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Winter thermal performance assessment of the UK's first Passivhaus-certified extra care home

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Abstract. This study presents an in-use winter thermal performance assessment of the UK's first Passivhaus-certified extra-care home, focusing on three representative zones (entrance area, staff room, and manager's cabin). Through stakeholder interviews and continuous indoor environmental monitoring during summer 2024 and winter 2024-25, indoor dry-bulb air temperature, relative humidity, and CO_2 concentrations were evaluated against thermal comfort and air quality thresholds. Results show interior spaces maintained stable winter temperatures (mean ~22°C) with <1% of readings outside 20–24°C, indicating consistent thermal conditions suitable for older occupants. The entrance area experienced greater heat loss during door-opening events, with temperatures dipping below 20°C about 59% of the time. Winter indoor relative humidity generally remained within the comfort range (30–50%), while CO_2 levels stayed within acceptable limits year-round (median ~550–700 ppm). Summer monitoring showed minimal overheating risk under the current climate, although indoor relative humidity frequently exceeded 50%. Stakeholder insights revealed operational factors (door/ window usage, ventilation settings) underlie spatial and seasonal variations. This first empirical winter evaluation of a Passivhaus extra care facility confirms the potential for such designs to deliver comfortable indoor environments for its occupants using ~90% less energy than conventional care facilities, while identifying opportunities for improvement (e.g. localised thermal management strategies in transitional spaces) to enhance year-round performance under a changing climate.

1. Introduction

Climate change and population ageing pose intersecting challenges that significantly impact specialised housing for older adults. Human-induced global warming, reaching approximately 1.1°C above pre-industrial levels, intensified the frequency and severity of extreme weather events and has elevated the necessity for stable and comfortable indoor thermal conditions [1]. Simultaneously, the UK's rapidly ageing population is projected to have one in four residents aged 65+ by 2042 [2]. This has increased demand for extra care housing, a growing care model which offers self-contained living with on-site support [3,4]. Unlike traditional care or nursing homes, these facilities promote independence while catering to diverse care needs [5,6] and have been recognised in UK government strategies for improving housing quality, resident health outcomes, and ageing-in-place support [7–9]. Maintaining appropriate indoor thermal environments is critical for older adults, who have a diminished ability to regulate body temperature and heightened vulnerability to thermal stress [10–12]. Winters pose particular challenges, contributing to an estimated 13,400 excess winter deaths annually in the UK (December 2021 to March 2022) [13], while indoor air quality issues are exacerbated by reduced ventilation during colder months

[14]. Cold indoor conditions increase risks of respiratory illnesses, cardiovascular events, and chronic condition exacerbation, significantly impacting residents' health [15,16]. These vulnerabilities are amplified by extended periods spent indoors [17], while fuel poverty remains a substantial concern, with rising energy costs imposing financial burdens on both residents and care providers [18,19]. Passivhaus certification has emerged as an effective strategy to simultaneously tackle energy efficiency, indoor comfort, and fuel poverty through rigorous standards for insulation, airtightness, and mechanical ventilation with heat recovery (MVHR), typically achieving heating energy reductions of 75–90% compared to conventional buildings [20,21]. While extensive research exists regarding Passivhaus's performance in residential buildings, studies examining care homes are limited, and empirical data on extra care homes remain scarce.

Previously, the authors conducted a pilot study evaluating the summer thermal environment in the UK's first Passivhaus-certified extra care home, providing initial insights into its thermal performance and overheating risks. The current study aims to deliver preliminary insights into its winter thermal performance by employing a mixed-method approach—combining three months of empirical monitoring (December 2024–February 2025) of indoor dry bulb temperature (DBT), relative humidity (RH), and CO_2 concentrations, alongside stakeholder interviews with four key personnel involved in the building's design and operation. This study specifically examines thermal stability in relation to window/door-opening events, ventilation effectiveness under winter conditions, and the relationship between spatial configuration and environmental performance. The research questions of this study are: (1) How well does the Passivhaus design maintain winter comfort conditions for vulnerable residents? and (2) What operational factors influence the building's winter performance? Given the absence of baseline data for Passivhaus extra care homes, this study significantly advances understanding of their indoor thermal environments, guiding future design decisions and operational practices.

2. Methodology

This case study employed a mixed-methods approach to investigate the winter indoor environmental performance of the UK's first Passivhaus-certified extra care facility located in southwest England. This five-storey building comprises 53 apartments with communal spaces, featuring a centralised MVHR system, underfloor heating (with a confirmed 22°C setpoint), and a well-insulated precast concrete frame with masonry façade meeting Passivhaus standards. The monitored zones were selected based on facility manager input: (a) the entrance area—a double-height space with one automatic external door (oriented northwest) and another door opening into the lobby (southeast)—representing a transitional space; (b) the staff room—a small break room/office with two external walls (oriented northwest and southwest), a window (southwest) and a door opening into the entrance lobby; and (c) the manager's cabin—a private office with one external wall and a window (oriented southwest) and a door typically kept closed for privacy. While residential apartments were not accessible for this phase of the study, the selected office spaces and entrance areas, which are parts of the same building envelope as residential units, provided an opportunity to gather initial data on the building's indoor thermal environment.

Indoor environmental monitoring was conducted from 1 December 2024 to 28 February 2025 (winter), with comparative data obtained from August-September 2024 (summer). HOBO MX CO_2 loggers (MX1102A) [22] were positioned away from direct drafts and heat sources in the occupants' breathing zone—entrance area sensors at ~1.5m height, and office sensors centrally at desk height (~1.2m). The devices recorded DBT (±0.21°C), RH (±2%), and CO_2 (±50 ppm) at 10-minute intervals, yielding approximately 12,817 data points per variable for winter (~90 days) with >99% data completeness. Equipment was calibrated before deployment, and display screens were disabled to prevent behavioural bias [23–25]. Outdoor DBT and RH data were obtained from the closest UK Met Office observation site [26]. Time-series analysis was performed on the collected data, with a statistical assessment of central tendency measures (mean, median), dispersion indicators (standard deviation), and frequency distribution of measurements relative to comfort thresholds. For assessment, this study adopted 20–24°C for DBT (particularly important for older occupants who may feel discomfort below 20°C)[27], 30–50% for RH (balancing dry air discomfort against increased risk of dust mites and mould growth above 50%)[28], and <1,000 ppm for CO_2 (indicating good ventilation)[29], aligned with ANSI/ASHRAE Standard 55, CIBSE Guide A, and BS EN 16798-1:2019. While direct occupancy data was not collected, CO_2 concentration patterns were used as proxies to infer probable occupancy periods and intensities. Short-term events in the data, such as temperature drops or CO_2 spikes, were examined to correlate with likely operational causes.

Qualitative data were collected through semi-structured interviews with stakeholders (n=4) involved in the building's design, engineering, and management. Interviews explored design philosophy, material choices, operational challenges, climate resilience considerations, and user experiences, including perceived comfort, problematic areas, and adaptive behaviours. Recordings were transcribed and coded using thematic analysis [30]. Interview insights were used to interpret anomalies in the monitored data and contextualise operational patterns observed in the thermal performance metrics. This integrated approach enabled assessment not only of whether Passivhaus performance targets were met but also of why certain patterns occurred, which is essential for interpreting the success of the design and identifying operational adjustments.

Due to constraints related to the approved research ethics application relevant to the pilot phase, direct engagement with older residents and access to private flats were not feasible within the timeframe. Future phases will aim to include resident interviews and environmental monitoring in residential units.

3. Results and Discussion

During winter, indoor DBT in staff areas were remarkably stable. The staff room maintained an average DBT of 21.9°C (median 22.0°C, σ≈0.7°C), while the manager's cabin averaged 21.5°C (median 21.8°C, σ≈0.7°C). These means align closely with the observed heating setpoint (22°C), indicating effective thermal control throughout the monitoring period. Nearly 99–100% of winter hours in these spaces remained within 20–24°C, fulfilling Passivhaus comfort expectations.

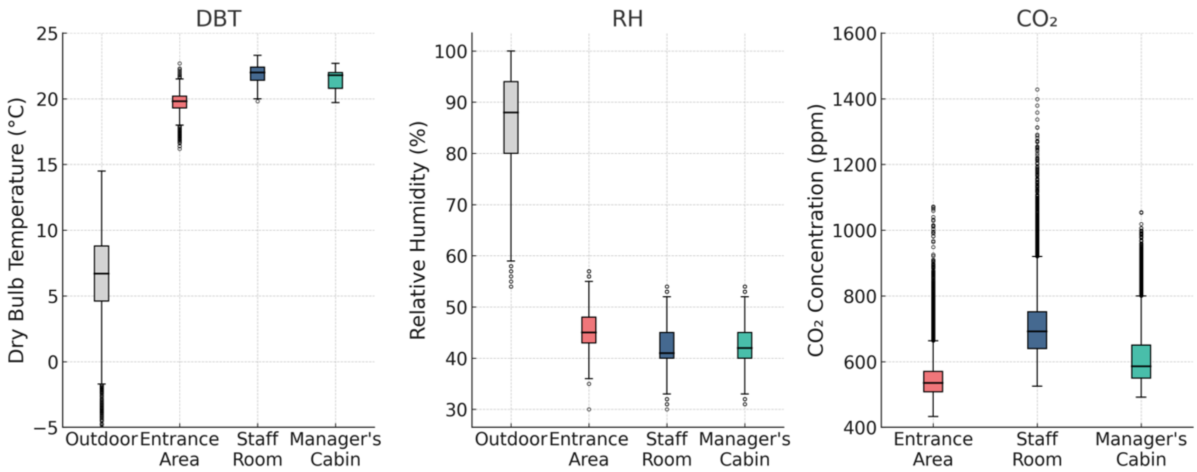

Figure 1. Comparison of monitored indoor DBT, RH and CO_2 across spaces (winter)

The entrance area—a double-height space with one external door and another door to the lobby—exhibited different thermal behaviour: mean DBT of 19.8°C (median 19.8°C, σ≈0.6°C), with temperatures at or above 20°C only ~41% of the time. The remaining ~59% fell below 20°C, occasionally dropping to 16.2°C during periods of frequent door openings (**Figure 1**). The entrance area's poorer performance stems from its double-height volume, direct external connections through the doors, consequent higher air exchange rates and its inherent nature as a transitional space—a phenomenon documented in other thermally efficient buildings where transitional spaces often experience greater environmental fluctuations [31]. Despite the building's high-performance envelope, frequent door openings likely contribute to heat losses that the underfloor heating system may require adjustment to address during periods of high foot traffic. Stakeholder interviews corroborated these findings, with facility management specifically identifying the area as problematic during winter, noting persistent resident feedback about cold drafts. This highlights a critical challenge in Passivhaus implementation: while the standard effectively addresses steady-state thermal performance, it may not adequately account for dynamic losses in high-traffic transitional spaces with frequent door operations. The staff room and manager's cabin showed similar indoor RH profiles (averages ~42–43% RH), with 91–94% of hours within the 30–50% target range. The entrance area averaged slightly higher at ~45.6% RH, with 87% of hours in range. Occasional rises above 50% typically corresponded with wet weather or higher occupancy periods, but levels never reached problematic thresholds for mould risk. Notably, there was almost exclusively excess humidity (>50% RH) rather than dryness (<30% RH), challenging conventional expectations of winter dryness in Passivhaus buildings.

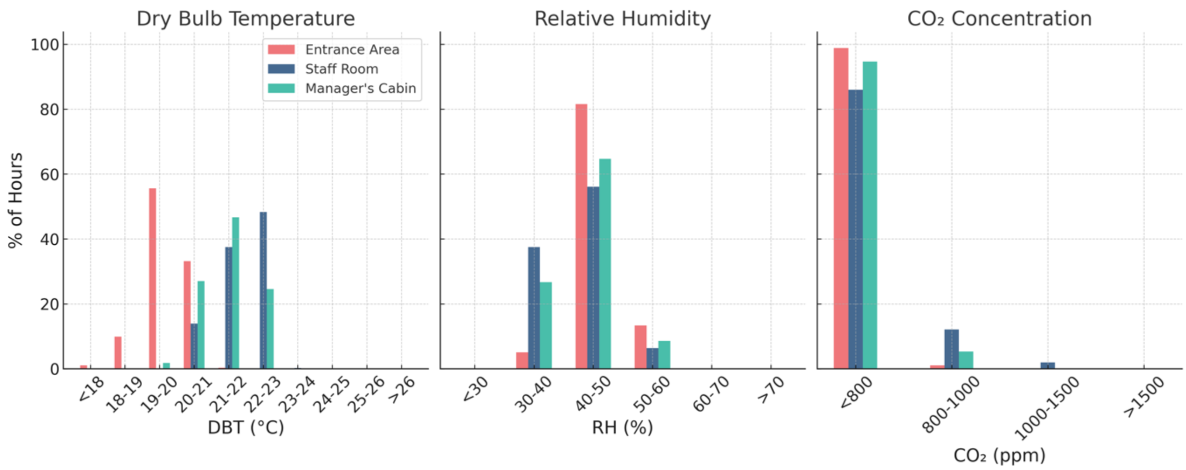

Figure 2. Percentage of hours in thermal and IAQ bands (winter)

CO_2 concentrations demonstrated excellent ventilation. The entrance area maintained the lowest levels (median ~535 ppm), while the staff room and manager's cabin showed higher but still healthy concentrations (medians of ~692 ppm and ~586 ppm, respectively). Over 98% of hours in all zones stayed under the 1,000 ppm guideline (**Figure 2**). Brief exceedances in the staff room (peak 1,428 ppm) coincided with likely higher occupancy periods, while the manager's cabin peaked at 1,055 ppm during probable meetings with closed doors. These results contrast favourably with findings from another Passivhaus care facility where winter CO_2 levels frequently exceeded 1,200 ppm [32], suggesting the rectified MVHR system in our case study is performing effectively despite the windows likely being closed during winter. The improved winter ventilation performance aligns with stakeholder confirmation that MVHR commissioning issues identified during the summer had been resolved before the winter monitoring period, empirically validating the importance of ongoing operation, maintenance and commissioning of the mechanical ventilation systems.

Summer monitoring during August–September (characterised by mild outdoor temperatures averaging ~15.5°C) revealed different performance patterns. Indoor temperatures generally remained within acceptable comfort limits despite the ventilation system underperforming, and confirmed operation of underfloor heating set to 22°C during parts of this period. The staff room, located adjacent to an external door with southwest-facing windows, was the warmest (mean 23.4°C, maximum 25.1°C), with about 15% of hours exceeding 24°C. This minor overheating tendency aligns with facility manager reports of afternoon solar gains. The manager's cabin—the most interior space—stayed cooler (mean 22.6°C), remaining within 20–24°C for 98% of the time. Interestingly, the entrance area was coolest in summer (mean 21.4°C), with its double-height volume and thermal mass dampening temperature fluctuations. Our findings demonstrate better summer thermal performance than typically reported in UK care settings, where temperatures frequently exceed 30°C [18]. The maximum observed temperature of 25.1°C is substantially lower than the 85% exceedance of 26°C reported in conventional UK care buildings [31], indicating effective passive design strategies. This performance is particularly significant given recent research [16] linking elevated temperatures to cognitive decline markers in older adults with dementia. Summer humidity presented more challenges than winter, reflecting the Southwest UK's mild, humid climate. Indoor RH averaged 55–60% across all zones, exceeding the ideal 30–50% band

68–82% of the time. In the entrance area, RH exceeded 50% nearly 90% of the time, with peaks up to ~78%. While these levels could cause slight discomfort and potential condensation risk, they remained below thresholds associated with mould growth (>80% RH). Stakeholder interviews revealed that the underperforming MVHR caused the boost function to fail in some residential units, forcing residents to rely on opening windows and doors for fresh air, echoing a similar behaviour documented in another UK Passivhaus care facility [32]. This likely increased indoor RH due to the ingress of humid outdoor air. CO_2 levels in summer remained excellent, with the entrance area maintaining median CO_2 at ~560 ppm and office spaces showing medians around 670–700 ppm with minimal exceedances above 1,000 ppm. During summer, reliance on natural ventilation likely contributed to these favourable CO_2 levels despite the MVHR commissioning issues that were later rectified.

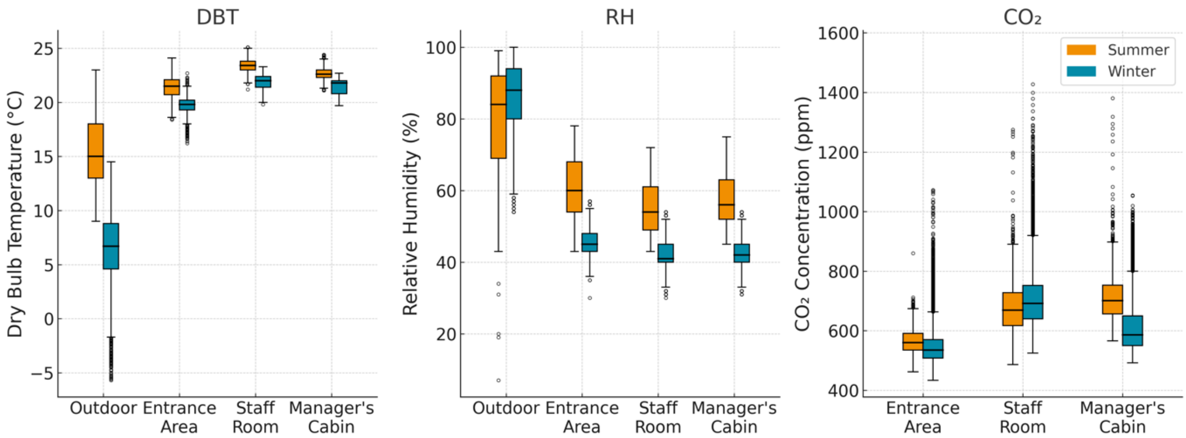

Figure 3. Seasonal comparison of DBT, RH and CO_2 across spaces (summer v winter)

The study revealed clear seasonal asymmetries (**Figure 3**): the entrance area experienced lower thermal comfort levels in winter but comfortable temperatures in summer, while the staff room exhibited good winter performance but slight summer overheating. These differences align with architect interviews highlighting design trade-offs between accessibility (large entrance doors) and thermal performance. Space design and function significantly influenced performance, with the staff room's proximity to external doors and solar-exposed windows creating different challenges than the more sheltered manager's cabin. These spatial variations emphasise the importance of zone-specific considerations in building performance assessment, also highlighted by findings from an earlier study [33], where 83% of the whole building but only 60% of individual rooms met overheating criteria. Importantly, occupant experience remained positive across seasons, with staff reporting comfortable winter conditions throughout the building, barring occasional resident feedback about cold drafts in the entrance area —a significant achievement for extra care housing given the vulnerability of older adults to cold-related health risks [15]. Interview data revealed operational adaptations like morning door openings for air flushing and blind management for solar control, highlighting the importance of occupant engagement with building systems—a factor critical for optimal building performance and particularly impactful in high-performance buildings like those certified to Passivhaus [34].

Although metered energy data were not available during the monitoring period, the total annual energy consumption of the case study, collected in 2023, was ~50 kWh/m².yr (electricity: 22.4 kWh/m².yr; gas: 27.5 kWh/m².yr), significantly lower than typical UK residential/nursing homes, which consume around 496 kWh/m².yr (electricity: 79 kWh/m².yr; gas: 417 kWh/m².yr) according to standard CIBSE benchmarks [35].

4. Conclusion

This study evaluated the thermal and ventilation performance of the UK's first Passivhaus-certified extra-care home, focusing primarily on winter conditions with a comparative summer assessment. Core occupied rooms maintained ~21–22°C in winter with minimal variation, staying within the 20–24°C comfort range nearly 100% of the time while using approximately 90% less operational energy than the typical care homes in the UK. The entrance area, though a bit cooler from the door openings, usually warmed up quickly, showcasing the building's efficient insulation and heat recovery systems. This stability addresses concerns about cold-related health risks, which contribute to excess winter mortality among older adults. Indoor RH in winter remained in a comfortable mid-range (40–50%), avoiding the excessive dryness common in conventionally heated buildings. CO_2 levels stayed mostly under 800 ppm, demonstrating excellent ventilation efficacy without compromising thermal comfort. The rectified MVHR system effectively balanced air quality and thermal performance, overcoming challenges reported in previous Passivhaus care facilities. Performance differences between zones highlight the impact of building interfaces on thermal conditions. Even in high-performance buildings, careful consideration of entryways and their management remains important for buildings housing vulnerable occupants. Strategies such as vestibules, higher heating setpoints locally, or staff awareness to limit door open duration could mitigate these effects. Summer indoor temperatures remained largely below 25°C without mechanical cooling, though elevated humidity (60%+ RH) indicates an area for operational improvement. No severe overheating was observed, which is particularly important for care environments. This suggests that, if well designed and implemented, Passivhaus's approaches can protect vulnerable occupants during mild summers under the current climate, though long-term monitoring during hotter periods and modelling using climate change weather files is recommended. Stakeholder interviews contextualised the data, confirming that observed anomalies had logical explanations in user behaviour or operational settings. This highlights that post-occupancy evaluations should pair quantitative data with qualitative feedback to fully understand building performance in use. This research provides the first empirical winter study of a Passivhaus extra-care facility, confirming that theoretical benefits translate into real-world occupant comfort. By identifying opportunities for improvement, the study provides lessons for future projects, such as integrating humidity control via MVHR adjustments and improving entrance area thermal management strategies, thereby contributing to evidence-based design guidance for future Passivhaus-certified extra care facilities that can effectively balance energy efficiency with the specialised comfort needs of vulnerable older populations.

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