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# Navigating heatwaves in a temperate climate: barriers to behavioural adaptation in Dutch urban areas

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A B S T R A C T

Heatwaves are no longer rare anomalies in temperate cities; they are lived, negotiated, and unevenly endured. Yet behavioural adaptation—a vital first line of defence—remains underexplored. Drawing on a sequential mixed-methods design integrating in-depth interviews (N = 21) and a nationwide survey (N = 1,849) across Dutch urban density gradients, this study shows that behavioural adaptation is less a matter of individual choice than of social, structural, and spatial constraint. Homeowners leveraged their control over private spaces to adopt both active and passive technological adjustments, achieving higher adaptation scores. Tenants, constrained by housing tenure, disproportionately relied on cultural adjustments rooted in social ties and experiential knowledge. Residents of very highly urbanised areas reported higher indoor temperatures and demonstrated the lowest adaptation scores, revealing density-driven limits to coping capacity. Gender and household composition further influenced adaptive capacity, with women and multi-person households displaying consistently stronger responses. By centring behavioural adaptation, the study identifies key barriers and exposes the mechanisms through which adaptation inequality takes shape in temperate urban settings.

## 1. Introduction

The global increase in heatwave intensity and frequency is one of the most visible effects of the climate crisis. Such events are posing growing risk to energy systems, infrastructure, nature and environment, and most importantly on human health and wellbeing (Tollefson, 2023; Witze, 2022). Historically less exposed and less familiar to extreme heat, temperate regions are gradually becoming vulnerable as current and projected climate scenarios indicate a substantial change in temperature patterns (Gulev et al., 2021; Vautard et al., 2023). The consequences of this shift are already having real impacts. In the last two decades, Western European countries like the Netherlands have experienced unprecedented hot summers, where temperature soared past 40 °C and caused thousands of excess deaths (Robine et al., 2008; ANP and NL Times, 2022). On top of this, cities and urban centres suffer more from rising heat due to the urban heat island effect (UHI) (Oke, 1987; Mentaschi et al., 2022; Zhao et al., 2018). Importantly, even within cities, there is an uneven geography of development and concentration of resources (Liu et al., 2024), therefore, vulnerabilities also differ spatially (Sheridan and Allen, 2018). Thus, treating the urban areas as a homogeneous entity risks overlooking significant intra-urban disparities particularly in temperate cities, where heatwaves have not traditionally been regarded as a major climate concern.

Although there is a growing recognition of extreme heat as a pressing hazard, knowledge about how people in temperate urban

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settings perceive, experience, and adapt to such conditions remains fragmented (Ahmed et al., 2023). Behavioural adaptation at the individual level, in particular, is often considered the key first line of defence against heatwaves, yet has received limited attention (Bourret Soto and Guillon, 2024; Hendel et al., 2017). Present vulnerability assessments typically revolve around measuring or modelling temperatures and quantifying relationships between heat and mortality or morbidity, whereas studies of heatwave inequality often rely solely on exposure and numerical socioeconomic indices (Soomro et al., 2025). In addition, climate research usually prioritises quantifiable, hazard-centric approaches for generalisable, objective findings overshadowing the socio-cultural specificity of places (Bremer et al., 2019; Thompson et al., 2023). Consequently, expert-driven centralised strategies are perpetuated with limited engagement with the lived experiences of those most affected (Guardaro et al., 2022; Preston et al., 2011; Weinberger et al., 2020). As a result, dominant analytical frameworks frequently marginalise intangible and non-physical factors contribute to heatwave vulnerability. Which makes it difficult to address underlying structural inequities and develop locally responsive strategies. Several research pointed to a clear disconnect between expert recommendations and community-led adaptive practices (Bremer et al., 2019; Haque et al., 2017), underscoring the necessity for integrated approaches that synthesise objective indicators with lived, subjective experiences.

Addressing the dual knowledge gaps of context specificity and absence of integrative approaches, this research investigates the question: ***How do urban populations in temperate climates perceive, live, and navigate heatwaves, with a focus on identifying structural and sociocultural factors that contribute to adaptation disparities?*** With an objective of understanding the process and motivations behind individuals' coping practices, and how their agency interacts with broader societal and environmental contexts.

The Netherlands serves as an ideal case study for this investigation because of its temperate maritime climate, where the built environment is mostly designed for colder conditions. Besides, Dutch urban areas have a high population density with a diverse demographic profile. Such a combination provides a valuable setting for the intended research question.

By foregrounding behavioural adaptation in a temperate urban context, this paper aims to advance a more nuanced understanding of heatwave vulnerability through an integrative and contextually grounded methodological approach. It seeks to contribute not only to academic debates on urban climate resilience but also to the development of socially just climate risk management strategies that resonate with the lived experiences of diverse urban populations—particularly those who are often marginalised in top-down planning processes.

## 2. Theoretical Background

### *2.1. Heatwaves in the Dutch urban context*

There is no universal definition of a heatwave; it remains location specific. In the Netherlands, the Royal Netherlands Meteorological Institute (KNMI) declares a heatwave when there is a period of five consecutive days with maximum temperatures of 25 °C or higher, including at least three days reaching 30 °C or above, as measured at their central meteorological station De Bilt (KNMI, 2021). Since 1901, 28 heatwaves have been recorded in the Netherlands. Strikingly, nearly half (12) of those occurred after the year 2000, showing a clear rise in frequency over time. In addition to frequency, heatwaves are also getting more intense. During the summer of 2020, the maximum air temperature exceeded 40 °C in multiple locations (AMS Institute, 2020) and in 2022, the surface temperatures (asphalt) surpassed 50∘C for the first time on record (Huiskamp, 2022). Report by the National Institute for Public Health and the Environment (RIVM) on healthy living environments in a changing climate anticipates that the trend will continue, leading to greater health risks (RIVM, 2024).

Now turning to the urban context, Statistics Netherlands (CBS) classifies the degree of urbanisation across the country using Average Surrounding Address Density (SAD) (CBS, 2024). According to CBS, areas with an address density of 2500 or more per square kilometre are classed as '*very highly urbanised*'. Those with 1500–2500 SAD are '*highly urbanised*', and areas with 1000–1500 SAD are '*moderately urbanised*'. Those with 500–1000 SAD are considered '*lightly urbanised*', while areas with fewer than 500 are classed as *'not urbanised'*. In order to maintain the urban focus, this study limits its scope to very highly urbanised, highly urbanised, and moderately urbanised areas only (CBS urbanisation classes 1–3). Besides, predictions anticipate continued urban growth and an increase in demographic diversity in these urban areas until 2050 (CBS, 2022). Consequently, regions susceptible to rising temperatures will also be inhabited by people from diverse backgrounds. Evidence says that low-income neighbourhoods are already experiencing greater heat stress due to reduced liveability and limited adaptive infrastructure (Van Der Hoeven and Wandl, 2018; van Oorschot et al., 2021). Moreover, heat exposure also varies significantly by gender and age (Mashhoodi, 2021). As such, conventional approaches of addressing heat are therefore insufficient; instead, locally grounded, pragmatic responses will be essential—particularly in temperate urban contexts undergoing demographic shifts within urban density gradients.

### *2.2. Perception and everyday behavioural adaptation*

This International Panel on Climate Change (IPCC) defines adaptation in general as a process of coping with any current or anticipated climate impacts. In practice, adaptation is often used and understood as a set of interventions, mostly physical, that are planned to tackle the effects of the changing climate. Studies say, such planned approaches leave out the nuances of personal level everyday adaptation practices during crisis (Castro and Sen, 2022; Nightingale et al., 2020). Moreover, in temperate regions where heatwaves are increasingly recognised as a major threat, lived experiences and individual level responses are even more likely to be overlooked in planned adaptation policies and interventions. Understanding citizens' perceptions of heatwaves and the behavioural changes they adopt to cope with extreme heat can be seen as missing elements that constrain the development of localised heat adaptation planning and interventions.

Behavioural adaptation, also referred to as everyday or autonomous adaptation, serves as a key theoretical premise in this research. Besides, for having a thorough understanding, individual adaptive behaviours are considered in conjunction with heatwave risk perception as it plays a critical role in shaping these adaptive behaviours (Frondel et al., 2017). Behavioural adaptation is one of the three key components of de Dear and Brager's (1998) human thermal adaptation framework. According to the framework, behavioural adaptation consists of three elements: *i) personal, ii) technological,* and *iii) cultural adjustments*. Personal Adjustment (PA) refers to individual-level responses taken to reduce exposure or discomfort; Technological Adjustment (TA) involves environmental modifications through active or passive means; and Cultural Adjustment (CA) entails changes in habits, routines, or social practices. Nevertheless, behavioural responses are strongly shaped by individual's perception of risk. Howe et al. (2019) outline this as encompassing attitudes and beliefs about the severity, frequency, and duration of heat events, along with awareness of the potential health implications and hazards associated with heatwave exposure. Collectively, the behavioural adaptation and risk perception frameworks underpin the theoretical grounding of this research.

## 3. Methodology

### 3.1. Research design

The study investigates citizens' behavioural adaptation practices in urban areas of the Netherlands. However, within the process of adaptation, there is a notable complexity and context-specificity in both individual and collective responses to extreme heat. Addressing this, the investigation requires an approach that is grounded in subjective, lived realities, yet also capable of providing some concrete findings so that it reflects the actual experiences of people living in temperate urban areas. Accordingly, the study adopts an exploratory sequential mixed methods design integrating both qualitative and quantitative strategies (Creswell, 2009;

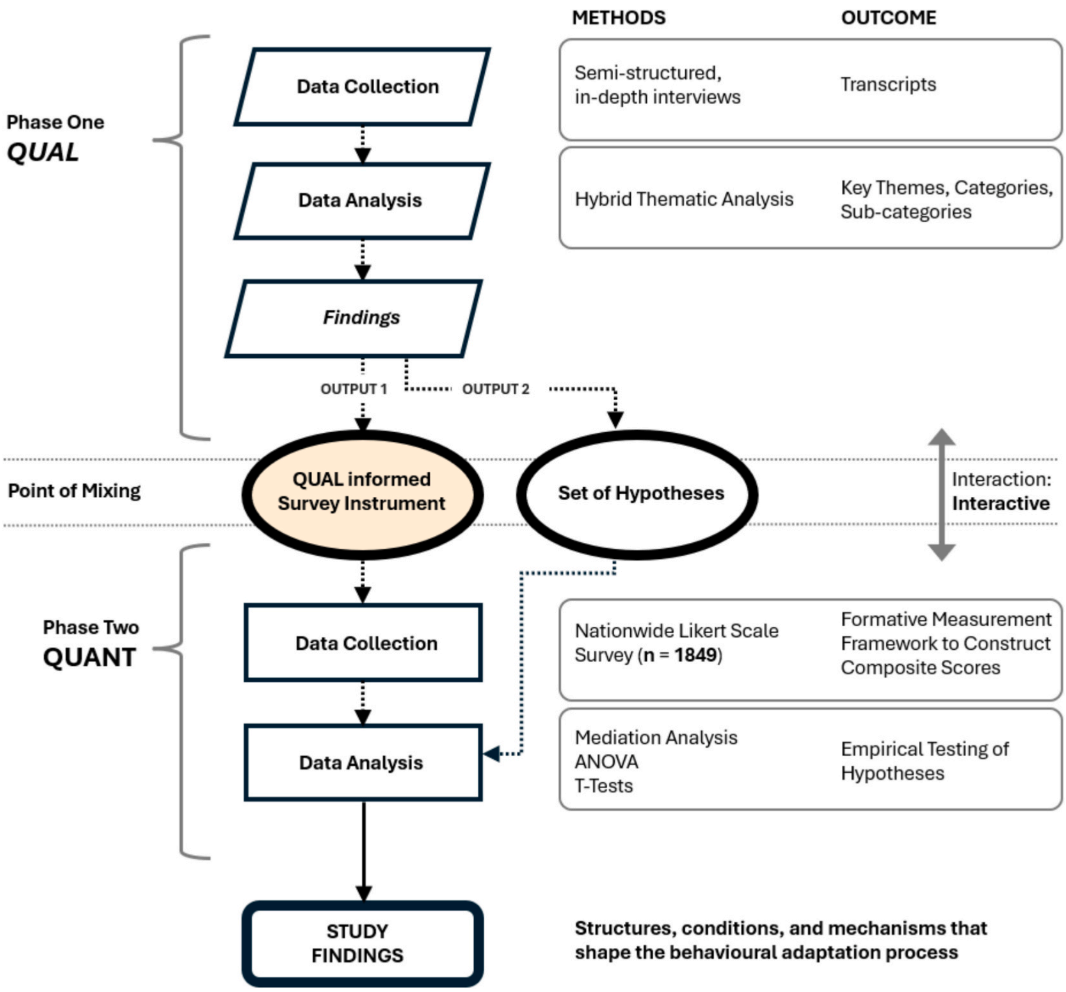


**Fig. 1.** Sequential Exploratory Mixed Methods Research Design Used in This Study.

Tashakkori and Teddlie, 2010). This combination of methods first captures urban residents' in-depth, personal accounts during heatwaves and their coping process, and then tests key insights across a broader population, providing both experiential depth and empirical evidence.

Methodologically, timing, point of mixing, and interaction among components are key aspects in the design of any mixed methods research (Morse, 2009; Tashakkori et al., 2020). In this study, the temporal relationship is sequential: qualitative and quantitative methods are applied in two distinct phases, starting with a qualitative phase followed by a quantitative phase. The point of mixing occurs at the transition between the two phases. Insights from the qualitative phase informed a set of hypotheses and guided the development of the survey instrument for data collection by operationalising qualitative constructs. Collected data then used to test the hypothesises in the quantitative phase. As the second phase (quantitative) is fundamentally dependent on the findings from the first phase (qualitative), the interaction among the components is therefore interactive (Tashakkori et al., 2020; Greene, 2007). Fig. 1 illustrates the overall research design.

The intended mixed-methods approach is well-suited because it follows a developmental rationale, where the findings from the qualitative phase inform the design of the quantitative phase, and a complementarity rationale, which allows for the combination of detailed, context-rich insights with generalisable patterns across a broader population (Bryman, 2006; Greene et al., 1989).

### *3.2. Phase One: Qualitative*

The qualitative phase aims to have a deeper and comprehensive understanding of individuals' lived experiences during heat events. It draws on 21 semi-structured, in-depth interviews with residents of Rotterdam. Among the four largest urban agglomerations in the Netherlands, collectively known as the Randstad, Rotterdam has been chosen as a critical case for this in-depth inquiry because of its heatwave exposure, urban configuration, and demographic diversity. Together, these characteristics make it an ideal setting for examining behavioural adaptation to heatwaves. Interviews took place both online and in person only during the summer periods of 2022 and 2023 (additional details are included in the supplementary material). Participants are selected using a non-probability purposive sampling method to ensure that interviewees can provide rich insights into everyday behavioural adaptation (Guetterman, 2015; Patton, 2002).

Afterwards, a hybrid thematic analysis is applied to capture prevailing patterns and themes within the data. This approach is particularly suitable, as key components of the study are informed by existing theoretical frameworks (Swain, 2018; Fereday and Muir-Cochrane, 2006). A detailed account of the findings is presented in Ahmed et al. (2025). The analysis yielded a survey instrument (Output 1) and hypotheses (Output 2).

### *3.3. Phase Two: Quantitative*

In Phase Two, the survey instrument developed in Phase One is used to collect data and test the hypotheses. The dataset comprises a nationwide four-point Likert-scale survey (n = 1,849), with items derived directly from the qualitative sub-categories and categories. A four-point scale is intentionally selected to exclude a neutral midpoint. Given respondents' limited familiarity with extreme heat in temperate contexts and the survey's self-administered, non-probing format, a midpoint would likely have attracted many neutral responses, reducing the ability to test the qualitative findings statistically.

In 2024, data are collected exclusively in urban areas (CBS urbanisation classes 1–3) via the *Longitudinal Internet Studies for the Social Sciences (LISS) Panel.* The LISS Panel is a GDPR-compliant, online research facility in the Netherlands managed by *Centerdata* (an independent non-profit organisation), and is drawn from the Dutch population register. In total, 2,897 panel members were invited; 2,305 responded (79.6%), and 1,849 complete and valid cases (63.8% of invited; 80.2% of respondents) are retained for analysis after standard completeness checks. Formulated hypotheses are then tested using various statistical methods such as mediation analysis, independent samples t-tests, and analysis of variance (ANOVA). The analyses provide insights into hazard perception and behavioural adaptation processes among Dutch urban populations.

## 4. Conceptual grounding and Operationalisation of thematic components

### *4.1. Formulation of hypotheses*

During in-depth interviews, participants articulated their lived experiences during heat events, particularly focusing on hazard perception and behavioural adaptation practices. This qualitative inquiry aimed to capture not only individuals' responses to heat but also understand the decision making processes and motivations driving these behaviours, thereby unpacking how socio-spatial realities enable, limit, or shape adaptive behaviours.

The qualitative investigation is informed by Howe et al.'s (2019) risk perception and de Dear and Brager's (1998) human thermal adaptation frameworks, providing the foundational structure for the development of (priori) themes. Subjective findings emerging from the data as codes are subsequently classified into categories and sub-categories under each predetermined theme. Each sub-category is then translated into survey items, thereby operationalising the qualitative insights into a quantitative survey instrument mapped to formative composites. Fig. S1 in the supplementary material provides an illustration of the overall process.

In the first phase of the study, based on participants' narratives and the thematic structure comprising identified categories and sub-categories, several hypotheses are developed to guide the quantitative phase of the research. A detailed hypothesis formulation table is available in the supplementary material (Table S3).

Beginning with the theme of *Hazard Perception*, in-depth interviews revealed that individuals' responses during heatwave events are shaped by the level of knowledge they possess and their attitudes toward the hazard. The qualitative inquiry highlighted that, in addition to factual or explicit knowledge, tacit knowledge—gained through personal experience or from one's social and environmental context—is a key determinant of adaptive behaviour. This led to the formulation of the following hypotheses:

***H1: Tacit knowledge, derived from experiences and surrounding network, positively related to higher behavioural adaptation score.***

***H2: Tacit knowledge has a stronger association with behavioural adaptation scores than explicit knowledge.***

***H3: Higher levels of tacit knowledge are positively related to PA, TA, and* CA.**

The second thematic structure centres on *Behavioural Adaptation*. A strong pattern emerged through participant interviews regarding the role of housing tenure while making behavioural adaptation choices. Participants living in rental housing frequently indicating limited control over their indoor environment in contrast to homeowners who have increased freedom in implementing adaptive changes to cope with extreme heat. This theme led to the following hypotheses:

***H4: Control over the living unit—operationalised as housing tenure—moderates residents' overall behavioural adaptation.***

***H5: Housing tenure significantly influences the adoption of different types of behavioural adjustments (PA, TA, and CA).***

In addition to housing, household composition also emerged as an important influencer in behavioural adaptation practices. Interview participants living with partners, with or without children described greater planning, consultation, and precautionary measures compared to those living alone. Interviewees who live alone, regardless of age, indicated a more reactive approach during heat events. Besides, having children in the family influence parents to be more conscious in any critical circumstances and heatwaves are no exception. Based on this, the following hypothesis was formulated:

***H6: Living in a multi-person household is positively associated with wider behavioural adaptation practices.***

During the interviews gender differences also emerged prominently. Female interviewees consistently reported broader use of PA and CA and a stronger concern about heat as a problem, in comparison to male participants. To validate this finding across a broader population, the following hypothesis is formulated:

***H7: There is a significant association between gender and hazard perception and different behavioural adaptation strategies (PA, TA, and CA).***

Participants residing in denser parts of the city strongly expressed indoor discomfort and difficulties in adapting to heatwaves. Besides, factors such as increased traffic, limited trees, constrained private space, and a lack of accessible "free" cool-off options are perceived as problem in such regard. These qualitative insights indicate that urban density may contribute to structural and environmental barriers to behavioural adaptation. Accordingly, the following hypothesis is deducted to verify whether residents in dense urban areas exhibit lower behavioural adaptation scores compared to those in less dense settings:

***H8: Urban density significantly influences behavioural adaptation practices.***

Keeping the overall qualitative thematic structure in mind a Likert scale survey questionnaire is developed and conducted nationwide urban areas in the Netherlands for collecting data for hypothesis testing and examining broader patterns of hazard perception and behavioural adaptation practices.

### *4.2. Development of the measurement framework*

In Phase One, in-depth interviews provided localized, context-specific components underlying the broader constructs of Personal Adjustment (PA), Technological Adjustment (TA), and Cultural Adjustment (CA), which together represent Behavioural Adaptation, as well as Knowledge (Kn) and Attitudes & Beliefs (Att), which together inform Hazard Perception.

After collecting data, we model Behavioural Adaptation (PA, TA, CA) and Hazard Perception (Kn, Att) as formative composites. In a formative specification, the indicators define the construct. This matches our theorisation and phase one findings as the identified behavioural and perception related components are conceptually distinct and do not necessarily co-occur or correlate. Each item reflects a unique aspect of adaptation or perception, contributing meaningfully to the overall construct without assuming internal consistency. In contrast, a reflective model assumes a single latent factor causes all items and therefore expects high inter-item correlations and interchangeable items, which does not hold here. Formative indices are appropriate for capturing multidimensional, context-specific constructs derived from qualitative inquiry. This approach aligns with established guidance on formative index construction (Coltman et al., 2008; Diamantopoulos and Winklhofer, 2001) and has been widely adopted in environmental vulnerability and behavioural adaptation research (Cutter et al., 2003). The formative measurement framework is detailed in Table S5 (see supplementary material).

Composite scores are calculated by averaging all responses for each theme. The majority of items are Likert scale items. Answers to a few dichotomous questions are converted to the same 1–4 scale (e.g., "Yes"=4, "No"=1) for maintaining consistency. Items are given equal weight because the research aim was not to prioritise specific behaviours over others. This approach preserves each item's unique meaning while enabling group comparisons, following transparent research practices common in environmental behaviour studies.

## 5. Quantitative analysis and findings

In phase two, formulated hypotheses are systematically tested using appropriate statistical methods, and the outcomes are discussed in relation to the earlier thematic findings. Statistically significant relationships are interpreted and contextualised with reference to the prominent patterns identified during the qualitative inquiry.

### 5.1. Thematic hypotheses on hazard perception

To examine the hypotheses **H1, H2,** and **H3**, which were developed concerning the theme of hazard perception, a mediation analysis was conducted. Mediation Analysis can help to find out direct and indirect effects of Explicit and Tacit Knowledge over the dependent variable Behavioural Adaptation Score (B_A), via intermediate variables, in this case components of B_A, which are PA, TA, and CA. Fig. 2 outlines how the mediation is theorised.

Table 1 shows the results of the all three mediation modes (CA, PA, and TA). Tacit Knowledge (T_K) demonstrated a statistically significant direct effect on B_A Score, as well as significant indirect effects via Personal Adjustment ($\beta = 0.122$), Technological Adjustment ($\beta = 0.096$), and Cultural Adjustment ($\beta = 0.102$). This strongly support **H1**, explaining in which ways tacit knowledge enhances adaptation behaviour.

Unlike the Tacit Knowledge, the direct effect of Explicit Knowledge on B_A Score is not significant in the CA, and PA models, and weaker than those of T_K in the TA model (T_K total effect: $\beta = 0.243$; E_K total effect: $\beta = 0.114$), which supports **H2**. However, the mediation analysis revealed that Explicit Knowledge (E_K) had significant indirect effects through Cultural and Personal Adjustments ($\beta = 0.099$ and 0.094, respectively).

Finally, the results support **H3** as the path coefficients from T_K to PA ($\beta = 0.212$), TA ($\beta = 0.132$), and CA ($\beta = 0.140$) are all positive and statistically significant ($p < 0.001$) which means Tacit Knowledge (T_K) is positively associated with all three forms of behavioural adaptations.

### 5.2. Housing tenure

To test the hypothesis **H4** and **H5**, developed based on the differences found in reported behavioural adaptation practices by the renters and house owners, Independent Samples T-Tests were performed. Results show a strong association between housing tenure and behavioural adaptability.

Table 2 demonstrates that houseowners have significantly higher overall Behavioural Adaptation (B_A) scores ($t = 3.097$, $p = 0.002$) and greater use of technological adjustments ($t = 6.154$, $p < 0.001$), indicating their ability to invest in active (fan, cooler, ac) or passive (shading devices) means of cooling. In contrast, renters' significantly higher cultural adjustment scores ($t = -2.007$, $p = 0.045$) and a stronger perception of heat-related risks ($t = -2.178$, $p = 0.030$), point to a reliance on communal facilities, social networks, experiential knowledge, and low-cost behavioural responses. While no significant differences were found in personal adjustments, this divergence illustrates how adaptation is shaped not only by individual choices but also by control over one's private living space, which is higher to homeowners than renters.

### 5.3. Household composition

To test whether living in a multi-person household is positively associated with wider behaviour adaptation practices (hypothesis **H6**), a one-way ANOVA was conducted (Table 3). Behavioural adaptation score was found to be strongly associated with household configuration ($F(4, 1844) = 4.060$, p = =.003). Individuals living alone had notably lower adaptation scores compared to those in multi-person households. Post hoc tests reveal that single person households scored significantly lower than both (un)married individuals with children (p = =.025) and (un)married individuals without children (p = =.006).

These indicate that multi-person households may enhance behavioural adaptive responses, likely through collaborative decision making and collective resource sharing. Whereas, individuals living alone may face elevated risk due to isolation or limited collective resources.

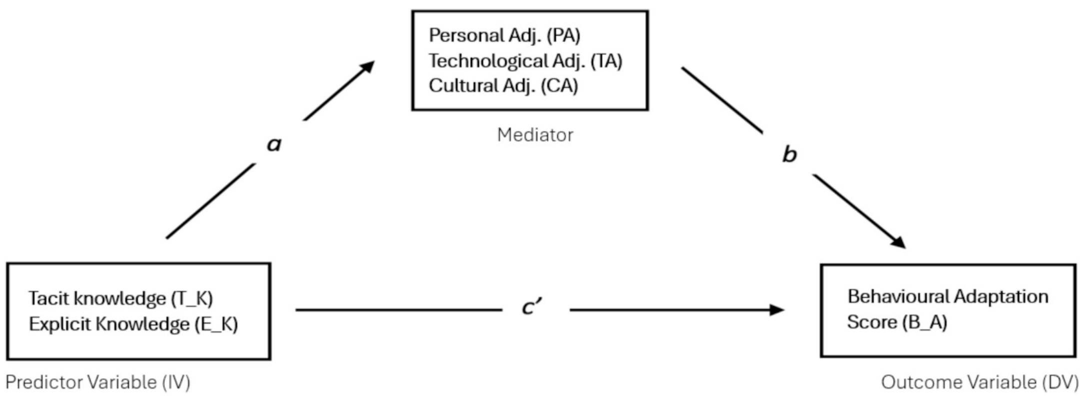


**Fig. 2.** Diagram of the mediation model.

**Table 1**
Mediation Effects of Cultural, Personal, and Technological Adjustment on the Relationship Between Knowledge Types and Behavioural Adaptation.

| Model | Predictor | Path | Effect Type | Std. Estimate | SE | z | *p* | 95% CI |
|---|---|---|---|---|---|---|---|---|
| **PA** | T_K | T_K → PA | Direct to Mediator | **0.212** | 0.027 | 8.07 | **0<.001** | [0.161, 0.264] |
| | E_K | E_K → PA | Direct to Mediator | 0.163 | 0.025 | 6.50 | 0<.001 | [0.112, 0.211] |
| | **T_K** | **T_K → B_A** | Direct Effect | 0.121 | 0.021 | 5.85 | **0<.001** | [0.078, 0.159] |
| | **T_K** | **T_K → PA → B_A** | Indirect Effect | 0.122 | 0.016 | 7.67 | **0<.001** | [0.091, 0.154] |
| | E_K | E_K → B_A | Direct Effect | 0.021 | 0.021 | 1.00 | 0.317 | [−0.020, 0.060] |
| | **E_K** | **E_K → PA → B_A** | Indirect Effect | **0.094** | 0.015 | 6.38 | **0<.001** | [0.064, 0.122] |
| **TA** | T_K | T_K → TA | Direct to Mediator | **0.132** | 0.025 | 5.18 | **0<.001** | [0.081, 0.181] |
| | E_K | E_K → TA | Direct to Mediator | −0.023 | 0.025 | −0.92 | 0.360 | [−0.071, 0.028] |
| | **T_K** | **T_K → B_A** | Direct Effect | **0.147** | 0.018 | 8.25 | **0<.001** | [0.110, 0.181] |
| | **T_K** | **T_K → TA → B_A** | Indirect Effect | **0.096** | 0.018 | 5.23 | **0<.001** | [0.060, 0.132] |
| | **E_K** | **E_K → B_A** | Direct Effect | **0.131** | 0.017 | 7.77 | **0<.001** | [0.099, 0.166] |
| | E_K | E_K → TA → B_A | Indirect Effect | **−0.017** | 0.019 | −0.91 | 0.361 | [−0.052, 0.020] |
| **CA** | T_K | T_K → CA | Direct to Mediator | **0.140** | 0.021 | 6.44 | **0<.001** | [0.097, 0.183] |
| | E_K | E_K → CA | Direct to Mediator | 0.168 | 0.026 | 6.53 | 0<.001 | [0.113, 0.217] |
| | **T_K** | **T_K → B_A** | Direct Effect | **0.140** | 0.020 | 7.09 | **0<.001** | [0.102, 0.181] |
| | **T_K** | **T_K → CA → B_A** | Indirect Effect | **0.102** | 0.017 | 6.09 | **0<.001** | [0.070, 0.136] |
| | E_K | E_K → B_A | Direct Effect | 0.015 | 0.019 | 0.78 | 0.433 | [−0.022, 0.055] |
| | **E_K** | **E_K → CA → B_A** | Indirect Effect | **0.099** | 0.016 | 6.35 | **0<.001** | [0.069, 0.133] |

***Note***. *All estimates are standardised. Bootstrapped bias-corrected confidence intervals based on 1,000 replications.*

**Table 2**
Hazard Perception and Behavioural Adaptation by Housing Tenure.

| | t | df | p |
|---|---|---|---|
| **Perception_Score** | −2.178 | 1275.214 | 0.030 |
| Kn | −1.637 | 1285.943 | 0.102 |
| Att | −1.910 | 1312.538 | 0.056 |
| **B_A** | 3.097 | 1281.515 | **0.002** |
| PA | −0.404 | 1298.900 | 0.686 |
| **TA** | 6.154 | 1428.916 | **< 0.001** |
| **CA** | −2.007 | 1232.924 | **0.045** |

Note. Welch's *t*-test. Significant differences are in 'Bold'.

**Table 3**
ANOVA, Descriptive Statistics, and Post Hoc Comparisons of Behavioural Adaptation Scores by Household (HH) Composition.

| Homogeneity Correction | Cases | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|---|
| None | HH_composition | 254.512 | 4.000 | 63.628 | 4.060 | **0.003** |
| | Residuals | 28898.757 | 1844.000 | 15.672 | | |
| Welch | HH_composition | 254.512 | 4.000 | 63.628 | 4.022 | **0.003** |
| | Residuals | 28898.757 | 311.905 | 92.653 | | |

**Post Hoc Tests (Games-Howell)**

| | | 95% CI for Mean Difference | | | | | |
|---|---|---|---|---|---|---|---|
| **Comparison** | **Mean Difference** | **Lower** | **Upper** | **SE** | **t** | **df** | $p_{tukey}$ |
| (Un)married, living together, with child(ren) − (Un)married, living together, without child(ren) | 0.079 | −0.643 | 0.801 | 0.264 | 0.301 | 586.044 | 0.998 |
| **(Un)married, living together, with child(ren) − Alone** | 0.810 | 0.066 | 1.554 | 0.272 | 2.977 | 637.344 | **0.025** |
| (Un)married, living together, with child(ren) − Alone with kid(s) | 0.801 | −0.358 | 1.960 | 0.420 | 1.907 | 161.999 | 0.318 |
| (Un)married, living together, with child(ren) − Otherwise | 0.663 | −0.719 | 2.046 | 0.499 | 1.330 | 112.395 | 0.673 |
| **(Un)married, living together, without child(ren) − Alone** | 0.730 | 0.138 | 1.323 | 0.217 | 3.367 | 1359.429 | **0.007** |
| (Un)married, living together, without child(ren) − Alone with kid(s) | 0.722 | −0.349 | 1.792 | 0.387 | 1.867 | 120.682 | 0.341 |
| (Un)married, living together, without child(ren) − Otherwise | 0.584 | −0.726 | 1.894 | 0.471 | 1.240 | 90.501 | 0.728 |
| Alone − Alone with kid(s) | −0.009 | −1.094 | 1.077 | 0.392 | −0.022 | 127.645 | 1.000 |
| Alone − Otherwise | −0.147 | −1.469 | 1.176 | 0.475 | −0.308 | 94.063 | 0.998 |
| Alone with kid(s) − Otherwise | −0.138 | −1.720 | 1.445 | 0.573 | −0.240 | 148.459 | 0.999 |

*Note.* Type II Sum of Squares
Note. Results based on uncorrected means. Significant differences are in 'Bold'.

### 5.4. Gendered dimensions

In an Independent Samples T-Test, gender differences emerged as a key dimension in behavioural responses to heat (Table 4). Women demonstrated significantly higher overall Behavioural Adaptation Scores than men ($t = –3.661$, $p < <.001$), with the largest difference in Cultural Adjustment ($t = –5.087$, $p < <.001$). Also, in personal adjustments, women score ($t = –2.118$, $p = =.034$). No significant differences were observed in Technological adjustment. Women also reported stronger heat risk perception ($t = –3.232$, $p = =.001$). These justify hypothesis **H7**. Patterns suggest women tend to engage more extensively in socially embedded adaptation, including early heat regulation, routine adjustments, and communal or cultural coping practices. This tendency may reflect women's gendered role in household management, as they are often the primary responders to disruptions.

### 5.5. Urban density influences adaptation practice

Finally, urban density emerged as a critical factor associated with adaptation. Testing the hypothesis **H8** a one-way ANOVA is performed (Table 5). Results indicate significant differences in B_A scores by urban density types ($F(2, 1846) = 5.452$, $p = 0.004$). Post hoc tests revealed significantly lower adaptation scores among residents in very highly urbanised areas compared to highly urbanised areas (mean difference = 0.697, $p = 0.004$). This supports the hypothesis that denser urban environments—often characterised by limited greenery, impermeable surfaces, and constrained private space—offer fewer opportunities for adaptation. These patterns suggest that the built environment itself mediates behavioural flexibility.

Interestingly, no significant differences were found between moderately urban areas and either of the other two categories. Perhaps moderately urban areas represent heterogeneous conditions with varying access to services, infrastructure, and social networks. It also underscores the limitation of using broad categorical typologies to capture what may be a more context-sensitive phenomenon.

However, urban density significantly affected self-reported indoor temperature. Participants mentioned maximum temperatures during heatwaves from their built-in indoor thermostats. The ANOVA reveals significantly higher temperatures in very highly urban areas ($F(2,1846) = 18.08$, $p < 0.001$), regardless of ownership and type of houses. Post-hoc tests also showed a strong increase across urban density levels, with the largest difference occurring between moderately and very highly urban areas (Table 6). These findings indicate that density gradients are closely linked to behavioural adaptation and indoor thermal conditions, thereby shaping overall heat experiences.

## 6. Discussion

This study addresses how urban residents adapt behaviourally to heatwaves in the Netherlands, producing specific knowledge about their adaptive agency. Throughout the investigation it becomes evident that behavioural responses during a heat event are not merely a product of individual awareness or rational decision making, rather they are deeply rooted in certain social, structural, and spatial conditions. As such conditions are unevenly distributed within the built environment, the capacity to act is likewise unequal. This inequity constitutes a critical climate justice concern because behavioural adaptation constitutes the first line of defence against escalating heatwaves. Still, this frontline of resilience is rarely acknowledged as a matter of justice. This study identifies social factors (gender, household composition), structural factors (tenure status), and spatial factors (level of urban density) as key intersecting determinants of behavioural adaptation to extreme heat (see Fig. 3).

Besides, tacit knowledge emerges as fundamental for real time decision making during heat events. These embodied, experiential understandings are socially acquired and reinforced through multiple pathways. The critical role of tacit knowledge aligns with the concept of social learning (Bandura, 1977). While explicit knowledge represents formal instruction about heat risks, tacit knowledge is constituted through direct experience with previous heat events (enactive learning), vicarious experience from observing effective adaptations within close networks, and social persuasion through conversations within communities. This helps understand why tacit knowledge exerts a stronger influence on the overall behavioural adaptation score than explicit knowledge. A justice centred heat governance should recognise community know-how, and aim to reduce existing structural barriers that constrain adaptive opportunity.

Taken together, the study findings reveal context-specific vulnerability profiles salient to the Netherlands:

**Table 4**
Hazard Perception and Behavioural Adaptation by Gender.

| | t | df | p |
|---|---|---|---|
| **Perception_Score** | −3.232 | 1779.570 | **0.001** |
| Kn | −1.618 | 1775.031 | 0.106 |
| **Att** | −3.663 | 1774.960 | **< 0.001** |
| **B_A** | −3.661 | 1769.741 | **< 0.001** |
| **PA** | −2.118 | 1792.072 | **0.034** |
| TA | −1.281 | 1749.058 | 0.200 |
| **CA** | −5.087 | 1794.690 | **< 0.001** |

*Note.* Welch's *t*-test. Significant differences are in 'Bold'.

**Table 5**
ANOVA, Descriptive Statistics, and Post Hoc Comparisons of Behavioural Adaptation Scores by Urban Density Types.

| Cases | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Urban_density_types | 171.179 | 2 | 85.589 | 5.452 | **0.004** |
| Residuals | 28982.091 | 1846 | 15.700 | | |

**Post Hoc Tests (Games-Howell)**

| | | 95% CI for Mean Difference | | | | | |
|---|---|---|---|---|---|---|---|
| **Comparison** | **Mean Difference** | **Lower** | **Upper** | **SE** | **t** | **df** | $p_{tukey}$ |
| Moderately urban – Highly urban | −0.241 | −0.778 | 0.295 | 0.228 | −1.057 | 893.822 | 0.541 |
| Moderately urban – Very highly urban | 0.455 | −0.121 | 1.031 | 0.245 | 1.856 | 948.642 | 0.152 |
| **Highly urban – Very highly urban** | 0.697 | 0.189 | 1.205 | 0.216 | 3.219 | 1296.203 | **0.004** |

*Note.* Type III Sum of Squares
Note. Results based on uncorrected means. Significant differences are in 'Bold'.

**Table 6**
ANOVA and Post Hoc Comparisons of Self-reported temperatures by Urban Density Types.

| Cases | Sum of Squares | df | Mean Square | F | p |
|---|---|---|---|---|---|
| Urban_density_types | 506.987 | 2 | 253.493 | 18.075 | **< 0.001** |
| Residuals | 25888.651 | 1846 | 14.024 | | |

**Post Hoc Tests (Games-Howell)**

| | | 95% CI for Mean Difference | | | | | |
|---|---|---|---|---|---|---|---|
| **Comparison** | **Mean Difference** | **Lower** | **Upper** | **SE** | **t** | **df** | $p_{tukey}$ |
| **Moderately urban – Highly urban** | −0.611 | −1.092 | −0.130 | 0.205 | −2.985 | 916.058 | **0.008** |
| **Moderately urban – Very highly urban** | −1.399 | −1.945 | −0.854 | 0.233 | −6.018 | 1003.598 | **< 0.001** |
| **Highly urban – Very highly urban** | −0.788 | −1.283 | −0.294 | 0.211 | −3.739 | 1211.420 | **< 0.001** |

*Note.* Type III Sum of Squares
*Note.* Results based on uncorrected means. Significant differences are in 'Bold'.

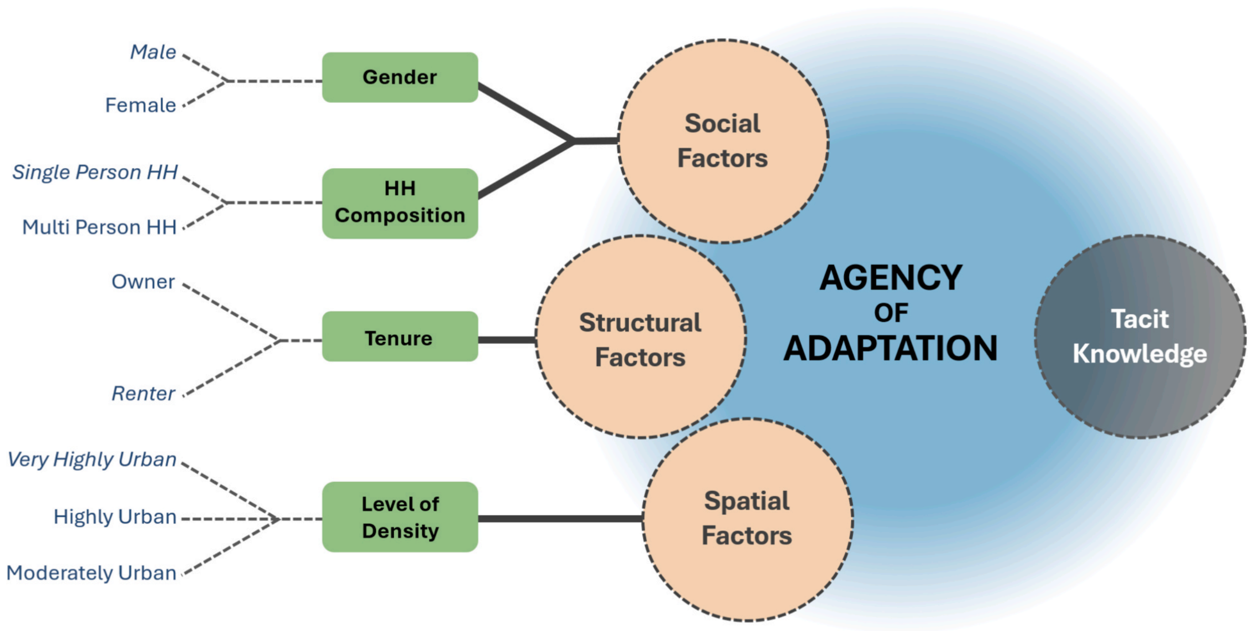


**Fig. 3.** Factors shaping residents' behavioural adaptation to heat in Dutch urban areas.

i) *High vulnerability cohort:* **Men** living **alone** in **rental** accommodations within **very highly urban** areas are likely to exhibit constrained adaptive capacity due to compounded spatial, structural, and social barriers.
ii) *The privilege cohort:* **Women** residents in **multi-family households** in **privately owned** accommodation within **moderately urban areas** are likely to demonstrate enhanced behavioural resilience, reflecting privilege in resource access and agency.

Beyond universal determinants (e.g., income, age, education, health), these findings highlight place based circumstances in shaping adaptive capacity. This challenges conventional frameworks that often presume equal agency while overlooking the embedded inequalities shaping urban heat resilience. Table 7 synthesises key risk factors and underlying barriers to behavioural heatwave adaptation identified in this study, alongside targeted risk management strategies and their expected outcomes.

Whilst planned adaptation and mitigation strategies like increasing urban greenery, tree canopy cover, reducing impervious surfaces, and using high albedo building materials are essential, they are time-consuming. Measures based on citizens' behavioural responses hence can provide some immediate and actionable solutions, as they are quicker to identify, communicate, and practice. Inclusion of behaviour-focused measures within existing heat plans can thus enhance resilience not only through infrastructural modifications but also by enabling and empowering residents. Taken together, these approaches will support achieving inclusive, heat-resilient urban communities.

### 6.1. Study limitations

The study has few limitations to be acknowledged. The study is cross-sectional and geographically limited within the Netherlands, therefore, the findings may not fully represent other regions with temperate climate. A longitudinal research design with multiple case study cities could enrich the findings. The qualitative phase was conducted in the city of Rotterdam, selected intentionally due to its high heatwave exposure, urban complexity and diverse demographics. Though this focus may elevate certain context-specific findings.

A four-point Likert scale format is used for data collection, which reduced neutral responses but may pushed some uncertain respondents toward agreement or disagreement. Future work could compare a five-point scale with an explicit midpoint. Regarding representativeness, minor deviations from CBS benchmarks remain, but cell sizes in all subgroups are ample, providing sufficient power for the subgroup comparisons central to our aims. Yet, potential selection bias cannot be ruled out and estimates should be interpreted as associations within the urban population, not precise population parameters.

Finally, in the analysis, composite scoring effectively synthesised multiple dimensions but may oversimplify the nuanced nature of behavioural adaptation. Equal weighting of items in the formative measurement framework assumes equal importance of components, which in reality may not be the case. Future research might test hybrid measurement models (combining formative and reflective components), with composite indices and alternate weighting scheme. Nevertheless, the methodological approach of this study offers a transferable framework for identifying such context-specific behavioural adaptive barriers in comparable urban settings.

## 7. Conclusion

Employing a sequential mixed-methods design this research attempted to move beyond conventional, exposure-oriented frameworks for understanding grounded realities of navigating heatwaves in cities with temperate climate. The main objective was to explore the question: *How do urban populations in temperate climates perceive, live, and navigate heatwaves, with a focus on identifying structural and sociocultural factors that contribute to adaptation disparities?* The first, quantitative phase of the research addressed hazard perception and behavioural adaptation, leading to the formulation and testing of eight hypotheses. The testing of the hypotheses underscored embedded inequities in heat adaptation processes, identifying statistically significant social, structural, and spatial factors that implicitly generate disparities in adaptive capacity.

One of the major findings, urban density, introduced an important paradox. Behavioural responses to urban heat differ with the level of urban density. Within the same city, very highly urbanised areas offer fewer adaptation opportunities than less dense urban counterparts. Which indicates that higher exposure to heat may not foster better coping, pointing to a critical mismatch between exposure and coping capacity. Future research can investigate which specific built-environment features are responsible for that and how it can be overcome.

Structural aspects like tenure ship, which is more related to the control over private spaces, has a stronger association with behavioural adaptation scores. Homeowners leveraging their higher control over their living unit are likely to adopt both active and passive technological adjustments, achieving overall higher adaptation scores. Tenants, constrained by housing tenure, disproportionately relied on cultural adjustments rooted in available neighbourhood facilities, social ties, and experiential knowledge during events. Besides, household composition significantly mediates adaptation, with multi-person households demonstrating substantially higher adaptation scores than those who live alone. The influence of gender also proved as a statistically significant factor, particularly in risk perception. Therefore, the study sheds light on how socially, spatially, and structurally embedded factors shape perceptions of and responses to heat in Dutch urban areas.

In conclusion, other than the generic vulnerability factors, hazard perception and behavioural adaptation practices can provide new insights regarding specific factors contributing to heatwave vulnerability. Moreover, behavioural responses are the first line of defence against any climate hazard like heatwaves. Understanding such practices within urban communities can help in formulating targeted interventions that directly address the unique local challenges. What also emerges from this study is that the perception of equal agency inadvertently will privilege who are already empowered and will retrofit the existing inequalities. Limited agency today may result in higher risk tomorrow. By foregrounding the uneven distribution of agency, the study recasts behavioural adaptation from

**Table 7**
Policy Table: Addressing Barriers to Behavioural Adaptation in Urban Netherlands.

| Risk Factor | Underlying Barrier | Management Strategy | Expected Outcome | Potential Actors |
|---|---|---|---|---|
| Knowledge Disconnect **(Cognitive Risk)** | Tacit knowledge excluded from formal planning and policy frameworks | – *Acknowledge useful local practices, validate efficacy, and include effective ones in municipal heat plans.* | – Validation and institutionalisation of tacit knowledge in formal policy.<br>– Development of critical components of soft social infrastructure. | Municipality, Neighbourhood Associations, Community |
| | | – *Repurpose public facilities (libraries, neighbourhoods community centres etc.) as cooling shelters during extreme heat.* | – Cohesion, knowledge sharing, and trust-building for developing critical components of soft social infrastructure. | |
| | | – *Dedicated online platforms for information sharing and public awareness* | – Improve heat literacy and foster adaptive behaviours | |
| Housing Tenure **(Structural Risk)** | Renters' lack of control over living space constraining primary adaptive agency | – *Develop "Pre-Approved" passive cooling measures for rental houses.*<br>– *Offer incentives for retrofits (passive/ active cooling/insulation).* | – Enhanced renters TA by reducing procedural barriers related to passive cooling. | Municipality, Housing Association, Community |
| | | – *Prioritise high tree canopy coverage areas for rental or social housing development.* | – Reduced spatial, and microclimatic barriers to behavioural adaptation (PA, CA). | |
| | | – *Temporarily adapt suitable outdoor spaces as cool-off zones.* | – Expanded opportunities for CA. | |
| | | – *Implement mandatory thermal comfort (heat/cold) standards in rental agreements.*<br>– *Involve renters in adaptation decision-making process.* | – Enhanced equity through tenant participation and procedural justice. | |
| Isolation **(Social Risk)** | Living alone significantly reduces behavioural adaptability | – *Target single-person households with tailored communication and outreach.* | – Provide social support and enhance adaptive capacity through community engagement. | Municipality, Neighbourhood Associations |
| | | – *Summer time community cooling lounges utilising underused indoor spaces in the neighbourhood.* | – Low-friction relocation (CA) and peer contact during heat events. | |
| Gender Disparities **(Social Risk)** | Gendered divergence in heat risk perception and adaptive capacity | – *Incorporate gender sensitive heat adaptation policies and communication by actively involving diverse gender perspectives.* | – Equitable and locally effective heat risk management across genders. | Municipality, Neighbourhood Associations, Community |
| Density Driven Vulnerability **(Spatial Risk)** | Limited adaptive opportunities due to density | – *Design interventions tailored to specific urban density gradients and local characteristics, guided by an equity-focused, multi-scalar framework.* | – Tailored risk management strategies based on urban density gradients. | Municipality, Local Government Agencies, Neighbourhood Associations, Community Organisations |
| | | – *Create mandatory cool refuge spaces in very highly urban areas.* | – Reduced disparities in heat vulnerability between neighbourhoods. | |

a question of individual responsibility to one of structural opportunity—a critical pivot for both climate justice scholarship and urban heat policy. Along with hazard and exposure oriented measures, heat adaptation planning and policies, therefore, should also account for these embedded grounded realities and specific challenges residents face. Whilst long term planning takes years to implement, interventions based on existing behavioural practices can support vulnerable populations who require immediate help.

## Ethical approval

This research received ethical approval (Ref. 2313) from the Human Research Ethics Committee (HREC) of Delft University of Technology (TU Delft), dated 04 July 2022. Informed consent was obtained from all individual participants included in the study. All personally identifiable information and research data are stored in a project storage drive provided by TU Delft that is only accessible by the researchers.

Survey is conducted via Longitudinal Internet Studies for the Social Sciences (LISS) Panel, a GDPR-compliant, online research facility in the Netherlands managed by Centerdata.

## CRediT authorship contribution statement

**Istiaque Ahmed:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Marjolein van Esch:** Writing – review & editing, Supervision, Conceptualization. **Ana Petrović:** Writing – review & editing, Formal analysis. **Frank van der Hoeven:** Writing – review & editing, Supervision, Conceptualization.

## Declaration of competing interest

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

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crm.2026.100794.

## Data availability

Data will be made available on request.

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