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Environmental Justice Dimension of Heatwaves in Temperate Cities

Reconceptualising Urban Heat Vulnerability through Investigating Behavioural Adaptation

Istiaque Ahmed

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Environmental Justice Dimension of Heatwaves in Temperate Cities

Reconceptualising Urban Heat Vulnerability through Investigating Behavioural Adaptation

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus,
Prof.dr.ir. H. Bijl,
chair of the Board for Doctorates
to be defended publicly on
Wednesday 7 October 2026 at 17:30

by

Istiaque AHMED

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Preface

This dissertation is the outcome of several years of learning, questioning, reasoning, reflecting, and researching how cities respond to one of the more understated consequences of climate change: urban heat. Over time, my interest moved beyond understanding heat simply as an environmental hazard towards questioning how we, as researchers, choose to understand it in the first place.

As a critical realist researcher, I was sceptical from the beginning about the dominant ways in which urban heat and heatwave vulnerability are approached. One question kept returning: why, across very different contexts, did so many studies rely on broadly similar approaches, and why did proposed solutions so often converge around certain familiar responses? like more trees and greenery, more efficient materials, improved shading, and other predominantly infrastructure-led interventions. These approaches and interventions are undoubtedly important, nor does this dissertation question their value. What concerned me, however, was whether particular ways of knowing and doing, partly because they are established and have demonstrated effectiveness, may gradually come to dominate the way we think about a problem. When certain approaches become conventional, they can begin to shape the questions we ask, the evidence we search for, and ultimately the kinds of solutions we imagine. Other ways of seeing the same phenomenon may then receive less attention. For me, questioning such assumptions is one of the fundamental purposes of research.

I therefore decided to take a different route, guided by a strong intuition that something important was being overlooked. I started from a simple proposition: knowing the presence, intensity, or spatial location of a hazard is insufficient to understand urban heat vulnerability. Heat is not only a matter of physical exposure; it is experienced, lived, and negotiated through everyday life. This led to a more fundamental question: who can cope with heat, who cannot, and why? People respond through everyday actions that may appear ordinary but collectively form the first line of defence. Yet, as I moved through the literature, I noticed how often this experiential and behavioural dimension remained in the background. Research understandably focused on temperature, exposure, urban form, physical sensitivity, and spatial patterns of risk, while less attention was given to how people experience heat, how they respond, and what enables or constrains those responses. That gap became the starting point of this dissertation and the space where I wanted to make a contribution.

The dissertation therefore places behavioural adaptation at the centre of the inquiry and investigates it through an environmental justice lens. This means asking not only how people respond to heat, but also whether they have equal possibilities to do so, and what conditions enable or constrain those possibilities. Vulnerability, from this perspective, is not only about the conditions to which people are exposed, but also about agency, resources, constraints, and the possibilities available to act.

Although the research is empirically situated in cities with temperate climates, I believe its broader theoretical framing, research approach, and methodological reasoning can also be useful in other contexts. I have always been particularly interested in the philosophical framing, the theoretical positioning, and the process through which an inquiry develops, not only in the final results it produces. I therefore hope readers engage with this dissertation in the same way.

I hope this dissertation contributes, even modestly, to a more human-centred understanding of climate adaptation: one that asks not only where the heat is, but what people are able to do when it occurs.

Acknowledgements

We often say that a PhD is a lone journey. That is true, but not entirely. It reminds me of the classic philosophical argument that human knowledge is always limited by perspective, time, and interpretation. Perhaps the same applies to our individual journeys. There is no truly self-sustaining individual. We may strive for independence, but none of us exists or progresses entirely on our own.

A PhD is no different. Even it may appears to be a solitary process, there are countless crossovers. Our paths merge, align, intersect, and sometimes diverge from the journeys of people with whom we live, work, or simply happen to become connected along the way. What appears to be a lone journey is therefore accompanied by many other pathways. This is what makes acknowledgements important to me: they recognise those intersections, moments, and phases, and make these pages something more meaningful than a formality.

I will start with my closest companion throughout this PhD journey, my better half, **Shaila Islam**. Our decision to move to the Netherlands and begin this chapter of our lives was a collective one, and in many ways the whole journey has been a team effort. Having someone as talented and sharp as Shaila beside me made life much easier. She has been a constant source of energy and, equally importantly, a place of relief throughout this process. I have deep gratitude and respect for Shaila for being my silent support system, often carrying much more of this journey than was ever visible.

Then, our parents, **Rehana Akter** and **Md Mujibur Rahman**, and **Sufia Begum** and **Mohammad Saiful Islam**, played an important role from back home in Bangladesh. Whenever we travelled to Bangladesh, their company, care, and affection gave us the energy to return and continue this long PhD journey. My mother, Rehana, is perhaps my ultimate well-wisher. Because of her constant prayers and unconditional belief in me, I may have finally reached the end of this highest academic degree.

My beloved sister, **Mehebuba Marshia**. I love her, and perhaps nothing more needs to be said. Sometimes it is not necessary for someone to do anything in particular; simply knowing that there is a person who will always be there for you can itself be an enormous source of relief. I also deeply admire the person she has become and the kindness and integrity she carries. Altogether, my partner, my parents, and my sister are the core engine behind the person I am today. Each of them deserves as much credit for this degree as I do.

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Talking about the degree itself, I wholeheartedly acknowledge my guardians, mentors, supervisors, and, over the years, friends: **Frank van der Hoeven** and **Marjolein van Esch**. I cannot be thankful enough that I had them as my supervisors. Beyond everything academic, what mattered most to me was that they are genuinely good human beings. Working with them for such a long period has also helped me reflect on, and gradually shape, the kind of academic and person I want to become. I particularly admire, and hope I have inherited something of, Marjolein's professionalism, commitment, and seriousness about her roles and responsibilities. Frank, on the other hand, repeatedly inspired me to think beyond the obvious: to look at a problem from a distance, from different perspectives, and to prepare not only for what is immediately visible but also for what might lie further ahead. Together, they trained me to be unorthodox and ambitious while remaining rational and grounded. I believe that balance is fundamental to becoming an independent researcher. They have been true promotors, in the actual meaning of the word, not merely by position.

I would also like to express my sincere gratitude to the independent members of my PhD committee: **Prof. Behnam Taebi**, **Prof. Marialena Nikolopoulou**, **Prof. Sanda Lenzholzer**, **Dr. Emmanuel Osuteye** (he was also my MSc thesis supervisor), and **Dr. Lore Van Praag** for their constructive evaluation and valuable comments, which helped improve the overall quality of this thesis.

Further along this journey are my friends, colleagues, and the people I encountered through my research. I would particularly like to mention **Leontine Moen**, such a beautiful soul. I first met Leontine as one of my research participants. From there we became friends, and she is now part of our extended family in the Netherlands. Although I cannot mention every research participant by name here, I remain deeply grateful to all of them. They welcomed my questions, shared their experiences, tried to understand what I was attempting to investigate, and contributed generously to the research. Without them, quite literally, this thesis could not have been written.

In the department, I met some friendly and warm people. **Daniëlle Hellendoorn** was the first person I met at the faculty apart from my supervisors. I also feel a strong connection with all of our secretaries: the boss, **Margo**; the wonderfully innocent **Martine de Jong**; the ever-professional **Astrid**; and **Romy**, always full of life. All of them supported me in different ways and made complicated things much easier, to me they are simply the best Secretariat ever.

My section, Urban Design, deserves a special acknowledgement. I was fortunate to be surrounded by an excellent group of people, and I am thankful to each and every one of them. One of the nicest things about doing a PhD is that, besides your own research, you also get opportunities to take part in various academic activities.

I particularly enjoyed working with **Marcin Dąbrowski** for ABE013 and had a fantastic time conducting the Q2 design studio together with **Alexander Mooi**, I enjoyed every bit of it. Supervising a Master's student alongside **Machiel van Dorst** and **Jacques Vink** was another experience I greatly valued. I also enjoyed several shorter but memorable collaborations and exchanges with **Daniela Maiullari**, as well as working on workshops and summer schools with **Ioana Forgaci**, **Verena Balz**, and **Claudiu Forgaci**.

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So, perhaps a PhD is a lone journey in the end, but only in the sense that one person must ultimately walk across the finish line. But you do not necessarily have to travel there alone. Mine has been crossed, shaped, supported, redirected, strengthened, and enriched by all these people and many others whose names may not appear on these pages. This dissertation carries my name, but the journey behind it was never mine alone.

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List of Abbreviations and Glossary of Key Terms

List of Abbreviations	
Abbreviation	Full form
CBS	Centraal Bureau voor de Statistiek / Statistics Netherlands
CR	Critical Realism
EJ	Environmental Justice
HREC	Human Research Ethics Committee TU Delft
IPCC	Intergovernmental Panel on Climate Change
KNMI	Koninklijk Nederlands Meteorologisch Instituut / Royal Netherlands Meteorological Institute
LISS Panel	Longitudinal Internet Studies for the Social Sciences Panel
PET	Physiological Equivalent Temperature
UHI	Urban Heat Island

Glossary of Key Terms	
Term	**Meaning in this dissertation**
Heatwave	The term 'heatwave' is used broadly to refer to sustained periods of elevated temperature during summer. It is not restricted to the official meteorological thresholds or formal KNMI definition used in the Netherlands. Therefore, terms like Urban Heat, Heatwaves, Heat Events are used synonymously across the dissertation.
Temperate cities	Cities in climatic regions where extreme heat has historically been less frequent, less culturally normalised, and less embedded in urban design and governance practices, but where prolonged heat is becoming increasingly relevant due to climate change.
Urban gradient	Variation across different levels of urbanisation, such as very strongly urban, strongly urban, and moderately urban areas.
Behavioural adaptation	The practices through which people cope with elevated temperatures. In this dissertation, 'everyday adaptation' is used synonymously with behavioural adaptation. It refers to adaptation embedded in ordinary routines and lived environments, not to the claim that heat is an everyday or continuous condition in temperate cities.
Formative composite	A measurement approach in which different indicators collectively define a construct. In this dissertation, behavioural adaptation and hazard perception are treated as formative composites because their components are conceptually distinct and do not need to strongly correlate.
Behavioural adaptation score	A composite score used to assess behavioural adaptation across personal, technological, and cultural adjustment practices.
Hazard perception score	A composite score used to assess heatwave perception through knowledge and attitudes/beliefs.
Environmental justice	A multifaceted framework linking the fair sharing of environmental benefits and burdens through (equal) recognition and (active) participation.

Summary

This dissertation investigates urban heatwave vulnerability in temperate cities by shifting beyond exposure-driven approaches and focusing on behavioural adaptation through an Environmental Justice (EJ) lens. While existing climate risk and urban heat research has made important advances in identifying where heat accumulates, it has paid less attention to explaining why some residents are less able to cope than others under similar thermal conditions. This thesis responds by arguing that heatwave vulnerability is not determined by hazard intensity or exposure alone, but is also shaped by unequal adaptive opportunities, constrained agency, and the socio-spatial conditions that enable or limit behavioural adaptation practices.

Against this backdrop, the central premise of the PhD is that behavioural adaptation is the first line of defence against heat, yet it remains insufficiently understood and is rarely treated as a justice concern. Rather than treating adaptive capacity as an abstract or residual category, the thesis conceptualises behavioural adaptation as a concrete, empirically investigable process that unfolds in everyday life. Coping with heat involves multiple forms of adjustment, including personal, technological, and cultural practices, and that these are spatially dependent, socially differentiated, and unevenly enabled. Accordingly, vulnerability is reconceptualised not simply as a condition of being exposed to heat, but as a question of whether people have the control, knowledge, social support, and spatial options needed to respond effectively when heat occurs.

Grounded in a Critical Realist ontology and a pragmatic–interpretivist epistemology, this research adopts a sequential mixed-methods design with three interlinked stages. First, a critical knowledge assessment is conducted through a systematic literature review to identify dominant patterns, blind spots, and recognition deficits in Dutch built-environment research related to urban heat. Second, a qualitative inquiry in Rotterdam explores residents' lived experiences of heatwaves and their everyday coping practices. Third, a nationwide quantitative survey empirically tests the wider patterning of behavioural adaptation disparities across urban residents in the Netherlands.

This design reflects the thesis's philosophical position that heatwave vulnerability is stratified and cannot be understood through a single methodological lens. Instead, the research moves progressively from empirical experiences, to observable patterns, and from there to the inference of deeper structural conditions and underlying mechanisms.

Findings

This dissertation demonstrates that Dutch urban heat research has been dominated by macro-scale, hazard-oriented, and expert-led approaches, while sensitivity, adaptive capacity, and lived experience have received considerably less attention. This imbalance has produced a recognition deficit in how heat vulnerability is framed and studied: dominant knowledge production has prioritised measurable and scalable indicators, marginalising bottom-up and experiential forms of knowledge essential for understanding how heat is actually encountered and negotiated in everyday urban life.

Through a qualitative case study in Rotterdam, the thesis shows that residents cope with heat through combinations of personal adjustments, technological responses, and cultural or socially mediated practices. These adaptations do not occur uniformly across space. Personal and technological adjustments rely strongly on the dwelling and immediate domestic environment, whereas cultural adjustments often extend into the neighbourhood and public domain through social networks, shared spaces, and informal support structures. Behavioural adaptation, then, is shaped not only by individual choice but also by housing conditions, neighbourhood resources, and the broader built environment.

A nationwide survey further reveals that disparities in behavioural adaptation are not random or merely subjective. Adaptive opportunities are systematically associated with socio-structural and spatial factors such as tacit knowledge, housing tenure, household composition, gender, and urban density gradients. Notably, vulnerability can emerge through everyday living arrangements and housing relations. This reframes vulnerability as relational and context-specific.

When behavioural adaptation is incorporated into vulnerability assessment, a different geography emerges. Some thermally hot areas do not coincide with the places where coping constraints cluster most strongly, while some less conspicuous areas become priority zones once socially and spatially constrained adaptive agency is considered. This refines hazard mapping by complementing exposure-based analysis with a socially grounded understanding of vulnerability.

Contributions

Taken together, these findings yield several contributions.

- Theoretically, the dissertation systematically operationalises EJ in the context of urban heat. Rather than reducing justice to distributive questions alone, it demonstrates that heatwave vulnerability is co-produced through failures of recognition, limitations in participation, and unequal distribution of adaptive resources and opportunities. Recognition is crucial because dominant heat research often overlooks lived experience and tacit knowledge. Participation is essential because these forms of knowledge can only be accessed through people-centred, bottom-up approaches. Distribution remains important, but is broadened beyond physical infrastructure to include the uneven socio-spatial distribution of adaptive opportunities and coping constraints. Through this framing, the thesis shifts the debate from static assessments of exposure toward a more process-oriented understanding of coping, capability, and constraint.

- Methodologically, the dissertation shows how behavioural adaptation constraints can inform spatial prioritisation. This approach complements, and refines hazard mapping, shifting the practical planning question from “where is it hottest?” to “where are people least able to cope, given their social and spatial conditions?”

- Contextually, the research addresses a gap in temperate cities, particularly the Netherlands. Urban heat research has historically been more strongly developed in warmer climates, whereas temperate settings have often been treated as secondary cases. This thesis shows that such contexts require specific attention. In temperate societies, heat is often socially underestimated, culturally normalised as temporary discomfort, or insufficiently recognised as a serious urban hazard. At the same time, the built environment, institutions, and everyday practices remain poorly adapted to increasing heat extremes. Vulnerability in temperate cities may therefore be less visible, but not less significant, and its invisibility may make it harder to recognise and address.

- From a societal standpoint, the dissertation demonstrates that heat vulnerability is not merely an environmental or technical issue, but also a socially differentiated and institutionally mediated condition. Behavioural adaptation is often the first line of defence during heat events, yet it is neither equally available nor fully under individual control. The ability to cope depends on unequal access to material resources, housing quality, social relations, knowledge, and supportive spatial environments. This suggests that equitable adaptation cannot be achieved through infrastructural interventions alone, but must also recognise social infrastructure, informal coping practices, and residents’ situated knowledge as integral components of adaptive capacity.

Conclusion

Overall, this dissertation concludes that urban heatwave vulnerability in temperate cities has been understood too narrowly. By applying an EJ lens to behavioural adaptation, it reconceptualises vulnerability as a socio-spatially produced and institutionally mediated condition shaped by recognition, participation, and distribution. The thesis advances a more context-sensitive and justice-oriented understanding of heat vulnerability, provides a basis for more differentiated vulnerability assessment and spatial prioritisation, and argues for adaptation strategies that attend not only to where heat occurs, but also to where coping is most constrained. Ultimately, cities become more just not simply by identifying their hottest places, but by recognising where residents have the least control, the fewest adaptive options, and the weakest institutional support during heat events—and by designing responses accordingly.

Samenvatting

Dit proefschrift onderzoekt de kwetsbaarheid van bewoners van stedelijke gebieden voor hittegolven in gematigde klimaatzones, en doet dat vanuit een perspectief van milieurechtvaardiheid of “Environmental Justice” (EJ) dat verder gaat dan de gangbare focus op blootstelling. Hoewel bestaand onderzoek naar klimaatricio’s en stedelijke hitte belangrijke vooruitgang heeft geboekt in het identificeren van plekken waar hitte zich ophoopt, is er veel minder aandacht voor de vraag waarom sommige bewoners onder vergelijkbare thermische omstandigheden minder goed in staat zijn daarmee om te gaan dan anderen. Dit proefschrift reageert daarop met het betoog dat kwetsbaarheid voor hittegolven niet uitsluitend wordt bepaald door de intensiteit van de klimaatomstandigheid of door blootstelling, maar ook wordt gevormd door ongelijk aanpassingsvermogen, beperkte handelingsruimte en de sociaal-ruimtelijke omstandigheden die gedragsmatige adaptatie mogelijk maken of juist begrenzen.

Gedragsmatige adaptatie vormt een cruciale, maar in de klimaatliteratuur onderbelichte dimensie van kwetsbaarheid. In plaats van aanpassingsvermogen te behandelen als een abstracte of restcategorie, positioneert dit proefschrift gedragsmatige adaptatie als een concreet (alledaags) proces dat empirisch te onderzoeken is. Omgaan met hitte kent verschillende vormen van aanpassing, waaronder persoonlijke, technologische en culturele praktijken, die plaatsafhankelijk en sociaal gedifferentieerd zijn, en ongelijk gefaciliteerd zijn. Kwetsbaarheid wordt daarom niet langer uitsluitend opgevat als een toestand van blootstelling aan hitte, maar als de vraag of mensen beschikken over de regie, kennis, sociale steun en ruimtelijke mogelijkheden die nodig zijn om effectief te reageren wanneer hitte toeslaat.

Het onderzoek vertrekt vanuit een kritisch-realistische ontologie en een pragmatisch-interpretivistische epistemologie, en volgt een sequentieel mixed-methods-ontwerp met drie onderling samenhangende fasen. In de eerste fase wordt via een systematische literatuurstudie een kritische kennisanalyse uitgevoerd, gericht op het identificeren van heersende patronen, blinde vlekken en vormen van ondererkenning in het Nederlandse onderzoek naar hitte in de gebouwde omgeving. In de tweede fase wordt middels een kwalitatieve studie in Rotterdam verkent hoe bewoners hittegolven in de praktijk beleven en hoe zij hun alledaagse omgangsstrategieën vormgeven. In de derde fase wordt via een landelijke kwantitatieve vragenlijst empirisch getoetst in hoeverre ongelijkheden in gedragsmatige adaptatie systematisch voorkomen onder stedelijke bewoners in Nederland.

Deze onderzoeksopzet weerspiegelt het uitgangspunt dat kwetsbaarheid voor hittegolven een gelaagd en veelzijdig fenomeen is dat niet vanuit één methodologische invalshoek kan worden doorgrond. Daarom ontwikkelt het onderzoek zich van empirische ervaringen naar waarneembare patronen, en van daaruit naar het duiden van diepere structurele condities en de mechanismen die hieraan ten grondslag liggen.

Bevindingen

Dit proefschrift laat zien dat Nederlands onderzoek naar stedelijke hitte wordt gedomineerd door macro-schaalgerichte, klimaatextreem-georiënteerde en door expertmatige benaderingen, terwijl gevoeligheid, aanpassingsvermogen en geleefde ervaring beduidend minder aandacht krijgen. Die scheefgroei heeft consequenties voor de wijze waarop hittekwetsbaarheid wordt geframed en onderzocht: de heersendende kennisproductie heeft prioriteit gegeven aan meetbare en opschaalbare indicatoren waarmee bottom-up en ervaringsgerichte perspectieven zijn gemarginaliseerd. Juist die perspectieven zijn echter onmisbaar om te begrijpen hoe hitte in het dagelijks stedelijk leven daadwerkelijk wordt ervaren en hanteerbaar gemaakt.

Aan de hand van een kwalitatieve casestudy in Rotterdam toont het proefschrift aan dat bewoners omgaan met hitte door middel van combinaties van persoonlijke aanpassingen, technologische strategieën en cultureel of sociaal gemedieerde praktijken. Deze aanpassingen doen zich niet overal op dezelfde manier voor. Persoonlijke en technologische aanpassingen zijn sterk afhankelijk van de woning en de directe leefomgeving, terwijl culturele aanpassingspraktijken zich vaak uitstrekken tot de buurt en het publieke domein via sociale netwerken, gedeelde ruimten en informele (zorg)structuren. Gedragsmatige adaptatie wordt daarmee niet alleen gevormd door individuele keuzes, maar ook door woonomstandigheden, buurtgebonden hulpbronnen en de bredere gebouwde omgeving.

De bevindingen uit de landelijke vragenlijst laten verder zien dat ongelijkheden in gedragsmatige adaptatie niet willekeurig of louter subjectief zijn. Adaptatiemogelijkheden hangen systematisch samen met sociaal-structurele en ruimtelijke factoren, zoals impliciete kennis, woonstatus, samenstelling van het huishouden, gender en gradiënten in stedelijke dichtheid. Kwetsbaarheid kan bovendien voortkomen uit alledaagse woonvormen en (sociale) verhoudingen rondom wonen, waardoor zij moet worden begrepen als relationeel en contextspecifiek.

Wanneer gedragsmatige adaptatie wordt meegenomen in de beoordeling van kwetsbaarheid, ontstaat een andere geografisch beeld. Sommige thermisch sterk belaste gebieden vallen niet samen met de plekken waar beperkingen in het vermogen om met hitte om te gaan het sterkst geconcentreerd zijn, terwijl ogenschijnlijk minder kwetsbare gebieden belangrijke zones worden zodra sociaal en ruimtelijk beperkte handelingsmogelijkheden in beschouwing worden genomen. Daarmee wordt het in kaart brengen van risico's verfijnd door blootstellingsgerichte analyse aan te vullen met een sociaal verankerd begrip van kwetsbaarheid.

Bijdragen

De gezamenlijke bevindingen leveren een aantal bijdragen op.

- Theoretisch operationaliseert dit proefschrift EJ systematisch in de context van stedelijke hitte. In plaats van rechtvaardigheid uitsluitend te benaderen als verdelingsvraagstuk, laat het onderzoek zien dat hittekwetsbaarheid mede wordt gevormd door vormen van miskenning, beperkingen in participatie en een ongelijke verdeling van hulpbronnen en kansen voor aanpassing. Erkenning is cruciaal omdat heersend hitteonderzoek geleefde ervaring en impliciete kennis vaak over het hoofd ziet. Participatie is essentieel omdat genoemde vormen van kennis alleen toegankelijk worden via mensgerichte, bottom-up benaderingen. Verdeling blijft belangrijk, maar wordt verbreed van fysieke infrastructuur naar de ongelijk verdeelde sociaal-ruimtelijke toegang tot adaptatiemogelijkheden en beperkingen in copingcapaciteit. Vanuit deze framing verschuift het proefschrift de aandacht van statische beoordelingen van blootstelling naar een meer procesgerichte benadering van coping, handelingsmogelijkheden en beperkingen.

- Methodologisch laat het proefschrift zien hoe beperkingen in gedragsmatige adaptatie richting kunnen geven aan ruimtelijke prioritering. De vraag verschuift daarmee van "waar is het het heetst?" naar "waar zijn mensen, gegeven hun sociale en ruimtelijke omstandigheden, het minst in staat om met hitte om te gaan?". Deze verschuiving is van essentieel belang voor een rechtvaardiger klimaatbeleid en stedelijke planningspraktijk.

- Contextueel vult het onderzoek een lacune in kennis over steden met een gematigd klimaat, in het bijzonder in Nederland. Onderzoek naar stedelijke hitte is historisch sterker ontwikkeld in warmere klimaten, terwijl gematigde contexten vaak een secundaire positie innemen. Dit proefschrift laat zien dat juist dergelijke contexten specifieke aandacht vereisen. In gematigde klimaten wordt hitte sociaal vaak onderschat, cultureel genormaliseerd als tijdelijk ongemak, of onvoldoende erkend als ernstig stedelijk risico.

- Tegelijkertijd zijn de gebouwde omgeving, institutionele structuren en alledaagse praktijken nog onvoldoende toegerust op toenemende hitte-extremen. Kwetsbaarheid in gematigde steden is daardoor misschien minder zichtbaar, maar niet minder ernstig. En juist die onzichtbaarheid maakt haar moeilijker te herkennen en aan te pakken.

- Maatschappelijk gezien maakt dit proefschrift duidelijk dat hittekwetsbaarheid geen louter milieukundig of technisch vraagstuk is, maar een sociaal gedifferentieerd en institutioneel gemedieerd fenomeen. Gedragsmatige adaptatie vormt vaak de eerste verdedigingslinie tijdens hitteperioden, maar is de mogelijkheden daartoe zijn noch gelijk verdeeld, noch volledig onder individueel te bepalen. Het vermogen om met hitte om te gaan hangt af van ongelijke toegang tot materiële hulpbronnen, woningkwaliteit, sociale relaties, kennis en ruimtelijke condities die aanpassing ondersteunen. Rechtvaardige adaptatie kan dan ook niet worden bereikt via infrastructurele ingrepen alleen. Sociale infrastructuur, informele copingpraktijken en de gesitueerde kennis van bewoners moeten worden erkend als integraal onderdeel van het stedelijk adaptief vermogen.

Conclusie

Al met al concludeert dit proefschrift dat de kwetsbaarheid voor stedelijke hittegolven in gematigde steden tot nu toe vanuit een te nauwe invalshoek is benaderd. Door gedragsmatige adaptatie te benaderen vanuit een EJ-perspectief wordt kwetsbaarheid geherconceptualiseerd als een sociaal-ruimtelijk geproduceerd en institutioneel gemedieerd fenomeen, gevormd door processen van erkenning, participatie en verdeling. Het proefschrift biedt daarmee een meer contextgevoelig en rechtvaardigheidsgericht begrip van hittekwetsbaarheid, legt de basis voor een meer gedifferentieerde kwetsbaarheidsbeoordeling en ruimtelijke prioritering, en pleit voor adaptatiestrategieën die niet alleen oog hebben voor waar hitte optreedt, maar ook voor waar de mogelijkheden om ermee om te gaan het sterkst beperkt zijn.

Steden worden uiteindelijk niet rechtvaardiger door enkel hun heetste plekken identificeren. Ze worden dat door te erkennen waar bewoners de minste regie, de geringste keuzemogelijkheden en de zwakste institutionele ondersteuning hebben op het moment dat hitte toeslaat, en door beleid en inrichting daar daadwerkelijk op af te stemmen.

1 Introduction

1.1 Heatwaves: A Compound Urban Risk

The Global Overview

The Earth's climate is warming. Global mean surface temperatures were approximately 1.3 °C above pre-industrial levels by 2020, with a warming rate of around 0.2 °C per decade. Warming trends are particularly pronounced in Europe, where average surface temperatures have already increased by nearly 2 °C, making it one of the fastest-warming continents globally (Copernicus Climate Change Service, 2023; World Meteorological Organization, 2023). Even moderate increases in average temperature substantially elevate the probability, intensity, and duration of extreme heat events. Under warming scenarios of approximately 2–3 °C, heatwaves are expected to become both more frequent and more severe. As a result, heatwaves have shifted from episodic seasonal anomalies to a systemic hazard with profound consequences for natural and human systems.

The impacts of heatwaves extend well beyond a period of elevated ambient temperature. Extreme heat is directly linked to excess mortality. It is also widely described as a silent killer. During the August 2003 European heatwave, one of the hottest Augusts recorded in many countries, estimates reach up to 70,000 excess deaths across Europe (Ballester et al., 2023). These included approximately 15,000 deaths in France, about 2,000 in the UK, around 2,100 in Portugal, roughly 3,100 in Italy, about 2,400 in the Netherlands, and nearly 300 in Germany (Schär and Jendritzky, 2004; Stott et al., 2004). Following 2003, the 2022 heatwave in Europe also caused a significant number of heat-related deaths (Ballester et al., 2023). Beyond mortality, heatwaves are also associated with increased morbidity. The WHO (2023) report indicates numerous health related problems due to heat. Rapid and sudden thermal spikes can intensify health risks by precipitating heat stress and associated conditions such as heat exhaustion, heat stroke, dehydration, hyperthermia, sleep disturbance, reduced cognitive

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performance, and adverse mental health outcomes. Extreme heatwaves can affect the way brains work, leading to changes in behaviour, mood and often exacerbating neurological conditions (Bongioanni et al., 2021). Heatwaves also cause indirect health impacts by degrading air quality by increasing smog and ground-level ozone (*summersmog*), which further compound respiratory and cardiovascular risks (Kalisa et al., 2018). These health burdens are accompanied by broader economic implications, such as reduced productivity and higher energy consumption, placing additional strain on urban infrastructure and energy systems (García-León et al., 2021; Kjellstrom et al., 2016). Therefore, heatwave effects are often cumulative, particularly during longer, multi-day events, making it a slow-onset but compounding public health hazard rather than a discrete climatic episode.

Crucially, the impacts of heatwaves are not evenly distributed across populations and geographic locations. A growing body of research demonstrates that sociodemographic factors (elderly, children, male, female, low socioeconomic, low education), and pre-existing medical conditions significantly influence sensitivity to heat (Arsad et al., 2022; Campbell et al., 2021). Geographically, cities and urban areas have elevated risks compared to rural areas due to a combination of environmental, infrastructural, and socioeconomic factors (Effat et al., 2022). A high concentration of people, rapid growth and development, industrial and economic activities increase impervious surface coverage, reduce greenery and vegetation, and modify surface albedo (Mentaschi et al., 2022). These processes intensify the urban heat island (UHI) effect, a phenomenon where urban areas become significantly warmer than adjacent rural areas (sometimes by more than 10 °C) with the temperature difference typically being highest during the nighttime (Arnfield, 2003; Oke, 1982). This phenomenon also interacts with heatwaves, amplifying the intensity and impacts and making cities more susceptible to prolonged and intense heat episodes (Katal et al., 2023; Mitchell et al., 2021). Consequently, a heightened UHI effect sustains elevated daytime and nighttime temperatures during heatwaves, raising cumulative heat exposure and impeding physiological recovery, placing urban residents at greater risk (He et al., 2024).

Importantly, these consequences are not uniform even within the same cities (Amorim-Maia et al., 2022). Among others, factors like density, land use, morphology, ecology, and socioeconomic characteristics contribute to intra-urban heat disparities - the temperature difference between areas in the same city. On the exposure side, spatial heterogeneity within cities generates strong microclimatic gradients that amplify the UHI and local heat stress (Nazarian et al., 2022). These microclimatic contrasts translate into unequal impacts because they intersect with socioeconomic and infrastructure conditions shaping differential levels of sensitivity, and adaptive capacity (Slesinski et al., 2025). Research has long

recognised these patterns and identified certain neighbourhoods, individuals, and groups as 'the vulnerables' because they face higher heat-related risks than the rest of the city. However, these disparities are not neutral, or organically developed within cities, rather, they are tied to planning, policy, and governance processes (Meerow and Keith, 2024; Wilson, 2020). At the same time, groups that may appear similarly vulnerable in broad categories are far from homogeneous in their actual circumstances. Vulnerability is further reconfigured by individual, social, cultural, historical, and environmental contexts, which together make urban heat a compound, multidimensional risk (Abunyewah et al., 2025).

The Dutch Context

For much of its history, the Netherlands has been understood as a cool, temperate country shaped by a maritime climate. Although the region is mostly cool, summers across Europe, including the Netherlands, are becoming hotter and more intense due to climate change (AMS Institute, 2020; KNMI, 2021; KNMI, 2023). Both average and extreme temperatures are rising, and scientific projections consistently anticipate a rising number of warm days and a growing frequency of heatwaves (KNMI, 2014). Consequently, what was rarely considered an environmental risk is now increasingly recognised as a serious threat. Periods of unusually high temperatures are commonly referred to as heatwaves or *hitzewelle* in German, *canicule* in French, and *hittegolf* in Dutch. Criteria used to define such events vary across countries and their respective meteorological institutions, so they are not uniform. The Royal Dutch Meteorological Institute (KNMI) defines a heatwave as a period of at least five days with maximum temperatures reaching 25°C or higher, including at least three days with temperatures of 30°C or above at the measuring station in De Bilt (KNMI, 2021).

Historical records illustrate this transformation. Between 1901 and September 2022, the country experienced 28 heatwaves, with 12 occurring after 2000 (as shown in Figure 1.1). The summer heatwave of 2006 lasted 16 days and was one of the most prolonged and severe in at least 100 years. July 2006 was the warmest month in the country's history, resulting in 1000 extra fatalities (CBS, 2006). That year, the Netherlands ranked fifth globally on the list of deadliest disasters by the number of deaths (CRED, 2007). In the more recent 2019 heatwave, the maximum temperature exceeded 40°C for the first time. During the summer of 2022, a maximum temperature of 39.5°C was reported, and surface temperatures (asphalt) in several areas surpassed 50°C (Huiskamp, 2022; ANP and NL Times, 2022). According to the 2021 Climate Signal report, the highest maximum temperature per year has increased by 2.4°C since 1960, more than twice as much as the increase in the annual mean temperature (KNMI, 2021). As heatwaves become more frequent, intense, and prolonged,

Dutch cities are increasingly confronted with substantial health, infrastructure, and environmental pressures. Heat is no longer an anomaly but an emerging urban crisis.

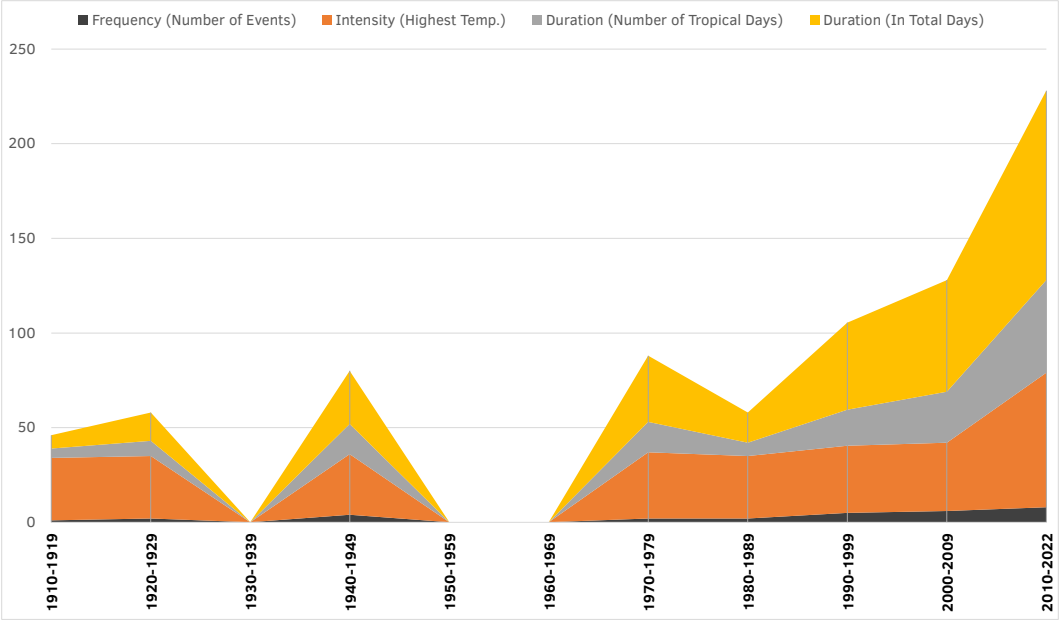

FIG. 1.1 Development of heatwaves per decade in the Netherlands – including maximum temperature, the accumulated number of days during the heatwaves (decade), as well as total number of tropical days. (data source: www.knmi.nl/nederland-nu/klimatologie/lijsten/hittegolven)

Alongside rising temperatures and heat related mortality, the compound nature of heat risk is also evident in Dutch cities. From a public health perspective, according to RIVM (National Institute for Public Health and Environment of the Netherlands) reports, prolonged high temperatures are already causing several health complications including respiratory disease, cardiovascular strain, dehydration, and renal dysfunction among vulnerable populations, including the elderly and those with chronic health conditions (Betgen et al., 2024). Empirical studies further show that extreme heat is linked to increased ambulance call-outs and higher emergency department attendance, indicating measurable pressure on health systems across the country (van Loenhout et al., 2018).

Additionally, factors that further exacerbate the impacts of heatwaves globally, such as the intra-urban climatic differences, and socioeconomic disparities, are also prominent in the Netherlands. Research has documented significant variations

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in heat exposure and the UHI effect linked to urban morphology, land use, and energy consumption (de Groot-Reichwein et al., 2018; Echevarría Icaza et al., 2016; Koopmans et al., 2020). Local urban characteristics also contribute to elevated night-time temperatures, preventing physiological recovery after daytime heat peaks (Heusinkveld et al., 2014; van Hove et al., 2015). Moreover, these spatial variations intersect with social inequalities. For instance, studies in Rotterdam reveal that elderly people are disproportionately affected by UHI effects (van der Hoeven and Wandl, 2015). In Amsterdam, lower-income neighbourhoods tend to have less vegetation and experience higher thermal stress (Rocha et al., 2024). At the national scale, exposure to high land surface temperatures has also been shown to vary by gender within residential areas, highlighting the socio-spatial character of vulnerability (Mashhoodi, 2021).

Taken together, these developments indicate that heat risk in the Netherlands is not merely a meteorological issue but a multidimensional phenomenon emerging from the interaction of climatic dynamics with social, spatial, and institutional conditions. Rising observed and projected temperatures in these regions call for a critical re-evaluation of how heatwave vulnerability is conceptualised and assessed. Existing methodological frameworks are largely derived from regions with historically hotter and often drier climates, leaving an important gap in understanding vulnerability in temperate settings. This research therefore seeks to develop a context-specific account of heatwave vulnerability for temperate climates, using the Netherlands as an empirical case.

1.2 The Contested Concept of Vulnerability

Vulnerability has long been recognised as a central but contested concept in research on risk, hazards, and climate change. It is a complex, multi-dimensional construct. Vulnerability is commonly understood as the degree to which individuals, households, communities, or societies are exposed and susceptible to risks, shocks, and contingencies. Generally, for a specific context, scholars distinguish exposure, sensitivity, and adaptive capacity as the three main components for determining the level of vulnerability. Exposure refers to the degree to which a system encounters a hazard, sensitivity captures how strongly it is affected, and adaptive capacity reflects its ability to cope with or adjust to adverse impacts (Buzási, 2022; Bhattacharjee et al., 2019; Wilhelmi and Hayden, 2010; Cutter et al., 2008; Acosta-Michlik and

Rounsevell, 2008). According to the Intergovernmental Panel on Climate Change (IPCC) approach, exposure and sensitivity share a positive functional relationship with vulnerability, whereas adaptive capacity has a negative functional relationship with vulnerability (IPCC, 2007).

The understanding and operationalisation of vulnerability vary substantially across disciplines, giving rise to a wide range of assessment approaches. According to Kelly and Adger (2000), there are three types of vulnerability assessments: end-point (i.e. vulnerability is measured as an outcome), focal-point (i.e. vulnerability is used as an overarching concept for the assessment), and starting-point (i.e. vulnerability is used for identifying the sensitivity of the system). These distinctions highlight that vulnerability can be framed either as a result of hazards or as a condition produced by social and institutional arrangements. Further differences emerge in the scale and focus of analysis. Some assessments adopt an actor-centred perspective, examining how specific groups or populations experience and respond to risk (Nelson et al., 2010). Others operate at broader spatial or systemic scales framing vulnerability as inherently context-dependent and purpose-driven (Füssel, 2007; Romero-Lankao et al., 2012). As a result, vulnerability is not a fixed or universally measurable attribute but a relational concept whose meaning and implications vary across purposes and settings.

Within vulnerability research, methodological choices have shaped not only how vulnerability is measured but also how it is understood. Broadly, assessments have developed along two dominant traditions: quantitative and qualitative approaches, each grounded in different assumptions about what vulnerability is and how it can be understood. Quantitative approaches have largely sought to produce generalisable and causal accounts of vulnerability which are common and widely used in disaster literature (Alwang et al., 2001). For hazards with visible impacts (i.e. earthquake, flooding) quantifiable approaches help to precisely calculate potential loss, damage, and populations at risk. A key strength of this orientation lies in producing standardised indices and spatial mappings which facilitate comparison and prioritisation (Kelly and Adger, 2000; Cutter et al., 2003; Emrich and Cutter, 2011). Yet these approaches can struggle to capture the intangible root causes of vulnerability. In contrast, qualitative methods excel at uncovering these underlying social, political, and economic drivers, providing rich, contextual understanding. Their limitations, however, include limited scalability and resource intensiveness, which often restricts them to local or regional case studies (Dessai and Hulme, 2004; Benzie, 2014).

These methodological differences are mirrored by a persistent conceptual divide between assessments that focus on biophysical vulnerability (tangible, related to

infrastructure and environment) and socioeconomic vulnerability (abstract, related to social structures and equity). This dualism has contributed to a fragmented understanding of risk, in which physical exposure and social susceptibility are often treated as separate analytical domains (Prall et al., 2024). For hazards such as heatwaves, whose impacts are frequently indirect and mediated through social, economic, and spatial conditions rather than through immediately visible damage, this fragmentation is particularly problematic. Moreover, because heat entails both quantifiable physical exposure and qualitatively differentiated lived experience, its associated risks are especially elusive and analytically challenging.

These challenges are especially pronounced in temperate contexts such as the Netherlands, where heatwave vulnerability cannot be theorised in the same way as in regions with long-standing exposure to extreme heat, which continue to dominate climate research. Hazard dynamics differ, with sudden temperature spikes rather than persistently hot conditions, and the built environment has largely been optimised for winter efficiency rather than summer cooling. Social and institutional factors also diverge, shaping how populations experience and respond to heat stress. In this setting, vulnerability is not determined by exposure alone but is co-produced through context-specific forms of sensitivity and adaptive capacity.

Addressing heatwave vulnerability in temperate climates therefore requires a holistic perspective that moves beyond hazard exposure and spatial distribution to examine the social and institutional conditions that structure unequal adaptive capacities. Such an approach recognises vulnerability not as a fixed attribute of climate or place, but as a relational outcome of environmental change and socio-spatial organisation.

1.3 Environmental Justice: A Critical Lens for Unpacking Vulnerability

Vulnerability research provides a set of frameworks to assess exposure, sensitivity, and adaptive capacity. However, despite their analytical strength, many vulnerability assessments often remain descriptive rather than normative. Conventional risk assessments with a strong hazard and exposure centric approach can adeptly map who is vulnerable and where, but they often fall short of explaining why these particular socio-spatial configurations of risk and limited adaptive capacity persist

over time. This limitation becomes especially apparent in the context of heatwaves. Unlike intensive hazards with immediate and visible consequences, heatwaves exert slow, diffused, and extensive impacts that are less visible, more unevenly distributed, and deeply entangled with everyday life. A vulnerability lens, while necessary, is therefore insufficient for unpacking the deeper social, structural, and spatial processes that produce unequal adaptive capacities in urban environments.

Addressing these shortcomings requires a conceptual shift from identifying vulnerability to questioning its production. Rather than treating vulnerability as a pre-given condition, it should be understood as emerging from overlapping processes that systematically generate and reproduce unequal risks and adaptive capacities (Eriksen et al., 2021). In this regard, the Environmental Justice (EJ) framework provides a critical and explicitly normative lens to move beyond hazard or exposure centric framings of heatwave vulnerability toward an examination of the social, structural, and spatial dynamics that contribute to producing adaptation disparities.

Originating from grassroots struggles against the disproportionate burdens of environmental hazards in marginalised communities, EJ was initially concerned with the unequal distribution of environmental burdens only (Bullard, 1993). Over time (Table 1.1), it has evolved into a robust conceptual framework that explicitly links environmental risk to questions of social inequality, power, and institutional responsibility (Taylor, 2000). Rather than stopping at the identification of uneven outcomes, EJ asks how and why certain populations are rendered more vulnerable than others, and through which social and political processes these inequalities are sustained (Agyeman et al., 2002; Pellow, 2000).

TABLE 1.1 Justice from Different Philosophical Orientations.

Orientation	Contributors	Conception
Liberal Egalitarian (Distributive Justice)	John Rawls (1971)	Fairness as justice; equitable distribution of primary goods
Libertarian / Neoliberal	Friedrich Hayek (1976); Milton Friedman	Justice defined procedurally via free markets and individual liberty; minimal state redistribution
Marxist / Political Economy	Karl Marx; David Harvey (1973)	Justice requires transformation of capitalist social relations; redistribution alone insufficient without changing production relations
Communitarian	Michael Sandel; Alasdair MacIntyre (1988)	Justice grounded in shared values, traditions, and social membership; critique of abstract universalism
Post-structuralist	Michel Foucault (1977); Judith Butler (1990)	Justice concerns how power produces subjects, norms, and categories; focus on domination through discourse and institutions
Feminist / Intersectionality	Bell Hooks; Kimberlé Crenshaw	Justice must address intersecting systems of oppression (gender, race, class); emphasis on lived experience and care
Capabilities Approach	Amartya Sen; Martha Nussbaum (1993)	Justice as expansion of substantive freedoms (capabilities) to live a life one has reason to value
Critical Pluralist	Iris Marion Young (1990); Nancy Fraser (1997)	Justice requires addressing structural oppression, cultural misrecognition, and political exclusion together (recognition–redistribution–representation)
Environmental Justice	David Schlosberg (2007); Robert Bullard (1993)	Justice links environmental risk to social inequality, power, and participation; integrates distribution, recognition, and procedural justice

EJ is situated within wider debates on justice that extend beyond environmental scholarship. Within justice theory, several distinct orientations can be identified. Liberal egalitarian approaches conceptualise justice primarily in terms of basic liberties and the fair distribution of social goods through institutional arrangements (Rawls, 1971). Out of this distributive orientation, Marxist political economy advances a more structural critique, arguing that redistribution alone is insufficient as long as the political–economic relations that systematically generate inequality remain intact (Harvey, 1973). The capabilities theorists extend this debate by shifting attention to people's substantive freedoms to achieve valued ways of living (Nussbaum and Sen, 1993). Post-structuralist and feminist critiques further challenged both liberal and Marxist frameworks for their tendency to privilege material distribution while under-theorising power, structure, social and cultural domination. Thinkers such as Foucault (1977) and Butler (1990) emphasised how prior frameworks failed to recognise diversity in race, ethnicity, and gender, instead subsuming them all under the single category of 'marginalised group'.

Building on these, Young (1990) and Fraser (1997) reconceptualised justice as a multidimensional concern involving not only maldistribution but also misrecognition and systemic exclusion, foregrounding the importance of difference, voice, and procedural inclusion.

Synthesising these traditions, Schlosberg (2007) coins Environmental Justice (EJ) as a normative framework comprising three interrelated dimensions: 'Recognition,' 'Participation,' and 'Fair Distribution'. Rather than treating these as separate domains, Schlosberg argues that they are mutually constitutive. Failures of recognition and participation undermine distributive justice by shaping whose needs are visible, whose knowledge is considered legitimate, and whose interests are represented in decision-making processes. In this sense, recognition and participation function as pre-requisites for fair distribution. EJ thus reframes inequality not merely as an uneven outcome of environmental risk but as the product of social, political, and epistemic processes through which vulnerability is produced and sustained.

Applied to heatwaves, EJ functions not merely as a theoretical stance but as an analytical tool. Heatwave vulnerability is not simply a matter of meteorological hazard, but a socially produced and unevenly distributed condition, particularly in heterogeneous urban environments. An EJ perspective makes visible whose vulnerabilities are systematically recognised and whose vulnerabilities remain obscured. Rather than re-labelling heat as unequal, EJ directs attention to the mechanisms through which such inequalities are produced and sustained, thereby rendering vulnerability research more accountable and action-oriented. It can also help to explain how adaptive capacities are shaped, how they are linked to the built environment, and how social stressors and cumulative burdens influence everyday experiences of heat. As a normative and analytical framework, EJ foregrounds misrecognised contextual realities and interrogates the processes through which vulnerability is constituted. Overall, EJ exposes, and seeks to respond to the social, structural, and spatial inequalities that heat hazards pose.

In this thesis, EJ therefore provides the conceptual foundation for moving beyond exposure-centred assessments toward a deeper examination of adaptation disparities. It creates the analytical space to foreground self-directed practices, contextual constraints, and differential capacities to respond to heat. These dimensions are central to vulnerability in temperate urban contexts and are taken up in the next section through the introduction of behavioural adaptation as both a first line of defence and a critical EJ concern.

1.4 Behavioural Adaptation: The First Line of Defence and a Key EJ Concern

If vulnerability to heatwaves is understood as partly socially produced rather than merely climatically induced, then behavioural adaptation occupies a central analytical position. Behavioural adaptation, also referred to as everyday or autonomous adaptation, is a set of actions taken before, during, or after a hazard event with the aim of preventing or minimising anticipated or negative consequences (Kreibich et al., 2015). Because these actions are immediate, situational, and embedded in lived practices, they represent the most proximate mode of response to heat stress and therefore constitute the first line of defence against heat-related harm.

The conceptual roots of behavioural adaptation in relation to heat can be traced to the human thermal adaptation literature. In 1981, Auliciems introduced the psychophysiological model of thermal perception, in which thermal adaptation was conceptualised as both a physiological and psychological response influenced by climatic and cultural determinants (Auliciems, 1981). Building on this, in 1997, de Dear developed the concept of 'human thermal adaptation', and de Dear and Brager (1998) later outlined three key components of the concept which are: (i) behavioural adaptation, (ii) psychological adaptation, and (iii) physiological adaptation. While traditional behavioural research is more focused on lab-based experimentation for predicting human responses in a static thermal environment, the human thermal adaptation framework is conceptualised to account for subjective responses in real-life thermal conditions. Within this framework, out of the three key components, behavioural adaptation refers to the deliberate actions through which individuals modify their behaviour or immediate environment in response to thermal discomfort. These adaptations can be analytically distinguished into three broad types, namely personal, technological, and cultural (de Dear and Brager, 1998). 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, daily routines, taking a siesta, that help individuals cope during heatwaves. The remaining two components include psychological adaptation, which relates

to the cognitive and perceptual processes that motivate adaptive behaviour, and physiological adaptation, which concerns the body's functional adjustments in response to increasing temperatures.

Since the study aims to investigate behavioural adaptation against heatwaves in urban environments, the 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 shows 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, to develop a thorough understanding, this study considers heatwave risk perception in conjunction with behavioural adaptation.

Building climate resilience requires the integration of behavioural practices at both individual and collective levels. These individual and collective adjustments often constitute the first line of defence against imminent climate hazards and are a key determinant of population's overall hazard sensitivity. The IPCC notes with high confidence that, as evidenced by numerous global examples, people with limited access to structural or financial resources predominantly rely on autonomous adaptation, a reactive and often individual-level response, as their primary and even only recourse against climate crisis (Birkmann et al., 2022). Yet, these autonomous behavioural adaptation practices are not merely a matter of personal choice but are deeply embedded in the social processes and institutional structures that determine what people are actually able to do in practice. For instance, the ability to seek relief in cooler spaces depends on the accessibility, distribution, and perceived safety of public spaces and cooling infrastructures (Hogeweij et al., 2025). Similarly, adaptive actions are strongly influenced by resources, norms, housing provisions, societal and governance structures (Berger et al., 2022). Moreover, disparities in monetary, material, and knowledge-based resources contribute to differentiated adaptation practices across communities (Madrigano et al., 2018; Palinkas et al., 2022). Because these enabling and constraining conditions are unevenly distributed across neighbourhoods and social groups, individuals exposed to similar thermal conditions may nonetheless possess markedly different capacities to practice adaptive behaviours, positioning it as a fundamental justice concern (Oppermann et al., 2018). However, a comprehensive understanding of these behavioural responses remains limited, particularly in temperate regions. This gap persists partly because few studies take a granular approach to exposure and vulnerability (Voelkel et al., 2018), or consider the nuanced, individual experiences of heat stress and

other climate impacts (Zhang et al., 2024). Consequently, the underlying factors that shape the behavioural adaptation processes are often overlooked, limiting the effectiveness of broader resilience strategies that ultimately depend on these localised, everyday practices.

1.5 Research Gap

As mentioned in the prior sections, this thesis responds to a set of interrelated gaps in how behavioural adaptation to urban heatwaves is conceptualised, empirically investigated, and translated into planning and policy practice in temperate contexts. Rather than treating heatwave vulnerability as a largely structural or infrastructural condition, the thesis foregrounds behavioural adaptation as a central yet systematically under-theorised component of heatwave vulnerability. It advances the argument that everyday adaptation practices are not simply peripheral responses but a critical entry point for understanding and addressing heatwave vulnerability in temperate regions. Anchored in the EJ framework, gaps at three interconnected levels, conceptual, empirical, and practical, are discussed below:

1 Conceptual Gap (The Recognition Dimension)

There is a growing recognition of extreme heat as a pressing hazard in temperate cities, yet knowledge about how people perceive, experience, and adapt to such conditions remains fragmented. Individuals autonomous, everyday coping practices form a vital part of heatwave resilience but have received limited attention (Bourret Soto and Guillon, 2024; Hendel et al., 2017). A dominant conceptual orientation in urban heat research has historically centred on quantifying thermal exposure and modelling its association with health outcomes such as mortality and morbidity, relying largely on standardised and measurable indicators (Basu and Samet, 2002; Gasparrini et al., 2015). Over time, a growing body of scholarship has extended this approach by incorporating social dimensions of vulnerability moving beyond purely climatic determinants (Schoessow et al., 2022; Wolf and McGregor, 2013; Wong et al., 2025). Despite this broader social turn, behavioural adaptation remains comparatively underrepresented and analytically fragmented within urban heat research. Where behavioural responses are considered, they are commonly framed as individualised or residual factors rather than as socially and spatially embedded practices (Smit and

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Wandel, 2006). As a result, dominant vulnerability assessments struggle to account for how place-specific conditions mediate people's actual ability to respond to heatwaves, particularly in temperate cities where behavioural responses are often less visible and less formally recognised (Bourret Soto and Guillon, 2024; Maller and Strengers, 2011).

As previously discussed, unlike many other environmental hazards, understanding the lived experiences of heatwaves is critical for developing effective and equitable adaptation strategies. Without such grounding, interventions risk being locally unresponsive, undermining their long-term sustainability and, in some cases, producing maladaptive outcomes (Bremer et al., 2019; Haque et al., 2017). This persistent gap highlights the need for integrative approaches that bridge objective, data-driven indicators with the lived and subjective experiences through which heat vulnerability is actually manifested and perceived.

2 Empirical Gap (Context-Specificity)

Despite growing global attention, temperate regions remain empirically under-represented in heatwave research. Much of the existing evidence and methodological frameworks follow examples from hotter, drier contexts where heat is chronic and continuous. In contrast, cities with a temperate climate experience shorter, more abrupt thermal extremes that interact with the built-environment which is designed primarily for winter. Not only the climate but also the social and institutional conditions differ. For instance, in highly developed contexts such as the Netherlands, everyday life is strongly formalised through reliable infrastructures, regulated housing systems, and institutionalised service provision. While this ensures efficiency and reliability, it can also make people less accustomed to dealing with uncertainties independently (van der Linden, 2015; Wachinger et al., 2013). Consequently, informal or personal coping mechanisms are often underdeveloped, leaving individuals less prepared to respond autonomously to unexpected events such as heatwaves. Examining behavioural adaptation therefore can provide a critical empirical lens for identifying differentiated coping capacities and the structural conditions that constrain or enable them.

At the same time, cities in the Netherlands are also undergoing a demographic shift, bringing together populations from diverse backgrounds. This produces a complex setting with distinct characteristics, advantages, and challenges. This demographic heterogeneity produces urban contexts in which exposure to heat may be similar, yet capacities to anticipate, interpret, and behaviourally respond to heat differ substantially (Amorim-Maia et al., 2022). Adaptive practices are therefore not solely shaped by climatic conditions but emerge from the intersection of social position,

spatial context, and institutional arrangements. Rather than relying on insights from warm-climate regions, temperate regions require their own empirically grounded studies that capture and address their unique social, spatial, and structural dynamics. Addressing this empirical void is essential for developing locally relevant strategies that reflect how vulnerability is actually produced and experienced, rather than assuming it operates uniformly across contexts.

Overall this empirical gap corresponds to the participation dimension of the EJ framework. Temperate regions lack context-specific research that foregrounds citizens' voices, lived experiences, and everyday adaptive practices, thereby limiting opportunities for their meaningful inclusion in knowledge production and decision-making processes.

3 Gaps in Policy and Practice

As a consequence of the fragmented and siloed nature of heatwave research where climatology, health, social, and urban design perspectives are often developed in parallel rather than in an integrated manner, adaptation policies and practices tend to privilege interventions that are most readily operationalised within existing planning and governance frameworks. Consequently, a dominant policy imaginary has emerged in which heatwaves are primarily framed as an external environmental problem to be mitigated through infrastructural and physical interventions, such as increasing greenery, reducing impervious surfaces, improving building insulation, using high albedo materials and so on (Castro and Sen, 2022; Nightingale et al., 2020). These structural interventions are important for long-term resilience, however, they take decades to yield tangible benefits.

At the same time, many European countries, including the Netherlands, have developed heat related action plans aimed at reducing immediate risks during extreme heat events. In the Dutch context, these are known as the *hitteplannen*, coordinated by the RIVM. These plans play an important role in raising awareness and providing behavioural guidance during heatwaves. However, while some measures are specifically targeted at care facilities such as elderly homes and daycare centres alongside general public advice, the overall approach remains largely standardised and tends to assume relatively comparable exposure conditions and adaptive capacities across urban populations. Such an approach inadequately accounts for intra-urban differences, socio-cultural practices, and neighbourhood conditions which eventually shape how heat is experienced and managed in everyday life. Therefore, behavioural guidelines are promoted in principle but remain weakly embedded in place-specific and spatially differentiated strategies. From

an EJ perspective, this unconscious homogenisation carries important risks. It can obscure uneven adaptive constraints, marginalise context-specific needs, and shift responsibility onto individuals without adequately recognising the structural and spatial conditions. Simultaneously, the distributive scenario of behavioural adaptation (the question of who is able to adapt, how, and under what conditions) remains largely unexplored within such action plans. Understanding the uneven distribution of behavioural adaptation opportunities can provide critical insight into how heatwave inequalities are produced and sustained across cities. Acknowledging and supporting residents' ability to engage in short-term actions can democratise adaptation and can also help formulating effective low-hanging solutions, offering immediate and accessible forms of resilience that complement long-term infrastructural strategies.

1.6 Research Aims, Objectives, and Questions

Research Aims

This dissertation aims to rethink how urban heatwave vulnerability is understood in temperate cities. Rather than conceptualising vulnerability primarily in terms of exposure or long-term infrastructural capacity, the study foregrounds behavioural adaptation as a justice issue, shaped by social, spatial, and institutional conditions rather than individual choice alone.

Using an EJ perspective, the research examines how urban residents experience heatwaves in everyday life, how their adaptive practices are enabled or constrained, and how capacities to adapt are unevenly distributed across social groups and urban contexts. In doing so, the study addresses the central question:

— **How does applying an Environmental Justice lens to behavioural adaptation reconceptualise urban heatwave vulnerability in temperate cities, and how can this inform just and context-sensitive short-term adaptation strategies?**

Taking the Netherlands as a case, the study develops a contextually rooted and empirically substantiated understanding of behavioural adaptation, and uses this understanding to identify priority areas for short-term action with implications for more just and targeted heat adaptation policy.

Research Objectives

Guided by the research aims, the dissertation pursues the following interrelated objectives:

1. **To critically examine how heatwave vulnerability is currently recognised and framed in dominant research and practice,** with particular attention to epistemic assumptions, spatial scales, and methodological orientations that privilege exposure while marginalising lived experience and adaptive processes.

2. **To empirically ground heatwave vulnerability in lived experience** by examining how urban residents perceive, negotiate, and practise behavioural adaptation during heatwaves, and associated spatial dependencies.

3. **To systematically assess the distribution of behavioural adaptation opportunities across socio-demographic groups and urban contexts**, identifying the social, structural, and spatial mechanisms that generate unequal adaptive capacity in temperate cities.

4. **To translate behavioural adaptation and EJ insights into a spatially explicit prioritisation logic**, enabling the identification of urban areas where residents face constraints in coping with heatwaves and where short-term interventions are most urgently needed.

Research Questions

To achieve the overall research aim and address the core research question, the study is organised around the following research questions:

1. How is urban heatwave vulnerability currently conceptualised and operationalised in dominant research and practice across different spatial scales in the Netherlands, and what epistemic limitations are associated with such framings?

2 How do urban residents perceive, experience, and negotiate heatwaves through behavioural adaptation in Dutch cities, and how do socio-spatial and structural conditions shape their adaptive agency?

3 How are behavioural adaptation opportunities unevenly distributed across socio-demographic groups and urban gradients in the Netherlands, and what social, structural, and spatial factors contribute to these inequalities?

4 How can behavioural adaptation constraints, through an Environmental Justice lens, be spatially operationalised to identify priority urban areas for short-term heatwave adaptation interventions in temperate cities?

1.7 Thesis Structure

This thesis follows a manuscript-based doctoral format, comprising three standalone manuscripts published in peer-reviewed journals. While each manuscript addresses specific research questions, they collectively contribute to the achievement of the overarching research goal. The texts from these published works have been reformatted for consistency and are included as Chapters 3, 4, and 5 of this dissertation. The following Table 1.2 details the status and bibliographic information for each manuscript included in this work.

TABLE 1.2 List of manuscripts included in this thesis.

Manuscript	Title	Journal	Status
I	Heatwave vulnerability across different spatial scales: Insights from the Dutch built environment	Urban Climate	Published
II	Behavioural adaptation to heatwaves in a temperate city: Insights from Rotterdam	Cities	Published
III	Navigating Heatwaves in a Temperate Climate: Barriers to Behavioural Adaptation in Dutch Urban Areas	Climate Risk Management	Published

To clarify how the research aim, objectives, and questions are operationalised across this dissertation, Figure 1.2 provides an overview of the conceptual alignment between the four research questions and the three empirical manuscripts.

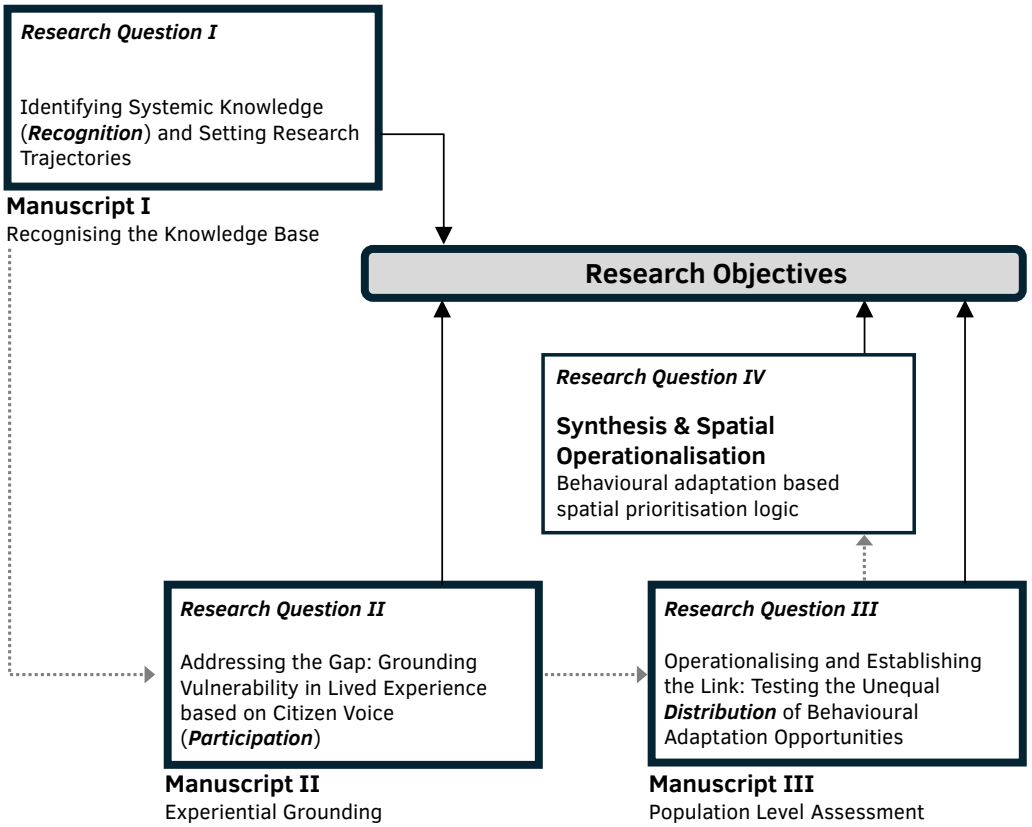

FIG. 1.2 Conceptual alignment of research objectives, research questions, and the three manuscripts comprising the dissertation.

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Research Ethics

This PhD research received ethical approval (Ref. 2313) from the Human Research Ethics Committee (HREC) of Delft University of Technology (TU Delft) on 04 July 2022. All research activities, including data collection, storage, and processing, were conducted in accordance with TU Delft's ethical guidelines for research involving human participants. Participants involved in the different phases of the study were provided with clear information about the purpose of the research, the voluntary nature of participation, and their right to withdraw at any stage without consequence. Informed consent was obtained prior to participation.

The survey was conducted through the Longitudinal Internet Studies for the Social Sciences Panel (LISS Panel), a GDPR-compliant online research facility in the Netherlands managed by Centerdata, which adheres to established protocols for secure data handling and participant protection.

Statement on the Use of Generative AI Tools

Generative artificial intelligence (AI) tools were used to support literature searching, reading and understanding concepts, academic articles, and improving grammar, clarity, and language. The overall conceptual development, research design, analyses, diagrams, interpretations, and conclusions presented in this dissertation are my own, and I take full responsibility for them.

N.B.: *One of the three published articles included in this dissertation, Manuscript I (Chapter 3), was completed before the generative AI era and therefore did not involve any AI assistance.*

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2 Methodology

This chapter delineates the philosophical and methodological underpinnings of this research. It begins by articulating the research paradigm, including the ontological, epistemological, and methodological standpoints, and then outlines the study design, data collection methods, and analytical procedures.

2.1 The Research Paradigm

The development of a contextually grounded understanding of heatwave vulnerability through an environmental justice lens requires a coherent and justified research framework. Each research initiative needs its own set of beliefs or assumptions known as a paradigm (the system of inquiry) (Creswell, 2009; Kuhn, 1970). This choice of paradigm is not merely a technical step but a foundational decision that informs what constitutes valid knowledge, how reality is understood, and how inquiry is procedurally conducted by the researcher (Guba and Lincoln, 1994). A research paradigm comprises an ontology, an epistemology, and a methodology.

1 Ontology

According to Michael Crotty (1998), ontology is the branch of philosophy concerned with the nature of reality. Ontological assumptions define and clarify a researcher's view on the very nature of the reality, determining whether it is understood as an objective, external reality that exists independently of human perception or as multiple, subjective realities that are socially and experientially constructed, or as stratified and only partially accessible through observation (Guba and Lincoln, 1994). These foundational beliefs regarding the reality directly shape the entire research process, from the formulation of the research question to the methods deemed appropriate for investigation (Bryman et al., 2021).

A key aim of this dissertation is the reconceptualisation of urban heat vulnerability in the context of temperate regions. Reconceptualising vulnerability requires an ontological stance that recognises reality as stratified. Vulnerability cannot be reduced to what is immediately measurable or verifiable, nor can it be treated as purely socially constructed. Instead, it must be understood as emerging from the interaction between physical conditions, social structures, institutional arrangements, and human agency. Our knowledge of these processes is partial and mediated through empirical observation. Any account of vulnerability must therefore acknowledge that observable patterns represent only a partial expression of deeper causal processes. Within this philosophical terrain, Critical Realism (CR) provides the most coherent ontological grounding for the study (Figure 2.1).

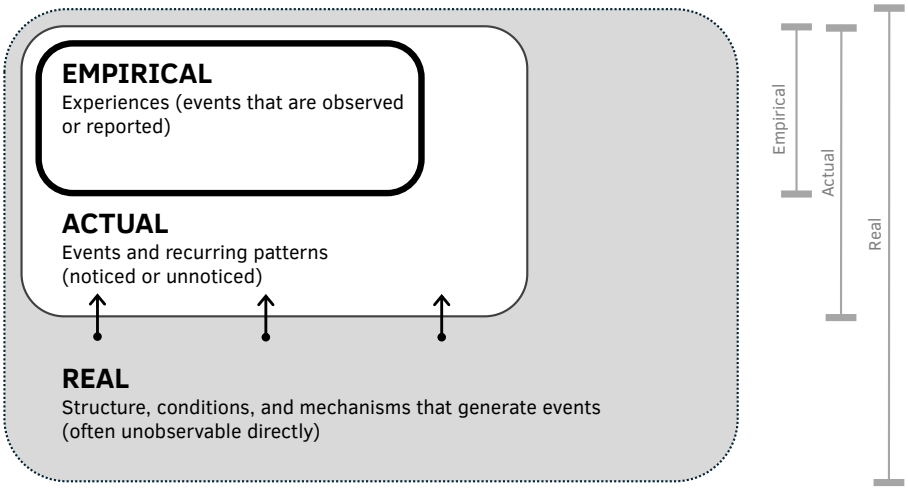

FIG. 2.1 Ontological standpoint of critical realism, adopted from Bhaskar (1975).

Developed primarily by Roy Bhaskar (1975), CR offers a robust philosophical framework for research queries that seek to understand the world in terms of its underlying structures and mechanisms. CR advances a stratified ontology composed of three interrelated domains. The empirical domain refers to what is experienced or observed, the actual domain encompasses events and patterns that occur whether or not they are observed, and the real domain consists of the underlying structures and generative mechanisms that produce those events and patterns (Alderson, 2013). While empirical observation and the identification of actual patterns can reveal associations, they do not by themselves explain the deeper generative mechanisms that produce those patterns. CR therefore aims not only to describe what happens, but to explain why and how particular events, experiences, and inequalities come into being.

Beyond facts and statistics, this dissertation acknowledges that urban heatwave vulnerability is produced by stratified, emergent socio-material realities. Beyond facts and statistics, this dissertation understands urban heatwave vulnerability as a stratified and emergent socio-material condition. To interpret the justice implications of this stratified reality, the research employs Environmental Justice (EJ) as its critical analytical and normative lens. The integration of CR and EJ is theoretically important. While CR provides the ontological scaffolding for analysing the complex and layered nature of reality, EJ interprets social mechanisms and institutional configurations that produce unjust patterns of vulnerability (Sayer, 2000; Walker, 2012). In combination, they enable the research to move beyond describing empirical experiences of heat (the what), and documenting spatial or social distributions (the who and where), towards explaining potential generative mechanisms (the why and how) that underpin unequal heat vulnerability in temperate cities.

2 Epistemology

Epistemology addresses the nature of knowledge and how we can justify what we claim to know. For instance, Bhaskar's key point was that ontology determines epistemology, which is the way things are determined the way we know them and the extent to which they can be known. Grounded in a critical realist ontology which posits a stratified reality that we can only know imperfectly, this research adopts a pragmatic-interpretivist epistemology. The interpretivist component recognises that social reality is provisional, constituted through intersubjective meanings that require understanding rather than explanation through causal laws alone (Berger and Luckmann, 1966). And from pragmatism, it treats knowledge as emerging from situated experience and as validated through its practical adequacy in addressing concrete problems (James, 1907; Peirce, 1878). Accordingly, knowledge of heatwave vulnerability is understood as inherently partial, fallible, and context-dependent. The goal is not to search for a single, ultimate truth, but rather to understand the different layers of reality underlying heat vulnerability, in order to develop useful interpretations that help unpack not all, but certain fundamental mechanisms that constitute vulnerability.

Following the pragmatic-interpretivist framing, the study rests on two complementary pillars. First, it holds an interpretivist core, acknowledging that social reality is accessed through meanings, beliefs, and intentions constructed in human interaction and lived experience (Schwandt, 1994). This perspective justifies the qualitative exploration of residents' experiences, because their narratives provide empirical access to experienced heat, reported coping practices, and the everyday contexts in which adaptation takes place.

Second, is the pragmatic core, where the value of knowledge is assessed by its usefulness and capacity to generate change. Within a CR ontology, this pragmatism bridges the interpretive understanding of lived experiences with the real domain, seeking to infer and explain the generative mechanisms that produce unequal behavioural adaptive opportunities (the unit of exploration). In this respect, the EJ lens functions as both an analytical and normative bridge. It re-conceptualises heatwave vulnerability from the ground up and then, normatively, it interprets unequal adaptation opportunities as matters of justice rather than as individual differences in coping.

Therefore, a pragmatic–interpretivist epistemology establishes the rules of engagement for this study: it recognises subjective experience as legitimate empirical evidence, employs abductive and retroductive reasoning to identify underlying mechanisms. Abduction helps reinterpret everyday heat-coping practices as justice-relevant behavioural adaptation opportunities, while retroduction helps infer the deeper social, spatial, material, cultural, and institutional mechanisms that generate unequal adaptive capacity (Figure 2.2).

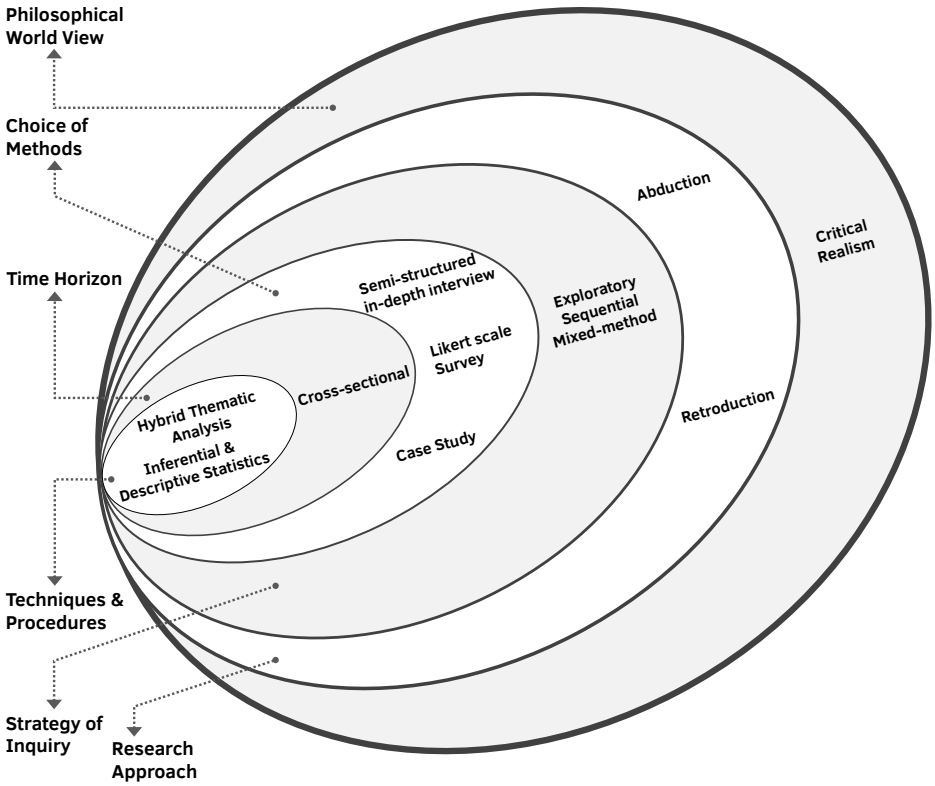

FIG. 2.2 The study's philosophical stance and its implications for design choices.

An outer-to-inner cascade from Critical Realism (ontological stance) through abduction and retroduction (reasoning), to an exploratory sequential mixed-methods approach (methodological choice), operationalised via case study and Likert-scale survey strategies within a cross-sectional time horizon, and implemented through semi-structured interviews, hybrid thematic analysis, and descriptive/inferential statistics.

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3 Methodology

Building on this ontological and epistemological position, the study adopts an exploratory sequential mixed-methods design to investigate vulnerability to urban heat in temperate urban contexts, using the Netherlands as the empirical case. Behavioural adaptation serves as the empirical entry point for this exploration. It is understood, and operationalised not as an individual preference, but as the practical capability to enact protective measures within given socio-spatial, institutional, and material conditions. This framing positions behavioural adaptation opportunity as a first line of defence against heatwaves and as a justice concern, since social, structural, and spatial conditions shape people's agency to adapt and, consequently, their vulnerability.

A CR approach therefore can explicate the underlying mechanisms and latent structures of heatwave vulnerability that are not immediately observable at the surface and are often overlooked in practice. Because behavioural adaptation is complex, context-specific, and shaped by both individual and collective conditions, the research requires a design that can first access residents' lived experiences and then examine whether the insights derived from those experiences appear as broader social and spatial patterns. This allows the research to move beyond description and measurement, and to explain what matters behind the unequal behavioural adaptation opportunities in specific urban contexts.

Following CR's three domains of reality, the research treats (i) the empirical domain as what is observed, reported, or represented, including both existing heatwave research and residents' accounts of heat experience; (ii) the actual domain as recurring events, tendencies, and patterns (in behavioural adaptation) that may or may not be noticed; and (iii) the real domain as the underlying generative mechanisms that, in specific contexts (the Netherlands in this case), contribute to the observed patterns.

Epistemically, the study couples an interpretivist core (accessing lived meanings) with a pragmatic commitment (judging knowledge by explanatory power and usefulness for near-term action). This epistemological alignment motivates an Exploratory Sequential Mixed-methods Design (Creswell, 2009; Tashakkori and Teddlie, 2010). In this design, qualitative inquiry precedes quantitative assessment. The qualitative phase, presented in Chapter 4, provides experiential and conceptual grounding by examining how residents experience heat, how they understand risk, what adaptation practices they use. These qualitative findings are then used to inform the quantitative phase by supporting the operationalisation of key constructs, the development of survey items, and the formulation of empirically

testable hypotheses. The quantitative phase, presented in Chapter 5, subsequently examines whether the insights derived from residents' lived experiences appear as broader social and spatial patterns across a larger urban population. The sequential ordering in the methodology is therefore not merely procedural. It is theoretically and epistemologically significant. Beginning with qualitative inquiry helps prevent the research from imposing predefined assumptions about vulnerability, adaptation behaviour, or justice. Instead, it allows relevant dimensions of adaptation opportunity to emerge from residents' lived experiences and situated practices. These insights then inform the quantitative phase, where they are examined through broader empirical pattern testing. The point of integration therefore occurs at the transition between phases and the design follows a developmental rationale, because Phase One informs Phase Two, and a complementary rationale, because contextual depth is combined with broader level pattern identification

Systematic comparison in line with CR's 'empirical' domain (knowledge assessment and lived experience) and the 'actual' domain (pattern testing) then helps reveal the structures, conditions, and mechanisms that shape the overall behavioural adaptation process (components of the real domain). The overall methodological framework is illustrated in Figure 2.3.

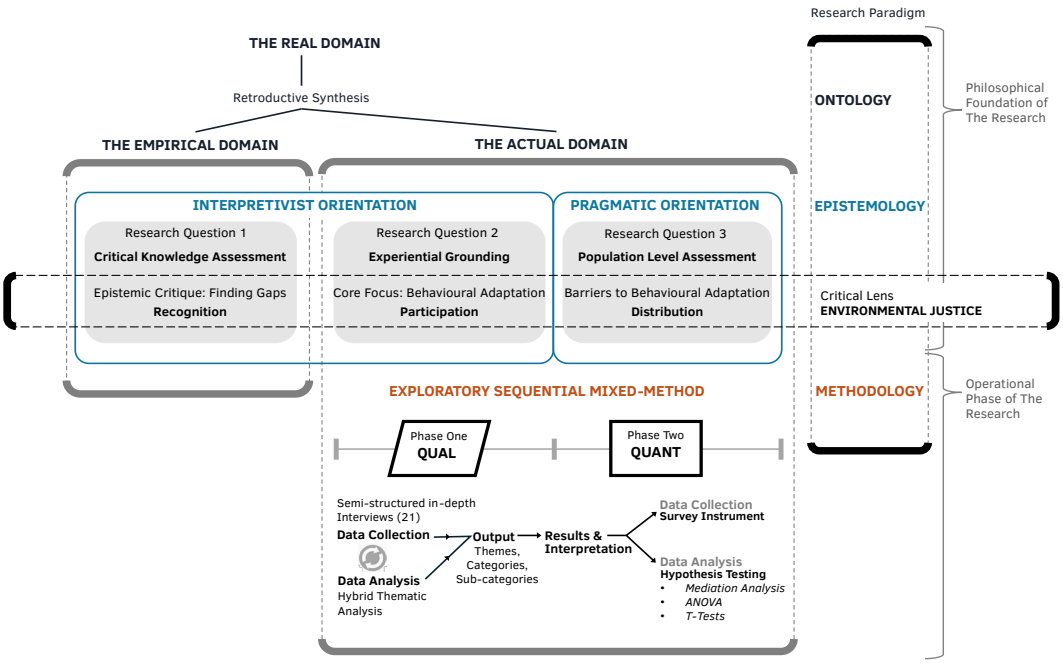

FIG. 2.3 Research Paradigm and Methodological Framework.

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3 Manuscript I

Critical Knowledge Assessment of Urban Heat Vulnerability

This chapter is based on the manuscript that had been prepared for peer-reviewed publication. It addresses Research Question 1, which asks how heatwave vulnerability has been conceptualised and operationalised in existing research in temperate urban contexts. Building on the theoretical positioning and Environmental Justice framing established in Chapter 1, the chapter critically interrogates the epistemic foundations of mainstream urban heat related literature.

To ensure coherence within the overall structure of the dissertation, minor modifications have been made to the original manuscript keeping the core components intact.

3.1 Rationale and Contribution

Several studies have been conducted in the Netherlands to investigate how Dutch cities and other urban areas contribute to heatwaves and how design and planning may be employed to solve such crises. Despite an increasing number of studies on the phenomenon, there is a scarcity of systematic reviews in the literature, notably on heatwave vulnerability in the Dutch built environment. Using a vulnerability framework, this study, therefore, aims to provide a systematic and comprehensive review of built environment research conducted on heatwaves in the Netherlands.

Moreover, within the field of urban climate, knowledge is being produced at a phenomenal rate, yet it remains fragmented and monodisciplinary at the same time. Hence, it is challenging to keep pace with cutting-edge research as well as to evaluate the body of evidence in a broader field of study. In this regard, a literature review is a useful tool for evaluating and understanding the existing body of research on a given topic. It can be defined as a systematic procedure to collect and synthesise previous research (Tranfield et al., 2003). Furthermore, a thorough and well-executed literature review can provide a solid foundation for the advancement of knowledge and expanding theoretical understanding (Webster and Watson, 2002).

The core objective of this review is to evaluate prior built environment research on heatwaves in the Dutch context based on the three components of vulnerability: exposure, sensitivity, and adaptive capacity. Firstly, the review identifies the vulnerability components that have received more attention, as well as those that have received less attention in the literature. Then it classifies previous studies into five different scales of the built environment in order to find out which scales have been given priority and where inadequacies exist. Finally, consolidating the findings, the paper concludes by indicating the knowledge gap that needs to be addressed to confront future urban heat challenges in the Netherlands.

As a case, the Netherlands is significant because it is one of the densest countries in Europe where heatwaves have not yet been taken seriously. Investigating which vulnerability components receive priority and which are overlooked in such contexts can shed light on effective strategies for tackling heatwaves in colder climate regions where they are not traditionally considered a primary concern. Besides, the approach followed in this study holds broader relevance beyond this specific case as it can work as a reflective framework for understanding how vulnerability components manifest in different spatial scales.

Within the broader argument of this dissertation, this chapter is treated as a critical knowledge assessment of existing Dutch heatwave research. It examines how vulnerability is made visible through dominant research practices, and equally, which dimensions remain less visible. In doing so, the chapter addresses the recognition dimension of environmental justice by identifying the epistemic assumptions through which some forms of vulnerability are prioritised while others are marginalised.

3.2 Conceptual Framework: Heatwave Vulnerability in Urban Areas Across Various Spatial Scales

3.2.1 Heatwave

Finding a universal definition of heatwave has not been possible due to the vast range of climatic conditions on earth, as well as the diverse socio-demographic backgrounds and acclimatization patterns of various communities throughout the world. At the country level, heatwaves are classified based on both natural and anthropogenic factors (Jyoteeshkumar Reddy et al., 2021; Marx et al., 2021; Hintz et al., 2018; Tong et al., 2015). In the Netherlands, according to the Royal Netherlands Meteorological Institute (KNMI), a “heatwave” is defined as a period of at least 05 (five) days with a maximum air temperature of 25°C or higher, with at least 03 (three) of those days having a tropical temperature of 30°C or above at their measuring station in De Bilt (KNMI, 2021). The summer heatwave of 2006 lasted 16 days and was one of the most prolonged and severe in at least 100 years. The hottest occurred in July 2019, with a maximum temperature of 37.5°C, although the duration was only six days. The KNMI publishes new climate scenarios every seven years; the next one is scheduled for mid-2023. For an interim overview of their work, they also publish a report named Climate Signal. The 2021 Climate Signal reports that the highest maximum temperature per year has increased by 2.4°C since 1960, more than twice as much as the increase in the annual average temperature (KNMI, 2021). Besides, along with the issue of rising temperature, the report specifically highlights urban climate, noting that as cities tend to be warmer than their surroundings, also known as the Urban Heat Island (UHI) effect, they are more susceptible to the changing climate. The UHI effect is typically defined as the urban-rural difference in air temperature and is brought about by radiative trapping between buildings, increased heat storage in (a large surface area of) high heat capacity building and paving materials, decreased turbulent heat transport caused by a reduction of wind speed, anthropogenic heat releases and decreased evaporative cooling as a consequence of limited vegetational cover (Oke, 1987). Interactions between UHI and heatwaves increase the difference between urban and rural temperatures (Li and Bou-Zeid, 2013; Zhao et al., 2018), leaving the urban population at even greater risk.

3.2.2 Vulnerability

Vulnerability can be defined as the exposure and susceptibility of individuals, families, communities, and countries coping with shocks, risks, and other contingencies. Generally, for a specific context, scholars distinguish exposure, sensitivity, and adaptive capacity as the three main components for determining the level of vulnerability (Buzási, 2022; Bhattacharjee et al., 2019; Wilhelmi and Hayden, 2010; Cutter et al., 2008; Acosta-Michlik and Rounsevell, 2008). According to the Intergovernmental Panel on Climate Change (IPCC) approach, exposure and sensitivity share a positive functional relationship with vulnerability, whereas adaptive capacity has a negative functional relationship with vulnerability (IPCC, 2007). In the 2007 IPCC report, exposure is viewed from a driver's perspective- considered as an external stress that makes a system vulnerable. However, the 2014 IPCC report defines exposure as the presence of life, livelihoods, ecosystems, infrastructure, resources, services, or any economic, social, or cultural assets in geographic locations and settings that could be adversely impacted. Exposure and vulnerability are therefore separated in the 2014 IPCC report, emphasizing that vulnerability is independent of exposure (and hazard). Nonetheless, it is essential to assess vulnerability in relation to a hazard, particularly when it comes to heatwaves since recent studies on urban heat island effect included several exposure indicators such as land surface temperature (LST) (Logan et al., 2020; Bhattacharjee et al., 2019), daily maximum surface air temperature and relative humidity (Mora et al., 2017; Inostroza et al., 2016). To avoid ambiguity, in this review, vulnerability to heatwave hazard is discussed including the exposure component (Figure 3.1).

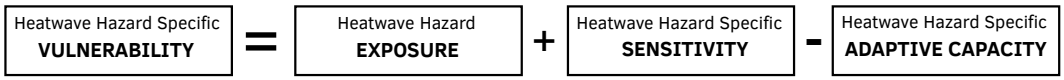

FIG. 3.1 Vulnerability framework used in this study.

`Sensitivity` or `susceptibility` is the second component that contributes to vulnerability. The IPCC 2014 report defined sensitivity as the degree to which a particular system is directly or indirectly affected by any climate variability or change, either adversely or beneficially. Sensitivity comprises modifying factors that may increase or decrease an individual's vulnerability to heat hazards. Consequently, sensitivity depends on various parameters such as demographic profile (age, gender, body composition), socioeconomic status, heat acclimatization level, pre-existing health conditions, and medications (Mac and McCauley, 2017; Inostroza et al., 2016; Aubrecht and Ozceylan, 2013).

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The third and final component of vulnerability is `adaptive capacity`, also known as coping capacity. The adaptive capacities of individuals and groups are the economic, sociocultural, and technical skills and strategies directed towards responding to a certain crisis. While adaptation and mitigation may sound similar, mitigation entails proactive measures taken to minimize the potential impact of a hazard, focusing on reducing the adversities before an event occurs. In the context of a heatwave, adaptive capacity refers to an individual's, group's, community's or even a city's capability to cope with the adversities posed by heatwave hazards (Mac and McCauley, 2017; Inostroza et al., 2016).

3.2.3 Spatial Scales in The Built Environment

While discussing the built environment, multiple scales and hierarchies within the system must be understood since they are strongly related to vulnerability. In the same way, it is crucial to understand that environmental issues can be interconnected and can have effects at various scales. For instance, local air pollution adds to regional and global air pollution, and global climate change may have local effects such as rising sea levels and extreme weather events like heatwaves. Moreover, environmental problems are often linked with the varied spatial scale of the built environment. The urban heat island effect, air pollution, and lack of urban greenery all can be considered urban built environment specific environmental concerns (Piracha and Chaudhary, 2022).

Erickson and Lloyd-Jones (2001) attempted to classify the scales in the built environment based on the related design activities. Although they acknowledge there is no distinct border between the design activities, Erickson and Lloyd-Jones (2001) provide a somewhat detailed idea about different scales in the built environment (Figure 3.2). The built environment comprises different levels of scales ranging from interiors, building units, and blocks at the micro-scale of the spectrum to neighbourhoods and districts at the mesoscale and cities and regions at the macro-scale. Environmental issues, such as heatwaves, can manifest differently at different spatial scales. To fully comprehend how the hazard interacts with the built environment, studying it from various spatial perspectives is essential.

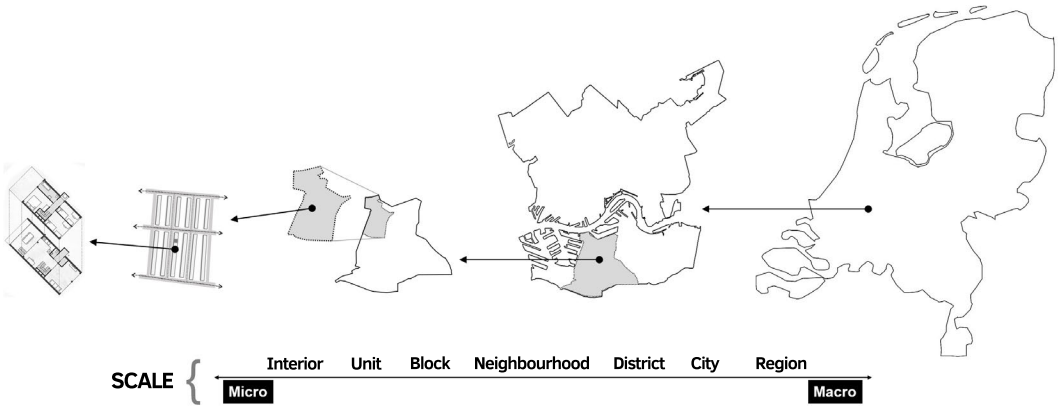

FIG. 3.2 Different territories (or scales) of design, adopted from Erickson, B. & Lloyd-Jones, T. (2001).

3.3 Methodology of the Review

This paper aims to map prior research on heatwaves in the context of the Netherlands with the notion of identifying less prioritised areas and existing knowledge gaps. Even within the realm of the built environment, the topic of heatwave is vast. For example, from meteorology to public health, there are multiple orientations for researching heatwaves in the urban context. Therefore, a semi-systematic or narrative review approach is best suited for this study. A semi-systematic or narrative review is designed for topics that have been conceptualised by various research disciplines and also aims to look at how research within a specific field, heatwaves in this case, progressed over time (Wong et al., 2013). So, a narrative review, following a systematic search, was conducted to find answers to the research question. The review followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to systematically identify, select, and report literature sources.

3.3.1 Search Strategy and Screening Process

This study focuses on articles published in peer-reviewed journals from 01 January 2010 to 31 July 2022. Before 2010, limited research on heatwaves in the Netherlands was available. Two major online databases, Scopus and Web of Science, were used for searching articles. In those two databases, Boolean operators ("OR" and "AND") were employed to merge correlated terms into a single search query. To obtain relevant sources to the research context, the search incorporated terms pertaining to the built environment. An identical search string was used in both databases to perform the search.

As this study specifically focused on the Dutch context, a total of 165 articles were initially identified, with 135 articles found in the Scopus database and 30 articles in the Web of Science database. After removing 27 duplicates, a total of 138 unique articles were found. Subsequently, a rigorous two-stage screening process was implemented, starting with the title and abstract evaluation, which resulted in 61 articles. Four additional articles were eliminated in the second stage based on the inclusion-exclusion criteria, leaving a final set of 57 papers for analysis.

The inclusion criteria encompassed empirical and theoretical studies, scientific reports, focusing specifically on urbanized areas in the Netherlands. Variables related to the field of study included built environment, architecture, urban design, urban planning, and landscape architecture. Similarly, for studies related to heatwaves, variables such as urban heat, extreme heat, heatwave hazard, and urban heat island were considered. The exclusion criteria involved articles that were beyond the scope of the review, studies emphasizing non-human factors or aspects, studies not focusing on the Dutch context, and studies unrelated to the built environment fields. Figure 3.3 provides the search, inclusion and exclusion criteria, as well as the logic behind the searches performed and the entire process sequence followed.

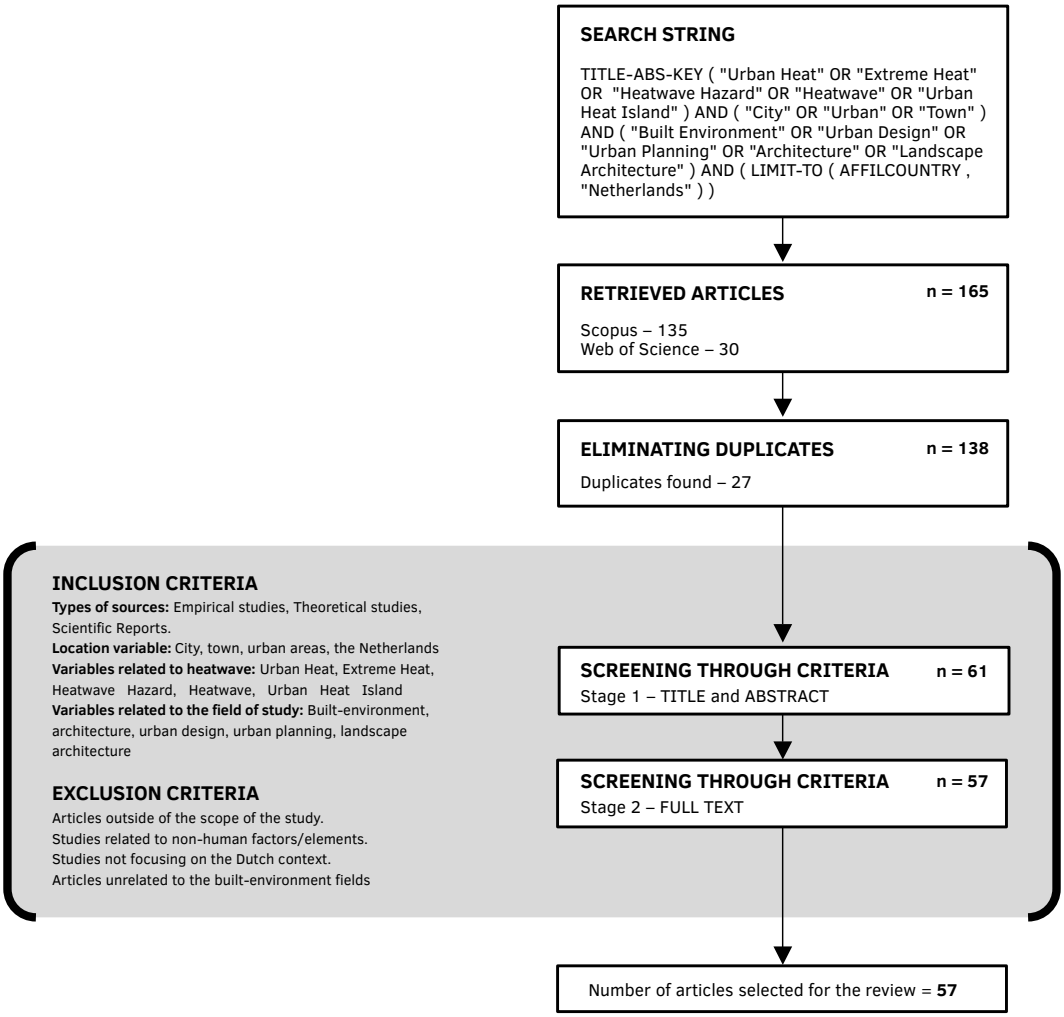

FIG. 3.3 The search process and selection criteria followed in the review.

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3.4 Findings

3.4.1 General Overview of the Literature

In general, research on heatwaves from a built environment perspective has been increasing with time, particularly since 2012. Articles reviewed for this study were published between 2010 to 2022. Only in the year 2016, the number of articles decreased substantially, but after that, the trend is mostly upward, and the issue of heatwaves is getting more attention than ever before (Figure 3.4).

Considering the subject area, most of the articles belong to the broader subject fields of Environmental Science (30.2%), Social Science (16.1%), and Engineering (13.3%). Reviewed articles were obtained from 35 journals. The annexes include a thorough list of papers, together with the names of the corresponding journals and their DOIs.

Among the three main elements of the vulnerability framework, studies on exposure to heatwaves and adaptive capacity are the most discussed topics. A total of 25 articles addressed exposure to the hazard, 21 focused on heatwave adaptation, and 10 covered sensitivity factors associated with heatwaves in urban areas. The sensitivity element may not have received as much attention as the other two components for a number of reasons. Several authors, including Hansen et al. (2014) and Hatvani-Kovacs et al. (2016), noted the difficulties in comprehending the effect of heat events on various socio-demographic population groups as one of the reasons for limited sensitivity-related studies on heatwaves in cities. Additionally, the need for more available data on the health impact of heatwaves on various age groups (Xu et al., 2017) and challenges associated with quantifying the effects and experiences during heat events may result in fewer research articles on heatwave sensitivity.

A bibliometric analysis was conducted using VOSviewer (version 1.6.18) to identify the core and peripheral topics in the field of heatwave research in the Netherlands. The results, as depicted in Figure 3.5, indicate that the nature of the hazard (climate, temperature, air temperature), its impact (modelling), and spatial implications (buildings, urban areas, urban heat island effect) received dominant attention. Besides, as evidenced by the number of citations, a strong inclination towards those core topics (research related to heatwave risk and its impacts) can be found.

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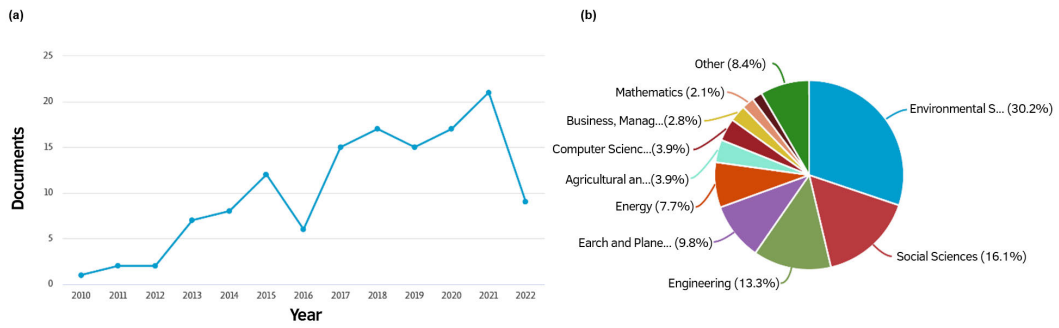

FIG. 3.4 Overall scenario in SCOPUS database (a) documents by year; (b) documents by subject area.

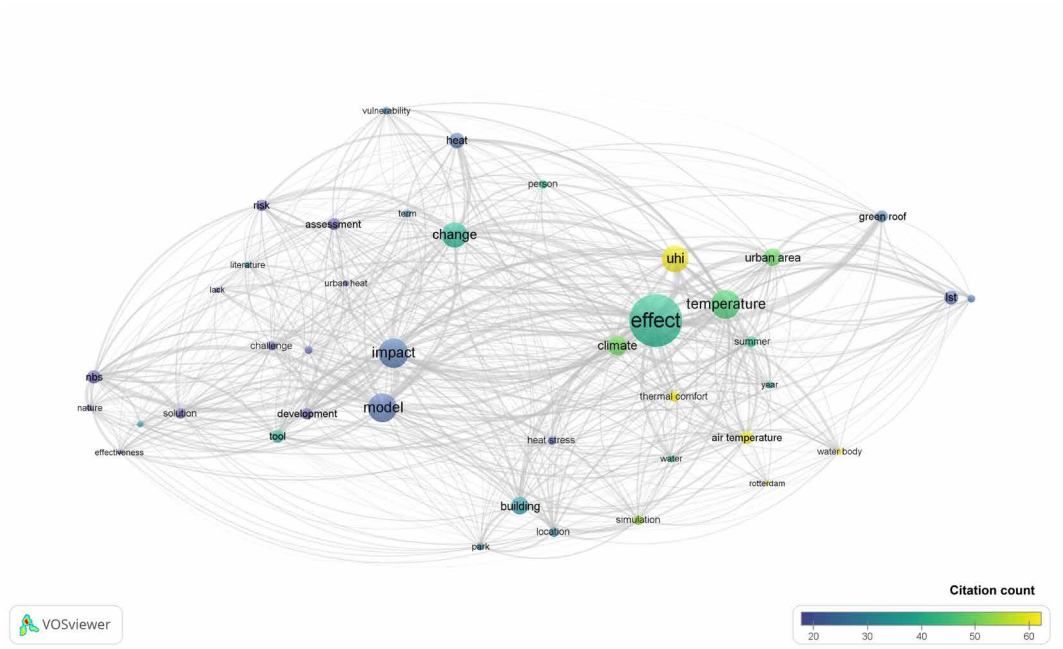

FIG. 3.5 Bibliometric analysis based on the Scopus database, showing the core and peripheral research topics on heatwaves in the Netherlands.

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3.4.2 Vulnerability to Heatwaves in The Dutch Context

3.4.2.1 Exposure

In the context of Dutch cities, scientific studies predict more warm days and an increase in the frequency of heatwaves (KNMI, 2014). The Amsterdam Institute for Metropolitan Solutions (AMS Institute) looked at the trajectory of summer temperatures in the Netherlands over a 100-year period, from 1920 to 2020, and discovered that the average number of summer days (+25°C) in the country doubled compared to the previous 10-year average (AMS Institute, 2020). In KNMI's report called Climate Signal'21, it was found that between 1961-1990 and 1991-2020, the annual mean temperature in the Netherlands increased by 1.1°C. That's more than twice as much as the increase in the global mean temperature in the same period. The highest maximum temperature per year increased by 2.4°C, more than twice as much as the increase in the annual mean temperature (KNMI, 2021). So, scenarios are worsening faster than predicted; therefore, there is an urgency to quantify the nature, behaviour, and impact of heatwave hazards. Consequently, heatwaves have drawn more attention in the scientific community since 2010 and are being studied by various disciplines to better understand the risk and how it might affect society. As a whole, in terms of exposure, earlier research focused primarily on air temperature observation data to develop indices (Steeneveld et al., 2014; Steeneveld et al., 2011). Long-term changes in temperature within a specific area can be explained using these data. Later researchers utilized satellite-derived estimates of land surface temperature (LST) (Mashhoodi, 2021a).

A substantial amount of studies attempted to either quantify the effects of the hazard (i.e increased temperature, heat stress and heat-related health issues, energy consumption) or map its spatial implications and visualise the impacts. Studies that explored ways to measure the hazard's impacts in the built environment mostly considered the urban heat island (UHI) effect as a primary driver that exacerbates the phenomenon of heatwave hazards in urban areas. Therefore, a dominant focus on investigating the current and future UHI impacts is noticeable. The UHI is measured based on the air temperature at the urban boundary layer, urban canopy layer, or near surface layer temperature (the temperature of the air closest to the surface of the earth) (Mashhoodi, 2021a; Echevarría Icaza et al., 2016; Toparlar et al., 2015; Essa et al., 2013; Klok et al., 2012; Steeneveld et al., 2011). Along with traditional approaches of measuring urban climate, usually from the data of meteorological monitoring stations, the potential and accuracy of non-traditional approaches, methods, and technologies are also being explored by researchers in the Netherlands (Cabrera et al., 2021). The use of smartphone sensors and citizens' personal

amateur weather stations (PWS) to sense air temperature and other meteorological parameters are a few of those approaches (Golroudbary et al., 2018). Although new ways of measuring are coming along, researchers also highlight the importance of long-term meteorological observations for Dutch cities. At the same time, Theeuwes et al. (2017) mentioned that small and tertiary cities are not having an extensive measurement network. Hence, enabling both large and small-scale cities with proper measurement networks can provide a more realistic image of the hazard itself.

Several studies also investigated heat stress, outdoor human thermal comfort, including urban landscape parameters, and relationships between urban morphology, land coverage and surface temperature. Maiullari et al. (2021) applied a typo morphology approach for examining the urban microclimate in Rotterdam and found that spatial conditions influence indoor and outdoor temperature. The finding resonates with what Zinzi and Santamouris (2019) stated: that urban form and its configurations influence overheating, either positively or negatively. Accurate prediction of urban microclimates has the potential to precisely identify problem areas in the built environment (Toparlar et al., 2015). Therefore, location-specific urban microclimate studies are becoming increasingly important to trace specific factors and conditions that contribute to the UHI effect and heat stress.

In parallel with studies concerned with quantifying the effects of heatwaves, a body of research also attempted to make those impacts and their potential consequences/associations more visual using a variety of mapping methodologies. These approaches range from mapping the UHI effect itself and its maximum hourly distribution, to mapping health, land use and energy consumption in relation to urban heat (Koopmans, Heusinkveld and Steeneveld, 2020; Golroudbary et al., 2018; de Groot-Reichwein et al., 2018; Klok and Kluck, 2018; Echevarría Icaza et al., 2016; van der Hoeven and Wandl, 2015; Essa et al., 2013; Klok et al., 2012). A recent study by Mashhoodi (2021b) found that certain gender groups are overexposed to land surface temperature and such overexposure differs across socioeconomic groups and locations. The research also highlights the urgency of investigating the phenomenon of heatwave hazard from an environmental justice standpoint. According to that study, anthropogenic factors, like pre-existing socioeconomic disparities and demographic conditions, are crucial in determining which particular group of society would be impacted more adversely by a heatwave hazard than others. Although such investigations exist in other contexts, the number of studies on the socio-political dimensions of heatwaves in the Netherlands is significantly limited. Table 3.1 offers an overview with a classification of how exposure to heatwaves has been addressed in the studies reviewed.

TABLE 3.1 Overview of how heatwave hazard exposure has been investigated in the Netherlands.

Themes	Topics Addressed	Description	Sources
Quantifying Effects	**1. Urban Heat Island (UHI) impacts and modelling:** – Determining the impacts of UHI – Developing a supporting equation for UHI modelling – Predicting urban temperature and potential future UHI patterns **2. Urban heat impacts on human comfort and health:** – Impact of urban heat on outdoor human thermal comfort – Canopy layer UHI and human comfort – Quantifying the local impact of tree volume on nocturnal UHI **3. Measuring and modelling urban heat:** – Impact of sky view factor on UHI. – Measuring urban air temperatures through crowdsourcing. – Hazard assessment and modelling for UHI and related hazards. **4. Seasonal variations in UHI impacts:** – Impact of UHI on the street canyon in different seasons	Studies on the distribution of the impact of urban heat and urban heat island effect. These include the development of tools and deterministic, measurable methods of analysing the existing climate situation and predicting potential future scenarios.	Cabrera et al., 2021; Dirksen et al., 2019; Rafiee et al., 2016; Theeuwes et al., 2017; Theeuwes et al., 2014; Toparlar et al., 2015; Overeem et al., 2013; Steeneveld et al., 2014; Steeneveld et al., 2011; Pena Acosta et al., 2020; Koomen and Diogo, 2017; Steeneveld et al., 2018
Urban Microclimate	Morphological classification of urban microclimate; Deterministic microclimate analyses; Urban design concerning microclimate;	Studies examining the relationship between temperature, urban form, morphology and the urban microclimate.	Maiullari et al., 2021; van Hove et al., 2015
Hazard Mapping	Mapping urban climate; Mapping maximum hourly urban heat island distribution; Visualising urban heat; Mapping health, land use, and energy consumption of the urban heat; Thermal image sharpening; Quantify the surface heat island (SHI);	Studies that aim to visualize the impact of urban heat using various mapping methodologies. This also helps to quantify the consequences of the hazard.	Koopmans et al., 2020; Golroudbary et al., 2018; de Groot-Reichwein et al., 2018; Klok and Kluck, 2018; Echevarría Icaza et al., 2016; van der Hoeven and Wandl, 2015; Essa et al., 2013; Klok et al., 2012
Anthropogenic Factors	Urban Inequality; Environmental justice;	Studies aimed to link heatwave hazards to various socioeconomic constitutions in order to determine how the hazard affects different groups differently based on the social construct.	Mashhoodi, 2021a; Mashhoodi, 2021b

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3.4.2.2 Sensitivity

In the context of the Netherlands, the least explored vulnerability component is sensitivity. Simply put, sensitivity is the degree to which exposure to a hazard might affect people and the things they value. Sensitivity to heatwave hazards, particularly in urban settings, is complex. On a larger scale, the sensitivity and coping capacity of the city influence how the hazard will impact in the first place (IPCC, 2014); yet, sensitivity varies on a micro-scale due to geographic, socioeconomic, and demographic differences.

Based on the articles reviewed, three particular factors can be outlined with regard to sensitivity to heatwaves in the Netherlands comprises socioeconomic and demographic aspects, including age, gender, ethnicity, and financial capability; and the third is prior knowledge and level of awareness. Out of these three factors, the physical-spatial factor is quantifiable, therefore, easier to measure, whereas the socioeconomic factors are always challenging to quantify.

Socioeconomic and demographic aspects: Research has revealed that certain groups in society, particularly senior citizens, bear a disproportionate share of the burden of heatwave hazards (Van Der Hoeven and Wandl, 2018). Using the records of mortality due to heatwaves in Europe, Mees, Driessen, and Runhaar (2015) found that the elderly, people with disabilities, and socially deprived populations are the most vulnerable groups in cities. They further highlighted that heatwave research gave little attention to the governance side, which particularly supports vulnerable citizens in society. Moreover, using a geographically weighted regression model (Mashhoodi, 2021b) found that exposure to urban heat in the Netherlands is gender sensitive. According to that study, women (over 65) are more exposed to high LST than men. It also highlighted some societal and spatial issues, such as gender imbalance in the workplace, overrepresentation of a certain gender in urban areas, unequal access to green etc., which can all significantly contribute to urban heat vulnerability. In general, the study found that regardless of socioeconomic characteristics, women are more exposed to higher LST than men, which applies in most Dutch residential zones. Similarly, Reckien et al. (2017) emphasized that socioeconomic status and gender are two fundamental underlying sensitivity factors that play a significant role in the urban equality concern to climate crises.

Prior knowledge and experience: Along with age, income, and gender issues, awareness about the phenomenon of a hazard is regarded as highly important. It has been found that citizens and other stakeholders have lower awareness regarding urban climate crises such as heatwaves (Lenzholzer et al., 2020b). Although there has been historical research on urban climate, literature on climate awareness is limited. From their international study, Lenzholzer et al. (2020a) also identified education as a critical parameter in exploring the awareness level of urban climate phenomena. It is also consistent with what Howe et al. (2019) found in US cities. In addition to education, they mapped people's perceptions of heat risk on a national and state-wide scale in the United States and revealed that perceptions influenced by ethnicity, income, and gender are key factors in heat sensitivity.

Physical and spatial configuration: This includes aspects such as the concentration of heat-absorbing surfaces like pavement and buildings, the availability of green spaces or shade, and the availability of cooling infrastructure. In their research in Rotterdam, Van Der Hoeven and Wandl (2018) identified that not all parts of the city are equally affected by the UHI effect. For example, Rotterdam's northern, southern and western districts are more exposed than other parts of the city. The research further highlighted morphological and land use factors, such as building envelope, greenery, shade, amount of impervious surfaces, and surface water, as important determinants of the accumulation of urban heat in a district.

Higher surface temperatures raise the surrounding ambient air temperature resulting in higher household energy consumption (Santamouris et al., 2015). This phenomenon is spatially variant and cannot be generalised. In the Netherlands, larger households face significant household energy consumption, for which the geometry and shape of the building play the most crucial role (Mashhoodi et al., 2020). Studies also mentioned that solar shading in highly dense urban areas could reduce energy demand (Ramponi et al., 2014). Overall, the sensitivity factors related to urban heat in the Netherlands can be outlined in the following Figure 3.6.

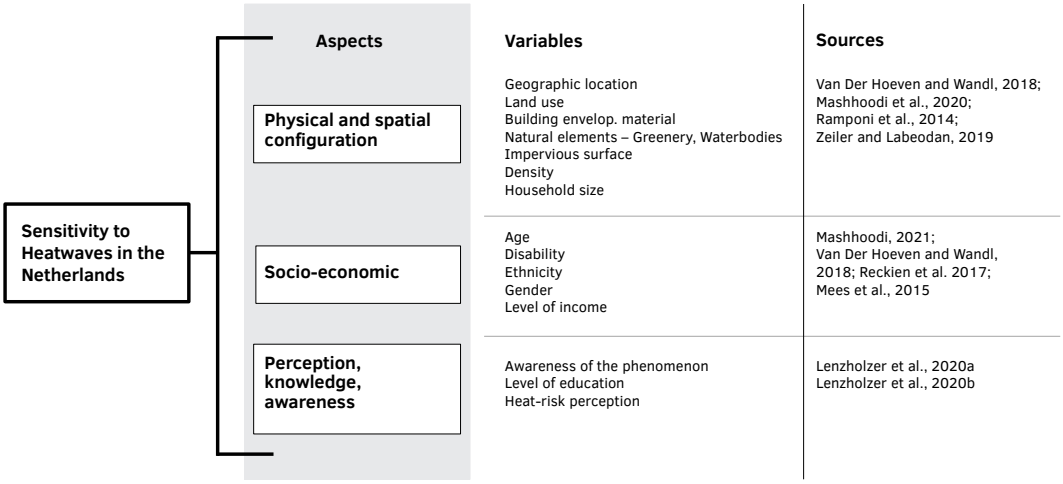

FIG. 3.6 Overall aspects and variables of heatwave sensitivity in the Dutch context.

3.4.2.3 Adaptive Capacity

Throughout the last decade, heat adaptation and mitigation strategies available for the Dutch context are primarily related to Ecosystem Services (ES), Nature Based Solutions (NBS), and Green Infrastructure (GI) (Table 3.2). Some studies also evaluate alternative urban forms to analyse microclimate design as a means for heatwave adaptation. Within various scales in the built environment, the highest number of studies are based on the city scale, whereas the neighbourhood scale has the fewest studies. House, Block, and Region received a somewhat similar number of studies in general.

Augusto et al. (2020) examined the short, medium, and long-term impacts of NBS in the city of Eindhoven using their meteorological and urban energy balance model. Their research indicated that an increase in green and blue spaces has a short-term cooling effect on the surrounding area. On the other hand, van Oorschot et al. (2021) assessed urban ecosystem services by examining the mean land surface temperature (LST) for various land cover types, including trees, grass and shrubs, sand, and sealed surfaces, in the city of Den Haag. Findings say trees reduce approximately 35% of the urban heat island effect compared to other land cover types. Klok et al. (2019) conducted a Physiological Equivalent Temperature (PET) assessment in 21 public spaces in Amsterdam, including both shaded and sunny areas.

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TABLE 3.2 Heatwave adaptation and mitigation approaches in the Netherlands.

Themes	Topics Addressed	Description	Sources
Nature-Based Solution and Ecological Services	Quantifying ecosystem services in relation to green infrastructure; Subsurface space in cities; Vegetation and horticulture interventions as sustainable heat mitigation method; Contribution of soil making cities climate proof; Open surface water in heat mitigation;	Studies on employing ecosystem- and nature-based approaches to lessen the effects of urban heat.	van Oorschot et al., 2021; Finesso and Van Ree, 2022; Stache et al., 2022; Claessens et al., 2014; Theeuwes et al., 2013
Green Infrastructure	Thermal performance of green roof; the Cooling potential of green infrastructure; Socio-cultural valuation of green infrastructure; Use of green roof and walls in heat mitigation; Cooling potential of urban water bodies	Studies that are more focused towards exploring various implementation strategies and actions drawn from the NBS and ES.	Solcerová et al., 2017; Zardo et al., 2017; Derkzen et al., 2017; Hop and Hiemstra, 2013; Steeneveld et al., 2014
Microclimate	Effective urban typologies for cooling at the neighbourhood scale; Quantifying thermal comfort in various urban forms; Urban courtyard blocks to alter microclimate for heat adaptation	Studies that investigated microclimate design as a means of heatwave adaptation by evaluating various urban forms.	Kleerekoper et al., 2015; Taleghani et al., 2015; Taleghani et al., 2014
Planning and Design Strategies	Regionalist concepts in UHI mitigation; Urban planning strategy consisting of certain building types and greeneries; Urban climate adaptation policy; Institutional setting for implementing climate adaptation policy; Urban design tools and strategies; Governance between public and private sector to tackle extreme heat	Studies related to governance, planning, policy, and design interventions for making cities climate-resilient.	Echevarría Icaza and Van der Hoeven, 2017; Koopmans et al., 2018; Boezeman, 2016; Tennekes et al., 2014; Kleerekoper et al., 2012; Mees et al., 2015

In terms of PET or heat stress, both natural shading (by trees) and artificial shading (by buildings) were perceived as being cooler and more pleasant. Study findings urged incorporating either natural or artificial shading in urban spaces to enhance thermal comfort. Additionally, the research highlighted that such meteorological measures could be efficient for quantifying spatial features for setting or meeting targeted values and guidelines to reduce urban heat.

In the reviewed studies on GI, green roofs are regarded as an effective solution to tackle increasing temperatures. In their study, Solcerova et al. (2017) monitored extensive green roofs (sedum) and their effect on air temperature 15 and 30cm above and substrate. The findings were consistent with previous research suggesting that, in a well-watered condition, a green sedum roof can help reduce air

temperature (Hop and Hiemstra, 2013). In addition, Zardo et al. (2017) evaluated the cooling capacity of green urban infrastructures (GUI). The results identified that tree canopy coverage, soil cover, and size play determining roles in GUI's cooling capacity. Addressing rising temperatures, planning interventions such as converting soil cover, increasing the amount of GI, and expanding tree canopy cover were recommended by the researchers. However, since various design alternatives are available when selecting GI for an area or region, socio-cultural validation of those options is essential before applying them in practice. Derkzen et al. (2017) discovered that while individuals favoured the most efficient choices, socio-cultural factors significantly influenced their willingness to pay.

Among a range of nature-based solutions and ecosystem services, transpirational cooling was found to be effective in reducing outdoor air temperature during hot summer days (Gromke et al., 2015). Evaporation from urban open water surfaces may also lower the temperature (Theeuwes et al., 2013), and efficient use of soil ecosystems and greenery can help cool down cities (Claessens et al., 2014).

Some studies also highlighted the importance of microclimate design in coping with climate change. Taleghani et al. (2014) conducted a parametric study into different geometries and orientations of urban courtyard blocks in the Netherlands on the hottest day in the Dutch reference year (19th June 2000, maximum 33°C air temperature). The research showed that placing a water pool in the middle of a courtyard or covering it with plants may dramatically lower both the mean radiant and ambient temperature. In another study, Taleghani et al. (2015) found that the courtyard building type provides the most comfortable microclimate in the Netherlands in June compared to the other studied urban forms. The urban typology in the Netherlands is diverse, and the characteristics of the built environment contributing most to increasing temperatures may differ by neighbourhood. At the neighbourhood scale, heat storage can be reduced by casting more shadow, increasing the use of high albedo roofs and surfaces, and adding vegetation (Kleerekoper et al., 2015). Koopmans et al. (2018), forecasting the 2050 scenario of urban heat for The Hague, suggest densification strategies consisting of tall buildings and preserved green areas as potentially the best way to respond to urban heat. Similarly, Kleerekoper et al. (2012) emphasize the potentiality of using design principles to tackle heat accumulation in cities.

Two key findings emerge from the existing studies on adaptation. Firstly, although approaches such as ES, NBS, GI got widely investigated, there is a lack of discussion on the interplay among blue, green, and grey infrastructures, despite their strong interconnectedness and complementarity, as highlighted by Graça et al. (2022). Besides, in humid contexts, such as the Netherlands due to the influence of the

North-Sea, nature based solutions, particularly increasing blue spaces may lead to thermal discomfort over time. According to Fung and Jim's (2020) research in Hong Kong, green space (lawns) adjacent to water bodies (pond) contributed to harsh thermal comfort conditions and prolonged periods of heat stress on sunny summer days. Therefore, adaptation strategies without considering their long-term implications may not be advisable.

And secondly, it is important to recognize that adaptation approaches explored in the Dutch context hardy addressed people's individual heat adaptation practices or behavioural adaptation practices such as using (electronic) devices, reducing physical activities, wearing different clothing, remaining indoors etc. In their research, Zander et al. (2021), surveying over 350 participants in Australia, found that almost 40% of the respondents deliberately changed their way of living due to extreme heat. Practices like passively cooling the house, making cultural changes, increasing water intake and taking cold showers are some of the most common forms of individual adaptation practices. Moreover, it has been found that one's level of knowledge regarding the heatwave hazard influences the adaptation measures one undertake (Beckmann et al., 2021). Therefore, in the context of Dutch cities, existing behavioural adaptation techniques are necessary to investigate as they can provide a fresh perspective on recognizing vulnerable populations and opportunities for increasing their agency. Hence, further studies are required in this area.

3.4.3 Netherlands' Vulnerability to Heatwaves in Urban Areas According to Varied Spatial Scales

Following the scales in the built environment as defined by Erickson and Lloyd-Jones (2001) the review findings are classified under five scales - block, neighbourhood, district, city, and region –to facilitate the identification of less prioritised scales in order to develop a future agenda for research. Figure 3.7 provides a comprehensive overview of the number of papers addressing the three vulnerability components at the different spatial scales.

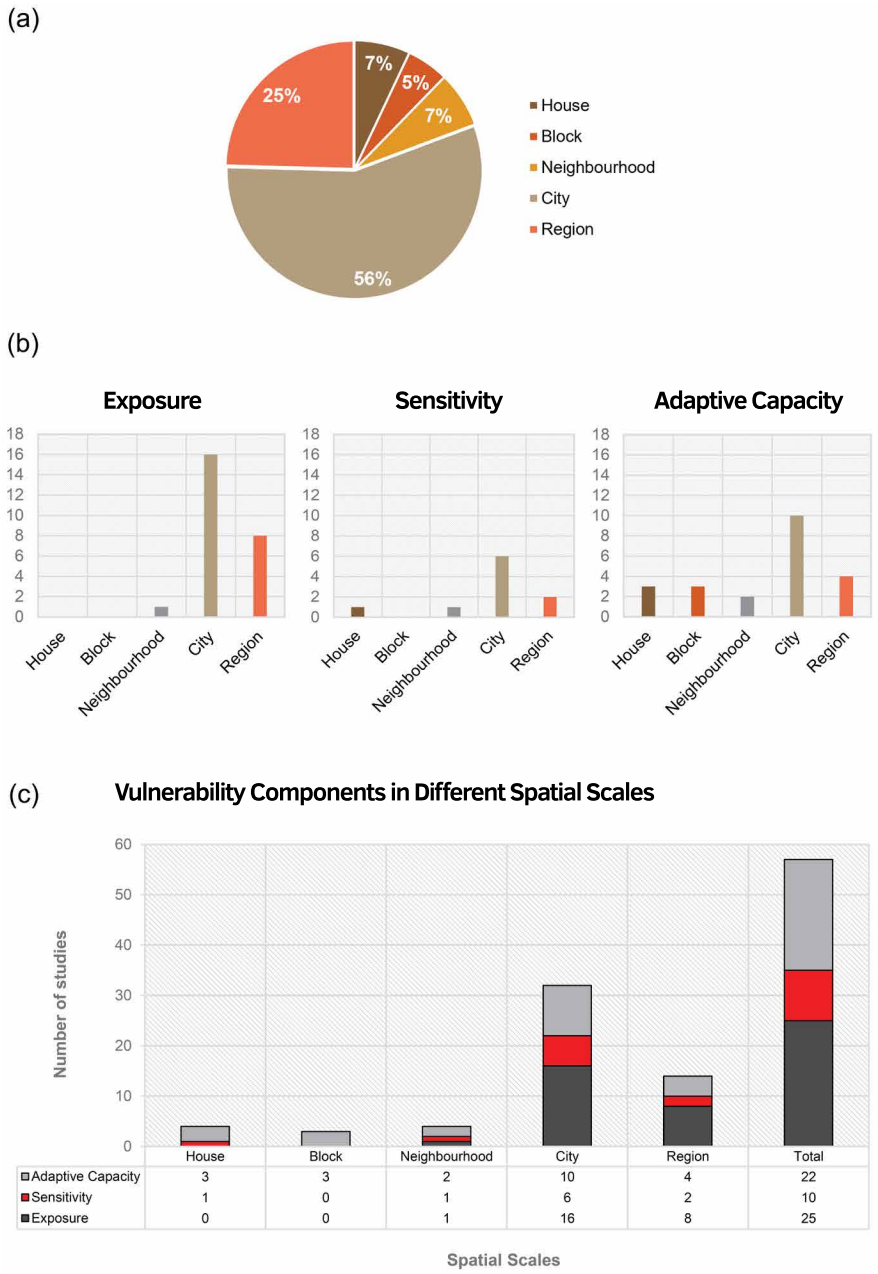

FIG. 3.7 (a) Share of studies per spatial scales (n=57); (b) Studies related to each vulnerability components across spatial scales; (c) Overall distribution of studies in different spatial scales incorporating all three vulnerability components reveals an emphasis on macro-level (city, region) investigations while micro-level (house, block, neighbourhood) studies are limited.

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Overall, sensitivity received the least attention of the three vulnerability components. The majority of the studies focused on the hazard itself, the level of exposure and its behaviour in the built environment. Adaptive capacity received a similar amount of attention. However, when the spatial scales are considered, it is evident that the city scale is dominating. Although some research on a national or regional scale exists, studies on a micro-scale, i.e. a house, block, or neighbourhood, are relatively few. Evaluating the hazards phenomenon from a broader, macro perspective yields standardized results that are primarily applicable to the overall context. Nonetheless, those findings can be inadequate while designing or planning small-scale interventions in cities or other urbanized areas, as physical-spatial as well as socioeconomic and demographic characteristics can vary widely and are highly contextual. Microscale studies are thus necessary, as they can contribute to comprehending how sensitive cities and their population are to urban heat. Furthermore, as cities are growing diverse and becoming more and more heterogeneous, small-scale investigations may also help to validate whether the broader, generalized findings are applicable to the whole city or just certain parts. These local studies may offer a more precise picture of how urban heat interacts with different neighbourhoods and how it impacts various demographic groups within cities. This data may then be utilized to develop more focused and effective measures for reducing the impacts of heatwaves in Dutch contexts.

The review also revealed a lack of studies addressing the phenomenon of heatwave combining two or multiple vulnerability components. Approaching the hazard based on multiple vulnerability components like exposure and sensitivity, or sensitivity and adaptive capacity may provide some new angles in the field of urban heat research. Moreover, the behaviour of heatwave hazard in urban areas is extremely complex. Aside from the interdisciplinary approaches of investigating the phenomenon, which has largely been the case so far, more wider multi-disciplinary or even trans-disciplinary approaches are needed. It has already been revealed that exposure to a hazard is influenced by pre-existing social, economic, and cultural disparities in society; thus, a more holistic research strategy including all stakeholders is the key.

3.5 Conclusion

The objective of this review was to explore built environment research on heatwaves in the Dutch context in order to identify the current state of the knowledge field, which vulnerability components have received more or less attention, and at which spatial scale those studies can be classified. Through a systematic approach, this review identifies the following limitations and key agendas for further research:

Mono to multidisciplinary approach: Research in different fields related to urban heat is currently being conducted with a disciplinary approach, without significant collaboration between different fields. The complexity of heatwave vulnerability necessitates the integration of knowledge from various disciplines such as climatology, urban planning, health, and sociology in order to have a holistic understanding of the dynamics of heatwaves in Dutch cities as well as to develop effective adaptation strategies to mitigate the negative impacts of the hazard.

Generalised to context-specific investigation: A significant number of studies conducted at the macro scale in the Netherlands indicate a prevalent inclination towards the production of generalizable findings, despite the acknowledged fact that heatwave vulnerability is highly context-specific. Besides, the built environment is not homogenous, and specific features, physical conditions, and spatial characteristics can contribute to discriminatory experiences during a heat event. Looking from different scales can help comprehend underlying factors and their interrelation contributing to heatwave vulnerability.

Integrating anthropogenic and socio-cultural variables: In the Netherlands, the physical factors of the built environment attained much importance in heatwave studies, but the social and cultural factors which shape people's experiences and responses to heat events in urban areas are yet to be explored. Although some recent studies are bringing anthropogenic factors such as inequality and, socioeconomic differences to the table, there still remains a lot to be investigated in this arena. Although the Netherlands is a developed and wealthy nation, there are significant socio-demographic differences, and therefore the impact of heat on minorities and people with different backgrounds, ethnicity, and cultural beliefs needs further study. Several studies have shown that deaths caused by heatwaves disproportionately impact socially disadvantaged groups throughout the world (Mitchell and Chakraborty, 2015). In the US, urban heat disproportionately affects certain communities and people of colour, and similarly, in Australia, ethnic minority groups are more susceptible to extreme heat due to their socioeconomic status, linguistic barriers, and living conditions (Hansen et al., 2014).

Exigency of bottom-up knowledge production: So far most of the studies in the Netherlands approached the phenomenon of heatwaves from a more expert driven, top-down perspective; and there is a visible bottom-up knowledge deficit. While several studies used socio-demographic indicators to understand vulnerability to heatwaves, very few of them engaged directly with vulnerable communities or individuals. It is critical to actively involve local communities in the process of investigating heatwave vulnerability. This includes gathering peoples experience during heat events, how they cope, and what their perceived strengths and weaknesses are. Understanding the demographic group, allowing them to participate in the process, and developing their own agency is arguably more important than providing external intellectual or technical support in addressing urban heat.

Through this review, the chapter demonstrates that prevailing approaches remain substantially hazard-centric and exposure-driven, with monodisciplinary approaches, largely depending on generalised socioeconomic indicators. In such process, context-specific grounded realities or bottom-up knowledge production like residents everyday experiences, practices, and behavioural responses are overlooked. From an EJ perspective, this pattern can be interpreted as a recognition deficit, wherein certain forms and aspects of vulnerability are systematically rendered invisible. This critique directly motivates Research Question 2, taken up in the following chapter, which responds to the identified recognition gap by grounding heatwave vulnerability in residents' lived experiences and everyday adaptive practices.

3.6 Chapter Synthesis: Responding to Research Question 1

This chapter addressed the first research question by examining how urban heatwave vulnerability has been conceptualised and operationalised in Dutch built-environment research and practice, and by identifying the epistemic limitations of these framings.

The review shows that vulnerability in the Netherlands is predominantly understood through the lens of hazard exposure like urban heat island effects, land surface temperatures, thermal comfort, and the physical characteristics of the built environment. Adaptive capacity is recognised, but mainly through planning, green infrastructure, and microclimatic interventions rather than through residents' own

coping practices. Sensitivity, particularly as it relates to socio-cultural conditions, lived experience, perception, and differentiated capacities to cope, remains comparatively underdeveloped.

The review also reveals a clear macro-scale orientation. City and region level studies dominate the Dutch knowledge field, while house, block, and neighbourhood scale investigations remain limited. This matters because vulnerability is not experienced at the scale of the city, but through specific dwellings, streets, social relations, and daily routines. Macro-scale analyses can identify broad exposure patterns, but risk producing generalised accounts that obscure the situated conditions through which people actually encounter and respond to heat.

The epistemic limitation identified here is therefore not simply a knowledge or data gap, but a narrower way of knowing vulnerability. Dominant approaches privilege what can be spatially modelled, quantified, and mapped, while giving less attention to lived experience, behavioural practices, and everyday coping. From an environmental justice perspective, this constitutes a recognition problem: certain dimensions of vulnerability become visible because they fit dominant methods and indicators, while others remain marginal because they resist exposure based or physically deterministic approaches.

In answer to Research Question 1: urban heatwave vulnerability in the Netherlands is currently conceptualised primarily as a problem of hazard exposure, physical, spatial configuration, and technical, infrastructure oriented adaptation at macro urban scales. This knowledge is valuable, but epistemically limited, it insufficiently recognises the situated, socially differentiated, and behaviourally mediated ways in which heat vulnerability is produced and experienced. This limitation provides the rationale for the next empirical step: moving from a critical assessment of dominant knowledge framings toward an experiential grounding of heatwave vulnerability through residents' lived experiences and adaptive practices.

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4 Manuscript II

Everyday Lived Realities During Heatwaves, Rotterdam as a Case Study

Responding directly to the conceptual gaps identified in Chapter 3, this chapter addresses Research Question 2, which explores how urban residents in a temperate climate perceive heatwaves and enact behavioural adaptation in their everyday lives. Whereas the previous chapter demonstrated why dominant approaches fail to adequately recognise experiential and behavioural dimensions of vulnerability, this chapter positions lived experience as a critical epistemic resource.

By addressing RQ2, this chapter makes two interlinked contributions to the thesis. First, it empirically grounds behavioural adaptation as a multidimensional construct rooted in everyday practices rather than abstract capacity measures. Second, it reveals how behavioural adaptation practices manifest across various spatial scales and are unevenly distributed.

This chapter is based on a manuscript prepared for peer-reviewed publication. To ensure coherence within the overall structure of the dissertation and to avoid repetition across chapters, minor modifications have been made to the original manuscript.

4.1 Rationale and Contribution

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 and 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 socioeconomic indicators may yield objective, generalised findings, yet they often render intangible, non-physical elements invisible, hindering deeper insight into 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). 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?

Focusing on the case of Rotterdam, the core objective is to explore people's agencies of heatwave adaptation and associated spatial dependencies in a diverse urban context with temperate climate. Such exploration can help unveil 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, emphasizing its relevance, the context of Rotterdam, and the methodological approach used in this investigation.

Within the broader argument of this dissertation, this chapter functions as the experiential grounding of heatwave vulnerability. Building on the recognition deficit identified in Chapter 3, it shifts the analytical focus from dominant expert-driven and exposure-based

framings to residents' own accounts of how heatwaves are perceived, experienced, and negotiated in everyday life. In doing so, the chapter treats lived experience not merely as illustrative evidence, but as an epistemic resource for understanding behavioural adaptation and adaptive agency. This allows heatwave vulnerability to be examined as a socio-spatial process rather than an external, environmental hazard.

4.2 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 cause 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 (Figure 4.1).

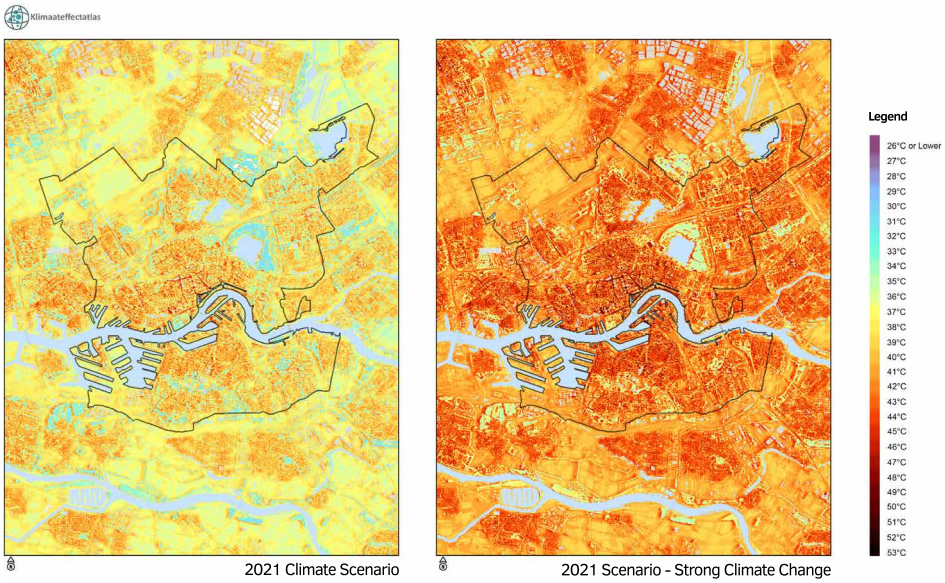

FIG. 4.1 Perceived temperature heat map of Rotterdam. 2021 Scenario (left) vs the 2050 Scenario (right). (Source: Klimaateffectatlas, 2023).

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 and Maarse, 2021).

In terms of population and social composition, Rotterdam is a complex urban setting with a tangled migration history. The city is highly diverse, 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 and 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 reveal a notable contrast between the northern and southern regions, corresponding to areas situated above and below the Meuse River, respectively. Besides, the diversity map (Figure 4.2) illustrates that neighbourhoods in the southern part of Rotterdam have the highest concentration of ethnic and social groups compared to other areas

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(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; 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.

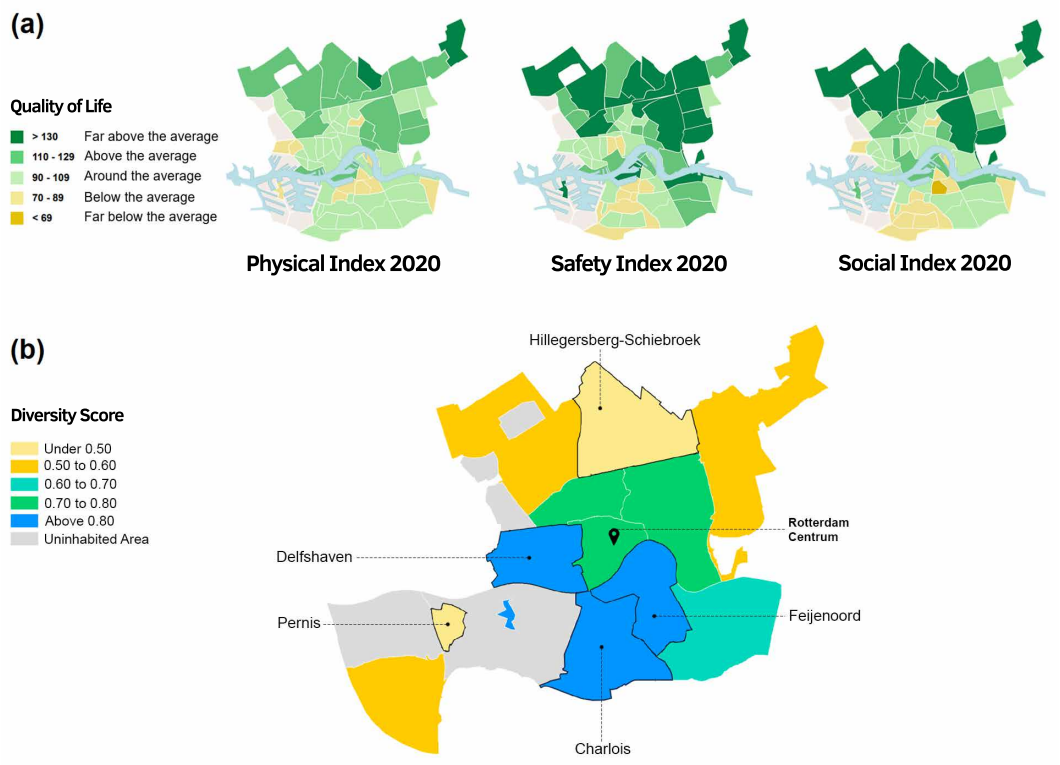

FIG. 4.2 (a) Physical, Social, and Safety indices (Source: Leefbaarometer, 2023); (b) Diversity Scores of areas in Rotterdam. (Source: Municipality of Rotterdam, 2019; Engbersen et al., 2019).

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4.3 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 outlined its three key components: (i) behavioural adaptation, (ii) psychological adaptation, and (iii) physiological adaptation (Brager and de Dear, 1998). 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 shows 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. Figure 4.3 illustrates the overall conceptual framework for this study.

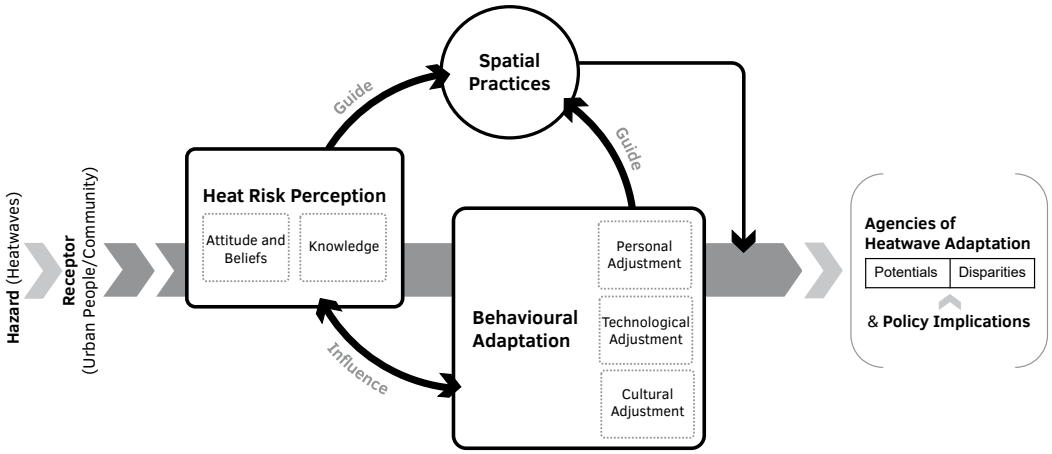

FIG. 4.3 Conceptual framework of the study; integrating components from Howe et al.'s (2019) risk perception and de Dear and Brager's (1998) human thermal adaptation framework.

4.4 Methodology

4.4.1 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 reasoning. 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 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 in 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.

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4.4.2 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 4.1 provides the sampling criteria used to recruit participants for the study.

TABLE 4.1 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.

Given the focus of the study, participants aged between 20 and 60 were considered suitable candidates. This age range was deliberately selected in accordance with the CBS (2022) population pyramid, encompassing a significant portion of the population and facilitating a comprehensive exploration of the research topic. Simultaneously, this research 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 4.2 presents an overview of participants and some key information related to interviews.

TABLE 4.2 Demographic and interview-related information of participants.

Demographics		
Total Participants		21
Gender	Female	13
	Male	8
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)*	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	

* Residents born in the Netherlands with one or two parents born abroad are called children of migrants

4.4.3 Data Collection

In-depth, semi-structured interviews are used as the primary method for collecting data. The interview protocol comprises 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 and 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 took place between June and September in the summers of 2022 and 2023. Respondents were invited to share their stories regarding the practices, techniques, and capacity to adapt during heat events. Additionally, their attitudes, beliefs, and past encounters with warmer conditions were also discussed. The interview questions were prepared prior to the start of interviews. Following a few pilot interviews, the questions were finalised. The protocol includes a total of 12 questions, supplemented by follow-up queries to delve deeper into the responses as needed (see Table S1 in the supplementary materials). Typically lasting around 45 minutes, interviews were conducted either in person or online based on participant preference. After obtaining informed consent, each interview session was recorded, and necessary notes were taken by the researcher to capture nuances and contextual information. Audio recordings were later converted into written transcripts by the researchers for analysis purposes.

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

4.4.4 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 and Clarke, 2006). The advantage of TA lies in its flexibility, as it allows modification to better align with the research needs (Braun and 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, theory-driven approach or deduction and a bottom-up, data-driven approach or induction (Swain, 2018).

The deductive component ensures that the analysis remains aligned with the theoretical foundations of the study, while the inductive component allows insights to emerge organically from participants' lived experiences (Crabtree and Miller, 1999). Deductive reasoning is guided by the theoretical frameworks of Howe et al. (2019), and de Dear and Brager (1998). These frameworks informed the initial analytical

scaffolding by structuring two predefined overarching themes: Hazard Perception, and Behavioural Adaptation.

Each theme comprised theoretically grounded a priori categories. For example, Hazard Perception incorporated categories related to Knowledge and Attitudes & Beliefs, while Behavioural Adaptation included personal, technological, and cultural adjustment. These deductive categories operated as flexible analytical guides rather than rigid classificatory principles, ensuring theoretical coherence without constraining empirical interpretation.

Induction, in contrast, allows insights to emerge organically from the data, fostering a grounded perspective on the findings (Boyatzis, 1998; Charmaz, 2006). The process captured dimensions not fully anticipated by the theoretical framework, resulting in the development of a posteriori categories and themes.

Analytical Procedure: The analytical procedure followed the three-phase structure proposed in hybrid thematic analysis (Swain, 2018), as illustrated in Figure 4.4. While the phases were implemented sequentially, the process remained iterative, with continuous comparison between transcripts, codes, and thematic structures.

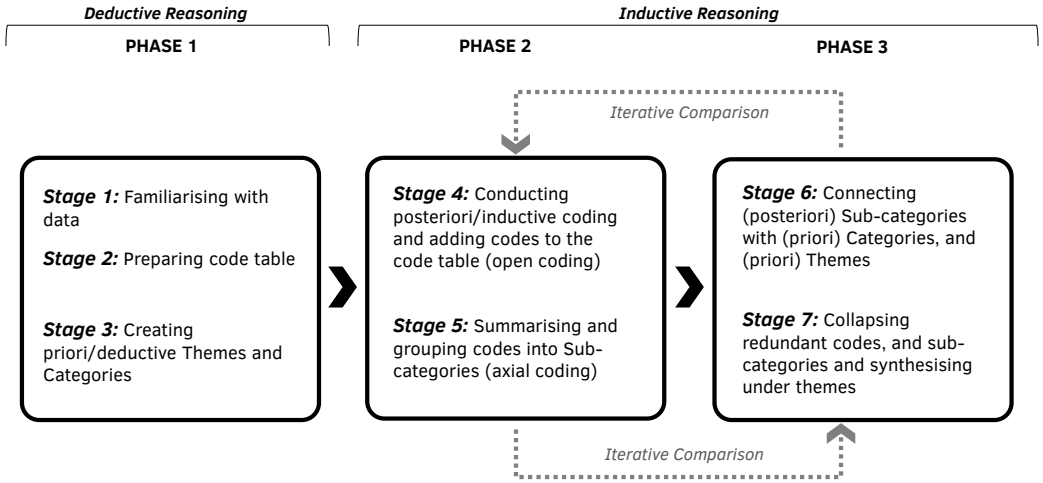

FIG. 4.4 The three phases and seven stages of data analysis (following Swain, 2018).

Phase 1 focused on deductive reasoning and establishment of the conceptual and organisational foundation of the analysis. The process started with the systematic familiarisation with the dataset (transcripts derived from 21 in-depth interviews).

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This stage is not limited to surface reading but involved careful engagement with narrative flow, contextual references, and implicit meanings. Reflexive notes were recorded to capture preliminary interpretations. Adhering to the procedure of Hybrid Thematic Analysis, two deductive themes, “Hazard Perception” and “Behavioural Adaptation”, were predefined as per literature, each comprising distinct (priori) categories that represent overarching concepts pertinent to the research objectives.

In phase 2, following familiarisation, a rigorous data coding and thematic development were carried out. The coding procedure was initiated when the first interview transcript became available. The computer-assisted qualitative data analysis software ATLAS.ti facilitated the systematic coding and data management. Coding was performed at the level of meaningful segments (phrases, sentences, or short passages), reflecting patterns of meaning rather than isolated keywords. In this phase when new posteriori codes emerged, earlier transcripts were revisited to ensure analytical consistency. This iterative comparison across interviews enabled the grouping of related codes into sub-categories and the clarification of conceptual boundaries, resulting in a coherent intermediate thematic structure.

Phase 3 focused on integration and synthesis. To seamlessly integrate these inductive findings with the predetermined deductive framework, the analysis employed 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 approach allowed deductive theoretical structure and inductive empirical insights to be systematically integrated, enhancing both analytical depth and conceptual coherence within the thematic analysis.

4.5 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' comprises 2 (posteriori) inductive categories and 4 (posteriori) inductive sub-categories (for the codebook see Table S2 in the supplementary materials). All 19 sub-categories and 51 codes are completely inductive elements. Categories, Sub-categories, and corresponding Themes can be found in Table 4.3, followed by their explanation.

TABLE 4.3 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

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4.5.1 Hazard Perception

Hazard perception is crucial for understanding how people perceive and react to a crisis (Ferrer and 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:

4.5.1.1 Knowledge

The category 'Knowledge' unpacks individuals' understanding of the hazard and its associated consequences. What is found is that knowledge about heatwaves is shaped by 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 of 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 to be 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 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 call 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.

4.5.1.2 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 4.4) provides the overall participant impressions found in this study.

TABLE 4.4 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

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 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.

4.5.2 Behavioural Adaptation

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

4.5.2.1 Personal Adjustments

De Dear & Brager (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 mentioned 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 highlighted hydration as a fundamental element, and they also emphasised 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 sub-category 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

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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 Dutch 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 have already found this to be 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 sub-category 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 demonstrates 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.

4.5.2.2 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. Figure 4.5 provides an overview of active and passive cooling practices, elucidating their respective prevalences.

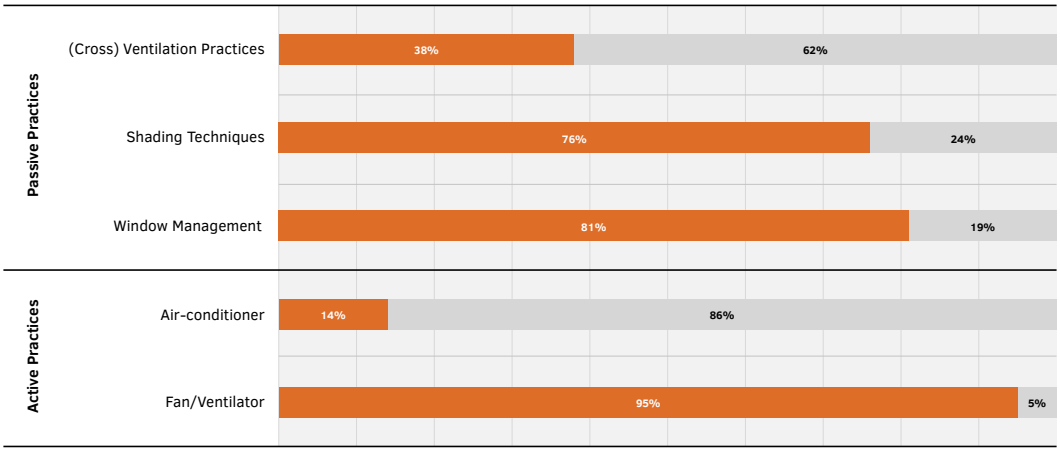

FIG. 4.5 Overview of active and passive cooling practices indicated by participants.

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 sunlight.

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, with the top level becoming uncomfortable or unusable and activities being shifted 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 (Figure 4.6) illustrates the findings of passive adaptation practices in relation to building type, occupant type, and occupancy characteristics.

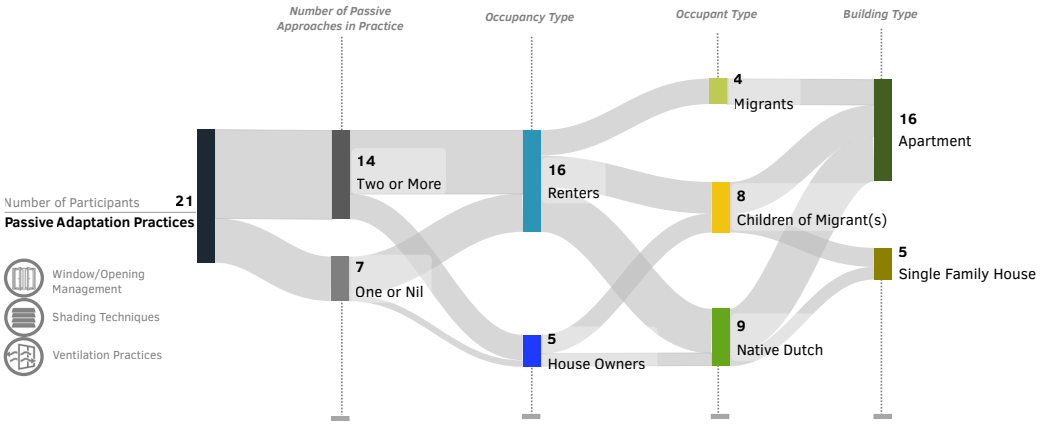

FIG. 4.6 Passive adaptation practices in relation to occupancy, occupant, and residential building type.

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. As a participant described, *"I was very young when I was in China, like in middle school or primary school.*

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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, who 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, revealing simple yet helpful approaches tailored to their circumstances and needs.

4.5.2.3 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 and homeowners.

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, drawing from their multi-contextual experiences and intergenerational knowledge. Interviewees reported that cultural practices in warmer contexts contribute to heatwave 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 that, when shared informally among peers and family members, 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 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 the 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."

According to another participant (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."*

Under certain circumstances, people even move to the houses of relatives and friends, offering additional avenues to escape heatwaves. *"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 really when you enter that house, it's very cool, I have done this a few times."*

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.

4.5.3 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 sub-categories. 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.

4.5.3.1 Indoor Oriented

Private Indoor

Narratives indicate that individuals initially aim to utilise their indoor living space. Such appropriation includes Spatial Navigation and Movement, Optimising for coolness, and Limitting 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."*

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.

4.5.3.2 Outdoor Oriented

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.

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 people's 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.

4.6 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.

4.6.1 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 (Esplin et al., 2019; Ban 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 and 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.

4.6.2 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 that 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 (Figure 4.7).

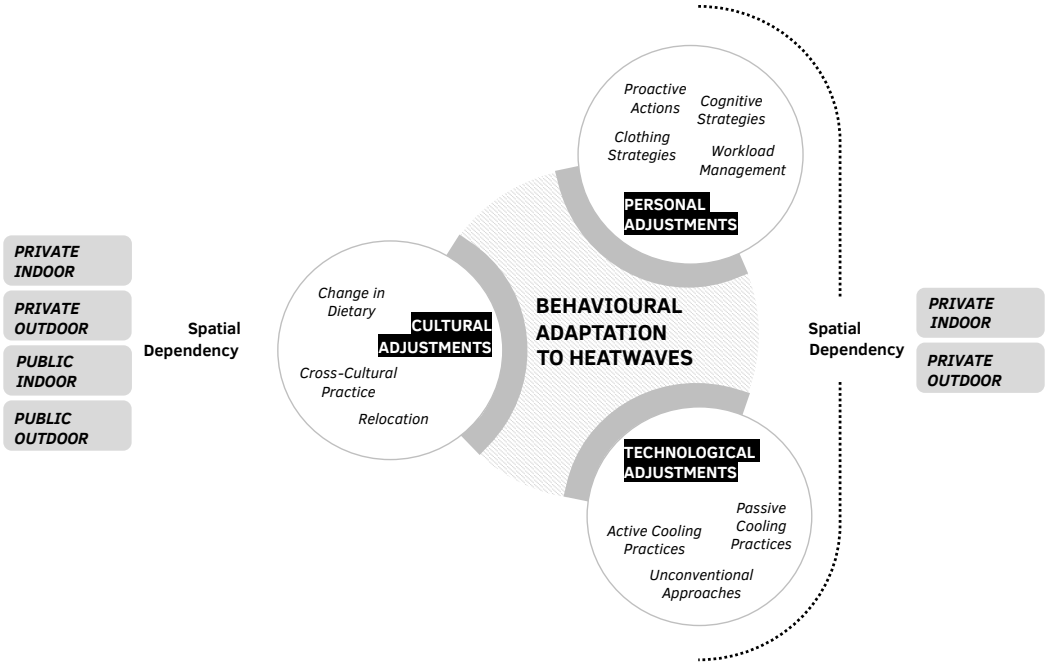

FIG. 4.7 Behavioural adaptation practices and their associated spatial dependencies.

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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 making them more reliant on neighbourhood resources and community support (see Figure 4.7). As a result, certain individuals have greater control over their adaptation choices and practices compared to others, highlighting broader inequalities in behavioural adaptation opportunities within urban communities.

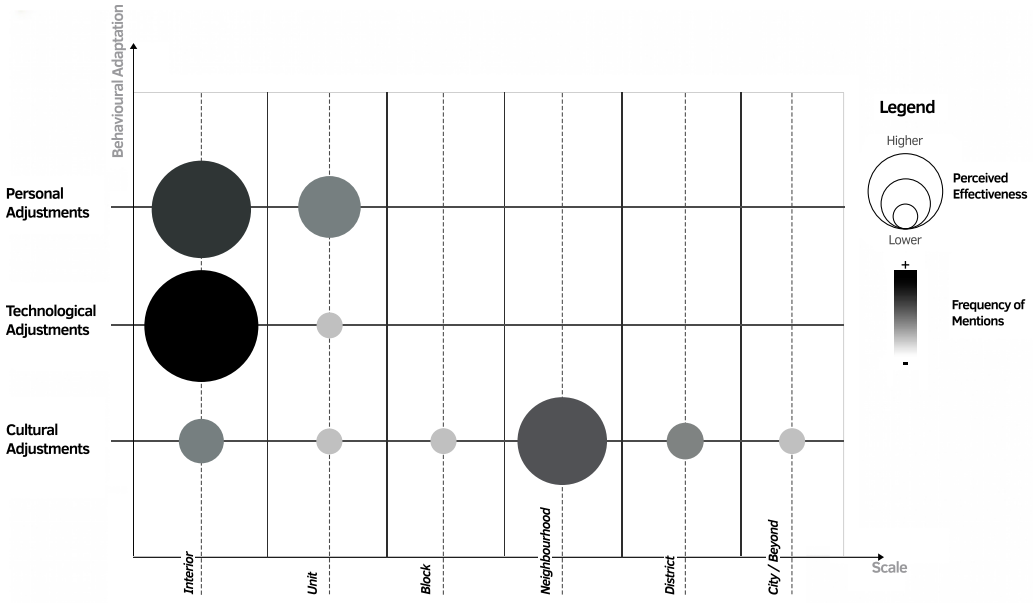

FIG. 4.8 Behavioural adaptation practices manifested in various spatial scales.

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4.6.3 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 help 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 (Johnson et al., 2016; Chen and Graham, 2011).

Additionally, the conceptual model derived from the study distils salient findings, offering a schematic representation of various behavioural adaptation practices and their spatial dependencies. Figure 4.8 illustrates the significance of scales in the adaptation process. Considering community characteristics and housing conditions, it is essential to formulate tailored adaptation plans across micro to macro spatial scales. 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 4.5 offers some possible policy and spatial interventions based on this study.

TABLE 4.5 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 to 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.

4.6.4 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.

4.7 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, including blue-green infrastructure and 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.

4.8 Chapter Synthesis: Responding to Research Question 2

This chapter addressed the second research question by empirically examining how urban residents perceive, experience, and negotiate heatwaves through behavioural adaptation in Rotterdam. The chapter shows that behavioural adaptation is a multidimensional and situated practice, and adaptation opportunities are unevenly distributed. The capacity to adapt depends on knowledge, structural and socio-spatial conditions which heavily influence who can effectively respond to heat and who cannot.

In answer to Research Question 2: residents negotiate heatwaves through a combination of embodied experience, self-regulation, experimentation, and spatial decision-making, yet not all adaptive practices are equally possible for everyone to enact. Behavioural adaptation is therefore both an expression of agency and a site of inequality. Overall, the findings further demonstrate why lived experience is indispensable for understanding heatwave vulnerability. This chapter provides the empirical basis for the next stage of the dissertation, where qualitative insights into behavioural adaptation are translated into a broader quantitative assessment of adaptive capacity and inequality across urban residents in the Netherlands.

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5 Manuscript III

Population Level Assessment

This chapter addresses Research Question 3, which investigates whether the behavioural adaptation practices and perception mechanisms identified through qualitative inquiry are observable across the wider urban population, and what are the key factors creating behavioural adaptation inequalities. Building directly on the conceptual grounding of Chapter 4, this chapter shifts the analytical focus from experiential depth to empirical testing.

The article presented here operationalises behavioural adaptation and heat risk perception as formative composite constructs derived from the qualitative findings. Using a nationwide survey of urban residents in the Netherlands, it tests how adaptive capacity varies across key dimensions. By answering RQ3, this chapter completes the empirical arc of the thesis. It demonstrates that the mechanisms identified through lived experience are not isolated or anecdotal, but systematically patterned across the urban population. These findings provide the empirical basis for interpreting behavioural adaptation as a key justice issue. Rather than concluding the thesis, the chapter feeds into the subsequent cross-manuscript synthesis.

This chapter is based on a manuscript prepared for peer-reviewed publication titled ‘Navigating heatwaves in a temperate climate: barriers to behavioural adaptation in Dutch urban areas’. To ensure coherence within the overall structure of the dissertation and to avoid repetition across chapters, minor modifications have been made to the original manuscript.

5.1 Rationale and Contribution

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

Addressing the knowledge gap, this manuscript investigates the question: How is the agency of (behavioural) heatwave adaptation distributed across different urban areas in the NL, and what are the key determinants of the unequal distribution of behavioural adaptation opportunities? The objective is to understand the processes and motivations behind individuals' coping practices and, in doing so, how their agency interacts with broader societal and environmental contexts.

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.

Within the broader argument of this dissertation, this chapter represents the distributional assessment of behavioural adaptation opportunities. Building on the recognition-oriented knowledge assessment in Chapter 3 and the experiential grounding in Chapter 4, this chapter examines whether the behavioural adaptation opportunities identified qualitatively are unevenly distributed across the wider urban population. The chapter therefore operationalises adaptive agency through measurable behavioural adaptation and hazard perception composites, and assesses how this agency varies across social, structural, and spatial conditions. This allows the dissertation to move from identifying lived adaptive practices to explaining how unequal adaptive capacity is manifested across Dutch urban contexts.

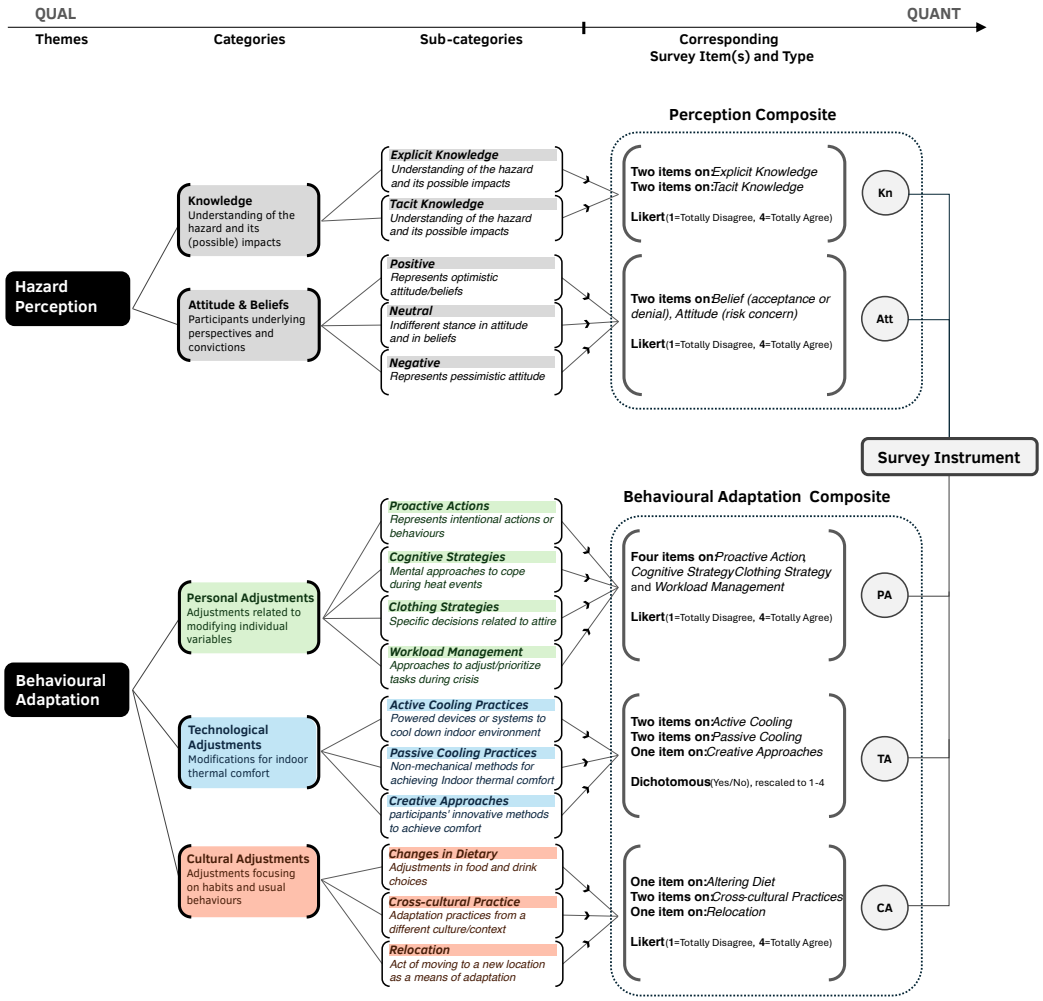
5.2 Methodology

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; 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 (Figure 5.1).

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 were then used to test the hypotheses 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). 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).

Chapter 4 of this thesis presented the qualitative phase in detail. Outcome of that phase yielded a survey instrument (Output 1) and hypotheses (Output 2). 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.



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Kn = Knowledge; **Att** = Attitudes & Beliefs; **PA** = Personal Adjustment; **TA** = Technological Adjustment; **CA** = Cultural Adjustment
◯ = Formative Indices

FIG. 5.1 Qualitative to Quantitative workflow.

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In 2024, data were 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) were retained for analysis after standard completeness checks (Table 5.1). Formulated hypotheses are then tested individually using various statistical methods. Statistical tests such as mediation analysis, independent samples t-tests, and analysis of variance (ANOVA) are chosen according to the nature of each hypothesis. The analyses provide insights into hazard perception and behavioural adaptation processes among Dutch urban populations.

TABLE 5.1 Profile of the survey respondents and corresponding Netherlands benchmarks.

Category		Analytic sample		NL benchmarks (%)
		n = 1849	100%	Jan. 2025
Age	16–24	74	**4%**	13%
	25–44	486	**26.3%**	28%
	45–64	642	**34.7%**	27.6%
	65+	647	**35%**	20.8%
Gender	Woman	990	**53.5%**	50.2%
	Man	859	**46.5%**	49.8%
Education	hbo/wo	827	**44.8%**	44%
	havo/vwo, mbo-2/-3/-4	602	**32.4%**	39%
	Basisonderwijs (primary education), vmbo, mbo-1	420	**22.8%**	17%
Tenure Categories	Owner-occupied home	1184	**64%**	56%
	Rental home	665	**36%**	44%
Household Composition	(Un)married, living together, without child(ren)	698	**37.8%**	26%
	Alone	679	**36.7%**	40%
	(Un)married, living together, with child(ren)	307	**16.6%**	24%
	Alone with kid(s)	90	**4.9%**	9%
	Otherwise	75	**4.1%**	1%
Level of Urban	Strongly urban (Sterk stedelijk)	822	**44.5%**	24%
	Very strongly urban (Zeer sterk stedelijk)	611	**33%**	25%
	Moderately urban (Matig stedelijk)	416	**22.5%**	17%

* *Source: CBS StatLine*

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5.3 Conceptual Grounding and Operationalisation of Thematic Components

5.3.1 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 to 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 (see Figure 5.1).

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 materials (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 Personal Adjustment (PA), Technological Adjustment (TA), and Cultural Adjustment (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 indicated 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 influences 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 problematic in such regard. These qualitative insights indicate that urban density may contribute to structural and environmental barriers to behavioural adaptation. Accordingly, the following hypothesis was formulated to examine 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 was developed and conducted in urban areas nationwide in the Netherlands to collect data for hypothesis testing and examining broader patterns of hazard perception and behavioural adaptation practices.

5.3.2 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, Behavioural Adaptation (PA, TA, CA) and Hazard Perception (Kn, Att) are modelled 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. For instance, behavioural adaptation practices like modifying daily routines, installing shading devices, using cooling technologies, seeking cooler public spaces, or relying on social networks represent different forms of adaptation that collectively define adaptive capacity. Similarly, for hazard perception, knowledge and attitude & belief are theoretically related but conceptually distinct dimensions. Each component contributes uniquely to the overall construct without assuming internal consistency or high inter-item correlation.

In contrast, a reflective model assumes that a single latent factor causally generates variation across all indicators, implying strong inter-item correlations and conceptual interchangeability. Such assumptions are not appropriate here. A change in one adaptive behaviour does not necessarily lead to change in others. For example, purchasing a fan does not imply modifying social routines, nor does increasing knowledge about heat automatically alter technological practices. The indicators therefore do not co-vary by necessity and cannot be treated as substitutable. Instead, the indicators identified in this research are deliberately heterogeneous. The multidimensional and context-sensitive nature of behavioural adaptation in temperate urban environments cannot be adequately represented by a unidimensional latent factor.

Formative indices are therefore 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 5.2.

Importantly, conventional internal consistency measures (e.g., Cronbach's alpha) are not suitable for formative constructs, as such diagnostics presuppose reflective causality and inter-item correlation. Instead, validity is ensured through theoretical coherence and alignment with the qualitative findings from Phase One.

Composite Construction and Aggregation Procedure: Composite scores are calculated at the individual level. First, theme-level scores are constructed: Personal Adjustment (PA), Technological Adjustment (TA), Cultural Adjustment (CA), Knowledge (Kn), and Attitudes & Beliefs (Att). Subsequently, Behavioural Adaptation Score (B_A) is computed by aggregating PA, TA, and CA and Perception Score (Perception_Score) is computed by aggregating Kn and Att.

The majority of items are measured using four-point Likert scales (1 = totally disagree; 4 = totally agree). A small number of dichotomous items are rescaled to the same 1–4 metric (e.g., Yes = 4; No = 1) to ensure metric consistency across indicators. This transformation preserves interpretability while enabling coherent aggregation.

All indicators are equally weighted. This decision is methodologically deliberate. The research does not aim to prioritise specific behaviours but to capture the breadth of adaptive opportunities available to individuals. Statistical weighting procedures (e.g., principal component analysis) would impose a structure not grounded in the qualitative findings and could obscure less frequent but conceptually important practices. Equal weighting therefore maintains conceptual neutrality and transparency in index construction while enabling robust group comparisons.

TABLE 5.2 Formative measurement framework.

Core Constructs	Sub-components	Example Indicators / Themes	Measurement Approach	Scoring Method / Notes	Contribution to Composite Scores
Hazard Perception	**Knowledge (Kn)**	*Explicit Knowledge (E_K)*			
		Two items: Heatwaves impact on health, and on Environment	Likert scale (1 = Totally Disagree, 4 = Totally Agree)	Mean of two Likert-scale items	50% of Knowledge Score (Kn)
		Tacit Knowledge (T_K)			
		Two items: Past experience, Knowledge from network	Likert scale (1 = Totally Disagree, 4 = Totally Agree)	Mean of two Likert-scale items	50% of Knowledge Score (Kn)
		Composite Knowledge Score (Kn)			
		Aggregated score of E_K and T_K	Mean of E_K and T_K (equal weight)		Contributes 50% to the Perception_Score
	Attitude & Belief (Att)	Two items: Belief (acceptance or denial), Attitude (risk concern)	Likert scale (1 = Totally Disagree, 4 = Totally Agree)	Mean of the two Likert-scale items	Contributes 50% to the Perception_Score
	Composite Hazard Perception Score (Perception_ Score)	Composite score of Kn and Att	Mean of Kn and Att Score (equal weight)	Each sub-score Kn and Att contributes equally	
Behavioural Adaptation	**Personal Adjustment (PA)**	Four items: Proactive Action, Cognitive Strategy, Clothing Strategy, Workload Management	Likert scale (1 = Totally Disagree, 4 = Totally Agree)	PA score = mean of four Likert-scale items	One-third of Behavioural Adaptation Score (B_A)
	Technological Adjustment (TA)	Five dichotomous items: Active Cooling (2), Passive Cooling (2), Creative Approaches (1)	Binary items (0/1) rescaled to 1–4, then averaged	Binary items rescaled for comparability; normalized mean used	One-third of Behavioural Adaptation Score (B_A)
	Cultural Adjustment (CA)	Four items: Changes in Dietary (1), Relocation (1), Cross-cultural Practices (2)	Likert scale (1 = Totally Disagree, 4 = Totally Agree)	CA score = mean of four Likert-scale items	One-third of Behavioural Adaptation Score (B_A)
	Composite Behavioural Adaptation Score (B_A)	Composite score of PA, TA, and CA	Mean of PA, TA, and CA subdomain scores (equal weight)	Each sub-score (PA, TA, CA) contributes equally; TA calculated as a normalized additive index	

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5.4 Quantitative Analysis and Findings

In phase two, formulated hypotheses are systematically tested using appropriate statistical methods following the nature of the individual hypotheses. The tested outcomes are then 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.

5.4.1 Thematic Hypotheses on Hazard Perception

The qualitative phase showed tacit knowledge (T_K) as an important component underlying behavioural adaptation (B_A) practices. While knowledge does not directly determine actions or practices, the qualitative findings indicated that it may facilitate all three behavioural adaptation domains: personal (PA), technological (TA), and cultural (CA). Consequently, in testing these hypotheses related to knowledge, the intention was not merely to determine whether knowledge was associated with overall behavioural adaptation, but also to examine how this association is expressed across its different behavioural domains. Therefore, to examine H1, H2, and H3, a mediation analysis was conducted as an exploratory pathway analysis. This allowed the relationship between knowledge (both explicit and tacit) and behavioural adaptation to be decomposed into direct and indirect pathways through PA, TA, and CA. Figure 5.2 illustrates the theorised model, in which tacit knowledge (T_K) and explicit knowledge (E_K) serve as predictor variables, and Behavioural Adaptation Score (B_A) serves as the outcome variable.

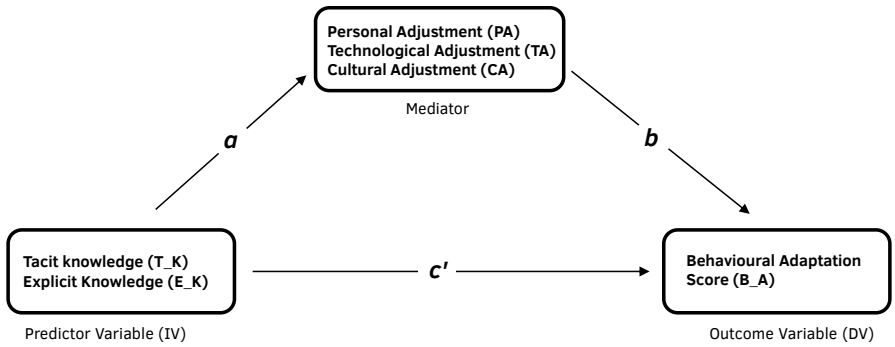

FIG. 5.2 Diagram of the mediation model.

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Table 5.3 shows the results of all three mediation modes (CA, PA, and TA). Tacit Knowledge (T_K) demonstrated a statistically significant direct association with B_A Score, as well as significant indirect effects via Personal Adjustment (β = 0.122), Technological Adjustment (β = 0.096), and Cultural Adjustment (β = 0.102). These strongly support **H1**, indicating that tacit knowledge is positively associated with behavioural adaptation and that this association is expressed across all three behavioural adaptation domains.

Unlike Tacit Knowledge, the direct effect of Explicit Knowledge (E_K) on the B_A Score is not significant in the CA, and PA models and is weaker than those of T_K in the TA model. Across the models, the total association of T_K with B_A was also larger in magnitude than that of E_K (T_K total effect: β = 0.243; E_K total effect: β = 0.114), providing support for **H2**. However, Explicit Knowledge also showed significant indirect effects through Cultural and Personal Adjustments (β = 0.099 and 0.094, respectively), while no significant indirect effect was observed through Technological Adjustment.

Finally, the results support **H3** as the path coefficients from T_K to PA (β = 0.212), TA (β = 0.132), and CA (β = 0.140) are all positive and statistically significant ($p < .001$) which means Tacit Knowledge (T_K) is positively associated with all three forms of behavioural adaptation. As PA, TA, and CA are formative components of the overall B_A score, the indirect effects are interpreted as an exploratory decomposition rather than independent causal mediation.

TABLE 5.3 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	**<.001**	[0.161, 0.264]
	E_K	E_K → PA	Direct to Mediator	0.163	0.025	6.50	<.001	[0.112, 0.211]
	T_K	**T_K → B_A**	Direct Effect	0.121	0.021	5.85	**<.001**	[0.078, 0.159]
	T_K	**T_K → PA → B_A**	Indirect Effect	0.122	0.016	7.67	**<.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	**<.001**	[0.064, 0.122]
TA	T_K	T_K → TA	Direct to Mediator	**0.132**	0.025	5.18	**<.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	**<.001**	[0.110, 0.181]
	T_K	**T_K → TA → B_A**	Indirect Effect	**0.096**	0.018	5.23	**<.001**	[0.060, 0.132]
	E_K	**E_K → B_A**	Direct Effect	**0.131**	0.017	7.77	**<.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	<.001	[0.097, 0.183]
	E_K	E_K → CA	Direct to Mediator	0.168	0.026	6.53	<.001	[0.113, 0.217]
	T_K	**T_K → B_A**	Direct Effect	**0.140**	0.020	7.09	**<.001**	[0.102, 0.181]
	T_K	**T_K → CA → B_A**	Indirect Effect	**0.102**	0.017	6.09	**<.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	**<.001**	[0.069, 0.133]

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

5.4.2 Housing Tenure

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

TABLE 5.4 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	**< .001**
CA	-2.007	1232.924	**0.045**

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

Table 5.4 demonstrates that houseowners have significantly higher overall Behavioural Adaptation (B_A) scores ($t = 3.097$, $p = .002$) and greater use of technological adjustments ($t = 6.154$, $p < .001$), 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 ($t = –2.007$, $p = .045$) and a stronger perception of heat-related risks ($t = –2.178$, $p = .030$) 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 greater for homeowners than for renters.

5.4.3 Household Composition

To test whether living in a multi-person household is positively associated with wider behavioural adaptation practices (hypothesis **H6**), a one-way ANOVA was conducted (Table 5.5). 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).

TABLE 5.5 ANOVA and Post Hoc Comparisons of Behavioural Adaptation Scores by Household (HH) Composition.

ANOVA						
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		

Note: Type II Sum of Squares

Post Hoc Tests (Games-Howell)							
Comparison	Mean Difference	95% CI for Mean Difference		SE	t	df	ptukey
		Lower	Upper				
(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	1.359.429	**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: Results based on uncorrected means. Significant differences are in 'Bold'.

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

5.4.4 Gendered Dimensions

In an Independent Samples T-Test, gender differences emerged as a key dimension in behavioural responses to heat (Table 5.6). Women demonstrated significantly higher overall Behavioural Adaptation Scores than men ($t = -3.661$, $p < .001$), with the largest difference in cultural djustment ($t = -5.087$, $p < .001$), also, in personal adjustments ($t = -2.118$, $p = .034$). 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.

TABLE 5.6 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	**< .001**
B_A	-3.661	1769.741	**< .001**
PA	-2.118	1792.072	**0.034**
TA	-1.281	1749.058	0.200
CA	-5.087	1794.690	**< .001**

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

5.4.5 Urban Density Influences Adaptation Practice

Finally, urban density emerged as a critical factor associated with adaptation. Testing the hypothesis **H8** a one-way ANOVA was performed (Table 5.7). Results indicate significant differences in B_A scores by urban density types ($F(2, 1846) = 5.452$, $p = .004$). Post hoc tests revealed significantly lower adaptation scores among residents in very highly urbanised areas compared to highly urbanised areas (mean difference = 0.697, $p = .004$). 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.

TABLE 5.7 ANOVA and Post Hoc Comparisons of Behavioural Adaptation Scores by Urban Density Types.

ANOVA						
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		

Note: Type III Sum of Squares

Post Hoc Tests (Games-Howell)							
Comparison	Mean Difference	95% CI for Mean Difference		SE	t	df	ptukey
		Lower	Upper				
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	1.296.203	**0.004**

Note: Results based on uncorrected means. Significant differences are in 'Bold'

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 ($F(2,1846) = 18.08$, $p < .001$), 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 5.8). These findings indicate that density gradients are closely linked to behavioural adaptation and indoor thermal conditions, thereby shaping overall heat experiences.

TABLE 5.8 ANOVA and Post Hoc Comparisons of Self-reported temperatures by Urban Density Types.

ANOVA						
Cases		Sum of Squares	df	Mean Square	F	p
Urban_ density	_types	506.987	2	253.493	18.075	**< .001**
Residuals		25888.651	1846	14.024		

Note: Type III Sum of Squares

Post Hoc Tests (Games-Howell)							
Comparison	Mean Difference	95% CI for Mean Difference		SE	t	df	ptukey
		Lower	Upper				
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	1.003.598	< .001
Highly urban – Very highly urban	-0.788	-1.283	-0.294	0.211	-3.739	1.211.420	< .001

Note: Results based on uncorrected means. Significant differences are in 'Bold'.

5.5 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 became evident that behavioural responses during a heat event are not merely a product of individual awareness or rational decision making, but are instead 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 Figure 5.3).

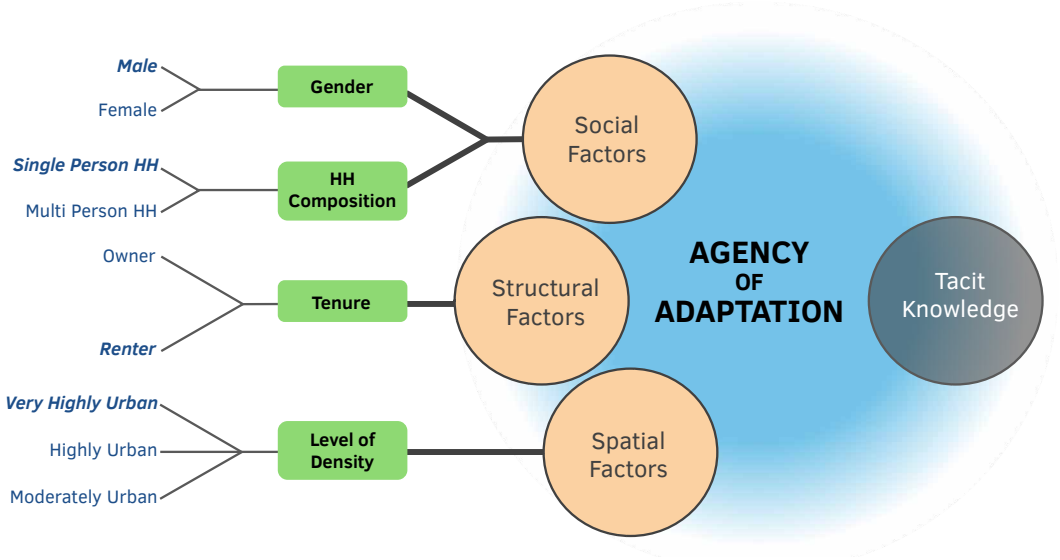

FIG. 5.3 Factors shaping residents' behavioural adaptation to heat in Dutch urban areas.

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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.

By conceptually synthesising the statistically significant individual findings from the hypotheses and considering them collectively, a context-specific vulnerability profile salient to the Netherlands can be interpreted as:

1 **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.

2 **The privilege cohort:** Women residents in multi-person 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 5.9 synthesises key risk factors and underlying barriers to behavioural heatwave adaptation identified in this study, alongside targeted risk management strategies and their expected outcomes.

TABLE 5.9 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. - Development of critical components of soft social infrastructure.	Municipality, Neighbourhood Associations, Community
		- Repurpose public facilities (libraries, neighbourhood 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. - 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. - 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.	

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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.

5.5.1 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 climates. 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 alternative weighting schemes. Nevertheless, the methodological approach of this study offers a transferable framework for identifying such context-specific behavioural adaptive barriers in comparable urban settings.

5.6 Conclusion

The main objective of this manuscript 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? Responding to the question, 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 housing tenure, which is more related to the control over private spaces, has a stronger association with behavioural adaptation score. 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 rely 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 to be 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 hazards such as heatwaves. Understanding such practices within urban communities can help in formulating targeted interventions that directly address the unique local challenges. What also comes forward through this study is that the perception of equal agency inadvertently will privilege those

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 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.

5.7 Chapter Synthesis: Responding to Research Question 3

This chapter addressed the third research question by systematically assessing how behavioural adaptation opportunities are distributed across socio-demographic groups and urban gradients in the Netherlands. Building on the qualitative findings from Chapter 4, lived adaptive practices were translated into composite measures of behavioural adaptation and hazard perception, allowing adaptive agency to be examined across a wider urban population. The findings show that adaptation opportunities are not evenly distributed, instead, they are patterned by intersecting social, structural, and spatial conditions that shape who can act and which options are realistically available during heatwaves.

In answer to Research Question 3: differences in behavioural adaptation opportunities are not reducible to individual awareness or preference, rather they are produced through unequal access to housing control, social support, tacit knowledge, and spatial environments that enable or restrict adaptive action.

This chapter therefore foregrounds behavioural adaptation opportunity as a distributional justice issue. The capacity to adapt is not a matter of personal responsibility, but an unevenly distributed opportunity embedded in social relations, housing systems, and urban configuration. In doing so, it completes the empirical arc of the dissertation: Chapter 3 identified the recognition deficit in dominant knowledge, Chapter 4 grounded vulnerability in lived experience, and Chapter 5 showed that adaptive opportunities are systematically patterned across the urban population, providing the basis for the synthesis chapter ahead.

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6 Cross-Manuscript Synthesis

This chapter interprets and synthesises the overall findings of the PhD research beyond the level of the three individual empirical articles that form the core of this thesis. Instead of repeating what is already presented and discussed in the preceding chapters, this section attempts to develop an integrated understanding of heatwave vulnerability in temperate urban contexts. This section structures the study's theoretical underpinnings and empirical findings, aiming to elaborate on the processes that contribute to heat vulnerability.

The thesis began by questioning the dominant approaches of heatwave vulnerability in climate risk and urban heat literature as they remain largely hazard centric and exposure driven. While such approaches have been instrumental in identifying spatial patterns of thermal risk, they tend to prioritise what can be readily measured at a broader scale, often at the expense of understanding sensitivity and adaptive capacity as lived, context-dependent processes. As a result, vulnerability is frequently inferred through generic spatial and/or socio-demographic proxies or aggregate indices that obscure the everyday mechanisms through which people actually cope with, respond to, and are constrained by heat stress in their daily lives.

This doctoral research offers an alternative to predominant accounts by foregrounding behavioural adaptation as a critical yet underexamined area of heatwave vulnerability. Here, behavioural adaptation is not conceptualised as an abstract component of coping capacity, but as a set of situated practices (personal, technological, and cultural) through which individuals negotiate heatwave related burdens in relation to their living conditions, social arrangements, and surrounding physical environment. Behavioural adaptation is treated as the first line of defence against increasing temperatures, and the discussion reframes vulnerability as a function of adaptive opportunity and agency, rather than exposure alone.

The purpose of this discussion chapter is therefore threefold. **First**, it re-interprets the empirical findings across the dissertation to demonstrate how behavioural adaptation is not simply an individual choice but is socially differentiated and structurally conditioned by certain factors. **Second**, it situates these findings within

broader discussions on Environmental Justice (EJ), arguing that inequalities are produced not only through uneven thermal exposure, but also through a lack of recognition of lived experiences and unequal behavioural adaptation opportunities. **Third** and finally, it reflects on the implications of this reframing for spatial analysis and urban policy, particularly with respect to how "priority areas" for design and policy intervention can be identified and justified from a behavioural adaptation standpoint.

In line with the critical realist ontological orientation, this chapter links empirical observations (experiences and behaviours), analytical regularities (statistical and spatial patterns), and underlying socio-structural mechanisms. By doing so, the discussion seeks to move beyond descriptive accounts of heat vulnerability towards a more nuanced explanation of how everyday adaptation practices are enabled or constrained within temperate urban contexts in the Netherlands. This integrative approach underpins the broader contribution of the dissertation: to advance a behavioural adaptation–centred understanding of heat vulnerability that is both empirically grounded and normatively relevant for urban climate justice and planning.

6.1 Heat Vulnerability: Shifting the Lens

Across climate risk and urban heat literature, vulnerability has traditionally been operationalised through a combination of hazard exposure, sensitivity indicators, and aggregate measures of adaptive capacity. While this framework works as a baseline for vulnerability assessments, its operationalisation in empirical research has been far from balanced. In practice, exposure has come to dominate vulnerability analysis, particularly in built-environment related research, where advances in remote sensing, environmental/microclimate modelling, and geospatial analytics have made temperature and heat-stress indicators readily quantifiable at fine spatial resolutions. By contrast, sensitivity and adaptive capacity have proven far more difficult to capture, resulting in their systematic simplification (Birkmann et al., 2022; de Sherbinin et al., 2019). For this reason, sensitivity and adaptive capacity are often operationalised using metrics that are readily measurable and that align closely with exposure-based indicators (e.g. age, income, education, mortality, ambulance/emergency calls). As a result, exposure tends to dominate prevailing framings of heatwave vulnerability. However, this predominance is not accidental. Ambient temperature, land surface temperature, and heat-stress indices can be studied, mapped consistently

across regions, enabling comparative analyses and rigorous outputs that can be quickly integrated into planning and policy frameworks. These also align well with technocratic decision making processes, in which vulnerability is often framed as a problem amenable to external, physical interventions like greening, shading, cooling infrastructure, or material modification. Such problem–solution framing neglecting the underlying processes through which risk is produced and reproduced often results in interventions that are narrowly solution-oriented and outcome driven (Eriksen et al., 2021; Nightingale et al., 2020). Ultimately, they get detached from the social, historical, and spatial conditions that shape vulnerability, rendering interventions disembodied, ahistorical, and weakly connected to people and place.

6.1.1 The Departure Point

The first article, addressing Research Question 1 (the 'recognition' aspect), examines **how urban heatwave vulnerability is currently conceptualised and operationalised across different spatial scales in the Netherlands**, thereby capturing the identified epistemic gap. Research on heat in the built environment in the Netherlands focuses heavily on hazard exposure and on infrastructure based adaptation and mitigation strategies. This imbalance reflects both methodological challenges and conceptual gaps in how vulnerability is understood and studied. In particular, sensitivity, and similarly adaptive capacity, have been relatively overlooked, creating a critical knowledge gap with significant implications for identifying who is truly vulnerable and why. Although sensitivity and adaptive capacity are frequently operationalised through certain combinations of socio-demographic factors, these are typically narrow, generic, and cross-hazard indicators like age, income, education, mortality, morbidity and similar indicators. This gap is particularly problematic because sensitivity and adaptive capacity determine whether exposure translates into actual harm. There is a tendency to assume people living in hotter areas are more vulnerable while those who are living in cooler areas are considered safer, but components that mediate this relationship remain underexplored. Without such knowledge, vulnerability assessments remain incomplete and interventions may fail to address those most at risk.

Additionally, the article identified a critical spatial scale mismatch. A majority of studies focus on macro-scale analyses at city and regional levels, while micro level studies at the level of dwelling, block or neighbourhood remain conspicuously scarce. This scale disparity represents far more than a simple research gap, it poses a substantive limitation for understanding and addressing vulnerability in meaningful ways. Reliance on coarse, broader perspectives, often conducted at metropolitan or municipal levels, can obscure granular socio-spatial drivers of heat risk that operate

at neighbourhood, or household scales (Hsu et al., 2021; Voelkel et al., 2018). In turn, large-scale action plans are privileged over smaller, targeted interventions that are often necessary (Hsu et al., 2021; Satterthwaite et al., 2020). Notably in urban contexts, where physical-spatial characteristics, socioeconomic and demographic compositions vary considerably, vulnerability is produced and experienced unevenly at the scale of everyday life. When these micro-level dynamics remain unexamined, policy responses tend to privilege large-scale, standardised action plans over smaller, spatially targeted interventions that are often more responsive. Without complementary micro-level insights into how heat interacts with specific places and people, interventions may not only be misdirected or inefficient, but may also reinforce inequality and lead to maladaptation.

Finally, and perhaps the most consequential finding of the article concerns fundamental methodological limitations. Firstly, heatwaves are studied across disciplines yet there is hardly any collaboration between the disciplines. Besides, there is a scarcity of studies that integrate multiple vulnerability components simultaneously as most research focuses on single components in isolation. This fragmentation means that the complex, interactive nature of vulnerability where the three components exposure, sensitivity, and adaptive capacity collectively determine risk remains understudied. Additionally, there is a striking bottom-up knowledge deficit, as top-down, expert-driven approaches are usually recognised as the right way to investigate heatwave vulnerability. Not just in the Netherlands, this methodological orientation reflects a broader pattern in climate adaptation research that often marginalises or gives lower priority to local and experiential knowledge. These methodological gaps have substantial consequences for both the validity and policy relevance of vulnerability assessments. For example, a neighbourhood with high heat exposure but strong adaptive capacity and low sensitivity may be less vulnerable than a neighbourhood with moderate exposure but high sensitivity and limited adaptive capacity. When sensitivity and adaptive capacity receive comparatively less analytical attention, such nuances cannot always be captured by exposure oriented studies. Moreover, the absence of bottom-up perspectives can further constrain analytical depth shadowing community assets, informal coping practices, and culturally embedded responses to heat. This gap is especially problematic given how little is known about heatwave dynamics in temperate urban contexts.

Overall, Research Question 1 highlights key aspects of the recognition aspect: it clarifies what counts as ‘valid’ knowledge on vulnerability (e.g., explicit and declarative knowledge over experiential or community-sourced knowledge), and what becomes visible (at the dominant large-scale spatial analyses). Rather than offering closure, Article I functions as a departure point, motivating a deeper experiential grounding and subsequent empirical testing of the identified gaps.

6.1.2 The Experiential Grounding

Focusing on the Dutch context, Article I identified a set of interrelated conceptual and methodological gaps in dominant heat vulnerability research, including the overemphasis on hazard exposure, the limited consideration of sensitivity and adaptive capacity, the dominance of macro-scale analyses, and the marginalisation of bottom-up and experiential knowledge. These gaps collectively point to a recognition deficit in how heatwave vulnerability is conceptualised and studied, particularly in temperate urban contexts. This recognition deficit makes clear the need for a shift in epistemic orientation. Building on this departure point, Research Question 2 (Article II) reinterprets heatwave vulnerability through the lens of behavioural adaptation, conceptualised as the first line of defence, by investigating **how urban residents perceive and negotiate heatwaves in Dutch cities, and how socio-spatial and structural conditions enable or constrain their adaptive agency.** This shift is not about questioning the importance of exposure, but about recognising that vulnerability is produced by unequal behavioural adaptation capacities and by socio-structural and spatial circumstances, dimensions that often remain largely invisible within exposure-centric approaches. In doing so, Article II responds to the recognition gap by shifting the analytical focus from hazard exposure to an agency-centred conception of heatwave vulnerability. At the same time, responding to the methodological implications identified in Article I, Article II deliberately adopts a bottom-up approach, treating citizens as agents of knowledge and allowing lived experience to guide the exploration of vulnerability.

Following de Dear and Brager's (1998) thermal adaptation framework, and specifically focusing on the behavioural dimensions of personal, technological, and cultural adjustment, Article II represents a shift towards understanding adaptation as an active, multi-dimensional process. In addition, drawing from Howe et al.'s (2019) framework, it establishes heatwave risk perception as a crucial mediating factor in adaptive behaviour. This is theoretically significant because it recognises that adaptation is not only shaped by physical capacity but also by cognitive and emotional responses to heatwaves. Unequal access to information, limited participation in decision making process, lack of social support, or uneven trust in institutions shape how risk is interpreted and acted upon (Shi et al., 2016). When certain groups are marginalised or excluded from knowledge production, their access to information, perceived agency, and confidence in institutional guidance may be constrained (Sovacool et al., 2015). In this way, the procedural dimension operates as a structural mechanism that indirectly shapes behavioural adaptation by influencing both risk perception and perceived adaptive capacity.

Research Question 2 therefore investigates how procedural inequities shape citizens' adaptive opportunities, centring their everyday experiences as a key source of vulnerability knowledge. This grounding phase treats residents not merely as recipients of adaptation measures but as situated knowers whose practices, constraints, and interpretations provide critical insight into how vulnerability is produced and negotiated in practice (van Valkengoed and Steg, 2019). Foregrounding lived experience thus provides the empirical foundation for understanding how urban residents perceive, interpret, and act upon heatwave risk in cities with a temperate climate.

Consistent with its Critical Realist orientation, the dissertation adopts an exploratory sequential mixed-methods design. A single-method approach would be insufficient to capture the layered and context-dependent nature of heatwave vulnerability. As temperate contexts are understudied, adopting the quantitative phase before the qualitative phase could possibly impose certain biases, as the literature review found a strong inclination toward quantitative methods in this field. To ensure the exploration of context-specific vulnerability, the qualitative phase was conducted first, followed by the quantitative phase, referred to as empirical testing, which is discussed next. As summarised in Article II, the qualitative phase provided deeper real-life insights into the human interactions with the hazard during heatwaves. **First**, perception-wise, it introduced cognitive dissonance, an uncertainty or tension between recognising increasing heat risks and simultaneously perceiving the Dutch climate as inherently mild/cold. This cognitive dissonance renders heatwaves shock events: residents anticipate relatively mild summers, and sudden temperature spikes leave even those originating from warmer climates unprepared. This finding challenges the common assumption that familiarity with hotter contexts necessarily translates into greater preparedness for heat. Another important issue relates to age-related vulnerability. Epidemiological studies focusing on morbidity and mortality understandably highlight elderly people, children, and individuals with pre-existing medical conditions as high-risk groups. Emphasis on such severe health endpoints may narrow the operationalisation of vulnerability to outcomes that are clinically measurable. According to Article II's findings, young adults also expressed difficulties and challenges during heat events. Thermal discomfort, sleep disturbance, and productivity loss represent significant but less visible forms of vulnerability. **Second**, the detailed exploration of behavioural adaptation, comprising personal, technological, and cultural adjustments, unveiled the procedural unfolding of interviewees adaptation practices. People rely first on personal measures, then extend their responses to technological adjustments (because they are associated with cost and control), and subsequently to cultural adaptations that even extend outside the private space. This relates to one of the major findings of Article II: behavioural adaptation is not static, isolated, or certain; rather, it is a dynamic and spatially contingent process. It operates as a network of practices that expands or contracts depending on individual circumstances, extending

from the housing unit to the neighbourhood, the city, or beyond when conditions and opportunities permit. Moreover, participants also draw on easy, unique yet effective adaptation practices from experiences in other climatic contexts.

Overall, a nuanced examination of behavioural adaptation through the active participation of people revealed several key factors for adaptive behaviour, such as individual agency, social ties, and cultural backgrounds. The findings highlight uneven adaptation opportunities among residents, with those having limited assets and restricted control over their living units facing greater difficulties in coping with heatwaves, regardless of their physical built environment. Additionally, spatial domains, private and public, indoor and outdoor, play a pivotal role in citizens' everyday adaptation practices against heatwaves, as people continually seek out and repurpose spaces and facilities in their everyday coping strategies against heatwaves. So, behavioural adaptation is not simply a matter of personal choice, rather, it is influenced by multiple socio-spatial factors.

Article II functions as the grounding phase of the dissertation, translating the recognition gaps identified in Article I into empirically situated understanding. By foregrounding behavioural adaptation as the first line of defence and centring lived experience as a legitimate source of knowledge, the study reveals how urban heat is negotiated in everyday life and spatial dependencies involved in the adaptation process. This grounding moves beyond vulnerability classifications, exposing the uneven procedural and spatial conditions under which adaptive practices become possible or implausible. In doing so, Article II provides the necessary conceptual and empirical foundation for moving from situated experience to systematic assessment, setting the stage for Research Question 3 (Article III).

6.1.3 Population Level Testing

Articles I and II collectively reposition heatwave vulnerability away from exposure-dominated framings by first identifying recognition deficits in dominant research approaches and then grounding vulnerability in lived experience through behavioural adaptation. While Article II demonstrated how behavioural adaptation operates as a socially and spatially conditioned first line of defence, these insights remained subjective and contextually situated. Building on this foundation, Article III extends the analysis through a population level testing of the identified agencies of behavioural adaptation and the mediating role of risk perception across the Netherlands with an objective of tracing the key determinants of the unequal distribution of such adaptive opportunities.

Article III operationalises the sequential exploratory mixed-methods design in which the qualitative findings from Article II directly inform hypothesis formulation and survey construction. It focuses on examining **how behavioural adaptation opportunities are unevenly distributed across socio-demographic groups and urban gradients in the Netherlands, and which social, structural, and spatial factors contribute to these inequalities** (Research Question 3). Behavioural adaptation is modelled as a multidimensional construct comprising personal, technological, and cultural adjustments, while heatwave risk perception, drawing on both explicit and tacit knowledge as well as attitudes and beliefs, is treated as a key mediating mechanism shaping adaptive behaviour. By adopting a formative measurement framework, the study preserves the conceptual distinctiveness of these dimensions and avoids collapsing behavioural adaptation under any single latent trait. It thereby, remains faithful to the experiential complexity identified in the qualitative phase and also provides a clear construct to compute respondents adaptive capacity score.

Empirically, one of the structural factors influencing adaptive capacity identified in the interview phase, notably housing tenure, was found to be statistically significant across the urban population in the Netherlands. It primarily affects the technological adjustments as renters usually face more procedural constraints than homeowners and have to rely more on surrounding neighbourhood facilities. These findings provide empirical support for the recognition claims in Article II by showing how unequal control over space translates into differentiated adaptive agency. They also indicate how uneven adaptation opportunities can be structurally embedded even in highly systematic and organised urban contexts like the Netherlands.

Besides, Article III identifies two key social factors, household composition, and gender, as intersecting determinants of behavioural adaptation. Multi-person households consistently demonstrate better adaptation scores than those living alone, indicating the importance of shared resources, collective decision-making, and social support in coping with heat. Interestingly, gendered differences reveal that women tend to exhibit higher levels of behavioural adaptation and stronger heat risk perception. This finding is not fully consistent with several exposure-oriented studies on urban heat. It is important to note, however, that even though women score higher than men in perception and behavioural adaptation, this does not imply that they are less vulnerable or out of the risk zone. The thesis does not make such a claim, as it remains unclear what level of behavioural adaptive capacity is required to counter specific levels of heat exposure or sensitivity. This gap highlights a valuable direction for future research.

At the spatial level, residents of very strongly urbanised (class 1 in CBS) areas report both higher indoor temperatures and lower behavioural adaptation scores than those in less dense urban settings (classes 2 and 3), underscoring how urban setting itself constrains adaptive opportunity. Crucially, these findings show that higher exposure does not necessarily generate stronger adaptation, revealing a structural mismatch between heat risk and adaptive capacity.

Another key finding of the article is that hazard perception plays an important role in shaping behavioural adaptation. This dimension remains insufficiently addressed in climate literature focusing on temperate regions. The mediation analysis substantiates this by demonstrating the central role of experiential knowledge in shaping vulnerability. Tacit knowledge, acquired through lived experience and social networks emerges as a significantly stronger predictor of behavioural adaptation than explicit, formal knowledge. It demonstrates that what people know through experience substantively shapes how they adapt. Importantly, the tacit-knowledge component first surfaced in the qualitative phase, and subsequent statistical validation confirmed it as a robust and influential factor in adaptive behaviour. Beyond its effect on overall adaptive capacity, tacit knowledge is identified as a key driver across all three domains of behavioural adaptation, with particularly strong influences on technological and cultural adjustments. Moving past generic claims that perception influences adaptation, the study specifies which adaptive practices are strongly shaped by hazard perception and which are not. This level of granularity is crucial for effective and locally grounded adaptation policy and strategy development.

In synthesis, Article III functions as the empirical consolidation phase of the dissertation. It transforms the recognition gaps identified in Article I and the lived realities documented in Article II into systematic evidence of how behavioural adaptation opportunities are distributed across urban Netherlands, and of the key factors creating uneven adaptive agency in this context. Consequently, heatwave vulnerability must be understood not merely as an issue related to hazard exposure but as a manifestation of pre-existing social, structural, and spatial inequalities.

6.2 Environmental Justice Revisited

Environmental Justice (EJ) literature has long provided a critical lens for examining how environmental burdens and benefits are unevenly distributed across populations. In the case of urban heatwaves, EJ related debates have traditionally centred around distributive inequities only, focusing mostly on who and what is exposed to higher temperatures and who lacks access to cooling infrastructure or facilities. While these concerns remain valid, the findings of this dissertation demonstrate that exposure alone is insufficient for understanding how heat-related vulnerability is produced, experienced, and reproduced in the temperate urban settings. This dissertation contends that a purely distributive focus is insufficient, and therefore attempts to examine the deeper relational and procedural dimensions of EJ that produce and perpetuate these visible inequalities. Drawing on David Schlosberg's (2013) reinterpretation of environmental justice, informed by the work of Iris Marion Young and Nancy Fraser, this research conceptualises environmental justice as a relational and multidimensional construct, constituted through recognition, participation, and distribution. In this framing, recognition and participation are not merely supportive of distributive outcomes, but function as epistemic preconditions through which injustice is rendered visible, intelligible, and contestable.

6.2.1 Recognition Aspects: Who and What Counts

Recognition determines whose experiences, needs, and everyday practices are taken seriously in defining environmental problems. Within EJ scholarship, recognition is fundamentally concerned with how certain experiences, socially differentiated identities, and forms of knowledge are rendered visible, intelligible, and legitimate in the structuring of environmental risk. In the context of this research, recognition extends far beyond identifying who is demographically vulnerable, rather, it (Article I) explored how vulnerability itself is conceptualised. In much urban hazard work, fundamental epistemologies assume that vulnerability is mainly a matter of hazard exposure and can be understood by mapping where the hazard is most intense. For intensive hazards such as earthquakes or floods, where impacts are immediate and visible, such an orientation works. By contrast, heatwaves have diffuse, cumulative, and invisible effects. And in temperate climates, this exposure-only lens is particularly inadequate where hot weather conditions are episodic rather than chronic, built environments are primarily designed for heat retention, and

populations are less habituated to sustained high temperatures. Nevertheless, heat in temperate cities continues to be investigated largely through conventional hazard frameworks that prioritise exposure, thereby obscuring the context-specific drivers of vulnerability.

The recognition aspect identified in this dissertation is therefore not simply an issue of missing variables. Rather, Chapter 1 shows that the body of literature reviewed in Article I tends to frame vulnerability in ways that prioritise larger-scale and exposure-based analysis, while giving insufficient recognition to lived experience and micro-scale realities. Recent scholarship likewise argues that heat justice must move beyond a purely distributional focus to examine how heat inequality is socially and politically produced, and whose experiences and epistemologies are granted legitimacy within research and policy practice (Hamstead, 2023; Oppermann et al., 2024). Such framing implicitly privileges a narrow understanding of harm, one that can be seen, mapped, and aggregated, while sidelining the more granular and relational processes through which people actually experience heatwaves. Recognition also operates through the spatial logics. When research defaults to larger scales (cities, regions), small-scale (unit, block, neighbourhood) realities become epistemic blind spots. Therefore, individual challenges (sensitivity component of the vulnerability framework) do not manifest at the scales typically privileged by conventional methods. Recognition failures stem from the dominance of expert-driven frameworks that rely on standardised indicators and technical reasoning. These approaches are valuable, but when they operate as the sole arbiter of vulnerability, they marginalise the forms of situated knowledge that arise from navigating heat in everyday urban lives.

A further aspect highlighted in Article I is the strikingly monodisciplinary orientation of heatwave research in the Netherlands. Despite the inherently cross-cutting nature of heat-related vulnerability research efforts remain largely within individual disciplines, with limited substantive collaboration across fields. This fragmentation is not simply a methodological inconvenience, it also constitutes an epistemic constraint that narrows what counts as relevant evidence. Eventually, such monodisciplinary approaches can systematically flatten the multidimensional character of vulnerability, particularly in urban contexts where the built-environment is highly heterogeneous and dynamic. From an EJ perspective, such monodisciplinarity may produce a form of structural misrecognition that obscures interactions that only become visible through interdisciplinary synthesis. Without integrative collaboration, scholarship risks yielding partial understandings that fail to identify who is most vulnerable, and why they are vulnerable.

6.2.2 The Procedural Aspect

The Participation angle of EJ foregrounds not merely the presence or absence of formal involvement but the deeper question of how adaptive possibilities are structured through processes of knowledge inclusion, decision-making, and socio-spatial negotiation. In the context of heatwaves, participation matters procedurally because it shapes whether residents' experiences are taken into account in adaptation planning and whether their coping strategies are recognised by formal institutions as valid and actionable. This perspective is therefore fundamentally epistemic and concerns the production, circulation, and validation of knowledge about vulnerability and adaptation. When participation is limited or symbolic, certain realities are systematically excluded, thereby narrowing the range of solutions 'considered' legitimate or effective.

Article II (Research Question 2) documents layers of everyday heat experience in Dutch cities. Through in-depth semi-structured interviews with urban residents, the study generates rich, situated accounts of how individuals interpret and respond to heatwaves. For instance, it shows how individuals mobilise resources from the private dwelling to surrounding urban facilities during heat events, often repurposing spaces and functions in unconventional ways. Facilities that are not primarily designed for cooling purposes become de facto heat-refuge choices. Simultaneously, it highlights the critical role of micro-scale spaces (e.g. private outdoor, shaded spaces, accessible air-conditioned facilities) in shaping the adaptation process. These everyday spatial resources are often overlooked in macro-scale vulnerability assessments, despite their significance for enabling short-term behavioural responses. Their uneven availability reveals how procedural and structural constraints operate: socio-demographic, spatial, and structural factors collectively condition individuals' capacity to cope behaviourally. Such first-hand engagement reveals an alternative landscape of adaptation practices specific to Dutch and, more broadly, temperate contexts. Yet these practices rarely translate into planning and policy, precisely because the participatory channels through which they might enter institutional decision-making remain weak and there is a tendency to overlook such realities as they do not align fully with established heat risk frameworks. When lived experiences, embodied distress, or context-specific adaptive practices fail to enter institutional vocabularies, the policy arena becomes constrained by a narrow imagination of what counts as vulnerability and what constitutes a legitimate adaptive response.

As a result, interventions derived from exposure-oriented assessments through top-down processes often end up in physical and technological fixes. If these fixes are not rooted in real-life realities, they may leave adaptation to be managed

reactively by individuals, rather than creating conditions for more supported, durable, and equitable forms of coping. This thesis strongly advocates substantiating effective local strengths and practices rather than adopting something out of the box. In this way, weak participation leads to what can be described as 'adaptive silencing': people adapt, but their adaptations do not speak back to the formal systems (Krueger, 2023). Most importantly, in temperate climates where heat is historically considered an anomaly, participation becomes the mechanism through which new forms of climatic reality should be collectively interpreted. Sole reliance on long-term, technocratic, external, global practices without understanding and substantiating effective local strengths and practices will eventually continue perpetuating the same cycle of unjust, improvised, exclusionary adaptation frameworks.

6.2.3 Distributive Aspect (Exposure to Adaptive Capacity)

Moving towards the distributive aspect of justice, informed directly by the preceding phases of recognition and participation, concerns far more than the spatial manifestation of risk. With distribution, this thesis refers to the underlying social, structural, and institutional arrangements that produce unequal capacities to avoid harm, cope with heat stress, and benefit from adaptation measures. The principal argument here is that distributive justice is not limited to the physical geography of temperature, rather it must be understood as the allocation of 'adaptive opportunities,' the degree to which individuals and groups can convert their resources, spaces, social relations, and knowledge into effective coping strategies. This PhD research offers an adaptation-centred reframing of heatwave vulnerability for temperate urban regions.

In Article III (research question 3), a distributive perspective grounded in behavioural adaptation reveals several deeper mechanisms that typically escape exposure-oriented analyses. First, adaptive capacity itself is not a neutral or freely available resource equally available to everyone. It is a product of agency, access to resources and support, availability of adaptive opportunities and the overall socio-physical configurations of everyday life. Control over space, the ability to modify indoor environments and leverage neighbourhood amenities, and access to social support networks fundamentally shape capacity to respond to environmental stressors such as heatwaves, irrespective of the exposure zones in which individuals reside. These differentiated conditions underscore that adaptation is unevenly distributed, often reinforcing existing patterns of vulnerability and privilege rather than mitigating them.

Secondly, Article III shows that inequities may arise not only from the unequal distribution of resources but also from the unequal distribution of barriers. Article III identifies and statistically validates certain social, spatial, and structural conditions contributing to limited adaptation capabilities. These constraints do not simply co-exist with exposure, they intensify it. Thirdly, knowledge resources carry adaptive value. Tacit knowledge, intergenerational practices, and locally shared understandings of heat for instance are subtle yet powerful determinants of who is positioned to respond effectively to heat.

Crucially, these distributive dynamics highlight that vulnerability is not simply a reflection of environmental conditions but a manifestation of broader social relations. Heat acts as a stressor that interacts with pre-existing inequality factors like housing tenure, gender, household configuration, level of urban density, and quality of neighbourhood-level amenities to produce differentiated outcomes. Interventions focused solely on mitigating exposure without addressing this structurally embedded distribution of adaptive opportunities risk reproducing or even intensifying injustice. By theorising distribution through the lens of behavioural adaptive opportunity rather than temperature or (cooling) infrastructure, the dissertation positions heatwave vulnerability as an expression of underlying socio-spatial inequity. Distribution thus becomes a question of who is structurally enabled to adapt and who is structurally constrained. This conceptual shift provides the basis for interpreting the empirical findings uncovered in Article III.

6.2.4 Implications for Environmental Justice Scholarship

This dissertation advances EJ scholarship along three principal dimensions. First, it offers a systematic empirical operationalisation of Schlosberg's multidimensional EJ framework within urban settings in a temperate climate – contexts in which heatwave vulnerability is frequently presumed to be limited or temporary. By demonstrating that such assumptions obscure persistent inequalities, the research shows that EJ concepts remain highly relevant even where climatic extremes are less visible. Second, it foregrounds behavioural adaptation as a justice-relevant domain, illustrating that everyday practices are not merely individual responses to heat but critical sites where recognition, procedural inclusion, and distributive equity intersect. Third, it shifts EJ debates from static assessments of risk toward a processual understanding of coping, constraint, and capability, thereby offering a more nuanced account of how climate justice is inhibited within everyday urban life.

Revisiting behavioural adaptation through the EJ lens, the chapter argues that heatwave vulnerability is not simply a matter of who is exposed, but who possesses the agency and capacity to respond. In urban environments, this agency is unevenly distributed, yet in climate scholarship it has often been misconceptualised as an individual/personal issue. The findings presented here decisively challenge this view. By demonstrating that adaptive practices are shaped and often constrained by social recognition, procedural access, and material resources, the dissertation shows that behavioural adaptation is neither solely individual nor uniformly available.

Failure to acknowledge and examine uneven adaptive agency obscures the true geography of vulnerability. Without participatory inquiry into residents' constraints and capabilities, and without assessing how these dynamics align or misalign with conventional exposure/risk maps, policy and planning risk misidentifying priority populations and places. This is where the PhD makes its major contribution. It utilises EJ not simply as a toolkit to identify and test, but rather as a lens to think, see, and identify intangible barriers to heatwave adaptation. In doing so, it enriches theoretical debates within EJ scholarship while providing a clear demonstration of how EJ principles can be effectively operationalised in the field, both for heatwaves and for climate adaptation more broadly.

6.3 Spatial Implications: Rethinking Priority Areas and Possible Policy Intervention (Refining Spatial Heat Vulnerability)

Beyond theory and methodology, the findings of this dissertation hold relevance for urban planning, design, and climate adaptation practice. A critical implication emerging from the synthesis of findings is the possibility of reframing how spatial heatwave vulnerability is identified and acted upon in practice. Common practices of identifying heat vulnerability areas rely mostly on hazard-oriented indices, such as urban heat island (UHI) intensity, land surface temperature (LST), perceived temperature, or heat stress indices. These maps are invaluable for identifying areas with elevated thermal exposure, yet they implicitly assume that exposure equals vulnerability, or at least that exposure is its primary determinant. Addressing research question 4, the dissertation therefore explores **how behavioural adaptation constraints, conceptualised through an EJ lens, can be spatially operationalised to identify priority areas for short-term heatwave adaptation interventions**.

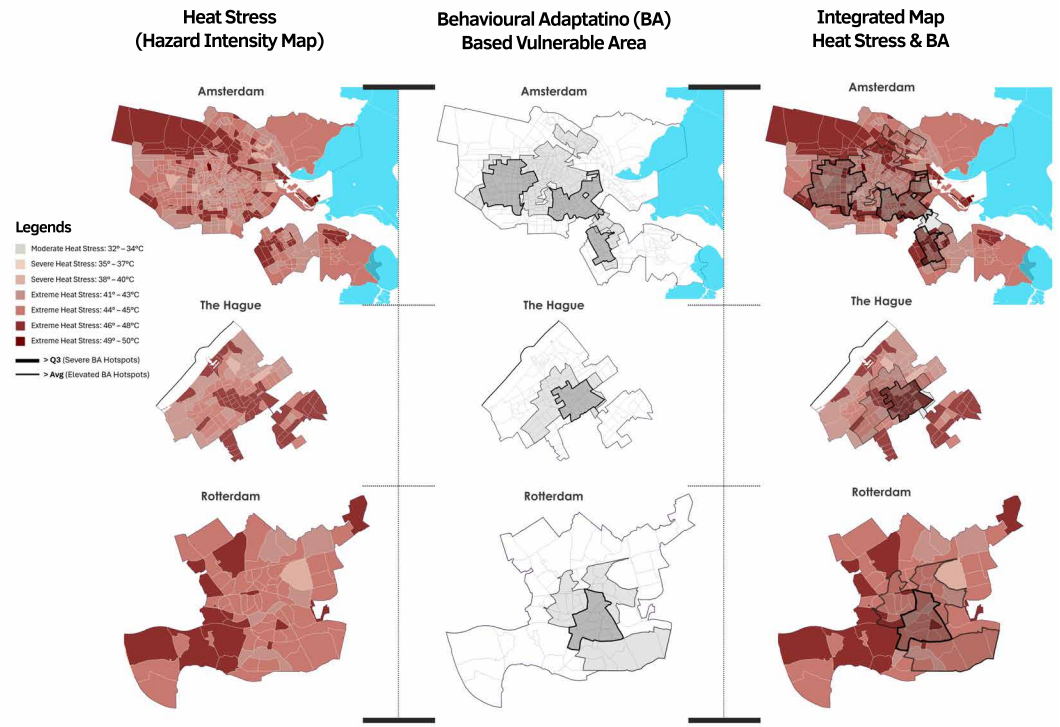

FIG. 6.1 Spatial convergence and divergence between exposure-based (heat stress) and behavioural adaptation based vulnerable areas across Amsterdam, The Hague, and Rotterdam.

The left column presents neighbourhood-level heat stress intensity (°C), the middle column marks areas identified as vulnerable based on behavioural adaptation criteria and the right column shows the integrated map. Black outlines indicate elevated BA vulnerability clusters (≥ average), while thicker boundaries denote severe BA hotspots (≥ third quartile).

Spatial operationalisation here does not mean converting behavioural adaptation into a purely technical index. Rather, it means translating empirically identified constraints on adaptive agency into spatially observable indicators that can inform short-term prioritisation. The aim is not to replace hazard or exposure maps, but to refine them by identifying where social, structural, and spatial barriers to coping are concentrated. Thus, the dissertation offers an alternative yet complementary behavioural adaptation-centred approach. By demonstrating that behavioural adaptation opportunities are systematically constrained for specific population profiles termed ‘high vulnerability cohorts’ (e.g. men, living alone, in rental housing, and located in very strongly urban areas) the research introduces a EJ-informed spatial logic. Consistent with the IPCC’s conceptualisation, vulnerability in this framing is not solely a function of how hot a place becomes, but of who lives there and what adaptive options they realistically possess when an event occurs.

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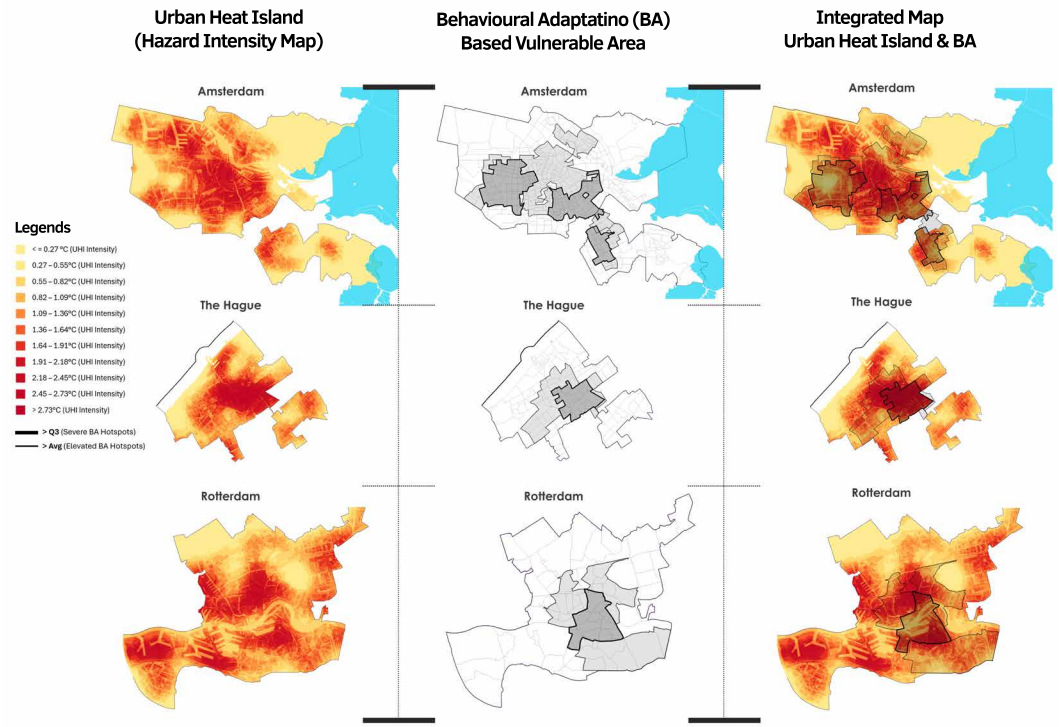

FIG. 6.2 Spatial convergence and divergence between exposure-based (urban heat island) and behavioural adaptation based vulnerable areas across Amsterdam, The Hague, and Rotterdam.

The left column presents neighbourhood-level urban heat island intensity (°C), the middle column marks areas identified as vulnerable based on behavioural adaptation criteria and the right column shows the integrated map. Black outlines indicate elevated BA vulnerability clusters (≥ average), while thicker boundaries denote severe BA hotspots (≥ third quartile).

Building on this insight, the dissertation advances a novel operational approach: using behavioural adaptation constraints as a spatial selection criterion to identify priority areas for intervention within cities (Figure 6.1 and Figure 6.2). The operational logic proceeds in four steps. First, behavioural adaptation constraints are identified empirically through the qualitative and quantitative findings of the dissertation. Second, these constraints are translated into spatially available proxy indicators: *gender composition, single-person households, rental tenure,* and *very strong urban density*. Third, neighbourhoods are classified according to the concentration of these constraints, distinguishing between elevated behavioural adaptation vulnerability and severe behavioural adaptation hotspots. Fourth, these layers are compared with existing heat-stress and UHI maps to identify where thermal exposure and constrained adaptive capacity converge or diverge. When applied to urban neighbourhoods, this approach reveals a markedly different geography of vulnerability, one that diverges from exposure-based maps and brings into view areas where structural and socio-spatial constraints limit residents' capacity to cope with heat.

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Following the developed adaptation-centric vulnerability logic, the illustrative maps of Amsterdam, The Hague, and Rotterdam demonstrate this divergence clearly. While hazard maps (Heat Stress, and UHI Effect) highlight certain areas as thermally exposed, the behavioural adaptation–based selection identifies a more targeted set of zones where residents face compounded constraints in coping with heat autonomously. Notably, some areas classified as high-risk in exposure maps do not appear as priority zones under the behavioural adaptation lens, while other neighbourhoods, less prominent in hazard intensity, emerge as critical due to their social and housing composition.

This divergence is analytically significant. It reveals that hazard intensity and adaptive capacity do not spatially coincide in a straightforward manner. In other words, places that are hot are not necessarily the places where people are least able to adapt, and vice versa. The behavioural adaptation lens therefore exposes a form of latent vulnerability that remains invisible when exposure metrics are used in isolation. It also enables more targeted interventions, for example by prioritising areas where high exposure coincides with low adaptive capacity.

The distinction between the two selection criteria used in the maps further strengthens this argument. Neighbourhoods where the proportions of men, renters, and single-person households exceed the third quartile (Q3) are classified as severe behavioural adaptation hotspots, where multiple constraints converge. The use of Q3 identifies the upper 25% of the distribution, capturing areas where these characteristics are markedly concentrated relative to the national urban baseline. In contrast, areas where the same indicators exceed the mean but remain below Q3 are categorised as elevated risk zones. While less extreme, these still signal elevated vulnerability relative to the baseline. This graduated threshold approach aligns closely with EJ principles, as it allows for the recognition of varying degrees of disadvantages. The composite criterion (≥3 indicators above the specified thresholds) further identifies neighbourhoods where vulnerabilities cluster. Table 6.1 explains how the criteria are used in the priority selection process.

TABLE 6.1 Behavioural Adaptation Centred Spatial Priority Selection Criteria (Policy Implications Derived from Chapter 5, Table 5.9).

Dimension	Indicator	Threshold	Policy Implication
Demography	% Men	> Q3 (Severe) > Avg (Elevated)	Policies Linked to – Social Risk
Household Structure	% Single-person households	> Q3 (Severe) > Avg (Elevated)	Policies Linked to – Social Risk
Tenureship	% Rental housing	> Q3 (Severe) > Avg (Elevated)	Policies Linked to – Structural Risk
Urban Configuration	Very Strongly Urban	CBS class 1	Policies Linked to – Spatial Risk
Composite Risk	≥3 indicators	Above thresholds	All Policies from Table 5.9

Note: Q3 refers to the third quartile (upper 25% of the distribution). "Avg" denotes the mean value of the analysed area. Neighbourhoods exceeding Q3 are classified as severe, while those exceeding the mean but below Q3 are categorised as elevated. CBS class 1 corresponds to "very strongly urban" areas according to the Dutch Central Bureau of Statistics (CBS) classification.

These indicators are not selected as generic demographic descriptors. They are selected because the preceding empirical chapters identified them as conditions associated with constrained behavioural adaptation. Gender and household composition represent social dimensions of adaptive agency, rental tenure represents structural control over the dwelling, and very strong urban density represents spatial constraint in the broader urban environment. The composite criterion therefore identifies places where multiple adaptation barriers overlap, rather than places where a single vulnerable population category is present. It is also important to clarify that the inclusion of gender should not be interpreted as a universal claim that men are more heat-vulnerable than women. Rather, within this study, men reported lower behavioural adaptation and heat-risk perception scores, making gender relevant specifically to behavioural adaptation in the Dutch urban context.

From a Critical Realist standpoint, this mapping approach illustrates how behavioural adaptation operates as a mediating mechanism between structural conditions and observed vulnerability outcomes. The hazard layer captures the empirical presence of heat, but the behavioural adaptation layer points towards the real generative conditions that shape whether exposure translates into harm. Crucially, this approach does not seek to replace hazard maps but to narrow and refine them. By intersecting exposure surfaces with behavioural adaptation constraints, the research offers a way to move from generic, city-wide vulnerability narratives towards a more sensitive prioritisation. This is particularly relevant for short-term adaptation planning, where immediate action is required. Rather than asking 'Where is it hottest?', the synthesis reframes the policy-relevant question as: 'Where do people face the greatest difficulty in coping with heat, given their social and spatial conditions?'

This reframing represents a substantive contribution of the dissertation. It demonstrates how behavioural adaptation research can be operationalised spatially, transforming abstract justice concerns into concrete selection tools for urban intervention. In doing so, the dissertation advances vulnerability assessment beyond exposure-centric logics and provides a pathway for integrating EJ considerations directly into heat adaptation decision making in temperate cities.

By demonstrating that behavioural adaptation constraints can be spatially operationalised, the research offers a distinct approach to identifying vulnerability within cities, complementing existing heat hazard and exposure maps.

6.3.1 Responding to Research Question 4

The fourth and final research question of this thesis asks how behavioural adaptation constraints can, through an EJ lens, be spatially operationalised to identify priority areas for short-term heatwave intervention.

The synthesis shows this is achievable by translating empirically identified barriers to adaptive agency into spatially observable indicators and using these to refine conventional heat exposure maps. The operationalisation rests on a simple premise: priority areas are not only those most exposed to heat, but those where residents are least able to cope. Constraints on adaptive agency are concentrated in identifiable ways across the urban population and can therefore be mapped.

When this behavioural adaptation layer is overlaid with existing heat-stress and urban heat island maps, it reveals both convergence and divergence. Convergence: where high exposure meets constrained adaptive capacity, signals urgent intervention priority. Divergence: where moderate exposure coincides with severely limited coping options, reveals latent vulnerability that exposure maps alone cannot detect. This is the core analytical contribution of the approach.

In answer to Research Question 4: behavioural adaptation constraints can be spatially operationalised by treating adaptive agency as a justice-relevant spatial condition. Rather than asking only where heat is most intense, the proposed logic asks where residents are least equipped to respond. This produces a more targeted and justice-sensitive basis for short-term intervention.

6.4 Limitations and Future Research Directions

No doctoral research can comprehensively capture the full complexity of urban heatwave vulnerability, particularly when addressing a phenomenon that is dynamic, context-dependent, and shaped by both material and social processes. This dissertation is no exception. The research acknowledges the following limitations:

The first limitation relates to the temporal and climatic specificity of the research. The empirical components of the dissertation were conducted within a specific time frame focused on heatwave experiences in a temperate climate, using the Netherlands as a case. While this context is suitable, and deliberately chosen to address a major gap in the literature, the findings should not be assumed to transfer directly to other temperate cities as each country has fundamentally different institutional and social arrangements.

In terms of methodology and research design, the dissertation prioritises behavioural adaptation, excluding the physiological and psychological domains as they are beyond the scope and require a different and more comprehensive multidisciplinary research design, data collection and analysis procedures. This is a conscious boundary-setting rather than an oversight. However, incorporating physiological and psychological dimensions could lead to a different identification and spatial configuration of vulnerability hotspots.

Similarly, the qualitative interviews were conducted during summer periods, when heat experiences are most salient. While this strengthens the experiential validity of the findings, it also means that seasonal adaptation practices and longer-term behavioural changes beyond acute heat events are less visible. The research does not claim to capture behavioural adaptation as a fixed trait, but rather as a situated response to episodic stress, shaped by immediate conditions.

Finally, in the analysis, composite scoring (Article III) effectively synthesises 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.

6.4.1 Directions for Future Research

The findings of this dissertation open several promising avenues for future research:

First, future research could extend this thesis by adopting more targeted, mechanism-oriented study designs that engage directly with the vulnerable cohorts identified in this thesis. One promising direction is cohort-specific (renters, gender, household type) qualitative follow-ups to uncover the structural, normative, and situational mechanisms that underpin their limited adaptive opportunities. Longitudinal or seasonal panel designs can also capture the temporal dynamics of vulnerability. More participatory and action-oriented approaches, such as co-design workshops or participatory action research with urban residents, could directly link lived experience to feasible intervention pathways, expanding policy recommendations to effective interventions.

Second, this thesis relies on equal weighting within a formative measurement framework assuming that each item (e.g. personal, technological, and cultural) contributes uniformly, which will not be the case in reality. Future research should therefore examine the differential contributions of individual practices, presumably leading to alternative weighting schemes to identify which adaptations most strongly shape overall individual adaptivity.

Third, the spatial operationalisation proposed in this dissertation could be refined through finer-grained data and the use of different vulnerability cohorts, possibly through participatory mapping, or ethnographic visual methods at the individual or neighbourhood level. Engaging residents directly in identifying the role of physical built-environment conditions in heatwave adaptation can strengthen the participatory dimension of justice or inequality-related exploration.

Fourth, it would be valuable to integrate behavioural adaptation indicators with complementary health-related datasets, including mental health outcomes, cognitive stress indicators, and pregnancy-related health measures. A combination of behavioural adaptation with health outcomes may enable a comprehensive assessment of how constrained adaptation translates into differential health impacts, ultimately even narrowing the intervention areas. Linking justice-oriented vulnerability analysis with urban health can certainly add further value.

Finally, comparative studies across multiple temperate cities could test the broader applicability/usefulness of the behavioural adaptation framework, examining how different urban forms and urban systems shape adaptive opportunities.

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7 Conclusion

Guided by the core research question: **How can applying an environmental justice lens to behavioural adaptation reconceptualise urban heatwave vulnerability in temperate cities, and what are the implications for developing just short-term adaptation strategies?** the dissertation set out to reconceptualise urban heatwave vulnerability in temperate cities using the Netherlands as a case. To address this overarching question, the manuscript-based thesis was structured around four interrelated research questions, moving from critical knowledge assessment to experiential grounding, empirical assessment, and spatial synthesis. Table 7.1 summarises how each question was addressed and the core outcome of each stage.

TABLE 7.1 Summary of research questions, analytical approaches, and core outcomes of the dissertation.

Research Questions	Approach	Findings
1. *How is urban heatwave vulnerability currently conceptualised and operationalised in dominant research and practice across different spatial scales in the Netherlands, and what epistemic limitations are associated with such framings?* [Chapter 3]	Addressed through a critical knowledge assessment of existing Dutch heatwave research.	Dominant knowledge production on heat in the Netherlands remains largely top-down, expert-driven, and weak in terms of bottom-up recognition of lived experience.
2. *How do urban residents perceive, experience, and negotiate heatwaves through behavioural adaptation in Dutch cities, and how do socio-spatial and structural conditions shape their adaptive agency?* [Chapter 4]	Addressed by grounding urban residents' lived experiences, hazard perception, behavioural adaptation, and spatial practices.	Behavioural adaptation unfolds through personal, technological, and cultural adjustments that are spatially dependent and unevenly enabled across private and public, indoor and outdoor environments.
3. *How are behavioural adaptation opportunities unevenly distributed across socio-demographic groups and urban gradients in the Netherlands, and what social, structural, and spatial factors contribute to these inequalities?* [Chapter 5]	Addressed through a broader empirical assessment of behavioural adaptation and hazard perception across the Dutch urban population.	Behavioural adaptation disparities are not subjective or random. They are systematically associated with socio-structural and spatial factors
4. *How can behavioural adaptation constraints, through an Environmental Justice lens, be spatially operationalised to identify priority urban areas for short-term heatwave adaptation interventions in temperate cities?* [Chapter 6]	Addressed through a cross-manuscript synthesis that translated the empirical findings into a spatially explicit prioritisation logic.	Behavioural adaptation constraints can be mapped alongside exposure-based heat indicators to identify areas where people face limited coping opportunities and where short-term interventions are most urgently needed.

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Collectively, the supporting research questions address the overarching inquiry of this thesis. The dissertation demonstrates that applying an Environmental Justice (EJ) lens to behavioural adaptation reconceptualises urban heatwave vulnerability as more than a condition of thermal exposure. It positions vulnerability as a socio-spatially produced, institutionally mediated, and unevenly distributed phenomenon, and therefore as a justice concern. In this framing, behavioural adaptation is not merely an individual response, but an unequally available form of adaptive agency. For short-term adaptation, this means that interventions should not only target the hottest areas, but also places where residents face constrained coping opportunities. Vulnerability, therefore, concerns whether people have the means, autonomy, social support, knowledge, and spatial conditions needed to respond when heat occurs.

7.1 Contributions of the Research

This dissertation makes both scientific and societal contributions, which are outlined below.

7.1.1 Scientific contributions

1 **Foregrounding behavioural adaptation as a core dimension of heatwave vulnerability:** The first scientific contribution of this dissertation is conceptual. It advances a behavioural adaptation-centred understanding of heatwave vulnerability in temperate cities. Existing research frequently treats adaptive capacity as a broad and abstract component of vulnerability, often operationalised through generic, cross-hazard indicators. This thesis instead demonstrates that behavioural adaptation is a concrete, empirically investigable domain through which vulnerability becomes visible in everyday life. By distinguishing between personal, technological, and cultural adjustments, and by linking them to both hazard perception and socio-spatial conditions, the dissertation provides a more fine-grained and context-sensitive account of how adaptive capacity is actually enacted.

2 **Operationalising Environmental Justice:** The second contribution is primarily theoretical. The dissertation systematically operationalises the multidimensional EJ framework within the field of urban heat research. Rather than reducing justice to distribution alone, the thesis shows that heatwave vulnerability is shaped through failures of recognition, limitations in participation, and unequal distribution of adaptive resources (tangible and physical) and opportunities (intangible, individual capacities).

Recognition is central because dominant heat research tends to privilege measurable and scalable indicators, often focusing on intensive physical variables while marginalising situated forms of knowledge such as lived experience and everyday coping practices. These experiential insights constitute an extensive dimension of urban life that is essential for understanding how heat is actually encountered and negotiated in practice.

Participation becomes equally important because accessing such knowledge requires people-centred, bottom-up approaches that bring residents' experiential and tacit understandings into the research and policy process. When these perspectives are treated as legitimate inputs, they allow adaptation strategies to better reflect local realities and constraints.

Grounded in recognition and participation, the distributive dimension then enables the identification and verification of unevenly patterned conditions within urban environments. Rather than focusing exclusively on the allocation of physical infrastructure, this framing of EJ also considers how adaptive opportunities and constraints are spatially and socially distributed. In doing so, the dissertation shifts EJ debates in the context of urban heat from static assessments of exposure toward a more process-oriented understanding of coping, capability, and constraint.

3 **Methodological contribution - a critical realist mixed-methods approach:** The third contribution is methodological. Grounded in a Critical Realist ontology and a pragmatic–interpretivist epistemology, the study employs a sequential mixed-methods design that combines a critical knowledge assessment through a systematic literature review, experiential grounding via a qualitative inquiry, and empirical testing based on a nationwide quantitative survey. This research design reflects the thesis's philosophical position that heatwave vulnerability is stratified and that underlying mechanisms cannot be understood through a single methodological lens. Instead, they must be approached by progressively examining observable experiences, recurring patterns, and the structural conditions that shape them. By linking these stages sequentially, the research design enables the study to move from empirical observations and identified patterns towards the inference of underlying mechanisms, thereby identifying certain factors of the real domain through the investigation of the empirical and actual domains.

4 **Urban heat vulnerability in temperate-climate cities:** Fourth, the thesis makes a substantive empirical contribution by generating context-specific evidence on heatwave vulnerability in the Netherlands as a temperate urban setting. Heat research has historically been more developed in warmer climatic regions, while temperate contexts have often been treated as secondary or transitional cases.

This dissertation addresses that gap by demonstrating that temperate cities are not only increasingly exposed to heatwaves, but also characterised by distinct recognition deficits, behavioural patterns, and institutional constraints. The findings show that the apparently less permanent character of heat in temperate climates does not make vulnerability less important; rather, it may render it less visible and therefore harder to address.

5 **Operational contribution - spatial prioritisation of adaptive constraints:** The fifth contribution is spatial and operational. The Rotterdam study showed that behavioural adaptation practices are spatially dependent and unfold across house, block, neighbourhood, city, and even regional scales. Personal and technological adjustments rely strongly on the dwelling unit, while cultural adjustments stretch into neighbourhood networks and public spaces. This means heat-sensitive design cannot rely on a single, one-size-fits-all strategy, whether in the form of macro green-blue interventions or building retrofits. It must also address the micro-geographies of coping situated at the individual and neighbourhood level. Technically, this advocates for a multi-scalar adaptation framework in relation to the spatial practices of residents, not only to thermal or exposure matrices.

The dissertation also demonstrates that behavioural adaptation constraints can be translated into and utilised as a spatial prioritisation logic. Traditionally, spatial identification of heat-vulnerable areas has relied primarily on exposure-based indicators such as air temperature, land-surface temperature, heat stress, and UHI intensity. When behavioural adaptation is applied in this way, it reveals a different geography of vulnerability than that generated by exposure maps alone. Some thermally hot areas do not coincide with the areas where coping constraint factors cluster most intensely, while some less visible areas emerge as priority zones once behavioural adaptation constraints are taken into account. This is a substantive contribution because it refines, rather than rejects, hazard mapping by complementing exposure-based assessments with a more socially grounded understanding of vulnerability. It moves the decision-making question from “where is it hottest?” to “where are people least able to cope, given their social and spatial conditions?”

7.1.2 Societal Contributions

The societal contributions of this dissertation lie in its ability to show that heatwave vulnerability in temperate cities is not only an environmental or technical issue, but also a socially differentiated and institutionally mediated condition. The key societal implications of the research are outlined below:

1 **Urban heat as an underestimated hazard:** The first societal implication is that urban heat risk in temperate cities remains socially underestimated. In hotter regions, heat is recognised as a persistent threat, whereas in temperate societies it is often normalised as temporary discomfort or even welcomed as pleasant summer weather. The qualitative findings show that many residents in the Netherlands still understand heatwaves through ambivalence, confusion, or underestimation, especially where previous summers were historically mild. At the same time, the rapid rise in Dutch heat extremes and the mismatch between rising temperatures and a built environment largely designed for cold conditions create a situation in which populations are both exposed and insufficiently prepared. Society is therefore dealing not only with heat itself, but with a delayed cultural and institutional recognition of heat as a serious urban hazard.

2 **Unequal capacity to cope:** The second societal implication is that the capacity to cope with heat is unevenly distributed. The dissertation directly challenges the dominant assumption that heat adaptation is primarily an infrastructural or environmental problem to be addressed through expert-led external interventions. Greening, shading, reducing imperviousness, and improving building materials remain essential, but they are slow, capital-intensive, and often spatially uneven in their implementation. In contrast, behavioural adaptation constitutes the first line of defence during actual heat events. It is immediate, actionable, and often the only resource available to people facing acute thermal stress. Yet, as this thesis shows, this seemingly “individual” line of defence is neither fully under individual control nor equally available to all. The capacity to defend oneself against heat is shaped by unequal access to resources, housing conditions, social support, and spatial opportunities. This has major societal implications because it reveals that residents do not begin from equal positions of ability, autonomy, or support.

3 **Rethinking vulnerability profiles:** The third implication is that the thesis reframes who should be considered vulnerable. Conventional heat policy often focuses on age, income, illness, or broad deprivation measures. Those remain important, but this dissertation shows that vulnerability also emerges through everyday living arrangements and housing relations. Men living alone in rental housing and in very highly urbanised areas appear as a particularly constrained cohort in terms of

behavioural adaptation, while women in multi-person owner-occupied households in more moderate urban conditions appear to have more favourable conditions to adapt behaviourally. This does not mean these are universal categories. It means that vulnerability is relational and context-specific. For society, the implication is clear: risk communication, public health interventions, and neighbourhood-based support systems must become more differentiated. A one-size-fits-all heat plan is analytically weak and socially unfair.

4 **Social infrastructure as heat adaptation:** The fourth societal implication concerns the importance of social infrastructure. The research shows that adaptation is often mediated through social ties and informal knowledge exchange, particularly where technological control is limited. This means that resilient societies are not built through infrastructure alone, but also through social relations, accessible public indoor spaces, community networks, and shared practical knowledge. Libraries, community centres, supermarkets, shaded courtyards, neighbourhood parks, and accessible air-conditioned spaces are not peripheral amenities. During heatwaves, they become part of the adaptation infrastructure of the city.

The thesis also shows that tacit knowledge, in other words, lived experience, embodied understanding, and socially transmitted know-how, is a functionally important component of coping capacity. For society, this means climate adaptation cannot be built exclusively on external infrastructural interventions, technical expertise, and centralised approaches. If cities fail to recognise residents' informal practices and situated knowledge, they will continue to produce adaptation strategies that are formally rational but practically misaligned.

7.2 Concluding Remarks

The overarching conclusion of this dissertation is that urban heatwave vulnerability in temperate cities has been understood too narrowly. Dominant exposure-driven approaches have made important advances in identifying where heat accumulates, but they have been less successful in explaining who is actually able to cope with heat in everyday life, under what conditions, and why. By applying an EJ lens to behavioural adaptation, this research reframes heatwave vulnerability not merely as a function of thermal intensity, but as an outcome of intertwined social processes. It demonstrates that vulnerability is co-constituted by failures of recognition, limitations in participation, and the unequal distribution of adaptive opportunities.

The scientific contribution of this dissertation lies in advancing a more context-sensitive and justice-oriented understanding of heatwave vulnerability in temperate cities. Its technical contribution lies in providing a basis for more socially differentiated heat vulnerability assessment and spatial prioritisation. Its societal contribution lies in showing that opportunities for heat adaptation are not evenly distributed, and that equitable adaptation requires attention not only to where heat occurs, but also to where coping is most constrained. In this sense, the dissertation does not argue against infrastructure, modelling, or hazard mapping, but rather, argues against their sufficiency when used in isolation. Temperate cities need heat adaptation strategies that recognise the invisible and incremental character of heat, treat lived experience as valid evidence, identify constrained adaptive agency as a justice issue, and refine spatial prioritisation accordingly.

Ultimately, cities become more just not simply by identifying their hottest areas, but by recognising where residents have the least control, the fewest adaptive options, and the weakest institutional support during heat events, and by designing adaptation responses accordingly.

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Supplementary Materials

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TABLE S1 In-depth (semi-structured) interview protocol.

Participants who provide informed consent to take part in the research project will be interviewed by a member of the research team based on the following criteria:

Step 1: Prepare Participants for the Interview

The following questions will be asked after briefly informing participants about the research project and helping them feel comfortable with the interviewer. **Based on the research scope, Step 2 outlines some 'Guided Questions' which are designed to be open-ended rather than directive**. Therefore, questions may be included or omitted, and the sequence adjusted based on participants' responses.

Step 2: Asking Questions

Topic	Sub-topic	Questions	Follow-ups
Hazard Perception	**Attitude & Beliefs**	Q1. How do you feel about (what is your impression) when we have consecutive warmer temperatures for multiple days during summertime? Q2. Is this something that we all should be worried of?	*If positive* – Although now it is fine, but what about the future, do you think it may cause difficulty for you or for others in the society? *If negative* – Move to Q3.
	Knowledge	Q3. Can you name few bad/harmful impacts of heatwave on your life? *(If necessary, give example, related to health, extra expenses etc.?)*	Ask how did they know, happened to them/ close network? or read/learned from the media?
		Q4. Do you have any real-life experience of such heat events in near past? What about 2019 or 2020 summertime?	Do you think it (the knowledge) will be useful for coping with the future events? *(Ask for elaboration if necessary)*
Following questions will start providing a brief context about warm summer condition in the NL. Participants will be asked to share their experiences in their own way.			
Behavioural Adaptation	**Personal Adjustments**	Q5. Could you please tell us about your personal adjustments that you take to cope with warm temperature? *(If necessary, give example)*	Ask for description when necessary. Supplementary questions – - *How do they decide? Is it spontaneous/ instant?* - *Any challenges faced?*
	Technological Adjustments	Q6. How do you keep your house/ surrounding cool when the weather gets really hot during summer? *(If necessary, give example)*	Specifically sort the responses under Active and Passive practices. Repeat the supplementary question(s) (Q5.) if required. In case of any new practices ask further about it – *how did they learn it, from where, how effective it is in the NL etc.*
	Cultural Adjustments	Q7. Do consecutive warm summer days impact your everyday life, daily routine, or activities? *(If necessary, give example)*	*If yes* – Follow-up questions on each of the impacts/changes mentioned by the participant. *If no* – Question about 'why not' and listen to the response. Move to Q8.
		Q8. What do you do and how do you do to cope that?	*If possible* – ask Q9.
		Q9. What do you think, having a mono or mixed cultural background, helps or creates barriers in the adaptation practices that you shared?	

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TABLE S1 In-depth (semi-structured) interview protocol.

Step 2: Asking Questions		
Topic	**Questions**	**Follow-ups**
Following questions are focused to spatial practices of participants. Being inductive, there are no pre-determined Sub-topics in this case. Before asking the questions, a short, generic description will be provided (For instance, on a day when the temperature is around/over 30 degrees)		
Spatial Practices	Q10. Where (space or place) do you (usually) prefer to spend the hottest period of a day and why?	Ask additional questions on the features/ characteristics of the space/place.
	Q11. How do you use your house?	What are the issues you encounter?
	Q12. How do you use your neighbourhood/ surrounding facilities?	What are the positive and negative aspects in your neighbourhood/surrounding?
Step 3: End of the Interview		
Closing Question: Is there anything else you would like to share that we have not covered?		
Conclude the interview by expressing gratitude to the participant for their valuable input.		

TABLE S2 Qualitative codebook for hazard perception, behavioural adaptation.

Themes (3)	Categories (7)	Description	Sub-categories (19)	
Hazard Perception	**Knowledge**	Understanding of the hazard and its possible impacts	*Explicit Knowledge*	
			Tacit Knowledge	
	Attitude & Beliefs	Participants underlying perspectives and convictions	*Positive*	
			Neutral	
			Negative	
Behavioural Adaptation	**Personal Adjustments**	Focuses on adjustments related to modifying personal variables	*Proactive Actions*	
			Cognitive Strategies	
			Clothing Strategies	
			Workload Management	
	Technological Adjustments	Environmental modification that tend to make living space comfortable	*Active Cooling Practices*	
			Passive Cooling Practices	
			Creative Approaches	
	Cultural Adjustments	Adjustments focus on habits and behaviours	*Changes in Dietary*	
			Cross-cultural Practice	
			Relocation	

	Description	Codes (51)
	Knowledge from external sources that are typically objective and verifiable (ex. news, documents, etc.)	Human Health, Demography, Physical Environment
	Knowledge that is subjective and personal (usually comes from experiences, observations, etc.)	Indoor Environment, Wellbeing, Adaptation Practices, Changing Climate
	Represents optimistic attitude/beliefs	Warm is Enjoyable
	Indifferent stance in attitude/beliefs	Short- term Crisis, Self- manageable
	Represents pessimistic attitude/beliefs	Hinder Lifestyle, Unexpectedly Warm
	Represents intentional actions/behaviours	Avoidance Strategies, Body Cooling Measures, Health and Preparedness, Mobility Choice
	Mental approaches to cope during crisis	Act on Intuition, Logical Thinking, Creative Response
	Specific decisions related to attire	Clothing Choices, Accessory Usage
	Approaches to adjust or prioritize tasks during crisis	Limiting Physical Activities, Reducing Outdoor Activities, Postponing Work
	Powered mechanical devices or systems to cool down indoor environment	Fan/Ventilator, Air- conditioner
	Techniques for achieving indoor thermal comfort without any power consumption	Window/Opening Management, Shading Techniques, Ventilation Practices
	Refers to participants' own innovative or non-standard method to achieve comfort	Evaporation Methods, Unconventional Cooling Techniques
	Adjustments in food and drink choices	Healthy Eating, Avoiding Warm Meals
	Refers to practices from a different culture/context	Cultural Wisdom, Alternate Use of Space
	Act of moving to a new location as a means of adaptation	Utilising Indoor Cooling Space, Remain outdoors during Hottest Period, Move to Relatives/Friends' Houses

TABLE S3 Hypothesis formulation table.

Qualitative Evidence (Quotes)	Summarised Insight	
1. *"When it is really hot in my home country you hear a lot of things… people give each other advice… not the case here in NL."*	Mutual advice, social learning	
2. *"Raised in a Portuguese family… my mother always told me not to go outside after 12pm, she also used to tell to drink water even if I am not thirsty."*	Familial tacit practice	
3. *"Culturally, I am accustomed to warmer temperatures… I know what I need to do… wear clothes that keep me cool… because of past experience."*	Prior heat experience	
4. *"I eat a healthy green soup from my home country… helps keep the body cool which I regularly eat here as well."*	Dietary know-how	
5. *"My living unit 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."*	Spatial literacy of the dwelling	
6. *"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."*	Spatial literacy of the dwelling	
7. "I wet some clothes… put them to evaporate… it moisturises the air… becomes a bit cool."	Creative cooling techniques	
8. *"I put ice in a bowl of water, and put it under the fan… it gives you kind of like air conditioning, I do it often."*	Creative cooling techniques	
1. *"In my home country we could do whatever we want, like add window shade, shutter… But here you need permission from the housing association… it's complicated."*	Limited control over dwelling (Renters)	
2. "So, like my parents, they own a house with a garden, and it was newly built…we spend the very hot days in that house because it's very cool…"	Ownership offers private cool refuges	
1. "I took my daughter… to an indoor play hall… we chose to spend two days consecutively… due to the extreme heat."	Care roles/collective concern in multi-person households	
2. "Being a mother, I always double-check, if there is any weather warning… when a heatwave comes, I know it 1-2 days before"	Care roles/collective concern in multi-person households	
3. "When it is 25 degrees or above, it is too hot inside my house… then we (family) often go outside for lunch… restaurants have AC and play-zone for kids"	Care roles/collective concern in multi-person households	
Emergent Hypotheses (Post-Interview)		
Gender: Female interviewees consistently reported broader use of PA and CA and a stronger concern about heat as a problem, in comparison to male participants.		
Urban context (density): Participants residing in denser parts of the city strongly expressed indoor discomfort and difficulties (high traffic, limited trees, constrained private space) in adapting to heatwaves. 1. *"In our neighbourhood, there are green spaces, but they are like green carpet…no shadow; only a few big trees… those green spaces are not useful."* 2. *"Indoors it is really difficult… it feels like I am stuck."*		

Abbreviations: PA = Personal Adjustment / TA = Technological Adjustment / CA = Cultural Adjustment / H = Hypothesis

	Associated Thematic Components	Derived Hypothesis
	PA, CA Knowledge (Tacit)	**H1:** Tacit knowledge, derived from experiences and surrounding network, is positively related to a 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.
	PA, CA Knowledge (Tacit)	
	PA, CA Knowledge (Tacit)	
	CA Knowledge (Tacit)	
	PA, TA Knowledge (Tacit)	
	PA, TA Knowledge (Tacit)	
	TA Knowledge (Tacit)	
	TA Knowledge (Tacit)	
	PA, TA, CA (All Behavioural Adaptation components)	**H4:** Control over the living unit—operationalised as housing tenure—moderates residents' overall behavioural adaptation. **H5:** Housing tenure significantly influences the individual behavioural adoption components (PA, TA, and CA).
	PA, TA, CA (All Behavioural Adaptation components)	
	PA, TA, CA (All Behavioural Adaptation components)	**H6:** Living in a multi-person household is positively associated with wider behavioural adaptation practices.
	PA, TA, CA (All Behavioural Adaptation components)	
	PA, TA, CA (All Behavioural Adaptation components)	
	PA, CA Hazard Perception	**H7:** There is a significant association between gender and hazard perception and different behavioural adaptation strategies (PA, TA, and CA).
	PA, TA, CA (All Behavioural Adaptation components)	**H8:** Urban density significantly influences behavioural adaptation practices.

TABLE S4 Journals and conferences where the PhD work was published or presented.

	Type	Title	Authors	Year	Journal / Conference Name	DOI
1.	**Journal**	Navigating heatwaves in a temperate climate: barriers to behavioural adaptation in Dutch urban areas	Ahmed, I, van Esch, MME, Petrović, A & van der Hoeven, FD	2026	Climate Risk Management (Elsevier)	10.1016/j.crm.2026.100794
2.	**Journal**	Behavioural adaptation to heatwaves in a temperate city: Insights from Rotterdam	Ahmed, I, van Esch, MME & van der Hoeven, FD	2025	Cities (Elsevier)	10.1016/j.cities.2025.106160
3.	**Journal**	Heatwave vulnerability across different spatial scales: Insights from the Dutch built environment	Ahmed, I, van Esch, MME & van der Hoeven, FD	2023	Urban Climate (Elsevier)	10.1016/j.uclim.2023.101614
4.	**Conference**	Behavioural Adaptation to Heatwaves in Urban Netherlands: A Sequential Mixed-Method Inquiry	Ahmed, I, van Esch, MME, Petrović, A & van der Hoeven, FD	2025	12th International Conference on Urban Climate	10.5194/icuc12-1044
5.	**Conference**	Environmental Justice Dimension of Urban Heatwaves in Dutch Cities: An Alternative Lens for Exploring Socio-Spatial (In)Equalities	Ahmed, I	2021	61st ACSP 2021 Annual Conference	N/A

Curriculum Vitae

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BArch, MSc

PhD Candidate (Urban Design), Department of Urbanism,
Faculty of Architecture & the Built Environment,
Delft University of Technology (TU Delft), The Netherlands

Nationality: **Bangladesh**
Email: **A.Ahmed-1@tudelft.nl**
Website: **www.istiaqueahmed.net**

Education

2015 - 2016 **MSc Environment & Sustainable Development**
The Bartlett, University College London (UCL), UK
No 1 in QS World University Subject Rankings 2026 (Architecture & Built Environment)
Pass with Merit (Upper 2.1)
Distinction Grade in MSc Dissertation

2007 - 2012 **Bachelor of Architecture (B Arch)**
Khulna University, Bangladesh
5-year Professional Degree
CGPA **3.62** out of 4.00
(Merit Position **1**st, **72.04%** Marks)

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Work experience

2024 - 2026 **Researcher (Part-time)**
Project: Invloed van de leefomgeving op gezondheid in de eerste 1000 dagen (Influence of the living environment on health in the first 1000 days)
Partners: Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (BZK), Erasmus MC, TU Delft

2014 - 2020 **Assistant Professor, Department of Architecture**
Dhaka University of Engineering & Technology (DUET) Gazipur, Bangladesh

2013 - 2014 **Lecturer, Department of Architecture**
Chittagong University of Engineering & Technology (CUET), Bangladesh

2012 - 2013 **Research Architect**
Saiful Haque Sthapati (SHS), Dhaka, Bangladesh

Teaching And Supervision During PhD

Teaching

Tutor, MSc Urbanism (Research & Design Studio), TU Delft
Level: Q2 - 1st year 2nd semester (Nov 2022 – Feb 2023)
Design Project: "*Retrofitting Modernism in a Changed Climate*"

Supervision

Research Mentor, MSc Thesis, TU Delft
Thesis: "*Community centres in climate change; building resilience for elderly in Rotterdam South"*
MSc Architecture, Urbanism and Building Sciences (2025)

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Course Contribution

Doctoral Education Course ABE 013, TU Delft
"*Qualitative Research Methods for Architecture and the Built Environment*" together with Associate Professor Marcin Dabrowski (2024 – 2025)

Publications

Refereed Journal Articles (from PhD)

Ahmed, I, van Esch, MME, Petrović, A & van der Hoeven, FD **2026**, 'Navigating heatwaves in a temperate climate: barriers to behavioural adaptation in Dutch urban areas', *Climate Risk Management*, vol. 51, 100794. https://doi.org/10.1016/j.crm.2026.100794

Ahmed, I, van Esch, MME & van der Hoeven, FD **2025**, 'Behavioural adaptation to heatwaves in a temperate city: Insights from Rotterdam', *Cities*, vol. 165, 106160. https://doi.org/10.1016/j.cities.2025.106160

Ahmed, I, van Esch, MME & van der Hoeven, FD **2023**, 'Heatwave vulnerability across different spatial scales: Insights from the Dutch built environment', *Urban Climate*, vol. 51, 101614. https://doi.org/10.1016/j.uclim.2023.101614

Conference Presentations (from PhD)

Ahmed, I, van Esch, MME, Petrović, A & van der Hoeven, FD **2025**, 'Behavioural Adaptation to Heatwaves in Urban Netherlands: A Sequential Mixed-Method Inquiry', **12th International Conference on Urban Climate**, Rotterdam, Netherlands, 7/07/25 - 12/07/25. https://doi.org/10.5194/icuc12-1044

Ahmed, I 2021, 'Environmental Justice Dimension of Urban Heatwaves in Dutch Cities: An Alternative Lens for Exploring Socio-Spatial (In)Equalities', **61st ACSP 2021 Annual Conference**.

Engagements

British Council Netherlands
Mentor, Study Abroad Mentoring Programme (In Partnership with Nuffic and ECHO)
2024 – Till Date

Human Research Ethics (HREC), TU Delft
Reviewer, Ethics Review Board
2023 – 2024

Journal Peer Reviewer
- *Urban Sustainability* – Springer Nature
- *Regional Environmental Changey* – Springer Nature
- *Global Health Action* – Taylor & Francis
- *Health & Place* – Elsevier

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Environmental Justice Dimension of Heatwaves in Temperate Cities

Reconceptualising Urban Heat Vulnerability through Investigating Behavioural Adaptation

Istiaque Ahmed

This PhD reconceptualises urban heatwave vulnerability in temperate cities through an Environmental Justice lens by examining behavioural adaptation as an unevenly distributed socio-spatial capacity. While urban heat research has advanced in mapping where heat accumulates, it has paid less attention to why some residents are less able to cope with elevated temperatures under similar thermal conditions. Grounded in Critical Realist ontology and pragmatic–interpretivist epistemology, the research adopts a sequential mixed-methods design comprising a critical knowledge assessment and a nationwide survey across Dutch urban density gradients, with the survey informed by in-depth qualitative inquiry. The findings show that heatwave vulnerability is shaped not only by hazard intensity or exposure, but also by unequal adaptive opportunities, constrained agency, housing conditions, household composition, tenure, gender, and the level of urbanity. By foregrounding behavioural adaptation, the dissertation advances a bottom-up, people-centred, and justice-oriented understanding of heatwave vulnerability.

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