Facades and the race to Net Zero Carbon

1. Introduction

The UK Government has set a legal deadline to achieve net zero carbon (NZC) by 2050 (1), which means achieving a balance between greenhouse gas emissions produced and removed from the atmosphere. To support this goal, several organisations have created 'NZC Roadmaps' for the building construction industry to follow as a guide to reach the upcoming 2050 target. These roadmaps also include interim targets along the way to achieve by 2030, where specific requirements for both operational and embodied carbon reductions are outlined. For example, the RIBA 2030 Climate Challenge (2) stipulates that buildings designed today must aim to achieve a minimum reduction of 40% embodied carbon from current baseline (business as usual) values. The LETI (3) roadmap towards a zero carbon trajectory states that by 2025 100% of all new buildings must be designed to be net zero operational carbon[1], and by 2030 all new buildings are to operate at net zero operational carbon in addition to achieving a minimum reduction of 65% embodied carbon from the baseline values.

This is a substantial task required of the building construction industry to respond to and meet upcoming interim targets on the pathway to NZC in 2050. The facade has a significant role to play in design decisions being made to meet NZC targets considering its influence on both the energy consumption of a building as well as a building's total life cycle embodied carbon, which often requires a balanced strategy (4).

An industry-led group is currently drafting a Net Zero Carbon Buildings Standard for the UK (5). This standard will set out a single agreed methodology for robustly demonstrating how buildings are to meet an agreed Net Zero Carbon performance. It is anticipated this standard will impose limits on both embodied carbon and operational energy use, both of which will further drive the demand for facades to optimise a balanced low-carbon design.

As embodied carbon calculations become commonplace on projects, and now also with an industry guide dedicated to providing a consistent methodology (6), the amount of embodied carbon associated with different facade systems is becoming more apparent. With this information, designers must start to interrogate the data and use this to better understand where reductions are best prioritised to meet NZC roadmap targets.

This article aims to highlight where efforts can be focused when looking to reduce the embodied carbon of facades generally as an indicator of where business-as-usual and current 2022 achievable improvements need to evolve in the near future.

To this end, this article explores four common facade system types in a series of facade studies and asks questions regarding where some of the biggest embodied carbon contributions currently occur, and what needs to be done to meet interim 2030 embodied carbon reduction targets with regards to both procurement and design. In these studies, it is assumed that a minimum 65% reduction in embodied carbon is required in line with LETI's zero carbon trajectory.

[1] 'Net zero operation carbon' is defined by LETI as a new building that does not burn fossil fuels, is 100% powered by renewable energy, and achieves a level of energy performance in-use in line with notional climate change targets.

While this article explores the facade as a stand-alone building element as a thought-piece, with the 65% embodied carbon reduction applied solely to the facade, it is important to note that whole life carbon reductions in buildings will require a coordinated approach between all building elements to achieve the best strategy, which will typically be project specific. In practice, other building elements such as the primary structure or MEP systems may be able to reduce overall emissions more easily or faster in comparison to the façade, ultimately resulting in not all facade systems requiring a 65% reduction to reach future NZC targets. Similarly, some façade systems may be able to achieve a reduction more readily than others. Furthermore, due to the facades large influence on operational carbon reductions, this may result in less need to reduce facade embodied carbon to reach NZC targets. Therefore, opportunities for carbon reductions in a whole building may not necessarily be uniformly distributed across all building disciplines, and this will require further exploration on a project specific basis.

2. Facade study assumptions

The assumptions used in the facade studies within this article are summarised in Table 1 for baseline embodied carbon calculations which were calculated in accordance with the CWCT guide for how to calculate the embodied carbon of façades (6). LETI's indicative fabric performance values for operational energy (3) are used for each system type for comparative purposes. Concept level design information is used as the basis of each assessment where a basic, flat external wall construction is assumed. Additionally, industry standard embodied carbon factors typical to the UK and Europe are assumed for baseline figures.

The product life cycle stage (A1-A3) embodied carbon including relevant off-site emissions is the boundary for this assessment, where the objective is to review where reductions from baseline embodied carbon are required 'upfront', which is generally where the majority of the embodied carbon occurs in facades. However, it is important to note that facade replacement and end-of-life stages (life cycle stage B-C), can also add a considerable amount of additional embodied carbon to different facade systems, especially where components are not anticipated to last the lifetime of the building. This must be considered according to project specific scenarios when applying the full embodied carbon methodology on projects in accordance with the CWCT guide (6). Exploration of the impact of additional life-cycle modules will be explored in future CWCT articles.

One of the more ambitious 2030 reduction targets was used for this exercise to represent a figurative 2030 facade system which achieves 65% less embodied carbon from the baseline value.

General assumptions for all the facade systems are listed below, followed by facade specific assumptions in Table 1 on the following page:

- Facade surface area (FSA): 5.25m^2;
- Curtain wall spandrel area: 0.5m^2;
- Opaque wall U-value: 0.15 W/m^{2}K;
- Glazing area weighted U-value (frame and glass): 1.2 W/m^{2}K;
- Opaque wall build-ups include an insulated SFS system;
- 1.2 carbon calculation scale-up factor[2] is applied for early design stage assessment uncertainty (in line with CWCT methodology);
- Open-source databases (e.g. ICE Database) values used typically for the baseline, with an estimate used for curtain wall framing based on a generic, standard system EPD;
- Material components considered in accordance with Appendix B of CWCT methodology for a Simplified calculation approach.

Reducing material quantities by building nothing or less should always be the first option to reduce embodied carbon on projects as exemplified in Figure 1 (7). As a next step, we need to design and

[2] This figure is used indicatively and a higher or lower value may be more appropriate for other project specific scenarios because it will dependent on the types and level of uncertainty associated with the project.

build in more clever and resource efficient ways. Additionally, we must reduce the embodied carbon factors of the materials and components used, which entails reducing the emissions associated with the processes to create facades (e.g. energy used to extract and process materials).

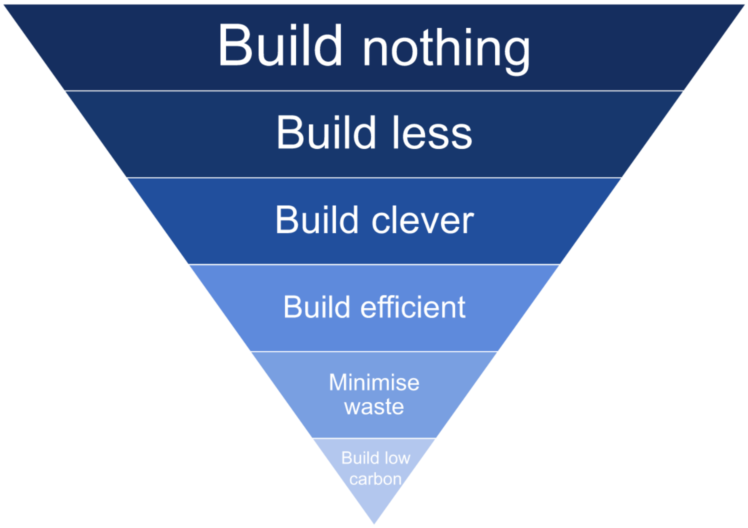


Figure 1 – Reducing embodied carbon: Hierarchy of action (adapted from PAS 2080 (8))

The approach used to assess embodied carbon reduction potential in this article focuses on the highest embodied carbon contributors in each system as target areas to reduce the embodied carbon factors of each. The facade study results present:

- **Baseline** – results using typical open-source database embodied carbon factors, not manufacturer specific;
- **2022 Achievable** – results with current achievable UK/EU manufacturer specific environmental product declaration (EPD) embodied carbon factors, subject to availability. These values are less than baseline values as a result of embodied carbon reductions achieved through various manufacturing efficiencies such as using more efficient fuels sources for fabrication, reducing transportation emissions when moving materials, or reduced emissions during raw material extraction. Further reductions are also possible through alternative design strategies as discussed for each system.
- **2030 NZC roadmap** – results that will be necessary by 2030 to meet CO_2 commitments, equating to an embodied carbon reduction of 65% applied to the complete façade system towards a NZC roadmap.

The baseline embodied carbon values presented in the following sections should not be considered as typical values for the purpose of target setting on projects, because the results can vary according to different project specific scenarios. Therefore, the embodied carbon values presented in this article are illustrative only for the purpose of this exercise. However, the principles discussed should be considered as applicable for consideration when designers are considering strategies to reduce embodied carbon in different facade system types.

Baseline values used here follow common practice where open-source database values can typically be used in early stage assessments. However, if more ambitious values can be used from the outset as a baseline, such as current achievable scenarios in 2022 presented, this can encourage more reductions to be achieved when setting targets.

Furthermore, it is important to note that the reduced numbers from baseline in all of the following graphs do not imply less material quantity (e.g. less insulation), but rather less embodied carbon, unless using less material has specifically been designed for as discussed in the examples.

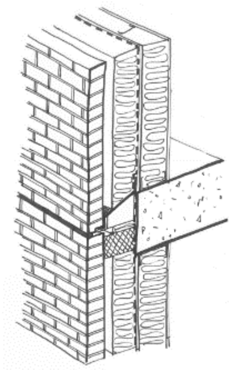
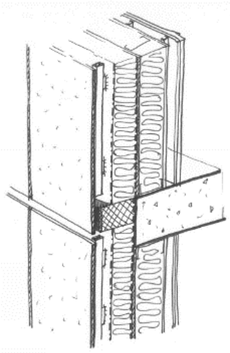
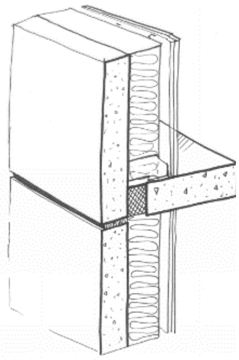
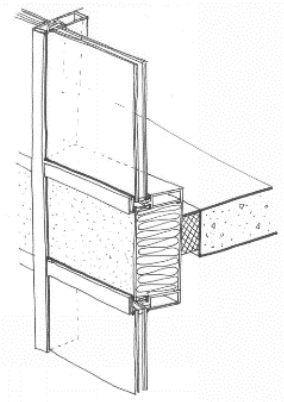
Facade system	Description
Brickwork cavity wall 	Hand-laid brick masonry, mineral wool external insulation, stainless steel bracketry, insulated galvanised steel SFS framing with plasterboard.
Aluminium rainscreen 	3mm thick semi-finished aluminium panel, extruded aluminium bracketry, mineral wool external insulation, insulated galvanised steel SFS framing with plasterboard.
Precast concrete 	150mm thick precast concrete, mineral wool external insulation, galvanised steel bracketry, galvanised steel SFS framing with plasterboard.
Unitised aluminium curtain walling 	Aluminium unitised curtain wall framing, double glazed unit infill, insulated opaque spandrel unit infill with aluminium internal and external panels with a mineral wool core.

Table 1 – facade system assumptions summary (sketches provided by Buro Happold Facade Engineering)

3. Façade study results

3.1. Brickwork cavity wall

As a baseline, the brickwork cavity wall results in approximately 320 $kgCO_2e/m^2$ FSA A1-A3. A 65% reduction in embodied carbon from the baseline is 112 $kgCO_2e/m^2$ FSA A1-A3 to meet the 2030 target.

The baseline results in Figure 2 show where the majority of the embodied carbon occurs within this system, where it is highest within the steel components, followed by the brick and insulation as the top contributors to the total embodied carbon of the system.

Applying some current 2022 achievable values to the metal, masonry and insulation shows the improvements possible today, which results in 225 $kgCO_2em^2$/FSA A1-A3, only a 30% reduction from the baseline. So, it is clear that further efforts are required to reduce the embodied carbon beyond current 2022 achievable values.

Figure 2 presents charts comparing the baseline A1-A3 embodied carbon for the brickwork versus the same figurative build-up with a reduction of 65% embodied carbon for 2030 as well as the current 2022 achievable scenario.

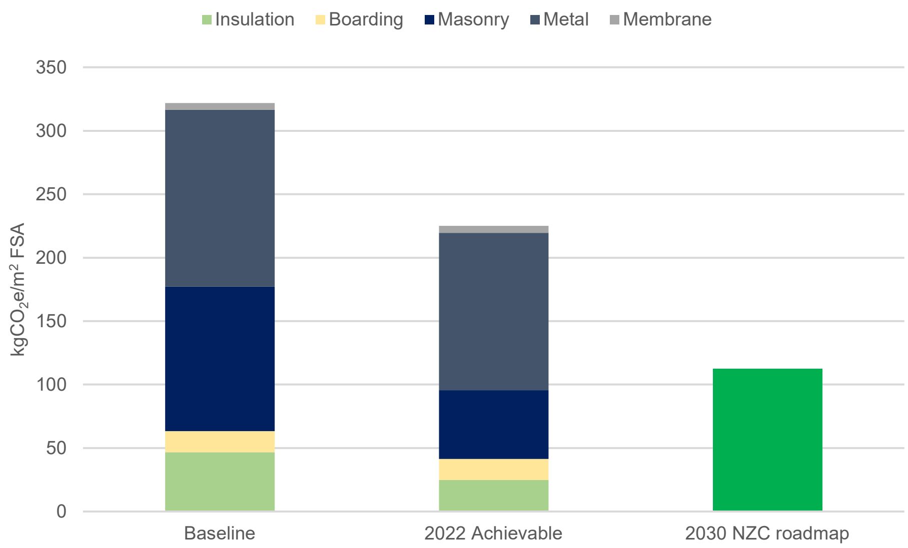


Figure 2 – Brickwork cavity wall baseline A1-A3 embodied carbon vs 2022 achievable and 2030 NZC roadmap

As shown in the 2030 target, significant interventions are required to the materials and design strategies, and it cannot be achieved only through the metal which has the highest A1-A3 embodied carbon factor using baseline and 2022 achievable figures. But is there a pathway to achieve such reductions now in the facade industry? And if not, what do we need to do now to ensure we can meet 2030 goals and beyond?

Some efforts are already being made to meet upcoming NZC targets in the steel and brick industries, however there are still barriers to reducing emissions in these materials which includes the need for more research and development.

Large steel fabricators have made carbon reduction pledges alongside launching dedicated 'Low-Carbon Roadmaps' to achieve net-zero steel by 2050 (9). Such pledges include using up to 50% low-embodied carbon steel by 2030, and 100% net-zero steel by 2050. Values that represent a low-embodied carbon steel have not been quantified to date. Considering the large impact of steel within this façade build-up, an indication of how much of a reduction may still need to be reached for facades is exemplified in the brickwork case study presented here in Figure 2.

In the brick manufacturing field, a 100% hydrogen fired clay brick is being investigated in an effort to decarbonise brick production (10). The proposed product could potentially reduce the embodied carbon of bricks by 60% by switching from natural gas to hydrogen in the manufacturing process. This would be a much-needed contributing step towards reaching carbon reductions required in brickwork facades.

Furthermore, from a design perspective, alternative support strategies for brick can help to reduce embodied carbon on projects, for example by stacking bricks over multiple stories in lieu of one to reduce the demand for dead load bracketry, which could also reduce deflection requirements at slab edges. Consideration can also be given to sourcing bricks from existing projects and demolition waste for re-use, where there is technology available to produce bricks made from at least 60% waste (11).

In regards to insulation, a common material in all facade types, major mineral wool producers have made similar announcements (12) (13) to decarbonise their products which includes efforts to reduce factory carbon emissions, and reductions in the carbon intensity of the products produced through waste reduction and recycling. The highly recyclable nature of mineral wool also has benefits which must be explored further to understand how reclaimed insulation can be implemented more widely to reduce emissions. The potential impact on mineral wool embodied carbon factors commonly used today are yet to be quantified to understand if we are where we will need to be in facades. Biobased insulation products are available but not produced at scale or readily approvable due to lack of product certification. Progress in certification and greater uptake of such materials will be necessary to ensure their viability.

3.2. Aluminium rainscreen

As a baseline, the aluminium rainscreen results in approximately 280 $kgCO_2e/m^2$ FSA A1-A3. A 65% reduction in embodied carbon from the baseline is 98 $kgCO_2e/m^2$ FSA A1-A3.

The baseline results in Figure 3 show where the majority of the embodied carbon occurs, which is highest within the metal components, followed by the insulation as the top contributors to the total embodied carbon.

Applying some 2022 achievable values to the metal (steel and aluminium) and insulation shows the improvements possible today when applied, which results in 158 $kgCO_2e/m^2$ FSA A1-A3. The current 2022 achievable reduction in this example entails use of an alternative aluminium product with a low-embodied carbon factor which includes higher recycled post-consumer scrap content of minimum 75% in comparison to an assumed baseline European average value with 30% post-consumer scrap. This results in an embodied carbon factor approximately 66% less than the baseline value for aluminium. Additionally, the embodied carbon factors of the steel and insulation were slightly improved using 2022 achievable values. These changes resulted in a total embodied carbon reduction for the system of only 43%. So further efforts are still required to reduce the embodied carbon of the metal, as well as the other components to meet the 2030 target.

Figure 3 presents charts comparing the baseline A1-A3 embodied carbon for the aluminium rainscreen versus the same build-up with a reduction of 65% embodied carbon for 2030 as well as the current 2022 achievable scenario.

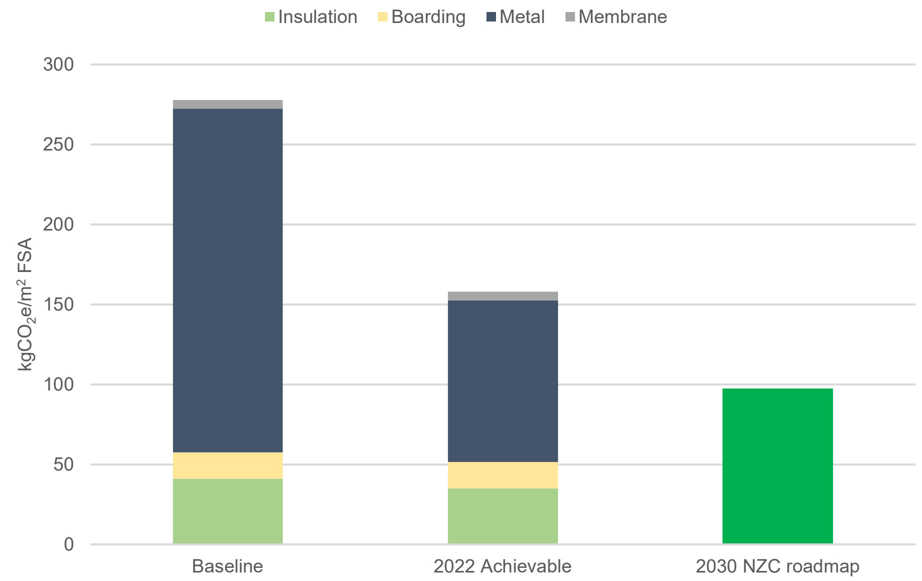


Figure 3 – Aluminium rainscreen wall baseline A1-A3 embodied carbon vs 2022 achievable and 2030 NZC roadmap

There is no question that aluminium has a significant role to play in the embodied carbon of this system, as well as facade systems in general. To address this issue, there has been some good progress to date where 'low-embodied carbon aluminium' options (14) are available as applied in the results of this study. The results here exemplify the beneficial impact of incorporating this type of aluminium, which includes a high amount of recycled, post-consumer scrap in addition to using more resource efficient fuel sources used in production. However, the use of a high amount of recycled content may result in limitations on manufacturing and procurement, where such low-carbon aluminium billet materials may currently be limited to a particular type of product (e.g. extrusions) with maximum die size limitations.

Low-carbon aluminium offerings must become the norm for more manufacturers and project specifications to reach 2030 targets especially as it has been proven to be feasible. More emphasis on removing barriers to this (e.g. cost and supply of post-consumer material) is needed in the NZC roadmap for aluminium to increase wide-spread adoption.

From a design perspective, designers can explore use of high performance or alternative materials for bracketry and thermal breaks to reduce the impact of thermal bridging, which could result in less insulation material required to meet specified U-value targets. An alternative cladding support strategy can also be explored, for example designing the cladding and rails to be fixed only at slab level in lieu of repeatedly through the insulation to mitigate thermal bridging and reduce insulation required to achieve thermal performance requirements.

3.3. Precast concrete

As a baseline, the precast concrete facade results in approximately 279 $kgCO_2e/m^2$ FSA A1-A3. A 65% reduction in embodied carbon for the system is 98 $kgCO_2e/m^2$ FSA A1-A3.

The baseline results in Figure 4 show where the majority of the embodied carbon occurs, which is highest within the precast concrete followed by the metal (steel and stainless steel) and insulation as the top contributors to the total embodied carbon of the system.

Applying some 2022 achievable values to the metal and precast concrete shows the improvements possible today, which results in 237 $kgCO_2e/m^2$ FSA A1-A3, only a 15% reduction from the baseline. The 2022 achievable reduction entails use of a precast concrete that is 20% better than the baseline concrete assumed. Again, the results show that efforts are not only required to reduce the embodied carbon of the concrete in the build-up, but the other components will similarly require drastic reductions beyond 2022 achievable values achievable to meet the 2030 target.

Figure 4 presents charts comparing the baseline A1-A3 embodied carbon for the precast concrete facade versus the same build-up with a reduction of 65% embodied carbon for 2030 as well as the current 2022 achievable scenario.

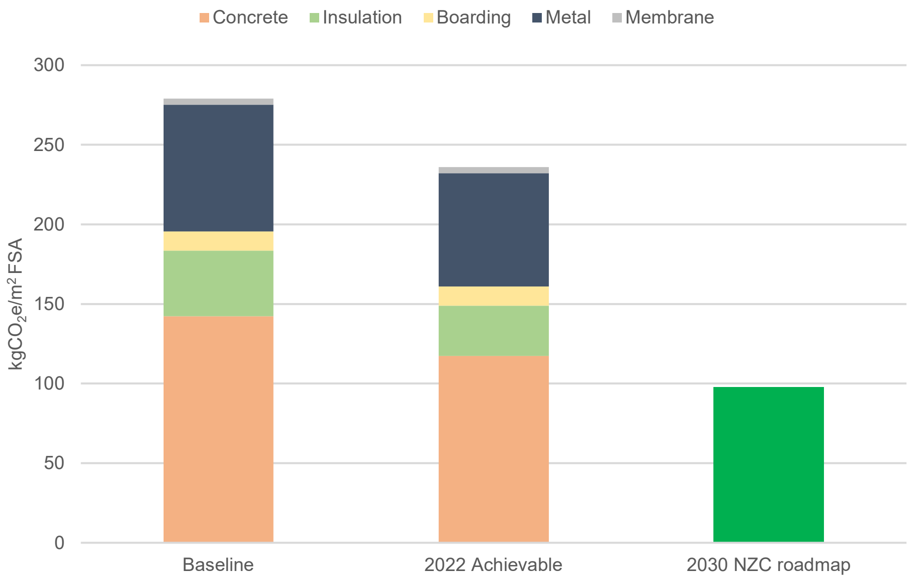


Figure 4 – Precast concrete wall baseline A1-A3 embodied carbon vs 2022 achievable and 2030

Reducing the carbon footprint of concrete in buildings and infrastructure is one of the most significant challenges the construction industry is faced with in order to meet upcoming NZC targets. When concrete is used in facades, the heavyweight precast systems can have detrimental knock-on effects to the embodied carbon of the primary frame due to the loading imposed on structures which requires more materials to support the systems in comparison to lighter-weight facade options (note that these effects on the structure have not been considered in this study). So, while precast concrete facades can often be a good strategy for the facade when considered in isolation, it may not always be appropriate when considering the environmental impact of the whole building.

However, there are some strategies that can be applied to help reduce the carbon footprint of concrete now. One being to reduce the impact of the cement in the mix design of the concrete. Cement is typically responsible for most of the embodied carbon in concrete. By specifying alternative cement types used in concrete mixtures as advised by The Institution of Structural Engineers (15), it is possible to reduce the embodied carbon of concrete in comparison to more traditional mixes. This of course will require consideration for impacts on curing time and strength requirements, as well as durability which will all need to be resolved during the design process. In the UK, a carbon neutral concrete was launched, which uses an innovative cement mix that allows for an embodied carbon reduction greater than 70% (16).

Furthermore, consideration should be given to using more efficient forms and shapes in the façade design to allow for material and production efficiencies, and/or using precast concrete facades structurally where possible to allow for further material efficiency. This must of course not compromise the thermal performance and potential for thermal bridging, all of which can be resolved with clever design and detailing during design development. Other strategies can be explored such as changing production fuel types to low-carbon alternatives (e.g. renewable energy) when manufacturing concrete to further reduce embodied carbon. Designers can also consider removing or reducing heavy gauge internal lining systems and use lighter weight systems if the external insulation can be completely fixed to the internal side of the precast concrete.

With significant embodied carbon reductions already possible over standard concrete solutions, a greater reduction is still required on projects to meet 2030 targets even though the resource is there to achieve significant carbon footprint reductions. Adoption by clients and specifiers is perhaps a contributing barrier to this, where greater efforts need to be made to move away conventional methods of concrete design and fabrication. However, a group of leading construction, engineering, and design professionals in the UK have made commitments to use 50% low carbon concrete by 2030, which can help to prove the viability and improve the adoption rate of using low carbon concrete (17).

3.4. Unitised aluminium curtain walling

As a baseline, the unitised aluminium curtain wall facade results in approximately 370 $kgCO_2e/m^2$ FSA A1-A3. A 65% reduction in embodied carbon for the system is 129 $kgCO_2e/m^2$ FSA A1-A3.

The baseline results in Figure 5 show where the majority of the embodied carbon occurs, which is highest within the aluminium curtain wall faming components, followed closely by the glazing units ("Glass" chart label) then metal used for bracketry as the top contributors to the total embodied carbon of the system. However, when considering the current service life of facade materials and components, and the likelihood of insulated glass units (IGUs) to require replacement (life cycle module B4) within the lifetime of a building, the impact of the glazing units in facade embodied carbon will quickly surpass all other components within these systems.

Applying some 2022 achievable values to the curtain wall frame, metal and glass shows the improvements possible today, which results in 200 $kgCO_2e/m^2$ FSA A1-A3, a 46% reduction from the baseline. This reduction entailed using a low-embodied carbon aluminium and steel as discussed in previous examples, a hybrid timber and aluminium curtain wall frame assuming 50% embodied reduction from a conventional aluminium frame (18), and glass with 40% lower embodied carbon than the baseline in line with some recent advancements in the glass manufacturing industry (19). Even with these reductions applied, further efforts are still required to reduce embodied carbon below current 2022 values.

Figure 5 presents charts comparing the baseline A1-A3 embodied carbon for the unitised curtain wall facade versus the same build-up with a reduction of 65% embodied carbon for 2030 as well as the current 2022 achievable scenario.

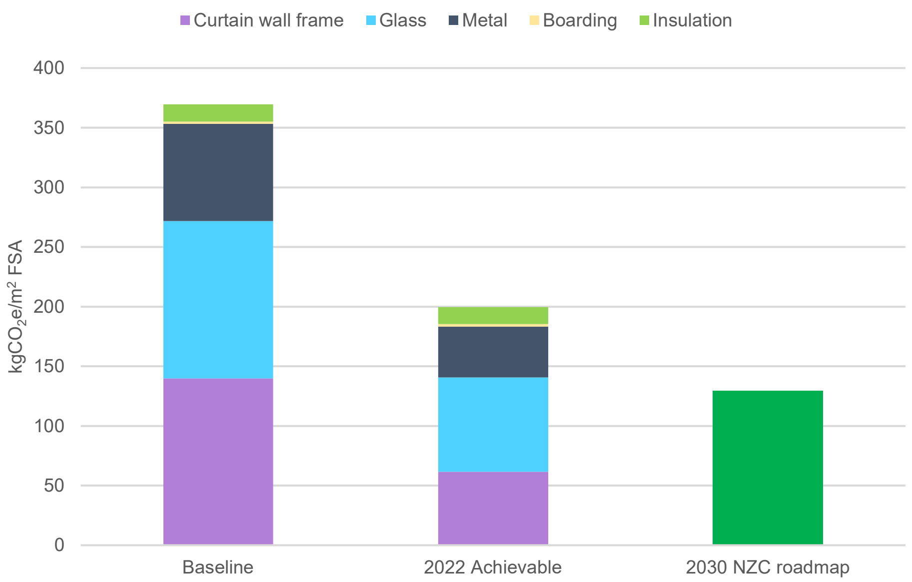


Figure 5 – Unitised curtain wall baseline A1-A3 embodied carbon vs 2022 achievable and 2030 NZC roadmap

Curtain wall framing is typically comprised of a lot of aluminium or steel as the primary material to form the component. As discussed previously, there are alternative low-carbon options that can be used to reduce the carbon footprint of metal in curtain wall framing elements. Additionally, consideration can be given to implementing a more efficient strategy to sizing the framing across a facade to avoid overdesigning elements to resist loads not applicable across the entire facade. For example, in lieu of sizing all curtain wall frames to suit the highest wind load which may only occur at a very limited area of a building, instead optimise designs to suit specific wind loads which may be lower at various locations to reduce material and waste.

Alternative materials to metal can also prove to reduce the embodied carbon in comparison to more standard metal systems. For example, hybrid timber and aluminium curtain wall framing systems, as applied in the 2022 achievable assessment, are available and verified to reduce the production stage global warming potential by up 50-70% when compared to a conventional aluminium system (18).

The reductions required for aluminium and steel in facades has been discussed in the other facade systems investigated above in this article, but one key material that remains to be discussed is glass. Glass can be a significant contributor to the embodied carbon of glazed facades often following closely behind metal. As shown in the 2022 achievable results, after reductions are applied to the metal and curtain wall framing, the glass now becomes a top embodied carbon contributor in the system.

There have been some recent advancements in glass production with the potential to reduce the carbon footprint of glass, which entails upcoming products with an increased amount of cullet (recycled glass content with increased post-consumer scrap) in combination with using renewable energy for manufacturing, ultimately offering approximately a 40% reduction in embodied carbon (19) in comparison to conventional, baseline glass production in Europe. However, as shown in the results in Figure 5, a greater effort is still needed to push glass in facades towards achieving 2030 targets. Can more be done to allow for greater service life potential, as well as more recovery and re-use of glass on facades? And similar to the curtain wall framing, can overdesign of glass units be avoided by relaxing deflection limits governed by visual tolerances, and loading criteria only applicable to limited areas of a buildings? This will require collaboration with clients, architects, engineers, specifiers, and manufacturers to work together to remove such barriers to meet 2030 targets and beyond.

4. Conclusions

A review of illustrative baseline and 2022 currently achievable embodied carbon figures for four common façade types was carried out. This included an investigation into what is required of each system to achieve a 65% embodied carbon reduction for 2030 when considering both the embodied carbon factor for production as well as design strategies, which revealed the significant challenge involved.

For facades to achieve 2030 goals, it will require change now from manufacturers, clients, designers, engineers, contractors and consultants in collaboration with one another to remove barriers and improve upon where we are currently falling short on the potential to stay on path to NZC in 2050.

The many pledges to reduce the carbon footprint of facade materials, as well as the efforts made to date are promising. But more can be done, and more must be done. Industry must work harder to minimise the impacts and quantity of material consumed on a project to achieve a required performance. The ideas presented in this article are intended to highlight potential areas to focus carbon reduction efforts now and in the future for facades.

Ultimately, to achieve the right balance in whole building embodied carbon reductions, there may be trade-offs that need to be made between different building elements and the facade to meet NZC goals. Exploration of this interaction could be investigated by studying different buildings and applying industry embodied carbon methodologies to the different building elements, such as the IStructE 's methodology for the primary frame, CIBSE's methodology for Building Services, and the CWCT's guide for facades, in addition to evaluating operational carbon reductions. This would help to review and better inform various NZC targets and standards currently available and being established with a more holistic perspective of the building.

But nevertheless, it cannot be denied that the façade has a large role to play in NZC aspirations, and the more embodied carbon that can be reduced just by making more low-carbon solutions available and implementing more clever and efficient design strategies will be a beneficial effort towards this in combination with other whole life carbon reduction strategies that must pursued.

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Centre for Window and Cladding Technology, The Studio, Entry Hill, Bath, BA2 5LY
Tel: 01225 330945, email: cwct@cwct.co.uk

www.cwct.co.uk