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# A wintertime thermal analysis of New Zealand Homestar certified apartments for older people

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**ABSTRACT**

The New Zealand Building Code mandates maintaining habitable spaces and bathrooms in elderly homes at a minimum internal temperature of 16°C with adequate ventilation. This study assesses the thermal wintertime performance of 40 subsidized apartments designed for older residents within a 7-Homestar certified building in Auckland. The building performs well, falling below the 16°C threshold only 5 per cent of the time across all units. However, inconsistencies exist, particularly on the top floor (Level 3), which is colder than other levels. This reveals a potential flaw in the typology approach of green certifications, like Homestar, where certifying a single dwelling within an apartment building does not guarantee uniform thermal performance across all units.

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**KEYWORDS**
Indoor Environment Quality; thermal comfort; green building; underheating

## Introduction

The world is experiencing a significant demographic shift, attributed to declining fertility rates and increased life expectancy, resulting in a higher proportion of older individuals (UN, 2022). The United Nations estimates that about one-third of the global population will be 65 or older by 2050 while Statistics New Zealand projects that individuals over 65 could reach 1.3 million by 2040 and 1.5 million by the 2050s (Statistics New Zealand, 2022). 65-year-olds spend over 85% of their time at home (rising to 95% at 85 years and above) (Hamza & Gilroy, 2011). As building design influences indoor environment quality and subsequently physiological and psychological well-being (Lee et al., 2013; Van Hoof et al., 2018; Engelen et al., 2022), the quality of the indoor environment experienced can influence health outcomes (Hughes et al., 2019).

Green building rating tools are employed globally to provide thermally comfortable indoor environments in buildings. The growing elderly population and heightened use of green building ratings for homes, aged care facilities, and retirement villages (Humpel et al., 2009) suggest an escalating likelihood of New Zealand's elderly residing in certified green buildings by 2050. Homestar is New Zealand's prominent residential green building certification tool and aspires to provide to healthy, quality home for vulnerable demographics like older people (NZGBC, 2018). The New Zealand Green Building Council (NZGBC) encourages retirement housing developers to attain Homestar certification (6 stars or higher) to ensure insulation and ventilation levels beyond the average NZ home, with aged care a core target market for the Homestar (NZGBC, 2018) and many large retirement providers (i.e. Metlifecare,[1] [2] Oceania Healthcare,[3] Bupa[4] etc.) adopting Homestar certification in their developments. However, few post occupancy evaluations have been completed on green certified retirement dwellings to date, particularly in the context of their thermal performance against healthy temperature thresholds.

## Literature review

While research has been conducted on aging in place, the required built environment characteristics to enable this (Pani-Harreman et al., 2021; Ahn et al., 2020) and how cost-effective green retirement villages can be built (Zuo et al., 2014), little research has been undertaken on green certifications for retiree's dwellings. Only a single study has reviewed the post-occupancy performance of Homestar Built dwellings for over-65s

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(Ade & Rehm, 2022). However, this study was limited to a single apartment building and only analysed summertime data. Thus, no insights can be gained on important wintertime thermal performance.

Seasonal mortality is highest in the elderly (Davie et al., 2007) with excess winter mortality a greater risk than heat-related excess death (Zhao et al., 2021; Vicedo-Cabrera et al., 2021). In addition, older people tend to lead more sedentary lifestyles (Wookey et al., 2014), which can necessitate higher internal temperatures to maintain health and comfort. This is seen as important as the literature on fuel poverty consistently identifies older people as being particularly susceptible. Fry et al. (2022, p. 1) states that in Australia 'energy poverty is a particular problem for older people (due to fixed and often relatively low incomes and the need for additional energy due to underlying health conditions)'. While Porto Valente et al. (2022) find that energy poverty is the central issue impacting the quality of life for low-income older Australians. In New Zealand Howden-Chapman et al. (2012) state that about a quarter of New Zealand households are estimated to be in fuel poverty, with fuel poverty thought to be a factor in New Zealand's high rate of excess winter mortality. Homestar aims to reduce the effects of fuel poverty on the vulnerable elderly demographic by requiring high insulation levels for Homestar certification (NZGBC, 2018).

During the formulation of New Zealand's initial performance-based building code in the late 1980s, the Building Industry Commission incorporated guidance from the Department of Health and established 16°C as a safe minimum internal dwelling temperature (Building Industry Commission, 1987; Isaacs & Donn, 1993). The aim of the legislation (clause G5.1 (a)) is to 'safeguard people from illness caused by low air temperature' and its first performance criteria (clause G5.3.1) states: 'Habitable spaces, bathrooms and recreation rooms shall have the provision for maintaining the internal temperature at no less [than] 16°C measured at 750 mm above floor level, while the space is adequately ventilated'. Unlike the clause's opening objective, G5.3.1's application is expressly directed at 'old people's homes and early childhood centres'. The safe threshold of 16°C aligns with, and may have originated from, Collins (1986) who found that winter indoor temperatures did not impair the health of those over 65 until they fall below 16°C. Like its requirement for above code thermal insulation, Homestar set its minimum temperature threshold at 18°C in Homestar version 3 and 20°C in Homestar version 4.

Neither New Zealand Building Code or Homestar currently mandate the assessment of thermal variations between bedrooms and other rooms (e.g. living spaces), even though Fanger et al. (1974) asserted that an individual's thermal comfort varies between day and night due to the decreased nighttime metabolism. Globally, researchers have investigated the correlation between temperatures in bedrooms and living rooms, with some studies indicating that bedrooms often exhibit lower temperatures than living rooms. (Hong et al., 2006; Oreszczyn et al., 2006; Kavgic et al., 2012; Lomas & Kane, 2013; Magalhães et al., 2016) whilst others found no difference (Beizaee et al., 2013). French et al. (2007) conducted a nationally representative study of New Zealand homes and found that the living room is the most heated space with an average temperature of 18°C. Just 5% of New Zealand houses had central heating and half of bedrooms were left unheated.

Like temperature fluctuations among rooms within dwellings, variations in thermal conditions can occur among different units within a single building. The literature presents evidence of temperature variations among different floor levels in multi-story buildings. Some studies have found warmer upper levels with potential overheating (Mavrogianni et al., 2012; Porritt et al., 2013; Hamdy et al., 2017; Baborska-Narożny et al., 2017; Lundgren Kownacki et al., 2019; Petrou et al., 2019; Schünemann et al., 2020), neutral lower ground floor temperatures with minimal variation (Franck et al., 2013; Ade & Rehm, 2022), and interestingly, cooler middle floors relative to upper and lower levels (Mammen et al., 2020). However, this literature often focuses on warmer seasons and heatwaves to assess overheating potential rather than examining within building temperature fluctuations during colder months.

These thermal fluctuations are noteworthy as a key distinction of Homestar from other multi-unit residential green rating tools like BREEAM, LEED, or Green Star is that Homestar certifications are granted individually to units rather than the entire building. Units in a building are categorized into typologies, grouping similar dwellings by factors like floor area, bedroom count, wall/ceiling areas, and construction (NZGBC, 2017). Assessment is undertaken on the assumed 'worst case' dwelling with the outcomes applied to all other dwellings within the typology. However, Homestar does not specify whether a dwelling more prone to underheating or overheating should be chosen as the 'worst case', posing a considerable challenge for Homestar Assessors.[5]

Post-occupancy evaluation (POE) is often used for assessing a building's environmental performance buildings (Boissonneault & Peters, 2023) and frequently in the analysis of green-certified buildings (Li et al., 2018). POE typically involves a combination of quantitative and qualitative approaches. However, Ade and Rehm (2022), which is the only study completed on green certified buildings utilizing a typology approach, only employed quantitative indoor environment quality monitoring methods (e.g. temperature, humidity) and omitted occupant surveys or interviews with residents. This omission limits POE assessments' comprehensiveness regarding environmental performance, occupant satisfaction, and well-being (Li et al., 2018; Boissonneault & Peters, 2023; Elsayed et al., 2023).

Common methodological shortcomings associated with undertaking POE include time sensitivity and scope limitations (Deuble & de Dear, 2014). These can be resolved by undertaking a mixed methods approach (Heinzerling et al., 2013; Liang et al., 2014). de Chavez et al. (2017) found that combining environmental monitoring with qualitative research methods allowed better cross-validation of data providing a richer and more insightful examination into the lives of people living in residential dwellings.

### *Summary*

The ongoing global demographic shift towards an ageing population underscores the imperative to address the housing needs of the elderly in alignment with sustainable development goals (United Nations, 2002). In this context, green building rating tools have gained prominence for creating thermally comfortable environments, particularly in housing for older individuals. However, the lack of emphasis on assessing the suitability of green buildings for the elderly in New Zealand is evident, despite the nation's aging population and the growing adoption of green building ratings (Humpel et al., 2009). While existing research explores aging in place and cost-effective green retirement villages globally, the specific assessment of green buildings for New Zealand's elderly remains limited, with only a solitary study on Homestar Built dwellings (Ade & Rehm, 2022).

The present study partially addresses this gap by examining the thermal performance of a 7-Homestar Built certified apartment building catering to individuals over 65 in Auckland, New Zealand, during the winter months of 2020 and 2021. The research assesses indoor environmental quality vis-à-vis the New Zealand Building Code's stipulated minimum temperature of 16°C for elderly homes and evaluates the relative performance of each dwelling within the building to determine the appropriateness of the typology-based certification approach.

## Methods

The case study comprises 40 one-bedroom apartments in Auckland, New Zealand, arranged across 4 levels with 10 apartments per floor (see Figure 1). Each floor shares the same layout. The building's orientation is east–west, with the main road situated along the eastern façade. Apartments facing east are equipped with mechanical ventilation to address possible window closure caused by traffic-related air pollution or road noise.

Each unit in the building holds 7-Homestar Built Certification. Following the typology-based certification approach, only one unit (Unit K, Level 0) underwent thermal analysis. Positioned on the ground floor and facing southeast, this unit was deemed the worst-case scenario during colder months.

The building developer supplied thermal envelope details for the building as outlined in Tables 1 and 2.

Tether EnviroQ data loggers were employed to monitor indoor environment quality (IEQ). For each dwelling, two devices were installed – one in the bedroom and another in the living room. Installation followed a standardized process on an interior wall, away from direct sunlight. Given the uneven temperature distribution within a room as noted by Fernández-Agüera et al. (2019), loggers were positioned at seated head height, 1.1 m above the floor. These battery-powered devices, similar in size to standard smoke alarms, measure temperature within a range of 40°C to 85°C with an accuracy of ±0.2°C. Data loggers capture readings every ten minutes, subsequently averaging the last three readings every thirty minutes. As a result, each device generates two temperature readings per hour.

Outdoor weather data for the nearest national weather station (8 km from the building) were acquired from the New Zealand National Climate Database, CliFlo. This resource offers access to long-term climate records for precise locations or regions, presenting raw and statistical data summaries at ten-minute, hourly, and daily intervals (Knox et al., 2017). CliFlo offers researchers an effective alternative to distant weather station data that might not pertain to the same area or climate zone (Tait et al., 2012).

Internal temperature data was gathered over a three-year span during the southern hemisphere's winter months (June, July, and August) in 2020, 2021, and 2022. With two hourly readings per room, each apartment was expected to yield 26,496 readings across the three-year monitoring period. However, some units provided fewer readings. A yearly analysis identified data loggers' consistent operation in the first year (2020) and a slight reduction in data reported in 2021.

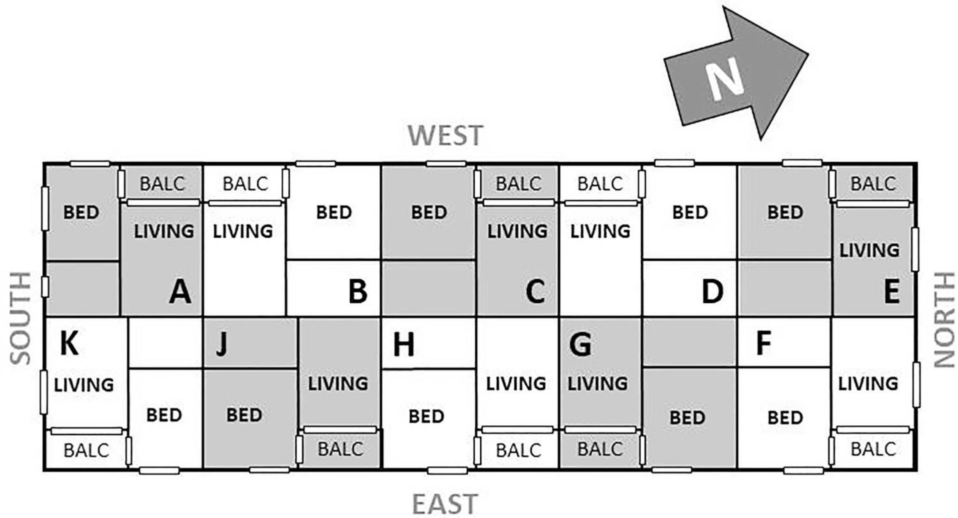



**Figure 1.** Abstracted building layout.

**Table 1.** Building element thermal performance summary.

| Building element | | Type | *R*-value ($m^2K/W$) |
|---|---|---|---|
| Floor | Level 0 | Concrete slab with 25mm XPS insulation under slab and 25mm XPS slab edge insulation | 3.25 |
| Walls | Level 0 | 190mm concrete block with 50 mm air gap and brick veneer. Steel studs with 375mm fibre wool insulation between studs. 13mm plasterboard. | 2.98 |
| | Level 1&2 | 190mm concrete block with 50mm air gap and brick veneer. Direct fixed 50mm XPS insulated, plasterboard on interior | 2.98 |
| | | 190mm concrete block with direct fixed 45mm timber battens and counter batten and profiled metal cladding. Direct fixed 50mm XPS insulated, plasterboard on interior | 3.18 |
| | Level 3 | 140mm timber framing @400c/c dwangs 800mm. 140mm polyester wall insulation between studs. 6mm rigid air barrier with ventilated cavity direct fixed 45mm timber battens and counter batten and profiled metal cladding. 13mm plasterboard to interior | 2.11 |
| Roof | Level 3 | Timber framed with rondo suspended ceiling, 210mm polyester insulation resting on 13mm plasterboard. | 3.29 |
| Glazing | All levels | Aluminium framed, doubled glazing with low-e film | 0.31 |

Numerous living room devices, however, did not record data in 2022 due to battery failures. Consequently, only data from 2020 and 2021 were analysed given the reduced records in the winter of 2022.

When analysing post-occupancy collected data, two commonly used approaches involve comparing measured interior temperatures to discrete temperature thresholds using parametric or non-parametric statistical

**Table 2.** Window-to-wall ratio (WWR) and shading summary.

| | | East WWR | East Shading | West WWR | West Shading | South WWR | South Shading | North WWR | North Shading |
|---|---|---|---|---|---|---|---|---|---|
| **A** | **Bed** | 0% | na | 44% | None | 79% | Heavy | 0% | na |
| | **Living** | 0% | na | 99% | Heavy | 18% | None | 0% | na |
| **B** | **Bed** | 0% | na | 44% | None | 79% | Heavy | 0% | na |
| | **Living** | 0% | na | 99% | Heavy | 0% | na | 0% | na |
| **C** | **Bed** | 0% | na | 44% | None | 0% | na | 79% | Heavy |
| | **Living** | 0% | na | 99% | Heavy | 0% | na | 0% | na |
| **D** | **Bed** | 0% | na | 44% | None | 79% | Heavy | 0% | na |
| | **Living** | 0% | na | 99% | Heavy | 0% | na | 0% | na |
| **E** | **Bed** | 0% | na | 44% | None | 0% | na | 79% | Heavy |
| | **Living** | 0% | na | 99% | Heavy | 0% | na | 18% | None |
| **F** | **Bed** | 44% | None | 0% | na | 0% | na | 79% | Heavy |
| | **Living** | 99% | Heavy | 0% | na | 0% | na | 18% | None |
| **G** | **Bed** | 44% | None | 0% | na | 0% | na | 79% | Heavy |
| | **Living** | 99% | Heavy | 0% | na | 0% | na | 0% | na |
| **H** | **Bed** | 44% | None | 0% | na | 79% | Heavy | 0% | na |
| | **Living** | 99% | Heavy | 0% | na | 0% | na | 0% | na |
| **J** | **Bed** | 44% | None | 0% | na | 0% | na | 79% | Heavy |
| | **Living** | 99% | Heavy | 0% | na | 0% | na | 0% | na |
| **K** | **Bed** | 44% | None | 0% | na | 79% | Heavy | 0% | na |
| | **Living** | 99% | Heavy | 0% | na | 18% | None | 0% | Na |

tests like Kruskal–Wallis and Mann–Whitney U tests (Derbez et al., 2018; Williams et al., 2019; Korsavi et al., 2020). The Kruskal – Wallis Test, akin to one-way ANOVA, assesses if the medians of three or more independent groups differ significantly (Armstrong & Hilton, 2010; Kruskal & Wallis, 1952). Another common approach involves using linear regression models (Feng et al., 2022). Multiple linear regression is a prevalent statistical technique in the indoor environment literature (Wei et al., 2019). Regression models predict a dependent variable, like indoor air temperature, based on linear relationships with independent variables.

The data underwent analysis using these two methods. First, measured interior temperatures were compared to the 16°C discrete temperature threshold via Kruskal–Wallis and Mann–Whitney U non-parametric statistical tests. Second, a linear regression model was created to ascertain the significance of specific independent variables on indoor air temperature. The multiple linear regression model is represented as:

1)where $T_a$ is the dependent indoor air temperature; $x_i(1 = i \leq k)$ are the k attributes from a range of possible independent variables; $\beta_i(0 = i \leq k)$ reflects the regression coefficients for each attribute and ε captures the random error.

The dependent variable (interior temperature) was derived from the above-mentioned Tether EnviroQ data loggers, while exterior environmental independent variables (hourly average wind speed in metres per second, sunshine hours ranging from 0 (dark) to 1 (full sun), and mean sea level air pressure in hectopascals) were acquired from CliFlo through the nearest weather station at the Museum of Transport and Technology in Auckland. Additionally, the model encompassed apartment-specific independent variables, including a set of dummy variables representing floor levels (with the top floor, Level 3, as the reference), as well as dummy variables indicating northern or southern end unit placement (with a middle, adjoined apartment as the reference) and orientation (with easterly orientation as the reference). Other apartment-specific independent variables like window-to-wall ratios were considered but ultimately excluded due to unit homogeneity.

Upon concluding the winter of 2022, a public meeting was held for building residents, during which researchers sought consent for semi-structured qualitative interviews with occupants. Out of the 40 units, sixteen residents agreed to partake in the interviews, with twenty interviews conducted in total (four participating units had two participants each). Interviews took place in November 2022.

## Results

Figure 2 outlines the exterior temperatures from June to August 2020 and 2021, showing that July 2021 recorded the lowest mean and median temperatures.

Figure 3 depicts a box and whisker plot for the study's coldest day (exterior temperature reaching −1°C), categorized by hours of the day. This figure reveals variation among building levels, with Level 3's mean temperature dropping below 14°C in the early morning, whereas other levels maintain mean temperatures exceeding the NZ Building Code's 16°C threshold for older people's homes.

Table 3 highlights the building's strong performance in colder months, with only 5% of time spent below the

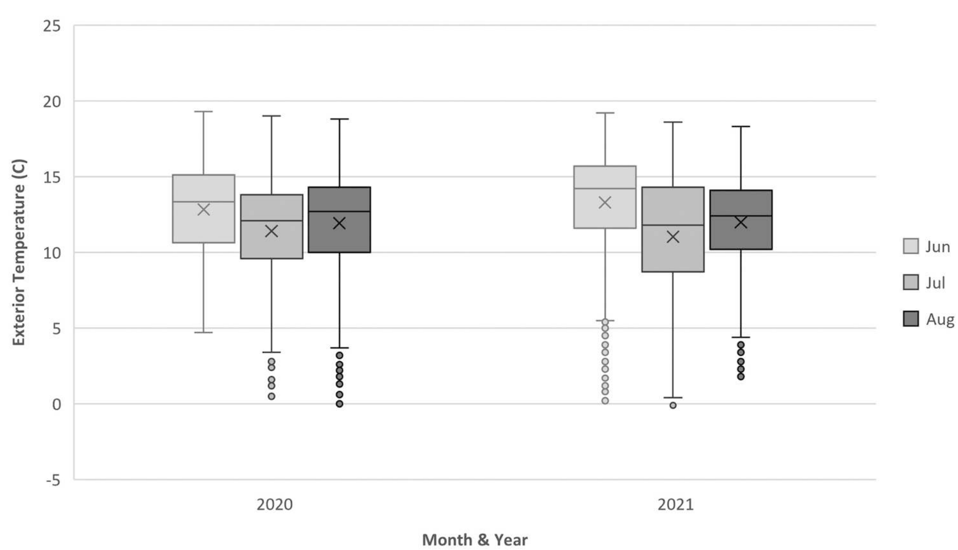



**Figure 2.** External temperatures for June, July and August respectively in 2020 and 2021.

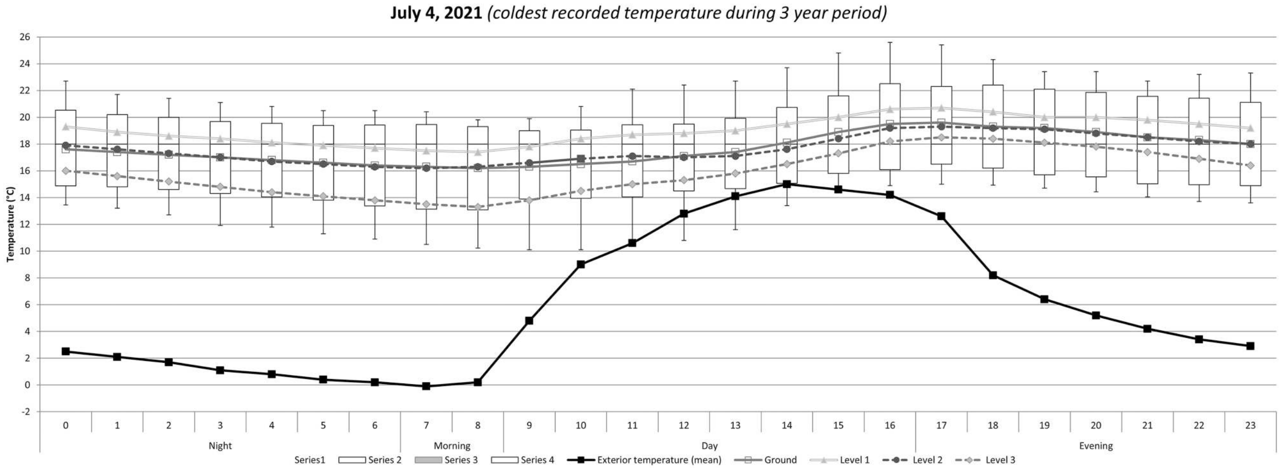



**Figure 3.** Interior and exterior hourly temperatures on July 4, 2021 – the coldest day of the study period.

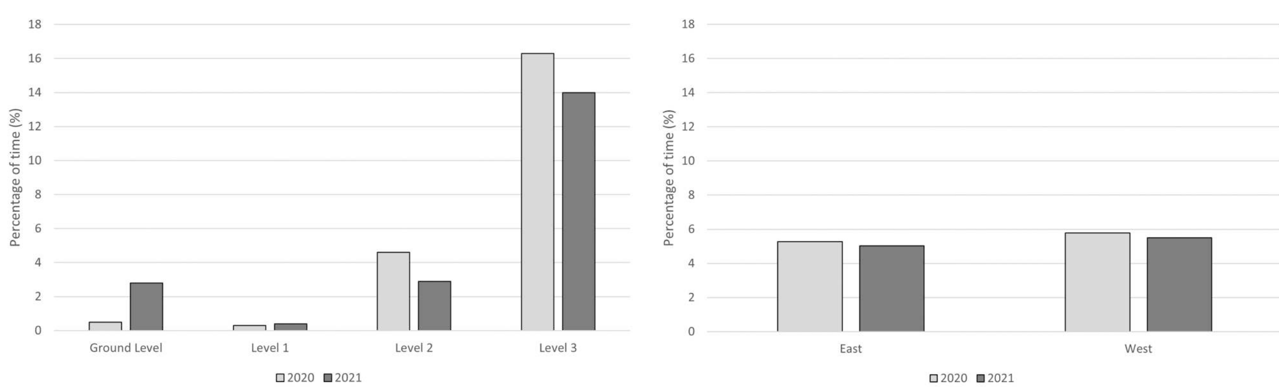
**Table 3.** Percentage of time spent within different mean temperature ranges in June through August 2020 and 2021.

| Cumulative % of time under key temperature thresholds | <12°C | <14°C | <16°C | <18°C | <20°C | <24°C | >24°C |
|---|---|---|---|---|---|---|---|
| 2020 | 0% | 0.5% | 5.5% | 31.5% | 75.9% | 99.0% | 1.0% |
| 2021 | 0% | 0.7% | 5.2% | 25.8% | 68.3% | 99.0% | 1.0% |

16°C threshold. However, when data is analysed per level and assessed for time spent below 16°C, Level 3's performance diverges notably from other floors in the building. Figure 4(a) illustrates that Level 3 can spend up to 16% of its time below 16°C, while other floor levels remain below this threshold for a maximum of 6% of the time.

Analysing unit aggregate data via a Kruskal–Wallis test (Table 4) reveals floor level as a significant factor influencing time spent below the 16°C threshold, with Level 3 having the highest mean rank. However, differences in unit orientation lack statistical significance. Mann-U Whitney tests comparing floor level pairs (Table 5) indicate that Level 3 spent a statistically significant amount of time below 16°C compared to other floor levels.

In addition to the non-parametric analysis of variance, a linear regression model was developed following the approach of Feng et al. (2022). The model regressed indoor temperature against independent variables: outdoor air temperature (Celsius), cloud coverage (Sunshine (Hrs)), and wind speed (m/s) as exterior weather control variables. Additionally, the model incorporated apartment-specific variables: floor level, orientation, and end unit dummies. While the regression model accounted for about one-third of indoor air temperature variance, it supported the non-parametric analysis by confirming that Level 3 apartment units experienced




a b

**Figure 4.** (a) Percentage of time each level spent under 16C in the winters 2020 & 2021; (b) Percentage of orientation each level spent under 16C in the winters 2020 & 2021.

**Table 4.** Kruskal-Wallis test results.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2020** | | *Percentage of time spent under 16°C by level* | | | | **Kruskal Wallis Mean Rank** | | | *Percentage of time spent under 16°C by orientation* | | | **Kruskal Wallis Mean Rank** |
| | | | **MIN** | **MAX** | **MEAN** | | | | **MIN** | **MAX** | **MEAN** | |
| | Level | 0 | 0.14 | 2.97 | 0.68 | 11.13 | Orientation | | | | | |
| | | 1 | 0.02 | 1.87 | 0.56 | 8.67 | | East | 0.02 | 22.47 | 6.04 | 36.46 |
| | | 2 | 0.02 | 19.07 | 5.90 | 16.56 | | West | 0.02 | 26.23 | 7.60 | 37.56 |
| | | 3 | 4.35 | 26.23 | 16.27 | 27.10 | | | | | | |
| | | | Kruskal-Wallis H | | | 18.339 | | | Kruskal-Wallis H | | | 0.049 |
| | | | Asymptotic *p*-value | | | <.001 | | | Asymptotic *p*-value | | | 0.825 |
| **2021** | | *Percentage of time spent under 16°C by level* | | | | | | | *Percentage of time spent under 16°C by orientation* | | | |
| | | | **MIN** | **MAX** | **MEAN** | **Kruskal Wallis Mean Rank** | | | **MIN** | **MAX** | **MEAN** | **Kruskal Wallis Mean Rank** |
| | Level | 0 | 0.02 | 13.76 | 2.78 | 10.44 | Orientation | | | | | |
| | | 1 | 0.07 | 2.88 | 0.91 | 8.4 | | East | 0.02 | 24.59 | 5.50 | 15.06 |
| | | 2 | 0.41 | 24.24 | 5.68 | 16.43 | | West | 0.05 | 24.24 | 8.28 | 17.14 |
| | | 3 | 3.33 | 24.59 | 14.01 | 24.50 | | | | | | |
| | | | Kruskal-Wallis H | | | 15.609 | | | Kruskal-Wallis H | | | 0.403 |
| | | | Asymptotic *p*-value | | | .001 | | | Asymptotic *p*-value | | | .525 |

**Table 5.** Significance of percentage of time where indoor environment is below 16C over the winter of 2020 and 2021 by floor level (Mann-Whitney U test).

| | | 2020 | | 2021 | |
|---|---|---|---|---|---|
| | | *Mann WhitneyZ value* | *Sig* | *Mann WhitneyZ value* | *Sig* |
| Level | L0 & L1 | −0.775 | | −0.200 | |
| | L0 & L2 | −1.251 | | −1.429 | |
| | L0 & L3 | −3.554 | *** | −3.103 | *** |
| | L1 & L2 | −1.650 | | −1.868 | |
| | L1 & L3 | −3.254 | *** | −3.062 | *** |
| | L2 & L3 | −2.531 | | −3.062 | *** |

**, *** Mann-Whitney U Test exact 2-tailed *p*-values at 5% and 1% significance levels respectively.

**Table 6.** Linear regression model results.

| | Independent variable | B | Std. error | *t* | VIF |
|---|---|---|---|---|---|
| 2020 | (Constant) | 32.866 | | 111.330*** | |
| | Ext_Temp(C) | .192 | .342 | 174.317*** | 1.889 |
| | Wind(m/s) | -.106 | −0.98 | −53.191*** | 1.667 |
| | Level_G | 1.655 | .387 | 222.578*** | 1.483 |
| | Level_1 | 2.103 | .484 | 277.798*** | 1.483 |
| | Level_2 | 1.021 | .235 | 135.268*** | 1.472 |
| | EndUnit_N | .400 | .086 | 58.834*** | 1.054 |
| | EndUnit_S | -.180 | −0.36 | −24.441*** | 1.067 |
| | Sunshine(Hrs) | -.200 | −0.35 | −21.630*** | 1.259 |
| | West | .440 | .118 | 82.296*** | 1.003 |
| | Pmsl(hPa) | −0.17 | −0.89 | −59.515*** | 1.103 |
| | Independent variable | B | Std. error | *t* | VIF |
| 2021 | (Constant) | 26.399 | .293 | 90.039*** | |
| | Ext_Temp(C) | .199 | .001 | 213.115*** | 1.592 |
| | Wind(m/s) | -.095 | .002 | −52.770*** | 1.517 |
| | Level_G | 1.220 | .008 | 160.991*** | 1.442 |
| | Level_1 | 2.565 | .008 | 338.561*** | 1.451 |
| | Level_2 | 1.353 | .007 | 181.301*** | 1.453 |
| | EndUnit_N | .422 | .007 | 62.178*** | 1.054 |
| | EndUnit_S | -.455 | .008 | −60.261*** | 1.066 |
| | Sunshine(Hrs) | -.389 | .008 | −46.891*** | 1.203 |
| | West | .28 | .005 | 51.866*** | 1.009 |
| | Pmsl(hPa) | -.011 | .000 | −36.917*** | 1.184 |

Dependent variable = Int_Temp(C)*N* = 341,797; Adj $R^2$ = .302; Std error of estimate = 1.55; F = 14,767

*, **, *** means the coefficients are at 10%, 5% and 1% significance level respectively.

Dependent variable = Int_Temp(C) *N* = 328,759; Adj $R^2$ = .367; Std error of estimate = 1.54; F = 19,023

*, **, *** means the coefficients are at 10%, 5% and 1% significance level respectively.

colder indoor temperatures compared to other floor levels, other factors held constant (Table 6).

When examining the building on a unit basis and contrasting it with the ‘worst case’ dwelling (Unit K on Level 0) used in the Homestar typology assessment, Table 7 demonstrates that several dwellings performed poorer than the ‘worst case’ unit throughout the study period. Most Level 3 apartments, along with a few on Level 2, spent over 5% of their time below the Building Code’s 16°C threshold during the winters of 2020 and 2021. Contrary to expectation, the ground-level dwellings in this building were not the coolest. Level 3’s under performance could be attributed to a wall construction difference. Table 1 reveals that lower floor levels possess insulated concrete block exterior walls (R2.98 to R3.18 ($m^2K/W$)), whereas the top floor (Level 3) features lightweight timber and polyester insulation (R2.11 ($m^2K/W$)). Moreover, Level 3’s dwellings have a larger portion of their thermal envelope exposed to outside air flow, possibly contributing to increased cooling effects. In contrast, the ground level comprises a suspended concrete slab with a still air void underneath, offering less exposure to moving air and potentially resulting in a reduced cooling effect.

Of interest is the potential temperature variance within different apartment areas. Space heating was allocated to each living room, but bedrooms lacked a fixed heating source. Table 8 highlights a noticeable temperature contrast between living rooms and bedrooms, with living rooms generally warmer (spending less time each winter below 16°C). Nevertheless, a Kruskal–Wallis test (Table 9) yielded no significant difference for either year.

### *Semi-structured interviews*

The resident interviews revealed several themes. One common topic was space heating, particularly significant since the building offers social housing for individuals aged 65 and above. One resident refrained regular use of either the provided heater or their own plug-in heaters to conserve energy, relying on extra clothing and blankets instead. Another resident attempted to use the wall heater twice but found it ineffective, opting for an additional jersey instead. This individual made clear that they weren’t concerned about heating costs, just the wall heater’s ineffectiveness. These interviews depict a variety of perspectives and approaches toward thermal comfort among occupants.

Other residents expressed the desire for heating in bedrooms alongside the living room. Although many keep the bedroom-living room door open to let heated air flow, the recorded bedroom indoor temperatures are generally cooler than living rooms where main heaters are positioned. Since the building’s fixed wall panel heaters are underutilized by residents, many opt for supplying their own personal plug-in heaters. Interviews suggest occupants tend not to move these portable heaters around their unit with some residents opting to use a second heater in their bedroom. Considering the feedback gather from residents, future social housing developments aimed at older individuals may consider providing effective space heating in both living rooms and bedrooms.

**Table 7.** Percentage of time dwellings spent under 16°C over the winters of 2020 and 2021.

| | | *2020* | | | | *2021* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Unit # | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 0* | *Level 1* | *Level 2* | *Level 3* |
| West | A | 0.70 | 1.00 | 19.07 | 18.03 | 1.68 | 2.88 | 24.24 | 21.60 |
| | B | 0.49 | – | – | 26.23 | 0.05 | – | – | 14.46 |
| | C | 0.37 | 0.02 | 0.17 | 25.62 | 0.10 | – | – | 17.76 |
| | D | – | 0.16 | 6.48 | 14.90 | 13.76 | 0.07 | 3.11 | 12.58 |
| | E | 0.14 | – | 4.01 | 4.35 | – | – | 0.41 | 3.33 |
| East | F | 0.24 | – | 17.10 | 22.47 | 0.35 | – | 5.86 | 24.59 |
| | G | 0.24 | 1.87 | 4.85 | 6.48 | 0.02 | 0.19 | 4.96 | 4.75 |
| | H | 2.97 | 0.25 | 0.02 | 6.81 | 5.93 | 1.27 | 0.66 | 9.73 |
| | J | 0.27 | – | 0.16 | 21.23 | 3.07 | – | – | 12.29 |
| | K | – | 0.03 | 1.2 | 16.60 | 0.09 | 0.16 | 0.51 | 19.10 |

**Table 8.** Percentage of time living rooms vs bedrooms spent under 16°C over the winters of 2020 and 2021.

| | | | *Level 0* | | *Level 1* | | *Level 2* | | *Level 3* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unit # | | *2020* | *2021* | *2020* | *2021* | *2020* | *2021* | *2020* | *2021* |
| West | A | Living Room | – | 0.1% | – | – | – | – | 11.0% | 16.2% |
| | | Bedroom | 1.4% | 3.3% | 2.0 | 5.8% | 19% | 24.2% | 24.8% | 24.6% |
| | B | Living Room | 0.3% | – | – | – | – | – | 20.3% | 11.8% |
| | | Bedroom | 0.7% | 0.1% | – | – | – | – | 32.1% | 16.8% |
| | C | Living Room | – | – | – | – | – | – | 18.5% | 12.8% |
| | | Bedroom | 0.8% | 0.2% | 0.1% | – | 0.3% | – | 32.5% | 22.7% |
| | D | Living Room | – | 12.9% | – | 0.1% | 0.8% | 1.2% | 10.7% | 9.3% |
| | | Bedroom | – | 14.7% | 0.3% | – | 12% | 5.0% | 19.1% | 15.9% |
| | E | Living Room | – | – | – | – | 0.8% | 0.6% | 1.3% | 0.7% |
| | | Bedroom | 0.3% | – | – | – | 6.6% | 0.2% | 7.5% | 6.0% |
| East | F | Living Room | – | .01% | – | – | 1.8% | 0.4% | 8.3% | 7.5% |
| | | Bedroom | 0.5% | 0.5% | – | – | 32.2% | 11.3% | 36.6% | 40.6% |
| | G | Living Room | 0.1% | – | – | – | 1.5% | 2.6% | 7.2% | 4.6% |
| | | Bedroom | 0.3% | – | 0.7% | 0.4% | 8.2% | 7.4% | 5.8% | 4.9% |
| | H | Living Room | 1.7% | 2.9% | – | – | – | – | 4.0% | 2.0% |
| | | Bedroom | 4.3% | 9.1% | 0.3% | 1.3% | 0.1% | 1.3% | 9.6% | 17.1% |
| | J | Living Room | 0.1% | 3.6% | – | – | 0.1% | – | 23.3% | 9.8% |
| | | Bedroom | 0.4% | 2.5% | – | – | 0.3% | – | 19.2% | 14.8% |
| | K | Living Room | – | – | – | 0.1% | 1.0% | 0.4% | 12.8% | 16.7% |
| | | Bedroom | – | 0.1% | 0.1% | 0.2% | 1.4% | 0.6% | 20.3% | 21.3% |

Many interviewed residents expressed satisfaction with the building, finding it significantly better than their previous homes. One resident highlighted the contrast between her cold, damp previous residence and the current unit. It's evident that residents are generally content with the building, including indoor temperature and humidity during winter. Notably, one resident mentioned the absence of chilblains on his feet for the first time in years since moving into the building.

**Table 9.** Kruskal-Wallis test results for differentials in living room and bedroom temperatures.

| | | *Percentage of time spent under 16°C* | | | |
|---|---|---|---|---|---|
| **2020** | | **MIN** | **MAX** | **MEAN** | **Kruskal Wallis Mean Rank** |
| | Living Room | .07 | 23.32 | 5.7 | 28.69 |
| | Bedroom | .05 | 36.56 | 9.4 | 25.77 |
| | | Kruskal-Wallis H | | | 0.448 |
| | | Asymptotic *p*-value | | | .504 |
| **2021** | | *Percentage of time spent under 16°C* | | | |
| | | **MIN** | **MAX** | **MEAN** | **Kruskal Wallis Mean Rank** |
| | Living Room | .02 | 16.65 | 5.05 | 23.78 |
| | Bedroom | .02 | 40.56 | 9.08 | 29.47 |
| | | Kruskal-Wallis H | | | 1.764 |
| | | Asymptotic *p*-value | | | .184 |

## Discussion and limitations

Both the data collected over the 2020 and 2021 winters and the results of the semi-structured interviews indicate the building has performed well, with only 5.2% and 5.5% of time spent below 16°C (the designated NZ Building Code threshold for older people's homes). However, a noteworthy concern is the concentration of lower temperatures on Level 3 (as discussed and illustrated in Table 7). This contrasts with prior studies suggesting higher building levels generally experience warmer indoor temperatures (Mavrogianni et al., 2012; Porritt et al., 2013; Hamdy et al., 2017; Baborska-Narożny et al., 2017; Lundgren Kownacki et al., 2019; Petrou et al., 2019; Schünemann et al., 2020). Yet, as discussed earlier, this building exhibits a difference in construction type between lower levels and the top floor (Level 3). Additionally, Level 3 units have more thermal envelope exposed to outside air flow, potentially leading to greater cooling effect due to moving air. This aligns, if not in results, with Mavrogianni et al.'s (2012) observation that top-floor flats may offer less protection (in their case from heat during hot periods).

Differences in thermal performance across building levels suggest deficiencies with the typology approach employed by the Homestar rating tool. Previous research by Ade and Rehm (2022) on the same case study building identified substantial temperature disparities between west and east-facing apartments in warmer months, with west-facing dwellings having statistically warmer mean temperatures in the evening and night. However, this performance contrast between orientations doesn't arise during colder months. Furthermore, Ade and Rehm (2022) found no significant level-based difference during summertime, whereas the present study reveals that building level matters during winter, with Level 3 units spending significantly more time below 16°C than lower levels. While isolated cooler dwellings might be attributed to occupant behaviour, the prevalence of Level 3 apartments performing worse than other levels suggests a structural difference (e.g. lower wall R-value and roof exposure), rather than behavioural differences.

This performance disparity between warmer and cooler seasons underscores a significant limitation of the typology analysis method. If dwellings on various floor levels and orientations exhibit varying performance in different seasons, selecting a single 'worst case' dwelling across all seasons becomes unworkable as the dwelling most susceptible to overheating might differ from the one more prone to underheating.

During the certification assessment of the case study building, only Unit K on Level 0 was analysed for green building certification. However, the current study's findings reveal a substantial performance disparity across the building, with many apartments performing notably worse than the 'worst case' unit. Consequently, the rating tool should contemplate incorporating either a whole-building analysis or, at a minimum, an analysis of each unit's thermal performance. This is particularly important given the significant performance differences observed among different floor levels (this study) and orientations (Ade & Rehm, 2022). These implications extend globally to other green building certification schemes that may adopt a similar typology-based certification approach.

The data richness from the semi-structured interviews reinforces de Chavez et al.'s (2017) assertion that a mix of quantitative and qualitative methods enhances cross-validation of findings. Without the interviews, the researchers would not have discovered the ineffectiveness and limited use of fixed wall panel heaters. Additionally, they would have remained unaware of residents' reliance on their own portable heaters. The data loggers alone could not have captured occupants' diverse satisfaction with their winter indoor environment. However, the semi-structured interviews covered only half of the residents and interviewees were not evenly distributed throughout the building in terms of levels, orientations, age, and gender. This clustering introduces potential limitations and biases, affecting the results' generalisability. Consequently, the reported results offer an intriguing case study rather than definitive findings applicable on a broader scale. That said, this building was conceived as a prototype with the potential for replication across various sites in Auckland. While this research retains its status as a case study, it imparts valuable insights to stakeholders including the building's owner, developer, operator, and the design team.

The 8km distance between the case study building and the nearest CliFlo weather station somewhat limits the depth of knowledge about the building's performance in relation to external weather conditions. Subsequent research could incorporate an on-site exterior data logger to obtain real-time temperature and other environmental readings from the study location, thus capturing any local microclimates that might deviate from the conditions at the nearby weather station.

## Conclusion

Indoor temperature results and resident feedback indicate the building performed well during the 2020 and 2021 winters, spending approximately 5% of the time below the mandated safe internal temperature of 16°C for the very young and old.

Residents in the case study building exhibited diversity in age, gender, and ethnicity, leading to varied thermal comfort feedback. Notably, some female residents seemed more sensitive to cold than their male counterparts, with anecdotal instances illustrating these differences. Additionally, occupants with larger builds perceived warmer indoor environments compared to slender individuals, suggesting potential areas for further research.

The statistically significant temperature difference on Level 3 compared to other levels underscores issues with the typology approach in green building assessment. While this study adhered to standard practice by assessing a single ground-floor unit, results varied significantly among units despite all receiving the same Homestar 7 certification. Future considerations could involve refining typology definitions or adopting whole-building modelling for apartments.

This study emphasizes the careful implementation of Homestar certifications for energy-efficient elderly-focused buildings. Stakeholders can take extra measures to enhance indoor air quality and thermal conditions in retirement homes. These findings offer valuable insights for architects, designers, and builders to optimize green residential designs for older residents. Acknowledging the impact on health and prioritizing the well-being of the elderly aligns such specialized property development with broader sustainability goals.

## Notes

1. https://www.metlifecare.co.nz/news/premium-retirement-village-for-whenuapai.
2. https://www.metlifecare.co.nz/news/all-systems-go-for-exciting-new-retirement-village-in-clevedon.
3. https://images.oceaniahealthcare.co.nz/wp-content/uploads/2022/06/02114537/2022-Annual-Report-Final.pdf page 30.
4. https://www.bupa.co.nz/why-bupa/corporate-responsibility-and-sustainability/.
5. Homestar Assessors represent the highest level of Homestar Professionals and have an in-depth understanding of green building practices and the Homestar tool. They form an integral part of the project team and manage the submission paperwork for Homestar Appraisals, Design ratings and Built ratings.

## Disclosure statement

The lead author was the case study building's design rating assessor. However, a different assessor was involved in the subsequent built rating assessment and certification process.

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