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An investigation on energy-efficient housing of past and their compliance to current standards

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Abstract: The building sector consumes 38.7% of total energy within the EU, and is therefore a major contributor to greenhouse gases emissions that cause climate change. Buildings should not just prioritize energy efficiency; they should also be able to adapt to increasing temperatures caused by global warming.
The case of BedZED, a widely acclaimed energy efficient housing scheme of yesteryear was studied. BedZED was tested and studied in today's climate and in future climate scenarios. Retrofit strategies were tested using dynamic simulation to investigate upgrading the homes to modern energy efficiency standards.
The results indicated overheating issues and the potential need for energy intensive mechanical cooling. Interventions were proposed and tested with a reduction of 40% of internal temperatures over the base-case was achieved. The findings reveal the need to design homes today that are resilient to future climate conditions.
Keywords: energy-efficiency, thermal comfort, future climatic data, building fabric, overheating

1. Introduction

Mounting evidence suggests that there is an impending global temperature increase of approximately 1.5 °C expected as early as 2023 (Diffenbaugh; Barnes, 2023: page 3). Simultaneously, buildings stand out as the primary energy consumers in Europe, accounting for as much as 40% (IONESCU; et al, 2015: page 243-253).

Elevated indoor temperatures give rise to situations of discomfort leading to an overreliance on mechanical methods to achieve comfort. This includes an upsurge in the use of residential air conditioning to combat summertime overheating (Chartered Institution of Building Services Engineers, 2016: page 3). This process initiates a vicious cycle where buildings undergo retrofits solely aimed at aligning them with modern standards, with a focus on enhancing energy efficiency. Therefore, it becomes crucial to establish a balance between thermal comfort and energy efficiency for both the present and the future. The key to achieving this equilibrium lies in the construction of energy-efficient buildings.

Buildings classified as energy-efficient can reduce their energy consumption, minimize the emission of detrimental greenhouse gases, and reduce their dependence on non-renewable resources (Gupta; Chakraborty, 2021: pages 457-480). With rising temperatures, ever evolving standards and technologies, energy efficient homes of past could fall short of modern standards. The following paper aims to research on exemplar energy efficient buildings of past, questioning their efficacy, whilst creating a performative timeline between the past, present and future.

2. Introduction

The term "Passivhaus," derived from "passive" and "house," alludes to the fundamental principle of this standard. It refers to buildings designed to rigorous energy efficient standards, allowing for near constant temperature with very little additional heating or cooling (Moreno-Rangel, 2020: pages 20-29). While there are various energy efficiency standards, Passivhaus and CIBSE standards were used for testing within this paper; setting the benchmark and creating a comparative matrix between projects. The research primarily focused on assessing the performance of building materials, construction methods, and layout. Additionally, this research narrowed its scope to examine how these factors impact thermal comfort within a defined space over several years and their subsequent effects on energy efficiency.

2.1 Case-study

Although there are several noteworthy energy-efficient residences, BedZed was selected as the primary case study and testbed. The study aimed to investigate hypotheses and their impact on comfort through modifications to the building's structure and fabric.

BedZed was purposefully crafted to encourage environmentally responsible living and nurture a strong sense of community. It incorporated passive design principles, omitting the need for a conventional central heating system, while also planning for the generation of renewable energy. The primary objective was to maintain a carbon-neutral footprint, striving for no net increase in CO2 emissions. It aimed to slash energy demand by 60%, with an impressive 90% reduction in heating requirements compared to new homes constructed under the 1995 building regulations that were in place during its design phase. Additionally, the goal was to reduce electricity consumption by 10% compared to typical residential dwellings. Its anticipated total energy consumption was projected at 75 kWh/m2/annum, in stark contrast to the 163 kWh/m2/annum required by the 1995 Building Regulations standard (Young, 2015) Additionally, the homes were well-insulated and designed with passive solar heating in mind. They were oriented facing the sun with unobstructed south-facing facades that were covered in glass. These areas acted as sunspaces, which rapidly warmed up during periods of sunlight, even in the winter. The warmth from these spaces could then be transferred into the homes by opening the doors and windows. The windows on the south side were larger and double-glazed, while those on the north, east, and west sides were smaller and triple-glazed (Williams, 2023).

Constructed in 1999 under the Building Regulations Part L, which are now considered outdated, BedZed's performance against modern Passivhaus standards and its thermal efficiency over more than two decades since its construction present a compelling case study. To conduct a thorough assessment of BedZed and measure adherence to Passivhaus standards, two modern projects were analyzed to assess how well they conformed to the specified criteria in comparison to these standards: Goldsmith Street and Camden Passivhaus.

Key inferences drawn were the effects of shading and airtightness on overall thermals within the homes. Ideal shading would reduce solar gains, thereby reducing thermals within a space. BedZed’s airtightness was high at 2 air changes per second- that accompanied with an array of glazing would reduce heat retaining properties of the structure. Low U-values with low thermal bridges would be vital to help retain heat during the colder winters. BedZed already employed low U-value components, windows while triple glazed however had a higher U-value of 1.2 (owing to the timber frames). (Williams, 2023)

2.2 Initial hypothesis and assumptions

Initial testing and assumptions raised a variety of concerns, namely overheating during summer months. The structures south side was predominantly adorned with large glass walls with a few on the north as well; south facing windows while ideal for solar gain could cause overheating without adequate shading measures in place (The Essex Design Guide, 2022). While windows used in the project were triple glazed (Young, 2015), employing extensive glass walls may result in heat losses that, resulting in indoor temperatures dropping below comfort levels during the winter. BedZed was designed around standards of past in accordance to dated climatic data. Testing was needed to corroborate the initial hypothesis. Reduction in glazing would further reduce energy consumption (for cooling) along with net losses during the winter periods.

Secondly, while the sunspaces acted as a thermal buffer, the use of double glazing could trap heat within while creating issues for ventilation. Given the substantial window size, there were doubts about the effectiveness of the shading projections. Testing was required to clarify if the extension at present was adequate or not. The hottest month in London accompanied by the highest radiation was July. Shading was thereby calculated to discount for excess solar gains during the month while accepting in useful equinox light/ gains.

If the sunspace was to be counted as shading, the space at current measured in at 2 meters of width. Solar shading calculations proved half that was required for effective shading. As it stood, useful solar gains were blocked leading to cooler rooms during winter, further useful equinox light remained blocked creating darker spaces. A simple solution would involve increasing the amount of glazing in the current setup. Alternatively, reducing the size of the sunspace would allow more natural light to enter the area with a reduced need for additional glazing.

2.3 Analysis and testing

The hottest months being May- August, care in terms of shading against solar gain was needed. November- March remained the colder months of the year, preserving warmth whilst increasing solar gain during these periods was ideal. The shading therefore needed to carefully consider the summer period vs winter; blocking solar gain only during summer. Through the year, the temperature varied from 6°C to 17°C and was rarely below -3°C or above 27°C. While an average wind speed of 4m/s could be seen, wind was not considered during testing; removing an inconsistent variable.

3. Methodology and Analysis

The table below indicated the categorization of various tests taken. The base case being the as-built project (BC). Case one (C1): added a shading of 1 meter to the structure (south facing, on top of the glazing), case two (C2): reduced the sunspace from 2 meters to a meter, case three (C3): altered the existing glazing- reducing the size from a curtain wall whilst adding shading as well. To further test thermals within the space, testing was further broken down to with ventilation and without. The lack of ventilation would serve as an extreme case scenario to better understand thermals within.

Table 1. Testing Matrix

	Base Case BC	Case one C1	Case two C2	Case three C3
With ventilation	BC	C1	C2	C3

The examination was conducted by simulating dynamic conditions using a digital twin. Multiple iterations of dynamic state tests were conducted, with a particular focus on thermals. The solid-state tests dealt with energy efficiency and was done via PHPP. Assumptions made during testing were as follows. Loads of 2 people per room- 75W/P sensible gain, 55W/P latent gain, lighting 15W/m2 and ancillary loads from cooking and computers 5W/m2. Infiltration of 0.250 ach and comfort of steady medium work. Windows were opened if temperatures were above 24°C internally and less than 26°C during summer (closed during winter). The window openable area was set at 50%. Although the current building had wind cowls on the roof to assist with ventilation, addressing them in the software proved challenging due to limitations. U-values were kept consistent with the existing structure due to falling in line with Passivhaus standards.

3.1 Analysis and inferences using climatic data of present (2023)

Base-case: Level one and two of the structure were occupied by small and medium sized families with the level three studio unit occupied by young professionals or couples. It was hence assumed that all floors were occupied by two people for most of the day.

The analysis indicates overheating through the year far exceeding the comfort range and at times dropping below as well. The comfortable hours for level one and two (2400 and 1750 respectively) are far outweighed by overheating (3600 and 4600 respectively) and lower temperatures (2600 and 2500 respectively).

C1 | No Sunspace: The scenario assessed the sunspace's impact on the housing unit's solar gains. Removing the 2m sunspace while introducing a 1m wide shading element-mitigating harsh summer sun exposure. The analysis of thermal performance revealed significant reductions in internal temperatures. The hours of overheating decreased notably for levels one (from 3600 to 2850) and level three (from 2500 to 500). However, for level two, although the number of hours of overheating decreased from 4500 to 3800, there was a substantial increase in the hours when temperatures fell below the comfort range. This indicated that the sunspace effectively contributes to thermal gain during winter months in the housing unit but also causes overheating in the summer months. In order to ensure consistent thermal comfort throughout the year, preserving the sunspace was essential. However, it is advisable to investigate potential enhancements in its width and glazing to achieve better outcomes.

C2 | Smaller Sunspace: Since the removal of sunspace led to an increase in the number of hours of temperatures falling under the comfort criteria, a reduction in the width of sunspace from 2m to 1m in analysed instead. The graphs shows that the modification of sunspace from 2m to 1m fails to counter overheating. There is still a significant amount of overheating. However, this iteration performs better than the base case in terms of thermal comfort. The dominant overheating could also be a result of the glazing which needs to be explored in the next iteration.

C3 | Reduced glazing for sunspace: Current south facing façade for the housing units is predominantly glazing, which may be the cause of overheating. Hence, reduced glazing needs to be explored. Moving away from the curtain wall approach, evenly spaced windows adequate for natural ventilation and daylighting were calculated and analyzed. The graphs showed overheating curtailed considerably with significant performance over prior iterations. The number of hours falling under comfort range were dominant and have significantly increased for level one(from 2400 to 4800) and for level two (from 1750 to 4500). There is a relevant decline in the number of hours of overheating for level one (from 3600 to 2500), level two (from 4600 to 1500).

From solid state testing, the various iterations corroborate theories mentioned- thermals and energy efficiency act proportionally. Changes that led to the final iteration saw overheating reducing by 18% and heating demand by 4kWh/m2a. While not within the

Passivhaus criteria, there is significant improvement over the base case. Changes to window and frames, saw gains and losses balanced significantly.

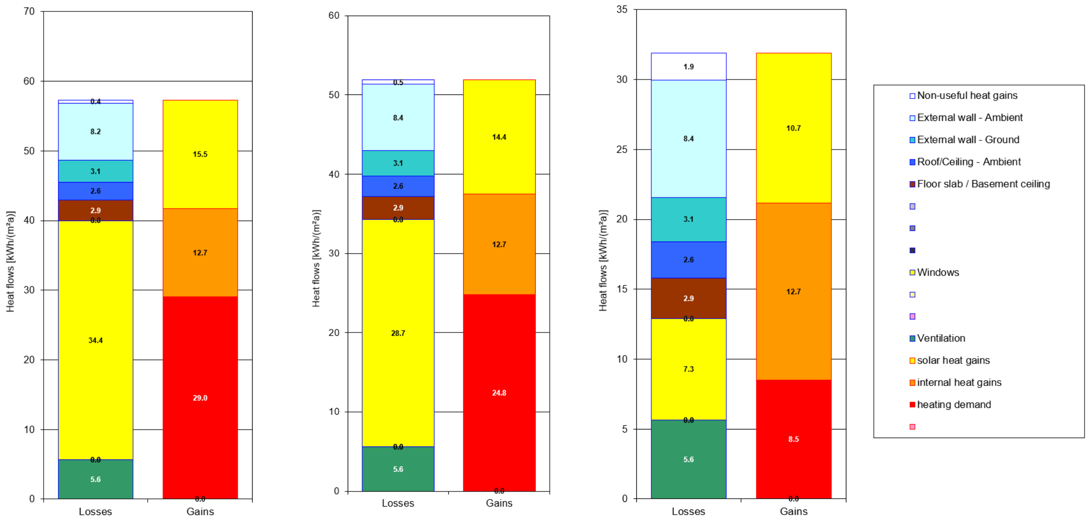

Figure 1. BedZed iterations compared losses vs gains (left: base case, middle: final iteration, right: final iteration improved windows)

3.2 Analysis and inferences using future climatic data

To study the effect of future climate changes on the performance of BedZED, the current scenario was analyzed for thermal comfort for the years 2020 (for reference), 2050, and 2080. Also, to further test the viability of the proposed final iteration, it was analyzed for thermal comfort for the same years. This helped draw a comparative analysis on how both scenarios would respond to future climate changes and whether the iterations proposed would help reduce overheating in the future as well. It can be observed from Table 1 that an increase of an average of 5% can be seen in the percentage of hours of overheating in both the cases for the years 2020, 2050 and 2080. Nonetheless, the final iteration demonstrated significantly improved performance compared to the initial case, with the overheating reduced to less than half base case's internal temperatures.

Table 1. Percentage of hours of overheating in base case and final iteration for the years 2020, 2050 and 2080

	BASE CASE			FINAL ITERATION		
Year	2020	2050	2080	2020	2050	2080
Ground floor Lounge Kitchen	68.1%	72.4%	76.2	24.7	31.4	36.9
First Floor Bedroom 1	55.1%	60.4	66.7	20.4	26.1	32
First Floor Bedroom 2	61.8%	66	71.1	24.6	30.5	38.6
Second Floor Studio	43.7	52.6	61.8	6.3	10.2	18.2

4. Conclusion

From the testing, the initial hypothesis was that energy-efficient buildings of the past (even exemplar projects) would need to be retrofitted to fit modern standards and aspirations. Furthermore, with rising temperatures, the case for retrofitting becomes a key concern.

As the relationship between thermals and energy efficiency is proportional, as explored in the project, reducing thermals internally would better aid in an energy-efficient home. Users in the POE survey conducted a mere 7 years post-construction (BIOREGIONAL, 2009) complained of overheating during summers. With the heatwaves of the past few years, this issue has been further exacerbated.

In terms of the research conducted, it is then evident that BedZED, a project of yesteryear, is not compliant with modern standards. Future climate change has increased the percentage of hours of overheating which further causes a surge in the dependence on mechanical means to maintain thermal comfort- hence reducing energy efficiency. However, the changes proposed do align it further to modern codes. Even though future climate changes show that the iterations proposed would still have around 30% of overheating by the year 2080, this has notably curtailed the 70% of overheating in the base case.

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