Facade Design Process to Establish and Achieve Net Zero Carbon Building Targets

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Abstract. As more stringent building energy codes and sustainability certification goals have become more prevalent in recent years, a focus for many building designers has been reducing the operational energy with the objective of reaching net-zero energy targets. More recently, as the efficiency in operational energy use has increased significantly, the focus is moving towards the environmental impact of building materials, primarily reflected in the embodied energy and emissions, and the potential (re)life options that allow circular material flows and reduced global warming potential. This paper investigates a methodology applied during early and advanced design development phases to assess and compare different façade typology carbon emissions. Embodied carbon is evaluated through Life Cycle Assessment (LCA) analysis, and operational carbon is analysed during the service life of the office building through energy simulation. Results show that overall carbon assessment of different facade solution can provide useful design feedback in the decision-making process.

1. Introduction

Currently the building sector generates nearly 40% of the annual global Greenhouse Gas (GHG) emissions, and we can observe that the emissions of the current building stock are split respectively in 60-70% building operation and 30-40% embodied carbon [1]. Considering the largest wave in urban growth in history with additional 230 billion m² of new floor area to the global building stock by 2050 and the 2050 UK carbon neutrality pledge it is imperative to develop design and construction processes that set carbon reduction as the main objective. Up to 50-60% of the average energy use for commercial buildings is directly affected by the building envelope thermal performance [2]. Designing high-performance façades with a specific focus on window to wall ratio, glazing and opaque thermal transmittance and solar control is crucial to significantly reduce GHG emission during the building service life [3]. Reducing embodied carbon is also essential to mitigating GHG emissions. Embodied carbon focuses on the emissions generated through the production, construction, use, and end of life processed of materials [4]. By considering the type of energy used to produce materials in addition to the materials themselves, embodied carbon can be strategically reduced and potentially offset or paid back from embodied energy savings to achieve a net zero carbon building. According to London Energy Transformation Initiative (LETI) and [5] in commercial buildings, the product/material stage (A1-A3) of a building’s lifecycle represents the biggest percentage of a buildings total embodied carbon at 48%, and the facade represents 16-20% of the embodied carbon within this stage. Due to the significant impact of the facade in influencing operational and embodied carbon emissions of a building, there is a great potential to minimise carbon with material and performance changes to a façade. However, while there is great opportunity to reduce both parameters through facade design, operation and embodied carbon must not be assessed in isolation due to potentially conflicting impacts performance criteria and/or material specification choices can have on energy consumption and embodied carbon.
2. Method
The objective of this study is to present a design decision process to holistically assess the carbon emissions of different facade system considering both embodied carbon and associated operational carbon generated during an office building service life. The proposed performance-based approach was applied to a case study office building situated in London, UK with the main facade facing south. The embodied carbon for a typical facade bay of 9m² was calculated considering varying window reveal depths using different opaque cladding configurations, such as precast concrete panel, light precast plus aluminum rainscreen and typical stud-wall with aluminum rainscreen, as well as different glazing U-values as shown in Table 1 and 2. The U-value remained constant between all variations. Embodied carbon was calculated for the A1-A3 stage only to represent the typical facade service life of 30 years. Calculations were carried out with an excel based calculation tool developed by EOC [6] in accordance with BS EN 15978:2011. Material data for calculations are primarily sourced from the ICE database and Environmental Product Declarations (EPD) for typical materials used in the UK. Embodied carbon for a facade was quantified in the CO₂eq·kg per total gross internal area (GIA), obtained by converting Global Warming Potential (GWP) per facade bay area as required by LETI.

Table 1. Facade embodied carbon, parameters and settings.

| Typical facade bay | Precast, reveal 10-50cm, DGU or TGU | Hybrid, reveal 20-50cm, DGU/TGU | Rainscreen, reveal 10-50cm, DGU/TGU |
|--------------------|-----------------------------------|---------------------------------|-----------------------------------|
| ![Diagram of facade bay](image1) | ![Diagram of precast concrete horizontal section](image2) | ![Diagram of hybrid precast/rainscreen horizontal section](image3) | ![Diagram of aluminium rainscreen horizontal section](image4) |

The simulations to assess the operational carbon were conducted in three main steps. Firstly, preliminary thermal calculations were carried out to calculate the thermal transmittance and thermal bridges values, of the envelope components. Secondly, annual energy simulations using IES VE 2019 were performed to simulate the Energy Use Intensity (EUI) for 6 different façade configurations. The EUI was simulated using a shoe-box model with the main façade facing south. The HVAC system was set as a Variable Air Volume (VAV) with airside economizer and an Air Source Heat Pump (ASHP). The thermal model and HVAC inputs are summarised in table 2. The EUI values include only the energy related to cooling, ventilation, heating and auxiliary, in order to track the impact of envelope performance parameters. Finally, the EUI value was converted into carbon emissions using the conversion parameter Standard Assessment Procedure (SAP) 10 (233 g CO₂/kWh) for the first 10 years and SAP 10.1 (136 g CO₂/kWh) for the next 20 years.

Table 2. Shoe-box model, main parameters and settings.

| Shoe box | HVAC and loads | Envelope | Cases |
|----------|---------------|----------|-------|
| Heating SP | 21 C | U-value IGU = 1.3 W/m²K | Case 1: IGU, Reveal 15 cm |
| Cooling SP | 24 C | U-value TGU =1.0 W/m²K | Case 2: IGU, Reveal 30 cm |
| CoP Heating | 2.5 | | |
| CoP Cooling | 3.8 | SHGC glass 0.4 | Case 3: IGU, Reveal 50 cm |
| Equipment | 10 W/m²² | Opaque U-value + thermal bridges = 0.6 W/m²K | Case 4: TGU, Reveal 15 cm |
| Lighting | 7 W/m²² | | Case 5: TGU, Reveal 30 cm |
| People | 0.08 p/m² | Reveal depth 15, 30, 50 cm | Case 6: TGU, Reveal 50 cm |
| Infiltration rate | 0.3 l/s m² | | |

The facade variations studied for embodied carbon were integrated into the cases listed in Table 2 to evaluate both embodied carbon and energy to determine the optimum combined solution.
3. Results
The results in Figure 1, shows:

- Increasing the reveal depth of a rainscreen (1 CO\textsubscript{2}eq/kg/m\textsuperscript{2} GIA per 10cm increase) has less impact than increasing the precast reveal depth (6 CO\textsubscript{2}eq/kg/m\textsuperscript{2} GIA per 10cm increase).
- A precast facade has lower embodied carbon than a rainscreen up to max 20 cm reveal depth.
- A hybrid facade of precast and rainscreen with deep reveals (case 3 and 6) should be avoided due to significant increase in embodied carbon in comparison to a lightweight solution. Increase in EC is significantly higher than the energy saving obtained by the extra shading.
- The difference between embodied carbon using a DGU and TGU is 1-2 CO\textsubscript{2}eq/kg/m\textsuperscript{2} GIA, increase that partially offset the benefit in operational carbon around 3-4 CO\textsubscript{2}eq/kg/m\textsuperscript{2}.
- All cases meet the LETI 2020 facade embodied carbon target in the A1-A3 stage with the exception of the precast and aluminium hybrid facades (case 3 and 6), and a precast facade and rainscreen with a reveal greater than 30cm and 40cm, respectively, with TGU. No cases meet the LETI 2030 target for facades, which stresses the need for low carbon strategies.
- Improvements in operational carbon due to better performing insulated glazing and deeper shading reveals are partially or entirely offset by increase in embodied carbon.

![Figure 1. Embodied, operational and total carbon emissions for precast and rainscreen facade.](image)

4. Conclusions
The proposed performance-based design approach can provide designers with important feedback to compare and select which facade solutions can have the lowest carbon impact. Solutions that at first can be discarded, for instance, because of higher operational emissions can represent valuable options considering lower embodied carbon emissions. Future research can investigate the impact of facade options considering a 60-year lifecycle in which components will be replaced. Furthermore, the impact on the embodied carbon of the primary structure and mechanical systems can also be explored.

References
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