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Identifying summer energy poverty and public health risks in a temperate climate

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ABSTRACT

Understanding the health risks associated with indoor overheating and the impacts of cooling energy poverty during summer is becoming increasingly urgent as anthropogenic climate change intensifies heatwave events in many places. We report on results from a cross-sectional postal survey undertaken in Summer 2021/2022, conducted in five regions of New Zealand that typically experience some of the highest temperatures nationally. The study revealed that energy poverty is significant issue during summer, with 43% of the respondents identifying cost as a cooling restriction. Indoor overheating commonly affected the health and wellbeing of participants, with 63% reporting adverse health outcomes. Households citing cost as a cooling restriction were significantly more likely to report adverse health outcomes. Renters and indigenous Māori households were disproportionately affected by indoor overheating and the associated health and energy inequities. These findings highlight the growing health risks from indoor heat exposure in warming climatesparticularly in temperate countries like New Zealand, where inhabitants and infrastructure are not adequately prepared to handle heat-related risks. Relying solely on energy-intensive active cooling exacerbates energy poverty and injustice, increasing residential energy demand. Policy interventions should focus on promoting passive, energy-efficient, and sustainable cooling strategies to protect vulnerable populations from heat-related health disparities.

1. Introduction

Growing scientific evidence indicates that rising temperatures, alongside more frequent and severe heat events, pose significant challenges to maintaining safe and healthy indoor environments due to the increased risk of indoor overheating. This issue is particularly pronounced in countries and regions characterized by temperate and colder climates, where building envelopes,

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ventilation systems, and solar gain strategies are primarily designed to retain heat in colder months, lacking adequate cooling mechanisms (Lomas & Porritt, 2017; Yannas & Rodríguez-Álvarez, 2020). Furthermore, the inhabitants of these cooler climates are not as well adapted to high temperatures and may lack knowledge of heat health risks (Sahani et al., 2022). Indoor overheating is emerging as a critical, yet unfamiliar, public health issue for these countries and regions. During heatwaves in 2020, France observed an 18.2 % increase in all-cause mortality (Pascal et al., 2021). A heatwave in late June 2021 across the Pacific Northwest region of Canada and the United States—where many homes lack air conditioning (Henderson et al., 2022)—led to over 1000 deaths, with the majority happening within private residences (White et al., 2023).

New Zealand is historically characterized by a temperate climate system (Beck et al., 2023). Despite having an overall temperate climate and experiencing less extreme heat than other countries, New Zealand is also facing rising temperatures, increased frequency and severity of hot days (where maximum temperatures exceed 25 °C), and a longer period of warm months (Bodeker et al., 2022; Harrington, 2021). Climate projections based on the SSP2-4.5 scenario suggest that mean air temperatures will rise further, increasing by 0.6 °C to 1.32 °C by mid-century and between 1.03 °C and 2.26 °C by the end of the century (relative to 1995–2014), with temperature increases expected to be larger in summer months (Bodeker et al., 2022). The frequency of hot days is anticipated to rise by 40 % under the SSP1-2.6 low emission scenario and by 100 % under the SSP5-8.5 high emission senario by 2040 (Ministry for the Environment, 2018).

The warming trend has direct implications for public health. There is a robust body of epidemiological evidence linking high temperatures and heatwaves to a spectrum of adverse health outcomes worldwide (Basu, 2009). Older people, infants, children, and individuals with chronic diseases, mental illnesses, or disabilities, are particularly vulnerable to heat-related mortality due to their bodies' less effective thermoregulatory mechanisms (Basagaña et al., 2011; Li et al., 2022) and limited behavioural adaptability (Kovats & Kristie, 2006; Kravchenko et al., 2013). In New Zealand where mean annual temperatures across regions range from 10 °C to 16 °C (Mackintosh, 2001), research conducted in Christchurch observed a 1 % rise in all-cause mortality for each degree Celsius increase on days the temperature exceeded 20 °C (Hales et al., 2000). In Auckland, higher temperatures were linked to increased mortality from respiratory issues (Cockburn, 2001). However, the indoor climate, influenced by the built form and design of dwellings and occupant behaviour (Lomas et al., 2024), can diverge significantly from the outdoors. The impacts of heat on health and wellbeing within indoor environments remain inadequately explored (Ige-Elegbede et al., 2023).

Energy poverty occurs when a household cannot achieve adequate energy services to meet their needs (Thomson et al., 2017a), including staying within the World Health Organization recommended temperatures for health (Telfar-Barnard et al., 2018). While research has widely documented the interrelationships between housing quality, health, and energy poverty, particularly in the context of cold temperatures (Liddell & Morris, 2010; Ruse, 2020), recent attention has broadened to include the impacts of cooling poverty during the summer months (Thomson et al., 2019). In New Zealand, research on summer energy poverty remains limited, largely due to the historically low use of active cooling in homes, which has made energy access in summer less of a pressing concern (French, 2008). With a warming climate and higher prevalence of heat pumps which have an air conditioning function in New Zealand houses, this is changing (Buckett et al., 2012; O'Sullivan et al., 2025). The energy demand for domestic cooling in New Zealand is projected to rise significantly due to climate change (Jalali et al., 2023), which will aggravate the challenges faced by vulnerable groups already affected by winter energy poverty.

Available international research on indoor overheating, cooling poverty and the detrimental health effects have documented disproportionate impacts on minority and Indigenous communities, low-income households, and renters (Hu et al., 2023; Huang et al., 2023; Longden et al., 2022; Mazzone et al., 2023; O'Neill et al., 2005; Thomson et al., 2019; Uejio et al., 2022; Uejio et al., 2016). These groups are often exposed to environments prone to overheating and have financial constraints and socio-economic challenges that hinder renovations and the implementation of cooling strategies (Thomson et al., 2019). In New Zealand, these vulnerable groups overlap with those disproportionately affected by cold, damp, and mouldy housing, as well as winter energy poverty (Ministry of Business Innovation and Employment, 2022; Oliver et al., 2017; Stats, 2021b; Telfar-Barnard et al., 2020), posing a significant risk of further exacerbating energy poverty and housing-related health inequities.

We have previously found nearly ¾ of New Zealanders living in warmer regions reported experiencing overheating, with passive cooling strategies proving no longer sufficient for maintaining thermal comfort during summer (O'Sullivan et al., 2025). This research examines the consequences of this emerging issue, focusing on the impacts of indoor overheating on health and wellbeing across the population, as well as its implications for health inequities and energy poverty.

2. Materials and methods

2.1. Survey questionnaire

This study received ethical approval from the University of Otago Human Ethics Committee (reference number: D21/39). Our survey included questions from national surveys, including New Zealand Census surveys (Stats, 2018a; Stats, 2022) and the 2018 New Zealand General Social Survey (Stats, 2018b), to facilitate comparison with the broader population, alongside questions drawn from previous New Zealand research on energy poverty (Harris Clark et al., 2022; Howden-Chapman et al., 2008; O'Sullivan et al., 2013; O'Sullivan et al., 2016). The survey[1] included self-assessments of housing quality and experiences with indoor overheating, self-

[1] A PDF copy of the survey is available at: https://www.sustainablecities.org.nz/our-research/current-research/heating–cooling.

reported difficulties in cooling homes and managing energy costs, alongside perceived impacts of indoor heat on health and wellbeing. The questionnaire primarily consisted of multiple-choice questions but also featured sections for open-ended responses, enabling participants to expand their answers. Demographic questions were included to identify populations vulnerable to indoor heat-induced adverse health and wellbeing outcomes as well as cooling-related energy poverty. While we acknowledge that personal cooling methods—such as adjustments in clothing, the use of water for evaporative cooling—also contribute to thermal comfort (Lin & Deng, 2008; Roaf, 2024; Song et al., 2023), this paper focuses on active cooling strategies and the implications of energy poverty.

2.2. Data collection

Data collection was conducted from December 2021 to February 2022. Participants received the surveys through mail and were provided the option to respond either by sending it back through mail or completing it online. The collection and management of survey data were facilitated by REDCap (Research Electronic Data Capture), a secure, web-based platform designed for conducting health research surveys (Harris et al., 2019; Harris et al., 2009). Each respondent received a $20 supermarket gift card by courier upon survey completion. The COVID-19 pandemic necessitated adjustments to our mailing schedule, with all correspondence sent out between December 21, 2021, and February 16, 2022. The final date for survey responses was February 28, 2022.

Our participant pool consisted of adults (aged 18 and older) registered on the New Zealand General Electoral Roll, with their contact information sourced from the New Zealand Electoral Commission. We utilized a stratified random sampling method based on age groups (20–29, 30–39, 40–64, and 65 + years old), aiming for a sample size of 641 individuals. We geographically targeted our sample to include five regions known for their significant number of hot days in summer, namely Northland, Gisborne, and Hawkes Bay in the North Island, as well as Canterbury and Central Otago in the South Island (Harrington, 2021).

2.3. Data analysis

Our study employs a mixed-methods approach with a sequential explanatory design (Creswell, 2021). The primary focus is on quantitative data derived from structured questions, followed by an exploration of qualitative insights from free-text responses to deepen the understanding of the quantitative findings. The quantitative analysis employed both descriptive and regression techniques to assess whether renters, Māori households, older adults, and households with vulnerable age groups (0–17 and 65 +) are disproportionately affected by overheating, cooling energy poverty, and indoor heat-induced health effects.

Summer indoor overheating was assessed subjectively by asking respondents to indicate how frequently they perceived their home temperatures as “too hot” during summer, with response options of “often,” “sometimes,” and “usually about right.” The survey also captured warning signs and symptoms of heat-related illness (Grubenhoff et al., 2007), which informed the design of question: “How do you feel being hot at home in summer affects you?” Additionally, identifying “cost” as a response to the question “What reason(s) restrict you from cooling your home?” served as an indicator of cooling energy poverty. Descriptive statistics provided an overview of the prevalence of these conditions across different demographic groups. Logistic regression was used for binary outcomes, such as the presence of heat-related health issues, while ordinal regression analysed ordered outcomes like perceptions of summer indoor temperatures (’usually about right,’ ’sometimes too hot,’ ’often/always too hot’).

2.4. Reflexivity statement

This study was conducted at the University of Otago under the Research Consultation with Māori Policy, a mandated framework designed to ensure that Māori perspectives are meaningfully considered. In accordance with this policy, we completed the required consultation process to address the needs and aspirations of Ngāi Tahu. As non-Māori researchers, we recognize that our cultural backgrounds shape our perspectives and interpretations, and we remain aware of the potential for unintentional biases.

3. Results

3.1. Demographic

A total of 219 people responded to this survey (response rate of 36 %). Demographic details are summarized in Table 1. We oversampled Māori in the invitation phase to gain Māori representation among respondents nearly proportional to the general population, while New Zealand European were overrepresented (Stats, 2020b). Annual household average income was lower than the national gross average of $107,196 (Stats, 2021a), with 84 % of participating households reported annual incomes below $100,000.

3.2. Subjective overheating

A considerable 72 % of respondents indicated their homes being too hot in summer, with 55 % indicating this occurred “sometimes” and 17 % “often,” despite generally positive perceptions of housing quality (75 % rating their housing condition as above average). Notably, overheating was more prevalent than cold temperatures, dampness, and mould across all subgroups (Fig. 1). For example, 85 % of rental households reported experiencing overheating (either sometimes or often), while 63 % encountered cold temperatures (whether sometimes, often, or always), 34 % experienced dampness (either sometimes or always), and 19 % reported mould (either sometimes or always).

Table 1
Demographic and socioeconomic characteristics of survey participants compared to the general population benchmarks from the 2018 New Zealand census.

Total Survey Participants	219		
	Study population		General population[a]
Average household size (persons)	2.9		2.7
	No.	Proportion	
Ethnicity[b]			
Māori	38	17 %	17 %
New Zealand European	183	84 %	70 %
Pacific People	3	1.4 %	8 %
Asian	11	5 %	15 %
Middle Eastern / Latin American / African	1	0.5 %	1.5 %
Other ethnicities	2	0.9 %	1.2 %
Gender [c]			
Male	94	43 %	48.6 %
Female	122	56 %	51.4 %
Another gender	1	0.5 %	N.A.
Home ownership/tenure status			
Owner-occupied	163	75 %	64.5 %
Rental	54	25 %	34 %
Did not reply	2	0.01 %	
Households with members who are			
Children (aged 0–17)	71	33 %	25 %[d]
Adults (aged 65 or over)	85	39 %	15 %
Total household income (gross) in the last 12 months			
Less than $20,000	30	14 %	35 %
$20,000 – $40,000	56	27 %	24 %
$40,000 – $70,000	61	29 %	24 %
$70,000 – $100,000	28	14 %	10 %
$100,000 – $150,000	22	11 %	5 %
More than $150,000	10	4 %	3 %
Did not reply	12	5 %	

Ordinal logistic regression analysis, detailed in Table 2, shows that renters were 2.78 times more likely to experience indoor overheating compared to owner-occupiers ($p < 0.01$). While a greater proportion of Māori households (84 %) reported overheating compared to non-Māori households (69 %), this difference was not statistically significant after adjusting for age, gender, residential tenure, and income. Female participants (75 %) were more likely to report overheating compared to male participants (66 %); however, this difference was not statistically significant after adjusting for age, income, residential tenure, and Māori ethnicity. Similarly, the higher proportion of overheating in households with children (80 %) compared to those without (67 %) did not retain statistical significance after adjusting for income, residential tenure, and Māori ethnicity.

Our analysis identified a significantly positive relationship between increased level of subjective overheating experience and the prevalence of dampness and mould (but not cold temperatures), as shown in Table 3. Among the qualitative data collected from the 184 answers to the free-text question "What is the most difficult thing about the temperature of your house in summer?", 'humidity' was identified as a point of concern by eight participants. The combination of high humidity and heat within indoor environments can be particularly hazardous for human health, as it compromises thermoregulation, amplifying the risk of heat-related symptoms and illness (Arundel et al., 1986; Quinn et al., 2014; Wolkoff et al., 2021).

3.3. Health and wellbeing

Our findings show that indoor heat-induced health effects were prevalent, affecting 63 % of the total respondents and 70 % of those who reported subjective overheating. The most reported effect was sleeping difficulties, which affected over half (54 %) of the total respondents. Qualitative responses further highlighted this concern, with 47 out of 180 respondents who provided answers specifically mentioning "hot nights," "hot bedrooms," and "sleeping" as the most challenging aspects of their home temperature in summer. Additionally, the qualitative results revealed that access to mechanical cooling did not always resolve heat-induced sleep difficulties, particularly in multi-level homes. In New Zealand, heat pumps are typically installed in the lounge and often fail to cool bedrooms or upstairs areas where bedrooms are often located, as reported by 21 respondents.

Mental health appeared to be more adversely affected by heat exposure at home than physical health in this study population. Irritability emerged as the most reported mental health impact of indoor heat, followed by difficulty concentrating. In terms of physical symptoms, headaches and general heat-related discomfort—such as cramps, sweating, faintness, and nausea—were the most commonly experienced. Notably, a small proportion of respondents (2 %) reported experiencing heatstroke, highlighting the potential severity of indoor overheating, particularly for populations that may be more sensitive or vulnerable to excessive indoor heat. However, these self-reported data may not strictly reflect medically defined heatstroke and should be interpreted with caution. Apart from the provided options, some participants noted other concerning symptoms, including lethargy, trouble breathing, eczema, and nosebleeds.

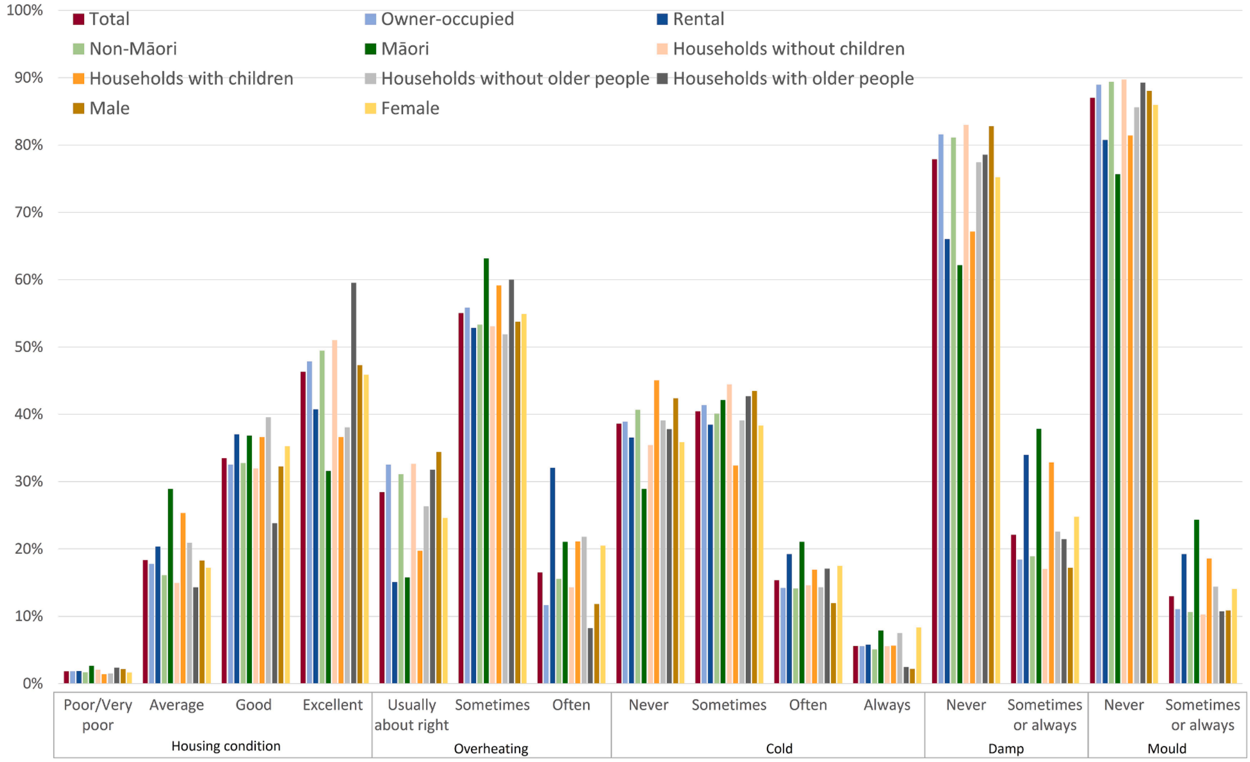

Fig. 1. Proportions of self-reported housing conditions, overheating, cold, dampness, and mould by tenure, ethnicity, presence of children, older adults, and gender. This figure illustrates the comparative prevalence of these issues across different demographic groups, highlighting which group (s) are most affected.

Table 2
Ordinal logistic regression analysis examining household characteristics associated with an increased likelihood of reporting higher levels of subjective indoor overheating (categorized as 'usually about right,' 'sometimes,' 'often'), including rental tenure, Māori ethnicity, gender (female), presence of children (aged 0–17), and presence of older adults (aged 65 +), with adjustments for relevant covariates.

Explanatory Variables	Odds ratio (OR)	95 % CI for OR	p-value
Rental tenure *(Adjusted for age, gender, Māori ethnicity, and income)*	2.78	(1.41, 5.55)	0.003**
Māori *(Adjusted for age, gender, residential tenure, and income)*	1.52	(0.73, 3.16)	0.262
Gender (female) *(Adjusted for age, residential tenure, Māori ethnicity, and income)*	1.61	(0.90, 2.89)	0.106
Households with child(ren) aged 0–17 *(Adjusted for income, residential tenure, and Māori ethnicity)*	1.80	(1.04, 3.15)	0.057
Households with older adults aged 65 and over (Adjusted for income, residential tenure, and Māori ethnicity)	1.52	(0.73, 3.16)	0.262

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.
For gender analysis, males are used as the baseline group.

Our study shows a significantly higher prevalence of negative effects on health and wellbeing from indoor overheating among renters, Māori households, and female participants (Fig. 2). Results of regression analyses (Table 4) reveal that renters were over twice as likely to report indoor heat impairing their enjoyment of summer ($p < 0.05$), and nearly three times as likely to report adverse health effects from indoor overheating ($p < 0.05$) compared to owner-occupiers. Māori households showed greater proportions of reporting indoor heat-induced health and wellbeing effects compared to non-Māori households. However, the statistical significance of differences observed did not persist after adjusting for income, residential tenure, gender, and age. This suggests that the observed disparities in health outcomes between Māori and non-Māori populations may be partly attributed to socio-economic inequities, with lower income and rented housing more prevalent among Māori households (Howden-Chapman et al., 2021). Female participants also reported a higher prevalence of indoor heat-induced health and wellbeing effects compared to their male counterparts, except for males reporting slightly higher (4 %) feelings of being down or depressed compared to females (3 %). In the regression analysis (Table 4), gender differences in reported physical health effects and trouble sleeping were not statistically significant—except that

Table 3
Simple linear regression results for relationships between indoor overheating and other housing habitability issues.

Dependent variable	Independent variable	Estimate	Std. Error	95 % CI	p-value
Overheating (usually about right = 1; sometimes = 2; often = 3)	**Cold temperatures** (never = 0; sometimes = 1; often = 2; always = 3)	0.07	0.05	(−0.04, 0.17)	0.197
	Dampness (never = 0; sometimes = 1; often = 2)	0.26	0.09	0.08, 0.43	0.005*
	Mould presence (never = 0; sometimes = 1; often = 2)	0.20	0.10	0.01, 0.39	0.038*

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.

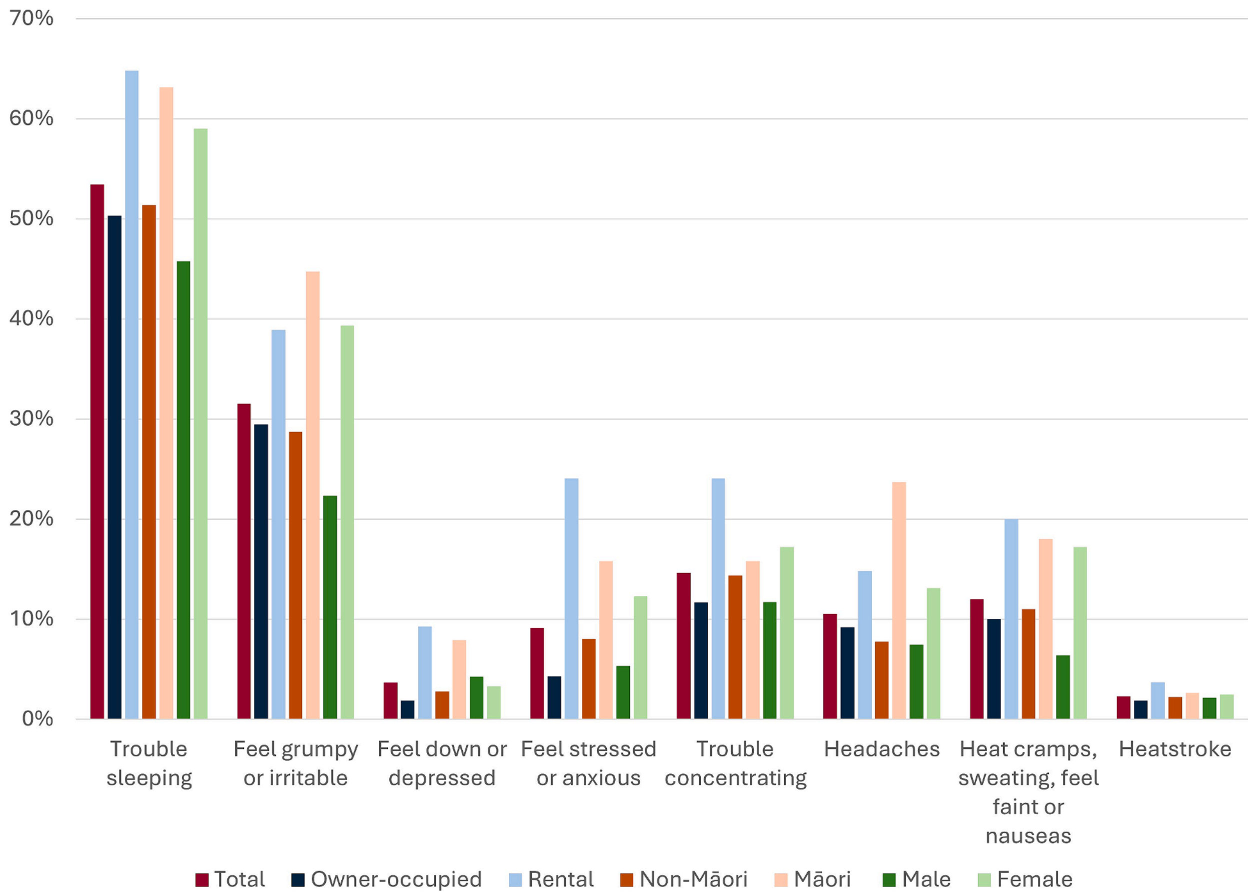

Fig. 2. Proportions of individuals reporting health and wellbeing effects associated with subjective home overheating, categorized by tenure (owner-occupied vs. rental), ethnicity (Māori vs. non-Māori), and gender (female vs. male).

females were more than twice as likely to report mental health effects associated with indoor heat ($p < 0.05$).

Regression analyses were also conducted to examine whether older people are more likely to be affected by indoor heat. Surprisingly, the findings indicate that respondents aged 65 and over were significantly less likely to report negative effects on health and wellbeing caused by indoor heat exposure. Older respondents showed a significant decrease in reporting indoor heat impairing their summer enjoyment (OR: 0.45, $p < 0.01$). They also exhibited a 70 % decrease in the odds of reporting negative mental health effects ($p < 0.01$), and trouble sleeping ($p < 0.001$) due to subjective home overheating compared to those aged less than 65.

While our survey did not specifically target children, qualitative feedback from the free-text sections highlighted the impact of indoor overheating on children's sleep. Four participants highlighted difficulties in cooling their children's bedrooms, expressing concerns about the impact on sleep quality. Passive cooling methods were found ineffective, with one remarking, "the kids' bedrooms are too hot (despite having curtains closed to stop the sun shining in) that it's not comfortable to sleep in and it's hard to cool naturally by opening all windows." Another parent also mentioned their children's reluctance to sleep with the windows open. Moreover, the limited effectiveness of electric fans was underscored by a respondent who observed that their children struggled to sleep even when a

Table 4
Regression analysis for indoor heat and health outcomes. Ordinal regression for indoor heat as a prevention from enjoying summer at home and logistic regression for health outcomes, comparing rental versus owner-occupier, Māori versus non-Māori, and older adults (≥65) versus adults aged < 65.

Outcome variables	**Total**		**Explanatory variables** **Rental tenure** Owner-occupied (N = 163)		Rented (N = 54)		Odds Ratios (95 % CI)	p-value	**Māori** non–Māori (N = 180)		Māori (N = 38)		Odds Ratios (95 % CI)	p-value
	No.	%	n	%	n	%	Adjusted for gender, age, income, and Māori ethnicity		n	%	n	%	Adjusted for gender, age, income, and residential tenure	
Indoor heat as a prevention from enjoying summer at home							2.28 (1.23, 4.27)	0.010*					1.59 (0.82, 3.07)	0.168
Never = *0*	72	33 %	59	36 %	12	22 %			66	37 %	6	16 %		
Rarely = *1*	74	34 %	60	37 %	14	26 %			57	32 %	17	45 %		
Sometimes = *2*	59	27 %	38	23 %	21	39 %			47	26 %	12	32 %		
Often/Always = *3*	13	6 %	6	4 %	7	13 %			10	6 %	3	8 %		
Overheated homes lead to:														
One or more negative health outcomes	139	63 %	95	58 %	44	81 %	2.93 (1.3, 7.22)	0.013*	109	60 %	30	79 %	1.77 (0.74, 4.62)	0.215
One or more negative mental health outcomes	84	38 %	58	36 %	26	48 %	1.29 (0.62, 2.66)	0.484	66	36 %	18	47 %	1.08 (0.49, 2.36)	0.848
One or more negative physical health outcomes	43	20 %	25	15 %	18	33 %	2.13 (0.93, 4.77)	0.070	30	17 %	13	34 %	1.92 (0.78, 4.55)	0.143
Trouble sleeping	117	53 %	82	50 %	35	65 %	1.6 (0.79, 3.32)	0.198	93	51 %	24	63 %	1.35 (0.62, 3.03)	0.458

Outcome variables	**Explanatory variables** **Gender** Male (N=93)		Female (N=122)		Odds Ratios (95% CI)	p-value	**Older people** Age < 65 (N=148)		Age ≥ 65 (N=69)		Odds Ratios (95% CI)	p-value
	n	%	n	%	Adjusted for age, income, Māori ethnicity, and residential tenure		n	%	n	%	Adjusted for gender, income, Māori ethnicity, and residential tenure	
Indoor heat as a prevention from enjoying summer at home					1.65 (0.96, 2.83)	0.07					0.45 (0.24, 0.81)	0.008 **
Never = *0*	37	40%	34	28%			40	27%	32	47%		
Rarely = *1*	34	37%	40	33%			53	36%	21	31%		
Sometimes = *2*	20	22%	37	30%			45	30%	12	18%		
Often/Always = *3*	2	2%	11	9%			10	7%	3	4%		
Overheated homes lead to:												
One or more negative health outcomes	50	54%	87	71%	1.59 (0.84, 3.05)	0.16	104	70%	33	48%	0.33 (0.16, 0.64)	0.001 **
One or more negative mental health outcomes	26	28%	58	48%	2.10 (1.10, 4.05)	0.03*	68	46%	14	20%	0.30 (0.14, 0.61)	0.001 **
One or more negative physical health outcomes	12	13%	31	25%	1.70 (0.75, 4.03)	0.21	34	23%	8	12%	0.48 (0.18, 1.14)	0.116
Trouble sleeping	43	46%	72	59%	1.25 (0.67, 2.30)	0.48	90	61%	25	36%	0.30 (0.15, 0.58)	<0.001 ***

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.
For rental tenure analysis, owner-occupiers are the baseline group; for gender analysis, males are the baseline group.

fan was in use.

3.4. *Energy poverty*

Our findings indicated a high prevalence of cooling energy poverty, with 43 % of respondents identifying "cost" as a barrier to cooling their homes. Regression analyses, detailed in Table 5, revealed that renters were especially vulnerable, being nearly three times more likely than owner-occupiers to report cost as a restriction on cooling their homes ($p < 0.01$). Financial constraints also influenced the choice of cooling devices (Table 6): households citing cost as a cooling restriction were more than twice as likely to use electric fans ($p < 0.05$) and were 63 % less likely to use heat pumps ($p < 0.001$). This aligns with previous research showing that households facing energy poverty prefer to use smaller (although often less efficient) heating devices during winter and avoid using their heat pumps to restrict their electricity costs (O'Sullivan et al., 2014).

Our study revealed a pronounced association between health effects of overheating and cooling energy poverty (Table 7). Households citing cost as a cooling restriction were significantly more likely to experience adverse health effects: they were 6.64 times more likely to report negative mental health effects ($p < 0.001$), 2.87 times more likely to report physical signs and symptoms related to heat illnesses ($p < 0.001$), and 3.64 times more likely to experience heat-induced trouble sleeping ($p < 0.001$). The results underscore the disproportionate health impacts of indoor overheating on individuals who are facing energy poverty.

4. Discussion

4.1. Socio-demographic variation in indoor overheating

This study provides preliminary insights into the prevalence of indoor overheating issues within homes across New Zealand based on subjective experiences, shedding light on its widespread occurrence and detrimental effects on residents' health and wellbeing. Despite New Zealand's temperate climate, almost three quarters (72 %) of our respondents reported experiencing uncomfortably hot conditions in their homes during summer at least sometimes, leading to adverse health outcomes for 63 % of respondents. To develop a comprehensive understanding of summer indoor overheating in New Zealand and to correlate subjective experiences with objective data, a future large-scale study employing continuous temperature monitoring is essential. There are currently only a few studies on summer indoor temperatures in New Zealand, and they either use single-point temperature measurement (Stats, 2020a) or involve small sample sizes (Ade & Rehm, 2021, 2022), limiting their generalizability.

While much of the existing research on the health impacts of indoor heat focuses on older adults (Hansen et al., 2022; Teyton et al., 2022; van Loenhout et al., 2016; Williams et al., 2019), our research reveals a broader age range of adults are affected. Our findings indicate that indoor overheating primarily impacts sleep quality and mental health of New Zealanders. In contrast, physical signs and symptoms of heat-related illness were less reported, similar to findings from Williams et al. (2019) that moderate to severe health symptoms were infrequently reported in the cooler climates of the U.S.A.

Our study also found that older participants reported significantly less impacts on their health and wellbeing from indoor heat. However, this may be influenced by the reliance on self-reported data, which could underestimate heat-related risks. Previous research has found that older people tend to perceive the environment as cooler, potentially leading to a reduced ability to perceive increased thermal and physiological strain during heat exposure (Baquero & Forcada, 2022; Beckmann et al., 2021; Millyard et al., 2020). This perception may result in underreporting of the impacts of indoor heat on the health of older participants of this study, so findings may not indicate a lower actual risk, but rather a diminished capacity to perceive and report these conditions. The limited awareness of heat-related health risks and prevention measures among older people, combined with a lack of proactive measures by healthcare professionals in temperate climates (Beckmann & Hiete, 2020; Vu et al., 2019), may further increase the vulnerability of older people to heat-related risks, warranting further research to assess the true extent of indoor overheating's impact on this demographic.

Adults we surveyed reported that children are susceptible to trouble sleeping induced by overheating, consistent with prior research findings (Huebner, 2022; Wailoo et al., 1990). Research conducted in diverse temperate climates—such as Australia (Kim & de Dear, 2018), England (Teli et al., 2014), South Korea (Yun et al., 2014), southern Portugal (Conceição et al., 2012), and the Netherlands (Mors et al., 2011)—shows that children prefer cooler temperatures than adults during warmer months. Our finding suggests increasing access to more efficient cooling solutions to ensure children's thermal comfort during hot periods is important.

Our study found that female participants were more likely to report indoor overheating and experienced greater health impacts, particularly on their mental health. Previous studies indicate that, while gender differences in thermal responses at neutral temperatures are relatively minor, women exhibit a narrower band of indoor thermal comfort and are more sensitive to deviations from their comfort range, whether the temperature is too warm or too cold (Haselsteiner, 2021; Karjalainen, 2007), with negative health impacts (Parkinson et al., 2021). Socially constructed gender roles often result in women spending more time in the domestic environment (Clair & Baker, 2022), increasing their exposure to suboptimal indoor thermal conditions. Women require greater individual temperature control and adaptive measures than men (Karjalainen, 2012); however, in practice, women tend to have less thermal control—they are less likely to use household thermostats or initiate discussions about thermal comfort (Karjalainen, 2007; Sintov et al., 2019). Women also have higher heat-related mortality rates and an increased risk for heat-related illnesses (Ballester et al., 2023; Venugopal et al., 2021). The combination of physiological and social factors contributes to gender inequities in thermal comfort and heightens women's vulnerability to indoor overheating. Our findings underscore the need for future interventions to incorporate gender-sensitive protocols. Whether through adaptive housing solutions or targeted public health strategies, it is essential that these

Table 5
Logistic regression analysis of the association between rental tenure, Māori ethnicity, households with children, households with older adults, and cooling energy poverty (measured by reporting cost as a cooling restriction).

Outcome	Explanatory variables	Odds Ratio (OR)	95 % CI for OR	p-value
Report cost as cooling restriction	Rental tenure	2.93	(1.56, 5.65)	0.001**
	Māori	1.27	(0.6, 2.67)	0.524
	Households with child(ren)	1.44	(0.79, 2.64)	0.235
	Households with older people	0.93	(0.52, 1.67)	0.818

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.

Table 6
Logistic regression analysis of electric fan and heat pump (cooling function) usage association with two energy poverty indicators.

Outcome	Explanatory variable	Odds Ratio (95 % CI)	p-value
Use electric fan for cooling	Reporting cost as cooling restriction	2.24 (1.15, 4.40)	0.017 *
Use heat pump for cooling	Reporting cost as cooling restriction	0.37 (0.18, 0.72)	0.004 **

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.

Table 7
Logistic regression of adverse heat-related mental health effects, adverse heat-related physical health effects, and trouble sleeping due to indoor heat, adjusted for age, gender, and Māori ethnicity, against cost as cooling restriction.

Outcomes	Explanatory variable (adjusted for age, gender, and Māori ethnicity)	Odds Ratio (95 % CI for OR)	p-value
Adverse heat-related mental health effects	Cost as cooling restriction	6.64 (3.53, 12.90)	$<$0.001***
Adverse heat-related physical health effects		2.87 (1.37, 6.23)	0.006**
Trouble sleeping due to indoor heat		3.64 (2.01, 6.71)	$<$0.001***

Significance codes: [0, 0.001] '***'; [0.001, 0.01] '**'; [0.01, 0.05] '*'.

interventions address women's unique thermal requirements and heightened vulnerabilities to indoor overheating.

The experience of thermal comfort in real-world environments is shaped not only by physiological mechanisms but also by the interplay of thermal history, cultural and technological practices (Brager & de Dear, 1998). Cultural and climatic contexts critically influence thermal adaptation practices (Kenawy & Elkadi, 2021). Future research is needed to understand the specific thermal experience and adaptive responses of diverse demographic groups and socio-cultural contexts within New Zealand, where previous research has shown colder indoor temperatures in winter were due to poor housing quality and energy poverty, rather than cultural preferences (Teariki et al., 2020).

4.2. Confronting housing, energy, and health inequities arising from indoor overheating

Our study found that households residing in damp and mouldy housing were more likely to report experiences of indoor overheating, suggesting a disproportionate impact of indoor overheating on vulnerable households already affected by housing habitability issues. Our findings align with the research conducted by Vellei et al. (2017) in the southwest of the UK, which found that households vulnerable to indoor overheating often experience unhealthy indoor air quality. These findings further amplify concerns over energy poverty, especially as the escalating energy demand for summer cooling imposes additional financial strain on those already struggling with the costs of winter heating (Thomson et al., 2019).

Our results demonstrated that cost is the primary restriction for New Zealand residents to maintain optimal indoor temperatures in summer, and that such restriction disproportionately affects renters and households experiencing energy poverty. In countries with cooler climates, such as New Zealand, the warmer months have traditionally been seen as a period of energy budget recovery (O'Sullivan & Chisholm, 2020). With growing energy demand for summer cooling, coupled with inadequate passive cooling methods (O'Sullivan et al., 2025), we anticipate existing energy poverty in New Zealand will be exacerbated.

Following on from O'Sullivan et al. (2025), we sought to explore consequences of the social transition to using active indoor cooling, on energy equity through exploring disparities in access to and affordability of cooling and the health consequences of indoor heat. Our study identified strong associations between the incidence of indoor overheating, cooling-related energy poverty, and adverse health and wellbeing outcomes. The association between poor housing quality, energy poverty, and compromised health is well established in the literature (Marí-Dell'Olmo et al., 2017; Michael et al., 2010; Thomson et al., 2017b). However, research on such associations tend to prioritise the impacts of indoor cold temperatures and the role of adequate heating (O'Sullivan, 2019). While there has been an increase in energy demand for space cooling in cooler climates, research on the consequences of summertime energy poverty is still in its infancy, particularly within the context of Global North (Chan & Delina, 2023; Thomson et al., 2019). Our study contributes to this evolving discourse by demonstrating a significant association between summertime energy poverty and adverse health outcomes. Our results align with Australian research (Awaworyi Churchill & Smyth, 2021), which identified an association between energy poverty and heat-related health issues, and a Canadian study (Riva et al., 2023), which shows a significant correlation between poor general and mental health and the inability of households to maintain comfortable indoor temperatures in summer.

Poor housing conditions act as a pathway for social and environmental inequities to manifest as disparities in health and wellbeing (Marí-Dell'Olmo et al., 2017; World Health Organization, 2018). Our study identified pronounced demographic disparities in the prevalence of indoor overheating, summer energy poverty, and their subsequent impacts on health and wellbeing, with renters and Māori being disproportionately affected. This is consistent with international literature showing that minority and Indigenous communities face an elevated risk of experiencing indoor overheating and its detrimental effects on health and energy security (Huang et al., 2023; Longden et al., 2022; O'Neill et al., 2005; Uejio et al., 2022; Uejio et al., 2016). The renters and Māori households in our study are also disproportionately affected by damp and mouldy conditions, echoing the documented disparities in housing quality and associated health outcomes within New Zealand (Howden-Chapman et al., 2021; Stats, 2021b). The pre-existing disparities in housing and associated health and energy inequities are likely to be intensified by indoor overheating, especially in cooler areas like New Zealand (Hernández, 2013; Howden-Chapman et al., 2021; O'Sullivan, 2019; Oliveras et al., 2021). This trend is further exacerbated by the projected increases in temperature and the anticipated rise in both the frequency and severity of heat waves across New Zealand (Bodeker et al., 2022; Howden-Chapman et al., 2021).

Heat risk arises from the interplay of hazards, exposure, vulnerabilities, and adaptive capacities (Singh & Nirwan, 2024). Our findings, echoing the insights of Singh and Nirwan (2024), demonstrate that indoor overheating disproportionately affects groups experiencing marginalization, poverty, legacies of colonization, limited access to quality housing and shading devices, and intersecting vulnerabilities related to gender and age. Mazzone et al. (2023) puts the concept of "systemic cooling poverty" (SCP), highlighting that cooling-related inequalities extend beyond financial constraints of households to pay for energy services to encompass intricate layers of physical, social, and infrastructural deficiencies. To address indoor overheating and summer energy poverty, strategies must address all dimensions of risk—hazards, exposures, and vulnerabilities (Singh & Nirwan, 2024). Future research should move beyond financial considerations to capture the multifaceted nature of SCP, enabling policymakers to pinpoint vulnerable regions, communities and individuals, and to implement targeted, context-specific mitigation (Mazzone et al., 2024; Mazzone et al., 2023).

Providing technical and financial support to vulnerable populations—such as passive housing retrofits, subsidies for cooling devices, and funding to offset energy costs—has proven essential (Siegel et al., 2024). Equitable and effective interventions also require collaboration with a broad spectrum of professionals and community stakeholders (e.g., architects, urban planners, community-based organizations, and health practitioners). By integrating urban planning with building design strategies at community and local levels, resilience can be strengthened across the built environment, thereby promoting thermal justice and health equity (Mazzone et al., 2023). This includes planning and improving the accessibility of climate-adaptive infrastructure that offers refuge from heat, such as cooling centres and other air-conditioned public spaces, like libraries and shopping malls, as well as green and blue spaces (Amorim-Maia et al., 2023; Fraser et al., 2016; Haddad et al., 2022).

4.3. Indoor overheating's impact on indigenous Māori wellbeing

Māori communities face numerous systemic barriers, including challenges related to home ownership, good quality housing, and the development of culturally appropriate housing, which stem from the enduring impacts of colonization (Logan, 2021; Penny et al., 2024). Our study shows that indigenous Māori households are disproportionately affected by indoor overheating, as well as cold, damp and mouldy conditions, which likely reflects broader socio-economic disparities, with lower income and higher rates of rental housing prevalent among these communities. Cultural factors can affect the experience of thermal comfort (Rupp et al., 2015; Wang et al., 2018), potentially intensifying the adverse effects on Māori populations.

The Whakawhanaunatanga Māori Wellbeing Model for Housing and Urban Development emphasizes the centrality of whānau (family/families) in Māori housing and wellbeing (Penny et al., 2024). Māori housing should allow for the ability of whānau Māori to discharge their cultural practices, such as demonstrating manaakitanga (hospitality) and tautoko (support) to others (Boulton et al., 2022; Penny et al., 2024). However, indoor overheating can compromise these practices by creating uncomfortably warm environments that discourage gatherings and social interactions.

To effectively address the challenges of indoor overheating faced by indigenous Māori, collaboration with Māori communities is essential. This involves integrating indigenous knowledge, practices, and worldviews into housing standards, designs, and policy interventions (Mazzone et al., 2023; Penny et al., 2024). Such collaboration not only supports the cultural sustainability of Māori communities but also honors Te Tiriti o Waitangi / the Treaty of Waitangi, enhancing hauora Māori (Māori health and wellbeing) through culturally relevant standards and interventions (Penny et al., 2024). Building codes and design guidelines need updating to reflect Māori cultural values, for example, by incorporating features such as communal spaces designed to stay cool and ventilated to encourage social interactions even during warm periods. Future research is warranted to develop sustainable and culturally appropriate adaptive strategies, particularly through Kaupapa Māori research (Walker et al., 2006), a research methodology defined as research by Māori, for Māori, and with Māori, which fully recognizes Māori cultural values and systems.

4.4. Advancing thermal regulation and resilience in New Zealand's housing sector

New Zealand's housing stock has faced persistent challenges in housing quality. Much of New Zealand's housing stock comprises timber-frame constructions, primarily clad with timber weatherboard or materials such as stone, brick, or concrete. Approximately 30 % of homes in New Zealand are poorly insulated (Organisation for Economic Co-operation and Development, 2017). Many old houses, especially those built before 1978, have little or no insulation (Building Performance, 2023). Stats (2021b) reports that about one in five New Zealand homes that are always too cold during winter. Dampness and mould are widespread issues: 2018 Census data revealed that 21.5 % of homes experience dampness, and 16.9 % have visible mould larger than A4 size at least some of the time (Stats, 2021b). Considerable efforts have been directed towards addressing issues of cold, damp, and mouldy conditions, such as mandatory wall and ceiling insulation in new homes since 1978 and the Healthy Homes Standards requiring insulation in rental properties since 2019. Existing initiatives in New Zealand aimed at addressing inadequate indoor thermal comfort and associated housing-related health effects predominantly focus on colder months, such as the Warm Up New Zealand: Heat Smart and the Winter Energy

Payment (Howden-Chapman et al., 2023).

Current measures for improving housing quality largely not recognize heat-related risks, which pose a significant risk, as strategies that focus only on enhancing wintertime warmth without integrating heat management measures could inadvertently raise overheating risks. Several studies showed evidence that poorly-designed housing with insulation improvements intended for cold months, if not paired with effective solar gain control (e.g., through glazing, shutters, and shading) and adequate ventilation, showed higher levels of overheating during warmer months (Chvatal & Corvacho, 2009; Elsharkawy & Zahiri, 2020; Fosas et al., 2018; Makantasi & Mavrogianni, 2016; Porritt et al., 2012; van Hooff et al., 2014). Research in New Zealand has highlighted this issue, with significant overheating observed in a newly constructed apartment certified as green (Ade & Rehm, 2021).

The effectiveness of active cooling in mitigating indoor overheating and associated health risks is well-documented (Baniassadi et al., 2019; O'Neill et al., 2005). However, reliance on energy-intensive cooling solutions is unsustainable (Kingsborough et al., 2017), especially in the context of New Zealand. The country's significant dependence on hydroelectric power generation, combined with the slow adoption of residential solar photovoltaic systems and the anticipated reduction in hydroelectric generation capacity during summer months underscores the imperative for energy-efficient and sustainable cooling solutions (O'Sullivan & Chisholm, 2020; Suomalainen et al., 2022).

Our study underscores the necessity to broaden New Zealand's building regulations to facilitate designs that provide year-round thermal comfort and bolster resilience against rising temperatures. The current Building Code establishes minimum performance standards that are primarily tailored to address issues with cold, damp and mouldy conditions but lacks measures to prevent overheating (Ade & Rehm, 2021), leaving some buildings at risk regardless of insulation levels (Ministry of Business Innovation and Employment, 2024). We recommend that building regulations be revised to prioritize energy-efficient and passive strategies that accommodate both warm and cold conditions. Specifically, the Building Code should incorporate mandatory features for solar gain control, such as shading devices such as window louvres, shutters, external blinds (Grussa et al., 2019). Regulations should promote the use of innovative materials for building envelopes, such as reflective surfaces and green roofs (Sun et al., 2021). Current ventilation standards within the Building Code and Healthy Home Standards primarily focus on improving air quality and removing contaminants through natural and exhaust ventilation, yet they overlook the critical role of ventilation in temperature control. Particularly, there is a lack of provisions for mechanical ventilation in settings where natural ventilation is limited due to privacy, security, or noise concerns (Lomas & Porritt, 2017). These comprehensive changes require robust support through funding initiatives that facilitate the development, testing, and implementation of integrated designs.

5. Limitations

Our study's reliance on the New Zealand General Electoral Roll as a sampling frame may have inherently limited participation from certain demographic groups, particularly lower-income individuals and Māori. The 2016 General Social Survey (Stats, 2018c) shows that individuals whose income barely meets or does not meet their daily needs are less likely to vote, potentially skewing our sample towards those with higher economic security despite the inclusion of a financial incentive. Additionally, those identifying as Māori have the option to enrol in either the Māori or General Electoral Roll, which could introduce further bias in our sample composition.

It is worth noting that homeowners were unintentionally overrepresented in the study sample, making up 75 % of the sample compared to just 64.5 % nationally (Stats, 2021b). Statistics NZ indicates that homeowners have better housing quality with fewer issues with dampness and mould than renters (Stats, 2021b), therefore, the overrepresentation of homeowners in the study population may account for the significant 79 % reporting good or excellent housing condition. This limits the ability of the data to reflect the experiences of many New Zealanders living in poor quality dwellings. Given the known association between poor quality dwellings and poor indoor thermal performance (Howden-Chapman et al., 2007), it is likely that a larger proportion of New Zealand population than data shown in this study experience indoor overheating issues and associated mental and physical health impacts. On the other hand, our study targeted regions including locations where we expected higher summer temperatures rather than aiming for representation from across NZ, so our study should probably not be generalised across NZ without further investigation.

Another limitation of this study is that, as an initial investigation to identify potential issues with indoor overheating, our survey did not capture specific housing attributes such as type, age, orientation, insulation, shading, presence of balconies. These factors significantly influence the thermal environment of homes and residents' thermal experiences (Lomas & Porritt, 2017; Ribeiro et al., 2024). Future research should aim to incorporate more comprehensive data collection methods that can accurately capture these crucial aspects, thereby facilitating a deeper understanding of which dwelling types and population groups are most affected by overheating risks.

The findings of this study are contextualized by the COVID-19 pandemic, during which there was a significant increase in the amount of time people spent at home due to large-scale work-from-home practices and policies such as lockdowns and stay-at-home orders in New Zealand (Dohig, 2023; Mayer & Boston, 2022). Additionally, public health restrictions often limited access to outdoor spaces and public places where people might seek cooler environments (Abdullah et al., 2022). This confinement could have influenced participants' thermal experiences and their responses to our survey, as prolonged periods at home and restricted outdoor activity could exacerbate the perceptions of indoor thermal discomfort. Such conditions are likely to have affected the generalizability of our results, highlighting the need for future research to consider the specific contexts in which data collection occurs.

6. Conclusion

Even in New Zealand's temperate climate, indoor overheating has emerged as an issue that significantly affects health and wellbeing. This has pronounced impacts on sleep quality and mental health. This problem exacerbates existing housing disparities and contributes to broader health and energy inequities. Socio-economically disadvantaged groups, including renters, Indigenous Māori, those living in mouldy and damp housing, and those facing winter energy poverty are disproportionately affected. Historically unprepared for summer heat, New Zealand's housing stock requires urgent development of climate-resilient housing with affordable and energy-efficient cooling mechanisms and design solutions for overheating.

Building codes and standards must be broadened to include mandatory features for mitigating overheating risks, including solar gain control and enhanced ventilation solutions. Collaboration among policymakers, building professionals, and community stakeholders is essential to ensure that new standards and initiatives are culturally responsive and tailored to the needs of vulnerable populations. Effective interventions should extend beyond financial and technical, as addressing indoor overheating integrate urban planning and building design strategies at local and regional levels.

CRediT authorship contribution statement

Zhiting Chen: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Data curation. **Kimberley Clare O'Sullivan:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition. **Rachel Kowalchuk Dohig:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Nevil Pierse:** Writing – review & editing, Writing – original draft, Validation, Supervision, Funding acquisition, Formal analysis, Conceptualization. **Terence Jiang:** Writing – original draft, Formal analysis. **Mylène Riva:** Writing – review & editing, Validation. **Runa Das:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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