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Life cycle energy and carbon assessment of double skin façades for office refurbishments

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ABSTRACT

In countries like the UK, the upkeep of existing buildings is where the greatest opportunities for achieving carbon reduction targets lie. Façades are the physical barriers between outdoors and indoors, and their upgrade can arguably be amongst the most effective interventions to improve the existing stock. Double Skin Façades (DSFs) represent a possible solution for low-carbon refurbishment due to their capability to reduce energy consumption, and the related carbon emissions, of the building they are applied to. Although much research exists on maximising the operational energy savings of DSFs, little is known about their life cycle performance. This article addresses such a knowledge gap through a comparative life cycle assessment between DSF refurbishments and an up-to-standard, single-skin alternative. This study adopts a parametric approach where 128 DSF configurations have been analysed through primary data. Energy and carbon (both operational and embodied) are the units assessed in this research. Results show that DSFs are more energy-efficient than single-skin in 98% of the cases, and more carbon-efficient in 85% of the cases. Not only does this study represent the first broad parametric approach to evaluating life cycle energy and carbon of DSFs within its given context, but it also informs environmentally-aware design and application of DSFs.

1. Introduction

Buildings in the UK account for over 40% of national energy consumption and carbon dioxide emissions [1]. Due to poor thermal performance, mainly related to their age of construction, existing buildings offer a vast opportunity for decreasing those emissions and energy consumption [2]. Furthermore, only 1–2% of the building stock is replaced each year [3], with 75% of non-domestic buildings built before 1985 [4] and predictions that 75–90% of them will still be in service by 2050 [5]. Offices are top contributors to energy consumption and carbon dioxide equivalent emissions (CO_{2e}) in the non-domestic sector [6], and reducing energy demand through retrofitting deserves to become a priority [7]. Nevertheless, existing buildings remain largely untouched, and many refurbishments fail to deliver low-carbon buildings [8,9] despite estimates which suggest innovations in non-domestic buildings can offer savings of up to 86MtCO_2 by 2050 [10]. Therefore, one of the major challenges for the future is “to promote the sustainable refurbishment of that consolidated [building] stock” [11].

In this respect, improvements to the building façade are arguably one of the most effective interventions. Façades provide physical barriers between outdoor and indoor spaces, thus playing a major role in energy consumption [12] and, consequently, in carbon dioxide emissions, which has been proven to be more valid in refurbishment projects [5]. Glazed Double Skin Façades (DSFs) have been identified as a suitable demand-side technology to reduce energy consumption and GHG-emissions [13], whilst providing comfortable conditions to the occupied spaces [14]. In refurbishments a DSF consists of a second, glazed skin installed in front of the existing building façade which creates an air space that acts as a thermal buffer, a ventilation channel, or a combination of both. The operational behaviour of DSFs has been widely studied and in temperate climates this technology seems capable of note-worthy reductions in the energy demand of the building they are applied to [12,15–17]. Conversely there are also studies reporting increased energy consumption directly linked to the DSF [18,19], which highlight the need for careful analysis at the design

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stage. To avoid the overheating of the upper floors Hamza et al. [20] showed the need to extend the cavity above the roof level to provide enough thermal stack. Pasquay [21] monitored existing buildings in Germany concluding that natural ventilation with the DSF is possible all year round. Artmann et al. [22] showed the need of operable inlets and outlets of the cavity to maximise natural ventilation whilst preserving the thermal buffer potential.

The wealth of studies on the operational phase of the DSF are starkly contrasted by an extremely limited knowledge about its embodied energy and carbon. This paper aims to address such a knowledge gap through a comparative assessment of DSF and an up-to-standards single-skin refurbishment alternative. The life cycle environmental impacts of DSFs for office refurbishments are assessed through a cradle-to-grave LCA with a twofold aim. First, the life cycle energy is assessed through the comparison of operational energy savings of DSFs over a single-skin solution against DSFs embodied energy figures to establish whether, and in which cases, the former outweighs the latter. Secondly, the same comparative assessment is then made from a carbon perspective, in terms of CO_{2e} emissions; to determine if DSFs can be considered as a low-carbon technology for the refurbishment of the existing office stock in Britain.

2. Life cycle assessment of double skin façades

Sustainability assessment of buildings throughout their whole life cycle is not currently regulated by policy in Europe [23], although there exists standards that address LCA in general [24,25], and the sustainability of construction works in particular [26,27]. Nevertheless, LCA scenarios are inconsistent and varying with regards to settings, approaches and findings. Such issues hinder consolidation and comparison of results. Different lifetime figures, lack of parametric approaches addressing multiple scenarios, little clarity in the functional unit (FU) considered, diverse methodologies and methods for conducting the studies, and the focus mainly on real buildings – which makes any generalisation hard to make – are the most important reasons [28]. Such diversity is justified by and originates from the inherent complexity of the construction sector where each material used has its own specific life cycle and all interact dynamically in both temporal and spatial variations [29–31]. The long lifespan of buildings combined with change of use during their service life also imply lower predictability and higher uncertainty of variables, parameters, and future scenarios [31,32].

Only few studies exist that provide a detailed analysis on DSFs from a life cycle perspective [33,34]. This on its own represents a significant knowledge gap considering that the DSF is a technology widely used in the Architecture, Engineering, and Construction (AEC) industry. Existing studies are mainly located in specific contexts, thus increasing the difficulty in comparing and replicating results and methodologies. They also refer to very particular and innovative DSF configurations which do not represent the current practice in the AEC industry.

Wadel et al. [33] adopt a simplified LCA for an innovative type of DSF with vertical shading devices placed at specific intervals. The use phase is not incorporated in the LCA and impacts assessed throughout the study are the EE and CO_2 emissions, the FU being 1 m^2 of façade with a lifespan of 50 years. With reference to those two impact categories the DSF, in its best configuration, is capable of a 50% reduction in energy consumption and CO_2 emissions compared to conventional façades [33].

de Gracia et al. [34] conduct a cradle-to-grave LCA of a DSF with phase change materials (PCM) in its cavity. Their LCA utilises the Eco-Indicator 99 (EI99) [35], an impact assessment method based on endpoints. This means that results from different impact categories are normalised and brought together to contribute to a final, single, cumulative score (known as an 'endpoint') for the product/process under examination [35]. The FUs used are two whole cubicles constructed in Spain, one with a DSF and the other without, assuming a lifespan of 50 years where the DSF appears to reduce the environmental impacts by 7.5% compared to the reference case [34].

Notwithstanding the importance of regional and local foci in LCA, neither of the studies allow for generalisations needed for better informed applications of DSFs. More generic perspectives would enable a broader use of the methods and also ease comparison of results from different contexts. A less context-specific environmental impact assessment of office façades has been conducted by Kolokotroni et al. [36]. They assessed one specific DSF configuration among many options for both naturally-ventilated and air-conditioned offices. As such the depth of the investigation is forfeited for the breadth. The authors assessed EE in their study and also environmental impacts through the EI99 method [35], finding the DSF has high EE and low EI99 score for both naturally ventilated and air-conditioned offices [36].

Apart from these three studies DSFs have not been investigated from a life cycle perspective. Nor have they been studied in a refurbishment context in comparison with single-skin solutions. Consequently, primary data related to DSFs' EE are still largely missing in the literature. This is mainly due to lack of information for glass-related processes, and echoes a known issue in the LCA community: the lack of reliable and complete data about buildings materials and assemblies [37–39] which, if existed, would allow for better informed environmentally-conscious decisions.

3. Research design

This article focuses on a comparative assessment between double- and single-skin strategies for office refurbishments in the UK, to answer the following two research questions:

(1) From a life cycle perspective, are DSFs more energy efficient than up-to-standards single-skin alternatives for office refurbishments in the UK?
(2) From a life cycle perspective, are DSFs more carbon efficient than up-to-standards single-skin alternatives for office refurbishments in the UK?

To answer those questions, a cradle-to-grave LCA of DSFs for office refurbishment has been conducted based on the aforementioned existing standards [24–27]. The LCA methodological framework consists of four phases [24]: (1) goal and scope definition, (2) life-cycle inventory analysis (LCI), (3) life-cycle impact assessment (LCIA), and (4) interpretation.

The first phase deals with defining the goal and scope of study; which has been given in the introduction of the paper. It also addresses system boundary, functional unit to ensure comparability and reproducibility, level of detail, and depth and breadth of the assessment. In this stage, questions and/or hypotheses are generally formulated. For the assessment, this research uses the attributional approach, which focuses on physical flows to and from a life-cycle and its components, this being the approach recommended by national documents to assess GHG-emissions of goods and services [40].

LCA literature provides case studies which are often based on specific buildings, thus hindering generalisation of the conclusions and comparability of the results. Therefore, a generic yet representative office with a very slender built form has been selected, this being the most common office building type in England [41,42]. It consists of 9 floors of 66.6 m × 16 m with an open plan layout, totalling 9590 m^2 of treated floor area (TFA). Window to wall ratio