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Insights from Rotterdam

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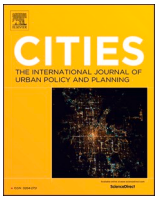

Behavioural adaptation to heatwaves in a temperate city: Insights from Rotterdam☆

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ABSTRACT

Urban heatwaves pose significant challenges to public health and well-being. Quantitative approaches focusing on heat hazards dominate the literature, while qualitative studies, particularly in temperate climates, remain underrepresented. Drawing upon the case of Rotterdam, a highly socially and spatially diverse city with a temperate climate, this research investigates residents' everyday lived experiences during heat events and their underlying coping mechanisms. Employing a hybrid thematic analysis based on 21 semi-structured in-depth interviews, the research discusses residents' behavioural adaptation, encompassing personal, technological, and cultural adjustments, along with their associated spatial dependencies. Findings indicate that adaptation practices occur across various spatial scales, with personal and technological adjustments primarily reliant on the house unit, while cultural adjustments extend to neighbourhood scales and beyond. Notably, control over the household unit emerges as a significant factor in shaping spatial dependence, highlighting an often-overlooked aspect of inequality. The study offers a conceptual framework for exploring residents' behavioural adaptation to extreme heat, facilitating the formulation of equitable and tailored planning strategies for temperate climates.

1. Introduction

Globally the number of extremely hot days is surging. A multitude of variables, including high concentration of people, land use, land cover, economic activities, and infrastructure, are making cities more vulnerable to heatwaves and the heat island (UHI) effect compared to rural areas (Mentaschi et al., 2022). Studies across the United States, Europe, and Asia (namely Japan, China, and India) reveal a notable association between socioeconomic vulnerability, UHI exposure and increased mortality risk during extreme heat events (Hsiang et al., 2017; Hu et al., 2019; Mitchell et al., 2021; Nayak et al., 2018; Rohat et al., 2019).

The literature on urban heat is dominated by studies that take top-down, expert-driven, technical approaches related to measuring or modelling temperatures and quantifying relationships between heat and mortality or morbidity (Guardaro et al., 2022; Bremer et al., 2019; Thompson et al., 2023). Such a quantitative and hazard-centric focus may limit the development of a holistic understanding of urban heat (Guardaro et al., 2022; Weinberger et al., 2020) and its impacts, as the cultural specificity of places is usually not accounted for (Krauß & Bremer, 2020), and a direct and meaningful engagement with those who are affected is lacking (Preston et al., 2011). Consequently, traditional approaches that investigate heatwave inequality based on exposure and numerical socio-economic indicators may yield objective, generalised findings, yet they often render intangible, non-physical elements invisible, hindering a deeper insight of heat inequality within specific contexts.

Qualitative studies, on the other hand, can offer deeper understanding of people's lived experiences during heatwaves, shedding light on the circumstances and conditions that heighten vulnerability beyond physical factors (Lanza et al., 2023). This context-specific knowledge is essential not only for creating effective strategies (Ellena et al., 2020) but also for preventing maladaptation (IPCC, 2022). The literature on climate risk management provides several instances of a discrepancy between the measures recommended by experts and the actions actually implemented by local communities (Bremer, Schneider, & Glavovic, 2019; Haque et al., 2017; van der Sluijs & Wardekker, 2015). Therefore, investigation of people's nuanced coping mechanisms, their perceptions of the hazard, as well as their strengths and weaknesses, can provide an enhanced contextualised understanding of the quantitative findings (Wilhelmi & Hayden, 2010) and can assist decision-makers in producing

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pragmatic and locally relevant adaptation strategies to address the crisis effectively. However, in climate literature, there is little interest in exploring the embodied and subjective experiences during heatwaves (Hamstead, 2023). Although some studies can be found in warmer climatic regions, such explorations in cities with a temperate climate are still scarce. In response to this research gap, by focusing on the city of Rotterdam, this study explores the following research questions:

(a) How do urban residents in a temperate climate experience heatwaves? **(b)** What are the behavioural adaptation strategies in practice? and **(c)** What are the spatial dependencies involved in the process of heatwave adaptation?

The core objective is to explore people's agencies of heatwave adaptation and associated spatial dependencies in a diverse urban context with temperate climate while also offering a conceptual framework to elucidate those practices. Such exploration can help unveiling potential disparities in individuals' behavioural adaptation opportunities within the built-environment, thereby advancing the understanding of heat inequality—a key indicator of climate justice—from a fresh perspective. The subsequent sections of this paper discuss the importance of behavioural adaptation, emphasising its relevance, the context of Rotterdam, and the methodological approach used in this investigation.

2. Heatwaves in the Netherlands

Like in large parts of the rest of the world, average and extreme temperatures are rising in the Netherlands (AMS Institute, 2020; KNMI, 2021; KNMI, 2023). Between 1901 and September 2022, the country experienced 28 heat waves, with 12 occurring after 2000 (as shown in Fig. 1). In 2019, the maximum temperature exceeded 40 °C for the first time.

Furthermore, Statistics Netherlands (CBS) forecasts that urbanisation will continue to flourish in major Dutch cities until 2040 and that the population of Dutch Antilles, Turkish, Moroccan, and Surinamese origin will increase until 2050 (CBS, 2022). This implies that regions susceptible to temperature increases will be inhabited by individuals with diverse backgrounds. On top of this, built environment characteristics, including the quantity of green space (Harlan et al., 2019), presence of waterbodies, urban form, and spectral reflectance, not only influence the UHI effect but also induce intra-urban temperature differences (Hamstead et al., 2016; Middel et al., 2014; Ziter et al., 2019). These intraurban differences lead to unequal heat exposures, which in turn create inequalities and an unjust distribution of adverse heat-related outcomes among various sociodemographic groups. One of the prime example of these intraurban differences is the city of Rotterdam, where vulnerable neighbourhoods are more likely to face higher heat stress due to reduced liveability and limited adaptive infrastructure (van Der Hoeven & Wandl, 2018; van Oorschot et al., 2021). In addition, urban heat exposure is also found to be gender and age specific (Mashhoodi's, 2021), highlighting the urgent need to explore anthropogenic and sociocultural aspects of heatwave vulnerability in the region (Ahmed et al., 2023).

2.1. The case of Rotterdam

Being the second-largest city in the country, Rotterdam has the highest urban conglomeration in the Netherlands. Prior studies have identified a significant UHI pattern within the city (Heusinkveld et al., 2014; Steeneveld et al., 2011). In Rotterdam, the diverse urban characteristics of various areas influence the atmospheric UHI effect to fluctuate in values, spanning from 4.3 °C to 8 °C (van Hove et al., 2015). During daytime, the surface heat island intensity difference between urban and surrounding non-urban areas can be as large as 10 °C (Klok et al., 2012). The perceived temperature heat map of the city exhibits a prominent urban climate phenomenon in the inner regions, with notable variation among different districts (Fig. 2). In addition, Rotterdam is also susceptible to the adverse impacts of future heat waves. The combination of high population density, diversity, and the heterogeneous nature of the urban environment, including factors like housing quality and the presence of trees and waterbodies, can significantly amplify the severity of heatwaves (Rød & Maarse, 2021).

In terms of population and social composition, Rotterdam is a complex urban setting with a tangled migration history. The city is extremely heterogeneous, with over 50 % of its population hailing from 180 countries. From a historical perspective, according to van de Laar and van der Schoor (2018), Rotterdam has a long history of migration, predating its rise as a prominent continental port city by the late 19th-century. Statistically, in 2015, the city shifted to a majority-minority status, and as per estimation, by 2030, people of Dutch descent will represent 40 % of the population in Rotterdam (Crul & Lelie, 2019). Despite the city's ethnically and socially diverse population, its spatial distribution reveals notable disparities. The Municipality of Rotterdam's (2019) assessments of the Physical, Social, and Safety indices show a significant contrast between the northern and southern regions,

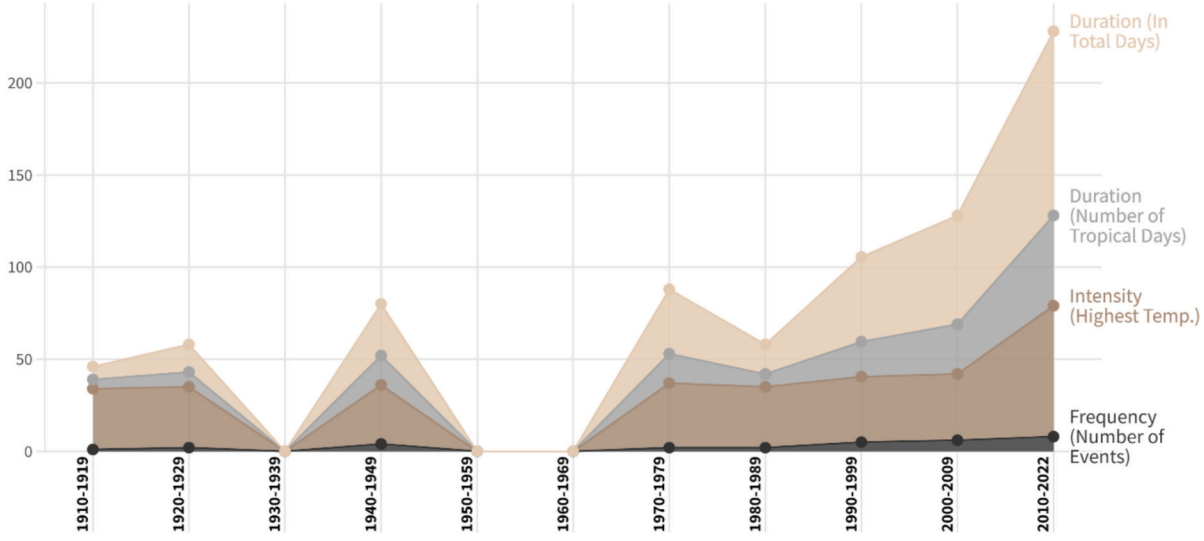

Fig. 1. Development of heatwaves per decade in the Netherlands – including maximum temperature, the accumulated number of days during the heatwaves (decade), as well as total number of tropical days.
(data source: www.knmi.nl/nederland-nu/klimatologie/lijsten/hittegolven).

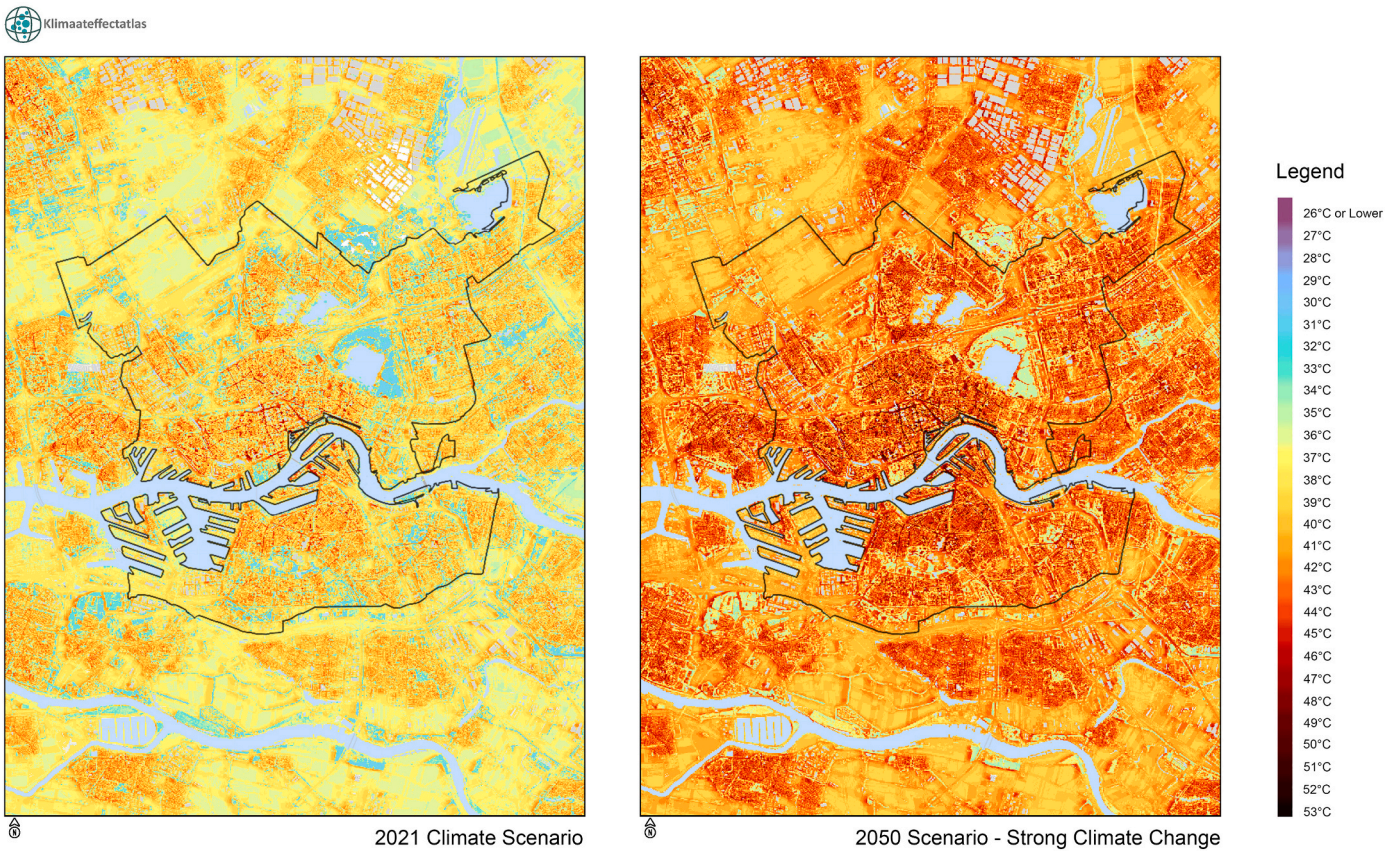

Fig. 2. Perceived temperature heat map of Rotterdam. 2021 Scenario (left) vs the 2050 Scenario (right). (Source: www.klimaateffectatlas.nl).

corresponding to areas situated above and below the Meuse River, respectively. Besides, the diversity map (Fig. 3) illustrates that neighbourhoods in the southern part of Rotterdam have the highest concentration of ethnic and social groups compared to other areas (Engbersen et al., 2019). While perceptions are slowly evolving, Rotterdam-South, the southern part of Rotterdam, still holds an image of being the poorest, least safe, and most "coloured" (Frijhoff, 2015; van Eijk, 2010). Therefore, Rotterdam-South's segregated and diverse characteristics, coupled with its heat stress and UHI profile, make it a unique and illustrative case for this explorative research.

3. The conceptual framework

In 1981, the 'psychophysiological model of thermal perception' was introduced, in which thermal adaptation was considered both a physiological and psychological response based on climatic-cultural determinants (Auliciems, 1981). Building on this, in 1997, de Dear developed the concept of 'human thermal adaptation', and later with Brager and de Dear (1998) outlined its three key components: (i) behavioural adaptation, (ii) psychological adaptation, and (iii) physiological adaptation. Of these three components, this study focuses on behavioural adaptation, more specifically on the three aspects defined by de Dear and Brager (1998): personal, technological, and cultural adjustment.

Personal adjustment involves individual measures taken to cope with increased temperature. As the term indicates, these adjustments are made individually without influencing the surroundings. Examples are intuitive decision-making, clothing choices, and a reduction in physical activity. In contrast, technological adjustment is about environmental modifications through active or passive means to cool down surroundings—actions ranging from opening/closing windows, operating shading devices, using a fan, ventilator, air diffuser, or even opting for an air-conditioning system. Finally, cultural adjustment is a set of adaptive behaviours like a change of habits or daily routines that help individuals cope during heatwaves.

Since the study aims to investigate behavioural adaptation processes and associated spatial practices, psychological and physiological aspects of thermal adaptation are considered outside its scope. Nevertheless, risk perception plays a key role, as it influences adaptive behaviour (Frondel et al., 2017). Research show that environmental risk perception is shaped by a variety of factors, including demographics, culture, knowledge, and experiences (van der Linden, 2015). Howe et al. (2019) outline risk perception as encompassing individuals' attitudes and beliefs regarding the severity, frequency, and duration of heat events, along with their awareness of the potential hazards associated with exposure to heatwaves. Hence, for having a thorough understanding, this study considers heatwave risk perception in conjunction with behavioural adaptation. Fig. 4 illustrates the overall conceptual framework for this study.

4. Methodology

4.1. Research design

This study employs a qualitative research design that enables a thorough comprehension of participants' perceptions, circumstances, and tactics concerning heat adaptation. Instead of a sequential, linear procedure, the research design incorporates a hybrid approach, combining both deductive and inductive reasonings. This flexible, concurrent process allows for reflexivity and reflection simultaneously (Swain, 2018). This design facilitates an iterative exploration, where deductive components—rooted in existing theory and

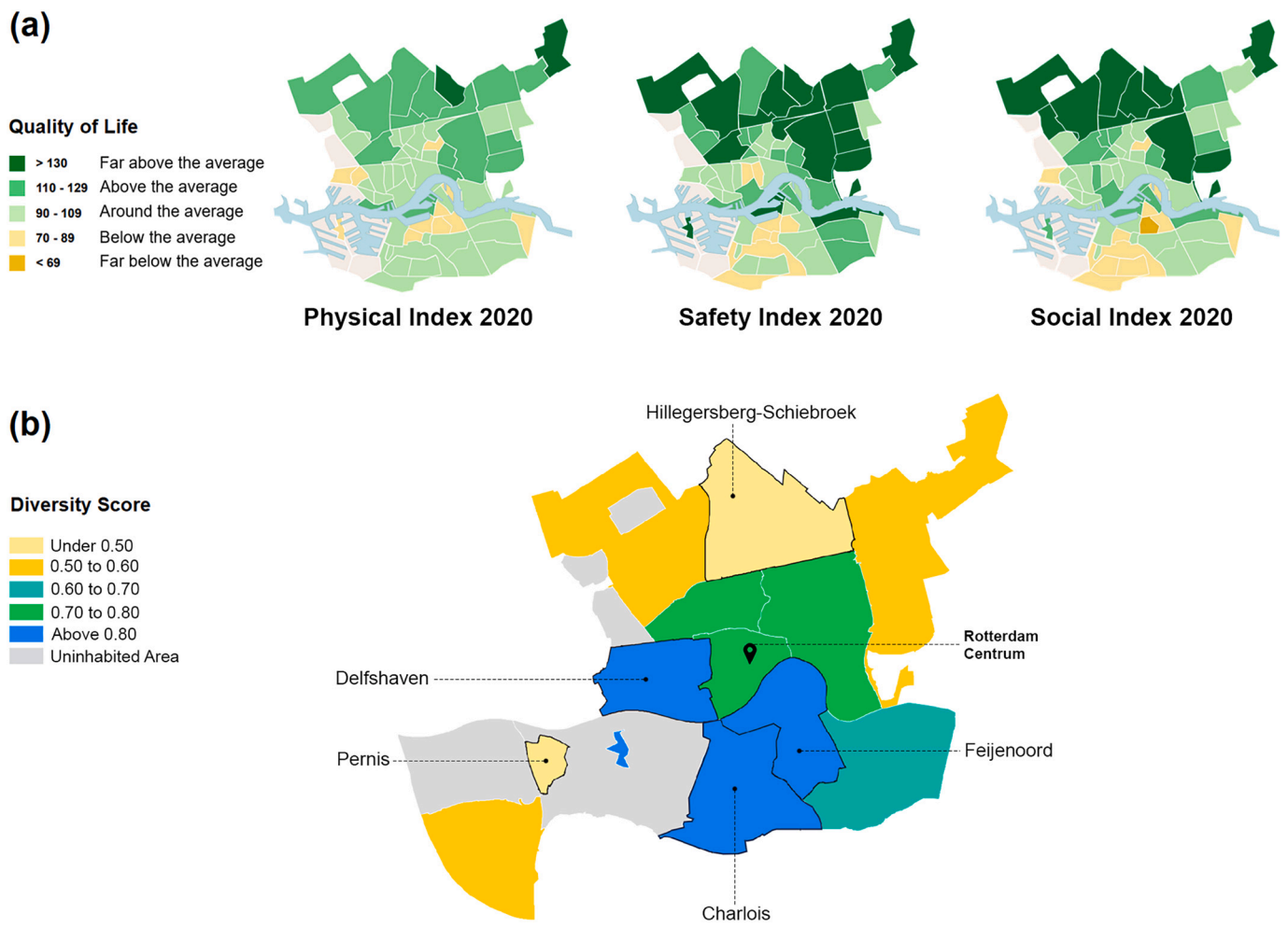

Fig. 3. (a) Physical, Social, and Safety indices (Source: Leefbaarometer, 2023); (b) Diversity Scores of areas in Rotterdam. (Source: Municipality of Rotterdam, 2019; Engbersen et al., 2019).

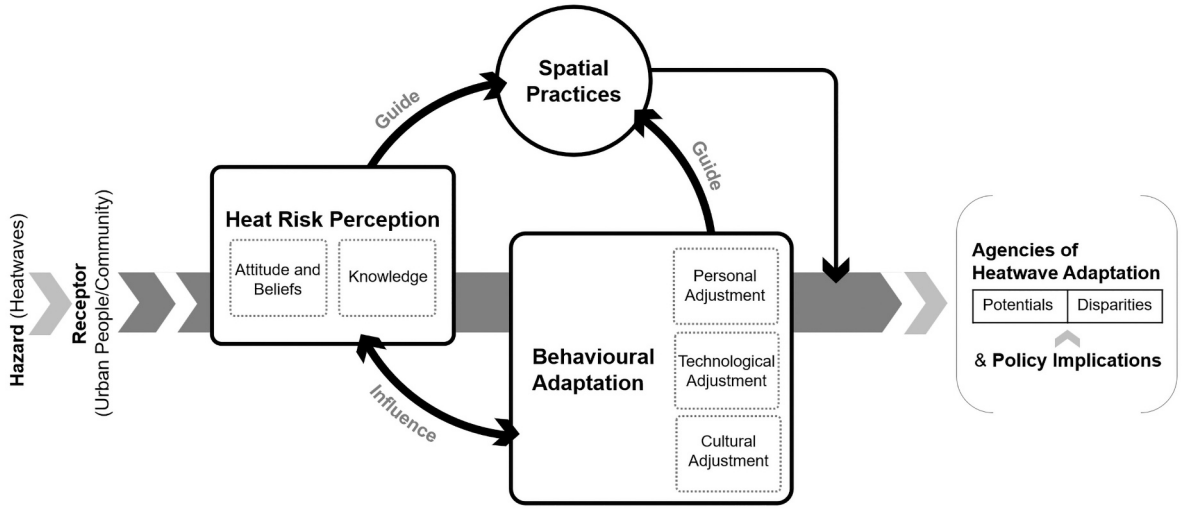

Fig. 4. Conceptual framework of the study; integrating components from Howe et al.'s (2019) risk perception and de Dear and Brager's (1998) human thermal adaptation framework.

literature—provide a structured framework for identifying key themes and categories, while inductive components uncover patterns and insights directly from the data itself, thereby enriching the thematic framework throughout the process. By concurrently using both approaches, the research design can accommodate a dynamic, responsive analysis grounded on participants' lived experiences. The methodological approach in this study is informed and guided by the process demonstrated by Fereday and Muir-Cochrane (2006) and Swain (2018),

which outline a hybrid approach to thematic analysis.

4.2. Participants of the research

The research attempts not to empirically generalise adaptation behaviours in a temperate climate but rather to comprehend the factors that influence these practices and their underlying spatial dependencies. Therefore, in accordance with Patton (2002) and Guetterman (2015), the non-probability purposive sampling method is used to select participants capable of offering rich insights into everyday behavioural adaptation during heatwaves in Rotterdam. Table 1 provides the sampling criteria used to recruit participants for the study.

Given the focus of the study, participants aged between 20 and 60 are being considered suitable candidates. This age range is deliberately selected in accordance with the CBS population pyramid, encompassing a significant portion of the population and facilitating a comprehensive exploration of the research topic. Simultaneously, this study consciously excludes the elderly and children, as their inclusion would necessitate a separate research plan because of their sensitivity and varied cognitive abilities. The recruitment process aims to represent all three population profiles classified by the CBS: Netherlands of origin, child of migrant(s), and migrant. Table 2 presents an overview of participants and some key information related to interviews.

4.3. Data collection

In-depth, semi-structured interviews are used as the primary method for collecting data. The interview protocol is comprised of three components: heatwave risk perception, behavioural adaptation, and spatial practices. The semi-structured nature of the interview empowers participants with the freedom to move between these components at their own pace, permitting them to express their stories and personal experiences in a way they find comfortable while maintaining a focus on the research topic.

The protocol is thoughtfully designed by involving deductive and inductive components. The first two components, heatwave risk perception and behavioural adaptation, are deductive, derived from the Heatwave Risk Perception (Howe et al., 2019) and Human Thermal Behavioural Adaptation Framework (de Dear & Brager, 1998), respectively. These deductive components are not followed rigidly. Instead, they serve as guiding principles for shaping overall findings, which facilitates the subsequent stages of analysis. The third component seeks to find out participants' spatial dependencies and how they use their house unit and surrounding network to cope during heat events. Open-ended questions encouraged participants to reflect on their lived experiences, coping strategies, and challenges faced during heatwaves.

The interviews take place between June and September in the summer of 2022 and 2023. Respondents are invited to share their stories regarding the practices, techniques, and capacity to adapt during heat events. Additionally, their attitude, beliefs, and past encounters with warmer conditions are also discussed. The interview questions are prepared prior to the start of interviews. Following a few pilot interviews, the questions are finalised. The protocol includes a total of 12 questions, supplemented by follow-up queries to delve deeper into the responses as needed (see Table 1 in the Appendix A). Typically lasting around 45 min, interviews are conducted either in person or online based on participant preference. After having informed consent, each interview session is recorded, and necessary notes are taken by the researcher to capture nuances and contextual information. Audio recordings are later converted into written transcripts by the researchers for analysis purposes.

In line with qualitative research principles (Charmaz, 2006; Seidman, 2019), data collection prioritises interview quality and depth over sample size. Besides, the exploratory nature of the study necessitates a deeper insights into individuals' lived experiences during heatwaves. After having 21 rich and insightful interviews, additional interviews confirm that no new insights emerge within the research scope, indicating that the existing data adequately addresses the research questions.

Table 1
Participant recruitment criteria.

Criteria	Description
1. Location	Participants must reside in one of the southern districts of Rotterdam, as this area is well known for its diversity and urban complexity.
2. Duration of Residency	Participants must have a minimum residency of 5 years in Rotterdam, ensuring their familiarity with the city context and exposure to multiple heatwaves in 2018, 2019, and 2020, allowing for richer insights into the research queries.
3. Ethnic Background	Participants must align with the population classifications outlined by the CBS Netherlands: Origin Netherlands, Child of Migrant, Migrant. This ensures a diverse sample population, crucial for capturing a range of perspectives and experiences.
4. Age Range	Participants should fall within the age bracket of 20 to 60 years, reflecting the predominant age group in the Netherlands according to CBS data.
5. Informed Consent	Participants must provide informed consent and participate voluntarily, so that the responses are neutral and authentic.

Table 2
Demographic and interview-related information of participants.

Demographics		
Total Participants	21	
Gender	13 Female	8 Male
Age Range	20–60 years old	(Median age group 30–40)
Occupancy Type	Rent (16)	Owner (05)
Ethnic Background (According to the categories by CBS)	Origin Netherlands	09
	Child of Migrant(s) Residents born in the Netherlands with one or two parents born abroad are called children of migrants	08
	Migrant Foreign-born residents	04

Interview		
Interview Period	June to Aug (in 2022, 2023)	
Interview Duration	28–50 min	(Median 40 min)
Mode of Interview	Online and In-person	

4.4. Data analysis

For assessing the interview data, Thematic Analysis (TA) is employed. TA involves identifying, interpreting, and categorising meaningful patterns within the dataset. It is an interpretative approach focusing on the contextual aspects of the text to discern clear meaning (Braun & Clarke, 2006). The advantage of TA lies in its flexibility, as it allows modification to better align with the research needs (Braun & Clarke, 2006; King, 2004; Nowell et al., 2017). This research adopts a hybrid approach to thematic analysis, blending two distinct modes of reasoning: a top-down, theoretically processed approach or deduction and a bottom-up, data-driven approach or induction (Swain, 2018). Deduction uses theoretical frameworks of Howe et al. (2019), and de Dear and Brager's (1998), to guide the analysis, ensuring that the data is interpreted within the established research scope (Crabtree & Miller, 1999). Induction, in contrast, allows insights to emerge organically from the data, fostering a grounded perspective on the findings (Boyatzis, 1998; Charmaz, 2006).

After collecting data from 21 in-depth interviews and transcribing them into transcripts, rigorous data coding and identification of themes have been carried out. The computer-assisted qualitative data analysis

software ATLAS.ti facilitates the analysis. An iterative, comparative, and reflexive coding process has been employed for an interpretation of participants' experiences during heat events (Fig. 5). The coding procedure is initiated when the first interview transcript becomes available. After a few iterations, the researchers collectively consolidated the initial codes and codebook. Afterwards, a designated researcher from the team carries-out the axial coding procedure, with subsequent assessment and revision conducted by the co-authors to ensure intercoder reliability.

Adhering to the procedure of Hybrid Thematic Analysis, two deductive themes, "Hazard Perception" and "Behavioural Adaptation", are predefined as per literature, each comprising distinct (priori) categories that represent overarching concepts pertinent to the research objectives. On the other hand, inductive reasoning allows to capture emerging nuanced insights from participants' responses. To seamlessly integrate these inductive findings with the predetermined deductive framework, the analysis employs a strategic introduction of (posterior) sub-categories. These sub-categories serve as bridging entities, adapted to encompass the inductive codes that elucidate the intricacies of the identified themes and categories. Notably, for the theme Spatial Practices, which is not theoretically driven, categories are developed completely based on the inductive process. The integration process of posteriori or post-empirical sub-categories with the deductive categories involves meticulous consideration of each inductive code, ensuring alignment with the corresponding deductive theme and category. This method facilitated a comprehensive exploration, combining the advantages of deductive and inductive approaches to enhance the depth and richness of the thematic analysis.

5. Findings

The overall findings from the analysis can be classified under 2 priori-deductive themes, 5 priori-deductive categories, and 15 (posteriori) inductive sub-categories, while a third theme, "Spatial Practices" is comprised of 2 (posteriori) inductive categories and 4 (posteriori) inductive sub-categories (for the codebook see Table 2 in the Appendix A). All 19 sub-categories and 51 codes are completely inductive elements. Categories, Sub-categories, and comprising Themes can be found in Table 3, followed by their explanation.

5.1. Hazard perception

Hazard perception is crucial for understanding how people perceive and react to a crisis (Ferrer & Klein, 2015). It can facilitate the development of robust and targeted strategies that resonate with communities. The (priori) theme of Hazard Perception comprises two categories that are discussed below:

5.1.1. Knowledge

The category 'Knowledge' unpacks individuals' understanding of the hazard and its associated consequences. What is found is that knowledge about heatwaves is shaped based on factual evidence as well as lived experiences. Therefore, the category 'knowledge' encompasses two emerging subcategories: 'Explicit Form of Knowledge' and 'Tacit Form of Knowledge'.

Explicit Form of Knowledge includes people's factual understanding about heatwaves acquired from various media sources, which is typically objective and verifiable. Throughout the conversations, concerns related to health, certain groups in the society, and environmental conditions came out pronouncedly. These are delineated into the codes 'Human Health,' 'Demography,' and 'Physical Environment.' In terms of health implications, participants shared concerns about dehydration, fainting, heat exhaustion, and even fatalities.

Participants also acknowledged that specific groups can be more vulnerable to prolonged exposure to extreme heat, namely the elderly and people with health issues. One of the participants, who is also a mother of two, considered children are highly vulnerable as they cannot make decisions on their own, especially when they are in school. Participants acknowledged disparities in adaptive capacities, with some having the means to afford cooling solutions such as air conditioning or well-insulated homes. Few participants even expressed deeper concerns regarding ecological disruptions, particularly how increased temperatures can cause distress among non-human species and animals.

The subcategory of Tacit Form of Knowledge encompasses implicit insights and experiential learning about heatwaves, which are typically derived from experiences, observations, and close networks. This type of knowledge is subjective and personal. It discusses nuanced perspectives encapsulated within the codes: 'Indoor Environment,' 'Wellbeing,' 'Adaptation Practices,' and 'Changing Climate.' Participants' descriptions painted a vivid picture of stifling indoor environments during a heatwave characterised by stagnant, warm air and limited natural ventilation. According to a participant, "It's like no wind, I do not feel

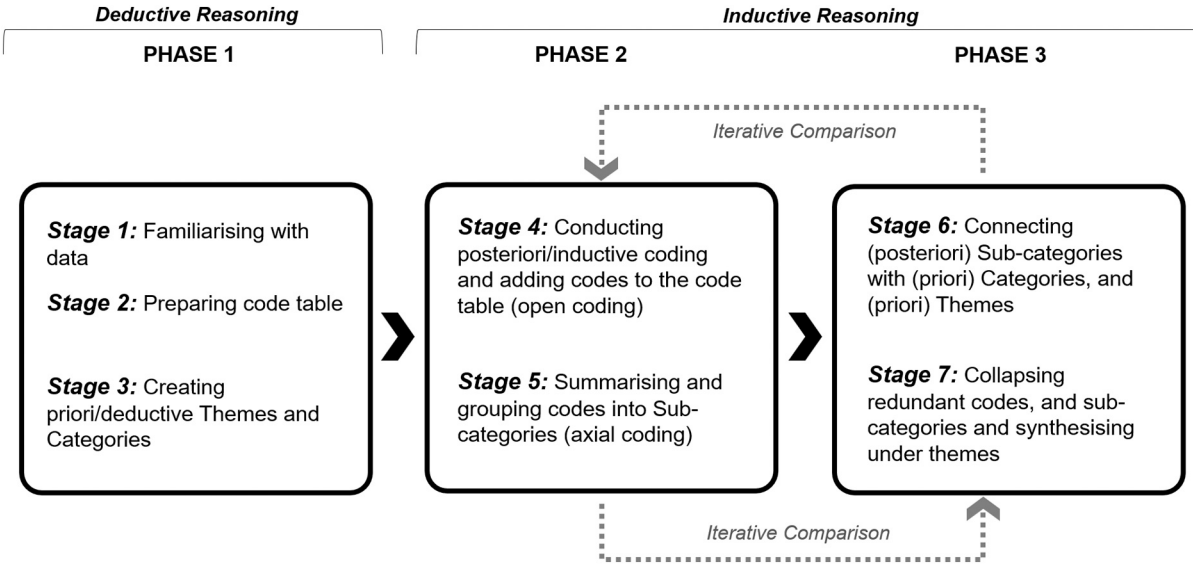

Fig. 5. The three phases and seven stages of data analysis (following Swain, 2018).

Table 3
Overview of themes, categories, sub-categories, and codes.

Themes (3)	Categories (7)	Sub-categories (19)	Codes (51)
Hazard Perception	**Knowledge**	Explicit Form of Knowledge	Human Health, Demography, Physical Environment
		Tacit Form of Knowledge	Indoor Environment, Wellbeing, Adaptation Practices, Changing Climate
	Attitude & Beliefs	Positive	Warm is Enjoyable
		Neutral	Short- term Crisis, Self-manageable
		Negative	Hinder Lifestyle, Unexpectedly Warm
Behavioural Adaptation	**Personal Adjustments**	Proactive Actions	Avoidance Strategies, Body Cooling Measures, Health and Preparedness, Mobility Choice
		Cognitive Strategies	Act on Intuition, Logical Thinking, Creative Response
		Clothing Strategies	Clothing Choices, Accessory Usage
		Workload Management	Limiting Physical Activities, Reducing Outdoor Activities, Postponing Work
	Technological Adjustments	Active Cooling Practices	Fan/Ventilator, Air-conditioner
		Passive Cooling Practices	Window/Opening Management, Shading Techniques, Ventilation Practices
		Unconventional Approaches	Evaporation Methods, Creative Cooling Techniques
	Cultural Adjustments	Changes in Dietary	Healthy Eating, Avoiding Warm Meals
		Cross-cultural Practice	Cultural Wisdom, Alternate Use of Space
		Relocation	Utilising Indoor Cooling Space, Remain outdoors during Hottest Period, Move to Relatives/Friends' Houses
Spatial Practices	**Indoor Oriented**	Private Indoor	Spatial Navigation and Movement, Optimising for coolness, Limit sunlight/heat exposure
		Public Indoor	Socializing AC Spaces, Leisure-Related AC Spaces, Taking advantage of AC spaces in the area
	Outdoor Oriented	Private Outdoor	Adding Cool off facilities, Appropriateness for heat, Benefit of ventilation
		Public Outdoor	Places with wind flow, Places with shade, Places with Trees, Places with water, Less crowded areas

any air, only warmth. It's a situation where the air is warm and trapped, making it difficult to stay inside the room."

Interviewees, specifically those who live on the top floor of the building, highlighted the discomfort of staying in overheated conditions. While describing the situation, a participant said, "In my house, specially this side (indicating the window side) turns into a greenhouse when the sun directly hits, I cannot open the windows at all; that is what I really dislike about warmer days". Such lived experiences shed light on the thermal discomfort within indoor living spaces.

The code Wellbeing encapsulates people's psychological and emotional toll during heatwaves. Their narratives revealed physical discomfort, sleep deprivation, feelings of lethargy, irritability, and the profound impact of high temperatures on mood and productivity. A working woman, age group 30–40, expressed, "I see the lack of sleep or, like, not being so productive, I see it more as a nuisance. It is kind of an annoying thing that you have to deal with temporarily.".

During the discussion, participants shared their observations of the changing climate within their lifetimes, highlighting the rapid change of summer in the Netherlands. National-level and municipality-level initiatives are there, but people urge for enhanced preparedness for the upcoming years. Participants drew parallels between their experiences in other warmer countries and the Netherlands, leveraging past knowledge to navigate present climatic challenges. This tacit understanding underscores the importance of historical context and cross-cultural perspectives in informing adaptive responses to climate change.

5.1.2. Attitude & beliefs

A person's attitude towards a hazard is pivotal in how they respond to a crisis. Under this category, three sub-categories emerged from the data: 'Positive,' 'Neutral', and 'Negative'. Regardless of their background, participants without a connection to a warmer context and with limited or no knowledge about the hazard primarily expressed their enjoyment of warmer summers in the Netherlands. Conversely, those with knowledge and prior experience in warmer contexts have identified heatwaves as a significant threat to their daily lives. Certain participants are also confused about the phenomenon, as they generally view heatwaves as a short-term, self-manageable problem. The following (Table 4) provides the overall participant impressions found in this study.

Moreover, some interviewees struggle with cognitive dissonance arising from past experiences of milder summers in the region. One participant said:

> "I am still used to a summer of 20 degrees that we had in the Netherlands in the past, but the last three summers were extremely hot, it is not for me. Then it's like, 'I don't know, yeah, okay, we need to get through these warm days during the summer." – [migrant male, age group 30-40]

The quote indicates confusion and conflicting thoughts, making it

Table 4
Participants attitude regarding heatwaves in the Netherlands.

Narratives	Exemplar/Statements	% of Participants
Positive (Warm is enjoyable)	"Warmer summers are nice; you are free, and you can enjoy the weather and do a lot of things. Many people love it" "For myself, I don't really experience it as harmful in that sense."	**10**
Neutral (Short term, self-manageable crisis)	"Like, that's fine. I always feel like it's just such a short period that's actually this hot that I can just adapt". "I think these heatwaves are only for one or two days, I think it's okay in general, it is difficult but not dangerous".	**28**
Negative (Hinders life and a future threat)	"It's getting unexpectedly warm in the Netherlands. When you go outside then you have this feeling like if you have opened an oven" "When the temperature rises and the summers become longer, I actually get super worried about it, and I really feel the direct effect in my life"	**62**

challenging to act accordingly with the rising temperatures. Something similar applies to the residents from warmer contexts, migrants and the children of migrants, or those who have previously lived in a warmer country. They may believe they are accustomed to higher temperatures, but the sudden spike in temperatures in a typically cool environment can be challenging, as expressed by a young migrant girl in the 20–30 age group:

> "I am from a really warm country where a high summer temperature is so common; it is nothing unexpected, but in the Netherlands it comes as a shock and makes everything difficult. You know, here we are concerned about cold, not heat."

Therefore, the experience of heatwaves in temperate climates is even more complex, as people from warmer contexts can become disoriented. This can potentially influence adaptive behaviour, which is discussed next.

5.2. Behavioural adaptation

The umbrella theme of behavioural adaptation comprises three priori-deductive categories and eleven posteriori, inductive subcategories that are discussed below:

5.2.1. Personal adjustments

Brager and de Dear (1998) defined personal adjustment as coping with the surrounding thermal environment by modifying personal variables. The study classified emerging variables under four (posteriori) subcategories: 'Proactive Actions,' 'Cognitive Strategies,' 'Clothing Strategies,' and 'Workload Management.' Collectively, these four underscore the dynamic and intricate ways in which individuals navigate the impact of increasing temperature on a personal level.

In the first sub-category, 'Proactive Actions', several 'Body Cooling Measures' came up throughout the discussion. Most of the participants noted that they take multiple showers a day, a practice uncommon under normal circumstances but which becomes routine during extreme temperatures, reflecting their conscious effort to cool their bodies. One participant stated, "If it is over 30 degrees, for sure I shower multiple times, at least two to three times a day, which never happens, and I use cold water, which is also something I never do." Participants also mention deliberately choosing to engage in certain (paid) activities or sports that can aid in cooling down during warmer conditions, such as water-based activities like swimming. 'Health and Preparedness' encapsulates participants' commitment to safeguarding their well-being during extreme heat. Participants highlight hydration as a fundamental element, and they also emphasise the importance of using sunscreen and taking supplements. Participants also shared certain workplace interventions that they find useful.

> "Last week, during the heatwave, I was at my work,.. it was nice and cool you know, because my workplace had AC, they kept the temperature low,.. also they provided us with water, and always reminded us to drink more and more water, extended our break time as well,.. which was good overall." – [migrant female, who works in a store, age group 30-40]

Three codes form the second sub-category, 'Cognitive Strategies': 'Act on Intuition,' 'Logical Thinking,' and 'Creative Response.' This subcategory brings out the multifaceted ways in which individuals engage in cognitive processes for adapting to heatwaves in a busy urban environment. For instance, following their intuitive responses individuals choose to minimise direct sunlight exposure. Additionally, in a busy urban setting like Rotterdam, participants showcase a nuanced understanding of the urban surroundings, acknowledging the drawbacks of popular summer destinations due to overcrowding. Instead, they adeptly seek out less congested spaces as alternative options for cooling off. Simultaneously, it was indicated that most of these areas are car-dependent. According to an interviewee:

> "Actually, what you have, like in a city like Rotterdam or similar, the thing is on really warm days you don't go to the seaside because it's so crowded. You have to really think a little bit creatively; where is a good place that is not crowded, like packed with people, and I think that I came to the realisation, like in Rotterdam you kind of need a car for that if you want to find those kinds of hidden spots." – [male, child of migrant, age group 30-40]

Similarly, 'Logical thinking' emerged in decisions related to ventilation and sunlight exposure, whereas creative responses include using Google Maps to locate green and watery areas in the neighbourhood or beyond and searching the internet for effective measures during heatwaves. These practices indicate how technological literacy may make a difference in the everyday adaptation process.

> "Yeah, well, we use Google Maps and then we start zooming in and searching for places that are close to water and then and we look for places that have access to water, where you can also have a little bit of shade. So that's basically how we look for places." – [origin Netherlands, female, age group 20-30]

The third sub-category is 'Clothing Strategies', which encompasses deliberate choices regarding attire to cope with the increased temperature. Several studies already found this a common adaptive behaviour for achieving comfort (Huang et al., 2019). Interviewees demonstrate a keen awareness of the need to adjust their wardrobe and use necessary accessories for optimal comfort, such as lighter summer clothes and breathable fabrics. Knowledge from a warmer context, particularly as shared by participants with a migrant background, children of migrant (s), or those who have lived in a warmer country for a substantial period, helps in deciding the type and property of the outfit that will perform better on warmer days. A participant said: "like in our home country, we mostly wear cotton, and don't keep our skin exposed to sun, and yes, I found that the same practice also works well here." – [migrant female, age group 20–30].

Finally, the codes 'Limiting Physical Activities,' 'Reducing Outdoor Activities,' and 'Postponing Work' collectively contributed to the thematic construct of the sub-category 'Workload Management'. This subcategory delves into the personal adjustments that people make in their work lives. Participants indicate a deliberate shift in their physical activities during heatwaves. One participant noted: "When it is really hot, you do less. You don't make the same plans you would if it weren't difficult to go out and engage in a lot of activity." Besides, participants also illuminate the pervasive impact of heat on their daily lives, particularly in household work. Several participants emphasise curtailing household activities during heatwaves because of sleep disturbances and a persistently irritable mood. According to a mother, age group 40–50:

> "It happened that I could not sleep, especially if it is warm at night. During the day I am always in a bad mood, do not enjoy doing household work, or any sort of work."

Not just within households, similar narratives also extend to outdoor activities, as exemplified by the code 'Reducing Outdoor Activities'. In certain situations, individuals mentioned limiting outdoor engagements and strategically planning outdoor activities to avoid peak heat hours. A male office worker (30-40 age group): "If I have the option, then I think I would avoid the middle of the day, between 12pm and 2pm, I would avoid going out." Those who have the option to work remotely noted the benefits of not having to go outside. Besides dealing with heatwaves, multiple participants also mentioned a noticeable reduction in their planned outdoor activities.

Summarising, the articulation of participants' experiences and corresponding actions demonstrate the overall complexity associated with personal adjustment against heatwaves, while at the same time showcasing both typical and unconventional methods of coping with such challenges.

5.2.2. Technological adjustments

Technological adjustment includes active and passive means to improve indoor thermal conditions. Active practice means using powered mechanical devices or systems to cool down the indoor environment, while passive cooling practices include techniques that can help reduce temperature without any power consumption (Bradshaw, 2010; Santamouris et al., 2017). Among the participants interviewed, a fan or ventilator is the most common active practice (95 % mentioned 'in practice'), whereas only one participant mentioned the use of air-conditioning (AC) at their house during the summer. A few others expressed having considered purchasing an AC, but due to high installation and maintenance costs, they decided not to do it. Fig. 6 provides an overview of active and passive cooling practices, elucidating their respective prevalences.

The participant responses broadly classify passive cooling practices into Window Opening Management, Shading Techniques, and Ventilation Practices. Notably, some participants exhibited knowledge of navigating increased temperature by opening windows during certain hours, like this participant: "When I leave my house for work early, I close all the windows of my house so that hot air cannot get in, and when I return home in the evening, I open them up so that cool air can enter my house." Another participant indicated employing both active and passive techniques strategically during heatwaves, stating: "I practice opening or closing the windows at certain times. When the sun starts shining, I close my windows, and at night I open up my window and I set up my fan in front of it towards my bed when I go to sleep, things like that."

There are also some contrasting narratives. Participants mentioned that when they feel warm they just open their windows and let the air come inside, as they believe outdoor air will cool down indoor spaces. Furthermore, several participants do not use curtains to block unlight.

Additionally, the position of the dwelling unit, whether it is situated on the top floor or not, significantly influences individuals' experiences during heatwaves. Participants living on the top floor of the apartment reported an intense experience of temperature during heat events. Single-family houses with multiple floors also reported the same; rendering the top level of their house uncomfortable or unusable and people either avoid or shift activities of that room elsewhere in the house.

> "I live in a house which is directly under the roof. So, what you see above me (pointing to his ceiling) is directly the roof, and the sun is strong in summer. Especially when it's 25 degrees or above. It is a bit hard for us because it gets very hot inside my house, so it is not enjoyable to stay at all.
>
> In such situations, we avoid being inside the house. For example, today is very hot and we went outside, and we enjoyed. But now we are inside the house (doing interview) and it is very warm. I do not like it". (Migrant male, 30-40 age group)

Such a statement indicates that depending on factors like orientation and the level of the living unit, experiences of heatwaves can differ greatly, even within the same building or site. This underscores the necessity of conducting a more in-depth investigation of the phenomenon. The following (Fig. 7) illustrates the findings of passive adaptation practices in relation to building type, occupant type, and occupancy characteristics.

Intriguingly, some interviewees disclosed unconventional adaptation practices. They know such practices from their personal experiences of residing in warmer environments and knowledge transmitted through familial and social networks. Based on such narratives, the third subcategory of the category Technological Adjustments, 'Unconventional Practices,' emerged. Like a participant described, "I was very young when I was in China, like in middle school or primary school. Every afternoon in the summer our class teacher always put water on the floor. I still do it in my house when it is warm, I feel it cools down a bit." A similar evaporative technique was also mentioned by another participant, she stated: "During warm summer days I wet some clothes, like a big towel, and put them to evaporate on my balcony or in front of a door or window where the wind comes. It moisturises the air and I really like it, because when the air passes through that wet towel it becomes a bit cool and feels more pleasant to my skin." It was also found that those who are highly educated (hold a university degree) and aware of the phenomenon follow the weather alert and prepare in advance. These people also search for cooling techniques on the internet. According to an interviewee: "I always double-check, like one or two days beforehand, if there is any weather warning. Most of the time, I just put my fan in the storage room. So when a heatwave comes, I know it 1-2 days before, and I just take it out and clean it and fix it." Another participant indicated: "For techniques, I just looked them up, and I think in the 2018 heatwave I looked for something on the internet, and there I also learned that if you can, like, a bowl and you put ice in it and a bit of water, and if you put the bowl under the fan, you almost get a kind of air conditioning, I do it, it works."

These accounts unveil the ingenuity of individuals in heatwave adaptation, drawing from personal and inherited knowledge and experiences. Simple yet helpful ways that are tailored to their circumstances and needs.

5.2.3. Cultural adjustments

The cultural adjustment category seeks to bring out the (collective) pattern of behaviours that are shared by a particular group. Through the process of iterative coding, three posteriori sub-categories emerged under the priori category of Cultural Adjustments: 'Cross-cultural practices,' 'Changes in Dietary,' and 'Relocation.' Factors such as familiarity with warmer temperatures and the type of home ownership have also become prevalent, influencing such adaptation practices. Insights from participants with migrant or child of migrant backgrounds varied from those of Dutch origin, attributed to prior experiences in warmer climates. Similar differences exist in the perspectives of renters

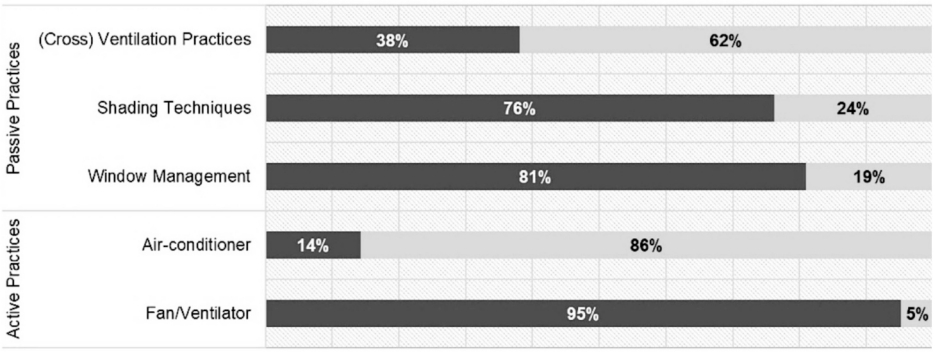

Fig. 6. Overview of active and passive cooling practices indicated by participants.

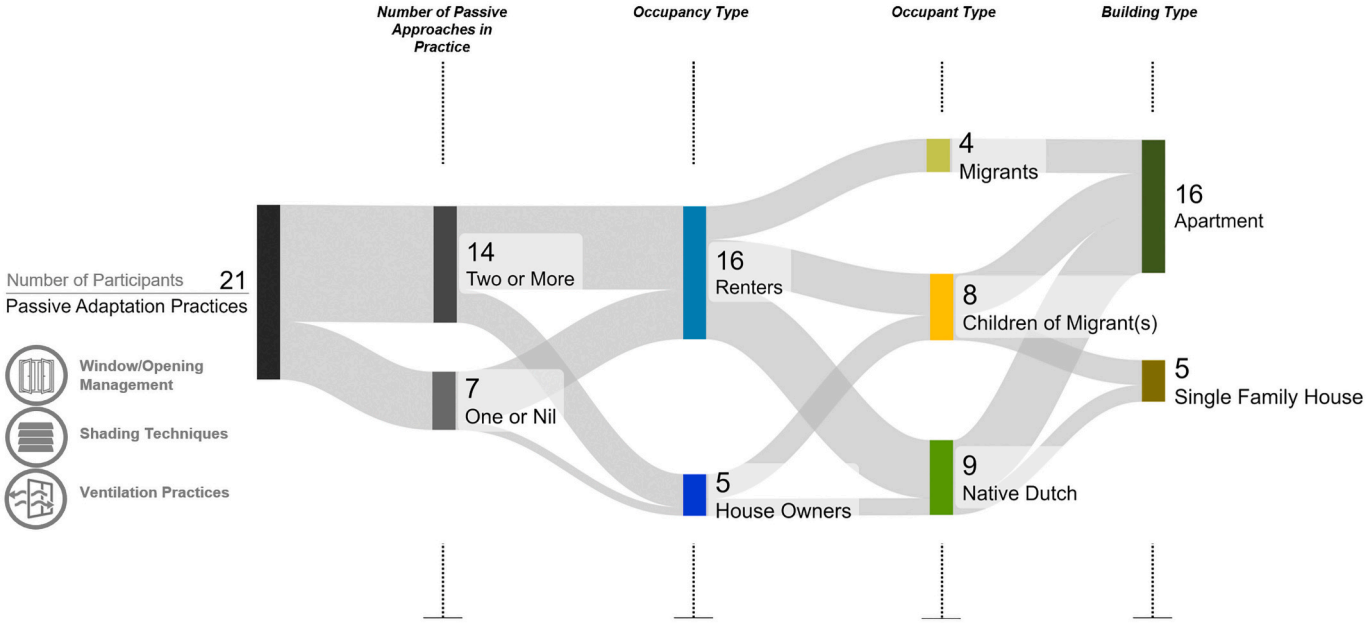

Fig. 7. Passive adaptation practices in relation to occupancy, occupant, and residential building type.

and houseowners.

From the interviews, participants with a migrant (or child of migrant) background living in a rental property tend to adopt a higher number of passive cooling practices, deriving from their multi-contextual experiences and intergenerational knowledge. Interviewees reported that cultural practices in warmer contexts contribute to heat-wave adaptation in the Netherlands. Previous exposure to a higher thermal environment helped individuals to culturally acclimate to the phenomenon, as one of the interviewees stated: "Culturally, I am accustomed to warmer temperatures, and my body can regulate in warm conditions, so I think it is inherently inside me. I also know what I need to do. I need to wear clothes that can keep me cool, and these are because of my past experience in my home country." Participants mentioned using practices learned from their parents or communities and drawing upon their prior experiences in warmer countries when temperatures rise in the Netherlands. According to a participant, "Being raised in a Portuguese family, I noticed that my parents always used to do the same things when it got hot. My mother always used to tell me not to go outside after 12 o'clock, she also used to tell to drink water even if I am not thirsty. These lessons are from my mother, not from here." Nevertheless, it is also noted that certain practices may not translate effectively due to building characteristics, notably building insulation properties and window sizes. A participant from Spain who has been living in Rotterdam for over seven years expressed surprise by the level of discomfort at the same temperature in both countries. She stated:

> "So in this country, if you are around 30 degrees, it's already quite a bit of suffering. Because, yeah, maybe the houses here (in the Netherlands) are really good, well insulated because it is mostly cold and stuff like that. But I don't know why,.. could be the humidity, or else, somehow you get really warm, much more than other places, like my home country (Spain). I don't know really why, but 30 degrees here (indicating the Netherlands) feels a lot different,.. just like a week ago (referring to a 2023 heatwave) we had close to 40 and it was insane, you cannot be at home,…"

Another interviewee, who lives in a rental property, mentioned the following:

> "In my home country we could do whatever we want, like add window shade, shutter, put something on the balcony. But here you need to have permission from the housing association and neighbourhood community. If everyone agrees then you can do something, it's complicated."

Moreover, participants with a Migrant, and Child of Migrant background indicated a difference in social structure, they expressed feeling greater support and a stronger sense of community in their country of origin, which facilitated the sharing of information and provided essential mental support during such crises. One participant noted, "When it is really hot in my home country you hear a lot of things around you, like people start giving each other advice on what to do, and if anything wrong happens to anyone, you immediately hear about it. It is not the case here." Such rich narratives indicate the value of collective wisdom, shared informally among peers and family members that can form a resilient framework for coping with increasing temperatures.

The second posterior sub-category 'Change in Dietary' emerged from the narratives of modifying dietary habits as a means of coping mechanisms during heatwaves. As people with a migrant background are used to different dietary practices, participants mentioned going against their usual dietary practices they often avoid consuming warm or heavy meals during heatwaves to keep themselves cool and focused. One participant explained, "I am from a South-Asian country, and culturally we eat warm dishes with lots of spices, and what I find during hot days is that it makes me even feel warmer,.. so I don't like it then. I avoid eating those types of food when it is warm in summer." Interestingly, in certain cases cultural dietary practices even help in adaptation process, as evidenced by the continuation of consuming cooling soups from their home country. One participant shared: "I eat a healthy green soup that we used to take in my home country (China), it helps to keep the body cool which I regularly do here in the Netherlands as well." Such contrasting experiences highlight how certain cultural habits can both aid and hinder individuals in coping with a hazard. Regardless of background, almost every participant indicated they try to remain hydrated and deliberately choose food options that have cooling properties, such as fruits, vegetables, and cold beverages.

Seeking potentially cooler spaces has emerged as a crucial practice for navigating heatwaves in the Netherlands. Consequently, relocation, which can be considered a form of social behaviour, becomes common during warmer summer times. The participants' lived experiences shed light on the steps taken to find relief from the heat. It starts within their own houses by shifting sleeping and working places, and then extends across their neighbourhood and beyond. Having access to private

transport plays a key role in the choice of cooling-off locations. Several interviewees, particularly renters, reveal that they deliberately utilise air-conditioned spaces in their neighbourhoods, such as libraries, supermarkets, cafes, cinemas, etc., and spend more time there than usual. The following few statements from interviewees indicate the deliberation behind the action:

> "On hot days, I go to supermarkets, they have strong air-conditioning, I casually walk around, spend time looking at items in stores, and sometimes do my regular purchases as well. It is fun, and a good way to keep yourself cool during extreme summer."

Another participant mentioned (a father, age group 30–40),

> "I took my daughter last Friday (during 2023 summer) to an indoor play hall. Typically, we do it once every two or three weeks, or once a month, you know. But this time we chose to spend two days consecutively within a single week due to the extreme heat. And the play hall has good air conditioning and it is a pleasure to stay inside. It is very cool, my daughter was happy too. So, I do this, but the play hall is not in my neighbourhood, yeah, it was, like, 20 minutes driving."

Additionally, individuals actively seek out outdoor locations offering ample shade and airflow. According to a participant, "Mostly after 13:00, because you know, at 12pm the sun comes directly on top of your head, it doesn't get that warm immediately, but after a few hours, say around 14:00 it starts to get hot and my house warms up, then I decide to go out and spend around 3-4 hours outside, I sit under trees at parks where there is wind."

During certain circumstances, people even move to the houses of relatives and friends, offering additional avenues to escape heatwaves. A middle-aged (age group 40–50) family man described "So, like my parents, they own a house with a garden, and it was newly built in 2009. When they are on holidays in summer, then we spend the very hot days in that house because it's very cool, I have done this a few times." Another participant (early career, origin Netherlands) shared,

> "I live in a studio in Charlois (a neighbourhood in Rotterdam-South) which directly faces the sun. During warmer days it just becomes unbearable for me. Luckily my boyfriend's place is nicer, and during such situations I just move there for few days."

By integrating routine adjustments, dietary modifications, cross-cultural practices, and relocation strategies, individuals can effectively cope with the challenges posed by heatwaves. This comprehensive approach enables adaptive responses tailored to individual needs and cultural contexts, fostering resilience and well-being amidst rising temperatures.

5.3. Spatial practices

The third and final theme, "Spatial Practices," stems from the participants' references to various types of spaces that aid in their adaptation process. Unlike the (priori) themes, this one is completely based on inductive reasoning encompassing posteriori categories and subcategories. Broadly, based on the shared experiences, individuals' spatial practices can be categorised either as indoor-oriented or outdoor-oriented and further subdivided into public indoor, public outdoor, private indoor, and private outdoor oriented practices.

5.3.1. Indoor oriented

5.3.1.1. Private indoor. Narratives indicate that individuals initially aim to utilise their indoor living space. Such appropriation includes Spatial Navigation and Movement, Optimising for coolness, Limit sunlight/heat exposure. People living in apartments, which typically feature a horizontal layout, frequently shift their location and alter their activity patterns within the room, as one participant noted:

> "My preference for spaces varies, I mean, it changes during the day. My house is linear, when the sun is on the front side of my house I try to remain on the other side of the house, and later, when the sun comes to the opposite location I also switch my position, it is like playing hide and seek with the sun."

It is also noted that all the previously discussed technological adjustments mostly take place within this domain of space. Regarding the private indoors, the situation can be quite complex. From the 21 participants interviewed for this study, it was surprising how many participants mentioned their indoor living conditions becoming worse than outdoor conditions during heatwaves. One of the participants said, "Outdoors I can get some flow of air, but indoor it is really difficult; it feels like I am stuck into something."

5.3.1.2. Public indoor. As previously mentioned, public indoor spaces that are air-conditioned work as an important avenue during heatwave adaptation. This is really prominent in the local adaptation practices. People who suffer from indoor thermal difficulties opt for the available public air-conditioned spaces. During heatwaves, individuals commonly seek out air-conditioned spaces within their neighbourhoods. Initially, people tend to visit nearby air-conditioned locations such as shopping centres, supermarkets, and cafés. Subsequently, they may opt for facilities like libraries, cinemas, indoor game zones, and other public amenities. Notably, during periods of higher temperatures, participants reported that they tend to visit these spaces more frequently and stay longer than usual. Access to private transport, such as cars, further expands the range of options. Therefore, the availability of air-conditioned spaces in a neighbourhood may serve as an important indicator for assessing adaptive capacity of different areas.

5.3.2. Outdoor oriented

5.3.2.1. Private outdoor. Participants' experiences highlight the varied usefulness of private outdoor spaces like balconies, terraces, and backyard gardens during heatwaves. The effectiveness of such spaces mostly depends on the orientation, which determines their exposure to the sun. While some interviewees find them useful, others report them as unusable during the day due to direct sunlight and glare. Renters mentioned limitations in modifying their private outdoors without permission, unlike house owners. However, both groups agree that a decent private outdoor space can enhance the potential for cooling off activities within their homes.

5.3.2.2. Public outdoor. Participants' insights highlight the critical role of public outdoor spaces in heatwave adaptation. The interviewees find shade, wind flow, and access to a waterbody to be important factors. Some participants' stories reveal their reliance on the neighbourhood's outdoor spaces. One participant expressed, "I love to go outside and sit under a tree. Even though it is still hot, it feels fresh, because I am close to nature, not like inside my house." Similarly, another participant said, "I feel good if I can go close to water because wind coming from it is soothing". Interviewees also raised concerns regarding the nature and quality of outdoor green spaces in their neighbourhood, emphasising the scarcity of trees for shade.

> "In our neighbourhood, there are many green spaces, but they are like a green carpet or grass field with small plants, so there is no shadow; there are only a few big trees that can provide shade, those green spaces are not useful".

These rich narratives provide indications of how outdoor spaces can be more effective in environmental crises like heatwaves. Overall, these insights reveal that peoples' spatial dependency is multifaceted and nuanced. It is not generic, rather, it has a local dimension that depends

on the nature of the place and the people. Within their network of available options, individuals tactfully choose spaces according to their unique circumstances, showcasing the dynamic nature of adaptation.

6. Discussion

Through 21 semi-structured, in-depth interviews, this study attempted a nuanced exploration of heatwave risk perception and behavioural adaptation practices in an urban environment in a temperate climate. Utilising a hybrid thematic approach, this study articulates two deductive (priori) themes alongside a (posteriori) inductive theme, while also outlining categories and subcategories that are specific to temperate cities.

6.1. Hazard perception in a temperate urban context

In line with prior studies, the study reaffirms the role of heatwave risk perception in the behavioural adaptation process, even in areas with relatively milder temperatures (Ban et al., 2019; Esplin et al., 2019). The study underscores the importance of tacit knowledge alongside factual information in shaping individuals' perceptions of heatwave hazards. Participants emphasised the challenges posed by rising indoor temperatures, an aspect often overlooked, and less explored in literature compared to outdoor environments. Besides, an important finding from this study is the contrasting experiences of individuals in cooler versus warmer climatic contexts when faced with heatwaves. In warmer regions, temperature increases are usually more gradual, allowing people to physiologically acclimatise over time (Hanna & Tait, 2015). However, insights gained from participants' experiences suggest that in temperate climates, a sudden rise in temperature can come as a shock, leaving individuals in a state of confusion that influences their adaptation practices. Consequently, there is a pressing need for broader-scale studies in temperate regions, focusing on risk perception and the impact of urban heat on indoor conditions.

6.2. Socio-spatial dimension of behavioural adaptation: An inequality concern

Through participants place-based narratives this study illustrates how behavioural adaptation to increased temperatures is materialising locally in a diverse, temperate urban context. As per Eakin et al.'s (2014) breakdown of adaptive capacity, the adaptation practices investigated in this study fall under the 'specific adaptive capacities' that enhance the overall comprehension of heatwave adaptation in Rotterdam. People's lived experiences during heat events indicate behavioural adaptations are tied to the unique spatial and social conditions.

The findings unveil that individuals initially begin negotiating the impacts of heatwaves at a personal level, primarily concerning their bodies. This often extends to technological adaptations for making private living units comfortable. At this stage, assets and factors like ownership and control over housing are crucial determinants, subsequently influencing cultural adaptation practices that extend outside of the private spheres, encompassing neighbourhoods and beyond (Fig. 8).

The adaptation process, therefore, becomes a spatially dependent network that expands or shrinks based on individual circumstances, level of control over living spaces, and the composition of the surrounding built environment. Renters, for instance, often have less control over their private living units, limiting their ability to implement certain cooling strategies and makes them more reliant on neighbourhood resources and community support (see Fig. 9). As a result, certain individuals have greater control over their adaptation choices and practices compared to others, highlighting broader inequalities in

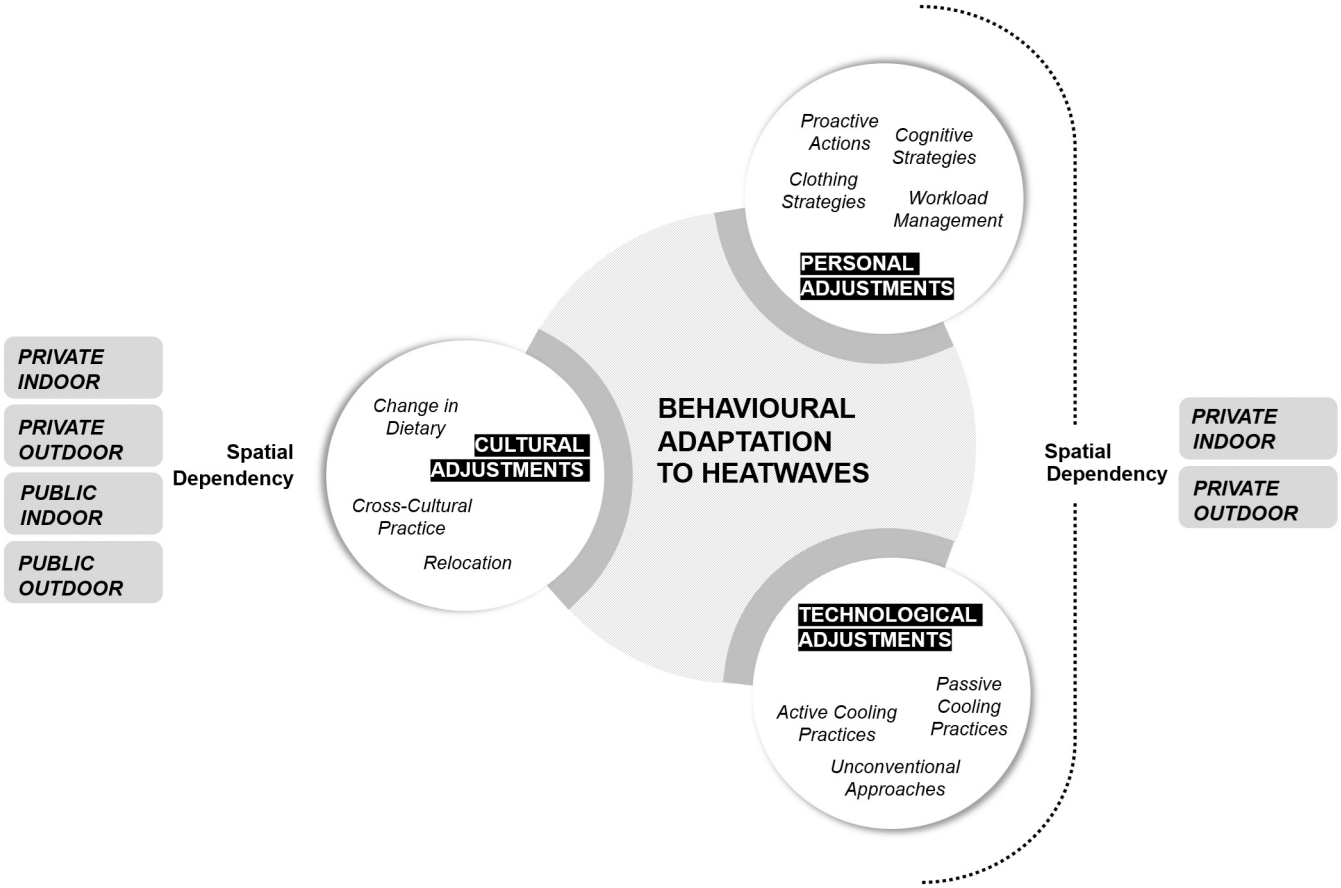

Fig. 8. Behavioural adaptation practices and their associated spatial dependencies.

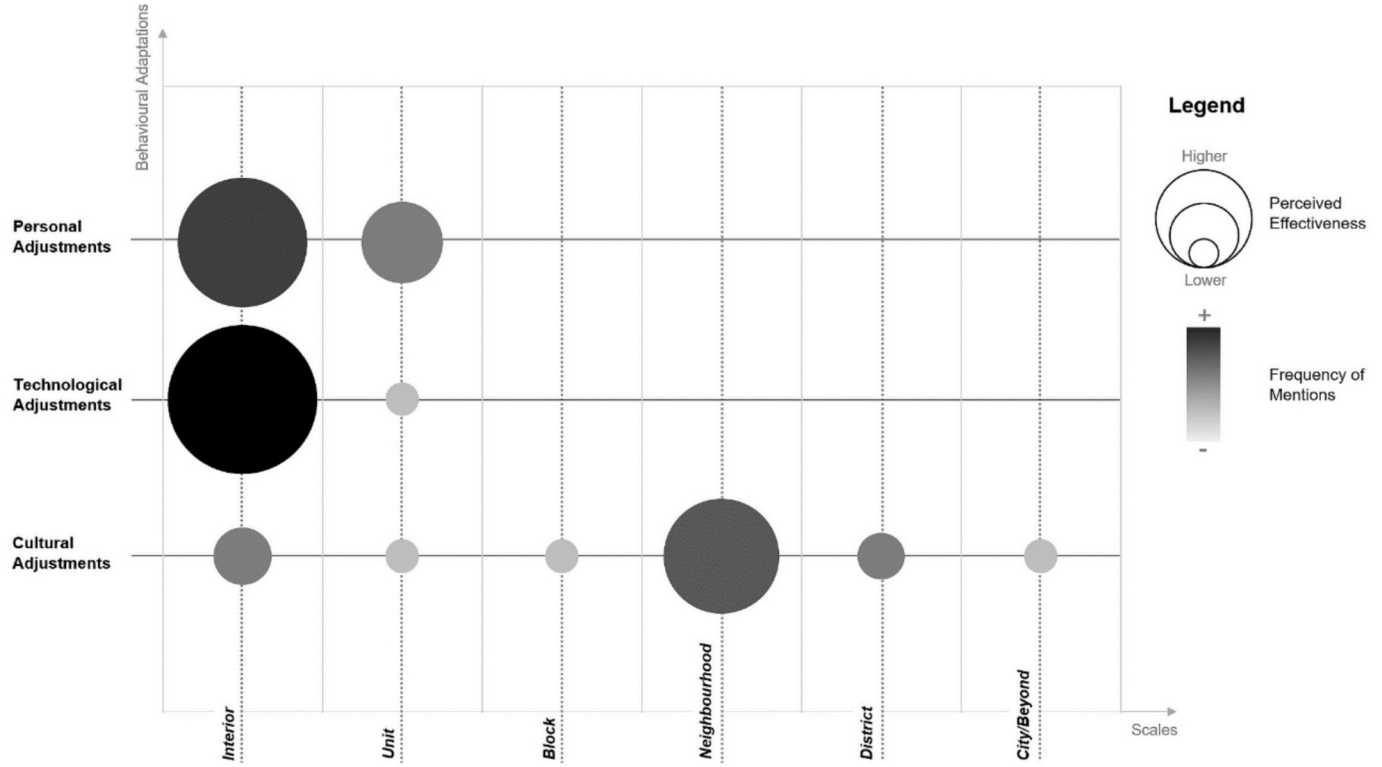

Fig. 9. Behavioural adaptation practices manifested in various spatial scales. Personal and technological adaptations are predominantly individual, while cultural adaptation spans across scales.

behavioural adaptation opportunities within urban communities.

6.3. Implications for policy and future research

Throughout the research, it also became evident that individuals with diverse backgrounds and prior experience in warmer climates often bring new knowledge and practices from their previous contexts to cope with heatwaves in the Netherlands. Recognizing and incorporating this local wisdom is crucial for crafting context-specific approaches to climate adaptation, rather than relying solely on top-down, centralised strategies. Combining experts' knowledge and local knowledge can be useful to build collective capital for local decision-making (McEwen et al., 2022; Hiwasaki et al., 2015) as well as for enhancing communities' resilience to sudden climate shocks (Chen & Graham, 2011; Johnson et al., 2016).

Additionally, the conceptual model derived from the study distils salient findings, offering a schematic representation of various behavioural adaptation practices and their spatial dependencies. Fig. 9 highlights the role of scale in adaptation, emphasising the need for interventions tailored to community characteristics and housing conditions across micro to macro levels. Future research could explore whether these scales have untapped potential and assess the relevance of the findings beyond Rotterdam to other temperate climatic regions. Table 5 links key research insights to potential policy implications, providing a foundation for evidence-based adaptation strategies.

Table 5
Policy implications of key research findings.

Insights	Policy / Spatial Intervention Recommendation
Heat Shock Response	1. Implement real-time heat alerts Before, During and After Summer season to enhance preparedness and response.
Rental Constraints	1. Revise rental regulations to permit and incentivise heat adaptation retrofits (e.g., adding window shades, cross-ventilation). 2. Enforce minimum thermal comfort standards (for both heat and cold) in rental agreements.
Multi-Scale Adaptation	1. Adopt a decentralised heatwave adaptation framework that empowers residents to actively contribute in decision-making. 2. Develop integrated multi-scalar (e.g., block, neighbourhood, district) adaptation plans to ensure that provided cooling infrastructure aligns with residents' adaptation measures.
Leverage Diverse Adaptation Knowledge	1. Establish community knowledge-sharing platforms and integrate local informal adaptation strategies into city/regional policies through participatory approaches.
Cooling Infrastructure Inequality	1. Equity-focused zoning to ensure strategic placement of cooling facilities (e.g., public pools, shaded communal courtyards, drinking fountains). 2. Expand publicly accessible cooling spaces by integrating indoor and outdoor spaces, tailored to diverse user needs.

6.4. Limitations of the study

The study operated within a constrained timeframe, requiring all interviews to be conducted in a three-month summer window (June to August) as participants are mostly accustomed to colder conditions. While peoples' narratives from 21 rich and insightful interviews provide valuable perspectives, a similar study with a longitudinal design combining multiple cases could add further depth and understanding. Additionally, exclusion of certain demographic groups such as the elderly may have limited the perspectives captured in the analysis. Despite these limitations, the findings offer a solid baseline for future research on behavioural adaptation to heatwaves in temperate climates.

7. Conclusion

The study explored the complex dynamics of heatwave adaptation in

the temperate, diverse urban environment of Rotterdam, with a specific focus on behavioural adaptation and associated spatial dependencies. A nuanced examination of participants' experiences and behaviours revealed key factors shaping adaptation practices, including individual agency, social ties, and cultural backgrounds. Findings highlight uneven adaptation opportunities among residents, with those having limited assets, restricted control over their living units facing greater difficulties in coping with heatwaves.

Additionally, spatial domains— private and public, indoor and outdoor spaces— play a pivotal role in citizens everyday adaptation practices against heatwaves. Disparities in the quality of outdoor spaces, such as blue-green infrastructure, public squares, can lead to adaptation inequalities. This underscores the necessity of multiscale adaptation plans and targeted design strategies that address both individual needs and collective practices. Therefore, alongside large-scale, centralised approaches, it is equally important to incorporate bottom-up, small-scale community driven approaches in planning and policymaking. The conceptual framework developed in this study serves as an assessment tool for investigating community behavioural adaptation to heatwaves, while the proposed policy recommendations contribute to the development of informed, evidence-based adaptation and mitigation strategies. Ultimately, fostering meaningful community engagement remains essential for achieving an equitable and climate resilient future for urban populations.

CRediT authorship contribution statement

Istiaque Ahmed: Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Marjolein van Esch:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Frank van der Hoeven:** Writing – review & editing, Supervision, Conceptualization.

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.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2025.106160.

Data availability

Data will be made available on request.

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