The retrofit of ‘70s office buildings curtain walls in London

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Abstract. The built environment accounts for 44% of UK emissions, of which 18% are from non-domestic buildings. Considering that a façade’s performance accounts for more than 50% of the energy consumption of a building, the retrofit of a ‘70s curtain wall system is analysed along with common issues such as poor insulation, fire risk, air infiltration and absence of natural ventilation, all of which are known to affect both occupants’ comfort and energy demand negatively. The methodology includes thermal and energy analysis of the Euston tower, results from which are used to inform an analytical model representing a more extensive building stock. Orientation, occupation, window to wall ratio and floor heights are examined as the main factors influencing heat gains, and different passive design solutions are tested to reduce them. Combining these passive design strategies shows a reduction of cooling demand by up to 91% and overheating hours down to 0% from base case to best case, demonstrating how the retrofit of curtain walls in office buildings is essential to cut emissions, reducing energy demand and improving comfort and productivity.

Keywords: curtain walls retrofit; natural ventilation; passive design; carbon reduction

1. Introduction
When considering London’s ambitious plan to become a zero-carbon city and that 75% of the existing building stock will still be in use in 2050 (London Environmental Strategy, 2017), particular attention must be paid to retrofit schemes to reduce emissions and achieve this goal. In the UK, 20% of the total CO₂ emissions come from commercial buildings, and as facades play a crucial role in energy consumption and comfort, their retrofit is essential to meet current sustainability standards. With growing awareness of the need for a sustainable economy, the circular economy principles of re-use and re-cycle can be drivers for this industry.

Within the commercial buildings sector, the retrofit philosophy does not only enable energy-efficiency improvements but also improved quality within the workplace, higher levels of productivity, and increases in capital and thermal comfort. After defining the value of retrofit, this work develops with a focus on façades as they affect more than 50% of the energy performance of a building, and they need to be renovated generally after 50 years. According to a study conducted by T.Ebbert in 2009, the office stock of the European countries consists of 604 million m², 510 million m² of this is façade, of which 34% are of a curtain wall typology. Considering that these façades are ageing, 180 million m² of curtain wall will be demolished in the near future.

As the city with the highest concentration of office buildings in the UK, London was chosen as the location of this research, with a focus on ‘70s buildings’ facades as they have already reached the end of their life cycle. The aim is to address the environmental issues of these old curtain walls with the installation of new climate-responsive, modular façades. Along with sustainability, different aspects of façade design have also been included. Fire protection and the influence of COVID-19 are also considered as drivers for a new conceptual envelope for office spaces.
2. The retrofit of Curtain Walls

The development of curtain walls started in the early 19th century in the US, when providing construction prefab elements was necessary to reduce the use of expensive skilled labour. Due to the evolution of the metallurgic industry, the widespread use of iron columns could support the façades entire weight, allowing more oversized windows than the traditional masonry external walls could support. Different materials have been used during the evolution of this modern architectural feature, until the arrival of fully glazed curtain walls in the ‘50s. The glass architecture industry increased even more from the ‘90s thanks to aluminium frames which were lighter and thinner, which gave façades a more transparent look. However, the price for transparency is a higher energy demand and, after the ‘70s energy crisis, the glazing industry had to develop different solutions to improve thermal properties such as tinted glass, multilayers windows and double skin façade (DSF). When the decisions to renovate a façade is made, the opportunity to invest in high-quality architecture comes to give a building an added value both for the users and the environment.

Reasons for facade retrofits are usually a combination of various aspects. Often these can be related to issues around building physics such as energy performance, condensation problems, airtightness, acoustic, safety, fire security, daylight, solar gains and thermal comfort. However, today the environmental challenge includes the consideration of embodied carbon and life-cycle assessment, increasing the interest in natural materials to build curtain wall frames. As previously mentioned, this study focuses on London’s ‘70s office building stock as they have similar features and issues while their age will put them towards the end of their 50-year lifecycle. Their typical plan distribution is a deep floor with a load-bearing core where lifts and vertical services are located. Sections include raised floors and suspended ceilings with allocated aeration services. The usual office type is cellular/open office, and the building frame can be both concrete or steel. Façade modules are mostly made of anodized aluminium, and the vision panel is usually single glazed with the operable part at the top and back spandrel metal panel at the bottom.

3. Preliminary design considerations

Preliminary design considerations like fire risk, cost/benefit analysis, covid-19 and carbon footprint were made at the first stage. Fire protection is recognized as one of the main drivers for a façade uplift following the Grenfell tower accident. As the focus on sustainability and low carbon material might cause fire-safety concerns, it is essential to evaluate which material, coating and insulation will be used. For example, polyurethane insulation which was largely used in ‘70s facades must be avoided for its high fire risk and replaced by Rockwool for its low embodied energy, high insulation property and fire resistance. Additionally, it must be said that cost/benefit estimation has a significant effect on the retrofit design decisions of every project, especially for non-domestic buildings due to their high running cost. The most common method to calculate it is the payback period, and its equation (\(PP=\frac{Vs}{Vi}\)) represents the value of saving compared to the value of the investment associated with a retrofit measure. As the retrofit market works in a 3-5 years payback period, HVAC and lighting systems are usually the preferred replacement for the immediate savings on the electricity bills. However, an aspect largely neglected in this calculation is the lack of comfort and productivity cost. As
the cost of people is 72 times the cost of energy bills, enhanced productivity due to naturally ventilated space and a better working environment can result in a quick retrofit investment offset (Brager, 2016).

To complete the preliminary study, particular attention has been paid to the current pandemic influence on office design. To reduce the spread of the virus, two different typologies of fixes were identified: short-term and long-term. Short-term fixes include reducing the number of staff in the office, work rotation and smart working from home. Long-term strategies consist of design upgrades and modifications that put hygiene at the heart of workplace planning as sneeze barriers, cellular office typologies, hand washing stations and natural ventilation to improve air quality. Finally, when it comes to sustainable buildings, it is a mistake to focus only on energy efficiency, and a whole-life carbon analysis must be taken into account. Aluminium is one of the most carbon-intensive materials and, as mentioned before, is generally used for curtain walls frame. Therefore, an effective way to reduce the embodied carbon is a composite aluminium-timber frame that can save up to 71% of CO₂ emissions when compared to the aluminium counterpart (Argent LLP et al., 2016).

4. Case study: The Euston tower

Subsequently, an analytical study was conducted on the Euston tower to understand mechanically ventilated office towers of the ’70s. The building presents an aluminium curtain wall DSF type, typical of that age. It was modelled using EDSL Tas, and from a first energy loads analysis, it emerged that the energy demand exceeds the Passivhaus target (30KWh/m²) in every part of the building except for the private office space (occupancy 12 m²/ person). Cellular offices (occupancy 8 m²/person) and meeting rooms (occupancy 3 m²/person) showed very high cooling loads (up to 100KWh/m²) due to high people gains. On the contrary, heating loads are within the thresholds revealing that internal gains due to occupancy, lighting and equipment make the space sufficiently warm during winter.

A following thermal analysis confirmed this theory and revealed that cellular offices also need cooling in winter. The analysis showed how the heating demand is only concentrated in the early morning where the outside temperatures are lower, making a pre-heating period necessary to warm up the office before it is occupied. These results confirmed that high energy demand for cooling is a significant issue for this building typology. Therefore, simple environmental strategies were applied such as scenario 1 which looked at replacing lighting systems with an energy-efficient LED system (5W/m²). Scenario 2 proposed an occupancy reduction (10W/m²), while scenario 3 was natural ventilation through the existing small apertures. The cumulative effect of these strategies showed a reduction in energy loads by up to 61% compared to the existing base case, as a result of these low-cost approaches.
5. Design Optimization

Following the Euston tower study, a further analytical model has been built with EDSL Tas. This model consists of a thirty floor, courtyard building surrounded by an eight-floor building to allow the analysis of obstructed and unobstructed views. Three different floor levels were studied: ground, middle and top. Values from the previous study informed the construction of this base case scenario such as an occupancy density of 8 m²/pp, lighting gains (5W/m²), and the use of natural ventilation as a primary strategy to reduce cooling loads. A conceptual window divided into three parts with the top and bottom apertures operable been designed to benefit from stack ventilation on a single-sided façade (typical of deep floor buildings) and three different WWR 40-60-80% have been created modifying the frame sizes and making the bottom panel opaque.

Fixed shading devices were calculated through grasshopper radiation benefit, resulting in the same horizontal louvres dimension on the east and south facade (360mm depth with 500mm pace), and vertical shading 350mm depth with 300mm pace for west orientation. Materials were assigned to the model according to the typical ‘70s office buildings with concrete structure. The curtain wall module frame considered is an alu-timber typology with a glass area double glazed and insulated with argon. Shading louvres are also made of timber. Seven different scenarios were tested on the middle floor, five on the ground floor and four on the top floor.
These scenarios considered external and internal variables (orientation, cellular office gains, floor height) and different environmental design strategies (WWR, shading, G value, natural ventilation with different % of window opening, night-time ventilation). The last scenario considered was the exposure of thermal mass by removing the suspended ceiling, typical of offices of that age and uncovering the concrete ceiling. The results obtained from the simulations refer to the passive zone, the depth for which is twice the floor to ceiling height. This is the area closest to the façade and most influenced by passive design (N. Baker, 2000). Finally, to compare the outcomes of the simulations, cooling loads and overheating hours were calculated and compared to Passivhaus and CIBSE TM52 standards.

The final results confirmed that a 40% WWR works better on all middle floor orientations while 60% is applied on the ground floor due to the obstructed views and following an average daylight factor calculation. The results for the top floor were different, where to reduce the overheating hours from 30% to 17%, a lower WWR of 25% was considered. However, taking into account that the main reason for overheating is not only solar gain but also gains from occupants, a lower occupancy was also tested on this floor. Thermal mass exposure showed its considerable effect on the ground and the middle floor making the overheating hours down to zero. Conversely, it did not work on the top floor because of the influence of the uninsulated roof. The analysis of the cooling load’s showed how the environmental strategies adopted were able to reduce the energy demand drastically from base case to best case in every floor and orientation. For the middle floor, this reduction is on average 90% while on the ground floor, around 85% from base case to best case. The ultimate scope of this analytical work was also to identify the effectiveness of the different environmental strategies. As a result, in order of importance, day-time ventilation shows to be the best strategy followed by night-time ventilation, thermal mass, shading and G-value reduction.
6. Research outcomes and conclusions
This study revealed how retrofitting curtain walls is of paramount importance to achieve the London zero-carbon goal. However, justifying a façade retrofit is not always easy, and a cost/benefit approach showed that productivity plays a crucial role to encourage both tenants and office owner to participate in the expenditure. The recent COVID-19 pandemic provides a new challenge for office design and social distancing restrictions will definitely influence future occupancy levels and introduce new design features like sneeze-barriers and handwashing stations. Additionally, considering the life-cycle carbon footprint of curtain walls, materials selections such as an alu-timber frame type is an excellent way to reduce this balance (up to 71% reduction compared to a typical anodized aluminium solution).

The Euston tower analysis provided a case study to understand how the old, uninsulated curtain walls of the ‘70s negatively influence cooling energy demands. The following design optimization implemented the data obtained from the Euston tower analysis by building a general analytical model based on previous findings. The outcome of this section revealed how a different WWR needs to be applied according to floor level to contrast the solar gain. Thermal mass is very effective on the ground and middle floors, but it cannot be used on the top floor if the roof is not insulated and sufficiently ventilated. The final results of this research process also revealed that ventilation is the best strategy to cut cooling loads (more than 50% respect base case) and improve comfort, followed respectively by the utilisation of thermal mass, shading and G-value reduction. Moreover, the focus on the passive zone confirmed that, as this area benefits the most from the environmental design strategies, a free-running mode is possible throughout all seasons. However, for the deeper parts of the building and at higher floor levels a mixed-mode strategy with efficient mechanical ventilation should be investigated.

To conclude the retrofit of office buildings curtain walls is essential to cut CO₂ emission, reducing energy demand and improving comfort and productivity within a workplace environment. Optimised climate-responsive buildings should consider façades that are non-uniform, with different WWR according to floor heights, shading devices and G-value calculated according to orientations.

Figure 7 External and internal views of the new curtain wall prototype

7. References
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