Whole-Life Carbon in Office Building Design:
Lessons from Built Precedents and Design Application

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ABSTRACT: CO_2 emissions of buildings are progressively shifting from operation to other lifecycle stages. Despite the increasing importance of embodied carbon, it remains unregulated, without defined standards or industry benchmarks. This paper presents research findings from the analysis of five exemplary built precedents, comparing both operational and embodied CO_2 emissions with benchmarks. Designed with a holistic approach, the whole-life carbon emissions from these buildings are shown to have been reduced by some 50%. Design guidelines resulting from study of these built precedents have been synthetized into a design application for central London, with estimated a 75% reduction in carbon emissions when compared to standard buildings.

KEYWORDS: whole-life carbon, office design, operational, embodied

1. INTRODUCTION

The increasing strictness of national energy standards combined with the gradual integration of renewable energy generation are effectively lowering CO_2 emissions from buildings. However, as buildings become more energy efficient, the embodied carbon accounts for an increasing proportion of their whole-life CO_2 liability. Yet, this is not regulated, there are no benchmarks, and no standard assessment methodology has been agreed [1-2].

2. METHODOLOGY

The paper draws from the results of a comparative study of five high-performance office buildings that were designed to minimise CO_2 emissions over their entire life-cycle [3]. The buildings' carbon emissions were calculated over 60 years with CO_2 intensity factors for space heating and cooling of 0.194 and 0.55 $kgCO_2$ / kWh respectively disregarding grid decarbonisation. Embodied carbon analysis includes lifecycle stages from cradle to gate, defined as A1-A3 by CEN/TC350. Results were extracted from technical reports produced by the design teams or calculated by the author based on project drawings and embodied carbon coefficients [3].

3. CASE STUDIES

Each of the five buildings selected for this comparative study manifests visionary concepts aiming at a new paradigm for sustainable architecture. Driven by challenging design briefs, the buildings tackle operational carbon through passive design while also addressing the CO_2 emissions associated with manufacture and construction.

The study has shown that internal heat gains drive the operational CO_2 whilst embodied carbon is subject to the built form and materiality of the buildings. Figure 1 shows operational CO_2 savings of some 60% compared to current Building Regulations [4-5]. Moreover, embodied CO_2 was reduced by 40-60% from reference values [6-9]. Absolute savings in embodied carbon are comparable to the reduction in operational CO_2.

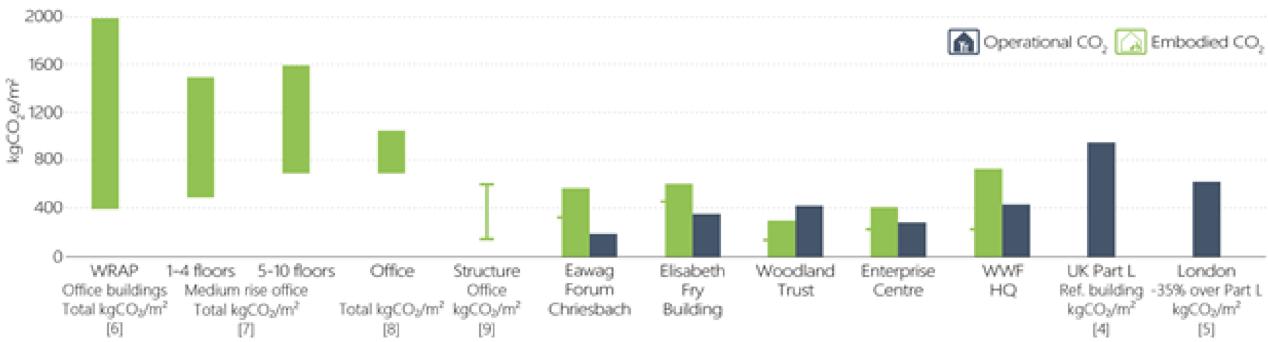

Figure 1: Benchmarks for embodied and operational carbon [4-9]

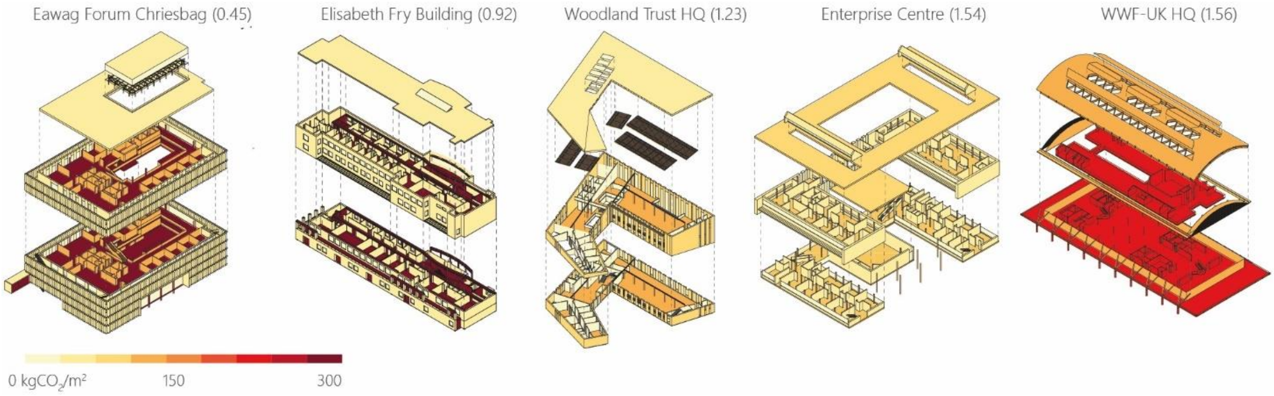

Figure 2: Embodied CO2 by floor area and compacity ratio

Embodied carbon results are summarised in Figure 2. In the case of Eawag and Elisabeth Fry buildings the CO_2 intensive components are balanced by the buildings' compact shapes, with an envelope to floor area ratio of 0.45 and 0.92 respectively. For Woodland Trust HQ and Enterprise Centre the result is influenced by their use of natural materials. WWF-UK HQ is subject to high exposure owing to strict site requirements.

4. DESIGN PROPOSAL

The comparative study was followed by a design exercise that synthesises the research findings. The design proposal is for a real site in Central London and thus responds fully to constraining site conditions as well as applying the design strategies extracted from the built precedents. The built form is designed to maximize daylight and winter solar access while maintaining a compact shape (Fig.3). The volume is perforated by two atria that help organise the plan as well as enhancing natural ventilation during summer.

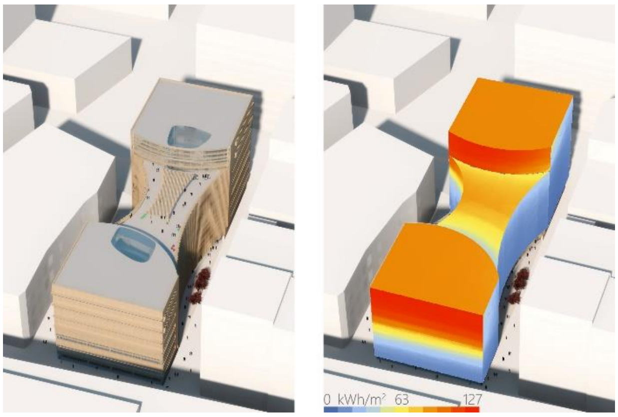

Figure 3: Design application in central London – aerial view and winter solar radiation analysis

Construction is of a CLT structure and acetylated timber envelope aimed at low embodied CO_2, whereas lateral stability and thermal inertia are provided by two concrete cores. The aforementioned design strategies reduce the whole-life CO_2 emissions of the project by 75% compared to a standard office building [3]. Operational emissions were calculated over 60 years using future weather files. CO_2 intensity factors are 0.194 $kgCO_2/kWh$ for heating and 0.49 $kgCO_2/kWh$ decreasing to 0.08 $kgCO_2/kWh$ in 2032 for cooling. Embodied carbon analysis includes life cycle stages A1 to A3.

5. CONCLUSION

Tackling the increasing importance of embodied CO_2 in buildings is fundamental to reduce their whole-life footprint. The effective manipulation of building shapes and materials is essential to lower both operational and embodied emissions. Design teams may be able to achieve reductions of 50-75% in whole-life carbon emissions by careful application of environmental design strategies from the inception of the project.

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