WMO) the global mean temperature for 2020 was 1.2 ± 0.1°C above pre-industrial levels, which places 2020 as one of the three warmest years on record globally and the warmest on record for Europe. This is already worryingly close to the 1.5°C Paris Agreement[8] goal.

Whilst the relationship between GHG concentration and average surface temperature is broadly linear, the relationship between average surface temperature and frequency of extreme events is highly non-linear, and an increased temperature rise of, say, 2.0°C above pre-industrial levels is forecast to lead to a disproportionate rise in the frequency and severity of extreme weather events.

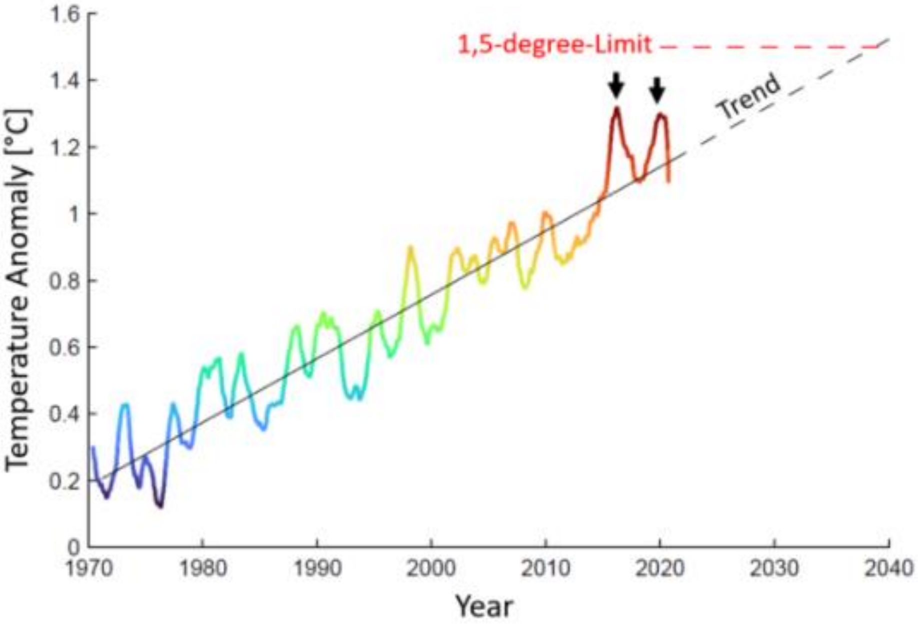

Figure 1: Global average temperature trend for the past 50 years.
Source: RealClimate: 'Two graphs show the path to 1.5 degrees'

Global warming and climate change generally are not only linked to extreme weather events (superstorms, flooding, heatwaves, droughts, wildfires) which cause a significant direct loss of human lives and assets, but they also contribute to crop failure, desertification, acidification of the oceans, sea level rise and loss of biodiversity. These issues then lead to food insecurity, freshwater scarcity, health hazards and displacement of human settlement.

Changes in atmospheric and sea temperatures are also linked to instability in sea currents, such as the Gulf Stream, and the high-atmosphere jet stream, both of which act as barriers between the polar regions and more temperate latitudes. Weakening of these ocean and air currents is predicted to have a devastating impact on weather patterns.

2.4 How are they measured?

GHGs are measured directly by their concentration in the atmosphere (as a scientific global climate indicator). In 2019, greenhouse gas concentrations reached new highs[7]. Figure 2 below shows the 'Big 3' GHGs carbon dioxide, nitrous oxide and methane measurements since the1980s.

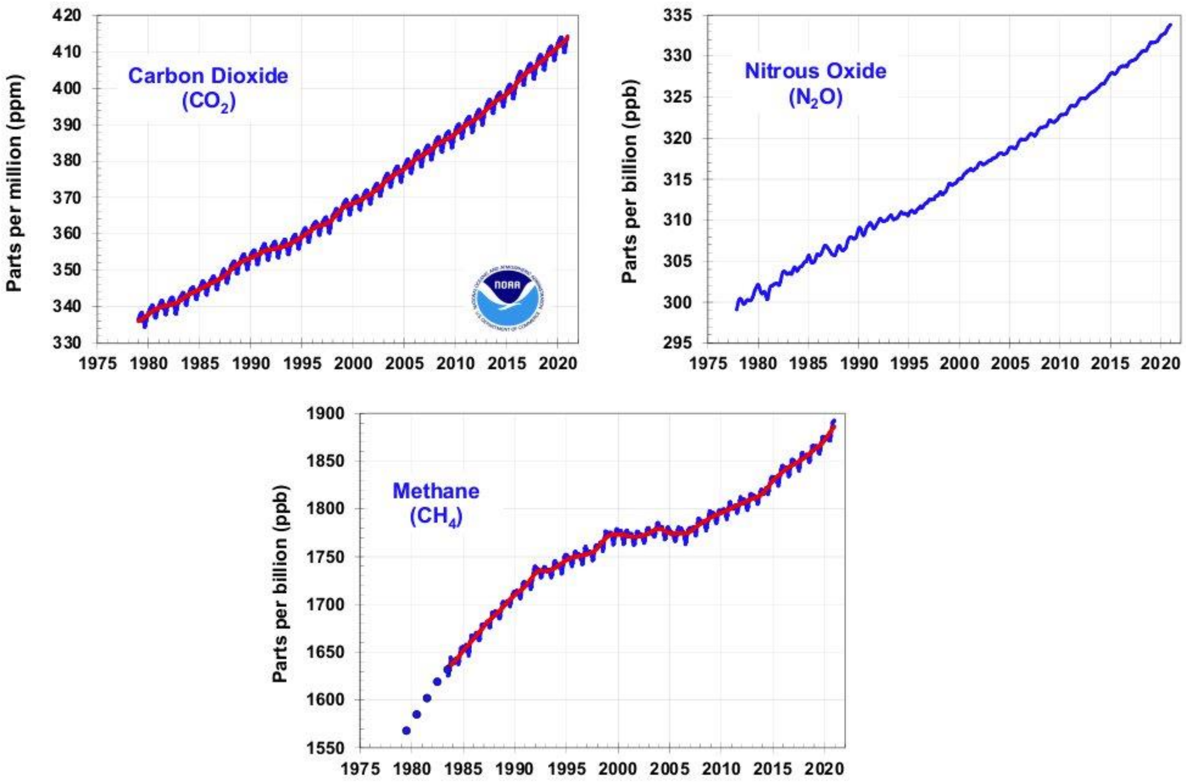

Figure 2, Graphs showing concentrations of CO_2, N_2O and CH_4
Source: https://www.co2.earth/annual-ghg-index-aggi

The significance of each GHG varies according to its composition. For comparison purposes we can calculate a Global Warming Potential (GWP) for each GHG. GHGs are therefore compared against CO_2 for GWP via the unit 'carbon dioxide equivalent' (CO_{2eq}). By default GWP is taken as 1 for CO_2.

The 'carbon footprint' of an activity, product or system is taken to be the sum of the CO_{2eq} of all the associated GHGs emissions.

However, to complicate matters, whilst CO_2 and N_2O are relatively stable in the atmosphere and may last for hundreds of years with little or no decomposition, methane and other GHGs will gradually decay and break down into other molecules.

With regard to methane there are several decay processes which are known to occur, including the breakdown of methane by soil-based bacteria and other organisms, and these processes are themselves affected to some degree by the effects of climate change – as global temperatures rise the rate at which methane breaks down may increase due to some mechanisms and reduce due to others. Some mechanisms rely on the presence of other molecules in the atmosphere which are broken down as they react with the methane, thereby limiting the amount of methane that can be consumed by that particular mechanism.

At the present time it is reckoned that methane released into the atmosphere is broken down in around a decade, but this will change with time. What is certain is that the concentration of methane in the atmosphere has increased by a factor of around 2.5 since pre-industrial times and is likely to increase further. In 2006 it was estimated that livestock farming was contributing around 37% of anthropogenic methane emissions.

As a means of capturing the GWP of different GHGs it is therefore commonplace to base the GWP on a defined time period, and a 100-year period is commonly used – this is identified with a subscript as GWP_{100}. Methane typically has a reported GWP_{100} of up to 36 and nitrous oxide a GWP_{100} of up to 300, making them more impactful relative to the same mass of emitted carbon dioxide. A perfluorocarbon such as CF_4 (tetrafluoromethane or carbon tetrafluoride, also known as R-14) has an atmospheric life of around 50,000 years, and a GWP_{100} of around 7,000 – although PFCs and related chemicals have been banned for some time, their impact will continue to be felt for many millennia.

Some authorities now prefer to assess GWP over a shorter time period, typically 20 years. Due to its relatively short lifespan, the GWP_{20} of methane is then higher, around 85, but that of CF_4 is lower, around 4,900.

The *IPCC Special Report on Global Warming of 1.5°C*[9] states that limiting warming to 1.5°C above pre-industrial levels implies reaching net zero CO_2 emissions globally by around 2050, with concurrent deep reductions in emissions of non-CO_2 climate forces – other GHGs and polluting aerosols which are very damaging in the short-term, i.e. have a very high GWP_{20}.

Climate scientists suggest we need to roughly halve current emissions by 2030 to have a chance to meet the 1.5°C target as shown in Figure 3 below.

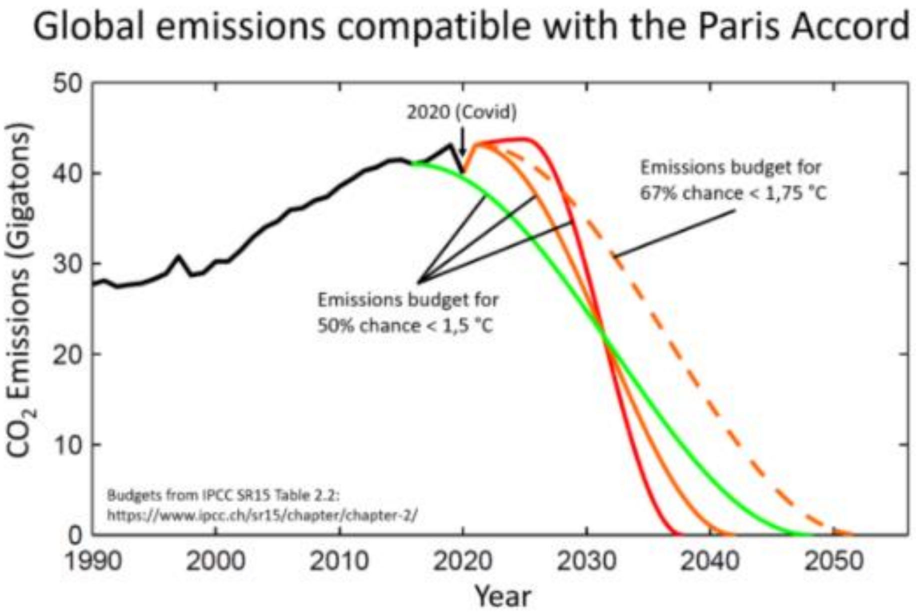

Figure 3, Emission trajectories required to meet Paris Accord targets.
Source: RealClimate: 'Two graphs show the path to 1.5 degrees'

2.5 How are they reported?

One of the ways companies, organizations, cities or even countries report their emissions is the method proposed by the GHG Protocol (www.ghgprotocol.org) jointly launched by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) in 2001.

Initially targeted at businesses, the protocol establishes comprehensive global standardised frameworks to measure and manage GHG emissions from private and public sector operations, value chains and mitigation actions. The GHG Protocol and its associated tools have become the most widely used accounting method for policy makers.

GHG emissions in this Protocol are categorised into three groups or 'Scopes'. The purpose of scoping is to help delineate direct and indirect emission sources, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals.

Scope 1 covers direct emissions from owned or controlled sources. For example, for float glass production it would include the gas used to fire the furnaces or for a façade contractor the fossil fuel used in the operation of machinery used within the factory or assembly plant.

Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting organisation. Using the same example from above, grid electricity for industrial purposes such as lighting the factory or powering the machinery falls into this category. If district heating or cooling were used, this would be accounted for here. Scope 2 emissions are directly related to the energy mix used to produce the purchased power – as electric grids increase the proportion of (or switch to) renewable energy the associated GHG emissions will decrease. This is known as 'decarbonisation' of the grid.

Scope 3 includes all other indirect emissions that occur in an organization's value chain. It would include for example the transport emissions from the source of the primary materials for a glass manufacturing facility and the delivery of the product to the glass processor facility. Likewise, all business travel and employee commuting to the glass factory or façade contractor facility should be reported under this scope.

Scopes 1 and 2 are carefully defined in the GHG protocol to ensure that two or more organizations will not account for emissions in the same scope. This is summarized in the Figure 4 below.

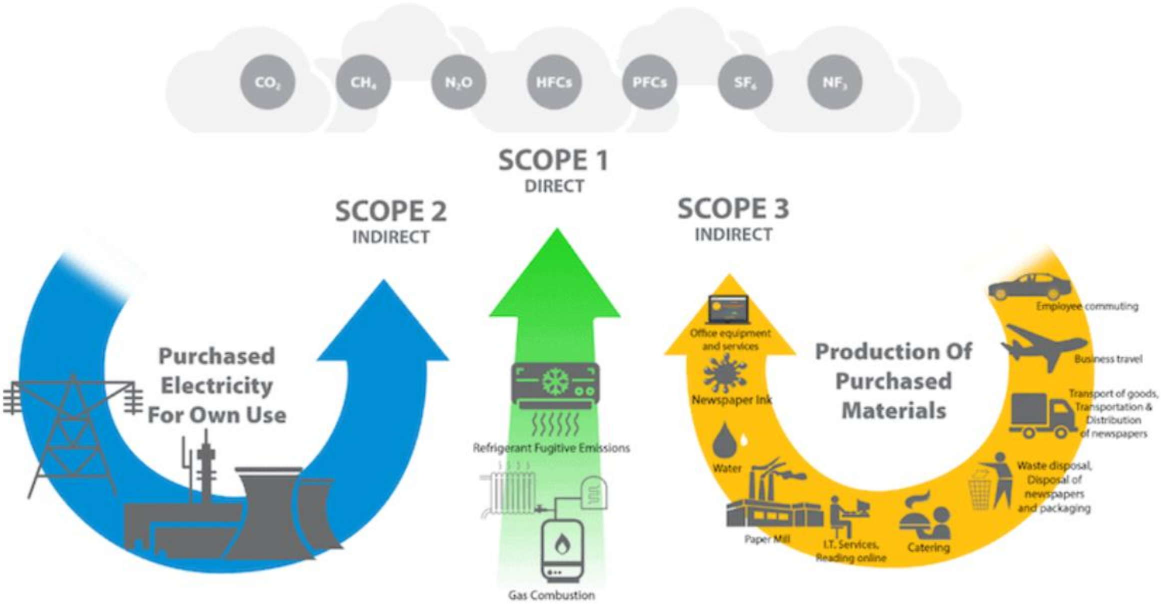

Figure 4 – Scopes 1,2 and 3
Source: www.greenelement.co.uk

For many companies, the majority of their greenhouse gas (GHG) emissions and cost reduction opportunities lie outside their own operations within their value chain, it is therefore very important to quantify Scope 3 emissions[10]. The GHG Protocol was designed to develop a verifiable inventory, it does not, however, provide a standard for how the verification process should be conducted. It is also policy neutral, meaning that the methodology is generic and applicable to any policy type.

It should also be noted that the Scope 2 and Scope 3 emissions for an organization are the Scope 1 emissions for their suppliers. It is not the responsibility of an organization to offset their suppliers' emissions, and it might be regarded as reckless for them to do so because this effectively excuses the supplier from taking responsibility for their own processes, and might even encourage the supplier to do less to protect their own local environment. However, it is important for an organization to know their Scope 2 and Scope 3 emissions so that they might seek out those suppliers who themselves offer the lowest emissions, thereby bringing pressure on their suppliers to deal with their own Scope 1 emissions.

In addition to the above, the International Standards Organization (ISO) has developed the ISO 14064 series of standards for GHG accounting. These were published in 2006 and updated in 2018 as part of the ISO 14000 series for environmental management. They provide government and industry with an integrated set of tools for programmes aimed at quantifying and reducing greenhouse gas emissions, as well as for emissions trading.

The construction and cladding industry produce infrastructure, buildings and facades. The businesses that are part of the value chain (designers, suppliers, manufacturers, contractors, developers, etc) should be concerned about their carbon footprint and commit to targets to reduce their environmental impact. Other issues may also need to be considered, including water conservation land use (natural capital) and waste disposal. The CWCT is producing further guidance on these subjects.

2.6 Carbon and construction

The life cycle of a built asset such as a building can be separated into several distinct stages. The environmental impact of a built asset can be considered across these life cycle stages or modules as defined in BS EN 15978. These are presented diagrammatically in Figure 5 below and are commonly referenced in carbon calculations to help communicate the source of emission.

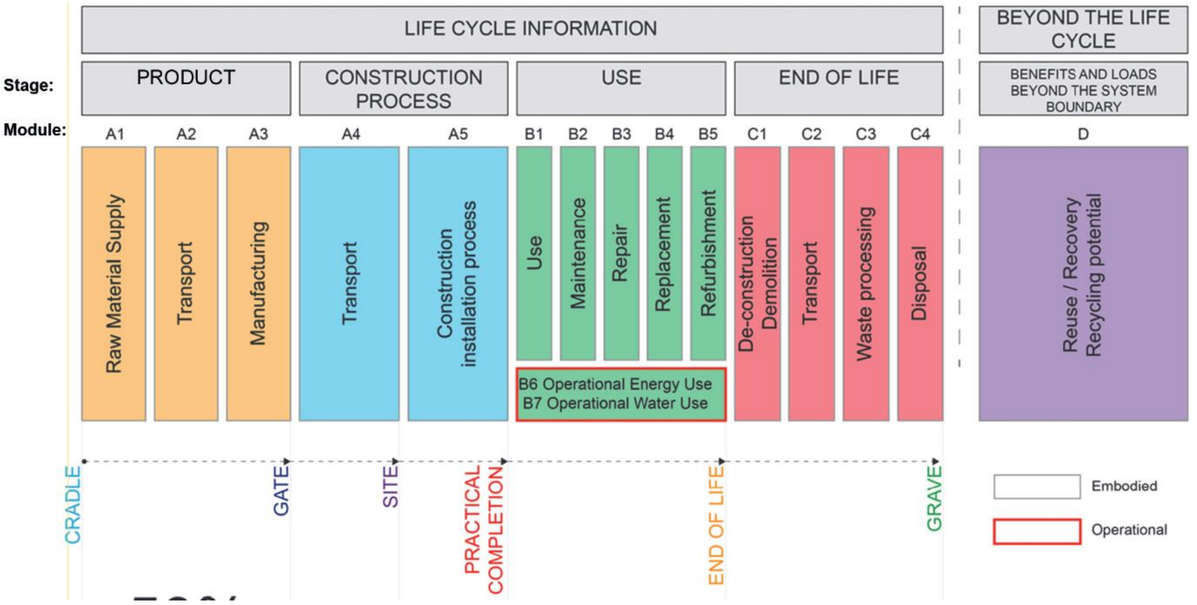

Figure 5: BS EN 15978 Life cycle stages, extract from IStructE *How to calculate embodied carbon*[11]

For a building, carbon emissions are divided into distinct elements – embodied carbon associated with the creation, construction and eventual disposal of the physical fabric of the building (or elements thereof), and operational carbon associated with the building in use. In additional Module D captures emissions beyond the lifecycle of the building and are important to report as part of a WLC assessment. Other resources such as water and waste can be considered within the same framework.

In the UK over the last few decades there has been a steady tightening of regulations relating to the energy use of buildings. As a consequence the operational energy performance of buildings has improved significantly, and we now have a much greater understanding of many factors that influence operational performance, although design still tends to be more piecemeal than holistic, and this does not necessarily mean that the best overall design will be achieved – examples of this are given in later sections.

The façade has been a key element in improving energy efficiency, with improvements in solar coatings, insulation, and innovation in terms of double skin facades, closed cavity facades and the like. However, some changes, such as the trend towards increasing the size and area of individual glazing units, have resulted in the use of fewer and deeper framing profiles and the need for thicker glass, changing the embodied carbon as well as the operational carbon. This highlights the need to consider the building lifecycle holistically and to assess operational carbon in the context of whole life embodied carbon, including reuse and recycling.

The façade industry now has a responsibility to examine the embodied carbon of different façade solutions, and to look at how these different solutions interact with the building as a whole, over its entire life cycle, and work with other designers to develop solutions which balance operational and embodied carbon considerations to arrive at the best (lowest) overall solution for projects.

From the point of view of façade design there is an urgent need for data which illustrates the effect, on both embodied and operational carbon, of simple changes in the design of the facade. Examples might include the increase or decrease of mullion and transom spacing for glazed curtain walling, the effect of increasing or decreasing floor-to-floor and column spacings for common cladding and glazing systems and the effect of increasing or decreasing the glazed fraction of a façade (which will depend on the elevation).

There is also very little available data relating to the embodied and operational carbon associated with different glass coating systems, the use of gas-fills in insulating glass units (IGUs) and the use of thermally strengthened, heat soaked, curved and laminated glasses. If we require a safety glass is it better or worse, from an environmental perspective, to use laminated annealed glass rather than a heat soaked toughened glass? Which kind of interlayer material has the best environmental credentials for laminated glass generally? If we want enhanced thermal performance are we better off using a double glazing unit (DGU) with coated glass and a gas-fill, or a triple glazing unit (TGU) made with a suspended film and a conventional air-fill?

3.0 Embodied Carbon

3.1 Introduction

Embodied carbon is defined by the UK Green Building Council as the '*total greenhouse gas emissions generated to produce a built asset. This includes emissions caused by extraction, manufacture/processing, transportation and assembly of every product and element in an asset and may also include maintenance, replacement, deconstruction, disposal and end-of-life*' (UK GBC, 2017).

The embodied carbon is essentially a mix of the carbon that has been expended/released during the entire construction process, plus the carbon that is locked into the materials used in the constructed asset, expressed as a CO_2 equivalent.

3.2 Significance

Historically for buildings the embodied carbon was a relatively small part of the total emissions once operational carbon emissions were taken into account. However, in recent decades considerable focus has been placed on lowering the operational carbon emissions of buildings by reducing the energy consumption from heating, cooling, lighting, and ventilation. The embodied carbon is therefore a growing percentage of the total and we are now seeing a significant shift in focus towards embodied carbon assessment and total life cycle consumption, as buildings are constructed to higher standards, and we move towards 'net-zero' buildings.

The embodied carbon of the façade is increasingly becoming one of the key drivers in design and must be balanced against other project considerations including purpose, architectural quality, operational carbon, thermal performance, cost, durability, structural integrity, supply chain availability and material stewardship. Façade professionals must become more conversant in understanding how the decisions they make affect the embodied carbon of the façade in the same way that they understand the impact of their design decisions on operational energy and construction professionals understand the likely impact of their decisions on cost. They should be able to compare and contrast how their actions affect both the embodied and operational carbon associated with the façade. This knowledge needs to be effectively shared within the group of consultants and contractors through a holistic design approach.

Façade professionals must be involved in wider project team discussions where decisions associated with façade selection could have a significant impact on the total embodied carbon of a building. For example, the adoption of a unitised cladding system, which is attached to the building structure at column positions only, will require more material to be used in order to stiffen the cladding panels over the longer fixing spans. However, the stiffness of the floor edges can be reduced because there is no longer a need to support the cladding at intermediate locations on the floor slabs. Reducing the material used for the floor slabs reduces the total weight on the columns, and so the columns can also be down-sized. The gains to be achieved by a relatively small reduction in material for the primary structure may far outstrip the losses associated with the extra material required for the cladding units.

Conversely, if we are looking to reclad an existing building which has a stick-system curtain wall (we might expect to reclad two or three times in the life of a typical building structure) the installation of a unitised cladding system will not gain anything – the extra material needed for the unitised cladding system will represent an increase in the embodied carbon of the building with little or no opportunity to downsize the existing primary structural elements.

Holistic embodied carbon calculations should be used to inform targeted design decisions that reduce carbon emissions, with an ambition to reduce whole life carbon of all assets to zero. To allow objective decisions to be made it is important that we have an agreed methodology for the calculation of embodied carbon in buildings, including the direct and indirect contribution of the façade. This can only be done based on a whole-life whole-building basis.

The designer's ability to reduce the embodied carbon in a façade reduces over time in a project's design development and critical decision-making phase, as shown in Figure 6 below. At an early stage where many options are on the table, the potential for decision making and change may be up to 100% when even the need to go ahead with a project can be challenged. At the latter stages the ability to drive down the embodied carbon reduces as the range of alternatives narrows and performance targets for each discipline become more fixed. At the latter stages the responsibility of designers and suppliers is best focussed on protecting the assumptions made by designers so that the low embodied carbon designs specified are actually delivered, and on ensuring that any lessons learnt are fed back into the façade and construction industries at large.

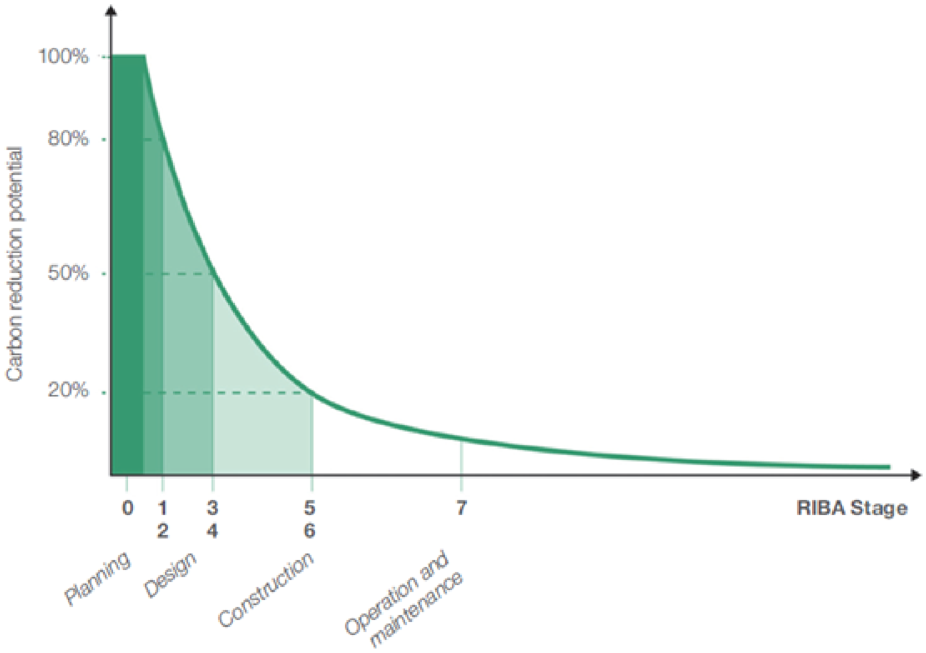

Figure 6: Conceptual diagram showing ability to influence carbon reduction across the different work stages of infrastructure delivery, based on PAS 2080

3.3 A hierarchic approach

When considering a design, a suggested hierarchy for carbon reductions is illustrated in Table 1 below which is adapted from the PAS 2080 framework for integrating carbon reductions into the design process for infrastructure projects. LETI's Embodied Carbon Primer[3] also provides useful 'rule of thumb' embodied carbon reduction strategies.

At the earliest stages of the project fundamental decisions drive the greatest opportunities for a reduction in embodied carbon whilst at the later stages a focus on optimised design and efficient practices is also expected.

Hierarchy	Description	Example design levers
Build nothing	Evaluate the basic need for an asset and consider	Challenge the brief and propose alternatives. Improve utilisation of existing assets.

Hierarchy	Description	Example design levers
	whether any new construction is needed	
Build less	Minimise demand for new construction: reuse, repurpose and refurbish existing assets and minimise extension sizes	Justify existing structures through analysis and surveying. Maximise usage efficiency of the existing asset and any new construction that may be required. Use designs with a longer service life to reduce the need for replacement materials in the future.
Build clever	Make low carbon solutions (technologies, materials, and products) your default option. Specify enough material and no more.	Design to minimum loads (within code allowance), set realistic SLS criteria, set utilisation ratios close to 1, reduce structural grids, spans and transfer structures, use efficient structural forms, make low carbon material choices, low carbon material specifications and suppliers, reuse existing materials where possible.
Build efficiently	Use of construction techniques to reduce resource consumption.	Utilise temporary structures in the permanent condition, avoid over-ordering, do not allow possible site errors to alter design choices. Monitor construction emissions. Design to enable offsite manufacture to reduce waste on site. Specify for low carbon rather than perfection.

Table 1: A suggested hierarchy for carbon emissions reduction based on PAS 2080 hierarchy

3.4 Embodied carbon methodology for facades

An agreed methodology to the calculation of the embodied carbon of a façade solution is not yet in place, however from a first principles perspective it is anticipated that, taking the example of a unitised façade system, such an approach would include assessments associated with:

- Material extraction, processing and transportation to factory,
- Use of recycled materials,
- Glazing including heat treatments, coatings, interlayers, spacers and seals (an appropriate final level of precision in the methodology needs to be agreed),
- Opaque infills,
- Framing including forming, thermal breaks and finishes,
- Bracketry,
- Gaskets and membranes,
- Assembly,
- Transport to site,
- Installation,
- Damage (and associated replacement),
- Transport from site,
- Maintenance,
- Component replacement during operation,
- Full or partial system replacement during the building life cycle,

- Disposal, recycling or reuse of materials at the end of the life of a building asset,
- Waste associated with any stage of the above processes.

Figure 7 below gives an indicative scale of the embodied carbon, ‘cradle-to-gate’ only, for some different materials and façade elements.

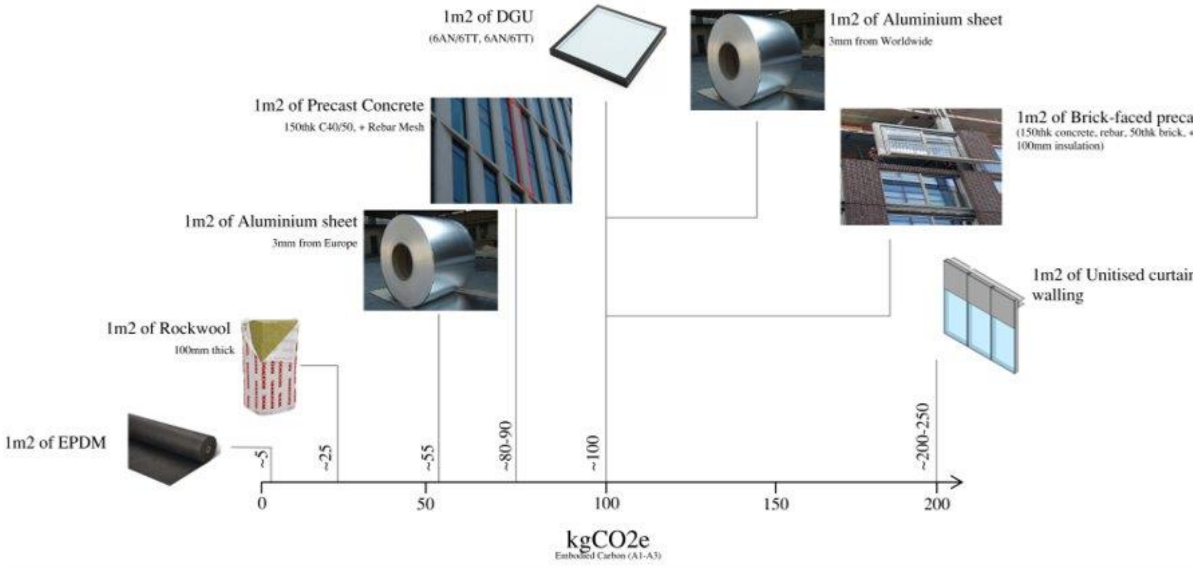

Figure 7: **A sense of scale on the embodied carbon of different assemblies (A1 to A3 only)**

It is noted that the production process chain used by different specialist contractor’s supply chains has a significant impact on the total embodied carbon of a façade solution. Each step in the production process has an impact on emissions and the magnitude will vary depending upon the processes adopted by a particular supplier and their local energy markets.

Taking the example of aluminium framing for example, if the energy source used to extract the aluminium is based upon fossil fuels, then the embodied carbon associated with that step will be significantly larger than if hydro-electric energy is used. Such factors in the detailed calculation make early assumptions particularly difficult precisely at the time when detailed comparisons setting the direction of a façade project are made, and this makes it critical that we have an agreed methodology for calculation and comparison. It is also critical that decisions are made on the basis of the actual performance of a supplier not an ‘industry average’ performance, albeit ‘industry average’ data may be useful at early design stages where suppliers are not known.

To address the uncertainties associated with the final supply chain selected for a project, before environmental product declarations (EPDs) are provided, it is anticipated that designers will need to initiate a ‘carbon thread’ as part of the development of a façade project that sets out aspects such as:

- A listing of the expected components within the façade;

- A take-off of measurements either explicit or taken from an agreed façade measurement guide such as ICMS (https://www.rics.org/uk/upholding-professional-standards/sector-standards/construction/icms-international-construction-measurement-standards/);

- A carbon factor based upon the materials used within the components taken from a components guide or database;

- Assumptions of recycled material usage;
- Assumptions of waste percentages;
- Transport assumptions;
- Production factors to address production considerations (curved glass for example may require a higher production factor than flat glass due to less thermally efficient tempering furnaces, non-rectangular glass may have a higher production factor due to greater handling per m^2 or less efficiency in glass processing lines);

and so on.

Designers, specifiers and the delivery end of the façade industry must work together to improve understanding of what embodied carbon figures are realistic and to identify how the industry can reduce the embodied carbon of available façade solutions.

3.5 Predicting and policing the unpredictable

Strictly speaking a contractor can only accurately and reliably assess their own direct impact on embodied carbon – the Scope 1 emissions, resource consumption and wastage that occurs whilst the product is under their direct control. This information must then be passed downstream with the product as it leaves the control of the contractor and moves into the possession of others.

The Scope 2 & 3 emissions that are associated with the contractors upstream supply chain are, strictly speaking, under the control of others, and are the responsibility of the supply chain to assess, control and account for. In an ideal world the first upstream supplier will know their own contribution to the embodied carbon of the product that they supply and should be able to provide a reliable statement as to their products 'carbon credentials'. To do this they in turn must rely on their suppliers to provide similarly reliable information to them, and so on to the farmers, quarriers and other raw material producers at the very beginning of the supply chain.

At present however, many of the parties at the start of the building and façade supply chain do not have the knowledge or resources to produce the required information, and those that do may be wary of lack of consistency between manufacturers and of openly releasing such information out of fear that their customers will simply look elsewhere for a 'lower-carbon' supplier.

Looking downstream there is the similar issue of what might happen when a material reaches its end of life and must be refurbished, re-purposed or recycled. It is possible to predict or even specify what should happen to a material at the end of its life, but this will inevitably be based on the current state of knowledge about such matters. Moreover, it is not practical for any contractor working now to dictate what should happen to its expired products fifty or a hundred years from now. Facades constructed today will be reaching their end-of-life in the mid-to-late 21st century at a time when the need to minimise the carbon impacts of our designs is anticipated to increase significantly.

The detailed consideration for the disassembly of façade systems to facilitate refurbishment, reuse and recycling of components is already a key consideration for today's designers. This necessarily includes the recording of detailed information associated with the façade disassembly plan and material of each component, and yet those who have had reason to look at an existing building which is only five to ten years old will be only too aware of the difficulties in obtaining reliable information about the construction of a relatively new building which may still be in the hands of its original owner.

The use of carbon offsetting is also an issue which triggers much debate. A number of organisations are already looking at the planting of new trees, or the acquisition of existing woodlands, as a means of offsetting embodied carbon. There is comparatively little reliable data on the sequestering of carbon by trees and other plants, and much of it is based on a raft of assumptions about growth density, effects of future climate on growth patterns, survival rates and the role of the tree in the ecosystem as a whole. There is also a physical limit as to how many new trees can be planted, and where, and in some cases the planting of new trees may simply replace an existing mechanism for carbon sequestration with another, resulting in very little net gain.

There is also a moral side to this argument: does a UK company have the right to claim the benefits of carbon sequestration from a rainforest in an undeveloped third world state, and what is the risk that the third world state will one day claim that carbon sequestration for its own industry. Likewise, should a UK company be able to tell a polluting supplier from halfway around the world that it is ok for them to keep polluting their local environment because we are planting trees in our countryside to offset their emissions. Either way how does a UK company ensure that their patch of South American rainforest is being properly managed, and not being ‘shared’ with other companies.

The impact of climate change on carbon sequestration is also highly significant. Droughts in some parts of the world have already led to farmers uprooting trees and other plants in a bid to conserve their increasingly limited water resources. How is this to be accounted for?

Strict rules will inevitably need to be agreed and followed for any company that wishes to apply offsetting as a means of reducing their own environmental impact.

4.0 Operational Carbon

4.1 Introduction

Operational carbon is carbon consumed in the use of a building through the supply of energy for heating and cooling, lighting, hot water, MEP systems, lifts and so on. This is referred to as regulated energy. The proportion of each of these components of energy demand varies from building to building, and according to patterns of occupancy, and may even change during the life of the building. Unregulated energy use, such as that due to IT equipment, catering and appliances, is not accounted for in building regulations assessments.

UK building standards and regulations have focussed on reducing operational carbon demand since the early 2000s, requiring better building envelope performance, more efficient MEP systems and favouring the use of low-carbon fuels and renewable energy. However, this has been done without consideration of embodied carbon, so that some practices such as simply increasing the thickness of insulation will increase embodied carbon, thereby counteracting at least some of the gains made in terms of reduced operational carbon emissions.

Building performance standards are now moving towards 'net-zero' buildings which have an operational carbon demand low enough to be met by a zero-carbon electricity grid, without the need to burn fossil fuels. Alongside the need to reduce carbon is the need to reduce and even out energy demand, as a low-carbon electricity grid will be less able to deal with spikes in peak demand[13]. The focus in building standards is therefore on operational energy rather than just operational carbon.

Operational energy is measured in $kWh/m^2/yr$, where the area defined is typically the gross internal area (GIA). Metered energy used by the building on site is referred to as Energy Use Intensity (EUI). If the energy use is tracked back to its source, such as the power plant, this is referred to as Primary Energy (PE) and takes into account transmission losses and generation inefficiencies.

Current UK regulations limit CO_2 emissions with a target value based on that from a notional building, though future regulations are likely to change the metric from CO2 emissions to PE usage. Alternative standards such as LETI advocate the use of EUI as a more meaningful measure of building performance.

4.2 Facade performance parameters

Facades play a significant role in achieving low operational carbon and evening out operational energy use. A 'fabric first' approach adopts passive measures to reduce the demand for heating, cooling and artificial lighting through well-insulated walls and levels of glazing and shading appropriate for the building use, climate, site orientation and exposure. The optimal facade design for a given building also depends on internal factors including density of occupation, wall-to-floor ratio, and the acceptable comfort conditions of its occupants. Because of these different factors, building codes rarely prescribe precise facade designs, instead stating limits for performance criteria.

Building energy codes typically set an overall operational energy target for the building and allow designers to offset poor performance in some areas by achieving better performance in others. Facade designers must therefore be aware that facade performance parameters will likely need to be tested iteratively in energy simulations to arrive at a result that is optimal for the overall building.

The facade performance parameters that are presently used to quantify energy use are:

- U-value: a measure of steady-state heat transfer through a facade element

- Thermal bridging ψ- and χ-values: a measure of the additional steady-state heat transfer associated with interfaces between facade elements, structural and services penetrations and changes of geometry
- Airtightness: a measure of the amount of uncontrolled air leakage through the building envelope
- g-value: a measure of the amount of solar radiation energy transmitted through glazing and other translucent or transparent elements
- Shading: the use of fixed or deployable elements external or internal to the façade to control solar gain
- Visible light transmission: a measure of the amount of visible light transmitted through a glazing unit
- Form factor: the ratio of a building’s external surface area to its internal floor area

The U-value is the measure of thermal transmittance through a wall or glazing unit under notional winter steady-state conditions . Building standards typically specify limiting opaque wall U-values and window U-values separately, though they may be combined in specifications as an overall area-weighted U-value.

Glazing centre-pane U-values of 0.6 W/m^{2}K can be achieved with triple glazing or 1.0 W/m^{2}K with double glazing. Accounting for framing losses these can translate to an overall U-value of 0.9 W/m^{2}K or 1.2 W/m^{2}K for a window unit, depending on the manufacturer, frame type, material and window size.

A wall U-value is driven by the thickness and specification of insulation and degree of necessary thermal bridging within a wall build-up. Repeating thermal bridges, such as those created by metal studs, wall ties and rainscreen brackets, must be accounted for in the wall U-value. These can have a significant impact on the wall U-value so must be calculated accurately as early in the façade design as possible.

Thermal bridging is a key contributor to the overall thermal transmittance, but it occurs in localised points or lines, such as at interfaces between facade systems, structural penetrations or at geometric irregularities like corners or parapets. Thermal bridging becomes proportionally more important in the overall thermal performance as U-values decrease.

Ensuring an appropriate level of airtightness is important to limiting heat transfer via mass transfer of air through the building envelope. Building standards require that new buildings be tested for airtightness on a whole-building, or in residential construction on a dwelling-by-dwelling basis, by means of an exfiltration test.

Good airtightness in a facade is achieved through ensuring the continuity of the air line, particularly across interfaces between wall types. Clear delineation of the airtightness line on drawings is recommended, along with clear assignment of responsibilities for airtightness between interfacing works that will be installed by different trade contractors.

Current regulations in the UK set a maximum air infiltration limit of 10m^3/hm^2 at a pressure difference across the façade of 50Pa, however a target whole-building airtightness of 5m^3/hm^2 at 50Pa is readily achievable with good detailing and workmanship. Target values of 3m^3/hm^2 or below are becoming more common. Such a low airtightness can be challenging to achieve with site-built facades and may lead to increased use of prefabricated systems. For buildings with very low airtightness below

$2m^3/hm^2$ (such as to meet Passivhaus standard) specialist advice should be sought. Further guidance on whole building air leakage tests is provided in CWCT Technical Note 44.

Glazing g-value is a measure of the solar energy transmission through a glazing unit. It is presented as a decimal value. Solar gain can be beneficial in winter months in reducing heating demand, but in summer months it can lead to overheating and increased demand for cooling.

In dense office environments or highly glazed buildings, cooling is a major component of energy demand, and a low g-value should be sought. However, reducing the required g-value of the glazing also reduces its light transmission, which can lead to lower internal light levels and push up artificial lighting energy demand. Modern spectrally-selective coatings can achieve a low g-value and high light transmission up to a ratio of 2:1, say 60% visible light transmission and 0.30 g-value.

Glazing light transmission is important to limiting the demand for artificial indoor lighting, but also for the wellbeing of building occupants. Lighting energy can represent a significant proportion of a building's energy use. The effective use of daylight can act to offset the lighting energy demand. The extent of such benefits will depend on project specific conditions and requirements. On the other hand, excessive daylight can lead to visual discomfort (glare) for occupants sitting near the facade, so there can be benefits in considering shading systems in combination with the glazing and potentially considering dynamic facades that can optimise solar control and daylight provision for different times of the day and year.

Solar shading devices can be an effective way of controlling solar gain in combination with the glazing. External shading is typically more effective than internal shading as it blocks solar radiation before it reaches the glass, although reflective internal shading devices can be beneficial. Active shading devices can be linked to sensors to maximise their effect.

A building's form factor is an important, and often overlooked, façade design parameter. A high form factor represents a large ratio of surface area to internal area and can be the result of high floor-to-floor heights or a large amount of articulation in a façade. An efficient building form with less façade area will lead to lower levels of heat transfer and usually greater operational energy efficiency.

Natural ventilation is itself not a facade performance parameter, but naturally ventilated buildings can have significantly lower energy demand than air-conditioned buildings, so ventilation through openings in the facade can contribute to NZC building design. As climate change is increasing the risk of extreme summer overheating, new dwellings will need to provide a greater level of purge ventilation which makes the need for operable windows or openings even more acute, and will put more emphasis on designing for openings which allow generous air flow, while also meeting essential safety and security requirements.

4.3 Future trends

To meet the UK's commitment to becoming net-zero by 2050, new buildings will have to be designed to net-zero standards by 2030, and a large programme of retrofitting existing buildings will need to have begun. The Future Homes Standard[14] and Future Buildings Standard[15] will be implemented in 2025 and will seek to reduce regulated CO_2 emissions by 75-80% from current standards. These standards will impose stricter limits on fabric performance, with standards for homes differing from those for non-domestic buildings.

Generally speaking, space heating is the dominant energy demand in UK housing; the emphasis is therefore on the reduction of U-values, thermal bridging and air leakage. New standards will likely require the use of triple glazing with excellent frame performance. Wall U-values will require thicker insulation and greater attention to thermal bridging, which becomes dominant as U-values decrease. Designers must be aware that some published standardised thermal bridging values for typical details are inappropriate for modern construction methods, and project-specific calculations are needed.

Designers should also be mindful of the potential need for increased natural ventilation to avoid overheating, which will increase the size or quantity of windows and lead to poorer U-values overall.

Facade design for low-carbon offices is more complex, as the proportion of energy used on lighting, cooling, heating and MEP systems varies greatly from building to building. The optimal design will need to be explored iteratively, but typically cooling, lighting and HVAC are the dominant components. Cooling is reduced by limiting solar gain through the use of appropriate areas of glazing, spectrally selective glazing and/or shading devices. Natural ventilation can be beneficial in reducing summertime cooling load if designed properly and holistically within the building's overall climate strategy, but equally must be controlled in winter to avoid conflict with the heating system.

U-values requirements are often less onerous in offices as internal heat gains from occupants and computers offset heat losses through the façade. In these situations, with higher internal heat gains, the use of very highly insulating walls and features such as triple glazing may increase the cooling demands of the building. Furthermore, triple glazing will also have a higher embodied carbon (less so if using glazing systems with suspended polymer films) and in some situations will not be beneficial in a whole-life carbon assessment, as discussed elsewhere in this paper.

4.4 Performance gap

A major issue in efficient building design is the *performance gap*, or the difference between predicted and actual energy use. The performance gap is partly due to inaccurate modelling in design, including the use of performance parameters based on steady-state conditions, and partly due to poor construction and poor building management. Known facade issues contributing to the performance gap include:

- Incorrect calculation of U-values, ignoring or miscalculating repeating thermal bridges
- Underestimation of thermal bridging at interfaces
- Poor detailing and installation of air barriers leading to poor airtightness
- Inaccurate modelling including a lack of consideration of solar shading devices
- Lack of understanding and misuse of ventilation strategies leading to inefficiencies
- Modelling assumptions lack an understanding of how users operate (or do not operate) solar control devices and blinds in practice
- Inadequate installation, commissioning and maintenance of the façade system e.g., automated openings, control systems on opening and shading devices
- Weather and climate data, used to simulate the external environment, may be taken from a source that does not accurately represent the local climate or context of the site of the building.

Most of these issues can be overcome via greater collaboration and communication of design assumptions from designers to contractors and to building managers, so it is vital that such feedback and data sharing is improved to enable net-zero aspirations to be met in reality. The value of such post-occupancy evaluation is being increasingly recognised, and it is becoming mandatory on many public projects.

5.0 Environmental Product Declarations (EPDs)

5.1 Introduction

An Environmental Product Declaration (EPD) is defined by ISO 14025 as a Type III declaration that quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function. A Type III declaration means that the data used are based on independently verified assessment methods, amongst other requirements intended to allow reliable comparisons between EPDs. The EPD methodology is based on environmental management tools that follow methodologies given in ISO series 14040 together with ISO 14044.

An EPD, undertaken in accordance with the guidance presented in BS EN 15804:2012+A2:2019, attempts to provide quantified environmental information for a construction product or service on a harmonized and scientific basis. It can also be used to provide information on health-related impacts during the in-use stage of the building. The information within the EPD provides the basis of the assessment of the environmental impact of façade systems or buildings. EN 15804 sets out the basis for comparing EPDs.

Companies are expected to implement EPDs in order to inform their environmental sustainability goals (by better understanding the carbon emissions, reuse and recycling and other environmental impacts associated with their products), and to demonstrate a commitment to the environment to their customers, through the environmental sustainability credentials of their product(s). To facilitate embodied carbon assessment on projects, EPDs will become a more frequently specified requirement.

Core product category rules (PCR) for Type III environmental declarations for any construction product and construction service are defined in BS EN 15804. The standard provides a structure to ensure that all EPDs of construction products, construction services and construction processes are derived, verified, and presented in a harmonised way. The standard does not describe the rules for applying an EPD in a building assessment, which is covered in BS EN 15978 (note, this is currently under review and likely to be become BS EN 15978-1 in the near future).

It is possible to have an EPD for a substance or preparation (e.g., cement), for a product (e.g., window), for a construction service (e.g., cleaning service as part of maintenance) and for an assembly of products and/or a construction element (e.g., wall) or technical equipment (e.g., lift).

An EPD may be based on a *functional* or on a *declared* unit. The functional unit defines the impact results for certain service level the product provides and is normally used in product EPD calculations when impacts related to the product use phase are also given. If the function of the product in the building level is not known (e.g., if the product has several applications in the building) or when the study does not consider all the life cycle modules, a declared unit is used. The declared unit represents the physical quantity of the product such as 1 m^2 of 50 mm thick insulation or 1 kg insulation.

EPDs typically expire after 3 or 5 years and so must be regularly reviewed and updated.

5.2 What is included in an EPD

An EPD is intended to communicate verifiable, accurate, non-misleading environmental information for products and their applications, thereby supporting scientifically-based choices and stimulating the potential for market-driven continuous environmental improvement. All construction products and materials declare the environmental impact against the life cycle modules identified in BS EN 15804.

As set out in EN 15804:2012+A2:2019, construction products and materials (with limited exceptions) shall declare Modules A1-A3, Module C1-C4 and Module D, refer to Figure 5. This minimum requirement is referred to as a ‘cradle to gate with modules C1-C4 and D’ EPD and all data is reported on a declared unit of measure.

BS EN 15804 describes additional life cycle stages that can be taken into account in an EPD to give a more accurate measure of products environmental impact. These options include considering the construction and process stage (A4 to A5) and the in-use stage (B1 to B7). The most comprehensive option considers all stages of a product life cycle and is referred to as ‘cradle-to-grave and module D’. Whilst typically undefined at the product level, modules A4, A5 and B1 to B7 should be accounted for within a project level assessment of a building.

5.3 How are they carried out

The first step in creating an EPD is defining the product, using the appropriate Product Category Rules (PCR). BS EN 15804 provides a common approach for the definition of Product Category Rules for EPD development in the construction sector. BS EN 17074 defines the Product Category Rules for flat glass products in buildings. BS EN 17213 sets PCR for windows and pedestrian doorsets and PCR for curtain walling are being drafted.

A PCR is of utmost importance as it sets the system boundary for the analysis. This not only makes it clear regarding what is, and is not, taken account of in the EPD, but also allows for more accurate comparison between EPDs produced for the same products provided by different manufacturers/suppliers.

The next step is to develop a Life Cycle Assessment (LCA) study, which starts with the production of a Life Cycle Inventory (LCI) and is an extensive set of data on the relevant energy and material inputs and environmental outputs. The LCI must be verified and from reliable sources (for example, from a manufacturing facility). A Life Cycle Environmental Impact Analysis (LCIA) is then performed by appropriately qualified sustainability consultants using a variety of software and assessment tools. This converts the inventory data into a potential set of impacts.

The EPD is then created and delivered as a document or report following a series of verification reviews; it is then ready for registration and publication by the EPD programme operator.

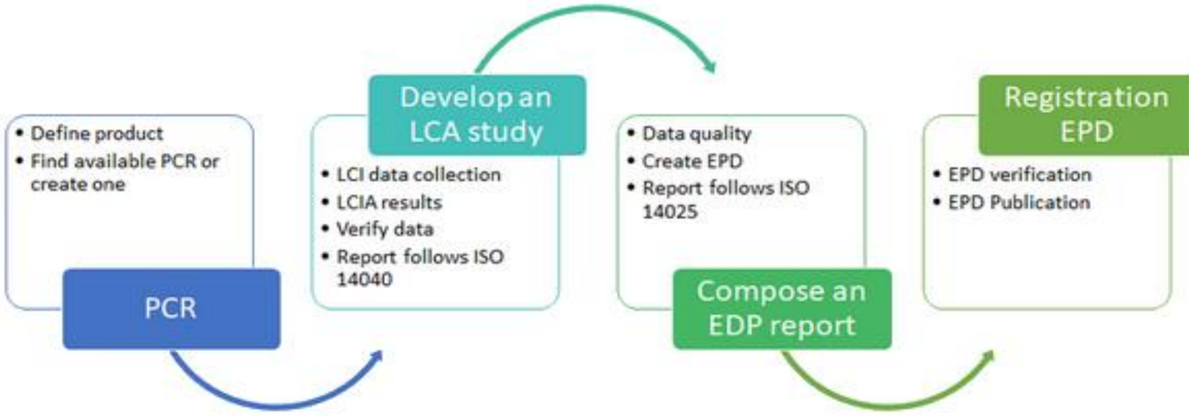

**Figure 8 Steps to creating an Environmental Performance Declaration
Source: Wikipedia**

5.4 Limitations

A number of limitations have been identified with environmental performance declarations, including:

- **Diverse range of PCR's**
    - The presence and adaptation of non-uniform PCR's for the same product can lead to inconsistent EPD's, which leads to an inaccurate comparison between the products. PCRs vary according to the geographical scope of the product, lack of specific standards of data and lack of coordination between program operators.
- **Complex and inconsistent database**
    - Due to the complex and time-consuming nature of data collection procedures, the Life Cycle Assessment (LCA) requirement for an EPD becomes prolonged. Due to lack of precise site-specific data and the use of generic data over specific data can lead to inaccurate declarations. CEN Technical Report 15941 states 'generic data should never replace specific data when specific data are available'.
    - A group of companies or a trade association may produce a generic EPD on behalf of its members in the absence of individual specific EPD. In this case, such generic EPD can provide a useful starting point.
- **Lack of satisfactory and acceptable third-party critical review**
    - Inconsistency on specific aspects and reviewing of only general aspects, leaving out more specific aspects, leads to varying interpretations of EPDs for similar products.
- **Cost**
    - Due to financial constraints in small scale companies and industries, publishing an EPD after performing an LCA becomes very cost intensive.
- **Incomplete information and interpretation of results**
    - Due to the unavailability of EPD's and PCR's for many products, it is difficult to publish a comprehensive EPD for a product or system which incorporates many component parts. Lack of transparency in declaration procedure and uniform interpretation leads to an inconsistent comparison between products. Note, BS EN 15804 sets out the basis to allow any comparability of EPD, including the need to consider all information modules and for the EPD to be in the context of the building. Couple this with elements typically excluded from analysis, highlighted in Figure 9 below, and the task of generating reliable, consistent data starts to become apparent.

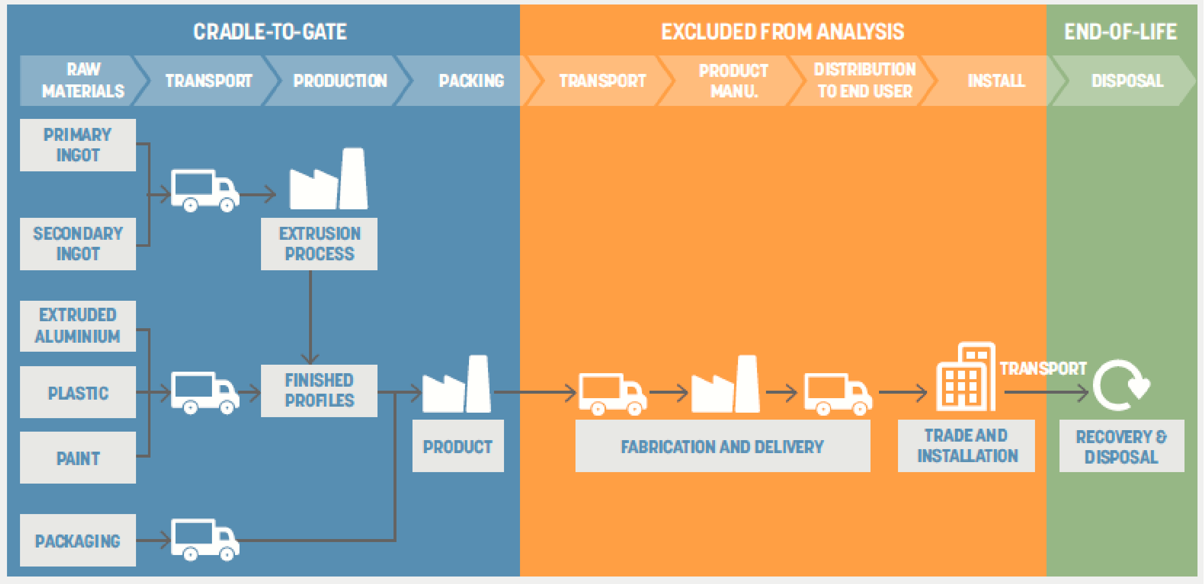

Figure 9: Typical stages of a life cycle assessment for an aluminium framing member
Source: 3Keel

For the façade industry specifically, it is evident that there is a need for more understanding between the relevant specialists and for the industry to be more joined-up in its approach. Only then will we be able to generate consistent and comparable LCA/EPD information which, in turn, will allow for more accurate calculation of embodied carbon within the façade.

6.0 Façade Materials

6.1 Introduction

As embodied carbon becomes more heavily scrutinised, whole-life carbon assessments become relevant, accounting for both the initial carbon investment in the materials used but also considering their long-term durability, operational and maintenance implications, and potential for reuse and recycling at their end of life.

The following tables present a brief overview of reported embodied carbon factors (Modules A1 to A3 only) for commonly used materials along with considerations around longevity and end-of-life recovery. The values presented are taken from published EPDs and databases but should be used with caution and help readers build an awareness of the range of published values. There is a high level of variation between suppliers and across geographic locations. Moreover, the values quoted are expected to vary over time. Designers should seek the most accurate information available for their projects. The tables are not exhaustive.

Material embodied carbon / GWP reference figures					
Material	**GWP (kgCO2e/kg) A1-A3 (Product stage)**			**Factors affecting GWP**	**Expected service life**
	High	**Mid-range**	**Low**		
Glass – float	1.44 (ICE[1])	1.30 (EPD[2])	0.97 (OKO[3])	Carbon intensity of electricity grid in source country. Amount of recycled cullet in the float material. Efficiency and throughput of processing plant: note the large variation in laminated glass. Around 200g of CO_2 is emitted for every 1kg of float glass produced as a result of chemical reactions and is unrelated to energy input.	25 in IGU, 60+ single-glazed
Glass – laminated	3.17 (EPD[2])	1.56 (ICE[1])	1.10 (EPD[2])		
Glass – toughened	1.67 (ICE[1])	1.58 (EPD[2])	1.38 (OKO[3])		
Aluminium extruded profiles	13.2 (ICE[1], world avg) 14.6 (ICE[1], China)	6.83 (ICE[1], EU avg)	2.33 (EPD[2], high-PCR content)	Carbon intensity of electricity grid in source country. Lowest is with high post-consumer recycled content. It should be noted that secondary aluminium is a constrained resource (i.e., we only have so much of it). Existing aluminium is typically recycled at a high rate. It follows that specifying a greater recycled content on a project will result in other projects using less. This may bring down a project's environmental impact but will do little to reduce the emissions of the construction industry as a whole. Increasing the supply of secondary aluminium by ensuring it can be extracted from building uncontaminated at the end-of-life will reduce the environmental impact of the industry.	60+ (less for finishes)
Aluminium sheet	10.64 (EPD[2])	6.58 (ICE[1], EU avg)	2.65 (EPD[2], high-PCR content)	Carbon intensity of electricity grid in source country. Lowest is with high post-consumer recycled content. Refer to comments regarding recycled content above	60+ (less for finishes)
Mild steel – plate	2.76 (ICE[1], hot-dip galvanised)	2.46 (ICE[1], plate)	1.55 (ICE[1], section)	Steel manufacturing process - Blast Furnace or Electric Arc Furnace. The latter allows a greater proportion of secondary steel in the mix. It should be noted that secondary steel is a	60+ (less dependent on corrosion protection)

Material embodied carbon / GWP reference figures					
Material	**GWP (kgCO2e/kg) A1-A3 (Product stage)**			**Factors affecting GWP**	**Expected service life**
	High	**Mid-range**	**Low**		
				constrained resource (i.e., we only have so much of it). Existing steel is typically recycled at a high rate. It follows that specifying a greater recycled content on a project will result in other projects using less. This may bring down a project's environmental impact but will do little to reduce the emissions of the construction industry as a whole. Increasing the supply of secondary steel by ensuring it can be extracted from building uncontaminated at the end-of-life will reduce the environmental impact of the industry.	
Stainless steel	-	4.41 (ICE[1])	3.43 (OKO[3])		60+
Precast concrete	0.19 (EPD[2])	0.15 (ICE[1])	0.13 (EPD[2])	Availability of a local supply chain for concrete aggregates Cement consists of c. 51% of the embodied carbon of concrete. Most cement-replacing materials will reduce the rate of hydration causing a slower strength gain, this will restrict through-put of the precast factory. Silica-fume replacement may act to improve the early-strength gain.	60+
Insulation – mineral wool	1.53 (OKO[3])	1.28 (EPD[2])	0.70 (EPD[2])		50+
Insulation – rigid	4.26 (ICE[1], PUR foam)	4.01 (EPD[2], phenolic)	3.29 (ICE[1]EPS)		30
Brickwork	0.53 (EPD[2])	0.21 (ICE[1])	0.16 (EPD[2])	Bricks are fired to over 1000ºC, which is energy intensive. The fuel source for firing has the greatest impact: currently this is fossil fuel (coal or natural gas) but hydrogen and electric firing are in development. Extruded bricks, single-fired have lower EC than double-fired bricks. Use of recycled materials. Refer to Kenoteq K-Briq for example.	60+
Timber	0.51 (ICE[1], glulam) / 0.68 (ICE[1], plywood)	0.31 (ICE[1], hardwood)	0.26 (ICE[1], softwood)	Figures are based on sustainably managed forests and are substantially higher for timber sourced from unmanaged forests. Carbon sequestration should be accounted for in module C. For further reading see IStructE article 'Timber and Carbon Sequestration' published Jan 2021	30-60
Natural stone - granite	0.70 (ICE[1])	0.43 (OKO[3])	0.13 (EPD[2])	Transport emissions (A4) can be high. Consider location of quarry and where processed, relative to site.	60+

Material embodied carbon / GWP reference figures					
Material	**GWP (kgCO2e/kg) A1-A3 (Product stage)**			**Factors affecting GWP**	**Expected service life**
	High	**Mid-range**	**Low**		
				Wastage rates are key. This will vary due to the method of extraction and specifics of the project visual range.	
Natural stone - limestone	0.16 (OKO[3])	0.09 (ICE[1])	0.06 (EPD[2])	Transport emissions (A4) can be high. Consider location of quarry and where processed, relative to site. Wastage rates are key. This will vary due to the method of extraction and specifics of the project visual range.	60+
Terracotta	-	1.36 (EPD[2])	1.0 (EPD[2])		50+
GRC	0.72 (EPD[2])	0.58 (EPD[2])	0.54 (OKO[3])		60

Sources:

1. ICE database v3.0 (v2.0 where current figures unavailable)
2. Representative supplier EPD
3. Oekobaudat database

Facade system and component recycling and reuse considerations				
Component	**Maximising design life (B1-B5, Use stage)**	**Design for disassembly (C1-C4, End of life stage)**	**Recycling potential (D, Beyond the life cycle)**	**Re-use potential (D, Beyond the life cycle)**
Glass	Good detailing of framing to limit exposure of glass edge to moisture will minimise the risk of IGU edge failure and delamination, prolonging the glass design life.	Adopt capped curtain walls in lieu of SSG systems to allow glass to be cleanly removed from framing without contamination from silicone. Use glass marking to fully describe the build-up, enable the glass unit to be recycled or repurposed.	Float glass can be endlessly recycled. Off-cuts and processing waste is routinely returned into the float line as ‘cullet’ and makes up ca. 20% of float glass raw material. Post-consumer recycled content is ca. 1%. Up to 40% of post-consumer flat glass is downcycled at its end of life for use in road base course and other uses, while the remainder ends up in landfill.	Numerous examples exist of glazing units being disassembled and reassembled as new IGUs. Refer to Lloyds Building and Triton Square by Arup. Change of function is possible with lower performance expectations (such as use in second skin, interior panels, shadings)
		IGU are subject to a short lifespan and warranties compared to single glazing. IGUs use glass compositely with edge spacers, sealants which are difficult to separate and can cause	Low-iron glass can accept a lower proportion of recycled content to maintain optical quality. Float glass processors have differing views on	

Facade system and component recycling and reuse considerations				
Component	**Maximising design life (B1-B5, Use stage)**	**Design for disassembly (C1-C4, End of life stage)**	**Recycling potential (D, Beyond the life cycle)**	**Re-use potential (D, Beyond the life cycle)**
		contamination. Innovation in sealant technology and removal is necessary to increase recycling rates.	the acceptability of coated or laminated glass for cullet. Guidance should be sought from specific suppliers. Fritted glass cannot be recycled as the ceramic material is a contaminant	
Curtain walling and windows	Minimise UV exposure of seals and membranes that are not easily replaced or repaired. Use ‘shearing layers’ principle to ensure that components with shorter lifespan are easily replaced while allowing longer lifespan elements to remain in place.	Promote dis-assembly tests after performance mock-ups to show how readily systems can be disassembled without damage. Good record keeping is essential. Disassembly method statements should be requested from contractors and saved in O&M manuals. Fixings shall be compatible with standard hand tools for disassembly. Interfaces between elements with different lifespans have to be carefully managed to allow disassembly.	Aluminium is 100% recyclable. Thermal break materials can be designed to be separated from the profiles – refer to manufacturer for details. This may lead to loss of composite action across a thermally broken profile. It can be laborious to separate alloys to ensure the quality of profiles with recycled content. Specialist facilities exist. Aluminium finishes other than anodised (i.e. PPC/paint) may require removal prior to recycling, this will require additional energy. Moreover, this may have environmental implications due to the chemicals required to remove the finish.	Curtain walling profiles can be reused, though practicalities exist around element size and appropriateness for new installation. Materials may be damaged during dismantling process Warranty and testing issues must be overcome. Process to be fully traceable and the product needs to be fully traceable and certified by a third party, according to ISO 14064.
Rain screen built-up walls	Use ‘shearing layers[1]’ principle to ensure that components with shorter lifespan are easily replaced while allowing longer lifespan elements to remain in place.	Adopt hook-on details or mechanical fixings to allow panels to be individually removed without damaging other components.	Individual components should be traceable to know their make-up and recycling potential. Composite products may be difficult to recycle. Ensure good records are kept from individual suppliers.	Use of standardised components and module sizes increases opportunity to reuse components on future installations.
Brickwork built-up walls	Ensure that all components in the build-up wall have a design life equal to the brickwork and backing wall, incl. insulation and cavity barriers. Ensure cavities are adequately drained to	Using lime mortar allows bricks to be salvaged during disassembly, while cement mortar cannot be removed from the brick surface without excessive effort.	Brickwork can be salvaged. Stainless steel ties and shelf angles can be recycled.	Salvaged brickwork may need testing to demonstrate strength and durability.

Facade system and component recycling and reuse considerations				
Component	**Maximising design life (B1-B5, Use stage)**	**Design for disassembly (C1-C4, End of life stage)**	**Recycling potential (D, Beyond the life cycle)**	**Re-use potential (D, Beyond the life cycle)**
	prolong the service life of brickwork and mortar. Note, for instance, that open-state cavity barriers may have a design life of only 30 years whereas other components will have 60+ years.			
Precast	Specify appropriate environmental exposure considering pollution, saline environment. Design fixings for maximum design life equal to panel. Ensure water- and air-tightness is well detailed to minimise risk of corrosion to panel and rebar.	Use of internal gaskets as first line of defence and sealants where they can be easily accessed.	Demolished concrete can be crushed for aggregate. Unwanted waste timber used to produce moulds and forms can be sent to a local recycler for chipping or incineration.	Rebar inspection is not possible, so strength testing may be required. Moulds should be designed to be reusable.

[1] The concept of 'shearing layers' involves splitting a building or part of a building into layers with different life cycles and designing appropriately so that those layers with shorter life cycles can be easily replaced without compromising the life cycle of longer lasting layers.

7.0 Application to Facades Typology

There is a need to analyse different façade typologies with respect to embodied carbon in order to allow reliable comparison between alternative façade options. This will form part of future work and will enable the creation of façade datasets. To support this objective CWCT are developing a methodology to enable the embodied carbon of a façade to be calculated in a consistent way.

Numerous façade embodied carbon comparisons can already be found in literature. However, due to a lack of transparency and agreed methodology the results are varied and subject to question, and examples are not included in this document.

8.0 Conclusions and Future Work

There is a growing body of work around the issue of sustainability, and what this might mean for construction in general, and it is strongly recommended that all practitioners in the façade and construction industry should read widely on the subject.

There is however a lack of detailed guidance on how sustainability principles should be applied to the façade. The façade is one of the most complex aspects of a building in terms of design, performance, range of materials available, supply chains and end of life considerations. In this initial guide we have grappled with these issues and in writing this document are seeking to engage with the industry to recommend a consistent and effective method of calculating the carbon cost of the façade.

A consistent approach to façade sustainability is key if we are to improve performance and provide a means by which realistic targets can be established. This starts with the methodology used to calculate the embodied carbon associated within the façade. Numerous consultants, contractors and suppliers have their own tools to do this, however without an agreed methodology the results are inconsistent and cannot be compared. It is our aim to provide further guidance in this area.

We all have a responsibility to try and react to the challenges faced as the sustainability agenda increases in significance. There is a lot of work to do in this area, and we welcome your comments regarding any future guidance we produce. Please email sustainability@cwct.co.uk with suggestions and feedback.

Key Definitions

1. **Absolute Zero Carbon**, is the elimination of all carbon emissions without the use of offsets. For more information refer to https://www.leti.london/carbonalignment.
2. **Biogenic Carbon**, refers to the carbon removals associated with carbon sequestration into biomass as well as any emissions associated with this sequestered carbon. For more information refer to https://www.leti.london/carbonalignment.
3. **Biomass**, is material of biological origin excluding material embedded in geological and/or fossilized formations. For more information refer to https://www.leti.london/carbonalignment.
4. **BRE Green Guide**. (recently cited by GLA's New London Plan) provides guidance on the relative impacts of the different elements typical to construction specifications. For more information refer to https://www.bregroup.com/greenguide/podpage.jsp?id=2126
5. **BREEAM**. The Building Research Establishment Environmental Assessment Method, provides a methodology for assessing, rating and certifying the environmental impact of building construction. This is the dominant environmental impact assessment method used in the UK. For more information refer to https://www.breeam.com/.
6. **BS EN 15804**, is the standard which provides core product category rules for all construction products and services. It provides a structure to ensure that all Environmental Product Declarations (EPD) of construction products, construction services and construction processes are derived, verified and presented in a harmonised way. For more information refer to https://www.bsigroup.com/en-GB/.
7. **BS EN 15978**, is the standard which sets out a framework for the assessment of the environmental impact of new and existing buildings. It shows the modules used in assessing Whole Life Carbon (Life Cycle Stages) and the various terms that are used to describe them (Modules A1-A5, B1-B7, C1-C4 and D). For more information refer to https://www.bsigroup.com/en-GB/.
8. **Carbon Capture and Storage** (CCS), is the process of capturing the CO2 arising from fossil fuel combustion or industrial processes, transporting it to a storage site and storing it where it will not enter the atmosphere. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.
9. **Carbon Equivalent.** Abbreviated to $kgCO_2e$ or $kgCO_2$-equiv, carbon equivalent is the unit of measurement of the Global Warming Potential (GWP) environmental indicator as recognised in Table 2 of BS EN 15978. Note carbon equivalent is informally often referred to simply as 'carbon'.
10. **Carbon Neutral**, is where all carbon emissions are balanced with offsets based on carbon removals or avoided emissions. For more information refer to https://www.leti.london/carbonalignment.
11. **Carbon Offset**, refers to the reduction or removal of carbon by using the savings or reductions of one element to counter another's. For more information refer to https://www.leti.london/carbonalignment.
12. **Circular Economy**. A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources. Source: Ellen McArthur Foundation https://www.ellenmacarthurfoundation.org/
13. **Climate Positive**, is any activity that goes beyond net zero by achieving an overall reduction in GHG in the atmosphere. Also referred to as Carbon Negative. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

14. **Declared unit,** is the quantity of a construction product for use as a reference unit in an EPD for an environmental declaration based on once or more information modules, for example mass (kg) or volume (m^3). BS EN 15804:2012 + A2:2019.

15. **Design for Adaptability**, is designing to support the continued use of a building by allowing for and accommodating potential future adaptations. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

16. **Design for Deconstruction** (DfD), refers to the design decisions that increase the quality and quantity of materials that can be reused at the end of a building's life. Also known as design for disassembly. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

17. **Embodied Carbon**, is the total GHG emissions (often simplified to "carbon") generated to produce a built asset. It is defined by the UK Green Building Council as the "total greenhouse gas emissions generated to produce a built asset, this includes emissions caused by extraction, manufacture/processing, transportation and assembly of every product and element in an asset and may also include maintenance, replacement, deconstruction, disposal and end-of-life". In the context of carbon calculations, the e*mbodied carbon* refers strictly to *lifecycle modules* A1-A5, B1-B5 and C1-C4. Source: Embodied Carbon: Developing a Client Brief - UKGBC March 2017. https://www.ukgbc.org/sites/default/files/UK-GBC%20EC%20Developing%20Client%20Brief.pdf

18. **Energy Use Intensity (EUI)**, is an annual measure of the total energy (regulated and unregulated) consumed in a building. EUI is expressed in terms of energy consumed per unit area (i.e. kWh/m^2) where the unit area may be calculated as the GIA (Gross Internal Area) or NLA (Net Lettable Area).

19. **Environmental Product Declaration** (EPD). This is a documentation process that measures the environmental impact of a product so that it can be compared to other similar products that perform the same function. The Life Cycle Assessment methodology is used to quantify the measurements being conducted. ISO 14025:2006 provides a framework for the principles and procedures for developing type 3 environmental declaration programmes and type 3 environmental declarations. Refer also to https://www.edie.net/.

20. **Functional unit.** Quantified performance of a product system for use as a reference unit. BS EN 15804:2012 + A2:2019.

21. **Global Warming Potential (GWP).** Is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The GWP is measure in kgCO2e (carbon equivalent). The GWP measure was developed to allow comparisons of the global warming impacts of different gases. For more information refer to https://www.epa.gov/ghgemissions/understanding-global-warming-potentials.

22. **Greenhouse Gases** (GHG). These are the family of gases that are associated with global warming and climate change. They collect in the atmosphere, trapping heat and contribute to a rise in overall temperatures. There are six main GHGs recognised in the 1992 Kyoto Protocol as being responsible for global warming and climate change: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

23. **Inventory of Carbon and Energy (ICE) database**, is a widely recognised database of embodied carbon for building materials. Established in 2004 by Craig Jones of the University of Bath (UK), the database is in essence a collation of EPDs for many thousands of products. Refer also to https://circularecology.com/embodied-carbon-footprint-database.html

24. **LEED**. Leadership in Energy and Environmental design, is a US based environmental building impact assessment method which is used throughout the world. LEED aims to provide guidance to the

design, construction, operation and maintenance of buildings designed to a sustainable agenda. For more information refer to https://www.usgbc.org/leed

25. **Life Cycle Assessment** (LCA), is a method for evaluating the environmental impact of a development taking into account its carbon emission over its lifetime, from cradle to grave. The assessment attempts to take into account the environmental effects caused throughout the lifetime of a development to produce a figure that represents its environmental load. There are three recognised levels of tools for determining a LCA; level one tools typically focus on individual components and materials. Level two tools consider the building holistically (form, mass etc) and work down through the different materials of the systems that compose the buildings (structural frame, internal walls etc). The third level of assessment tools are whole building assessments, such as BREEAM or LEED, which look at the carbon emissions of the building itself as well as its impact on wider social sustainability issues and healthy living considerations. For more information refer to https://www.designingbuildings.co.uk/wiki/Life_cycle_assessment

26. **Living Wall**. A living façade is a vertical surface, incorporating vegetation into its structure or face, to facilitate various aesthetic environmental, social or economic functions and benefits. While research and studies on the subject are limited, it is thought that living facades could make a significant contribution to sustainability if properly integrated. Source: https://www.designingbuildings.co.uk/wiki/Living_facade

27. **Material Passport**, is a document that describes all the materials and components that comprise a product or construction in order to give them a value for their original intended purpose, their recycling capacity and their reusability. For more information refer to https://www.bamb2020.eu/wp-content/uploads/2018/01/Framework-for-Materials-Passports-for-the-webb.pdf

28. **Material stewardship.** The process by which the societal value of materials lent to projects is preserved. Material stewardship relies upon data exchange, book keeping, and prevention of activities that would trigger downcycling by all those parties involved in the extraction, processing, working or fabricating, shipping, maintaining, disassembling and returning to the supply chain. For more information refer to paper '*Towards Materials Sustainability through Material Stewardship'* C. Tylor, et al. 2016. (https://www.mdpi.com/2071-1050/8/10/1001/pdf)

29. **Minimum Energy Efficiency Standards** (MEES), are standards that came into force in 2018, requiring that rented office property meet an Energy Performance Certificate (EPC) rating of Band E or better. In 2020 the government issued an Energy White Paper stating their commitment to a future tightening of MEES, requiring a minimum EPC Band B by 2030. At the time of writing (June 2021), the government is establishing a framework for how this requirement will be applied and enforced. For more information refer to https://www.gov.uk/government/consultations/non-domestic-private-rented-sector-minimum-energy-efficiency-standards-future-trajectory-to-2030.

30. **Net Zero Carbon**. This refers to the ambition to achieve a balance between the amount of carbon dioxide released by an action with the amount that that action removes overall. Typically, the usual route is to reduce the amount of carbon emissions generated by an action as much as possible and then by offsetting the remaining carbon production with activities such as replanting of natural habitats or carbon sequestration to capture and store carbon, thereby removing them from the atmosphere. For more information refer to https://www.edie.net/definition/Net-zero-carbon/232.

31. **Net Zero Embodied Carbon**, is where the sum total of GHG emissions and removals over a building's life cycle (Modules A1-A5, B1-B5 and C1-C4) are minimised, meets local carbon targets (e.g.$kgCO_{2e}/m^2$), and with additional 'offsets', equals zero. For more information refer to https://www.leti.london/carbonalignment.

32. **Net Zero Upfront Carbon,** is where the sum total of GHG emissions, excluding 'carbon sequestration', from Modules A1-A5 is minimised, meets local carbon targets (e.g.kgCO2e/m2), and with additional 'offsets', equals zero. For more information refer to https://www.leti.london/carbonalignment.

33. **Net Zero Carbon – Operational Energy**, is where no fossil fuels are used, all energy use (Module B6) has been minimised, meets the local energy use target (e.g. kWh/m2 /a) and all energy use is generated on or off site using renewables that demonstrate additionality. Any residual direct or indirect emissions from energy generation and distribution are 'offset'. For more information refer to https://www.leti.london/carbonalignment.

34. **Net Zero Carbon – Operational Water**, is where water use (Module B7) is minimised, meets local water targets (e.g. litres/person/year) and where those GHG emissions arising from water supply and wastewater treatment are 'offset'. For more information refer to https://www.leti.london/carbonalignment.

35. **Net Zero In-Use Asset**, is where on an annual basis the sum total of all asset related GHG emissions, both operational and embodied, (Modules B1-B7 (plus B8 and B9 for Infrastructure only)) are minimized, meets local carbon, energy and water targets, and with residual 'offsets', equals zero. For more information refer to https://www.leti.london/carbonalignment.

36. **Nearly Zero Energy Buildings** (NZEB), is a definition from the European Union's European Performance of Buildings Directive (EPBD). The EPBD was transposed into UK domestic legislation in 2020. The definition of NZEB is decided by each EU member state (and the UK) but in principle is a building with low energy demand. As the definition of a NZEB varies widely, it may not meet net-zero standards and the two definitions should not be confused.

37. **Operational Carbon**, refers to the GHG emissions arising from all energy and water consumed by a building in use over its life cycle (Modules B6 and B7). For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

38. **Operational Carbon – Energy**, are the GHG emissions arising from all energy consumed by a building over its life cycle. For more information refer to https://www.leti.london/carbonalignment.

39. **Operational Carbon – Water**, are the GHG emissions arising from water supply and wastewater treatment for a building over its life cycle. For more information refer to https://www.leti.london/carbonalignment.

40. **Passivhaus**. A building performance standard, originating in Germany, for the construction of new dwellings which minimise energy input to the building via heating or cooling. Buildings designed to the standard typically feature high levels of insulation and very low levels of air leakage. The standard has expanded over time to now address non-residential buildings and has also been used for refurbishment works. For more information refer to https://www.passivhaustrust.org.uk/

41. **Primary Energy**. The Original source, or form, of energy that is used to power an action or generate a product without any additional processes or refinements. Primary energy refers to that created by natural processes without the intervention of human engineering, such as the production of electricity. This might take the form of oil based fuels, solar, hydro, nuclear or wind energy. For more information refer to https://www.edie.net/.

42. **Recyclability**. A measure of the ease with which a material or product can be recycled into its constituent parts in order to be reused.

43. **Regenerative Design**, is an approach to design that seeks to ensure the built environment has an ability to go beyond net zero carbon and actively give back to the environment it was created from by

restoring or renewing its own sources of energy and materials. For more information refer to https://www.hdrinc.com/insights/6-things-know-about-regenerative-design

44. **Reuse**, is to use a product again while largely maintaining its original form. Unlike recycling, reuse requires minimal reprocessing. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

45. **Recycled Content**, is a measure of how much material within a product is from a non-virgin source. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

46. **Recycling Rate**, is an indication of how much of a product is collected and returned to the manufacturing process. A high recycling rate reflects that the product is technically recyclable and that the market infrastructure exists for it to be reclaimed. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

47. **Regulated energy** - Energy consumed by a building, associated with fixed installations for heating, hot water, cooling, ventilation, and lighting systems. For more information refer to https://www.leti.london/carbonalignment.

48. **Sequestration** - Carbon sequestration can be defined as the capture and secure storage of carbon in organic materials such as timber, that would otherwise be emitted to, or remain, in the atmosphere. Source: Howard Herzog, Dan Golomb, in Encyclopedia of Energy, 2004.

49. **Science Based Target**, is a target that is consistent with the pace recommended by climate scientists to limit the worst impacts of climate change. For more information refer to https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/climate-jargon-buster/.

50. **UKGBC**. The UK Green Building Council, established in 2007 to bring clarity, cohesion and leadership to the construction and property development sector, they aim to campaign for a sustainable built environment. The UKGBC have produced a number of papers and guidance documents for tackling sustainable issues arising from the building procurement process. For more information refer to https://www.ukgbc.org/.

51. **Upfront Carbon**, are the GHG emissions associated with materials and construction processes up to practical completion (Modules A1-A5). Upfront carbon excludes the biogenic carbon sequestered in the installed products at practical completion. For more information refer to https://www.leti.london/carbonalignment.

52. **Unregulated energy** - Energy consumed by a building that is outside of the scope of Building Regulations, e.g. energy associated with equipment such as fridges, washing machines, TVs, computers, lifts, and cooking. For more information refer to https://www.leti.london/carbonalignment.

53. **User Carbon**, refers to the GHG emissions relating to a 'users' utilisation of infrastructure and the service it provides during operation (Module B9). For more information refer to https://www.leti.london/carbonalignment.

54. **Whole Life Carbon**, is a measure of the total emissions generated by a building from construction to occupation and operation, through to demolition and disposal. A whole life carbon assessment of a built asset should provide an accurate account of its carbon impact on the environment. For more information refer to https://www.london.gov.uk/sites/default/files/wlc_guidance_april_2020.pdf

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Further reading

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