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The Retrofit of '70s Office Buildings Curtain Walls in London

Alessandro Cirillo[1]

[1] MSc Architecture & Environmental Design, University of Westminster, London, UK, alessandro.cirillo@hotmail.com

Abstract: The built environment accounts for 44% of the UK emissions, of which 18% is from the non-domestic buildings. Although new buildings are becoming more environmentally friendly, low retrofit rate offsets this trend. The retrofit of curtain walls of the '70s is here analysed as they present similar issues like poor insulation, fire risk, air infiltration and absence of natural ventilation which affect both internal comfort and energy demand negatively. The methodology includes thermal and energy analyses of the Euston tower, which results are used to inform an analytical model representing a more extensive buildings stock. Orientation, occupation, window to wall ratio and floor height are examined as the main factors influencing internal gains, and different passive design solutions are tested to reduce them. The new facade module includes alu-timber windows frame, shading devices, reduced G value, different WWR and natural ventilation strategies which result in a significant environmental performance improvement.

Keywords: curtain walls retrofit; natural ventilation; passive design

1. Introduction

Considering the ambitious plan of London to become a 0-carbon city and that 75% of the existing building stock will be still in use in 2050 (London Environmental Strategy,2017), particular attention must be paid on the retrofit to reduce emissions and achieving this goal. In the UK, 20% of the total CO2 emission comes from commercial buildings, and as facades play a crucial role in energy consumption and comfort, their retrofit is essential to meet current sustainability standards. Moreover, the growing awareness in sustainable economy and the re-use and re-cycle concepts are the favourable background for the expansion of this industry.

Concerning the commercial buildings sector, the retrofit does not only allow energy-efficiency improvement but also better quality of the work-place, productivity, capital and thermal comfort. Once defined the retrofit value, this work develops focusing 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 m^2, 510 million m^2 of façade, of which 34% are curtain wall type. Considering that these façades are ageing, 180 million m^2 of curtain wall will be demolished in the nearly future.

As the city with more concentration of office buildings in the UK, London is chosen as the location of this research, and the '70s buildings facades are studied as they already reached their end of life. Therefore, the aim is to address this old curtain walls environmental issues thanks to the installation of a new climate-responsive modular façade. Along with sustainability, different aspects of façade design have also been included. Fire protection and the COVID-19 influence are considered as the drivers of a new concept envelope for office space.

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. Besides, 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. Different materials have been used during the evolution of this modern architecture 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, lighter and thinner, which gave to façades a more transparent look. However, the price for transparency is high 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 environmentally and for the users.

Reasons for facade retrofits usually combined different aspects most of the time related to the building physic like 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 '70s office buildings as they have similar features and issues and they reached their end of life. Their typical plan distribution is a deep floor with 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 aluminum, and the vision panel is usually single glazed with the operable part at the top and back spandrel metal panel at the bottom.

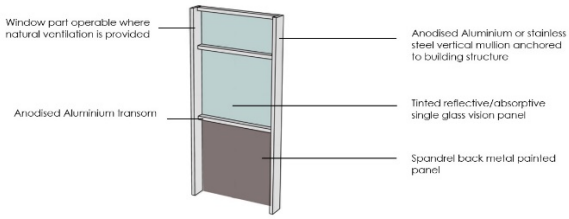

Figure 1. Typical façade module

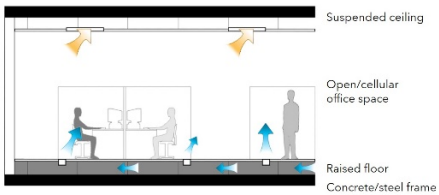

Figure 2. Typical office section Historic England,2013

3. Preliminary design considerations

Preliminary design considerations like fire risk, cost/benefit analysis, covid-19 and carbon footprint were made at a 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 problems, it is essential to evaluate which material, coating and insulation will be used. For example, polyurethane insulation which was largely used in the '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 for their high running cost. The most common method to calculate it is the payback period, and its equation (PP=Vs/Vi O. Duran,2018) represents the value of saving compared to the value of the

investment associated with a retrofit measure. As the retrofit market works in 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 better work environment, can result in a quick retrofit investment offset (Brager,2016).

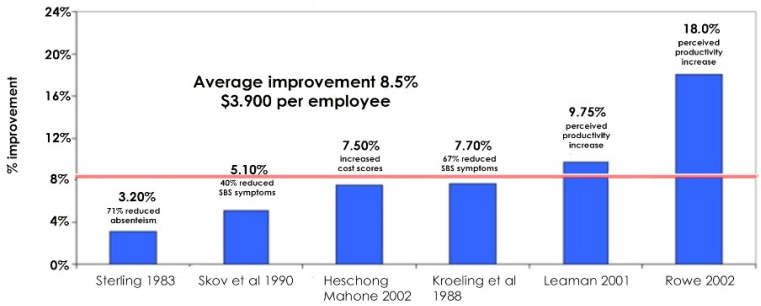

Figure 3. Productivity gains from mixed-mode conditioning to natural ventilation. Brager,2016

To complete the preliminary study, particular attention has been paid to the current pandemic influence on office design. To reduce the virus spreading 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 type, 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. Aluminum is one of the most carbon-intensive material and, as mentioned before, is generally used for curtain walls frame. Therefore, an effective way to reduce the embodied carbon is a composite aluminum-timber frame that can save up to 71% of CO_2 emissions when compared to the aluminum counterpart (Argent LLP et al.,2016).

4. Case study: The Euston tower

Subsequently, an analytical study was conducted on the Euston tower to understand the mechanically ventilated office towers of the '70s. The building presents an aluminum 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 private office. Cellular offices and meeting rooms 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.

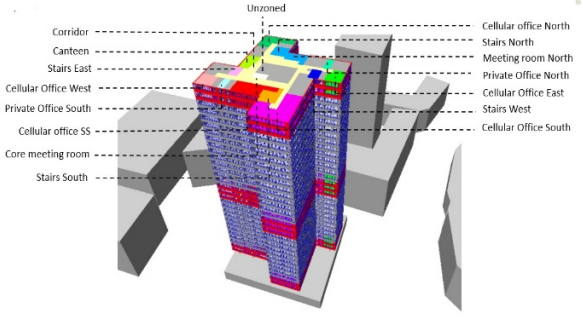

Figure 4. Euston Tower Tas model

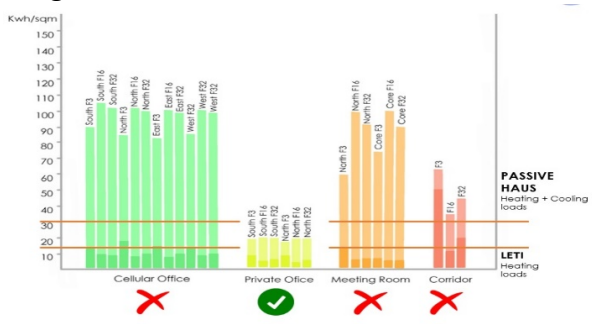

Figure 5. Annual Heating and cooling loads

A following thermal analysis confirmed this theory and revealed that cellular offices need cooling also 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 buildings typology. Therefore, simple environmental strategies were applied like lighting replacement with an LED system (5W/m^2) with scenario 1, occupancy reduction (10W/m^2) with scenario 2, and natural ventilation through the existing apertures with scenario 3. All these easily applicable strategies showed an energy loads reduction up to 61% compare to the existing case, thanks to this low-cost approach.

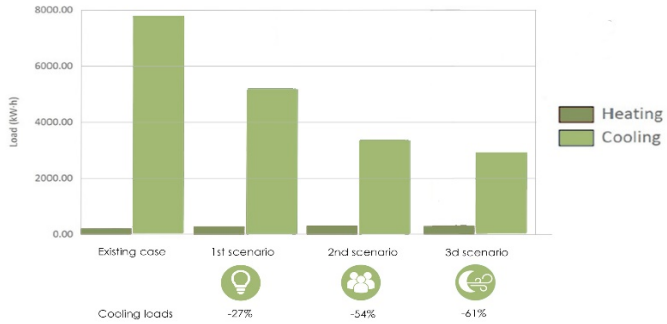

Figure 6. Environmental strategies loads reduction graph

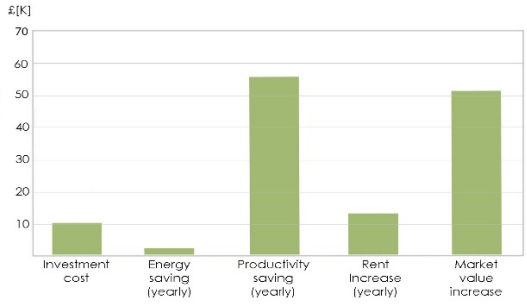

Figure 7. Cost-benefit values graph office analyzed

To conclude the study and obtain substantial numbers to justify a retrofit choice, a cost-benefit calculation was conducted for an office located in the south part of the building. Productivity improvements related to a natural ventilated healthier environment were therefore calculated, in terms of saving on employee's hour cost and less absenteeism due to sickness, resulting in a £55,000 of saving a year (almost six times the investment cost).

5. Design Optimization

Following the Euston tower study, a further Tas analytical model has been built. This model consists of a thirty floors courtyard building surrounded by an eight-floor building to analyze obstructed and unobstructed view. Therefore, three different floor levels were studied: ground, middle and top. Considerations made from the previous work informed the construction of the base case scenario such as occupancy of 8 m^2/pp, lighting gain (5W/m^2), and natural ventilation as primary strategy to reduce cooling load. A conceptual window divided into three-part with top and bottom operable has been designed to benefit from the stack ventilation of a single-sided façade (typical of a deep floor building) and three different WWR 40-60-80% have been created modifying the frame sizes and making opaque the bottom panel.

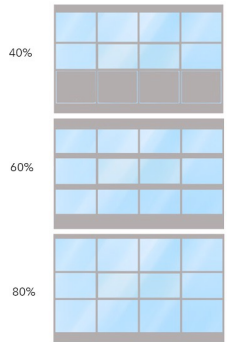

Figure 8. WWRs used

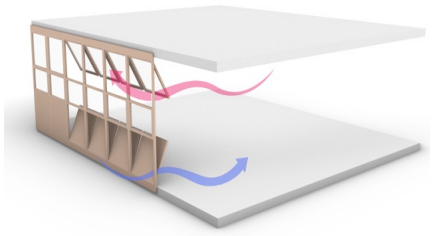

Figure 9. Three parts window 'ventilation

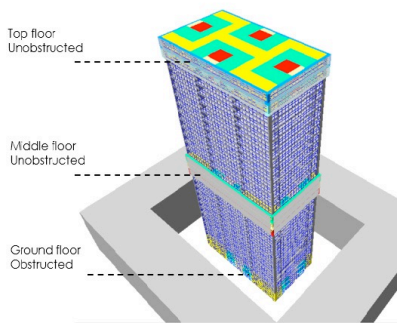

Figure 10. General Tas model

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 alu-timber type with a glass area double glazed and insulated with argon. Shading louvres are also made out of timber. Seven different scenarios were tested on the middle floor, five on the ground floor and four on the top floor.

South	Cooling loads [Kwh]	% reduction	sqm	Kwh/sqm	Overheating [%]	Hours	Solar gains[Kw]	% reduction
1	1001	-	22	46	100%	1086	349	-
2	901	10%	22	41	97%	1056	190	-45%
3	842	-7%	22	39	95%	1038	145	-24%
4	332	-61%	22	15	39%	424	145	0%
5	215	-35%	22	10	16%	175	145	0%
6	125	-42%	22	6	13%	141	145	0%
7	83	-34%	22	4	2%	18	145	0%

West	Cooling loads [Kwh]	% reduction	sqm	Kwh/sqm	Overheating [%]	Hours	Solar gains[KW]	% reduction
1	957	-	22	44	100%	1085	307	-
2	891	-7%	22	41	99%	1074	226	-26%
3	830	-7%	22	38	97%	1062	173	-24%
4	350	-58%	22	16	44%	484	173	0%
5	223	-36%	22	10	19%	210	173	0%
6	136	-39%	22	6	15%	159	173	0%
7	92	-32%	22	4	4%	46	173	0%

East	Cooling loads [Kwh]	% reduction	sqm	Kwh/sqm	Overheating [%]	Hours	Solar gains[KW]	% reduction
1	959	-	22	44	100%	1086	302	-
2	895	-7%	22	41	98%	1073	210	-30%
3	833	-7%	22	38	97%	1061	160	-24%
4	346	-58%	22	16	44%	477	160	0%
5	221	-36%	22	10	19%	203	160	0%
6	134	-39%	22	6	14%	158	160	0%
7	91	-32%	22	4	3%	30	160	0%

North	Cooling loads [Kwh]	% reduction	sqm	Kwh/sqm	Overheating [%]	Hours	Solar gains[KW]	% reduction
1	636	-	22	29	99%	1084	68	-
2	364	-43%	22	17	47%	509	68	0%
3	232	-36%	22	11	20%	214	68	0%
4	145	-38%	22	7	7%	77	68	0%
5	99	-32%	22	5	0%	0	68	0%

Figure 11. Middle floor results chart

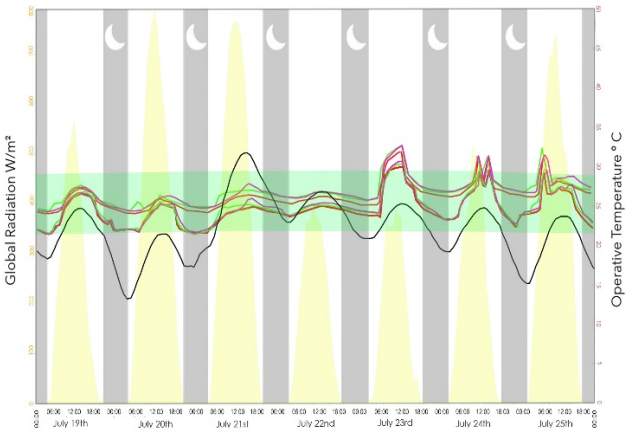

Figure 12. Middle Floor, Scenario 5-6 Op. Temperature, summer

These scenarios were obtained considering 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 removing the suspended ceiling typical of offices of that age and uncovering the concrete ceiling. The results obtained from the simulations all refer to the passive zone which depth is twice the floor to ceiling height. This is the area closest to the façade and the mostly influenced by passive design (N. Baker,2000). Finally, to compare the simulations outcomes cooling loads and overheating hours are calculated and correlated to Passivehaus and CIBSE TM52 standards.

The final results confirmed that 40% WWR works better on all middle floor orientations while 60% is applied on the ground floor due to the obstructed view and following an average daylight factor calculation. Different is the case for the top floor 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 gains but also people gains, 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 uninsulated roof influence.

The cooling load's analysis showed how the environmental strategies adopted were able to reduce the energy demand drastically from base case to best case in every floors 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 added up new challenges for office design and social distancing restriction will definitely influence future occupancy levels and introduce new design features like sneeze-barriers and hand washing stations. Additionally, considering the life-cycle total carbon of curtain walls, alu-timber frame type is an excellent way to reduce this balance (up to 71% reduction compared to typical anodized aluminum solution).

The Euston tower analysis provided a case study to understand how the old uninsulated curtain walls of the '70s influence negatively cooling energy demands. The following design optimization implemented the information obtained from the Euston tower analysis by building a general analytical model based on the previous findings. The outcome of this section revealed how different WWR need to be applied according to floor level to contrast the solar gain. Besides, thermal mass is very effective on the ground and middle floor but it cannot be used at the top floor if the roof is not insulated and ventilated. This research final results of also revealed that ventilation is the best strategy to cut cooling loads (more than 50% respect base case) and improve comfort followed respectively by 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, free running mode is possible throughout all seasons. However, for deeper part of the building and at higher floor levels a mix -mode with efficient mechanical ventilation might be investigated.

To conclude the retrofit of office buildings curtain walls is essential to cut the emission, reducing energy demand and improving comfort and productivity. Climate responsive buildings show façades that are not uniform, with different WWR according to floor height, shading devices and G value calculated according to orientations.

Figure 13-14. External view and internal office section of the new curtain wall prototype

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