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Exploring Resilient, Adaptable and Feasible Approaches to Retrofitting Listed Commercial Buildings: Douglas Primary School Case Study

Elsa Guadalupe Mendoza Durón[1] and Prof. Lucelia Rodrigues[2]

[1] MArch Architecture and Sustainable Design, University of Nottingham, UK, laxem10@nottingham.ac.uk;
[2] Supervisor, Department of Architecture and Built Environment, University of Nottingham, UK, lucelia.rodrigues@nottingham.ac.uk

Abstract: From the building stock available, 70% of UK non-domestic buildings were built before 2000 and therefore will greatly impact the Net Zero roadmap. Standards for retrofitting housing exist, but not for commercial buildings. The aim was to explore resilient, adaptable, and feasible retrofit strategies for a listed commercial building, for improving its energy performance and to understand the potential and limitations of retrofitting historic buildings. The methodology ranged from a comparative analysis of existing approaches, post-occupancy evaluation, and assessment of operational carbon. The case study was a former Victorian school currently occupied as a community art centre. Performance data and simulations were complemented with comfort perception interviews. The fabric-first approach resulted in an 83% reduction of operational WLC, although it did not achieve heating demand targets. The findings provided a step forward in the understanding of the limitations of retrofitting the over 400,000 listed buildings in the UK.
Keywords: Retrofit, Listed Buildings, Energy Efficiency, Comfort, Operational Carbon

1. Introduction

In the UK's path to meeting 2050 Net Zero greenhouse gas targets, emissions from the built environment need to be reduced by 50% by 2030 (HM Government, 2022). The housing stock is responsible for 69% of the operational emissions from buildings and the commercial buildings for 6% (UKCCC, 2019). As a result, standards and regulations are focusing first on the housing stock. The importance of retrofitting is considerable given that around 80% of the building stock that will be occupied in Europe in 2050 already exists today, and new buildings will represent only one-fifth of it (Penoyre and Prasad, 2014). Moreover, approximately 70% of the UK's non-domestic building stock was constructed before 2000 (UKGBC, 2022). The preservation of the historic building stock of the UK lies within this scope and needs a broader assessment that can impel the sense of belonging and tradition while enhancing energy performance for emissions reduction and delivering resilient solutions. As part of this extent for intervention, the National Heritage List for England consists of over 400,000 entries and over 10,000 conservation areas with heritage value (LETI, 2021).

2. Methodology

This research aimed to explore retrofit strategies on listed Victorian commercial buildings, to improve the performance efficiency towards the existing benchmarks and a lifespan beyond the 2050 target, aiming for resilience and longevity of solutions. The methodology was divided into three stages: the case study analysis and baseline for Douglas Primary School, the post-occupancy evaluation (POE), and operational carbon with retrofit iteration proposals. Different retrofit approaches and standards were analysed to extrapolate domestic retrofit guidelines and methodologies to commercial buildings and to identify the gaps consequence of the lack of specialised commercial retrofit standards.

The POE was assessed as a baseline for the retrofit proposal to understand the occupancy behaviour, comfort perception, significance value, and construction condition of the building. The baseline heating demand and retrofit iteration proposals were assessed by the Passive House Planning Package (PHPP). The second stage was the dynamic simulation analysis by a digital twin of the building assessed on IESVE (Integrated Environmental Solutions Virtual Environment) to test thermal performance and ventilation through the Apache application. The methodology limitations were the time availability for data gathering and the weather conditions, considering the summer period when the research was developed. Additionally, a limitation of the research scope was the lack of information available about the construction materials, section plans, and details to develop a trustable embodied carbon assessment to complement the WLC impact.

3. Guidelines, Standards, and Retrofit Strategies

Building regulations in the UK, specifically Part L performance requirements are felt to be inadequate and unlikely to meet the ambitious net zero targets (HM Government, 2021). Some initiatives in the UK are working on providing retrofitting assessments for the construction industry's stakeholders. Some of these are LETI, Passive House EnerPHit, the AECB, and BREEAM. These standards can work as a complementary tool to the Publicly Available Specifications (PAS) 2030, 2035, 2038 and the BS-7913 Guide to the Conservation of Historic Buildings, which provides the significance assessment framework to understand the impact of design decisions. Other publications as the Old House Eco Handbook (Suhr et al, 2013) provide guidance and recommendations for a sensible and efficient retrofitting approach to heritage buildings.

4. Case Study: Douglas Primary School

The selected case study was the former Douglas Primary School, a grade II listed building from 1885 in Nottingham, UK, in a cool temperate climate zone, with a Treated Floor Area of 1343.50 m^2 (Figures 1 and 2). It is currently used as a mixed-used commercial building, as it was purchased and adapted by Primary, an arts organisation with large community participation. The building had two storeys plus a basement, traditional Victorian red brick facades with terracotta dressings, and hipped plain tile roofs. The building displays some of the most distinctive features used by Thomas Hine, the most important architect in Nottingham at that moment, including shaped gables and round-headed sash windows.

Figure 1: Primary from Ilkeston Rd. Source: Author 20.07.2023

Figure 2: Primary 1st floor gallery. Source: Primary https://www.weareprimary.org/about

5. COMPARATIVE ANALYSIS OF APPROACHES

The different approaches and targets of the guidelines and standards were compiled and compared with five scenarios: (i) target value for constrained buildings, (ii) the average semi-detached house in Nottingham, (iii) precedent study Zetland Houses, (iv) precedent study Foundry Office, and (v) the Primary baseline (Table 1).

Table 1: Retrofitting Approaches for Constrained Buildings (abstract version)

Strategies	Energy Reduction	Heating Demand	Overheating Risk	Wall U-Val	Roof U-Val	Floor U-Val	Airtightness
	%	kWh/m²/yr	%		W/m².K		ach @50Pa
(i)	70%	50	10%	0.32	0.22	0.20	3.0
(ii)	-	168	*a	1.35	0.25	1.04	11.50
(iii)	98%	12	0%	0.17	0.14	0.16	0.9
(iv)	40%	45	8.6%	0.20	0.19	0.45	5.0
(v)	-	512	0%	1.35	2.94	2.70	12.0

*a: 20% of homes in the UK are in overheating risk (LETI, 2021).

The EnerPHit certification of case (iii) achieved the highest energy reduction and considered climate-resilient strategies for flood and storm risk. The baseline Primary building (v) has a 10 times higher heating demand. Case (iii) and (iv) assessed overheating by passive means with the design of the windows and crossed ventilation, respectively. The case study (v) did not show overheating risk because of its northwest and northeast orientation, however, this is proportionally related to the heating demand in winter.

6. POST-OCCUPANCY EVALUATION (POE)

The fabric of the Primary building is a traditional breathable solid wall, 3 brick leaves, in an English Bond for 338mm thickness, with a calculated U-value of 1.35 W/(m²K). Performance data monitoring for daylight, temperature, relative humidity, and sound were gathered for four rooms with different occupancy uses around the building: (i) studio, (ii) bakery, (iii) bookshop, and (iv) office. The thermal assessment showed a delay of one day for the peak temperatures comparing the exterior and interior temperatures (Figures 3 and 4). A significant thermal gap between room (iv) and the rest was shown given its southeast and southwest corner orientation (Figure 4).

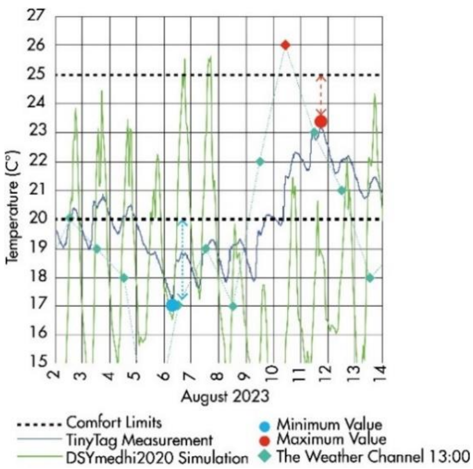

Figure 3: Room (i) thermal measurements compared to exterior temperature

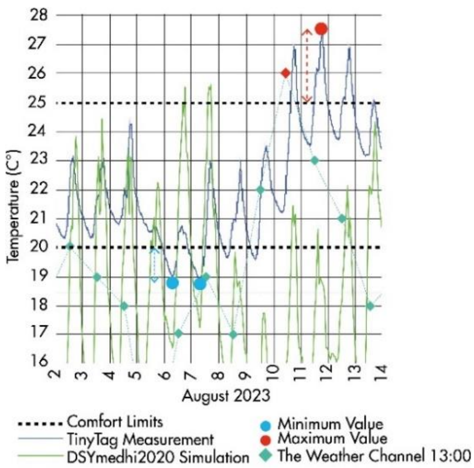

Figure 4: Room (iv) thermal measurements compared to exterior temperature

The dynamic simulation analysis on IESVE showed the same overheating risk in the room (iv), however, it achieved the highest percentage of hours in the PH comfort band between 20° and 25°C. Nevertheless, all rooms were found to be cold most of the time (Figure 5). This indication of a high heating demand was proved in the PHPP assessment, where the baseline conditions required 512.8 kWh/m^2/yr and where the highest energy losses were through the roof, unintentional ventilation, external walls, and windows (Figure 6).

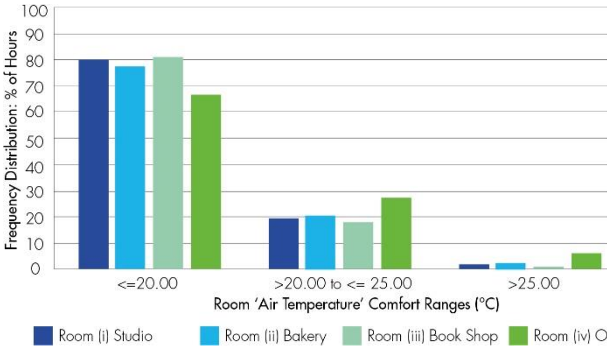

Figure 5: Baseline Rooms Thermal Performance. No Ventilation. Period: Whole Year, General Occupied Hours 08:00-18:30

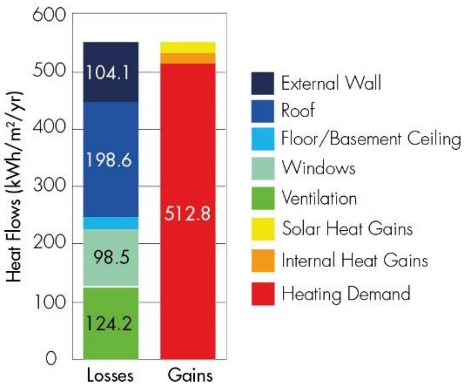

Figure 6: Baseline PHPP Energy Balance Heating, Annual Method

7. Operational Carbon Fixed Geometry

The PHPP energy balance heating provided an insight into the building's components' performance, so a series of retrofit interventions on the fixed geometry was proposed to reduce the heating demand by element. The methodology was additive, where each iteration was tested from the previous iteration result. The first iteration was to (i) insulate the roof, followed by (ii) interior wall insulation to preserve the historic facades, (iii) replacing the single-glazed windows with a traditional timber frame with double glazing, (iv) improving airtightness level, (v) introducing Mechanical Ventilation with Heat Recovery (MVHR) system and (vi) insulating the ventilated ground floors between joists (Figure 7).

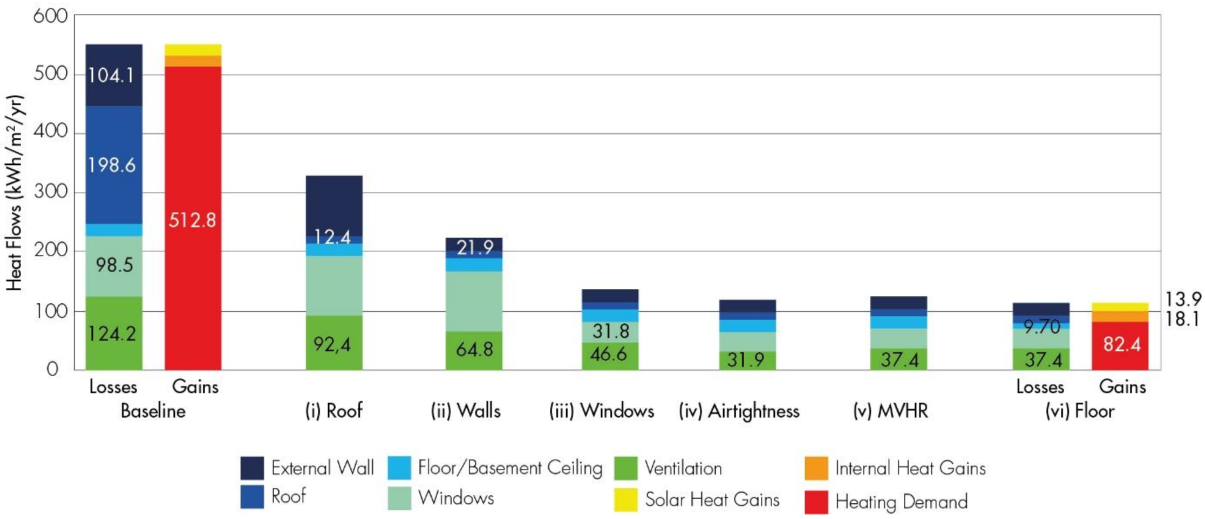

Figure 7: Proposal iterations PHPP Energy Balance Heating, Annual Method

According to Stephen, R. (2000), 71% of the air infiltration in domestic buildings is through the structure and fabric and 16% through windows and doors' draughts. The airtightness of the PHPP model was modified on each iteration according to these percentages. The airtightness iteration (iv) assumed the remainder leakage paths to be sealed and all the vents and chimneys to be closed to achieve the LETI target for constrained buildings of 3.0 ach@50Pa. The following dynamic simulations were assessed with this value (equal to 0.15 ach infiltration). All the rooms showed significant improvement in thermal performance, increasing by at least to 30% of the comfort hours. Nevertheless, room (i), northeast oriented was more than 50% under 20°C. Rooms (ii – iv) presented overheating risk without ventilation (Figure 8). Hence further simulations on climate resilience were performed, highlighting room (iv). Enhancing natural ventilation, including the winter period, reduced the overheating risk under 10% even in the 2080 climate scenario (Figure 9).

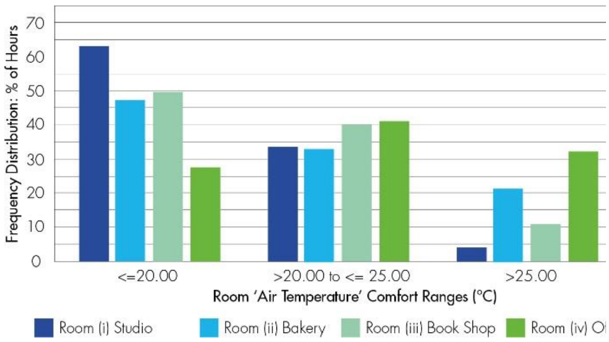

Figure 8: Proposal Rooms Thermal Performance: No Ventilation. Period: Whole Year, General Occupied Hours 08:00-18:30

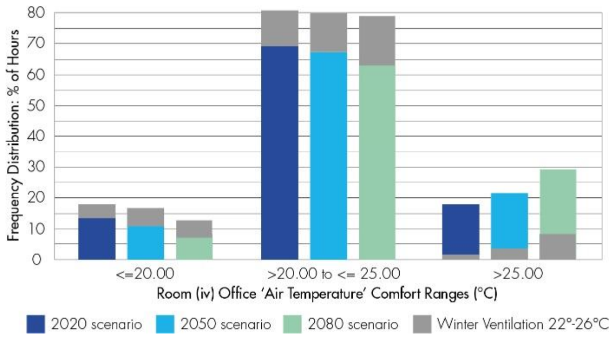

Figure 9: Room (iv) Overheating Assessment. Ventilation Summer, 50% openings. Period: Whole Year, General Occupied Hours 08:00-18:30

The Whole Life Carbon (WLC) of operational energy was assessed with the PHPP assumed electricity values. The baseline energy demand was 47,955 kWh/yr in addition to 688,910 kWh/yr heating demand. Considering the LETI split carbon factor methodology, the total carbon emissions were 10,656 tonCO_2e in a 60-year building lifespan. The improved proposal had an energy demand of 56,311 kWh/yr and a heating demand of 166,955 kWh/yr, with an operational WLC of 1,731 tonCO_2e.

8. Conclusion

The retrofit standards and guidelines provided more flexible targets than new building regulations, e.g. LETI provided specific targets for constrained, hard-to-treat buildings. However, best-practice precedent studies demonstrated the potential to surpass those and aimed for new building PH standards. The airtightness value presented the furthest distance from the baseline case, as the constrained LETI target for airtightness (3.0 ach @50Pa) is four times lower than the assumed baseline for buildings built before 1900 (Stephen, 2000).

The POE as a retrofit baseline was very useful in understanding the building's condition and the occupancy patterns as a mixed-used commercial building. The thermal mass was proved to retain the heat from the warmest day and release it one day after when the exterior temperature dropped, a characteristic that would be beneficial for future climate resilience scenarios. Room (iv) was the only room that presented overheating, responding to its different orientation and smaller size and height in comparison to the other spaces.

The envelope components presented the greatest energy loss and therefore were prioritised for the proposal iterations, in line with the fabric-first approach of the guidelines. The first proposal of roof insulation achieved the highest improvement with a 93% loss reduction through it. In contrast with the domestic standards suggestions, the MVHR increased the heating demand by 6%, with the default standard system from PHPP. Therefore, a detailed analysis of the airflow rate and efficiency of the system needs to be quantified to counter this result. The use of domestic standards to assess a commercial building resulted in a significant improvement in thermal performance with an overall heating demand reduction of 84%. Nevertheless, the achieved heating demand was 37% above the LETI target for retrofitting constrained domestic buildings. The WLC from the operational energy of the proposal achieved a reduction of 83% from the baseline projection for 60 a year's lifespan.

Passive natural ventilation resulted in a positive climate-resilient approach for comfort and overheating in future climate scenarios. Flood risk resilience was not assessed given the avenue's slope and the "very low-risk" level of the building location. The low internal gains from the PHPP results indicated the building is under-used and further design iterations under the adaptability retrofit approach would be beneficial to improve the internal heat gains by increasing the occupancy/m^2 and to reduce the heating demand. Long-term adaptability was considered in the wall insulation construction with a service void. Furthermore, under the feasibility assessment, the listed restrictions of the building limited the capacity of increasing solar gains through the fabric. Additionally, the components' specifications, like glazing and windows were limited by the use of traditional methods and materials to retain the character of the building.

9. References

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10. Abbreviations

IESVE: Integrated Environmental Solutions Virtual Environment
MVHR: Mechanical Ventilation with Heat Recovery
PAS: Publicly Available Specifications
PH: Passive House
PHPP: Passive House Planning Package
POE: Post-Occupancy Evaluation
WLC: Whole Life Carbon