CLIMATE RESILIENT CITIZENRY & STAYING COOL
Strengthening Heat Resilience Of Vulnerable Communities

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN | Lee Kuan Yew Centre for Innovative Cities

Technical Report

Towards a Climate Resilient Citizenry:

POPULATION HOUSEHOLD STUDY FOR UNDERSTANDING SHARED EXPERIENCE OF URBAN HEAT IN SINGAPORE

January 2026

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN | Lee Kuan Yew Centre for Innovative Cities
NUS National University of Singapore
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Collaboration Agency:
Ministry of Sustainability and the Environment SINGAPORE

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Strengthening Heat Resilience Of Vulnerable Communities

Towards a Climate Resilient Citizenry: Population Household Study for Understanding Shared Experience of Urban Heat in Singapore

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EXECUTIVE SUMMARY

Heat has long been part of everyday life in Singapore. However, rising temperatures and urban heat island (UHI) effect are intensifying thermal conditions in ways that increasingly strain residents' comfort, health, and household energy demand. This report presents findings from Working Group 1: Population Household Study, conducted under the project *Leveraging Shared Experience of Urban Heat and Bridging Spatial–Temporal Dissonance: Towards a Climate Resilient Citizenry (CRC) in Singapore*. The study examines how households perceive, experience, and adapt to heat within the home environment.

Study Design and Scope

Data were collected from 1,009 individuals from 416 households across 10 planning areas, spanning all public housing dwelling types in Singapore. The methodology included:

- Household survey capturing dwelling characteristics, domestic thermal conditions, cooling devices, and consumption patterns.
- Individual surveys assessing climate knowledge and attitudes, heat experiences and cooling behaviours, social norms, and risk preferences.
- Home environmental audit recording objective indoor microclimatic measurements (e.g., temperature, wind speed, dry-bulb and wet-bulb temperature) and unit-level spatial layout conditions.

Key Findings

- Climate change is widely recognised and linked to rising temperatures, yet a gap remains between this broad awareness and lived heat experiences, with limited understanding of localized drivers of urban heat such as UHI.
- Climate concern and personal responsibility are high, but everyday climate actions tend to remain low effort, revealing a persistent gap between awareness and practice.
- Household cooling behaviours vary significantly, with daytime reliance on fans and natural ventilation and night-time reliance on air-conditioning, alongside substantial differences across individuals and households.
- Cooling access and vulnerability to heat are uneven, with seniors, smaller units, and rental households reporting more heat-related disruptions and fewer cooling options.
- Indoor microclimates differ considerably between households, and indoor temperatures and wind speeds often diverge from outdoor readings, underscoring the importance of in-situ home measurements for understanding lived heat exposure.
- Awareness of the national Climate Vouchers scheme is high, but redemption (within the first six months of access) remains modest and primarily directed toward lower-cost appliances.

Implications for Policy and Design

- Improve thermal literacy and practical heat communication, particularly around UHI and effective heat adaptation at home.
- Support households with higher thermal vulnerability, including seniors, public rental units, and low-income families, through improved access to cooling options and awareness of healthy cooling practices.
- Promote energy-efficient cooling behaviours, balancing comfort and efficiency, especially given strong night-time reliance on air-conditioning.
- Enhance passive cooling potential by enabling residents to make better use of natural ventilation where feasible.
- Refine financial incentives to increase relevance, accessibility, and uptake, ensuring that schemes effectively address household cooling needs.

Contribution to the CRC Programme and Next Steps

The population household study (Working Group 1; WG1) established the empirical baseline for subsequent CRC work:

- Ethnographic Household Study (WG2): Anchoring qualitative work in population-level patterns to triangulate and identify key themes on social dynamics shaping heat resilience.
- Citizen Dialogues (WG3): Guide the design of dialogues by identifying key knowledge, concerns, and adaptation gaps to be explored collectively.
- Co-Design Workshop and Field Experiments (WG4): Provide baseline and inform the design of targeted interventions.

Chapter 1

Introduction

1. Introduction

Climate change poses complex and multi-scalar risks to human well-being, particularly in urban environments where rising temperatures compound existing vulnerabilities. In dense, tropical cities such as Singapore, the interaction between global warming and the Urban Heat Island (UHI) effect intensifies everyday thermal stress and places mounting pressure on physical, psychological and social resilience. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), even under optimistic emissions pathways, global surface temperatures will continue to rise until at least mid-century, with current trajectories pointing to accelerated warming of up to 1.5°C within two decades and potentially 4.4°C by 2100.

Singapore's national assessments reflect this reality. The Centre for Climate Research Singapore projects an increase in mean daily temperature of 1.4–4.6°C by the end of the century, driven by both climate change and UHI intensification (National Climate Change Secretariat Singapore, 2016). Urban heat is therefore no longer a marginal or episodic discomfort, but a persistent feature of everyday life with implications for health, productivity, energy demand, and social well-being.

Singapore has made substantial progress in climate mitigation and adaptation efforts, guided by the Inter-Ministerial Committee on Climate Change (IMCCC) and the national Climate Action Plan. Yet a persistent challenge remains translating high levels of public awareness into everyday behavioural change. For instance, the inaugural OCBC Climate Index (2021) found that while 87% of respondents recognised air-conditioners as the household appliance associated with the highest carbon emissions, over one-third still used air-conditioning for more than seven hours per day. Such patterns reveal a pronounced knowledge-action gap, which may be attributed to temporal-spatial-scalar dissonance, where individuals perceive climate change to be a distant issue occurring in the future ("not now"), elsewhere ("not here"), or being too complex an issue for individuals to make any meaningful impact on ("too big"), thus reducing personal urgency and agency.

Urban heat offers a unique entry point to bridge this dissonance. Heat is immediate, tangible, and shared; it cuts across socio-economic groups and is experienced daily in homes, neighbourhoods, and public spaces. Previous studies in Singapore show that greater awareness of the urban heat challenge correlates with higher support for UHI-mitigation policies and greater willingness to participate in climate initiatives (Borzino et al., 2020; Schubert et al., 2020). Heat can therefore act as a psychologically "near" phenomenon that anchors broader climate understanding and motivates action.

The Climate Resilient Citizenry (CRC) programme builds on this premise. It is a transdisciplinary, multi-institutional research initiative which aims to establish a comprehensive understanding of how individuals in Singapore perceive climate change across temporal, spatial, and scalar dimensions, and how heat can be leveraged to activate meaningful climate action. CRC spans across four Working Groups (WG). This report is an outcome of WG1 which conducted a population-representative household study to address four broad research questions (RQs):

> **RQ1:** How are climate change and urban heat perceived along temporal-spatial-scalar dimensions, and how does this impact practices related to climate change?
>
> **RQ2:** How strongly is urban heat associated with climate change?
>
> **RQ3:** What are the links between thermal comfort, individual-household-built characteristics, and cooling practices?
>
> **RQ4:** To what extent are climate-related individual attitudes and cooling practices shaped by social and built features in the household?

This technical report presents the methodology and descriptive findings of the population household study, covering four domains central to understanding everyday climate action in Singapore: (1) Climate Knowledge, Attitudes, and Environmental Behaviours, (2) Heat Experiences, Perceptions, and Cooling Practices, (3) Built Features, Devices, and Practices in Household Cooling, and (4) Economic Dimensions of Household Adaptation.

Findings from WG1 establish the empirical foundation and directly support the remaining CRC WGs:

- WG2 (Ethnographic Household Study) by triangulating broad population-level findings to model social resilience and cooling practices
- WG3 (Citizen Dialogues) by informing the design of deliberative groupings and communication frames
- WG4 (Co-creation Workshop and Field Experiments) by providing a behavioural and psychosocial profiling of the population to guide intervention design
- Broader CRC objectives by mapping behavioural pathways that can enhance public engagement, resilience, and sustainability in a warming Singapore.

By providing a comprehensive dataset and descriptive baseline, WG1 also serves as an open resource for researchers, agencies, and organisations interested in collaborative analysis, modelling, and translation of findings into policy and practice.

Chapter 2

Methodology

2. Methodology

2.1 Study Sites and Sampling Frame

The household survey was conducted across ten planning areas in Singapore from October 2024 to July 2025, with two areas selected per region (Central, East, North, Northeast, West) as shown in Figure 2.1. These sites were chosen to reflect diverse public housing typologies, building ages, and microclimatic conditions, enabling coverage of households exposed to different thermal and built-environment contexts.

Household recruitment involved door-to-door canvassing, online advertisements (e.g., Telegram, GoodHood), and printed flyers. Interested households were contacted and scheduled for visits if they met the sampling criteria.

Stratified random sampling was based on HDB dwelling type (i.e., 1- or 2-room, 3-room, 4-room, 5-room). Dwelling type was prioritised over planning area as a stratifier because housing typologies are unevenly distributed across neighbourhoods. To maintain geographic balance, a cap of 50 households per planning area was applied. This produced a sample that is both diverse and structurally representative, with minimal neighbourhood bias.

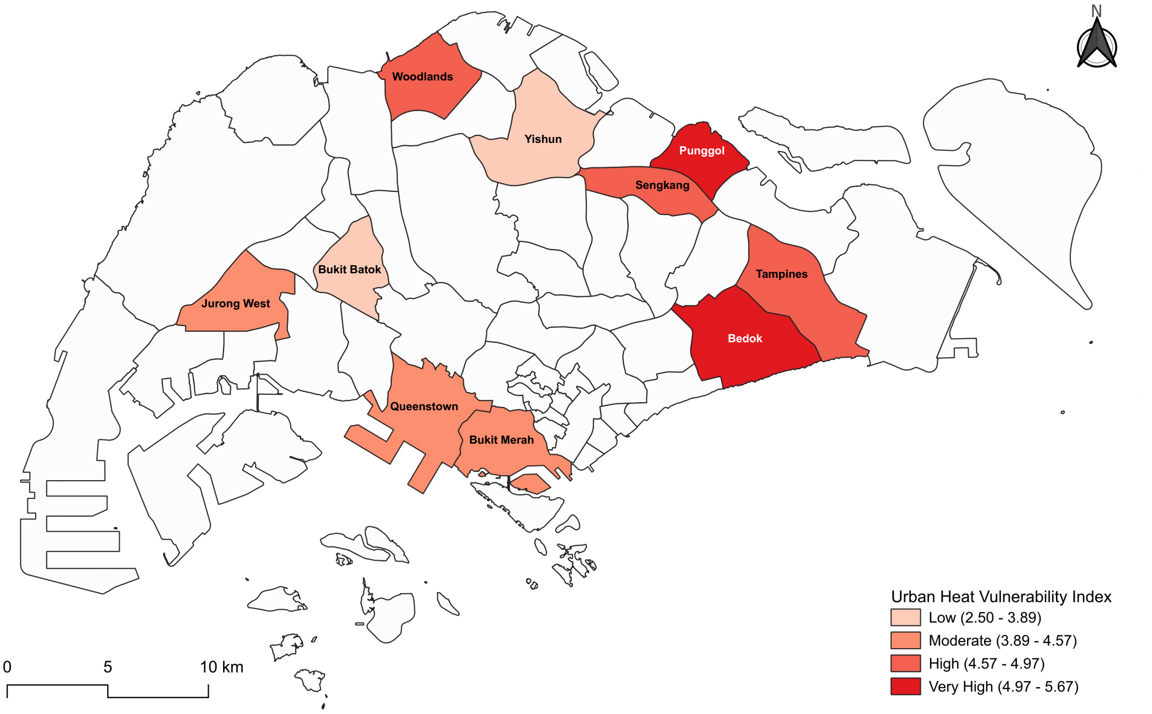

Figure 2.1 Urban heat vulnerability in 10 study sites (Philipp & Chow, 2020)

2.2 Research Approach and Data Collection Protocol

Participating households were required to host two researchers for a 30–40 minute in-person household visit. During the visit, an adult household representative (aged 18+) received a study briefing before filling up the household survey.

All household members aged 13 and above who could read and comprehend English also completed an individual survey online, which they could do at their own time and convenience within 48 hours from the house visit. Youth aged 13–16 completed a simplified version tailored to their age group.

A researcher conducted a home environmental audit in parallel (Figure 2.2), documenting unit and room characteristics, ventilation features, shading, and appliance use. Indoor thermal conditions (e.g., temperature, humidity, wind speed) were measured using the Kestrel™ 5500 which was set-up in the living room. Outdoor thermal conditions were measured at the ground floor of the building (void deck) within 15 minutes (before or after) of the visit. When permitted, 360° photos of the home were taken using Insta360™ cameras, with identifying features blurred.

This integrated design allows subjective thermal experiences to be interpreted alongside social and physical conditions of the home, providing a holistic understanding of adaptation strategies and vulnerabilities.

Figure 2.2 In-person household visit and data collection

2.3 Ethical Procedures and Consent

The study received approval from the SUTD Institutional Review Board (IRB-24-00659) and adhered to the principles of the 1964 Helsinki Declaration and its amendments. All study materials and procedures underwent ethical review.

Informed consent was obtained from the household representative before the household survey. Each adult completing an individual survey provided digital consent, and youth aged 13-17 provided assent alongside parental consent. Participation was voluntary, and respondents could opt out of any component. Participating households received remuneration for each completed component.

2.4 Survey Instruments and Measurement Blocks

The study employed a multi-component assessment consisting of (i) a household survey completed by the household representative, (ii) individual adult and youth surveys completed by household members, and (iii) a home environmental audit conducted by a trained researcher. For each component, Table 2.3 summarises the mode of administration, major measurement blocks, and total item counts. The table is intended as a high-level guide to the structure of the instruments; full variable lists and construct descriptions are provided in the Supplementary Materials.

Table 2.3 Description of WG1 study components

Component		Completed by	Mode	Block	Item Count
Self-reported surveys	**Household Survey**	Household representative	In-Person	Household makeup	9
				Household features	23
				Estate	19
				Utilities	3
	Individual Survey (Adult)	All household members aged 17 years and above and know English	Online	Demographic variables	14
				Psychological variables	273
				Economic evaluation	2
				Picture task	13
	Individual Survey (Youth)	All household members aged between 13 and 16 and know English	Online	Demographic variables	5
				Psychological variables	89
				Picture task	13
Objective assessment	**Home Environmental Audit**	Researcher	In-Person	Unit characteristics	7
				Room characteristics	13
				Kestrel measurements	2
				360° picture	1

2.4.1 Household Survey

The household survey was completed by the household representative during the in-person visit. It collected essential information on household composition, socio-economic characteristics, physical dwelling features, cooling and ventilation practices, and resource use. These data enable comparisons across socio-economic groups and built-environment conditions, forming the structural foundation for interpreting individual-level behaviours.

The survey included four blocks: (i) household makeup, (ii) household features, (iii) estate cooling characteristics, and (iv) utilities. These covered variables such as household size, incomes, tenants, pets, room count, cooling devices across rooms, perceived thermal conditions, design considerations, and monthly bills for electricity, gas, and water. A full variable list, including item counts and measurement scales, is provided in Table S1 (Supplementary Materials).

2.4.2 Individual Survey

Adult household members completed an online survey capturing demographic information, climate-related knowledge and concern, psychological distance, environmental identity, perceived behavioural control, personal and social norms, heat experiences, cooling practices, and pro-environmental behaviours. These constructs were drawn from established behavioural and psychosocial theories (e.g., value-belief-norm theory, construal level theory of psychological distance, environmental identity frameworks), complemented by several self-developed items tailored to Singapore's urban-heat context.

The adult survey also incorporated: (1) a contingent valuation (willingness-to-pay; WTP) module, capturing respondents' willingness to invest in household heat-mitigation improvements, including affordability constraints and behavioural trade-offs and (2) a picture-selection task, used to assess strength of associations between climate change and heat.

All adult survey constructs, including theoretical sources, item counts, and scale types, are documented in Table S2 (Supplementary Materials). Youth participants (13-16 years old) completed a streamlined, age-appropriate version of the adult survey. All youth-level items are documented in Table S3 (Supplementary Materials).

2.4.3 Home Environmental Audit

The home environmental audit provided objective data on the physical characteristics of each dwelling and its thermal conditions. Conducted by trained researchers during the household visit, the audit documented unit attributes (e.g., floor level, unit type, presence of indoor/outdoor plants), room-level features (e.g., window type, shading devices, lighting, clutter), and ventilation pathways. The researchers also recorded indoor thermal conditions in the household living room and outdoor thermal conditions at the block's sheltered ground floor area, using a calibrated Kestrel™ 5500 meter that captured temperature, humidity, wind speed, dew point, heat index, and wet-bulb temperature.

When permitted, 360° photos of the living room and bedrooms were taken using Insta360™ cameras, with all identifiable information blurred during post-processing. These visual records document room layout, furniture placement, shading elements, and ventilation potential, supporting detailed interpretation of thermal behaviours.

A full list of environmental audit measurement blocks and variables is presented in Table S4 (Supplementary Materials).

2.5 Reporting Approach

The results presented in this report focus on descriptive patterns across the instruments outlined above. Summary statistics and cross-tabulations are used to illustrate key trends, supported by figures and tables where appropriate. Subgroup comparisons are reported using age group for individual-level constructs and dwelling type for household-level constructs. Age group reflects meaningful life-stage differences in perceptions, behaviours, and vulnerability, while dwelling type captures variations in socioeconomic status and built-environment conditions. These stratification dimensions were selected for their conceptual relevance and practical utility for interpreting patterns and informing interventions. While the present report focuses on descriptive findings, extended inferential and multivariate analyses will be developed for academic publications.

Chapter 3

Sample Description

3. Sample Description

This chapter provides an overview of participating households and individuals. It establishes the empirical baseline necessary to interpret subsequent findings on climate attitudes, heat perceptions, cooling practices and household decision-making dynamics.

3.1 Section Highlights

Key findings of this section are as follows:

- **Comprehensive sample:** The final dataset includes 1,009 individuals from 416 households, after excluding inattentive responses, domestic helpers, and tenants.
- **Demographically representative individual sample:** Respondents mirror Singapore's population across sex, age, ethnicity, educational attainment, and employment.
- **Coverage of dwelling types:** The sample spans all major HDB flat types, with intentional oversampling of 1–2 room units to capture groups more vulnerable to heat.
- **Diverse households:** Households include single-occupant, 1-generation, 2-generation, and 3-generation families**,** enabling analysis of intra-household decision-making on heat management.
- **Socioeconomic variation:** More than half of households fall within low or lower-middle income bands**,** providing representation of groups facing adaptation constraints.
- **Geographically distributed sample:** Coverage across 10 planning areas supports analysis of spatial differences in microclimate exposure and housing conditions.

3.2 Overview of the Sample

A total of 423 households completed the household survey, and 1,060 individuals completed individual surveys. After excluding inattentive responses (n = 24), domestic helpers (n = 17), and tenants living in owner-occupied units (n = 10), the final analytical sample comprises 1,009 individuals from 416 households.

All participating households reside in HDB public housing, where 76.4% of the population lives (Housing and Development Board, 2024). The distribution of dwelling types within our sample closely aligns with national patterns (Figure 3.1), with smaller units (1–2 room flats) intentionally oversampled to ensure adequate coverage of groups often under-represented in large-scale surveys but highly relevant for understanding heat vulnerability and climate adaptation. The breakdown of dwelling types across the ten planning areas is provided in Figure S5 (Supplementary), offering finer spatial resolution for readers interested in estate-level variation.

The spatial distribution of participating households is shown in Figure 3.2. Tampines contributed the largest share of sampled households (12.5%), while Jurong West contributed the lowest (6.5%). The broad geographic coverage across Singapore's central, eastern, north-eastern, northern, and western regions allows the study to capture variability in microclimate, urban form, and estate design.

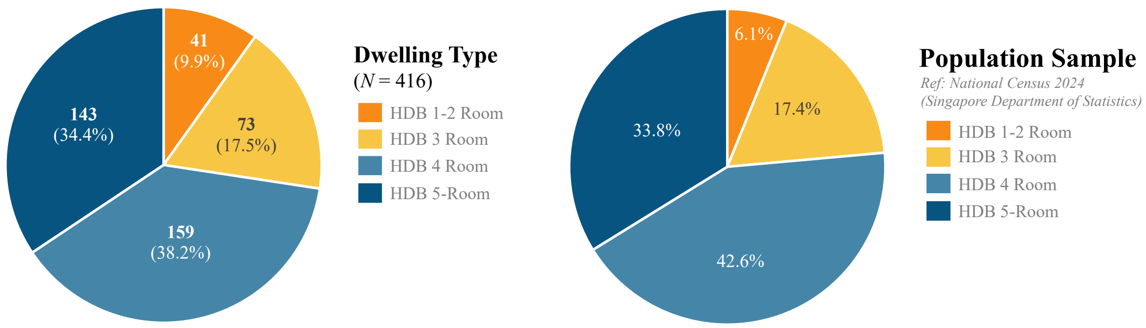

Figure 3.1 Distribution of dwelling types across (a) our sample, (b) national census

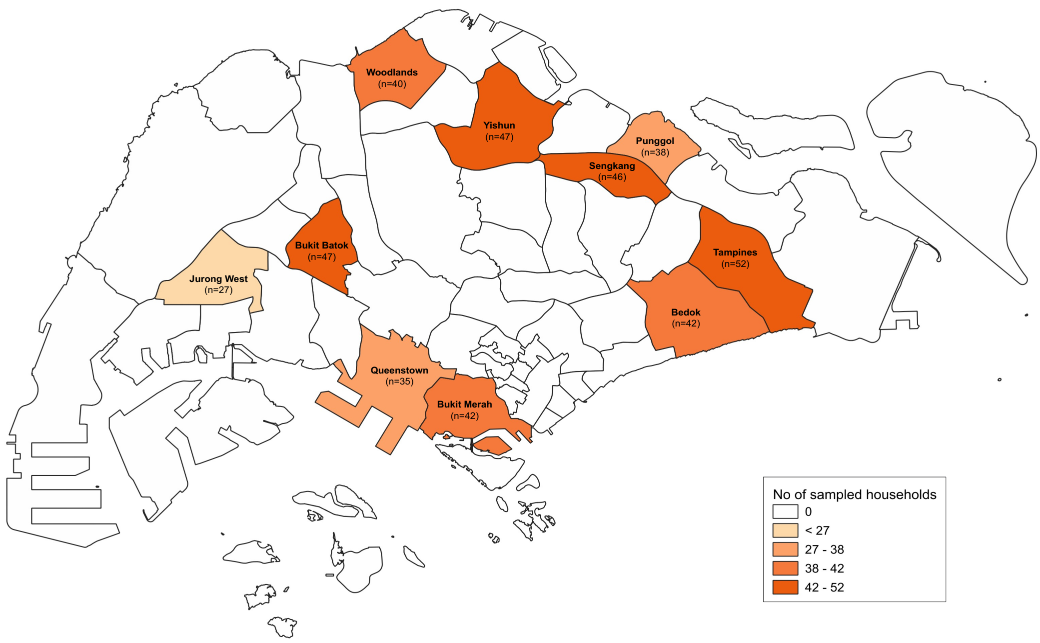

Figure 3.2 Distribution of sampled households across 10 study areas

3.3 Household Characteristics

Table 3.3 summarises the characteristics of the 416 surveyed households. Most households reside in 4-room (38.2%) or 5-room/executive flats (34.4%), followed by 3-room (17.5%) and 1–2 room units (9.9%). A small but meaningful proportion of households are public rental flats (5.1%) or privately rented units (1.0%).

Household composition is diverse. The largest groups include two-generation households with children under 18 years old (32.2%) and two-generation adult households (28.6%), followed by one-generation spousal households (19.5%) and single-occupant households (8.7%). Their overall distribution is shown in Figure S6 (Supplementary) and distribution across planning areas is visualised in Figure S7 (Supplementary).

Table 3.3 Household characteristics

Housing type, *n* (%)	
Studio, 1- or 2-room HDB	41 (9.9 %)
3-room HDB	73 (17.5 %)
4-room HDB	159 (38.2 %)
5-room or executive HDB	143 (34.4 %)
Housing rental status, *n* (%)	
Public rental from HDB	21 (5.1 %)
Private rental of whole HDB unit	4 (1.0 %)
Household composition, *n* (%)	
1-generation spousal	81 (19.5 %)
1-generation non-spousal	23 (5.5 %)
2-generation, <18 years old	134 (32.2 %)
2-generation, >18 years old	119 (28.6 %)
3-generation	23 (5.5 %)
Single occupant	36 (8.7 %)
Household income per capita[*]	
Low Income (<= S$1478)	124 (29.8 %)
Lower-Middle Income (> S$1478, <= S$2641)	116 (27.9 %)
Middle Income (> S$2641, <= S$3995)	79 (19.0 %)
Upper-Middle Income (> S$3995, <= S$6095)	51 (12.3 %)
High Income (> S$6095)	46 (11.1 %)
Household profile, *mean*; range	
Household size	3.3; 1-9
Number of respondents per household	2.4; 1-7
Number of years living	11.4; 0-70
Total number of households	**416**

Note. [*]Based on 20th percentiles (Singapore Department of Statistics, 2024)

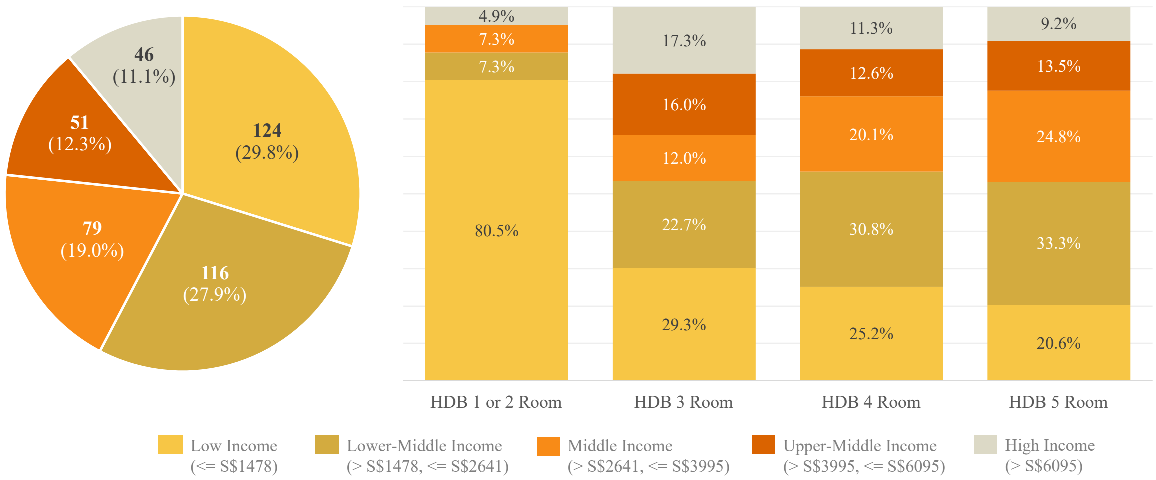

Figure 3.4 Distribution of household monthly income per capita across different dwelling types (*N*=416)

Household income per capita displays substantial variation. More than half of all households fall within the low (29.8%) or lower-middle (27.9%) income categories based on the 20th percentiles by Singapore Department of Statistics (2024), indicating meaningful representation of households with limited adaptive resources. The distribution of income categories across dwelling types is shown in Figure 3.4.

On average, households consist of 3.3 members and have lived in their current unit for 11.4 years, suggesting stable residency patterns that support meaningful interpretations of long-term environmental exposure.

3.4 Individual Characteristics

Table 3.5 summarises the characteristics of the 1,009 individuals included in the analytical sample. The sex distribution is balanced (54.7% female; 45.3% male) and spans the full life-course. Respondents range from 13 to 88 years old (mean = 40.9), with substantial representation in all age groups: early adults (25–44) 47.9%; middle-late adults (45–64) 23.8%; seniors (65+) 11.8%; young adults (18–24) 8.1% and teenagers (<18) 7.8%.

Ethnic composition mirrors national proportions: Chinese 76.1%, Malay 12.4%, Indian 7.1%, Others 4.3%, ensuring cultural representativeness. Figure 3.6 visualises the intersections of ethnicity, gender, and age groups, demonstrating broad demographic coverage across all categories.

Educational attainment spans from primary schooling to postgraduate qualifications, with the largest group holding bachelor's degrees (36.2%). Employment status similarly reflects a wide distribution: 63.0% employed, 31.6% not in the workforce, and 5.4% actively job-seeking.

Marital status shows substantial diversity across the sample. Majority of respondents are married (58.2%), followed by those who are single (27.2%). Smaller proportions are separated or divorced (4.3%) or widowed (2.7%), with 0.9% preferring not to disclose.

Most respondents are Singapore Citizens or Permanent Residents (89.9%), making the findings directly relevant to national adaptation policy. Domestic helpers and tenants in owner-occupied households were excluded from main analyses due to their distinct autonomy and exposure profiles.

Table 3.5 Respondent characteristics

Sex, *n* (%)	
Female	552 (54.7 %)
Male	457 (45.3 %)
Age group, *n* (%)	
Teenagers (below 18)	79 (7.8 %)
Young adults (18-24)	82 (8.1 %)
Early adults (25-44)	483 (47.9 %)
Middle to late adults (45-64)	249 (24.7 %)
Seniors (65 and above)	116 (11.5 %)
mean; range	41.0; 13-88
Ethnicity, *n* (%)	
Chinese	769 (76.1 %)
Malay	125 (12.4 %)
Indian	72 (7.1 %)
Others	43 (4.3 %)
Education, *n* (%)	
Primary & below	46 (4.6 %)
N/O levels	119 (11.8 %)
Nitec/Higher Nitec	46 (4.6 %)
A levels/Diploma	240 (23.8 %)
Bachelors	365 (36.2 %)
Postgraduate	96 (9.5 %)
Other qualification / Prefer Not to Say	28 (2.8 %)
Children (did not answer)	69 (6.8 %)
Employment, *n* (%)	
Employed	636 (63.0 %)
Unemployed, not in workforce or prefer not to say (Including Children)	319 (31.6 %)
Unemployed, Job-seeking	54 (5.4 %)
Residency Status, *n* (%)	
Singapore Citizen or Permanent Resident (PR)	907 (89.9 %)
Non-Citizen or PR	33 (3.3 %)
Children (did not answer)	69 (6.8 %)
Marital Status, *n* (%)	
Single	274 (27.2 %)
Married	587 (58.2 %)
Separated or divorced	43 (4.3 %)
Widowed	27 (2.7 %)
Prefer not to say	9 (0.9 %)
Children (did not answer)	69 (6.8 %)
Total number of respondents*	**1009**

Note. *Domestic helpers and tenants in owner-occupied unit were excluded for purposes of analysis

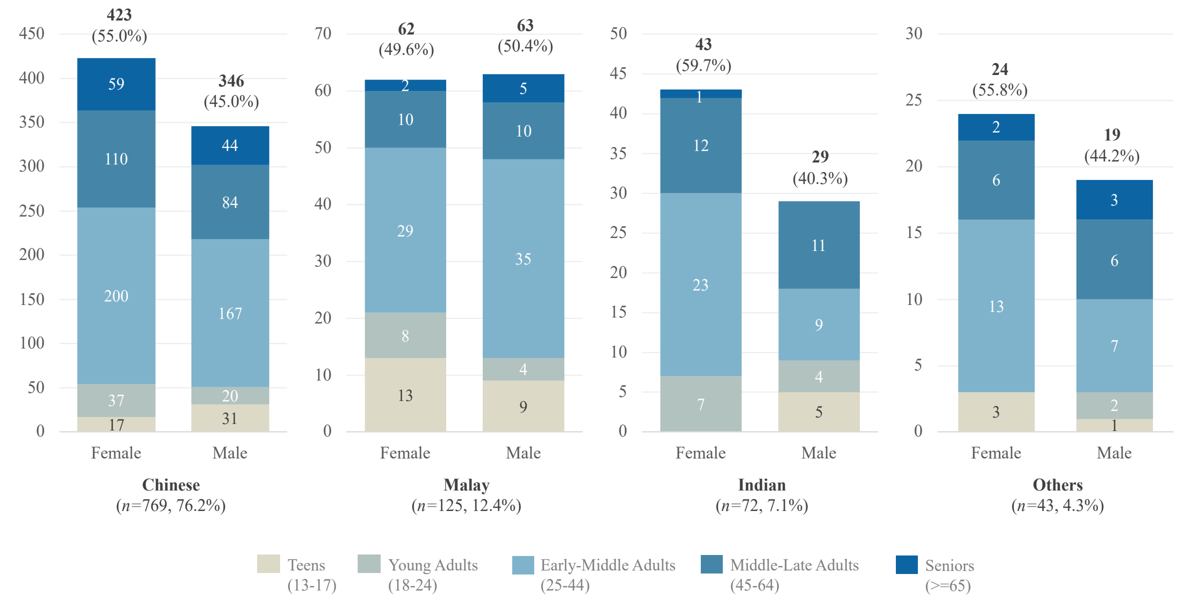

Figure 3.6 Distribution of sample by ethnicity, gender, and age group (*N*=1009)

Chapter 4

Key Findings

4. Key Findings

This chapter summarises the broad patterns observed across the descriptive results which are detailed in Chapters 5–8. These cross-cutting findings provide a high-level snapshot of the diverse thermal experiences, cooling practices, resource conditions, and climate-related perceptions reported by households and individuals in the sample.

(a) **Residents feel the burden of heat but have limited knowledge of localised thermal risks.** Awareness of climate change is high and its link to rising temperatures is well-recognised, but knowledge of the UHI effect is low which reflects low recognition of how neighbourhood-level urban design and collective cooling practices affects domestic thermal conditions.

(b) **Climate perceptions reveal both engagement and distancing.** There is high concern for climate change yet reported pro-environmental behaviours tend to be low effort, a pattern that aligns with broader tendencies toward perceived psychological distance to climate change and scalar discounting in the way that individual climate actions and impacts are perceived.

(c) **Thermal vulnerability and cooling access are unevenly distributed.** Seniors, lower-income households, smaller dwelling types, and rental units are exposed to greater impacts of heat on daily activities and face lower access to cooling options, including air-conditioning ownership.

(d) **Behavioural adaptation is widespread but constrained.** Respondents report varied behavioural and environmental adaptation for heat management including clothing choice, staying indoors, and using fans and natural ventilation. However, barriers such as noise, odours, and pests, limit passive cooling potential.

(e) **Indoor microclimatic conditions often diverge from outdoor measurements.** Objective temperature and wind-speed data reveal considerable indoor–outdoor variation across households, underscoring that ambient environmental readings do not necessarily capture the thermal environments residents experience at home.

(f) **Financial incentives for sustainable cooling remain under-utilised.** Despite high awareness, only a minority of households spent Climate Vouchers within the first 6 months of their launch, suggesting possible behavioural frictions such as limited perceived relevance or mismatches between eligible products and residents' priorities.

Chapter 5

Climate Knowledge, Attitude, and Environmental Behaviors

5. Climate Knowledge, Attitudes, and Environmental Behaviours

This chapter presents respondents' understanding of climate- and heat-related concepts, their perceived distance from climate change impacts, levels of concern, perceived responsibility, environmental norms, pro-environmental behaviours, and risk-taking tendencies. Together, these constructs provide the psychosocial foundation for interpreting adaptive capacity and household decision-making.

5.1 Section Highlights

Key findings of this section are as follows:

- **Strong climate knowledge but uneven UHI awareness:** Most residents report good understanding of climate change, but knowledge of the UHI effect is substantially lower, with notable generational gaps.
- **Climate change feels both near and far:** Residents perceive climate change as immediate and real (low temporal and hypothetical distance), yet its most severe consequences are seen as affecting future generations and people in other places (high social and spatial distance).
- **High levels of climate concern:** Concern is strongest for personal and environmental impacts, with only a very small share of residents expressing no concern at all.
- **Shared sense of responsibility:** Most respondents believe they play a role in contributing to and mitigating climate change, indicating strong perceived personal responsibility.
- **Moderate environmental identity:** Many residents view being environmentally friendly as important, but a sizeable group remains neutral, pointing to opportunities to strengthen pro-environmental identity.
- **Social norms differ between society and close circles:** Residents perceive environmental concern and behaviours as somewhat stronger within close social circles than among the wider society.
- **Pro-environmental actions are common but uneven:** Low- and medium-impact behaviours (e.g., turning off lights, hang-drying laundry) are widespread, while higher-impact and advocacy behaviours remain relatively infrequent.
- **Risk aversion varies by age:** Most residents demonstrate moderate risk tolerance, with risk-taking progressively declining among older age groups.

5.2 Climate Knowledge

Respondents self-assessed their knowledge of two topics: climate change and the UHI effect. Figure 5.1 provides an overview of response patterns. Self-reported understanding of climate change was substantially higher (mean = 3.38) than understanding of the UHI effect (mean = 2.42). Majority of respondents (81.8%) have at least a basic understanding of climate change. On the contrary, only 18.1% reported moderate or strong UHI knowledge, while 24.1% had never heard of the term – compared with just 2.5% who had never heard of climate change.

Age differences reveal systematic patterns (see Figure S8–9 in Supplementary). Young adults reported the highest understanding of both climate change (mean = 3.99) and UHI (mean = 3.00), while seniors reported the lowest (mean = 2.60 and mean = 1.97 respectively). These gaps highlight generational differences in climate literacy and the need for targeted communication.

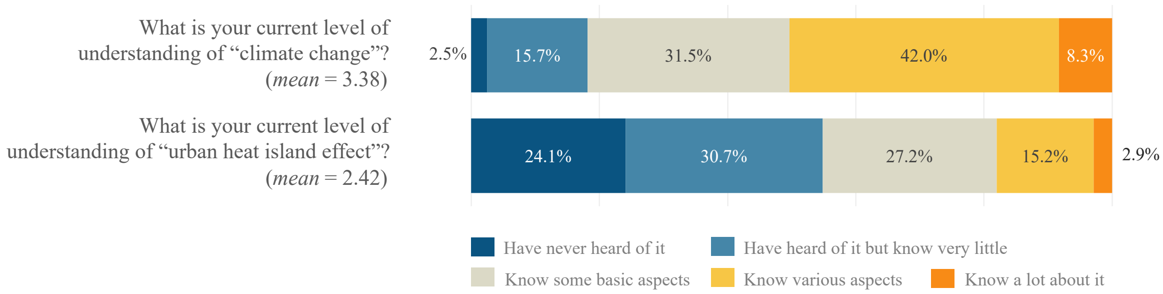

Figure 5.1 Self-assessed levels of understanding on "climate change" and "urban heat island effect" (%; *N*=1009)

5.3 Psychological Distance to Climate Change

Psychological distance was assessed using 20 items, with 5 items for each theoretical dimension: spatial, social, temporal, hypothetical, and scalar. Stronger agreement (i.e., higher mean scores) reflect greater distance (items reverse-coded where necessary). As shown in Figure 5.2, responses did not indicate uniformly high or low levels of distance within each dimension. Instead, patterns varied across items.

Spatial and social distance were generally moderate. While most respondents rejected the idea that they or their families are insulated from climate impacts, many agreed that serious effects of climate change are mostly experienced by people they do not know or those living far away.

Temporal distance was generally low, indicating that respondents recognise climate change as a present concern. The main exception was the item stating that climate change will affect future generations more than the current generation, which received the highest agreement (mean = 4.00).

Hypothetical distance was moderate. Notably, the statement that "the science of climate change is far from settled" drew relatively high endorsement (52.0% agreeing or strongly agreeing), suggesting lingering perceptions of scientific uncertainty despite broad scientific consensus.

Scalar distance showed the least variation across its items. Since relevant items were reverse-coded, weaker agreement (i.e., lower scores) indicate stronger perceived personal agency. Respondents generally disagreed that individual actions have little impact.

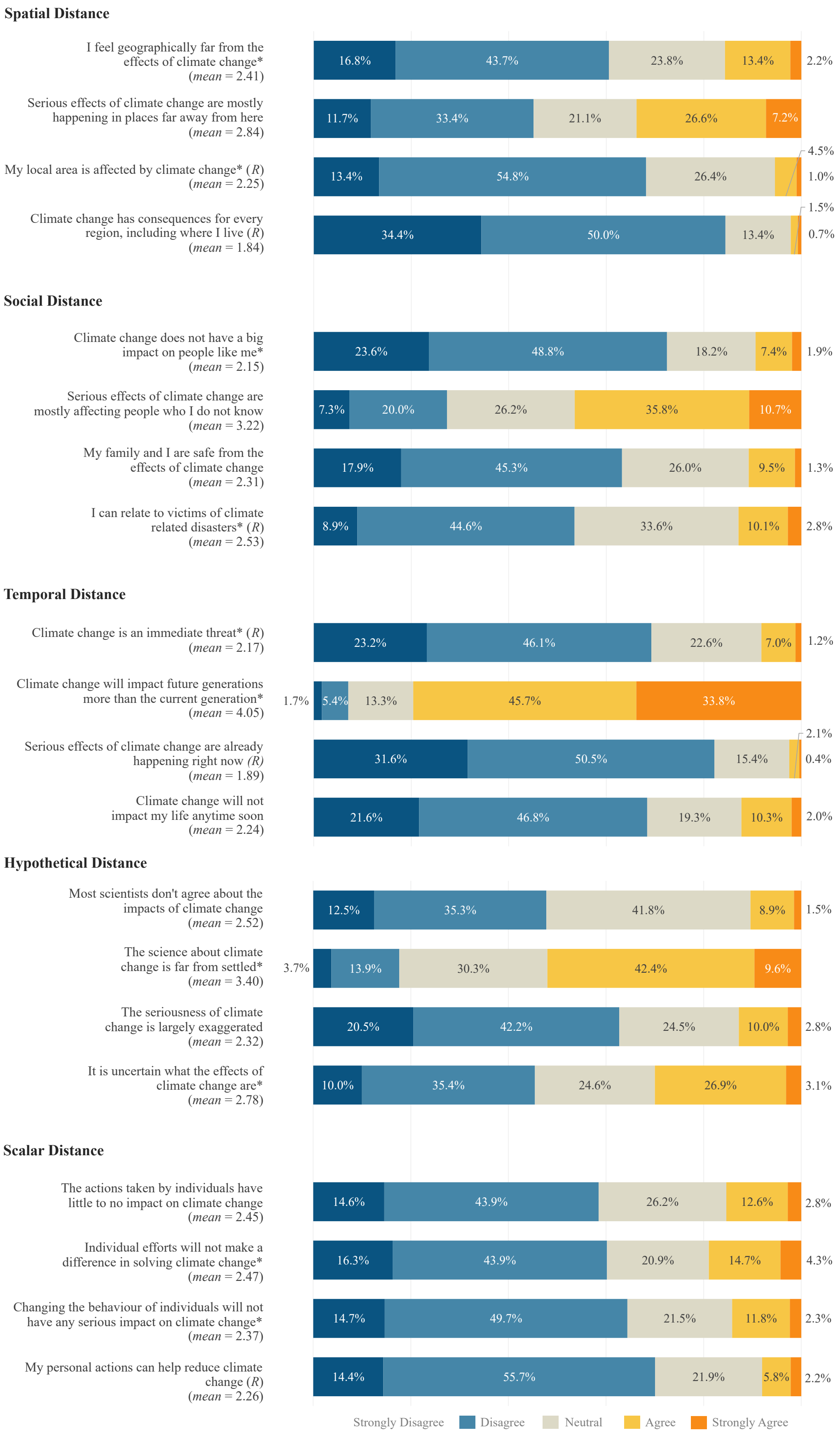

Figure 5.2 Rating of statements on psychological distance to climate change (%; *N*=1009); *Note*: Items marked with * were only included in adult survey (*N*=940); items marked with (R) were reversed-coded in results shown

To complement the item-based scale, dimensions of psychological distance to climate change was also assessed using a 0–100 visual analogue scale. Figure 5.3 displays the distribution of scores.

Overall, ratings clustered toward the “closer” end of the scale. Temporal distance was the lowest (mean = 26), indicating that most respondents viewed climate change as a present rather than distant issue. Hypothetical distance was also low (mean = 27), suggesting widespread acceptance of climate change as real and not speculative. The remaining items capturing general distance and the other dimensions were slightly higher (means = 31–35).

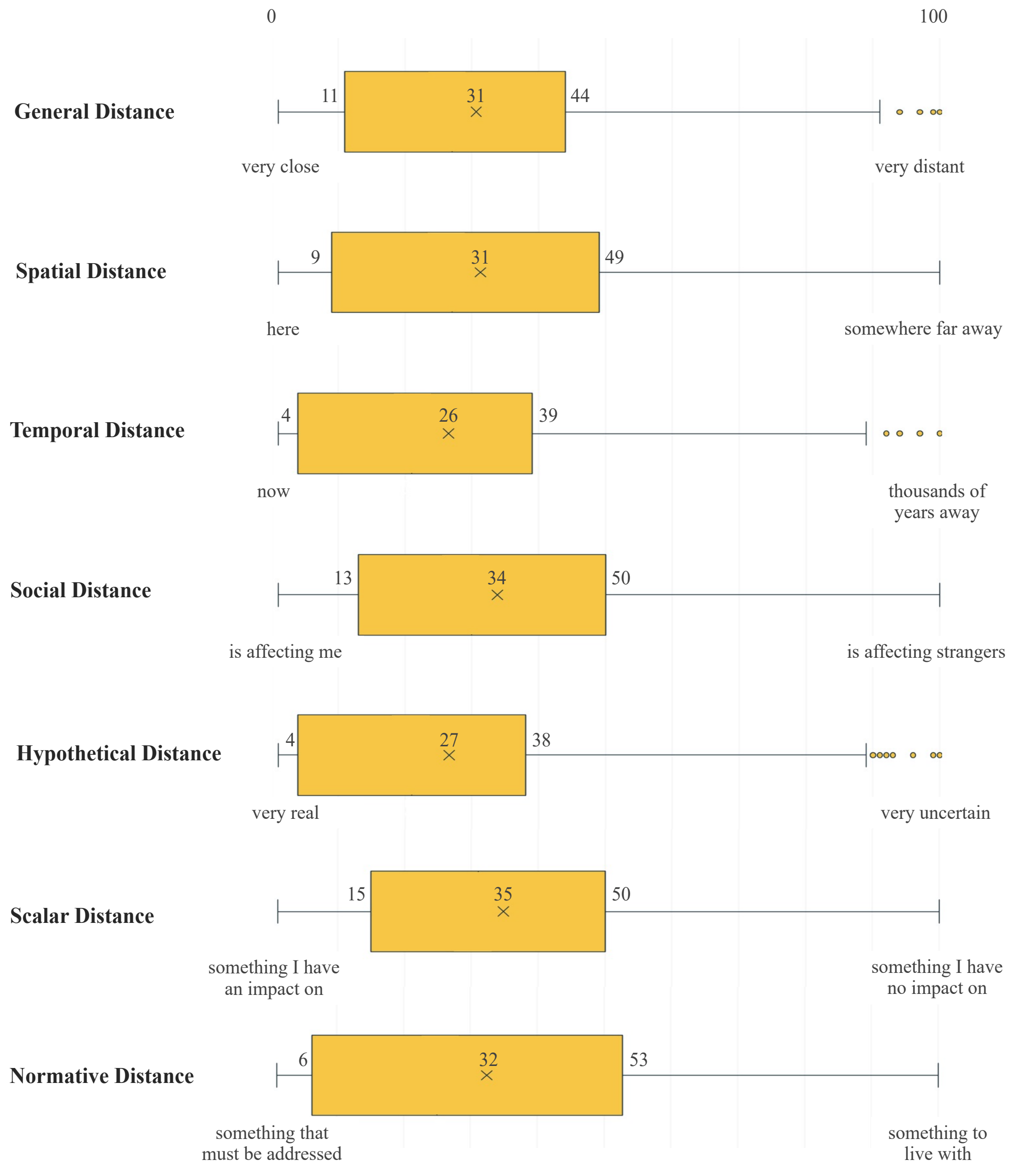

Figure 5.3 Distribution of responses across psychological distance to climate change items
Note. Items were framed as “To me, climate change feels like”
(25th percentile, mean and 75th percentile; *N*=1009)

5.4 Climate Concern

Respondents expressed moderate to high concern across four domains of climate concern: climate change in general, and the consequences of climate change on a personal level, societal level, and on the natural world. As shown in Figure 5.4, very few respondents (<3.2%) reported not being concerned at all, indicating that climate indifference is rare.

Age-based comparisons, shown in Figure S10 (Supplementary), reveal that concern peaks among young adults (mean = 3.70) and middle-late adults (mean = 3.59). Teens and seniors expressed comparatively lower concern (mean = 3.21 and 3.16 respectively), suggesting an inverted U-shaped pattern in which concern is highest among those in active working life and slightly lower among the youngest and oldest cohorts.

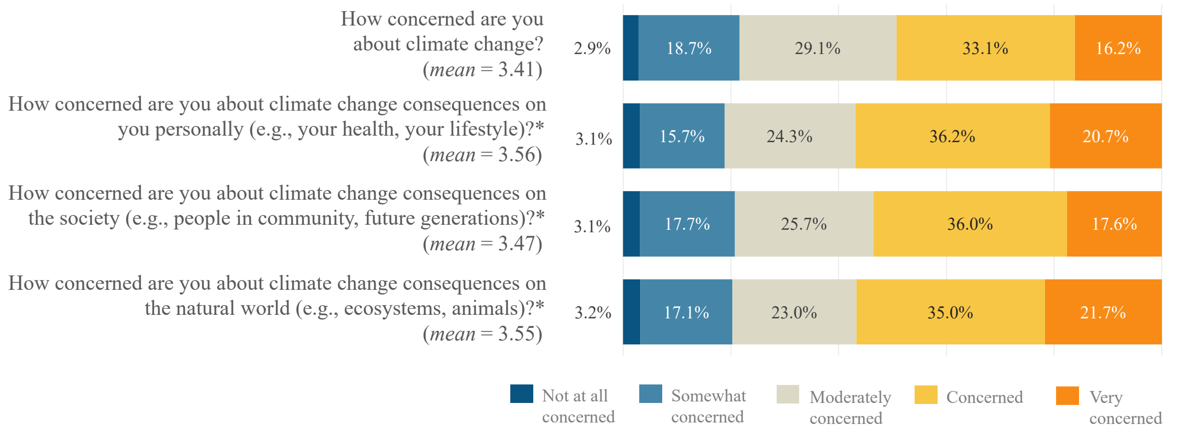

Figure 5.4 Responses to concern about climate change (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940)

5.6 Ascription of Responsibility

Respondents generally endorsed the idea that individuals share responsibility for climate action (Figure 5.5). Agreement was high for statements on the environmental impact of personal choices (74.0%) and responsibility to reduce personal emissions (74.3%). Neutral responses were more common for responsibility in causing climate change, suggesting uncertainty in attributing the cause of climate change to individuals alone.

Age differences, shown in Figure S11 (Supplementary), were minimal.

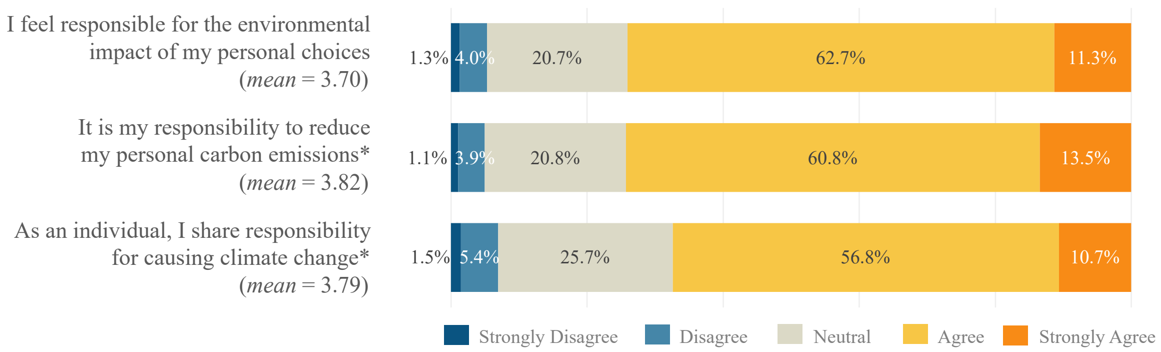

Figure 5.5 Rating of statements on ascription of responsibility (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940)

5.7 Environmental Personal Norms

Environmental personal norms capture the extent one considers environmental friendliness as part of their identity. Respondents expressed moderate agreement across the three items. Figure 5.6 illustrates these distributions. Neutral responses were notably high (33.4–36.1%), suggesting that a significant proportion of respondents do not hold strongly defined environmental identities.

Age-group differences were minimal and are depicted in Figure S12 (Supplementary).

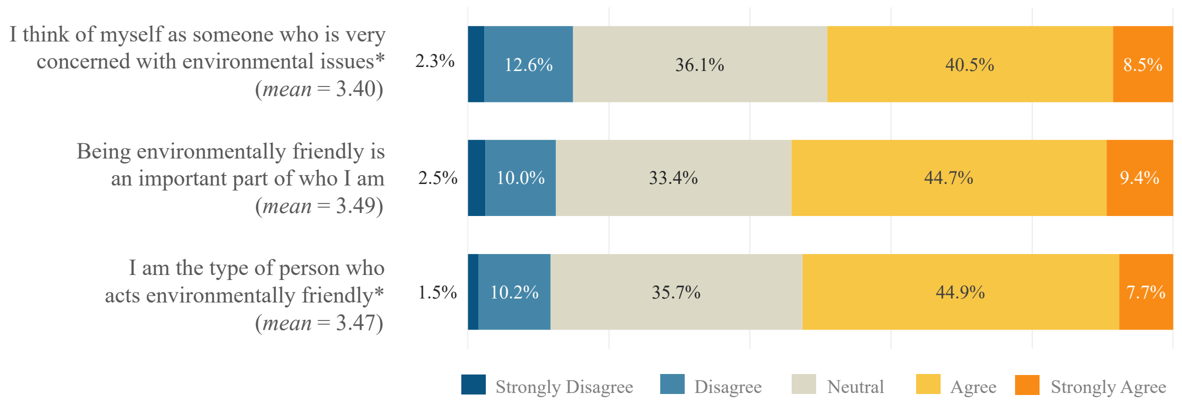

Figure 5.6 Rating of statements on environmental personal norms (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940)

5.8 Environmental Social Norms

As depicted in Figure 5.7, respondents distinguished between norms at the societal level and those within their close social circles.

At the societal level, perceptions of environmental concern (mean = 3.07) and environmentally friendly actions (mean = 2.96) were moderate. In contrast, norms within close social circles were perceived more positively, with higher agreement that family and friends care about climate change (mean = 3.24) and behave sustainably (mean = 3.22). These items capture perceptions of what others do (descriptive norm).

Expectations showed the opposite similar pattern. Respondents perceived stronger expectations from Singapore society (mean = 3.27 for both) than from close friends or family (mean = 3.11–3.13). These items reflect perceived social expectations about what people ought to do (injunctive norm).

Overall social norms, averaged across all items, showed some age differences (Figure S13, Supplementary). Seniors perceive the strongest environmental social norms (mean = 3.40), while early-middle adults perceive the weakest (mean = 3.21).

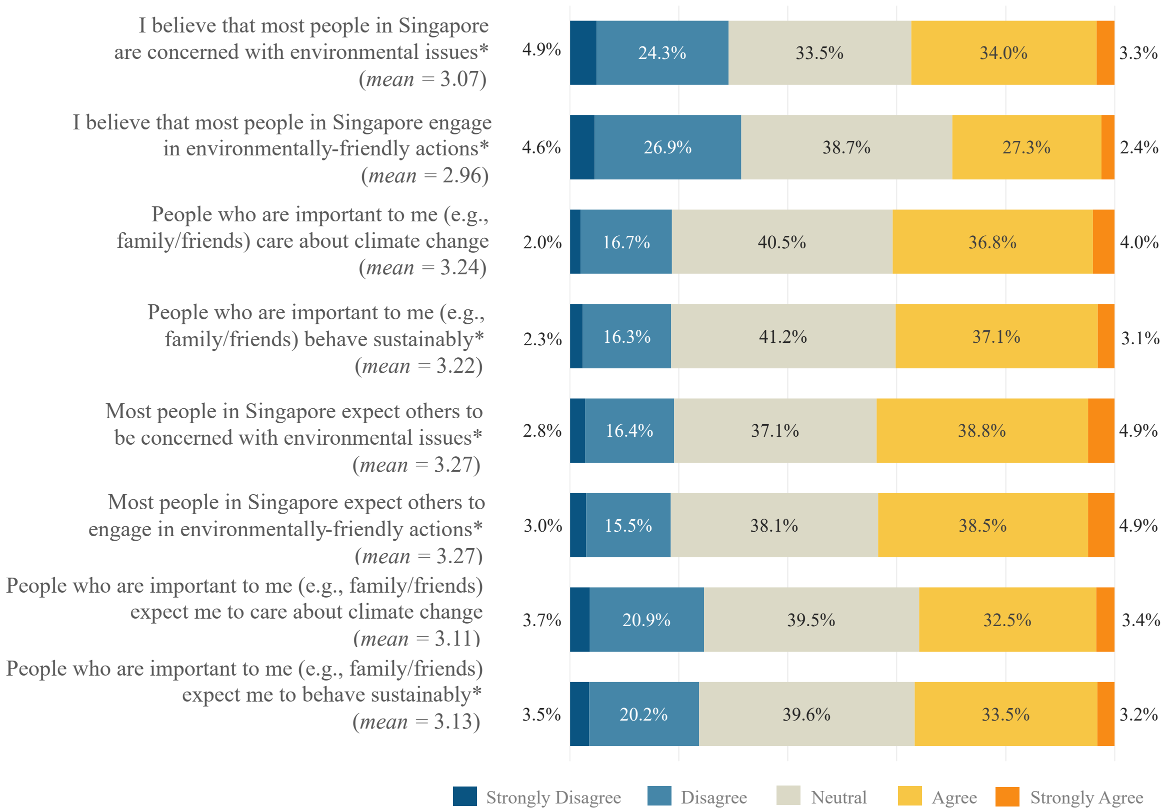

Figure 5.7 Rating of statements on environmental social norms (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940)

5.9 Pro-Environmental Behaviours

Respondents were asked to report the frequency of 13 pro-environmental behaviours classified into high-, medium-, low-, and variable-impact categories. Figure 5.8 presents the distribution of responses.

Low-impact and medium-impact behaviours were commonly practiced, with some behaviours showing higher uptake than others. Turning off lights (low-impact) was the most widely practiced action (84.0% often or always) followed hang-drying laundry instead of using a dryer (medium-impact, 76.3%).

Engagement with high-impact behaviours was more mixed. Many reported frequent use of public transport (71.8%) and fans instead of air-conditioning (65.9%), but few regularly reduced air travel (26.6%) or meat consumption (14.9%).

Behaviours of varying-impacts, namely emission offsets or advocacy were the least common. This is notable given that advocacy behaviours (e.g., encouraging others to care about climate change or talking about climate change) are materially low-effort yet remain uncommon, pointing to untapped engagement potential alongside possible social or psychological barriers.

Age-group differences were small and are shown in Figure S14 (Supplementary). Seniors and middle-late adults reported slightly higher engagement overall (mean = 3.34), while early-middle adults reported the lowest frequency of pro-environmental behaviours (mean = 3.15).

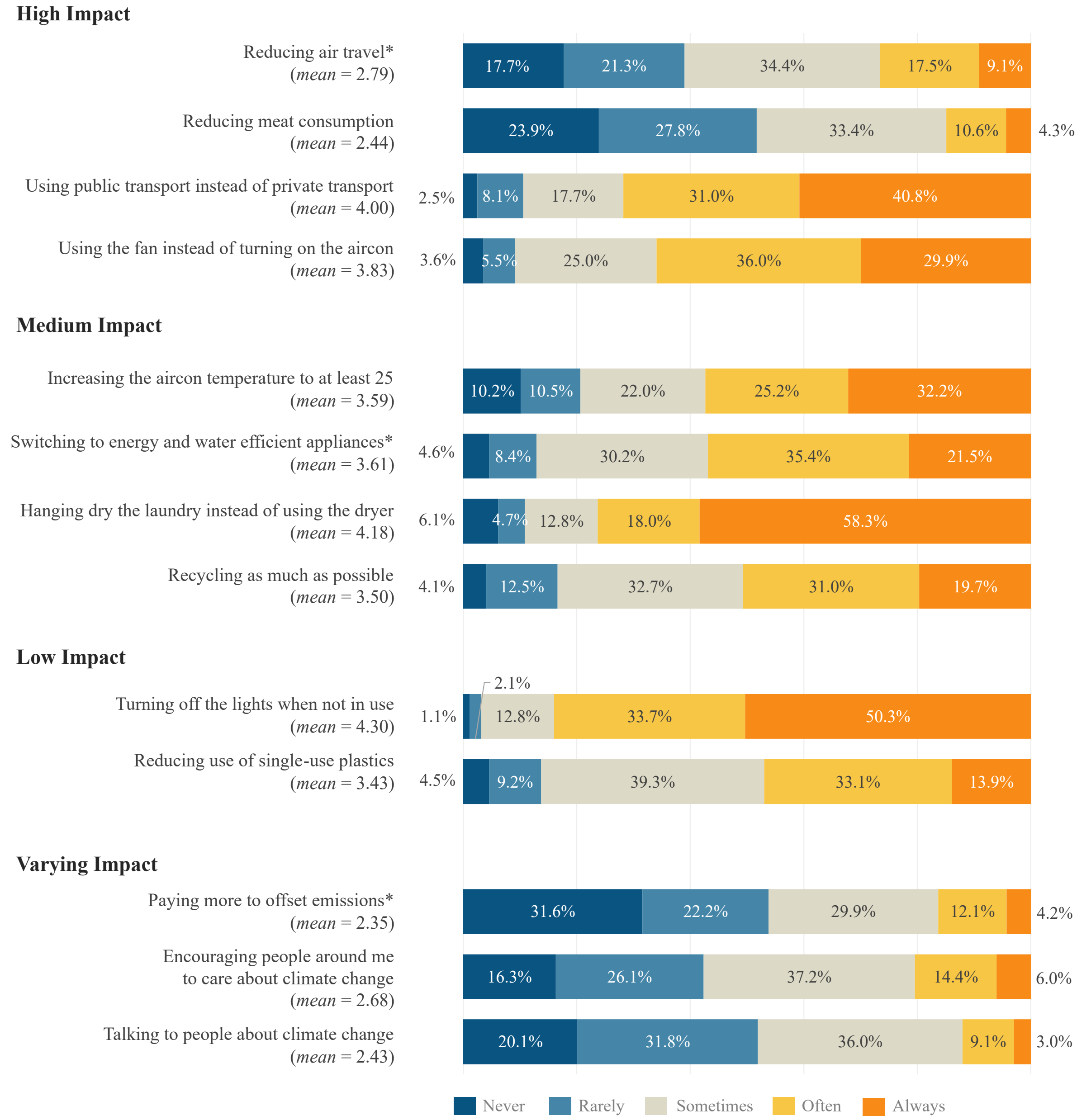

Figure 5.8 Responses to frequency of performing pro-environmental behaviours (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940)

5.10 Risk Aversion

Respondents' willingness to take risks was generally moderate. As shown in Figure 5.9, most respondents identified as moderately or slightly willing to take risks, with only a small minority reporting high risk tolerance (15.4% willing and 2.2% very much willing to take risks). Approximately 9.6% reported not being willing to take risks at all.

Age-based variation in risk tolerance is illustrated in Figure S15 (Supplementary). Young adults reported the highest willingness to take risks (mean = 2.96), whereas seniors reported the lowest (mean = 2.19). Risk tolerance appears to decline gradually with age, likely reflecting differing life priorities, health considerations, and perceptions of vulnerability.

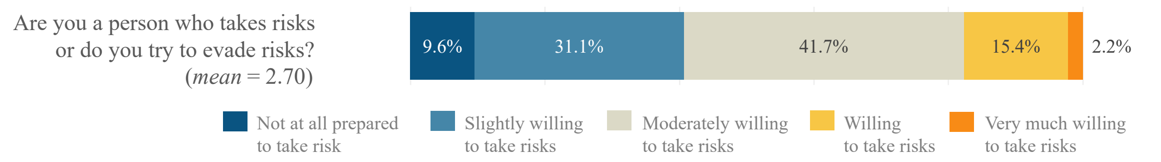

Figure 5.9 Responses to risk-taking (%; *N*=1009)

Chapter 6

Heat Experiences, Perceptions, and Cooling Practices

6. Heat Experiences, Perceptions, and Cooling Practices

Building on the previous chapter's exploration of climate knowledge and attitudes, this section shifts from abstract perceptions of climate change to the tangible experience of heat in everyday life. We examine how respondents interpret the relationship between heat and climate change, how psychologically "close" or "distant" heat feels to them, how strongly heat affects daily life, and how they manage heat through behavioural and technological strategies, among other heat-relevant dimensions.

6.1 Section Highlights

Key findings of this section are as follows:

- **Strong association between heat and climate change:** Most respondents believe Singapore's increasing heat is linked to climate change.
- **Heat is perceived as immediate and close:** Psychological-distance scales show that respondents experience heat as a present, real and ongoing problem, even while expecting its future impacts to intensify for subsequent generations.
- **Heat disrupts daily life:** Outdoor activities, sleep, work/study, commuting and social activities are the most affected domains. Younger and working-age adults report the greatest disruption.
- **Clear preference for air-conditioned environments:** Respondents strongly prefer air-conditioned indoor spaces, especially for sleep.
- **High awareness of the environmental consequences of air-conditioning:** Respondents widely recognise that air-conditioning contributes to climate change and local heat, and understand the impact of temperature settings on energy use.
- **Indoor thermal control is high; outdoor control is low:** Respondents feel they can influence indoor thermal conditions but have little control over the heat outdoors.
- **Limited outdoor exposure:** Most respondents spend limited hours outdoors and significant time in air-conditioned environments, especially working-age adults.
- **Diverse indoor and outdoor heat management strategies:** When indoors, fans, window opening, showers, behavioural adjustments and night-time air-conditioning are common. When outdoors, sun avoidance, clothing adjustments, and using nearby cooled public spaces dominate.
- **Mechanical cooling perceived as most effective:** Air-conditioning, especially during sleep, is seen as the most effective cooling strategy. Fans, shade-seeking and showers are viewed as moderately effective; psychological coping-based strategies are rated lowest.

6.2 Association Between Heat and Climate Change

Overall, there is a strong cognitive association between Singapore's heat with climate change. A large majority agree that climate change is making Singapore hotter, with 86.1% either agreeing or strongly agreeing with this statement. At the same time, 67.7% also agree or strongly agree that they see a clear connection between Singapore's hot weather and climate change. This suggests that respondents can connect specific episodes of hot weather to broader climate processes. These patterns are illustrated in Figure 6.1.

Age-group comparisons shown in Figure S16 (Supplementary) showed a minor inverted U-shaped pattern where teenagers (mean = 3.77) and seniors (mean = 3.68) reported marginally weaker connections relative to the other groups (means = 3.94–3.96).

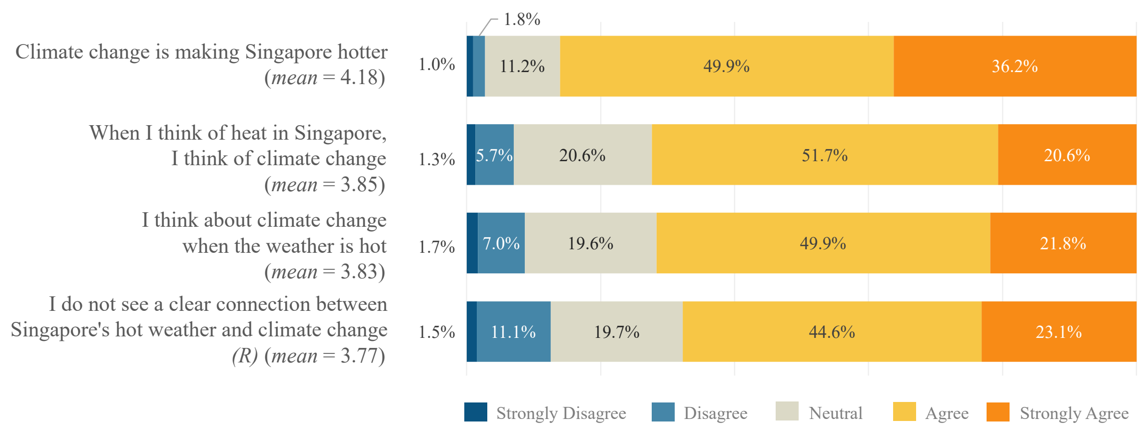

Figure 6.1 Rating of statements on association between climate change and heat (%; *N*=1009)
Note: Items marked with (R) were reversed-coded in results shown

6.3 Psychological Distance to Urban Heat

Psychological distance to heat was assessed using the same scale as climate change reported in section 5.3. Stronger agreement (i.e., higher mean scores) reflects greater distance. Figure 6.2 summarises the overall pattern of responses.

Overall, the results closely mirror those observed for climate change (Section 5.3, Figure 5.2). While most items indicate low to moderate levels of psychological distance, respondents tended to agree that the most serious impacts of heat occur in places far from Singapore, affect people they do not know, and will be worse for future generations than the current one. Respondents also expressed some uncertainty regarding the scientific understanding of heat.

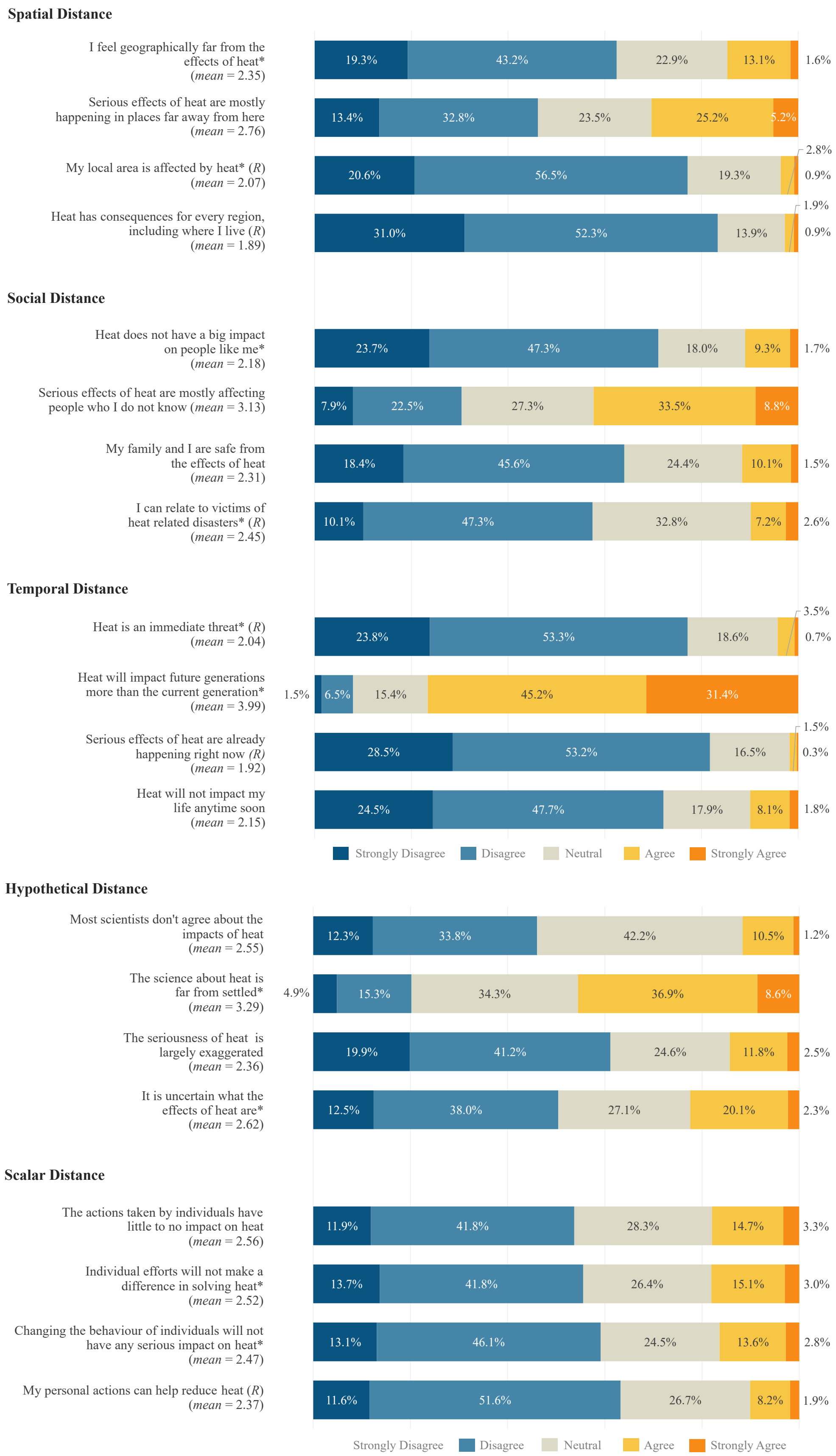

Figure 6.2 Rating of statements on psychological distance to heat (%; *N*=1009)
Note: Items marked with * were only included in adult survey (*N*=940);
items marked with (R) were reversed-coded in results shown

Perceived psychological distance to heat was also assessed on a 0–100 visual analogue scale as presented in Figure 6.3. Like climate change (Section 5.3, Figure 5.3), ratings clustered toward the "closer" end of the scale.

General, spatial, temporal, hypothetical, and social distance were low (means = 22–26), appearing slightly closer than climate change where the lowest dimension (temporal) had a mean of 26. This suggests that respondents perceived heat impacts as particularly immediate and locally relevant. Scalar distance was once again higher (mean = 35, same as climate change), suggesting uncertainty about the extent to which individual actions can influence heat. Normative distance was highest (mean = 38 vs. 32 for climate change), indicating a stronger tendency to view heat as a condition to be lived with rather than a problem that must be actively addressed. This is significant and points to a notable normalisation of heat in everyday life.

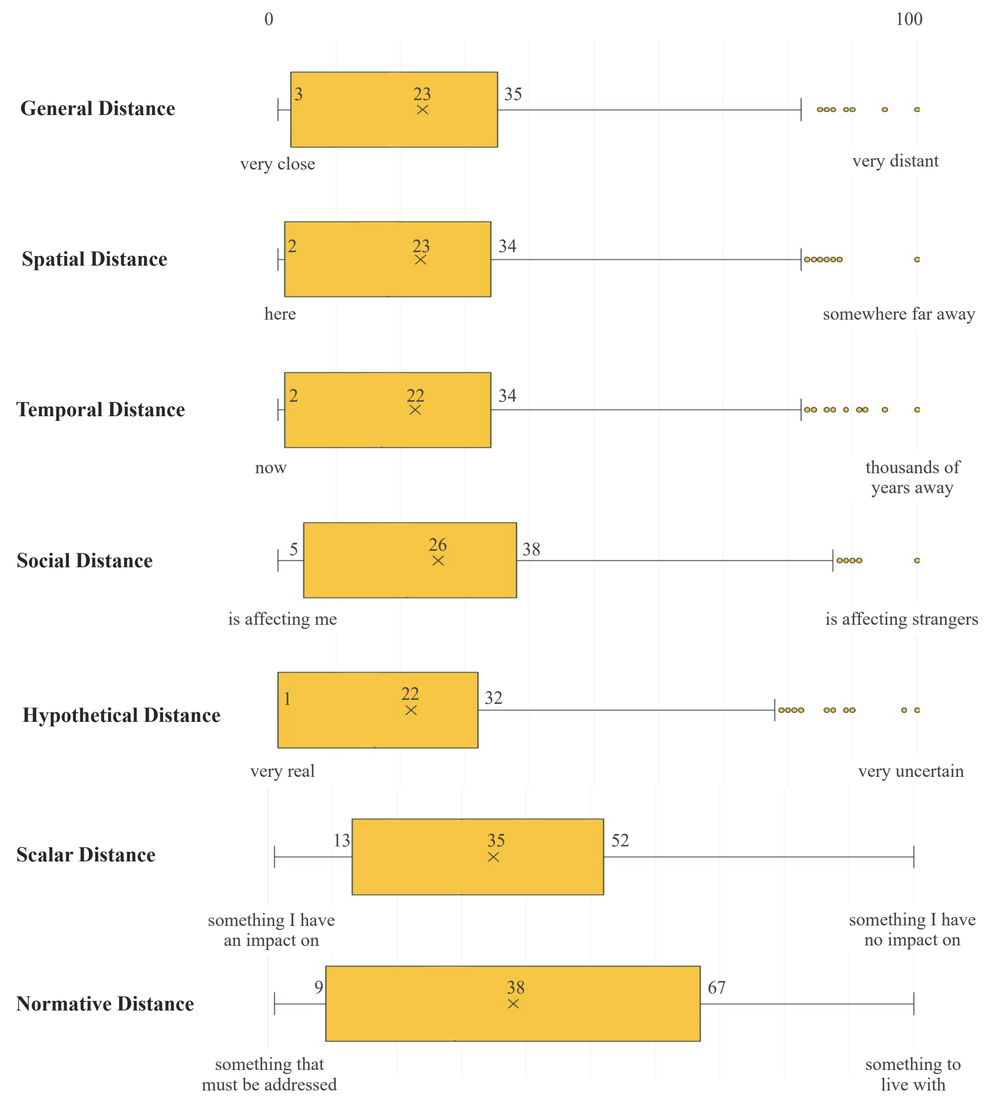

Figure 6.3 Distribution of responses across psychological distance to heat items (25th percentile, mean and 75th percentile; *N*=1009)

6.4 Heat Stress Impact

There were varied impacts of heat across eight domains of daily life: outdoor activities, work or study, transportation, sleep or rest, diet, social activities, physical health, and mental health. Figure 6.4 shows the distribution of responses.

Outdoor activities were reported as most affected (mean = 3.25), with more than 40% rating the impact as severe or very severe. Sleep followed (mean = 2.79), with nearly 30% rating the impact as severe or very severe, indicating nighttime heat disruption as an important concern. Work or study (mean = 2.74) and social activities (mean = 2.75) were moderately affected, while transportation (mean = 2.63), physical health (mean = 2.57), and mental health (mean = 2.54) registered somewhat lower but still noticeable impacts. Diet was least affected (mean = 2.20), with many respondents reporting minimal disruption.

Age-group comparisons, presented in Figure S17 (Supplementary), show that seniors reported the lowest impact (mean = 2.50) relative to the remaining sample (means = 2.66–2.75).

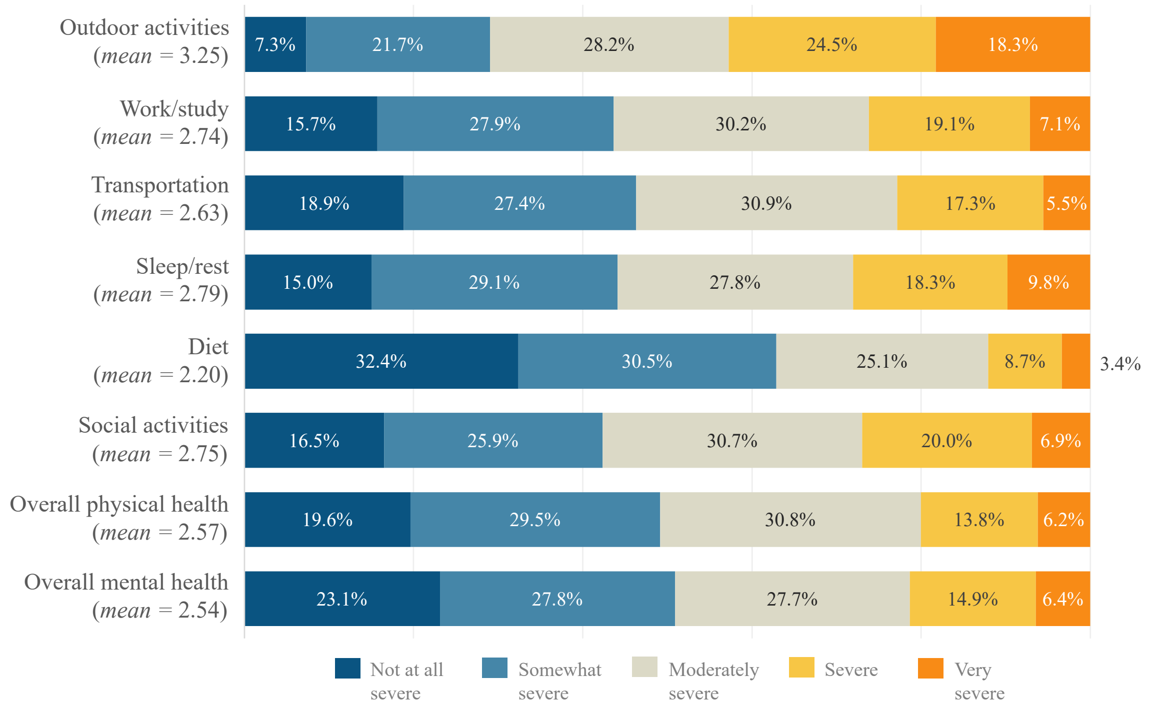

Figure 6.4 Responses to how severely heat impacts daily life functions (%, *N*=1009)

6.5 Thermal Preference

Thermal preferences were captured using three items. Respondents expressed a clear preference for air-conditioned indoor environments with nearly two-thirds agreeing or strongly agreeing to the statement "I prefer to be in an air-conditioned indoor place". Figure 6.5 presents the overall distributions.

There was a divergence between age groups with teens (mean = 3.59), young adults (mean = 3.61), and early-middle adults (mean = 3.52) showing stronger preferences for air-conditioned environments compared to the older groups of middle-late adults (mean = 3.29) and seniors (mean = 3.35). These are presented in Figure S18 (Supplementary).

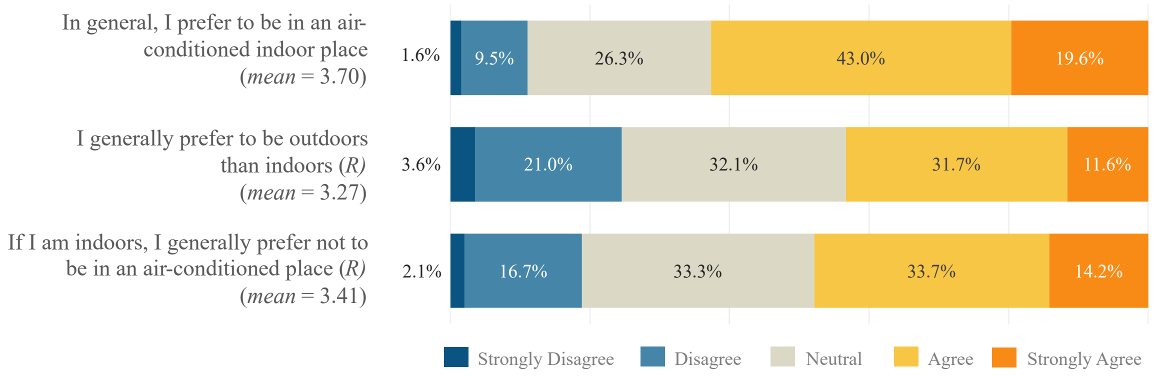

Figure 6.5 Rating of statements on thermal preference (%; *N*=1009)
Note: Items marked with (R) were reversed-coded in results shown

6.6 Awareness of Consequences of Air-Conditioning

Respondents demonstrate high awareness of the environmental and energy implications of air-conditioning as shown in Figure 6.6.

A large majority of respondents agreed or strongly agreed that temperature settings on air-conditioning influences energy consumption (83.7%) and that an increase of 1° could save energy (75.0%). There was similar consensus that air-conditioning contributes to climate change (77.1%) and heat production (74.8%). The statement describing how air-conditioning increases temperature in the surrounding area received the lowest agreement (70.2%).

Age-group differences are small (Figure S19, Supplementary). Awareness is somewhat lower among teens (mean = 3.85) and seniors (mean = 3.72), relative to young (mean = 4.02), early-middle (mean = 3.95), and middle-late adults (mean = 3.93).

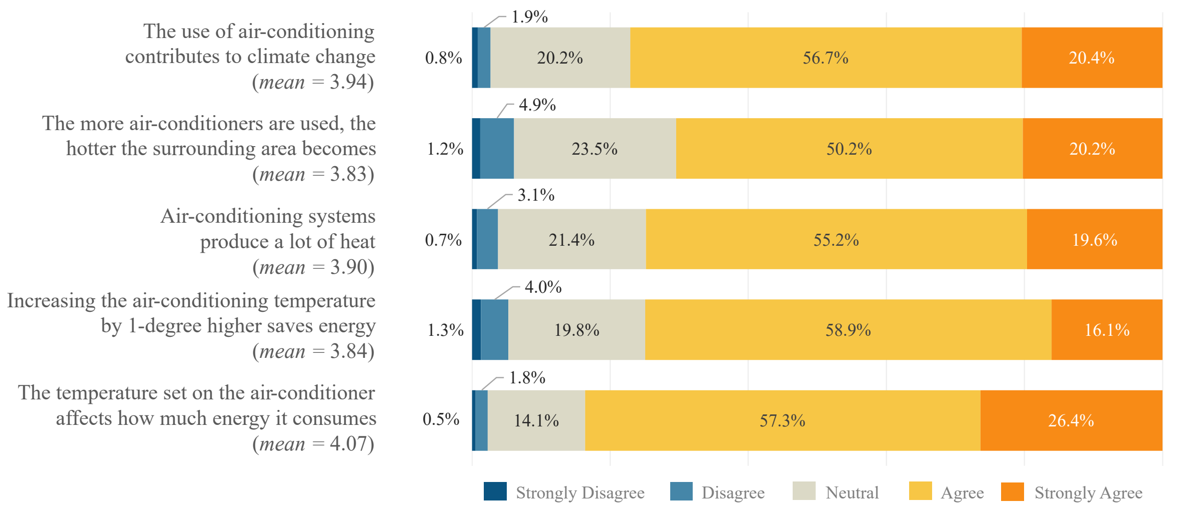

Figure 6.6 Rating of statements on awareness of consequences of air-conditioning usage (%; *N*=1009)

6.7 Perceived Thermal Control

Perceived ability to manage thermal conditions diverged across contexts. As shown in Figure 6.7, respondents feel a stronger sense of control at home (*mean* = 3.87) compared to outdoors (*mean* = 2.87).

Age-group analyses provide further nuance. At home, young, early-middle, and late-middle adults report higher perceived control (means = 3.91, 3.96, 3.82 respectively) compared to teens (mean = 3.65) and seniors (mean = 3.72) which may reflect the latter's dependence on others for household decisions. The pattern reverses outside the home: teens (mean = 3.13) and seniors (mean = 3.12) report higher perceived control than the remaining cohorts (means = 2.73–2.97), perhaps because they spend more time in shaded or managed outdoor spaces (e.g. school grounds, neighbourhood areas) rather than in transit or work environments. These patterns are detailed in Figures S20 and S21 (Supplementary).

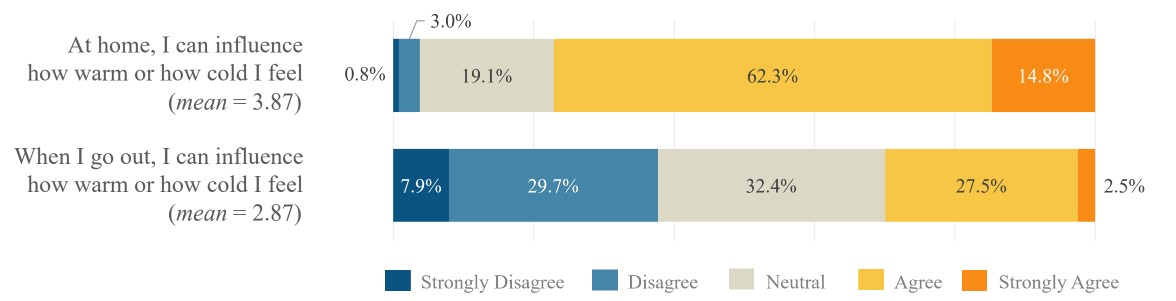

Figure 6.7 Rating of statements on perceived thermal control (%; *N*=1009)

6.8 Thermal Sensation

Thermal sensation was elicited for five scenarios: outdoors during the day, outdoors at night, at home without air-conditioning during the day, at home without air-conditioning at night, and in air-conditioned spaces. Figure 6.8 summarises responses.

The daytime outdoor scenario was clearly perceived as the most uncomfortable setting with roughly half of respondents (47.7%) feeling hot and another 41.8% feeling warm or slightly warm. Outdoors at night showed substantial variation with about a third each reporting feeling on the warmer end (37.4%), comfortable (33.9%), and on the cooler end (28.7%).

Majority of respondents report feeling at least slightly warm at home without air-conditioning in the day (66.4%) and night (55.5%).

In contrast, and unsurprisingly, majority report feeling at least slightly cool in air-conditioned spaces (64.4%).

Age-group differences, depicted in Figure S22 (Supplementary), show an overall trend where teens and young adults tend to report warmer sensations across all five scenarios relative to older respondents.

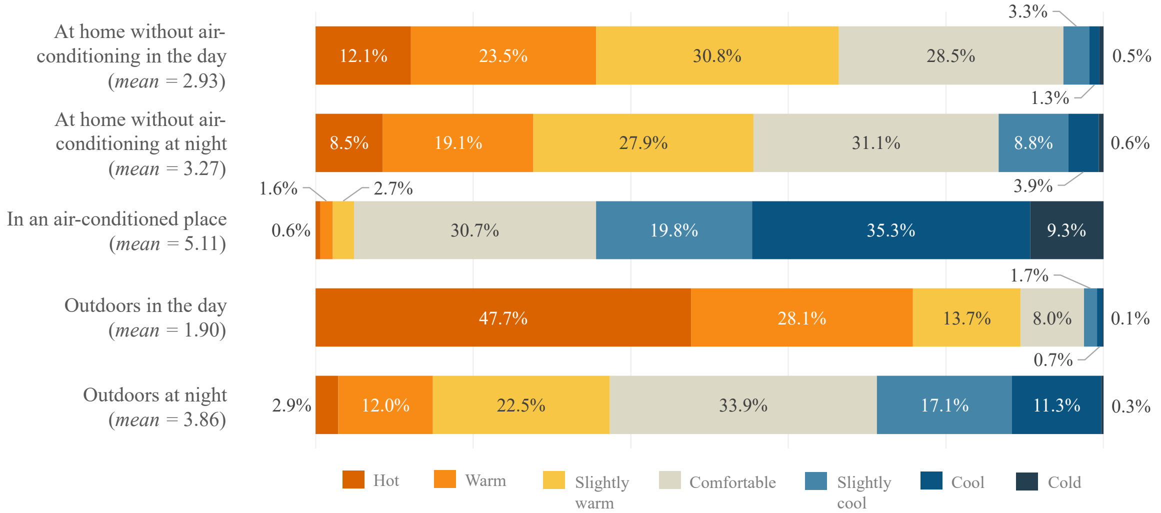

Figure 6.8 Thermal sensation across different settings (outdoor day/night; indoor with/without air-conditioning) (%; N=1009)

6.9 Outdoor and Air-Conditioning Exposure

Daily exposure to outdoor environments and air-conditioned spaces provide important context for understanding individuals' thermal experiences. Most respondents spend limited time outdoors: 44.0% report 2–4 hours and 22.7% report less than 2 hours per day. Only a small minority (15.1%) report 6 or more hours outdoors. These are illustrated in Figure 6.9.

Air-conditioning exposure is more evenly spread. A quarter of respondents (25.4%) spend 8–10 hours per day in air-conditioned environments, and slightly over a tenth report 0–2, 2–4, 4–6 and 6–8 hours each. Notably, a non-trivial minority report extremely high exposure: 7.7% spend 10–12 hours, and 14.5% spend more than 12 hours per day in air-conditioning. These patterns are shown in Figure 6.10.

Age-group differences, presented in Figures S23 and S24 (Supplementary), reveal that teens spend the most time outdoors, while early-middle adults spend the most time in air-conditioned environments. Teens and seniors have the lowest air-conditioning exposure.

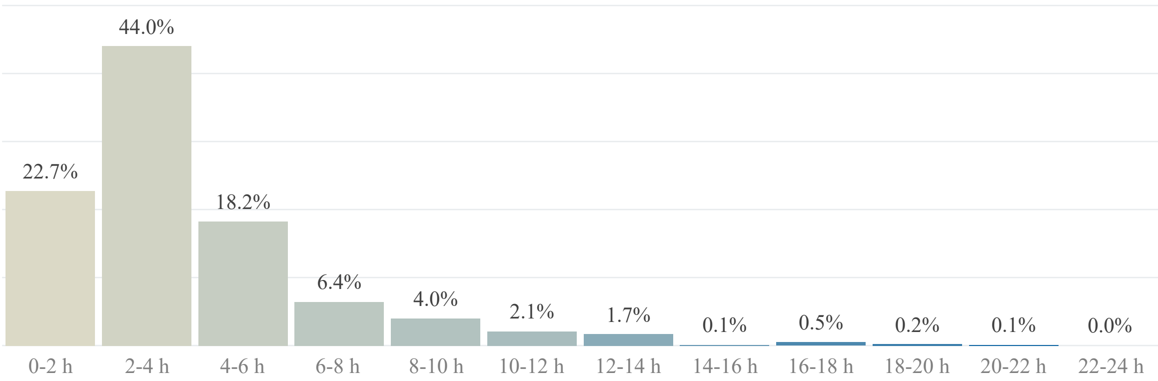

Figure 6.9 Distribution of reported outdoor exposure time (%; *N*=1009)
Note: Each bin represents a half-open interval (e.g., 0–2 hr includes responses ≥0 and <2)

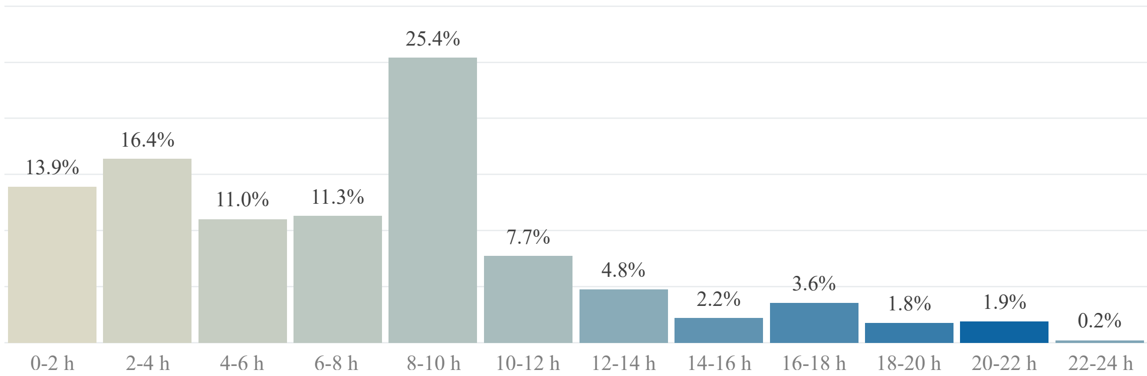

Figure 6.10 Distribution of reported air-conditioning exposure time (%; *N*=1009)
Note: Each bin represents a half-open interval (e.g., 0–2 hr includes responses ≥0 and <2)

6.10 Frequency of Indoor Heat Management Strategies

Indoor cooling practices were assessed across 18 strategies grouped into air-conditioning, environmental adjustment, behavioural adjustment and psychological coping. Figure 6.11 shows their usage frequency.

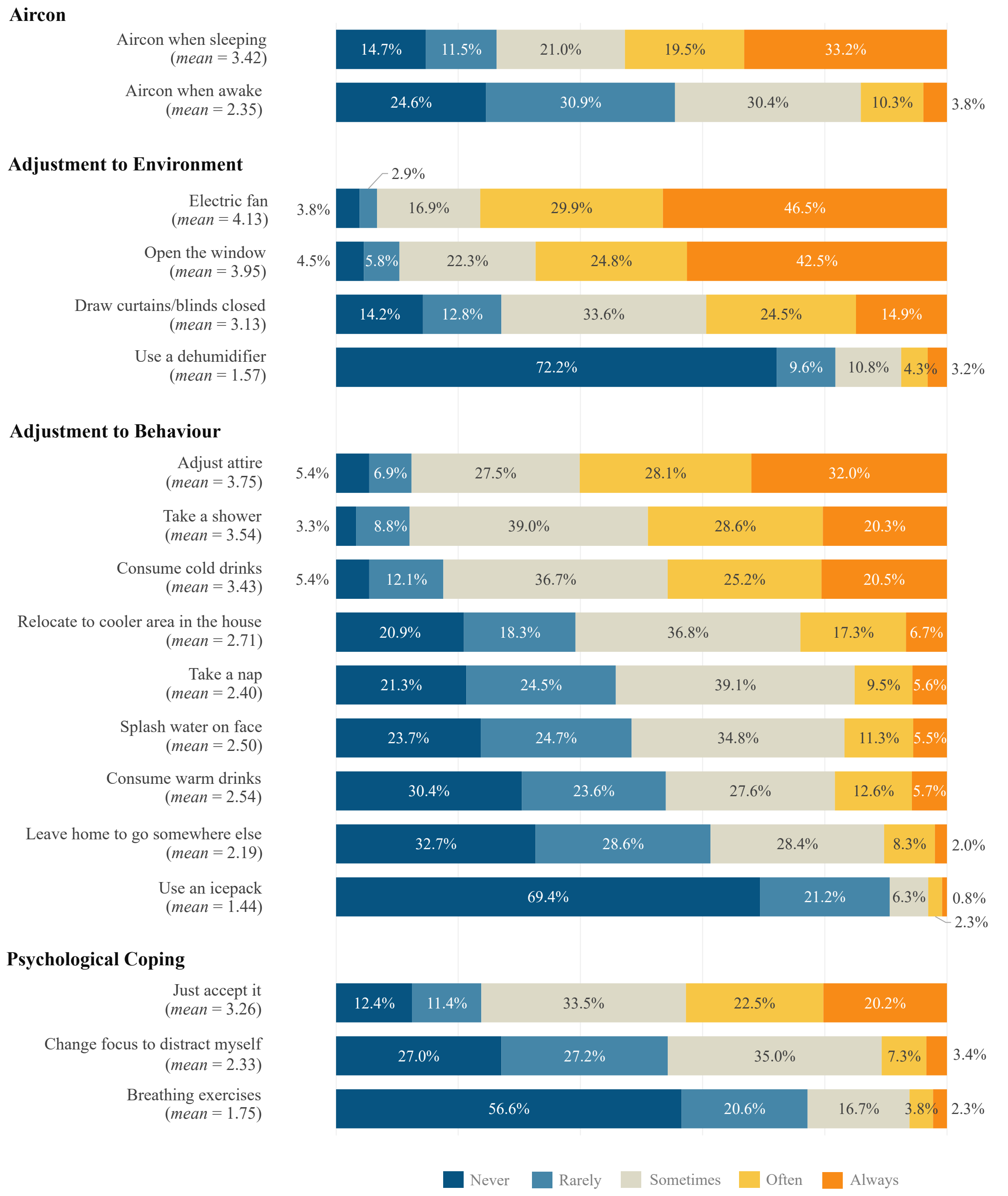

Figure 6.11 Responses to frequency of performing different indoor heat management strategies (%; *N*=1009)

The use of electric fans is the most common strategy (mean = 4.13), with 76.4% of respondents using fans often or always. Opening windows (mean = 3.95) is similarly widespread, reflecting a strong reliance on low-cost environmental adjustments involving natural ventilation. Air-conditioning usage exhibits a clear day–night contrast. Only a small share (14.2%) report using air-conditioning while awake regularly, whereas more than half (52.7%) use it at night during sleep often or always. Behavioural adjustments such as clothing, taking showers, and consuming cold drinks are also widely used, though not as universally as fans and window opening. The psychological coping strategy of "just accepting" the heat is reported to be practised regularly by 42.7% of respondents, suggesting a degree of acceptance and/or adaptation through mindset rather than active mitigation.

Age-group differences in strategy frequency are summarised in Table S25 (Supplementary). Electric fans dominate across all age groups, while seniors rely particularly on opening windows. Teens show relatively higher use of showers and cold drinks compared to attire adjustments, and early-middle adults and teens report more frequent use of air-conditioning during sleep than seniors.

6.11 Perceived Effectiveness of Indoor Heat Management Strategies

Respondents also rated how effective they perceive each indoor strategy to be in terms of cooling. Figure S26 (Supplementary) summarises these ratings, and age-group means are reported in Table S27 (Supplementary).

Across all age groups, air-conditioning during sleep is considered the most effective strategy (overall mean = 3.92), with 73.3% rating it effective or very effective. Air-conditioning while awake is also rated highly (mean = 3.42), although slightly lower than night-time use. Electric fans (mean = 3.39) and taking showers (mean = 3.35) are perceived as moderately effective, followed by adjusting attire (mean = 3.08) and consuming cold drinks (mean = 3.05). Window opening is seen as somewhat effective (mean = 2.95), whereas dehumidifiers are rated as largely ineffective for cooling (mean = 1.71). Psychological coping strategies are rated least effective, suggesting that residents see mechanical and behavioural adjustments as the primary means of coping with heat indoors.

Notably, effectiveness ratings differ substantially from actual usage, pointing to differences between what respondents believe works best and what they ultimately adopt in practice.

6.12 Frequency of Outdoor Heat Management Strategies

Outdoor cooling behaviours mirror some of the indoor patterns but also reveal distinct reliance on avoidance and spatial strategies. Figure 6.12 presents the frequency of outdoor strategies.

Avoiding direct sun exposure (mean = 3.61), adjusting clothing (mean = 3.55), consuming cold drinks (mean = 3.44), and visiting air-conditioned public spaces (mean = 3.24) are the most frequently used outdoor strategies. In contrast, cancelling plans due to heat (mean = 2.47) and taking taxis or private cars instead of public transport (mean = 2.26) are used only occasionally, suggesting that heat rarely disrupts major daily activities and routines. Portable cooling tools such as umbrellas, portable fans, hand fans and face mist are used rarely in general, indicating that they may be secondary to the avoidance and behavioural strategies.

Age-group patterns are detailed in Table S28 (Supplementary). Teens rely more on cold drinks than on sun avoidance or attire adjustment, while young adults and early-middle adults make more frequent use of nearby air-conditioned public spaces. Seniors report relatively high use of umbrellas and clothing adjustments but lower utilisation of cooling public spaces, possibly reflecting mobility constraints.

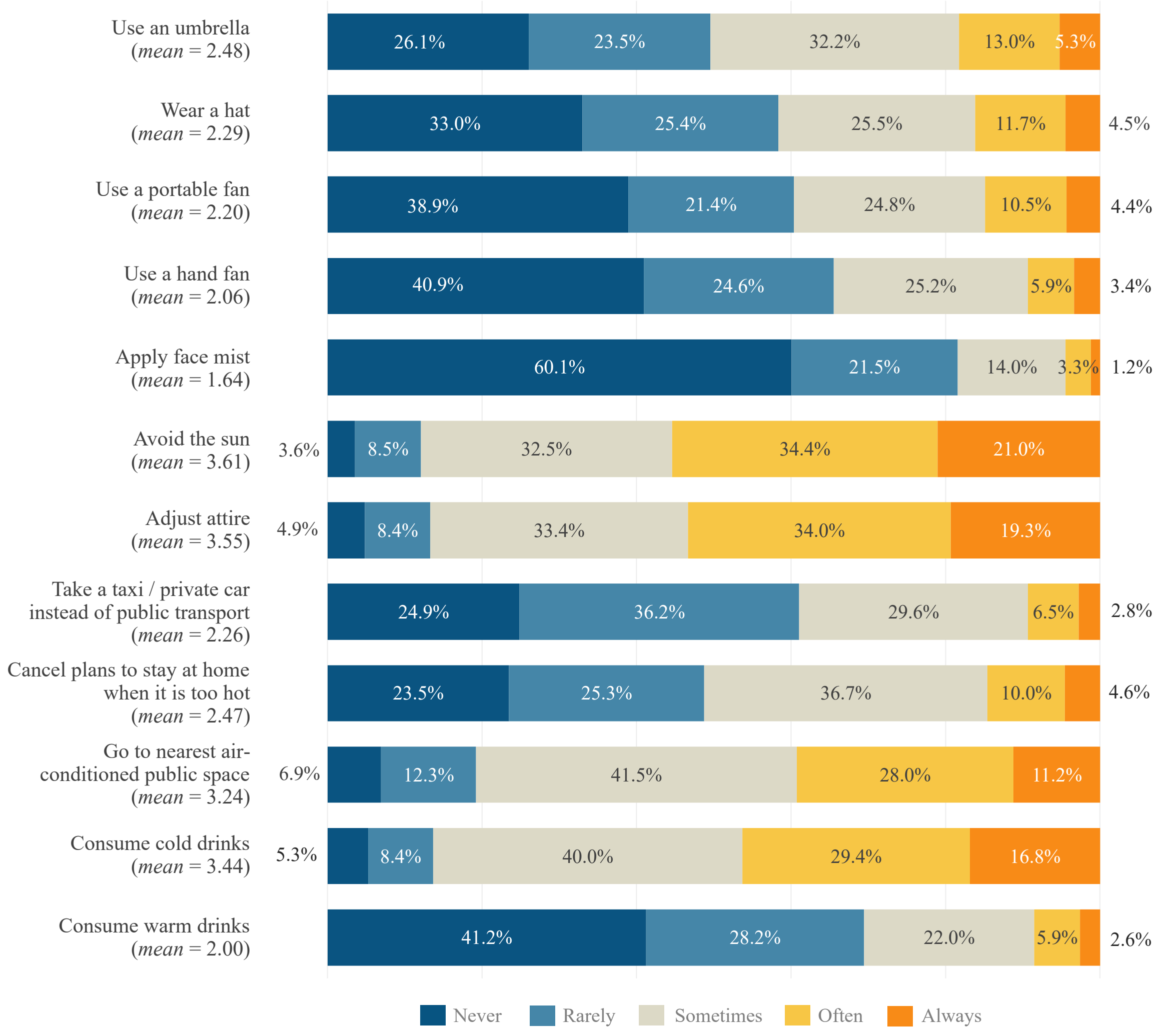

Figure 6.12 Responses to frequency of performing different outdoor heat adaptation strategies? (%; *N*=1009)

6.13 Perceived Effectiveness of Outdoor Heat Adaptation Strategies

Finally, respondents rated how effective each outdoor strategy is at keeping them cool. Figure S29 (Supplementary) and Table S30 (Supplementary) summarise these perceptions.

Across the sample, visiting air-conditioned public spaces is considered the most effective outdoor strategy (mean = 3.57), underscoring the value of accessible shared cooling infrastructure. Avoiding the sun is also rated as highly effective (mean = 3.29). Behavioural adjustments such as consuming cold drinks (mean = 3.23) and adjusting attire (mean = 3.10) are seen as moderately effective. Taking taxis or private cars instead of public transport, cancelling plans to stay at home, and portable cooling tools (umbrellas, portable fans, hand fans, and hats) are generally rated as moderately effective, while face mist and warm drinks are rated as the least effective.

Across age groups, visiting air-conditioned public spaces remains the top-rated strategy for young, early-middle, and middle-late adults, whereas teens place slightly greater emphasis on cold drinks. Among older adults, avoiding the sun and adjusting clothing exceed the perceived effectiveness of cold drinks, reflecting adaptation strategies that may be more compatible with their routines and preferences.

Chapter 7

Built Features, Devices, and Practices in Household Cooling

7. Built Features, Devices, and Practices in Household Cooling

This section shifts from individual perceptions to the household environment, where building characteristics, cooling devices, and daily practices interact to shape thermal comfort. Focusing on public housing contexts, we describe how homes are configured for cooling and how indoor conditions compare to outdoor microclimates. Together, these findings highlight structural constraints and behavioural choices that may influence heat exposure and energy use.

7.1 Section Highlights

Key findings from this section are:

- **Heat is rarely considered in long-term home decisions:** Renovation, layout, furniture, wall colour, and unit selection are typically guided by other factors – possibly aesthetics, cost, and functionality – rather than heat mitigation, despite their long-lasting impact on thermal comfort.
- **Natural ventilation is widely used but constrained:** Most households rely heavily on window opening when at home, but rain, insects, odours, outdoor air quality, and security concerns limit maximum ventilation potential.
- **Cooling inequality exists across dwelling types:** Air-conditioning ownership is high in larger flats but much lower in 1–2 room units, particularly public rental housing. These disparities leave heat-vulnerable households with less cooling options.
- **Day–night cooling patterns show structural dependence on AC:** Fans and natural ventilation dominate daytime cooling, while nighttime cooling shifts sharply toward air-conditioning, underscoring sleep-driven comfort needs and increasing nighttime energy demand.
- **Fans are the universal backbone of household cooling:** Standing and ceiling fans are nearly ubiquitous across all flat types and are used as both substitutes for and complements to air-conditioning, highlighting their central role in affordable cooling.
- **Indoor clutter may constrain passive cooling:** Indoor clutter, especially in smaller flats, may impede airflow and restrict opportunities for passive cooling.
- **Indoor greenery is limited across households:** Most households have few or no plants at home or along their corridor, indicating an area that may warrant further exploration in relation to comfort, wellbeing, evapotranspiration and cooling.
- **Mitigation infrastructure varies across neighbourhoods:** While sheltered walkways and drop-off points are common, shade-providing vegetation is much less prevalent.
- **Indoor and outdoor conditions can differ substantially:** Objective measurements reveal that many homes are only slightly cooler, or even warmer, than outdoors, with indoor wind speeds typically lower than ambient conditions, indicating that neighbourhood or block-level metrics may not fully capture what residents experience indoors.

7.2 Built Environment Context and Characteristics

Table 7.1 summarises the built-environment characteristics of responding households. On average, buildings are 26.7 years old (range 2–76 years) with a mean floor area of 95m² (range 29–177m²). Units are located on a broad spread of floors (mean 9th floor; range 1–38), indicating coverage across both low- and high-rise environments. Around half of households are in corner units (50%), with the remainder split between corridor units with and without corridor-facing windows.

Kitchen layouts are predominantly partially open (45%), followed by fully enclosed kitchens (34%) and fully open layouts (21%). Only 7% of households reported having made wall modifications, suggesting that most thermal and spatial configurations still reflect original HDB designs. Pets are present in only a minority of homes.

Cooling infrastructure is varied. On average, households have 2.8 wall-mounted air-conditioning units, 2.1 ceiling fans, and 2.0 standing fans, with smaller numbers of wall-mounted fans, personal fans and other devices such as dehumidifiers and air purifiers. These figures indicate that most households manage heat through a combination of fixed and portable devices rather than a single dominant system.

Table 7.1 Household built-environment characteristics

Household profile, *mean*; range	
Building age (years)	26.7; 2-76
Floor area	95.1; 29-177
Unit floor	9.1; 1-38
Has any pet, *n* (%)	
Yes	75 (18.0 %)
No	341 (82.0 %)
Unit-facing type, *n* (%)	
Corner unit	207 (49.8 %)
Corridor unit without corridor-facing windows	108 (26.0 %)
Corridor unit with corridor-facing windows	101 (24.3 %)
Kitchen layout type, *n* (%)	
Fully close	143 (34.4 %)
Partial open	185 (44.5 %)
Fully open	88 (21.2 %)
Has any wall modification, *n* (%)	
Yes	29 (7.0 %)
No	387 (93.0 %)
Cooling devices, *mean*; range	
Wall-mounted air-conditioning	2.8; 0-7
Portable air-conditioning	0.1; 0-1
Window air-conditioning	0.0; 0-2
Ceiling fan	2.1; 0-8
Wall-mounted fan	0.5; 0-6
Standing fan	2.0; 0-9
Personal desktop fan	0.1; 0-6
Dehumidifier	0.0; 0-1
Air purifier	0.0; 0-3
Exhaust vent	0.0; 0-1
Total number of households	**416**

7.3 Heat Considerations in Household Decisions

Figure 7.2 shows the extent to which households consider heat when making longer-term home layout decisions. Across all five decision types, mean scores range from 2.33 to 2.47, indicating that heat is generally considered “to a small” or “medium extent”. Only a small minority report considering heat “to a very large extent”, and between roughly one-fifth and one-third of respondents report not considering heat at all. These patterns suggest that, despite living in a hot and humid climate, residents rarely treat thermal performance as a primary home design criterion.

Differences across dwelling types are modest. Supplementary Figure S31 shows that mean heat-consideration scores are lowest among 1–2 room rental units, slightly higher among 1–2 room owner-occupied units, and clustered near the overall mean for 3-, 4- and 5-room flats.

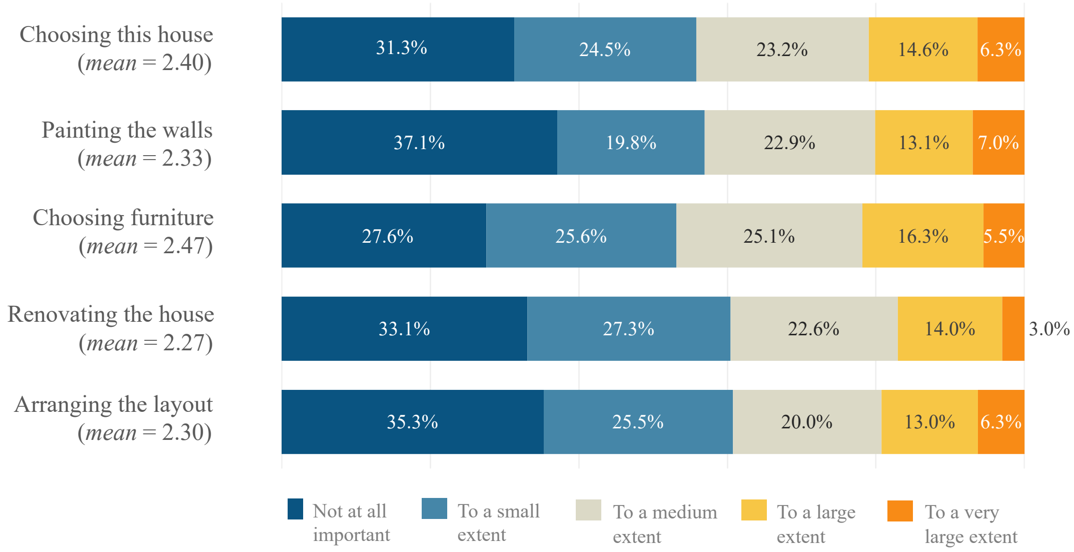

Figure 7.2 The extent to which heat was a factor taken into consideration for the list of decisions related to respondents' homes (%; *N*=416)

7.4 Natural Ventilation Practices and Barriers

Natural ventilation is a key strategy for sustainable household cooling. Figure 7.3 shows that when someone is at home, window opening is very common: nearly three-quarters (73.8%) of households report opening windows “often” or “always”. The main door is used less frequently for ventilation, with many households never (24.0%) or rarely (17.3%) opening it for airflow even when someone's at home.

When the house is unoccupied, ventilation drops sharply with almost two-thirds (64.9%) of households rarely or never leaving windows open. This sharp decline when units are unoccupied may reflect the role of security concerns in influencing home ventilation.

Supplementary Figure S32 shows small differences across dwelling types: natural-ventilation use is slightly higher in 1–2 room rental units (mean = 3.21), but overall usage is fairly consistent across flat sizes (means = 2.95–3.09 for other dwelling types). This suggests that natural ventilation is a broadly collective practice rather than one confined to particular housing segments.

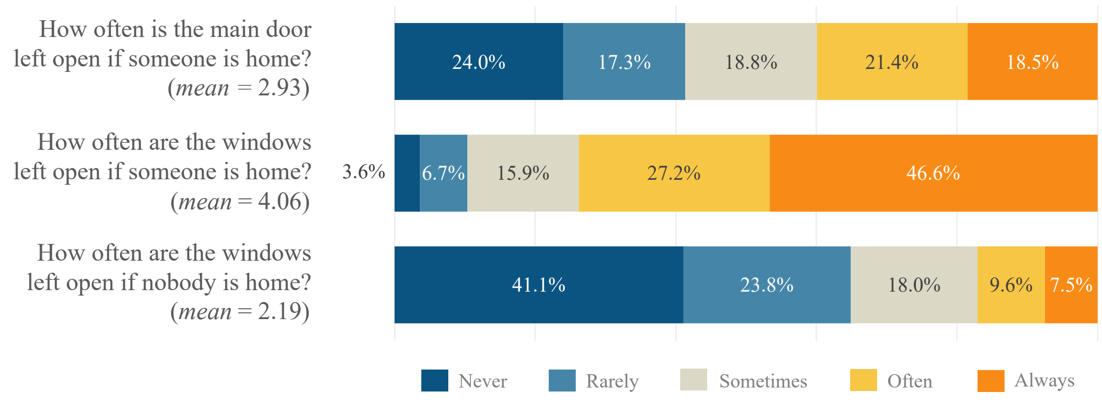

Figure 7.3 Responses on natural ventilation practices (%; *N*=416)

Barriers to window opening are depicted in Figure 7.4. Rain is the most frequently cited constraint (mean = 3.83), followed by outdoor air quality (mean = 3.04), insects and pests (mean = 2.90) and outdoor odours (mean = 2.85). Outdoor noise also influence behaviour, though typically at lower frequencies (mean = 2.63). Sunlight is the least common reason for closing windows (mean = 2.47), indicating that residents are generally willing to tolerate direct sun if other nuisances are manageable.

To summarise the cumulative influence of non-thermal concerns, Supplementary Figure S33 averages responses to noise, odours, air quality and insects across dwelling types. Scores centre between "rarely" and "sometimes" for all flat types (mean = 2.86), with slightly higher sensitivity in 5-room flats (mean = 2.93) and lower reported sensitivity in 1–2 room rentals (mean = 2.63).

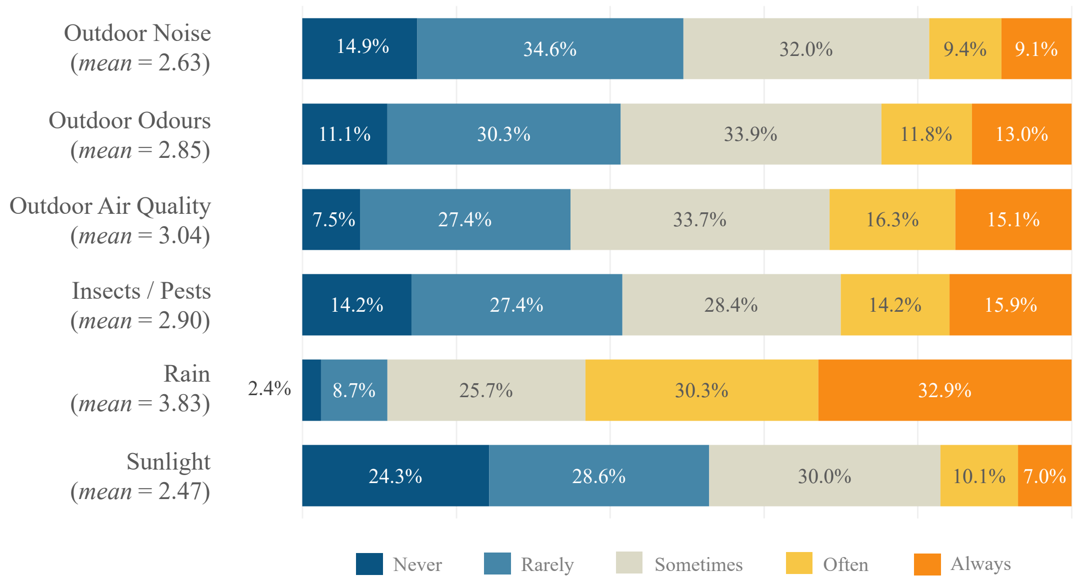

Figure 7.4 Responses to frequency of closing windows due to different reasons (%; *N*=416)

7.5 Cooling Devices and Main Cooling Practices

7.5.1 Air-Conditioner Ownership

Figure 7.5 shows that 81.0% of households have at least one wall-mounted air-conditioning unit, but access is uneven. Ownership is highest in 3-, 4- and 5-room flats, where more than four in five households have air-conditioning. In contrast, only 60.0% of owner-occupied 1–2 room units and 14.3% of 1–2 room rental units have wall-mounted air-conditioning. Portable and window units are much less common, and their higher presence in 1–2 room units may reflect adaptation when standard installations are not feasible.

These patterns point towards cooling inequity: households in smaller and rental flats likely face both regulatory and financial barriers to air-conditioning installation, leaving them more reliant on low-energy strategies and exposed to the greater risks of indoor overheating.

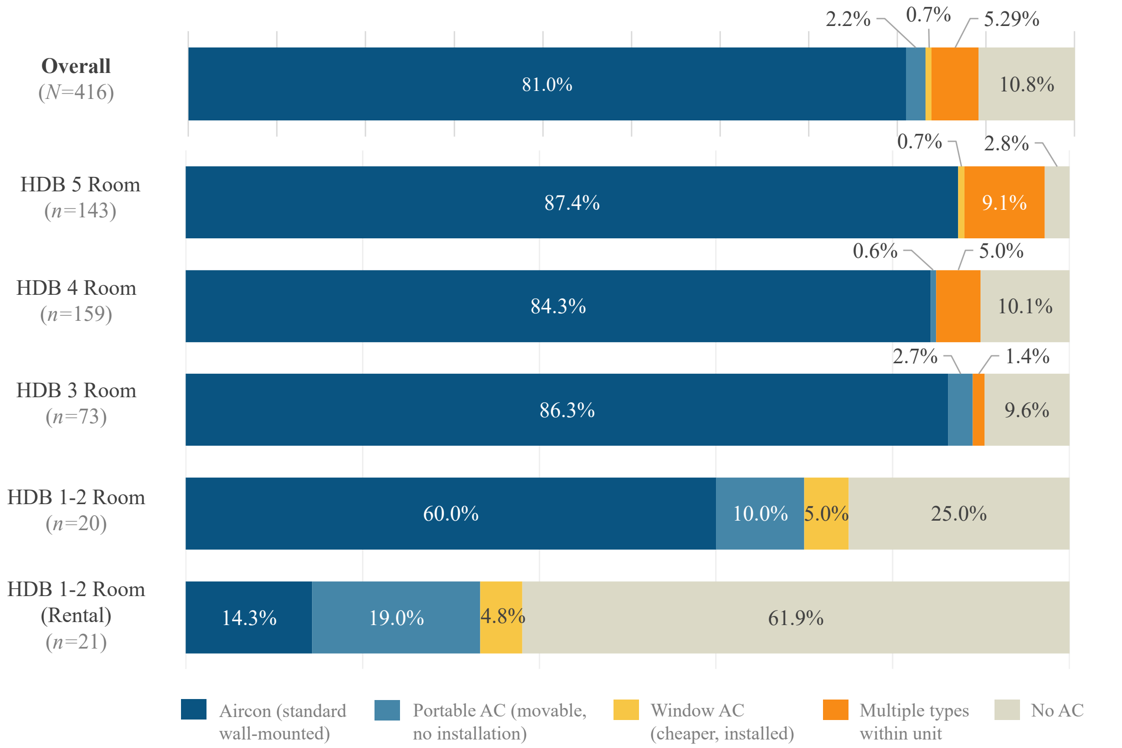

Figure 7.5 Ownership of different air-conditioning device types overall and across dwelling types (%)

7.5.2 Fan Ownership

Fan ownership is nearly universal as depicted in Figure 7.6. Almost all households have at least one fan, and an overwhelming majority (68.3%) have multiple types: standing fans are most common, followed by ceiling and wall-mounted fans. Personal desktop fans are rare. Larger flats tend to have more ceiling fans, while rental 1–2 room units rely heavily on standing fans and multiple portable devices.

These patterns show that fans are the backbone of household cooling, used both as a substitute for air-conditioning in low-income households and as a complement to air-conditioning in higher-income ones.

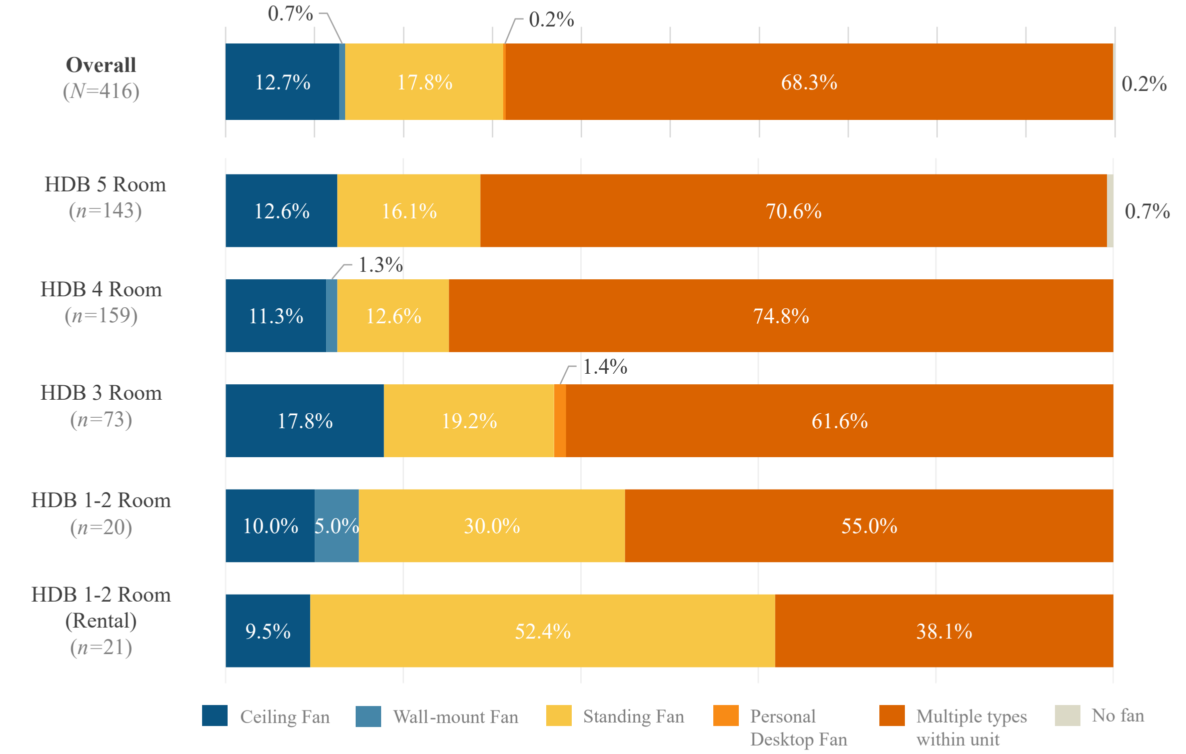

Figure 7.6 Ownership of different fans overall and across dwelling types (%)

7.5.3 Main Cooling Practice by Time of Day

Figure 7.7 summarises the main cooling practices used during day and night by households. During the day, households overwhelmingly rely on low-energy strategies: nearly 69.7% combine fans with open windows, and another 18.0% rely on either natural ventilation alone or fans alone. Only around 12.2% use air-conditioning (with or without fans) as their main daytime strategy. At night, patterns shift markedly. Around 61.2% of households use air-conditioning (alone or combined with fans) as their primary cooling mode, while the share relying solely on fans or natural ventilation falls sharply. Night-time cooling is thus more energy-intensive, reflecting heightened comfort expectations and the importance of sleep quality. These patterns mirror the individual-level heat management strategies.

Differences by dwelling type are detailed in Supplementary Figures S34 and S35. Larger flats show heavier night-time reliance on air-conditioning, whereas 1–2 room owner and rental units maintain higher use of fans and mixed strategies. This reinforces the link between dwelling size, cooling infrastructure and energy use.

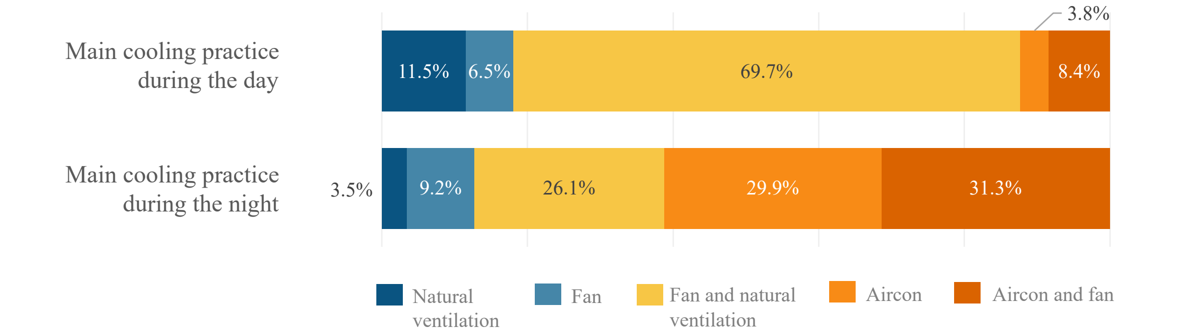

Figure 7.7 Main cooling practice used most of the time during the day and night (%; *N*=416)

7.6 Indoor Environmental Features and Precinct Mitigation

7.6.1 Clutter and Plants

Figure 7.8 shows clutter ratings from the home environmental audit. Overall levels are low (mean = 1.73), indicating relatively clear living spaces. However, clutter is higher in smaller flats, especially 1–2 room rentals where space constraints and dense furniture or appliance placement may limit circulation.

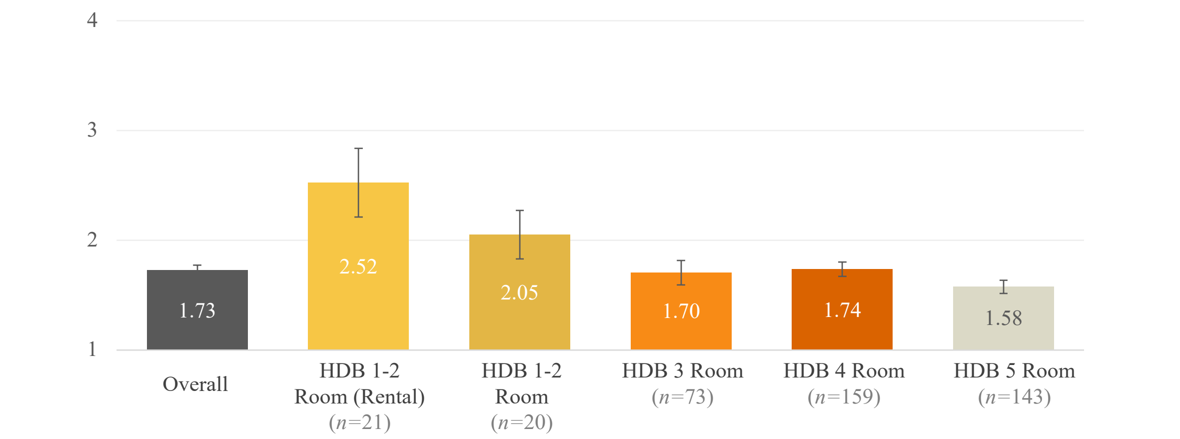

Figure 7.8 Average indoor clutter across dwelling types (*mean*) rated on a scale of 1 to 9

Figure 7.9 shows that plant ownership is limited. Around three-quarters of households (75.5%) had no indoor plants and two-thirds (67.3%) had no outdoor plants, although a minority of households maintain many outdoor plants. Taken together, higher clutter in small units and low greenery integration reduce opportunities for passive cooling via unobstructed airflow and evapotranspiration.

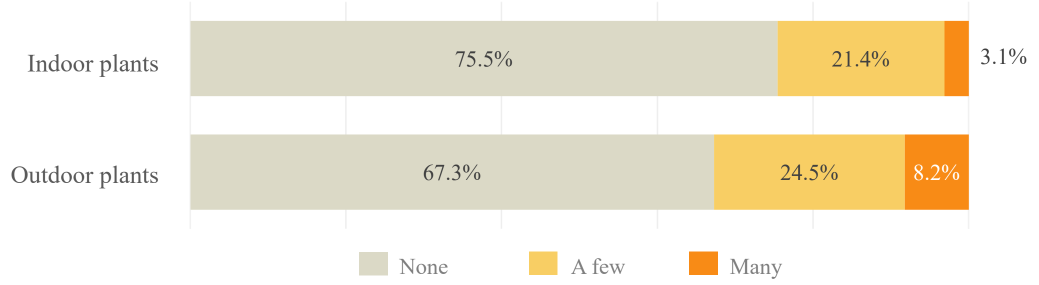

Figure 7.9 Environment audit on presence of plants (%; *N*=416)

7.6.2 Precinct-Level Heat Mitigation Features

Figure 7.10 describes heat-mitigation infrastructure within residential precincts. Most households report access to covered walkways (92.6%) and sheltered pick-up/drop-off points (82.2%), offering widespread protection from direct solar exposure and heavy rain. In contrast, shade-providing vegetation is less common: only a quarter of households (28.4%) report trees or greenery that provide meaningful shade, and another 40% report vegetation that does not provide shade.

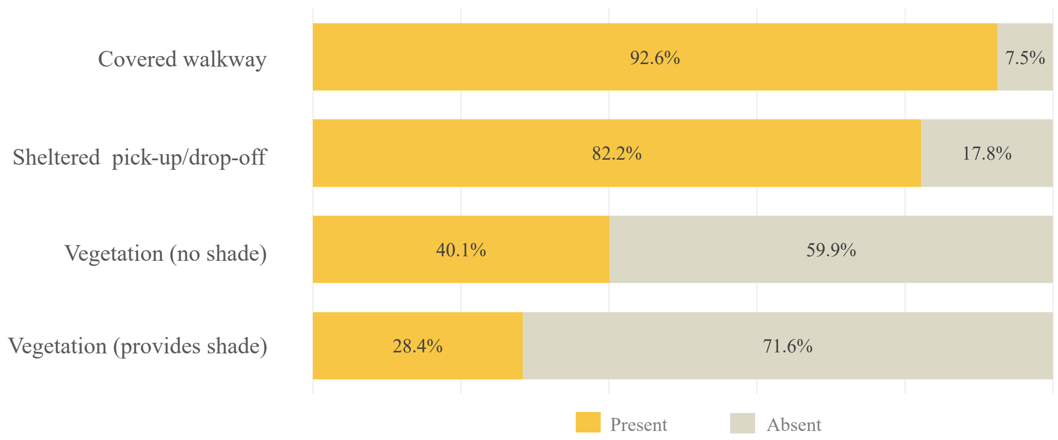

Figure 7.10 Responses to cooling facilities provided within the precinct (%; *N*=416)

7.6.3 Block-Level Air-conditioning Penetration

Block-level air-conditioning penetration, measured through the ratio of units equipped with air-conditioning per block, is summarised in Supplementary Figure S36. Over 60% of blocks have air-conditioning ratios above 0.8, indicating near-universal air-conditioning presence within those blocks, while a small minority of blocks have ratios below 0.1. This spatial clustering suggests that cooling infrastructure is unevenly distributed not only across dwelling types but also across blocks, with implications for neighbourhood-level electricity demand and heat emissions.

7.7 Thermal Conditions and Household Microclimates

7.7.1 Perceived Thermal Conditions at Home

Figure 7.11 shows how households perceive indoor temperatures relative to outdoors (e.g., corridor). Around 43.5% perceive their home as cooler, 30.8% perceive it as hotter, and 25.7% perceive no meaningful difference.

Figure S37 (Supplementary) details which areas are perceived as hottest and coolest. Living rooms were identified almost equally as the hottest (38.9%) and coolest (35.1%) areas. Bedrooms, however, were more consistently perceived as cooler, with 55.8% per cent of households identifying them as the coolest area, compared to 35.8% who considered them the hottest. A notable 25.2% of respondents selected "others" when identifying the hottest area. Among these, over two-thirds cited the kitchen, highlighting its role as a heat-intensive zone due to cooking activities and limited ventilation.

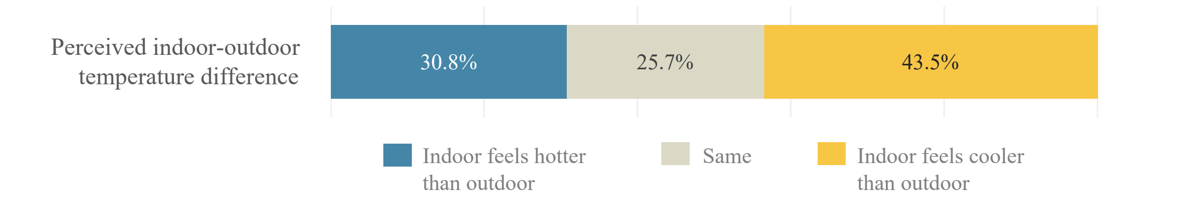

Figure 7.11 Rating of typical indoor house temperature relative to outdoors (e.g., in the corridor) (%; *N*=416)

7.7.2 Microclimate Measurements

Household microclimates were assessed in the living room (indoor) and at the sheltered ground floor void deck (outdoor). Figure 7.12 shows the distribution of indoor–outdoor heat index differences. Over one-third of households are up to 2°C warmer indoors, and another one-third are up to 2°C cooler, with roughly 5.0% registering zero difference. A smaller but important subset experiences more extreme deviations: around 10.1% are up to 5°C hotter indoors, and another 6.5% are more than 2°C cooler indoors, including a small share (3.4%) more than 5°C cooler.

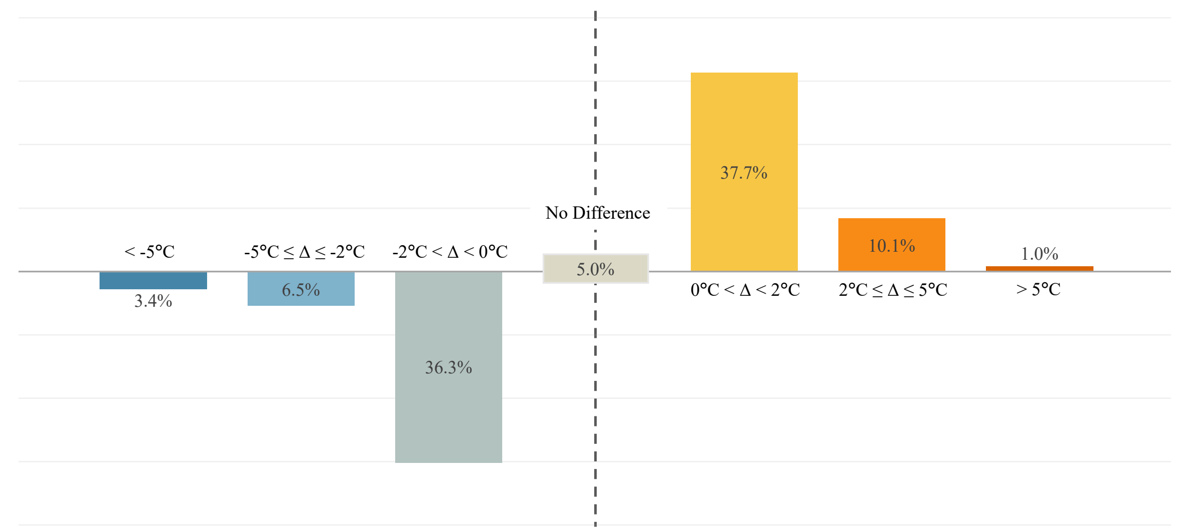

Figure 7.12 Distribution of indoor–outdoor heat index (°C) difference by Kestrel meter (%; *N*=416)

Indoor–outdoor wind speed differences are summarised in Supplementary Figure S38. Most households have lower indoor wind speeds than outdoors, with around 15.9% experiencing up to 0.5 m/s lower airflow indoors, with another 13.7% showing moderate (up to 1 m/s lower) and 28.4% strong deficits (over 1 m/s lower). Only one fifth of the sample experience higher indoor airflow. This points to widespread limitations in natural ventilation, especially where clutter, layout, closed windows or surrounding block configurations impede airflow.

Indoor–outdoor dry-bulb temperature and wet-bulb temperature differences (combining temperature and humidity) are presented in Supplementary Figure S39 and S40. Patterns are similar: most homes cluster within ±0.5°C of outdoor temperature, but a non-trivial fraction experience significantly warmer indoor conditions, 14.4% in dry-bulb temperature and 13.4% in wet-bulb temperature.

Overall, these microclimate measurements confirm that indoor thermal conditions often differ markedly from outdoor conditions, and that a sizeable subset of households experience hotter and less ventilated conditions indoors.

Chapter 8

Economic Dimensions of Household Adaptation

8. Economic Dimensions of Household Adaptation

This section examines household-level energy use and the uptake of Singapore's Climate Vouchers scheme, which subsidises energy- and water-efficient appliances and fittings. Together, these indicators shed light on the economic side of heat adaptation.

8.1 Section Highlights

Key findings from this section are:

- **Household utility use varies widely, with clear differences by dwelling type:** Electricity, gas and water consumption are generally similar to national averages. Larger flats consistently consume more electricity, while 1–2 room units display high variability, suggesting diverse energy consumption and occupancy patterns.
- **Awareness of Climate Vouchers is nearly universal, but usage remains modest:** Although almost all households know about the scheme, fewer than half have used their vouchers, suggesting potential behavioural frictions to participation.
- **Voucher usage concentrates on low-cost, high-efficiency items:** Households most commonly redeem vouchers for DC fans, LED lights and washing machines. These choices reflect affordability and immediate utility rather than large capital-intensive upgrades.
- **Energy-efficient air-conditioning uptake remains limited:** Even among voucher users, air-conditioner purchases are rare, suggesting that financial support is insufficient relative to upfront costs, installation barriers or perceived long-term expenses.
- **Unredeemed vouchers indicate ongoing but unmet cooling needs:** Among households with unused vouchers, DC fans remain the most desired future purchase, signalling demand for affordable, low-energy cooling alternatives.
- **A meaningful subset expresses no intention to redeem vouchers:** This reflects possible misalignment between eligible products and household needs, inadequate perceived benefits, low salience or remaining hassle factors, even when financial incentives are available.

8.2 Household Energy, Gas, and Water Use

Figures 8.1–8.3 summarize monthly household electricity (kWh), gas (kWh) and water (m^3) use. Average electricity use is 346 kWh per month, closely aligned with the national average of 340 kWh. Half of the sample consumes between 212 and 460 kWh while a small group of households use more than 800 kWh, likely reflecting extensive air-conditioning use or high appliance loads.

Average gas use is 55 kWh per month, with most households using substantially less than the national average of 91 kWh. Similarly, water use averages $13m^3$ per month, with three-quarters of households using less than the national average of $16.2m^3$.

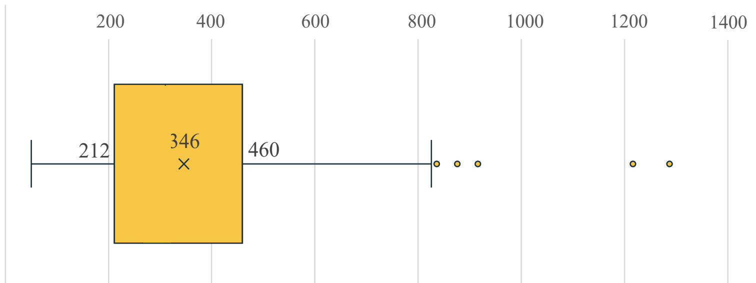

Figure 8.1 Distribution of monthly average electricity usage across households (kWh)
(25th percentile, mean and 75th percentile; *N*=393 due to unavailable data from some households)
Note: National average = 340 (Energy Market Authority, 2025)

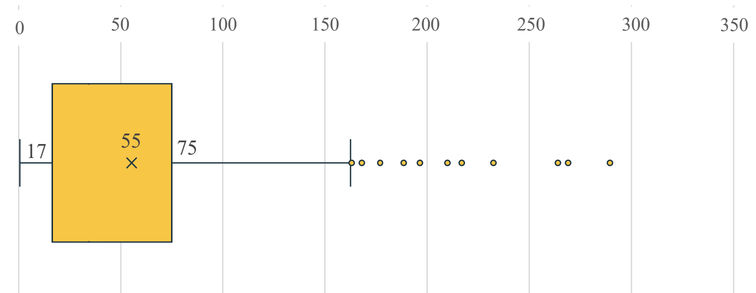

Figure 8.2 Distribution of monthly average gas usage across households (kWh)
(25th percentile, mean and 75th percentile; *N*=239 due to unavailable data from some households)
Note: National average = 91 (Energy Market Authority, 2025)

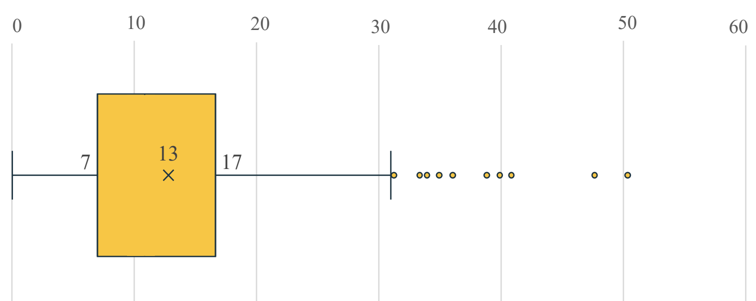

Figure 8.3 Distribution of monthly water usage across households (m^3)
(25th percentile, mean and 75th percentile; *N*=391 due to unavailable data from some households)
Note: National average = 16.2 (Ministry of Sustainability and the Environment, 2021)

Figure 8.4 depicts electricity use by dwelling type. There is a clear gradient with 5-room flats showing the highest average consumption (~400 kWh), followed by 4- and 3-room flats. 1–2 room owner-occupied units have the lowest mean electricity use (~216 kWh), but variation within this group is large. Interestingly, 1–2 room rental units have higher average use than 1–2 room owner units, despite lower air-conditioning ownership, suggesting that occupancy patterns, appliance mixes, or other constraints may be driving concentrated demand in a subset of rental households.

Overall, these patterns indicate that electricity use is strongly structured by dwelling size**,** with implications for both energy expenditure and cooling-related emissions.

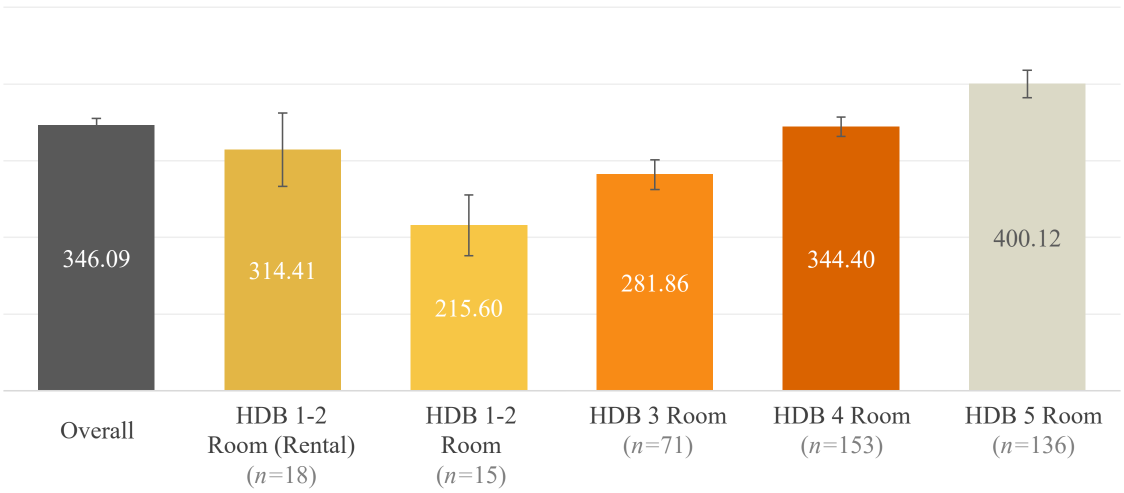

Figure 8.4 Monthly average electricity usage across dwelling types (*mean, N*=393)

8.3 Climate Vouchers: Uptake, Purchases, and Intentions

Figure 8.5 summarises the uptake of the Climate Vouchers scheme. Awareness is very high: only about 3.1% of households report not knowing about the vouchers. However, utilisation is much lower. Around 18.8% of households have fully used their S$300 voucher allocation, and another 18.0% have partly used it; roughly 60.1% have not used their vouchers despite being aware of the scheme.

It should be noted that the Climate Vouchers scheme was launched in April 2024, and the present survey was conducted from late October 2024 onwards, capturing approximately the first six months of household access to the vouchers. Nevertheless, within a similar timeframe, uptake appears lower compared with the other major national voucher initiatives. The 2024 Community Development Council (CDC) Vouchers Scheme was launched in January 2024 and recorded that by late June 2024 (around 6 months after launch), 97% of households had claimed their vouchers, with 80.4% of claimed vouchers already spent (Community Development Council, 2024).

The combination of high awareness but low utilisation of the Climate Vouchers suggests that there may be behavioural and practical frictions such as perceived hassle, lack of immediate need, low salience of eligible items, or uncertainty about installation, even when financial barriers are reduced.

Purchase patterns among voucher users are detailed in Table 8.6. Spending is heavily concentrated on a few appliance types, notably direct current (DC) fans, LED lights and washing machines. DC fans dominate both replacement and new purchases, reflecting their relatively low cost, direct cooling impact and clear energy-efficiency benefits. LED lighting upgrades and washing machine replacements likewise feature prominently.

Air-conditioning units account for a relatively small share of voucher-supported purchases, even among households that redeem vouchers, suggesting that the current voucher amount is often insufficient to overcome the high upfront costs of air-conditioning installation. Other eligible water-saving fixtures (e.g., efficient taps, shower fittings, water closets and heat pump water heaters) are used at much lower rates.

Table 8.7 summarises planned purchases among households who have not yet fully used their vouchers. Intentions broadly mirror actual purchases: DC fans and LED lights are again the top priorities, followed by washing machines, refrigerators and shower fittings. Around 18% express interest in using vouchers for air-conditioning, but many others either prioritise smaller items or report no intention to purchase anything (11.2%).

Taken together, these patterns indicate that the Climate Vouchers scheme is most effectively supporting incremental efficiency upgrades, particularly in fans and lighting, rather than capital-intensive appliances. To support deeper cooling transitions for heat-vulnerable households, especially in smaller or rental flats, future policy design may need to consider higher-value co-funding or targeted top-ups for high-impact items, alongside behavioural interventions that reduce hassle and increase the perceived value of participation.

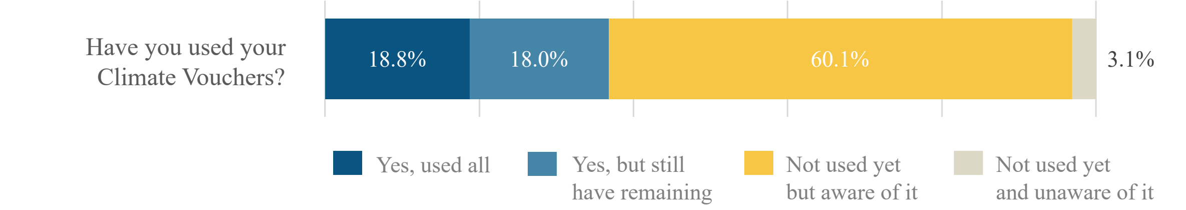

Figure 8.5 Responses to usage of Climate Vouchers (%; *N*=416)

Table 8.6 Distribution of household purchase patterns across ten appliance categories (%)

	Purchased as replacement (*n*=154*)	**Purchased a new additional item** (*n*=154*)
Direct current fans	26.6%	33.1%
Air-conditioning	9.7%	6.5%
Washing machine	14.3%	5.8%
LED lights	13.0%	6.5%
Refrigerator	11.0%	7.1%
Basin taps and mixers	7.1%	2.0%
Sink/bib taps and mixers	6.5%	2.6%
Shower fittings	5.2%	4.6%
Water closets	3.3%	3.3%
Heat pump water heaters	2.6%	4.6%

Note: * only include households who have already used Climate Vouchers

Table 8.7 Distribution of household purchase intention across ten appliance categories (%)

	Planned for purchase with Climate Voucher (*n*=338*)
Direct current fans	48.2%
Air-conditioning	18.0%
Washing machine	24.6%
LED lights	36.4%
Refrigerator	24.9%
Basin taps and mixers	19.8%
Sink/bib taps and mixers	8.3%
Shower fittings	24.9%
Water closets	3.9%
Heat pump water heaters	8.6%
Unlikely to purchase anything	11.2%

Note: ** only includes households who have not fully used Climate Vouchers

Chapter 9

Discussion and Implications

9. Discussion and Implications

This technical report provides a comprehensive, multi-scalar description of how households in Singapore understand, experience, and adapt to urban heat within the broader context of climate change. By integrating individual perceptions, household practices, dwelling characteristics, cooling infrastructures, and in-situ microclimatic measurements, this study establishes a robust empirical foundation for examining thermal resilience in Singapore' public housing.

The findings highlight important variation in heat experiences, climate perceptions, cooling practices, and indoor thermal conditions, as well as differences in access to cooling options across dwelling types. While most respondents recognised the link between climate change and rising temperatures, localised UHI effects remain less well understood. This creates a gap between broad climate knowledge and the everyday contexts in which heat is felt. A wide range of cooling practices is reported, yet their availability and usage vary across households, pointing towards constraints related to dwelling type and household routines. Indoor–outdoor comparisons further show that outdoor ambient measurements alone cannot capture the thermal environments residents inhabit, underscoring the importance of in-situ household data for understanding lived heat exposure.

These findings offer practical insights for policy, design, and public engagement including:

- **Strengthening thermal literacy and heat communication.** Low UHI awareness signals a need for clearer messaging about localised heat drivers and practical cooling strategies at home and in neighbourhoods.
- **Supporting vulnerable households.** Targeted schemes for rental units, low-income households, seniors, and households with heat-sensitive members should ensure both equitable access to cooling options and awareness of healthy cooling practices.
- **Promoting energy-efficient cooling behaviour.** Households' reliance on fans and natural ventilation provides a strong base for scaling energy-efficient cooling, but night-time air-conditioning dependence highlights the need for flexible strategies combining comfort and efficiency.
- **Enhancing passive cooling opportunities.** Findings point to the value of improved unit-level ventilation and heat-mitigation solutions, especially in smaller units.
- **Improving uptake of climate incentives.** Simplifying redemption processes, revisiting eligible appliances, and increasing relevance to household cooling needs may strengthen the Climate Vouchers scheme's impact.

Beyond immediate policy and design implications, WG1 serves as a foundational input for subsequent phases of the CRC programme. The descriptive baselines established here will complement in-depth ethnographic study of lived experiences (WG2) and inform citizen dialogues (WG3), co-creation workshop and field experiments (WG4). It further establishes the baseline for modelling behavioural, structural, and psychosocial pathways to heat resilience. As Singapore continues to warm, understanding these interconnected multi-scalar dimensions of household heat resilience will be essential for developing citizen-centred and equitable strategies that support long-term climate adaptation.

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Supplementary Material

Table S1 summarises all household-level variables grouped by blocks

Variable	Description	Items	Scale Type
Block 1: Household Makeup			
(1) Household Representative	Age, gender and room information of household representative	3	Multiple (Categorical, Discrete)
(2) Household Size	Total number of individuals residing in the household	3	Continuous (Ratio)
(3) Household Composition	Age, gender, relationship, and room information of each household member	4/member	Multiple (Categorical, Discrete)
(4) Household Income	Monthly household combined income bracket	1	Ordinal
(5) Length of Residence	Duration of stay in current residence (in years)	1	Continuous (Ratio)
(6) Renting	Number of individuals renting and rooms rented	3	Discrete (Ratio)
(7) Domestic Helper	Whether the household employs a domestic helper	1	Binary (Yes/No)
(8) Pet Ownership	Type and number of pets owned by the household	2	Multiple (Categorical, Discrete)
Block 2: Household Feature			
(9) Housing Type	Type of housing and floor area	2	Multiple (Categorical, Continuous)
(10) Kitchen Layout	Layout of the kitchen space	1	Categorical
(11) Room Count	Number of physically enclosed rooms	1	Discrete (Ratio)
(12) Balcony	Whether the unit has a balcony and how it is used	2	Categorical
(13) Cooling Devices	Information on different cooling devices in living room, kitchen and each bedroom	5/room	Multiple Options (Binary, Discrete)
(14) Household Thermal Features	To measure how thermal condition of home environments and corridors are perceived	5	Multiple Options (7-point Likert, Categorical)
(15) Design Consideration	Extent to which heat was considered in home design or management decisions	5	5-point Likert
(16) Cooling Practices	Information regarding main cooling practices used by the household	11	Multiple (Categorical, 5-point Likert)
(17) Climate Voucher	Whether climate vouchers are used for purchasing different household features and requirements	12	Categorical
Block 3: Estate			
(18) Cooling Features	Availability and type of cooling facilities in the estate	1	Categorical
Block 4: Utilities			
(19) Utilities Bills	Billing amount and usage of electricity (kWh), gas (kWh), and water (Cu M)	3	Continuous (Ratio)

Note. The order of items was randomised for respondents; the sequence shown here may not reflect the actual order.

Table S2 details all individual-level variables completed by respondents above 16 years old.

Variable	Description	Theoretical Source	Item Count	Scale Type
Block 1: Demographic Variables				
Demographics	Age, gender, and ethnicity of the respondent	-	3	Multiple (Categorical, Discrete)
Personal Income	Monthly	-	1	Range
Marital Status	Current marital status of the respondent	-	1	Categorical
Education Level	Highest level of educational attainment	-	1	Categorical
Employment	Employment status, remote work arrangement (if employed)	-	3	Categorical
Residence Status	Current residence status of the respondent	-	1	Categorical
Tenure Status	Whether the respondent is the owner, co-owner, living with an owner family member or renting	-	1	Categorical
Block 2: Psychological and Behavioural Variables				
Environmental Knowledge	Current level of understanding of climate change and urban heat island effect	Self-developed	2	5-point Likert
Environmental Concern	Degree of concern the respondent has regarding climate change	Adapted from Schultz (2001)	4	5-point Likert
Psychological Distance of Climate Change Scale	Perceived psychological distance to climate change using a structured Likert-type scale	Adapted from Jones et al. (2017); Spence et al. (2012); Wang et al. (2019)	20	5-point Likert
Psychological Distance of Climate Change Analog	Perceived psychological distance to climate change using a visual analog scale	Adapted from Brügger et al. (2016)	7	Visual Analog (0–100)
Psychological Distance of Urban Heat Scale	Perceived psychological distance to urban heat using a structured Likert-type scale	Adapted from Jones et al. (2017); Spence et al. (2012); Wang et al. (2019)	20	5-point Likert
Psychological Distance of Urban Heat Analog	Perceived psychological distance to urban heat using a visual analog scale	Adapted from Brügger et al. (2016)	7	Visual Analog (0–100)
Association Between Urban Heat and Climate Change	Whether the respondent perceives urban heat in Singapore as being associated with climate change	Self-developed	4	5-point Likert
Impact of Urban Heat	Extent to which heat affects the respondent's daily functioning and activities.	Adapted from He et al. (2022)	8	5-point Likert
Ascription of Responsibility	Extent to which the respondent feels personally responsible for their climate-related actions	Adapted from Rosenthal (2022)	3	5-point Likert
Awareness of Consequences	Awareness of the environmental and energy consequences of air conditioning use	Adapted from Han (2015)	5	5-point Likert
Environmental Personal Norms	Perception of the respondent on their own environmentally friendly behaviours	Adapted from de Groot & Steg, (2007)	3	5-point Likert

Environmental Social Norms	Perception of the respondent on the environmentally friendly behaviours of others in Singapore	Adapted from Thøgersen (2006)	8	5-point Likert
Thermal Preference	Preference of the respondent's own thermal environment	Self-developed	3	5-point Likert
Perceived Thermal Control	Perceived level of control on the respondent's own thermal comfort	Adapted from Langevin et al. (2012); Rissetto et al. (2022)	2	5-point Likert
Thermal Sensation	Thermal comfort with or without air conditioning and outdoors during day and night	Adapted from ASHRAE-55 thermal sensation vote (2020)	5	7-point Likert
Aircon Exposure	Duration of air-conditioning exposure and usage pattern at home	Self-developed	4	Multiple Options (Continuous, Binary, 5-point Likert)
Outdoor Exposure	Duration spent in outdoor settings	Self-developed	1	Continuous
Usage Frequency of Indoor Thermal Adaptation	Frequency of personal indoor thermal adaptation practice used	Adapted from Indraganti (2010); Srithongchai & Gadi (2020)	21	5-point Likert
Usage Frequency of Outdoor Thermal Adaptation	Frequency of personal outdoor thermal adaptation practice used	Adapted from Srithongchai & Gadi (2020); Wu et al. (2025)	21	5-point Likert
Perceived Efficacy of Indoor Thermal Adaptation	Perceived effectiveness of personal indoor thermal adaptation practice used	Adapted from Indraganti (2010); Srithongchai & Gadi (2020)	21	5-point Likert
Perceived Efficacy of Outdoor Thermal Adaptation	Perceived effectiveness of personal outdoor thermal adaptation practice used	Adapted from Srithongchai & Gadi (2020); Wu et al. (2025)	21	5-point Likert
Ecological Behaviour	Frequency of habituating pro-environmental behaviours	Adapted from *Getting to Net Zero Report* (2024)	17	Multiple Options (5-point Likert, Categorical)
Risk Aversion	Extent of tendency toward risk-taking or risk aversion	Dohmen et al. (2011)	2	Multiple Options (5-point Likert, Categorical)
Block 3: Economic Evaluation				
Mitigation Strategies	Perceived effectiveness of government-led heat mitigation strategies	Borzino et al., (2020)	6	5-point Likert
Willingness to pay: Mitigation	Willingness of the respondent to pay for government-led heat mitigation strategies	Borzino et al. (2020)	28	Binary (Yes/No)
Willingness to pay: 1°C decrease	Willingness of the respondent to pay for 1-degree Celsius decrease in temperature of their housing block and unit	Adapted from Borzino et al. (2020)	28	Binary (Yes/No)
Block 4: Picture Task				
Climate-Heat Picture Task	Whether the picture makes the respondent think about climate change	Self-developed	13	Binary (Yes/No)

Table S3 details all individual-level variables completed by youth respondents (13–16 years old).

Variable	Description	Theoretical Source	Item Count	Scale Type
Block 1: Demographic Variables				
Personal Demographics	Age, gender, and ethnicity of the respondent	-	3	Multiple Options (Categorical, Discrete)
Block 2: Psychological and Behavioural Variables				
Environmental Knowledge	Current level of understanding of climate change and urban heat island effect	Self-developed	2	5-point Likert
Environmental Concern	Degree of concern the respondent has regarding climate change	Adapted from Schultz (2001)	1	5-point Likert
Psychological Distance of Climate Change Scale	Perceived psychological distance to climate change using a structured Likert-type scale	Adapted from Jones et al. (2017); Spence et al. (2012); Wang et al. (2019)	10	5-point Likert
Psychological Distance of Climate Change Analog	Perceived psychological distance to climate change using a visual analog scale	Adapted from Brügger et al. (2016)	7	Visual Analog (0–100)
Psychological Distance of Urban Heat Scale	Perceived psychological distance to urban heat using a structured Likert-type scale	Adapted from Jones et al. (2017); Spence et al. (2012); Wang et al. (2019)	10	5-point Likert
Psychological Distance of Urban Heat Analog	Perceived psychological distance to urban heat using a visual analog scale	Adapted from Brügger et al. (2016)	7	Visual Analog (0–100)
Association Between Urban Heat and Climate Change	Whether the respondent perceives urban heat in Singapore as being associated with climate change	Self-developed	4	5-point Likert
Impact of Urban Heat	Extent to which heat affects the respondent's daily functioning and activities.	Adapted from He et al. (2022)	8	5-point Likert
Ascription of Responsibility	Extent to which the respondent feels personally responsible for their climate-related actions	Adapted from Rosenthal (2022)	1	5-point Likert
Awareness of Consequences	Awareness of the environmental and energy consequences of air conditioning use	Adapted from Han (2015)	5	5-point Likert
Environmental Personal Norms	Perception of the respondent on their own environmentally friendly behaviours	Adapted from de Groot & Steg, (2007)	1	5-point Likert
Environmental Social Norms	Perception of the respondent on the environmentally friendly behaviours of others in Singapore	Adapted from Thøgersen (2006)	2	5-point Likert
Thermal Preference	Preference of the respondent's own thermal environment	Self-developed	3	5-point Likert
Perceived Thermal Control	Perceived level of control on the respondent's own thermal comfort	Adapted from Langevin et al. (2012); Rissetto et al. (2022)	2	5-point Likert
Thermal Sensation	Thermal comfort with or without air conditioning and outdoors during day and night	Adapted from ASHRAE-55 thermal sensation vote	5	7-point Likert
Aircon Exposure	Duration of air-conditioning exposure and usage pattern at home	Self-developed	2	Multiple Options (Continuous, Binary)

Outdoor Exposure	Duration spent in outdoor settings		1	Continuous
Usage Frequency of Indoor Thermal Adaptation	Frequency of personal indoor thermal adaptation practice used	Adapted from Indraganti (2010); Srithongchai & Gadi (2020)	21	5-point Likert
Usage Frequency of Outdoor Thermal Adaptation	Frequency of personal outdoor thermal adaptation practice used	Adapted from Srithongchai & Gadi (2020); Wu et al. (2025)	21	5-point Likert
Perceived Efficacy of Indoor Thermal Adaptation	Perceived effectiveness of personal indoor thermal adaptation practice used	Adapted from Indraganti (2010); Srithongchai & Gadi (2020)	21	5-point Likert
Perceived Efficacy of Outdoor Thermal Adaptation	Perceived effectiveness of personal outdoor thermal adaptation practice used	Adapted from Srithongchai & Gadi (2020); Wu et al. (2025)	21	5-point Likert
Ecological Behaviour	Frequency of habituating pro-environmental behaviours	Adapted from *Getting to Net Zero Report* (2024)	10	Multiple Options (5-point Likert, Categorical)
Risk Aversion	Extent of tendency toward risk-taking or risk aversion	Dohmen et al. (2011)	2	Multiple Options (5-point Likert, Categorical)
Block 3: Picture Task				
Climate-Heat Picture Task	Whether the picture makes the respondent think about climate change	Self-developed	13	Binary (Yes/No)

Table S4 details items captured through the environmental audit.

Item	Description	Item Count	Scale Type
Block 1: Unit Characteristics			
Unit Floor	Floor level of the unit	3	Multiple Choices
Unit Type	Whether the unit is corner unit, corridor unit (with/without corridor-facing windows) or others	1	Categorical
Plants	Presence of indoor and outdoor plants in the unit	2	Categorical
Unit Layout	Room or spaces available in the unit	1	Categorical
Block 2: Room Characteristics			
Flooring	Type of flooring in the room (e.g., vinyl, tiles, parquet/hardwood, carpet, cement screed, others)	1/room	Categorical
Walls	Colour tone of walls (light, dark, or others)	1/room	Categorical
Lights	Type of light bulbs (incandescent, CFL, halogen, LED) and colour tone (cool, warm, or mixed)	2/room	Categorical
Windows	Window type (top-hung, casement, sliding, louvred, others) and shading features (tinted, grilles, curtains, blinds)	5/room	Multiple Options (Categorical, Binary)
Orientation	Whether the room is facing North, South, East or West in °	1/room	Categorical
Indoor Clutter	Level of clutter present in the room	1/room	Ordinal
Block 3: Kestrel Measurement			
Indoor Thermal Condition	Measurement of indoor temperature, heat index, relative humidity, wind speed, dew point and wet bulb temperature and cooling condition during measurement	7	Multiple Options (Continuous, Categorical)
Outdoor Thermal Condition	Measurement of outdoor temperature, heat index, relative humidity, wind speed, dew point and wet bulb temperature	6	Continuous
Block 4: 360° Picture			
360° Picture	A 360° picture of the room to document appliance and furniture arrangement, clutter, and indoor built features	1	-

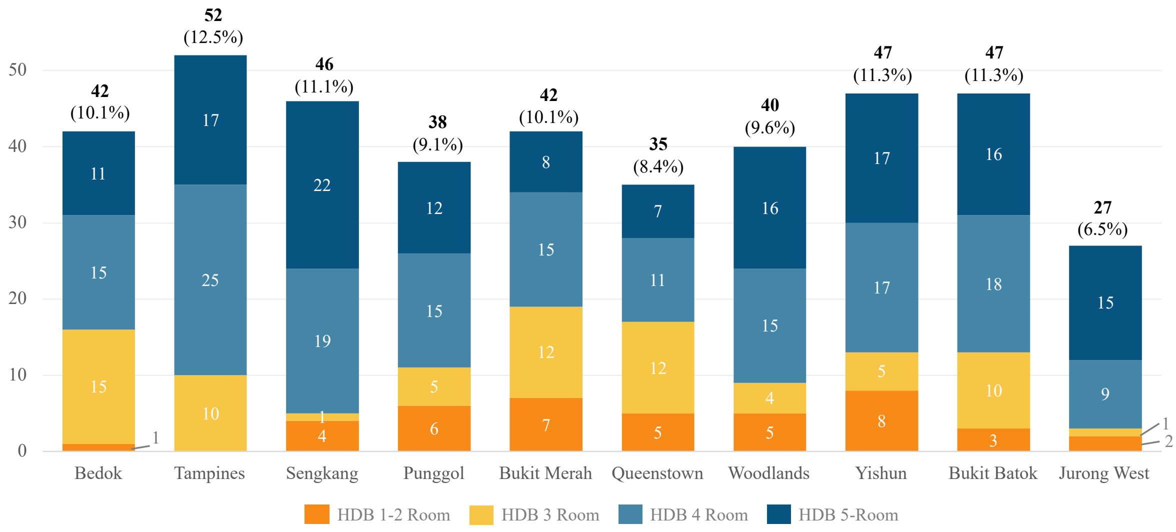

Figure S5 Distribution of dwelling types across 10 study areas (*N*=416)

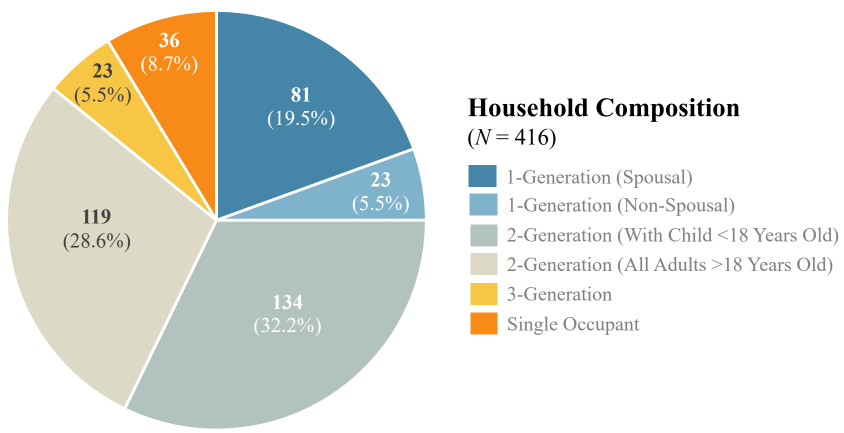

Figure S6 Distribution of household composition

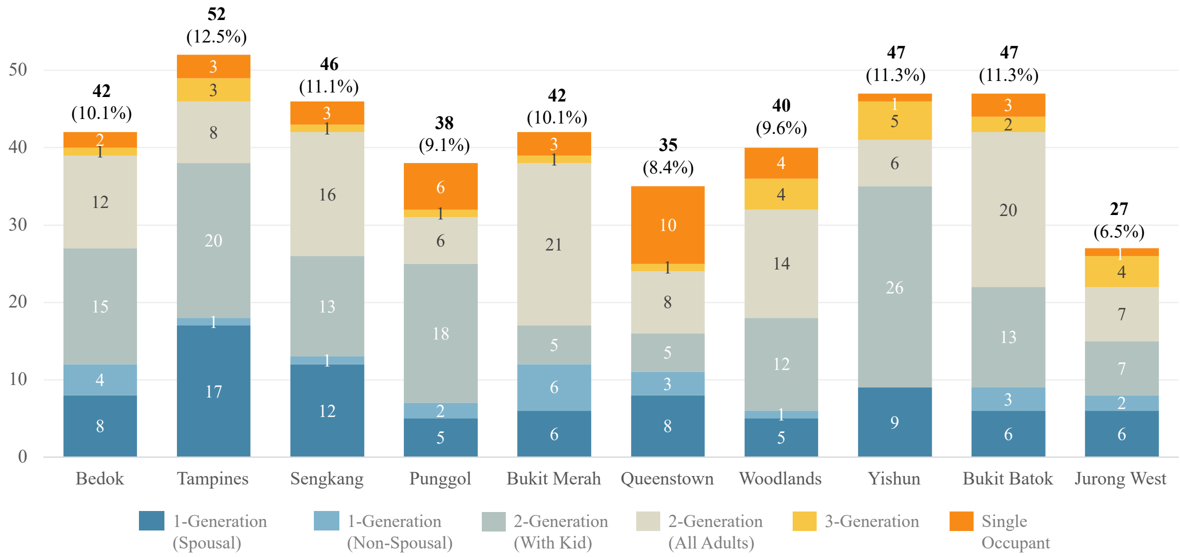

Figure S7 Distribution of household composition types across 10 study areas (*N*=416)

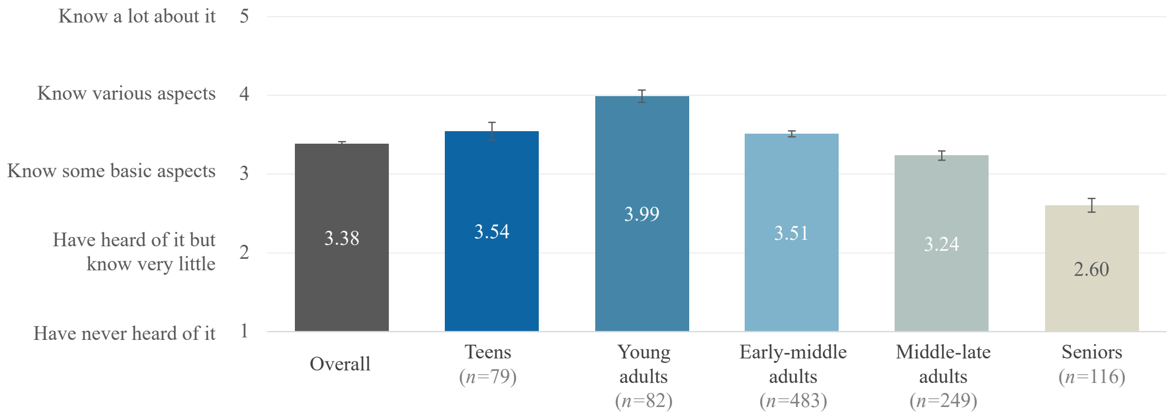

Figure S8 Response average of "climate change" knowledge across age groups (*mean*)

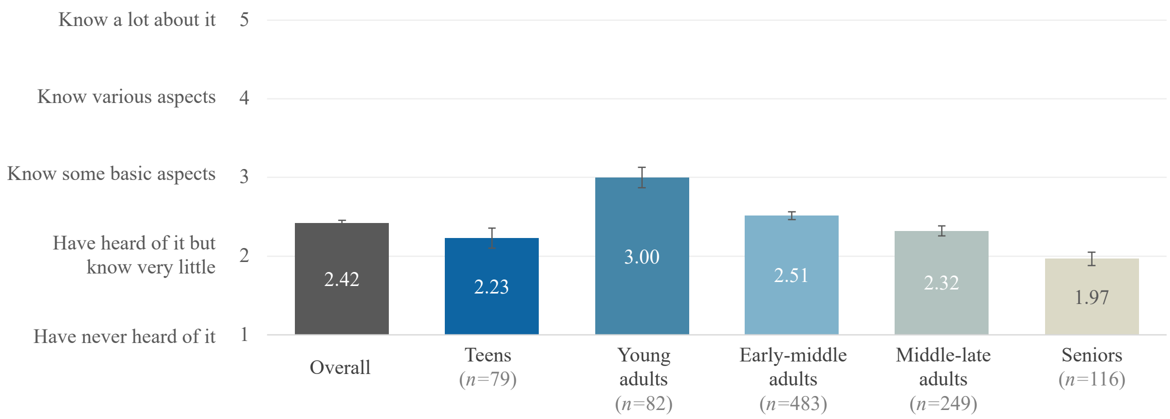

Figure S9 Response average of "urban heat island effect" knowledge across age groups (*mean*)

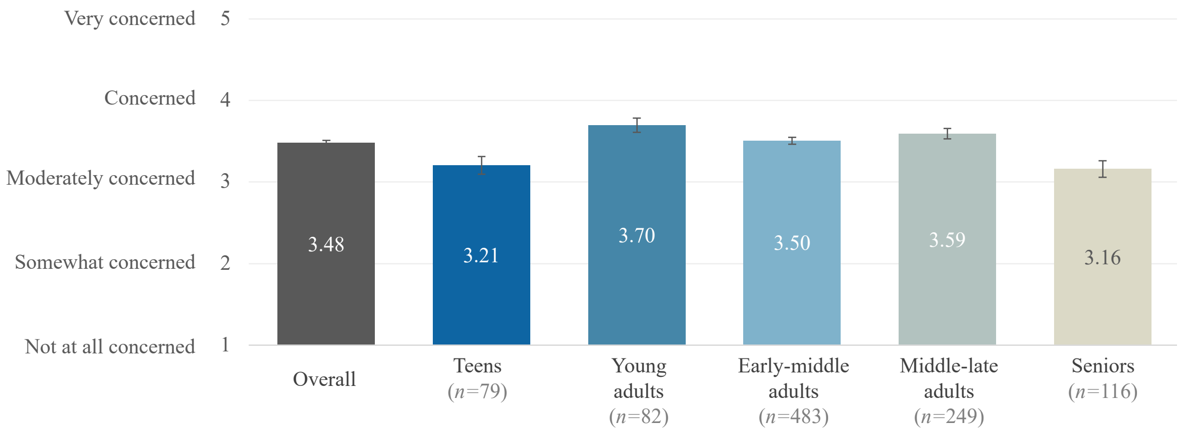

Figure S10 Response average of climate concern across age groups (*mean*)

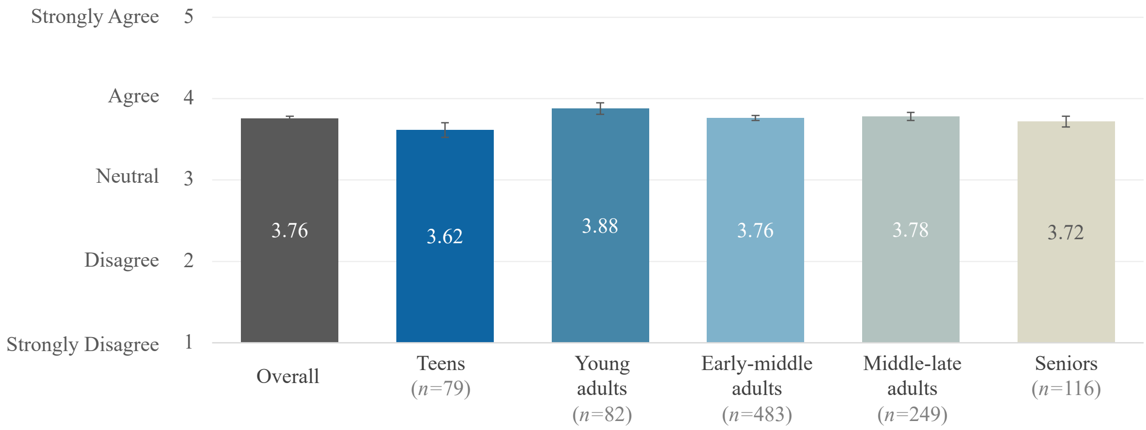

Figure S11 Response average of responsibility ascription across age groups (*mean*)

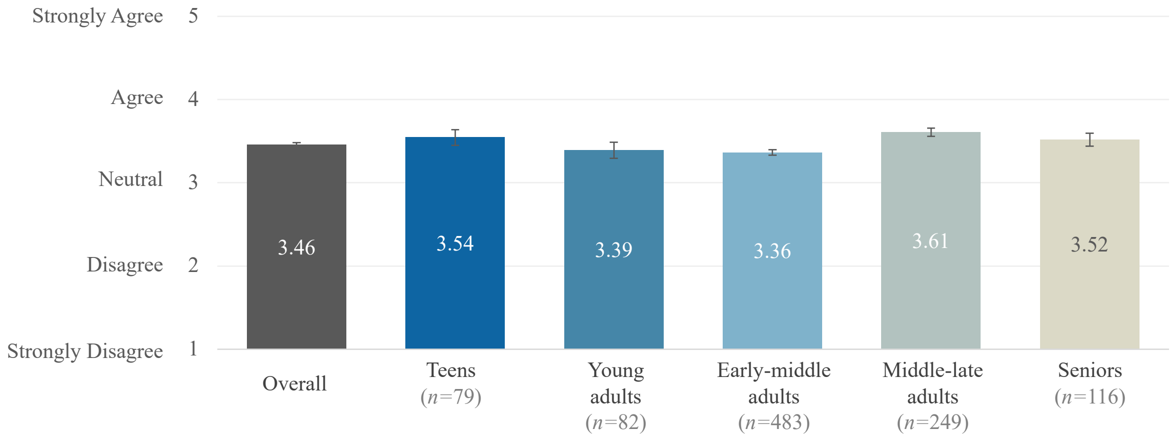

Figure S12 Response average of environmental personal norms across age groups (*mean*)

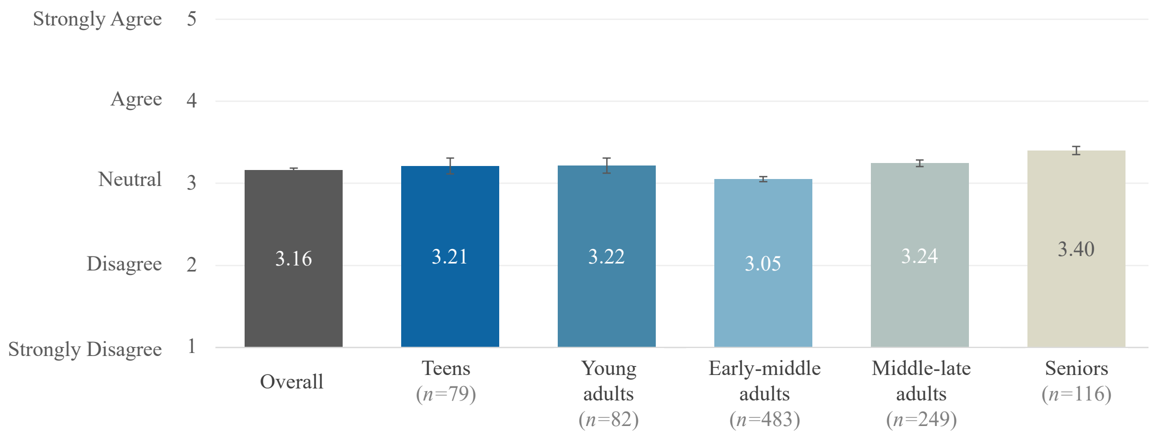

Figure S13 Response average of environmental social norms across age groups (*mean*)

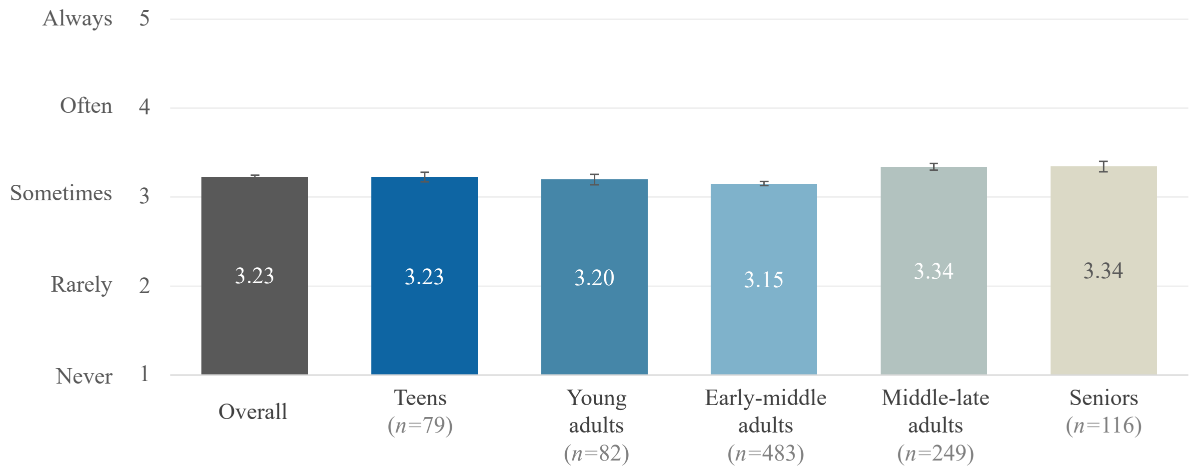

Figure S14 Response average of pro-environmental behaviours across age groups (*mean*)

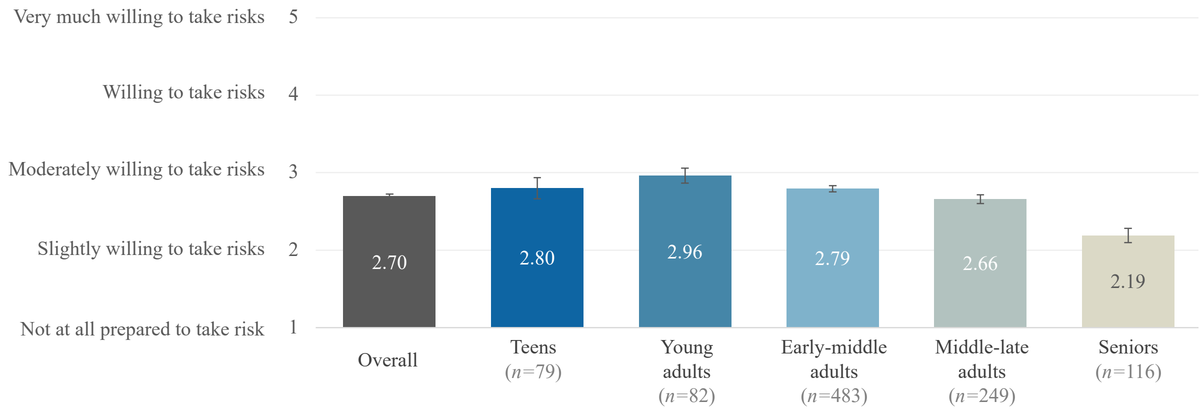

Figure S15 Response average of risk aversion across age groups (*mean*)

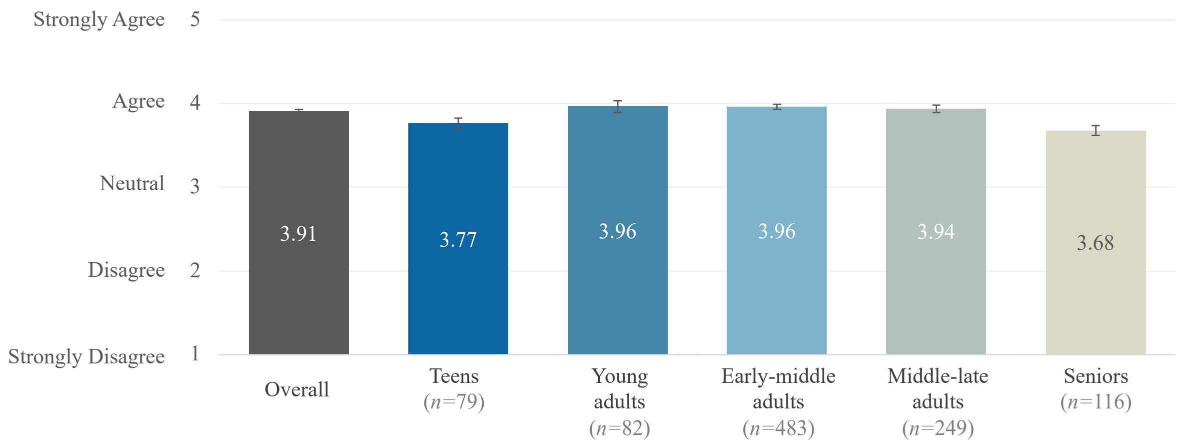

Figure S16 Response average of association between heat and climate change across age groups (*mean*)

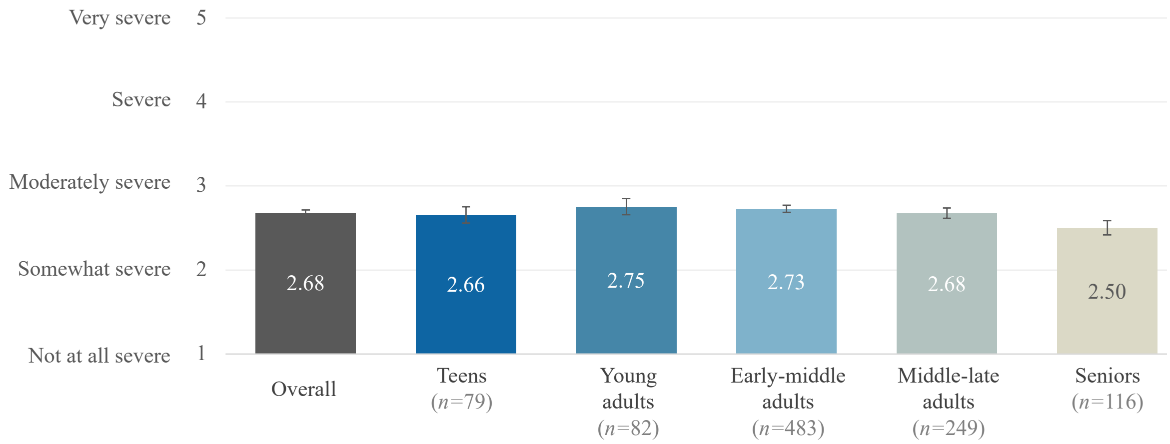

Figure S17 Response average of heat stress impact across age groups (*mean*)

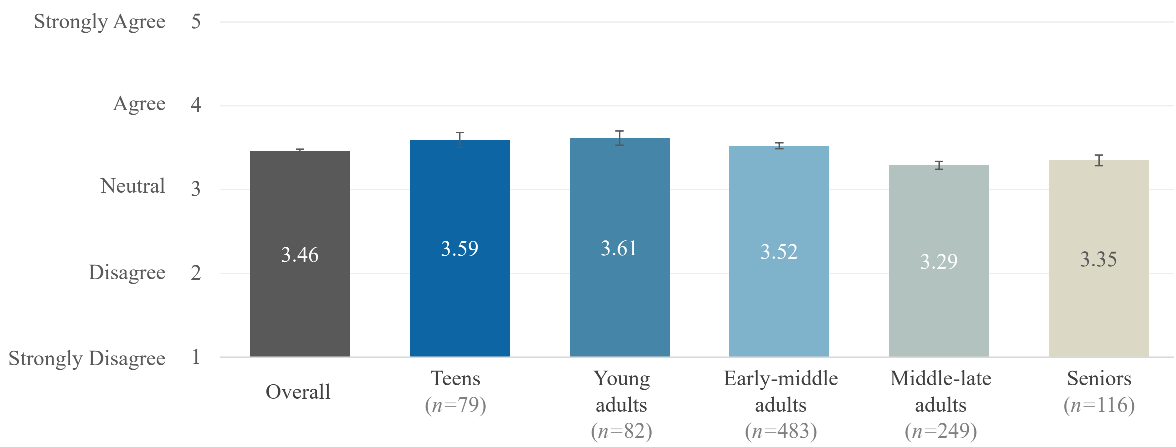

Figure S18 Response average of thermal preference across age groups (*mean*)

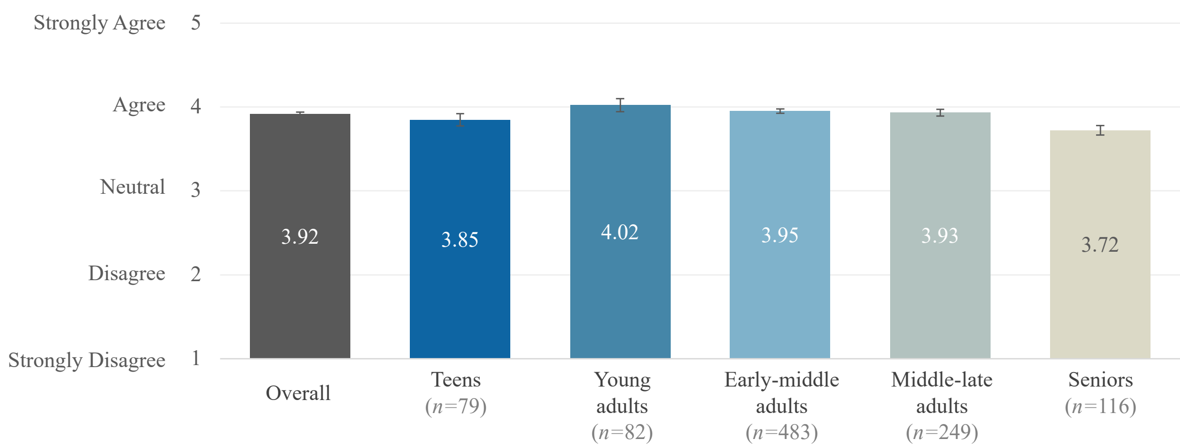

Figure S19 Response average of awareness about air-conditioning's environmental consequences across age groups (*mean*)

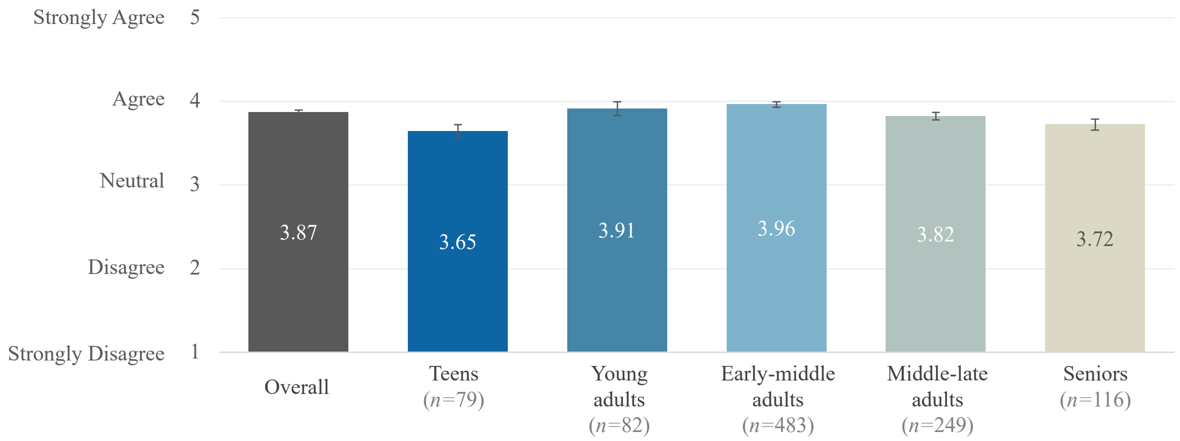

Figure S20 Response average of perceived control over indoor thermal conditions across age groups (*mean*)

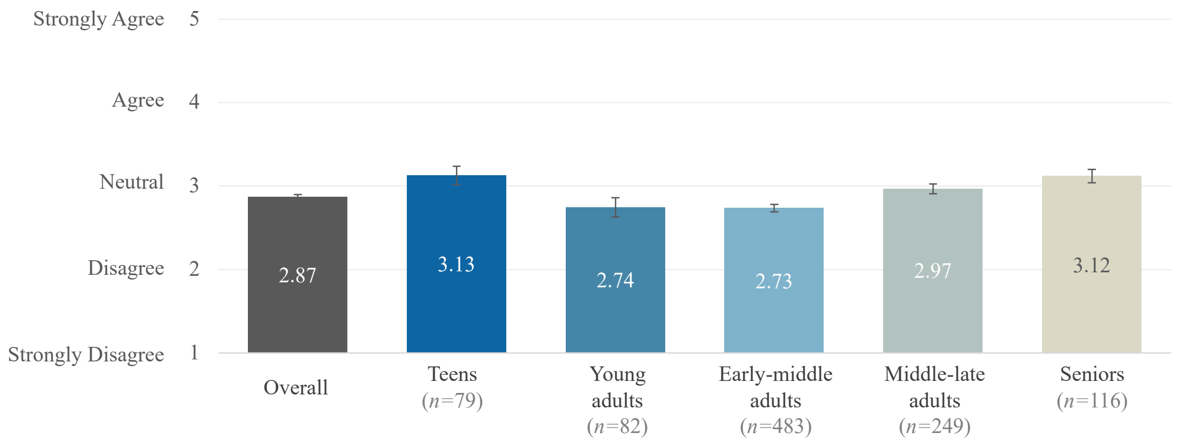

Figure S21 Response average of perceived control over outdoor thermal conditions across age groups (*mean*)

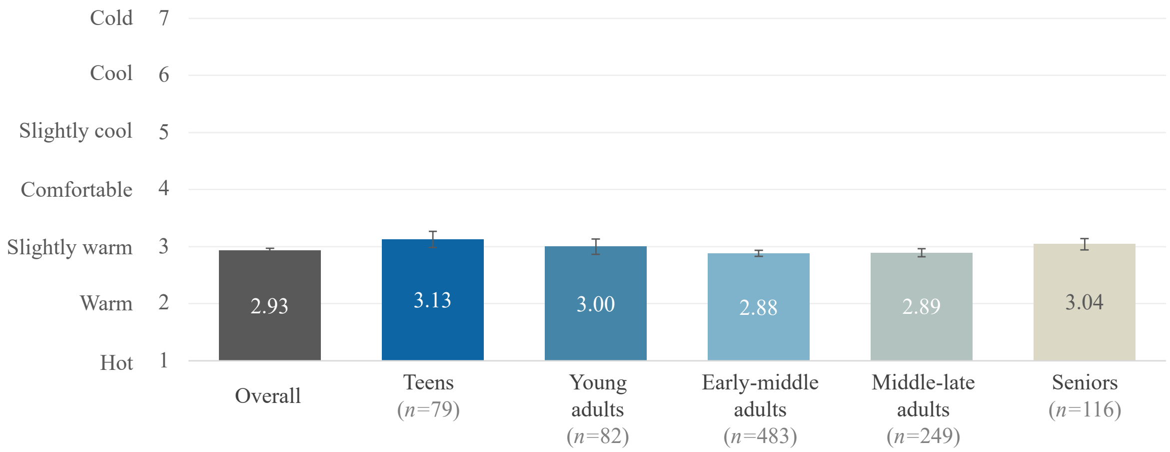

Figure S22 (a) at home without air-conditioning in the day

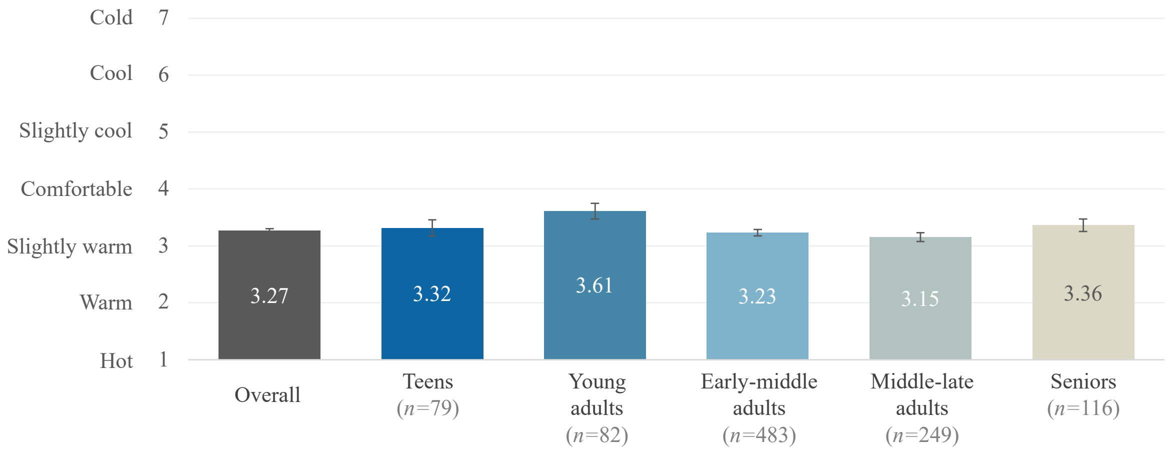

Figure S22 (b) at home without air-conditioning at night

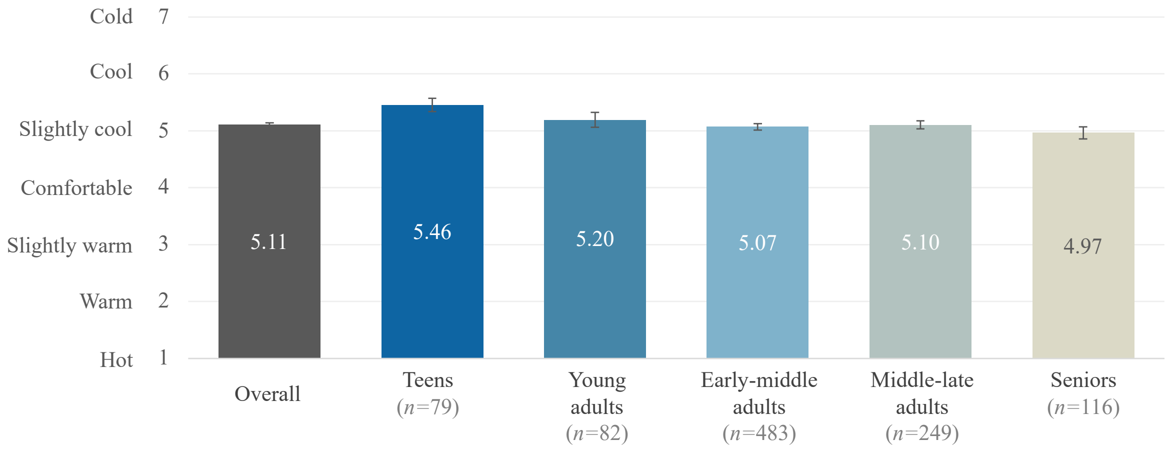

Figure S22 (c) in an air-conditioned place

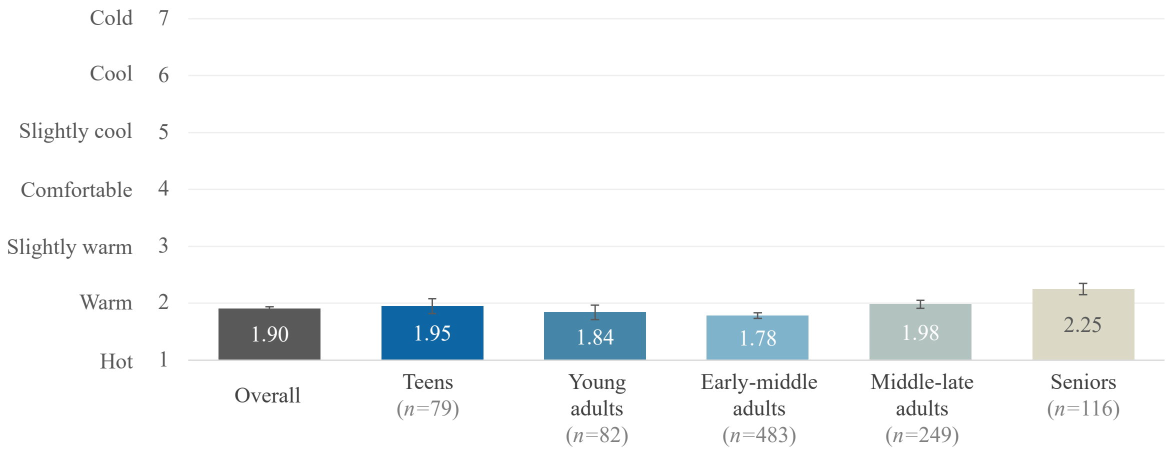

Figure S22 (d) outdoors in the day

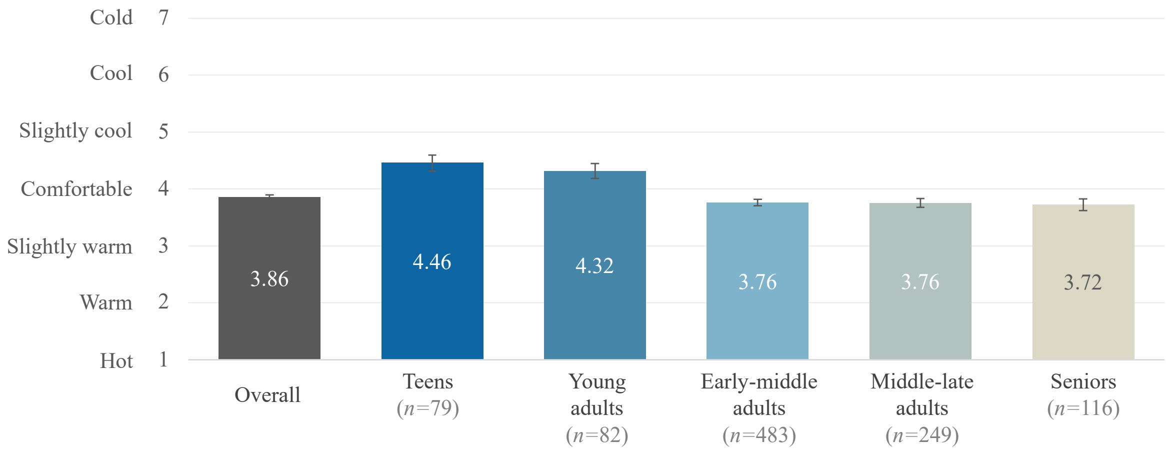

Figure S22 (e) outdoors at night

Figure S22 Response average of five thermal sensation scenarios across age groups (*mean*)

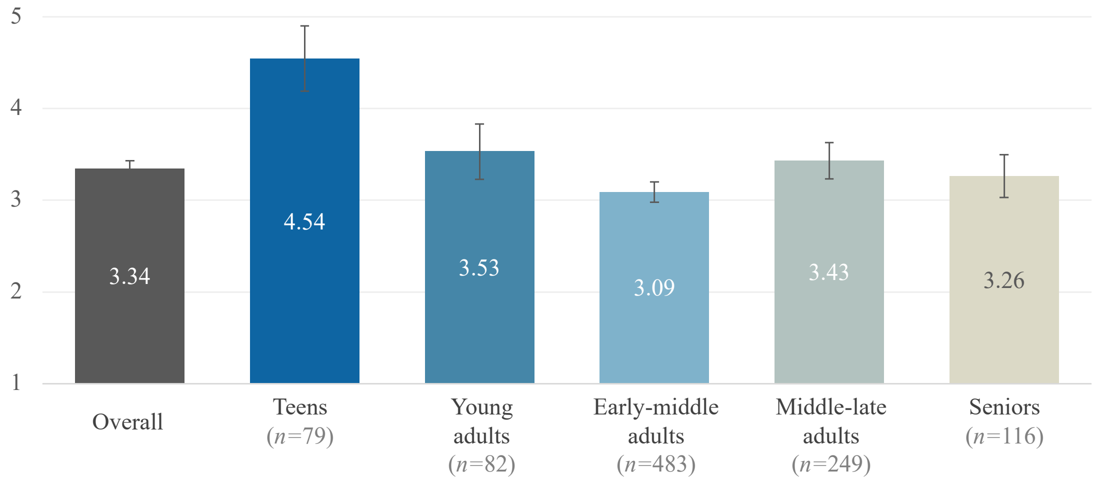

Figure S23 Response average of outdoor exposure (hr) across age groups (*mean*)

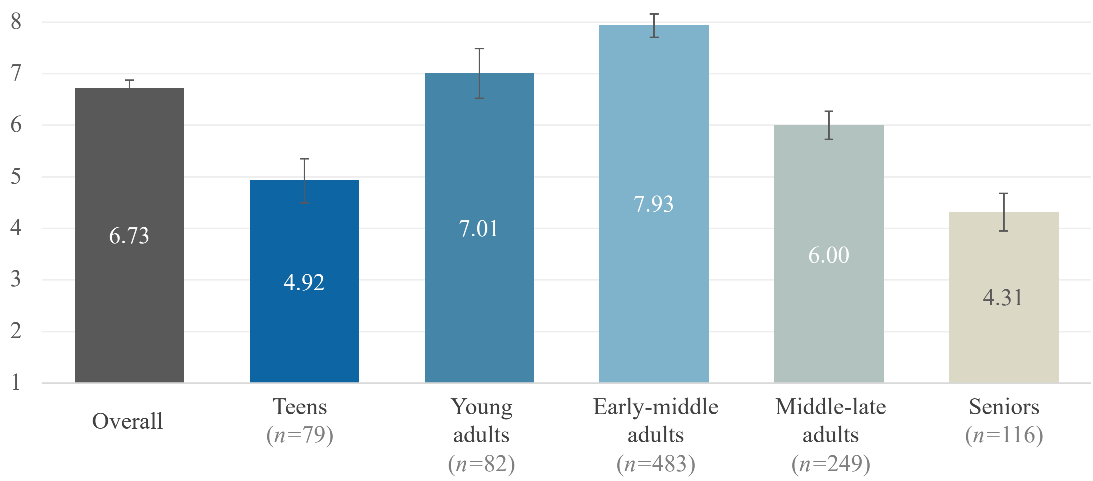

Figure S24 Response average of aircon exposure (hr) across age groups (*mean*)

Table S25 Average usage frequencies of indoor heat adaptation strategies across age groups (%)

	Teens (*n*=80)	Young adults (*n*=83)	Early Middle adults (*n*=485)	Middle-Late adults (*n*=249)	Seniors (*n*=116)
Aircon					
Aircon when sleeping	3.51	3.07	3.66	3.28	2.87
Aircon when awake	2.23	2.52	2.53	2.16	2.02
Environmental Adjustment					
Electric fan	4.27	4.05	4.09	4.23	4.03
Open the window	4.03	3.71	3.86	4.12	4.08
Draw curtains/blinds closed	2.85	3.35	3.20	3.24	2.66
Use a dehumidifier	1.58	1.49	1.70	1.48	1.22
Behaviour Adjustment					
Adjust attire	3.33	3.93	3.77	3.87	3.55
Take a shower	3.73	3.65	3.48	3.64	3.40
Consume cold drinks	3.67	3.71	3.63	3.22	2.68
Relocate to cooler area in the house	2.76	2.61	2.72	2.73	2.63
Take a nap	2.22	2.13	2.35	2.59	2.51
Splash water on face	2.86	2.61	2.47	2.53	2.28
Consume warm drinks	2.76	2.70	2.50	2.53	2.44
Leave home to go somewhere else	1.97	2.17	2.10	2.41	2.23
Use an icepack	1.54	1.60	1.42	1.43	1.34
Psychological Coping					
Just accept it	3.48	3.34	3.15	3.34	3.39
Change focus to distract myself	2.63	2.61	2.27	2.32	2.16
Breathing exercises	1.80	1.61	1.69	1.79	1.95

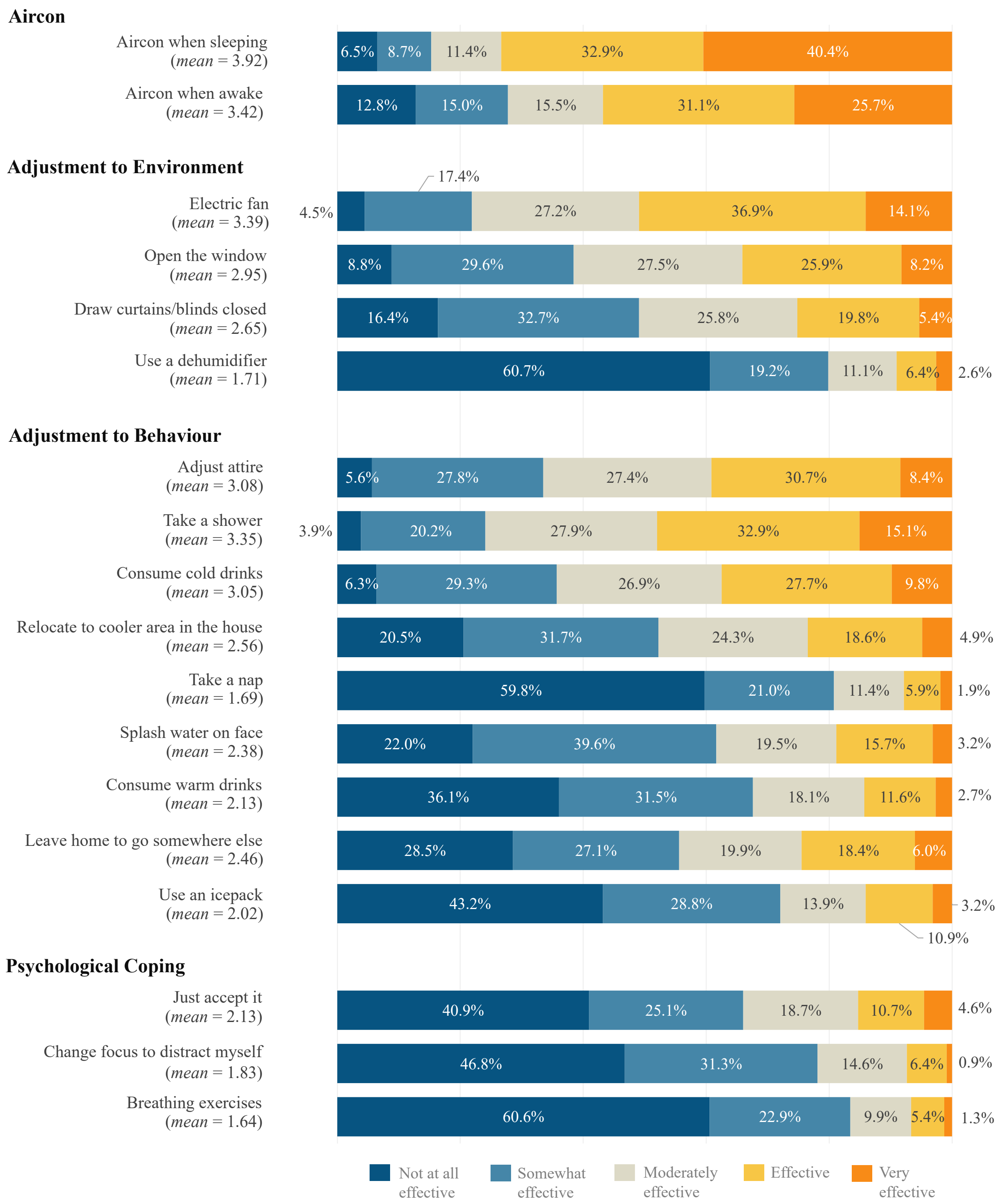

Figure S26 How effective different indoor heat adaptation strategies are at keeping you cool? (%; *N*=1009)

Table S27 Average perceived effectiveness of indoor heat adaptation strategies across age groups (%)

	Teens (*n*=80)	Young adults (*n*=83)	Early Middle adults (*n*=485)	Middle-Late adults (*n*=249)	Seniors (*n*=116)
Aircon					
Aircon when sleeping	3.82	3.87	4.13	3.78	3.46
Aircon when awake	3.20	3.74	3.62	3.24	2.89
Environmental Adjustment					
Electric fan	3.63	3.52	3.31	3.41	3.37
Open the window	3.14	2.83	2.79	3.13	3.18
Draw curtains/blinds closed	2.59	2.80	2.69	2.75	2.20
Use a dehumidifier	1.89	1.71	1.73	1.69	1.56
Behaviour Adjustment					
Adjust attire	3.15	3.29	3.03	3.17	2.94
Take a shower	3.37	3.60	3.35	3.33	3.21
Consume cold drinks	3.42	3.37	3.11	2.89	2.71
Relocate to cooler area in the house	2.71	2.57	2.52	2.60	2.48
Take a nap	1.90	1.60	1.57	1.86	1.75
Splash water on face	2.84	2.54	2.31	2.42	2.18
Consume warm drinks	2.57	2.23	2.06	2.13	2.07
Leave home to go somewhere else	2.38	2.57	2.36	2.67	2.42
Use an icepack	2.33	2.18	2.03	1.93	1.84
Psychological Coping					
Just accept it	2.43	2.24	1.96	2.30	2.16
Change focus to distract myself	2.30	1.94	1.72	1.88	1.80
Breathing exercises	1.71	1.68	1.54	1.74	1.77

Table S28 Average usage frequency of outdoor heat adaptation strategies across age groups (%)

	Teens (*n*=80)	Young adults (*n*=83)	Early Middle adults (*n*=485)	Middle-Late adults (*n*=249)	Seniors (*n*=116)
Use an umbrella	2.09	2.15	2.54	2.50	2.68
Wear a hat	1.90	2.05	2.31	2.43	2.36
Use a portable fan	2.33	2.12	2.25	2.16	2.04
Use a hand fan	2.20	2.06	2.08	2.02	1.98
Apply face mist	1.73	1.62	1.64	1.65	1.58
Avoid the sun	3.19	3.80	3.61	3.69	3.59
Adjust attire	3.24	3.76	3.50	3.68	3.51
Take a taxi/private car instead of public transport	2.39	2.06	2.39	2.16	2.01
Cancel plans to stay at home when it is too hot	2.20	2.30	2.48	2.64	2.33
Go to the nearest air-conditioned public space	2.90	3.52	3.34	3.16	3.05
Consume cold drinks	3.75	3.74	3.60	3.24	2.81
Consume warm drinks	1.77	1.63	1.90	2.33	2.18

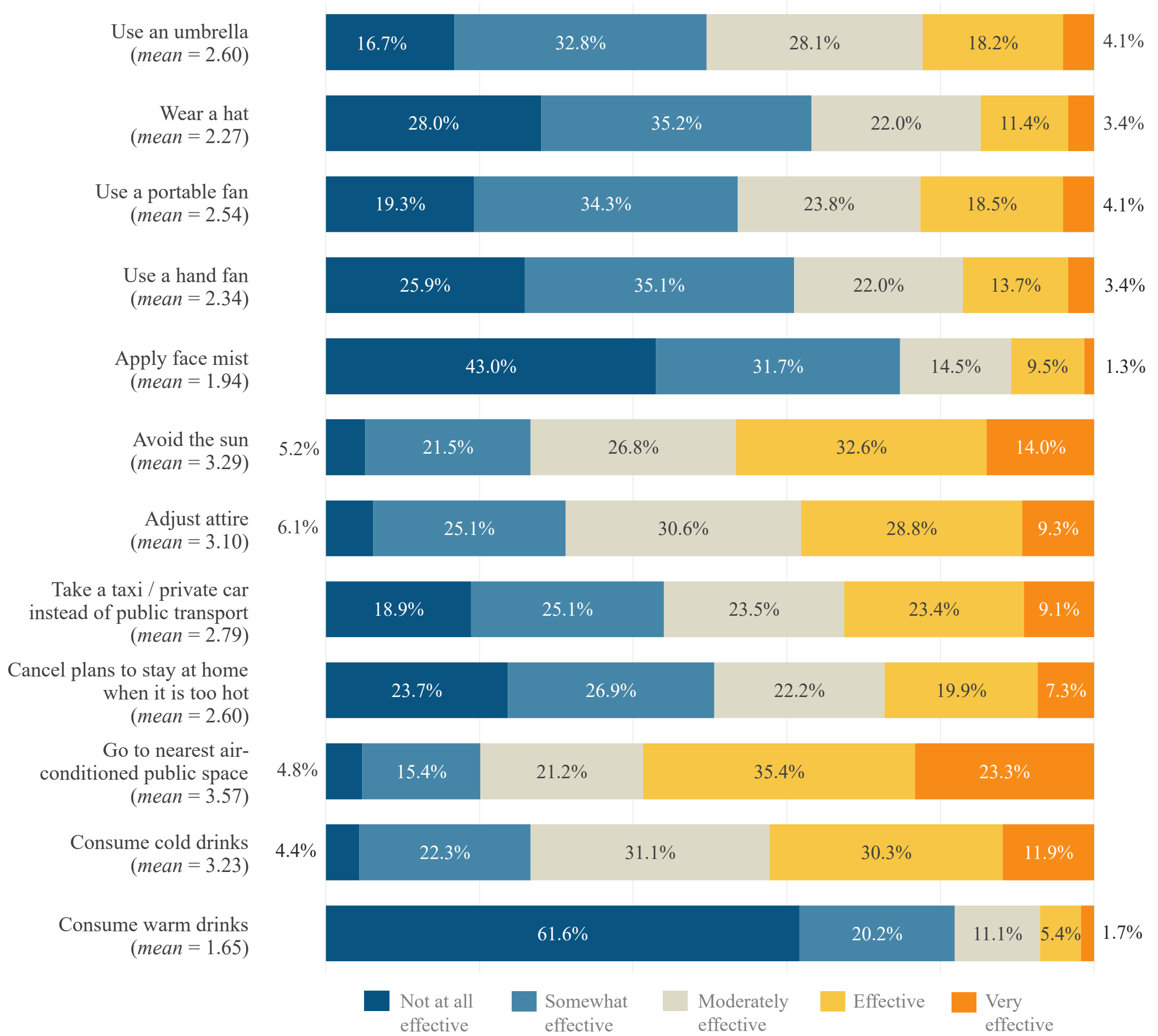

Figure S29 How effective different outdoor heat adaptation strategies are at keeping you cool? (%; N=1009)
Note: Items marked with * were only included in adult survey (N=940); marked with (R) were reversed-coded

Table S30 Average perceived effectiveness of outdoor heat adaptation strategies across age groups (%)

	Teens (n=80)	**Young adults** (n=83)	**Early Middle adults** (n=485)	**Middle-Late adults** (n=249)	**Seniors** (n=116)
Use an umbrella	2.46	2.50	2.63	2.57	2.73
Wear a hat	2.15	2.22	2.25	2.33	2.34
Use a portable fan	2.71	2.72	2.58	2.48	2.24
Use a hand fan	2.61	2.49	2.33	2.32	2.10
Apply face mist	2.24	2.00	1.93	1.89	1.90
Avoid the sun	3.18	3.43	3.28	3.31	3.25
Adjust attire	3.13	3.33	3.06	3.12	3.05
Take a taxi/private car instead of public transport	3.00	2.72	2.96	2.55	2.48
Cancel plans to stay at home when it is too hot	2.47	2.61	2.67	2.65	2.34
Go to the nearest air-conditioned public space	3.46	3.89	3.68	3.42	3.28
Consume cold drinks	3.63	3.50	3.29	3.08	2.85
Consume warm drinks	1.87	1.54	1.51	1.87	1.72

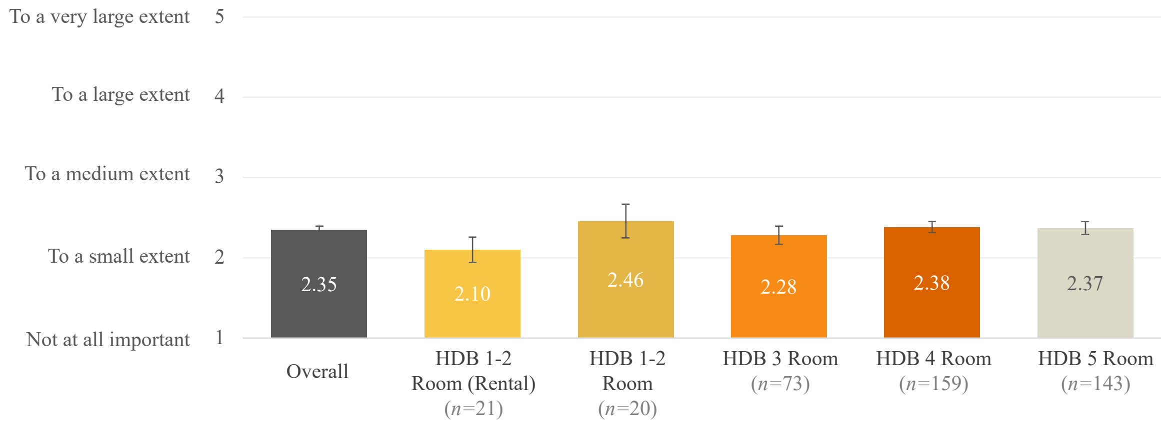

Figure S31 Response average of heat consideration across dwelling types (*mean*)

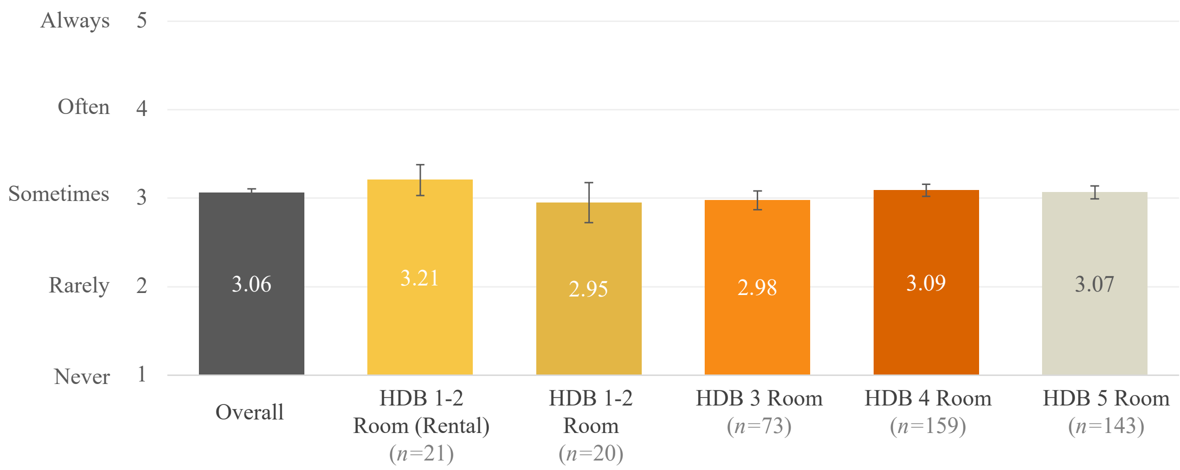

Figure S32 Response average of natural ventilation at home across dwelling types (*mean*)

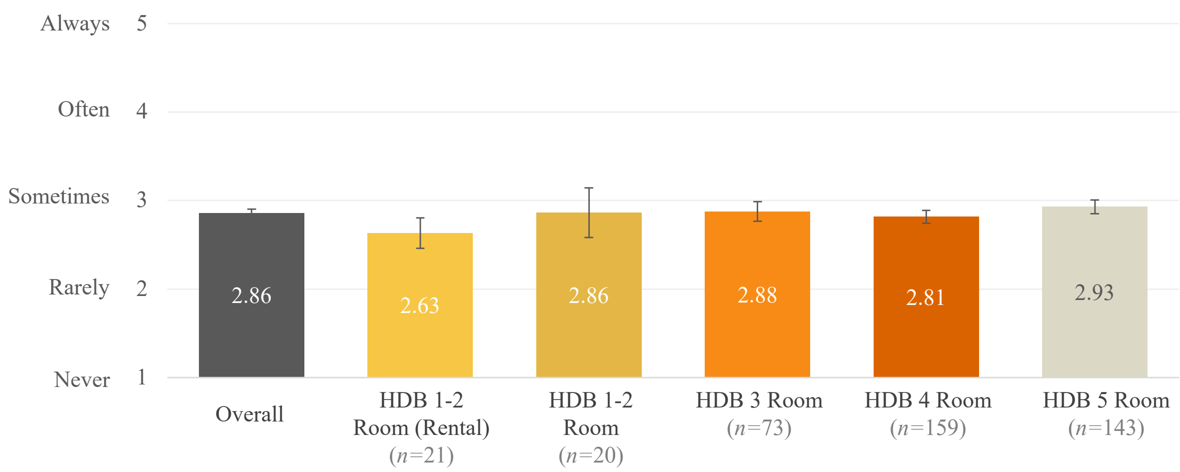

Figure S33 Response average of non-thermal reasons for window closing across dwelling types (*mean*)

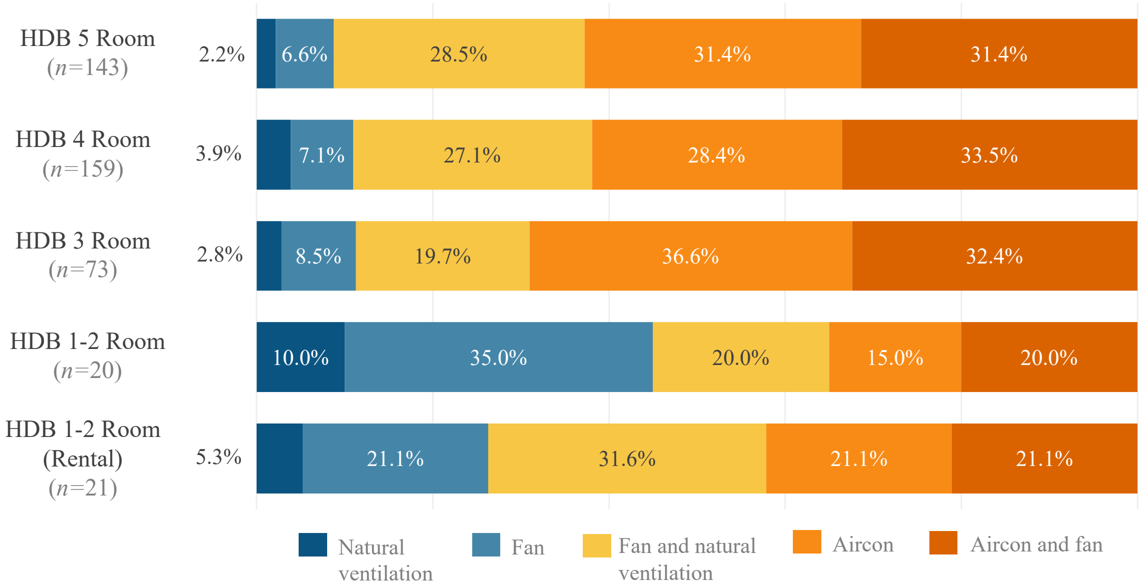

Figure S34 Distribution of main cooling practice used most of the time during night across dwelling types (%)

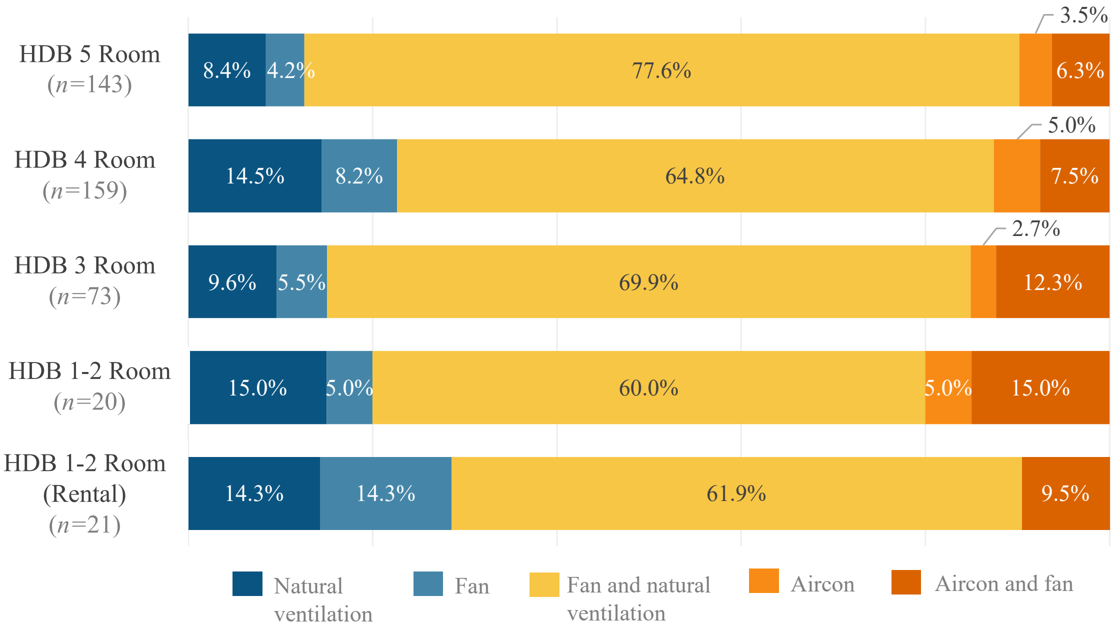

Figure S35 Distribution of main cooling practice used most of the time during day across dwelling types (%)

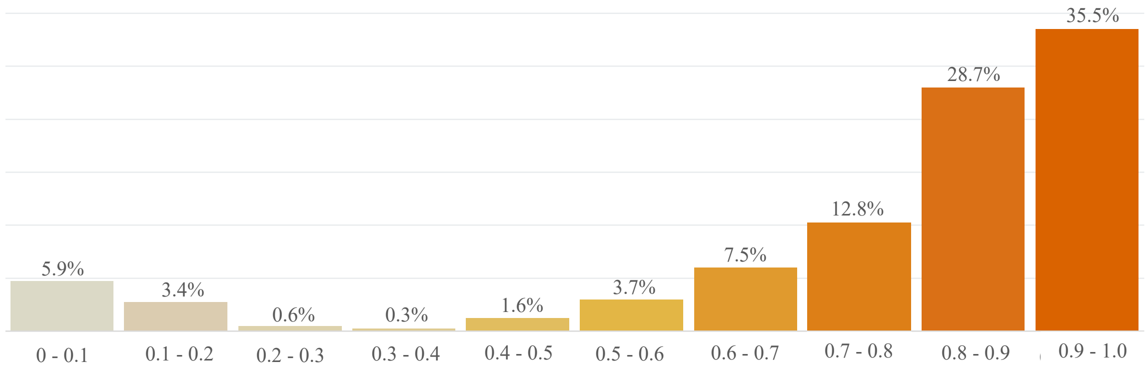

Figure S36 Distribution of unit-to-block air conditioning ownership ratios (%; *N*=312*)

Note: Each bin represents a half-open interval (e.g., 0 - 0.1 includes value ≥ 0 and < 0.1); *Newer HDB flats are designed with dedicated air-conditioner ledges and not mounted on the exterior facade making a visual count impossible; as blocks can consist of mixed-housing types, we do not report the breakdown by HDB dwelling type.

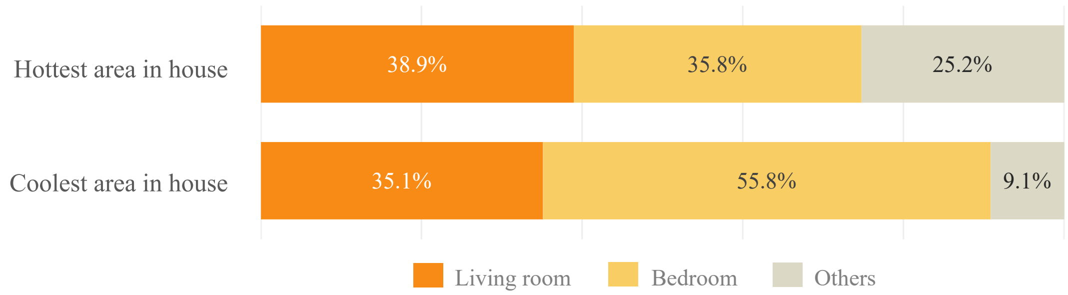

Figure S37 Which area in your house is the hottest or coolest? (%; *N*=416)

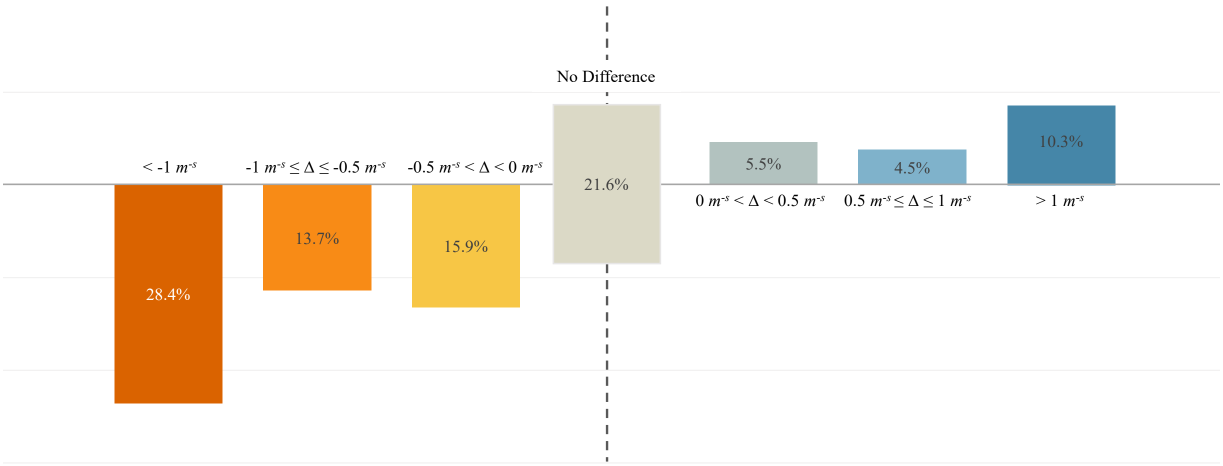

Figure S38 Distribution of indoor-outdoor wind speed (*m/s*) differences measured by Kestrel metre (%; *N*=416)

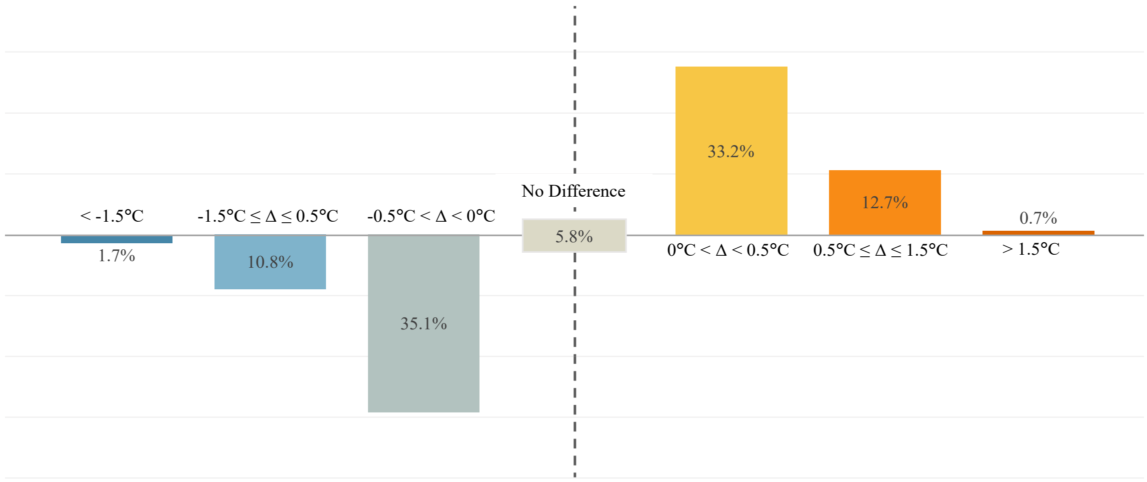

Figure S39 Distribution of indoor-outdoor temperature (°C) differences measured by Kestrel metre (%; *N*=416)

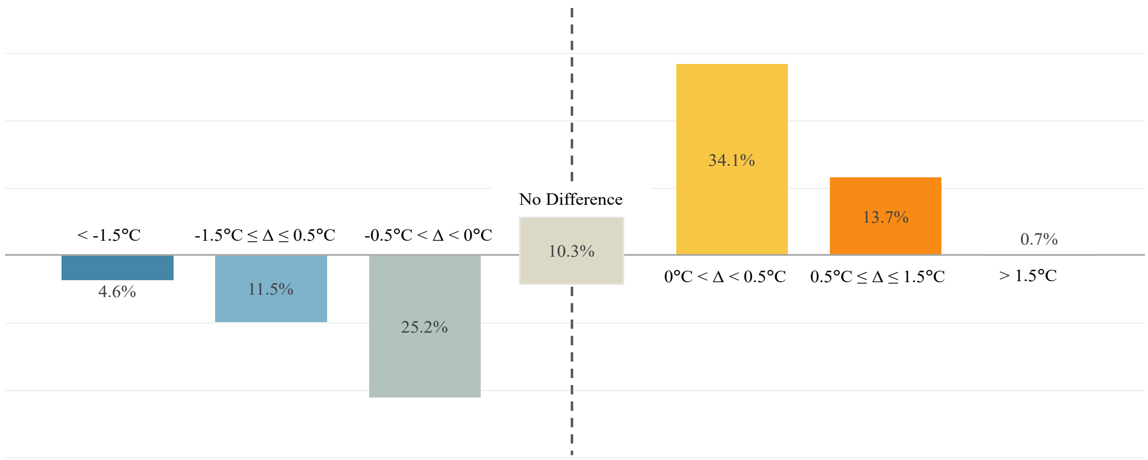

Figure S40 Distribution of indoor-outdoor wet-bulb temperature (°C) differences measured by Kestrel metre (%; *N*=416)

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