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Passivhaus building and health

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Abstract: This study presents an assessment of Passivhaus design on resident health through a case study of the indoor environmental quality within Wilmcote House, a Passivhaus standard renovation social housing project. A hybrid methodology included environmental monitoring, semi-structural surveys, and building modelling. Indoor temperature and indoor relative humidity were monitored in five units in 2013 and 2017. The semi-structural survey collected interviews on the influence of the renovation intervention on comfort and health and modelled the future performance of the building, as well as the potential impact of future renovation measures. Results show that Passivhaus increases indoor environmental quality by stabilising and increasing indoor temperatures. However, these buildings could be prone to overheating in summer, a situation that could be mitigated by the use of external horizontal shading. The results from this study provide evidence for the potential of Passivhaus renovation practices in improving indoor environmental quality.
Keywords: Passivhaus, indoor environment quality, overheating, health

1. Introduction

The reduction of carbon emissions has formed a core aspect of the development of energy-efficient residential buildings since 2010. A few strategies have been adopted by the United Kingdom for near-zero emission buildings. Other sustainable certifications emanating include LEED, BREEAM, and Passivhaus(Moreno-Rangel, 2020). Passivhaus is a German low-energy building standard that is meant to reduce energy consumption and CO_2 emissions. It was established in 1990 (Dequaire, 2012).

According to a research report, people typically spend around 87% of their time indoors (Leech et al., 2002). Many studies consider indoor air quality and its possible effects on human health in a Passivhaus. A study in Sweden on 20 Passivhaus and 21 conventional houses investigated indoor and outdoor environmental parameters and found that the quality of the indoor environment in new Passivhaus buildings was either equal to or better than conventional houses (Langer et al., 2015). However, recent research found overheating to be a risk in UK homes, with the highest prevalence occurring in the summer months and mainly in homes in the central or southern parts of England(Tabatabaei Sameni et al., 2015). In a review involving 23 UK Passivhaus buildings, both the Passivhaus standard and the CIBSE TM52 standard were used to determine the likelihood of overheating (Tabatabaei Sameni et al., 2015). Their results showed a significant risk of overheating during the summer, with over two-thirds of the dwellings surpassing the set standards.

This research aims to investigate the indoor environmental quality of Passivhaus and provide evidence for future Passivhaus, thereby creating a building indoor environment that is conducive to the occupants' health and promotes the sustainable development of buildings.

2. Methodology

2.1 Case study-Wilmcote House

Wilmcote House, a residential complex owned by Portsmouth City Council, is located in the centre of Portsea Island, Portsmouth. Constructed in 1968, it includes three 11-storey blocks (Bock A, B and C) with 100 similar duplex apartments and 7 ground floor apartments. Block A and B are oriented East-West and Block C is oriented North-South. Between 2014 and 2015, the complex underwent retrofitting to meet the EnerPHit standard, a Passivhaus certification for retrofits. Key renovation features included adding external insulation, replacing all windows with triple glazing, and installing a mechanical ventilation heat recovery system.

Figure 1 Wilmcote House pre- and post-retrofitting

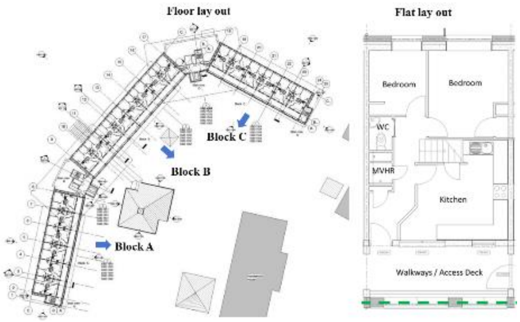

Figure 2 Wilmcote House floor plan

2.2 Environmental investigation

The environmental monitoring at Wilmcote House was conducted in three distinct phases. Before refurbishment (phase 1, pre-), the indoor environment of 18 units was monitored for temperature and humidity, between 19th March and 19th April 2013. Sensors recorded data at three-minute intervals. The second phase (post-) comprised post-renovation monitoring of 5 units between 2017 and 2019, with sensors taking readings at five-minute intervals. The sensors were positioned in the living room and master bedroom, away from heat sources. The data logger employed was a MadgeTech Model 2.04, with an accuracy of ±0.5°C and ±3% relative humidity, respectively, following the ISO 7726 standard (Teli et al., 2016). The third phase (follow-up), conducted in 2024, includes post-surveys with three residents.

It has been demonstrated that the indoor temperature is susceptible to fluctuations in outdoor climate conditions, even when space heating is employed (Yan et al., 2016). To address this, this study selected a period with little difference in outdoor temperature before and after the renovation to determine the study period. In 2013, the outdoor ambient temperature range was between 1.5°C and 10.7°C and the median was 4.0°C. The 2017-19 data was reviewed using the running mean over 27 days, this process identified the period of the 27th November to 23rd December 2017 as the closest match. Then, the outdoor ambient temperature range was between 1.9°C and 9.9°C and the median was 4.7°C. The median outdoor ambient temperatures differed by only 0.7°C between the two periods (pre- and post-). The Wilcoxon test had a p-value of 0.71 (>0.05), indicating that there was no statistically significant difference in outdoor temperatures between the two periods.

This study applied R analysis. To ascertain whether notable discrepancies existed between the pre- and post-retrofit, the Wilcoxon test was applied.

2.3 Occupant survey

The semi-structured interviews conducted for this study were divided into two sections: a pre-retrofit survey conducted during the autumn of 2014 with 18 residents (Teli, et al 2016) and a post-retrofit survey undertaken in March 2024 with 3 residents. The residents were the same; the household composition changed for one resident having had children. The two surveys included the same questions, focused on the evaluation of the indoor environment, living behaviour habits, and socio-demographic information.

2.4 Building simulation

To conduct an evaluation of the long-term performance of passive buildings, TRNSYS was employed to simulate the dynamic behaviour of the top-floor apartments of all three blocks under a range of future climate scenarios. The model employs CIBSE Southampton DSY2 meteorological data to simulate the potential for overheating in relatively warm years, which is of guiding significance for subsequent design (Virk and Eames, n.d.).

3. Result

3.1 Flat Environmental Investigation

Between phase 1 (pre-) and phase 2 (post-), the minimum indoor temperatures of all five flats increased after the retrofit, as shown in Table 1. This may be due to the building fabric upgrade and new heating systems (MVHR) being used more often. The average indoor relative humidity showed a downward trend, with Flat 16 showing a notable fall in humidity of about 19%. Figure 3 shows post-retrofit less variation in humidity and temperature within Flat 110. The largest variation in indoor ambient temperature happened between 8 a.m. and 6 p.m., concurrent with regular residents’ activity. Even though they were more noticeable, variations in relative humidity were less evident than before the retrofit.

Table 1 Summary of Pre- and Post- retrofit indoor temperature (°C) and relative humidity (%)

Flat	Pre						Post					
ID	T_{min}	T_{mean}	T_{max}	RH_{min}	RH_{mean}	RH_{max}	T_{min}	T_{mean}	T_{max}	RH_{min}	RH_{mean}	RH_{max}
110	8.7	15.6	22.9	46.6	67.0	85.3	18.8	20.6	22.3	31.6	46.0	69.8
107	14.6	18.4	28.1	33.5	54.4	75.9	15.9	17.6	20.9	28.9	40.5	52.3
34	13.7	17.4	22.6	23.4	46.3	73.0	19.0	19.9	22.2	39.6	52.7	67.8
23	20.5	22.8	24.8	39.9	52.5	59.3	20.7	21.8	22.7	42.6	50.1	59.1
16	16.7	19.5	23.6	34.5	51.2	81.9	17.9	19.0	22.7	36.1	44.7	62.5

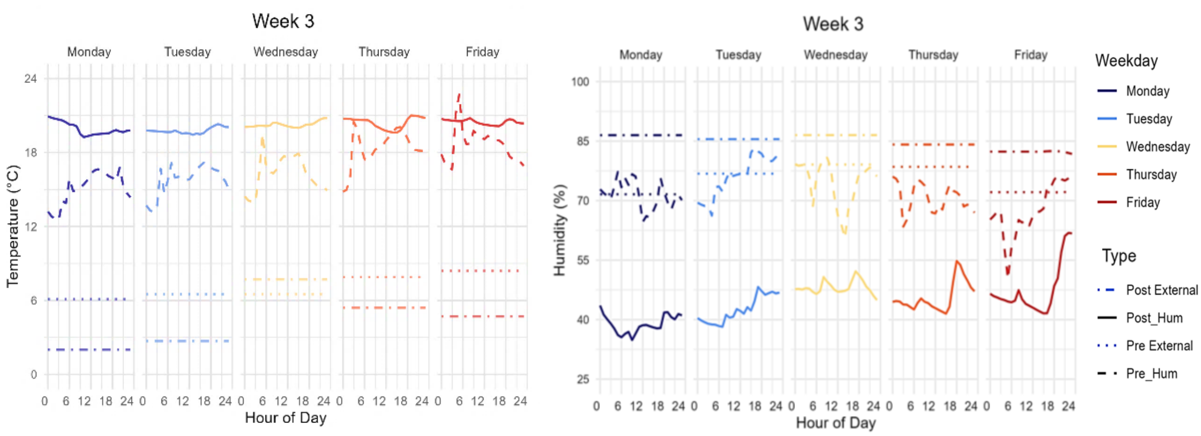

Figure 3 Flat110 weekday hourly temperature(°C) (on the left) and relative humidity(%) (on the right) for the third week of monitoring

3.3 Semi-structural interview

The pre-retrofit survey was conducted by the Sustainable Energy Research Group at the University of Southampton and Portsmouth City Council. The demographic profile of Block C was comprised of a younger age group, with 47% of residents under the age of 18. A notable proportion of residents (57%) reported experiencing health issues, including asthma and diabetes. Furthermore, 28% of residents had never utilized a night storage heater due to financial constraints and perceived inefficiency, with 67% of the population relying on portable electric heaters(Teli et al., 2016).

The post-retrofit survey revealed a notable increase in overall satisfaction with living conditions. However, certain issues were identified, including instances of poor air quality in some flats, despite the presence of MVHR systems. No evidence of mould or condensation was observed. However, residents of Flat 23 reported that the indoor temperature was uncomfortably warm, indicating a need for cooler conditions.

3.4 Wilmcote House indoor temperature simulation in the future scenario

Results show that Wilmcote House is predicted to maintain stable minimum and average temperatures in the context of future warming scenarios (Figure 4). The only notable variation is in the maximum indoor temperature, which increases in conjunction with elevated global emissions and an increase in the number of years. Table 2 also shows that Block A shows the highest indoor temperature, followed by Block B and finally Block C as the maximum temperature of each block surpasses 30°C.

Table 2 Wilmcote House indoor temperature in a future scenario

Scenario	Block A			Block B			Block C		
	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}
2020High50	19.2	23.8	32.6	19.3	23.42	31.2	19.3	23.42	31
2050Medium50	19.3	24.1	33.3	19.3	23.77	31.9	19.4	23.76	31.7
2050High50	19.3	24.2	33.4	19.4	23.85	32	19.4	23.85	31.8
2080Low50	19.3	24.2	33.4	19.4	23.82	31.9	19.4	23.82	31.8
2080Medium50	19.4	24.2	34.0	19.4	24.1	32.5	19.4	24.09	32.3
2080High50	19.4	24.3	34.5	19.5	24.38	33	19.4	24.37	32.8

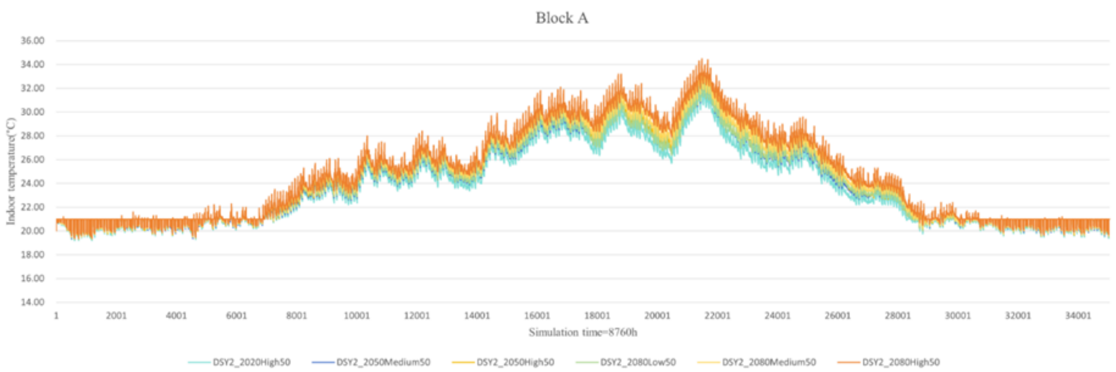

Figure 4 Wilmcote House indoor temperature simulation in future scenarios

Using the CIBSE TM52 criteria for assessing indoor overheating, Block A was found to have significantly higher hours of overheating than Blocks B and C, with 43% exceedance hours in the 2080 high emission scenario—well above the TM52 standard of 3%. Despite reductions, Buildings B and C still did not meet TM52's first Criteria, with Building C showing the best performance at 16% exceedance. In the 2020 high emissions scenario, Block A had 50 days failing to meet Criteria 2's standards. However, all blocks met the temperature differential requirement of Criteria 3, where the temperature differential (ΔT) must not exceed 4°C. By the Criteria delineated in CIBSE TM52, a room is deemed to be in an overheated state if two or more of the specified Criteria are not satisfied (Virk and Eames, n.d.). It can be concluded that, under any future scenario modelling conditions, each block at Wilmcote House would be overheated. It is therefore imperative that any prospective modifications consider the potential for overheating and that suitable measures are implemented to mitigate the risk.

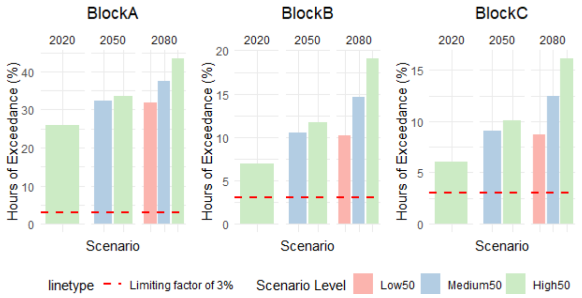

Figure 5 Percentage of occupied hours where the operative temperature exceeds the maximum acceptable temperature by 1 K- Criteria 1

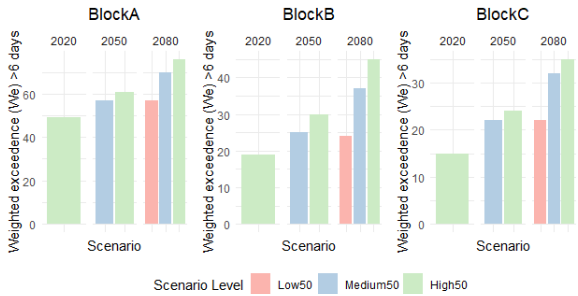

Figure 6 Number of days in each monitoring period where the weighted exceedance (We) exceeds the limit of 6- Criteria 2

In this study, external horizontal shading will be added to the south side of the building, and as shown in Figure 7 with the addition of horizontal shading, it will significantly reduce the number of hours that the building exceeds the standard.

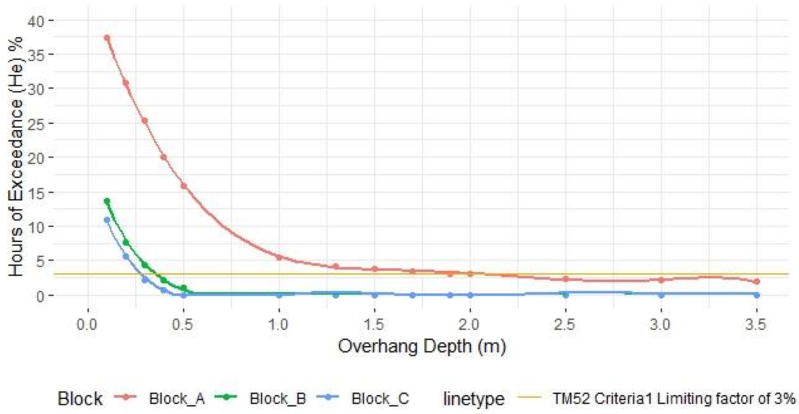

Figure 7 Relationship of external overhang depth and H_e in Wilmcote House

4. Discussion And Conclusion

Following the implementation of the passive standard renovation, the results show that Wilmcote House has a more stable and comfortable indoor temperature and relative humidity. The passive house ventilation system (MVHR), ensures the supply of dry air and the extraction of moist air, thereby reducing the indoor relative humidity. This effect can enhance the indoor environmental quality, which in turn has a beneficial impact on the health and well-being of residents. This is because high relative humidity can lead to mould growth, deterioration of fabrics, and an increase in health problems like asthma and allergies (Langer et al., 2015). Further simulation results from the overheating assessment of Wilmcote House under various future climate scenarios showed the Passivhaus to be exposed to greater risks in the future. Passive buildings with low U-value window glass boost thermal resistance and reduce heat movement from one environment to another. This ensures that the internal temperature remains at a comfortable level throughout the heating season. In contrast to conventional constructions, the building's extreme airtightness might trap heat from inside sources, raising the possibility of summertime overheating. According to the study, there are different risks of overheating depending on the orientation of the buildings; Block A, which faces east-west, has the largest risk. Results show that Wilmcote House is prone to summertime overheating, which may have an impact on residents' comfort and quality of sleep. Currently, the building has vertical shading, but these panels are far from the windows and shallow. Specifically, there are no shade structures on the south face of the building, which receives the most solar radiation. To mitigate the risk of overheating, we simulated the effect of adding horizontal shading on the south side and found that when the shading depth increased, the risk of overheating could be reduced. Selecting appropriate shading depth is essential to save construction costs. The analysis suggests that the suitable shading depths for the three building blocks, each with a distinct orientation, are 2 m(Block A), 0.36 m (Block B), and 0.27 m (Block C),. However, a horizontal overhang length of 2 m is excessive; a multiple-blade overhang on the upper portion of the window for Block A would be a more effective solution. This approach will not impede the view of the majority of residents and will also mitigate the risk of overheating. This study identifies apartments with an elevated risk of overheating, which is contingent upon the orientation and location of the apartment within the block. The findings may help social housing developers in relocating their tenants in a manner that is both appropriate and prioritizes vulnerable occupants to homes that are less prone to overheating. Future work should include the calibration of the model with monitoring data. The findings of this study illustrate the potential of sustainable retrofit measures to enhance indoor environmental quality and offer guidance for future passive building development. This study's limited post-occupancy feedback suggests a need for broader evaluations to better inform building strategies. Furthermore, while MVHR systems can enhance indoor air quality and mitigate the risk of asthma, improper installation can elevate indoor CO_2 levels and lead to occupant discomfort (McGill et al., 2014). Future studies should expand monitoring of indoor CO_2 concentrations and occupant evaluations to evaluate the passive building design and its influence on indoor environmental quality.

5. References

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