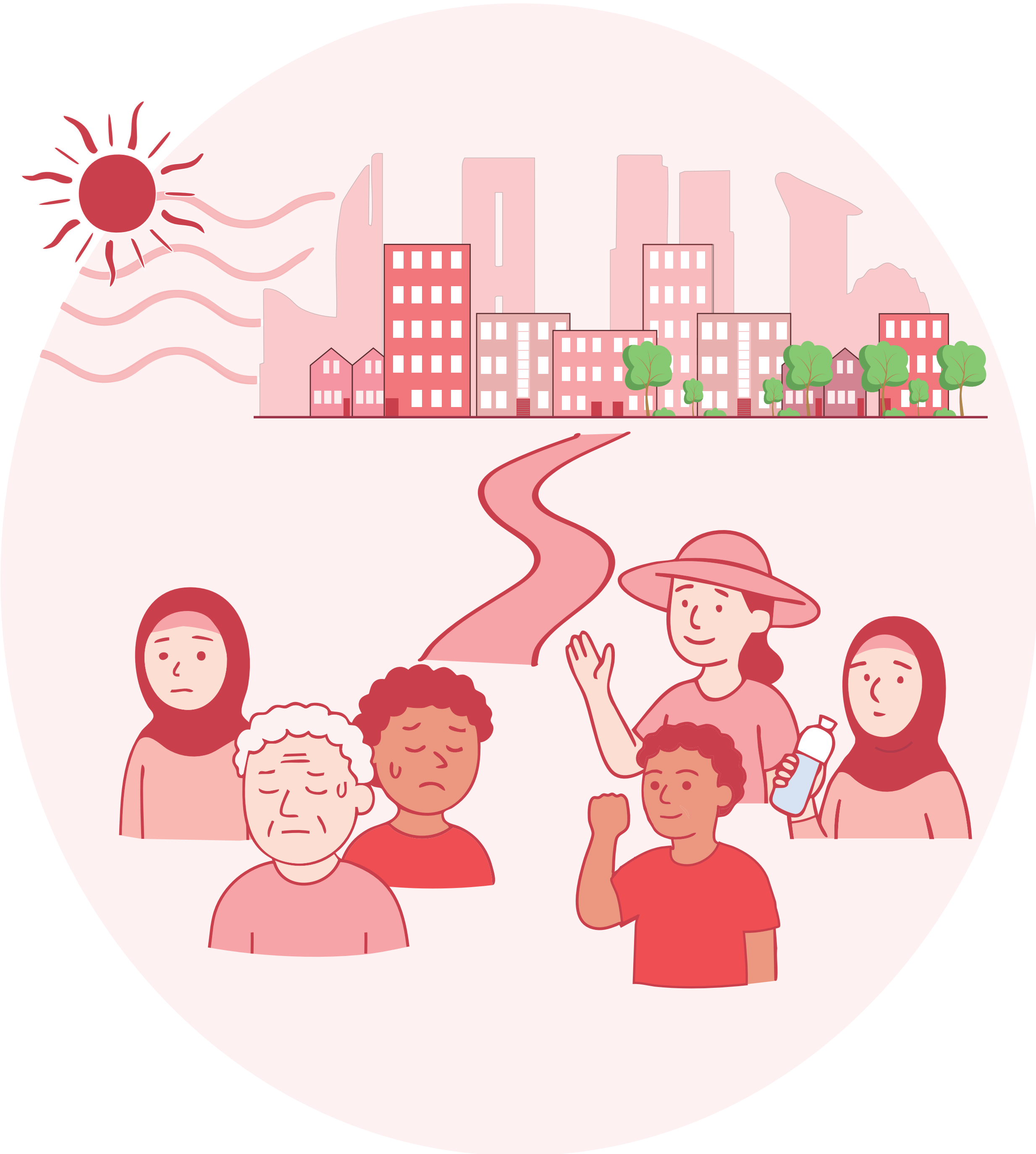
# More than Just Vulnerability

## A Multidimensional Approach to Urban Climate Adaptation in The Hague



Milou Mulder

# More than Just Vulnerability

Multidimensional Approach to Urban Climate Adaptation in The Hague

by

Milou Mulder

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*All images are created by the author unless stated otherwise.*

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# Contents

# Executive Summary

Climate change is intensifying the frequency and severity of heatwaves (Zscheischler et al., 2020). This is particularly concerning in urban areas, where the Urban Heat Island (UHI) effect significantly amplifies temperatures (Kleerekoper et al., 2012). However, the impacts of rising temperatures are not equally distributed: In cities where social inequalities and spatial disparities are deeply rooted, heat disproportionately affects vulnerable populations, often leading to the poorest neighborhoods to be the warmest (Endreny, 2024; Guardaro et al., 2022; IPCC, 2022c; Rocha et al., 2024). Although previous studies have focused extensively on either the physical or social dimensions of heat vulnerability (Ahmed et al., 2023), the interaction between these concepts, across different spatial and social scales, has received limited attention. This disconnect hinders the development of effective adaptation strategies, overshadowing the full spectrum of vulnerability. Failing to recognize this diversity risks a misalignment between the measures offered and the actual needs of affected communities.

By analyzing how a multidimensional approach to climate vulnerability in the context of urban heat can improve tailored adaptation strategies, this thesis develops and applies a multidimensional framework by integrating social, spatial, and political dimensions across scales, from individuals to neighborhoods. Using The Hague as a case study, a mixed-methods approach was applied, combining literature review, principal component analysis (PCA), observations, street interviews, and policy analysis. The PCA revealed four vulnerability typologies, showing clear spatial patterns and links to socio-economic inequalities. Observations and interviews conducted in the, according to the results of the PCA, most heat-vulnerable neighborhood of The Hague, Schildersbuurt-West, provided deeper insight into the personal experience of heat, (local) coping mechanisms, and institutional trust.

This research finds that climate vulnerability cannot be understood through singular lenses of exposure, sensitivity, or adaptive capacity alone: These components manifest differently depending on the spatial context and social dynamics, emphasizing the need for place-based solutions. For example, the PCA provided insight that the two main typologies of vulnerabilities are residents with non-European migration backgrounds, low resilience, poor health, and living in corporation housing on the one hand, and on the other hand, low-income, female, single parents, and often unemployed. Nonetheless, the four vulnerability typologies resulting from the PCA show some local nuances and spatial differences.

The research furthermore highlighted a gap in current adaptation instruments: based on analyzing existing climate tools, it was concluded that most toolkits target municipalities, focus narrowly on physical interventions, and rarely incorporate

behavioral strategies or bottom-up resources.

To address this gap, the thesis introduces *Beat the Heat*, a multi-scale, customizable adaptation toolkit that supports both municipalities and residents in coping with urban heat. The toolkit includes preventive and responsive measures, ranging from household-level behavior changes to neighborhood infrastructure adaptations. Interventions can be filtered by responsible stakeholder, target group, and implementation location, and are accompanied by information on costs and expected cooling effects. This enables residents to explore strategies compatible with their living situation, routines, and resources.

Designed to translate complex research findings into clear, actionable insights, *Beat the Heat* recognizes the diverse realities of heat vulnerability and promotes tailored adaptation. Its flexible format makes it suitable for both digital use, such as through a website or an interactive information board in public facilities like libraries, and as a physical card set to support in-person conversations. This ensures relevance across various actors, including municipalities, housing corporations, community organizations, and individual residents.

This research provides theoretical and practical contributions by bridging the divide between spatial and social data and connecting institutional efforts with local insights. It strengthens the understanding of urban heat as a multidimensional problem and offers actionable strategies for cities to respond to heat in more just, effective, and inclusive ways.

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# 1 Introduction

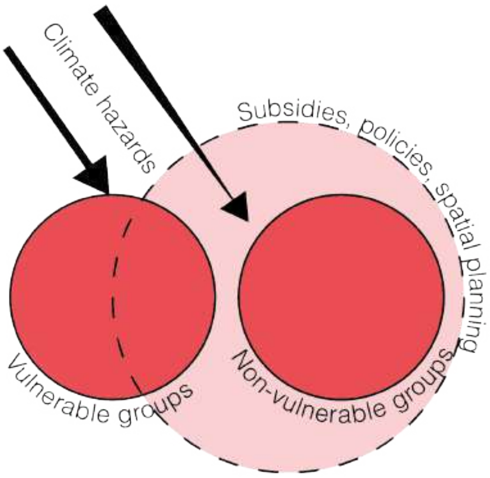


Figure 1.1: Problem Statement

## 1.1 Facing the Heat: The Problem in Context

According to the IPCC (2023), an estimated 3.3 to 3.6 billion people currently live in areas with elevated climate risks. Urban areas are particularly vulnerable to climate change's impacts, which are severe and unequally distributed. Socially and economically marginalized groups are disproportionately affected (IPCC, 2022f). Rising temperatures, exacerbated by the Urban Heat Island (UHI) effect, heighten this vulnerability in cities (Ahmed et al., 2023; Kleerekoper et al., 2012; Tapia et al., 2017). Although urban heat is increasingly recognized as a critical climate challenge, existing adaptation strategies often take a one-size-fits-all approach. This overlooks the complex, multidimensional nature of climate vulnerability (Hulscher et al., 2023; IPCC, 2022c; Mashhoodi, 2021; Samen Klimaatbestendig, 2023). The lack of acknowledgment of the diversity of socio-spatial situations leads to a mismatch between offered support and adaptations, and the tools that benefit the population the most (cf. Sen, 2008).

This oversimplification is partly due to an overreliance on socioeconomic indicators (IPCC, 2022c; Samen Klimaatbestendig, 2023), while climate vulnerability is a multidimensional phenomenon that impacts entire systems, including individual, social, and spatial domains (Ahmed et al., 2023; Eklund et al., 2023; Gamble et al., 2016; IPCC, 2022c; United Nations [UN], 2022). For example, research on the 1995 Chicago heatwave revealed that differences in neighborhood mortality rates could not be explained by income levels alone. Instead, social cohesion and the presence of strong local networks, key components of adaptive capacity, played a decisive role in residents' ability to respond (Klinenberg, 2018).

Heat waves are considered one of the deadliest climate events (EEA, 2024): In 2022 alone, over 60,000 heat-related deaths were registered across Europe (Endreny, 2024). However, the impacts of prolonged high temperatures go beyond mortality. They also cause economic disruption due to reduced labor productivity (Nationaal Kennis- en innovatieprogramma Water en Klimaat [NKWK], 2020), damages to road and rail infrastructure (Hogeschool van Amsterdam [HVA], 2019), and even collapses of water- and energy systems (HVA, 2019; Klinenberg, 2018; Martín & Paneque, 2022).

The city of The Hague is no exception; Its dense urban fabric, limited greenery, and aging infrastructure create a starting point for heat-related challenges. Vulnerability to urban heat is influenced by a range of factors, including age, income, housing conditions, access to green spaces, and urban morphology (Ahmed et al., 2023; Tapia et al., 2017; van der Hoeven & Wandl, 2018). Despite growing awareness of these risks, many of the city's current adaptation strategies remain narrowly focused on physical fixes, like installing cooling infrastructure, without addressing the deeper social and spatial dimensions that make certain groups more exposed and less able to respond. This limited approach not only overlooks important drivers of vulnerability but can also lead to unintended consequences, such as reinforcing existing inequalities and leaving the most at-risk communities behind (cf. Diekmann et al., 2023; Hulscher et al., 2023; IPCC, 2022c; Samen Klimaatbestendig, 2023).

This research responds to these challenges by applying a multidimensional framework of climate vulnerability, based on exposure, sensitivity, and adaptive capacity, to analyze urban heat risk in The Hague across social and spatial scales. By identifying key vulnerability variables and gaps in current policy, the study developed a tailored strategy that reflects the lived realities of residents and urban environments. These strategies are directed at both municipalities and local communities, with a focus on improving prevention and enhancing response capacity during heat waves.

## 1.2 Research Aim: Towards Tailored Resilience

This research aims to develop a comprehensive, multidimensional approach to climate vulnerability by including multiple social and spatial scales, specified to the context of heat waves in The Hague, The Netherlands. Dutch climate policies often fail to address the layered complexity of climate vulnerability, which limits the effectiveness of strategies to reduce climate impacts and contributes to increased injustice. This gap can be filled by first highlighting which factors contribute to individuals' exposure and sensitivity to urban heat (sub-research question 1), emerging heat-vulnerability patterns in The Hague can be analyzed (sub-research question 2), and inform how current adaptation strategies can be improved (sub-research question 3).

Recognizing the multidimensional nature of climate vulnerability enables the development of tailored policies that reduce vulnerability and increase climate justice. To emphasize the importance of multidimensionality, this thesis combines multiple research fields: concepts and theories of both urbanism (spatial realm) and sociology (social dimension) have shaped the understanding of this thesis (Fig. 1.2).


Figure 1.2: Personal Motivation

## 1.3 Why This Research Matters

### Scientific Relevance

This research contributes to a deeper understanding of the multidimensional nature of climate vulnerability by exploring the interplay between social and spatial factors across various scales. Applying the IPCC framework of exposure, sensitivity, and adaptive capacity, the study emphasizes how these dimensions influence residents' vulnerability to urban heat. Despite the importance of this comprehensive perspective for effective and targeted adaptation strategies, it remains underdeveloped in current research.

Additionally, this study offers a transferable framework to guide future research on climate vulnerability in other urban contexts. By highlighting the connections between social and spatial domains, it supports the creation of more tailored and equitable solutions for urban heat resilience.

### Societal Relevance

As urban areas face rising temperatures and more frequent heat waves, the societal impacts of urban heat vulnerability are becoming increasingly evident. Vulnerable populations, such as the elderly, low-income households, and residents in poorly insulated housing, are disproportionately affected, leading to heightened health risks and social inequities. Current adaptation strategies often fall short because of their one-dimensional focus.

This research aims to bridge the gap by identifying the social and spatial factors contributing to heat vulnerability, emphasizing the importance of tailored, multidimensional solutions. By focusing on The Hague, the findings aim to provide policymakers and urban planners with actionable insights to design equitable and effective heat adaptation strategies. These strategies can reduce health risks, improve the quality of life for vulnerable populations, and foster community resilience. Furthermore, the created user-friendly toolkit can help residents to find suitable measures to better deal with heat. An easy-to-understand tool, focusing on residents' empowerment, is currently missing within the heat adaptation strategies.

Moreover, the proposed framework has the potential to inform similar efforts in other cities, ensuring that climate adaptation measures not only address environmental challenges but also promote social justice and inclusivity in the face of a warming world.

## 1.4 The Structure of the Report

This research aims to answer the following research question: *How can a multidimensional approach to climate vulnerability in the context of urban heat improve tailored adaptation strategies?*

To address this question, the research is divided into three phases: first, an understanding of the current knowledge in literature, then analyzing heat vulnerability in The Hague, and lastly, developing a tailored adaptation strategy.

**Literature Foundation: Factors of heat vulnerability**

The literature review introduces the key theories and concepts used throughout the study. This helped identify the main social and spatial variables contributing to climate vulnerability. These findings are collected in a vulnerability matrix, which summarizes the answers to the first sub-research question: *Which factors contribute to individuals' exposure and sensitivity to urban heat?*

Additionally, the literature informed the conceptual and multidimensional frameworks applied in this research, as explained in the research approach. This chapter also outlines the methodological approach to analyzing vulnerability in a specific urban context.

**Research Results: Vulnerability in The Hague**

After explaining the approach, the report highlights the results. The quantitative analysis explores The Hague's exposure and sensitivity to heat, using the principal component analysis and answers the second sub-research question: *What patterns emerge when analyzing heat vulnerability in The Hague?*

These findings are contextualized with qualitative fieldwork. Furthermore, an analysis of existing adaptation instruments and their stakeholders is conducted, creating the foundation for the Adaptation Toolkit and answering the third research question: *How can The Hague's existing heat adaptation strategies be improved?*

**Design Results: The development of a toolkit**
Ultimately, the research results are translated into practice by introducing the evidence-based Toolkit 'Beat the Heat'. This toolkit includes multi-scale interventions and policy recommendations tailored to vulnerable groups and urban conditions.

**Discussion and Conclusion**
The final part reflects on the findings, highlights limitations, and discusses how a multidimensional lens can enhance targeted policy interventions. It concludes by answering the main research question and offering scientific and societal recommendations.


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# 2 Literature Review

## 2.1 There is More to Being Vulnerable

Initially, vulnerability research, particularly within disaster studies, focused primarily on physical components, such as infrastructure. However, there is growing recognition of social vulnerability (Flanagan et al., 2011). This includes increased awareness of community variations based on local population dynamics and existing social inequalities (Eklund et al., 2023; IPCC, 2022b; Turner et al., 2003). The following section will explain how the understanding of (climate) vulnerability changed over time.

### 2.1.1 The Paradigm shift around Vulnerability

The open-ended definition and application of vulnerability led to significant concept transformations over time. The main driver was a change in perspective on who is at risk of being adversely affected by climate hazards and why.

Early frameworks, such as the *Risk-Hazard Paradigm* (1950–1970), characterized individuals as helpless victims of climate hazards. Natural disasters were often seen as 'God's will'; therefore, there was no distinction in risk between different people.

In contrast, the *Bounded Rationality Paradigm* (1970–1990) emphasized the active role of decision-making to reduce one's risk. Yet, it was seen that a lack of knowledge limited individuals' decisions. This overemphasis on individuals' choices can be interpreted as blaming people for their own risks, without considering structural socio-political inequalities.

Critiques on this led to the emergence of the *Vulnerability Paradigm* (1990–2010), highlighting the roots of uneven vulnerabilities, including social, political, and economic differences. Geographers emphasized the role of location (exposure) in individuals' vulnerabilities (Eklund et al., 2023; Martín & Paneque, 2022).

Similar to the Risk-Hazard Paradigm, the Vulnerability Paradigm was criticized for characterizing people as passive victims of external circumstances. The *Resilience Paradigm* (2010 onward) therefore shifts the focus to the positive capacity of communities to adapt, self-protect, and recover from hazards. This final paradigm concludes with the perspective that one's risk depends on the specific (climate) hazard, an individual's exposure to that hazard, and their susceptibility to harm (together, these form vulnerability). The risk can be reduced by the ability to cope and adapt to future changes (resilience) (Gamble et al., 2016; Martín & Paneque, 2022; Yu et al., 2021).

With the Vulnerability Paradigm, the focus shifts from risk to vulnerability. Based on the differences between these paradigms, it can be interpreted that ‘being at risk’ was seen as something that happened to you. ‘Being vulnerable’, on the other hand, has underlying causes based on differences and inequalities. With the Resilience Paradigm, both understandings come together since a climate hazard affects everybody (risk), but the degree of impact varies based on exposure, susceptibility (or sensitivity), and adaptive capacity (vulnerability).

That exposure, sensitivity, and (adaptive) capacity, the three main components, define the degree of risk, is undebatable. The confusion lies in what vulnerability, as part of risk, is: Martín and Paneque (2022) see vulnerability as the product of sensitivity and exposure. The IPCC (2022a), however, sees exposure as a separate component from vulnerability and rather focuses on the lack of adaptive capacity in sensitive populations.

The IPCC (2014) extracted exposure from hazard as a separate component: in IPCC (2007) exposure was seen as “the magnitude and duration of the climate-related stress" (Vulnerability = Exposure x Sensitivity - Adaptive capacity), whereas in 2014, with a more risk-centered focus, the definition shifted to ‘the presence of people in places that could be negatively affected’ (Risk = Hazard x Exposure x Vulnerability (Sensitivity - Adaptive Capacity)) (IPCC, 2014).

When comparing the research of Martín and Paneque (2022) to IPCC (2022a), no explanation could be find why the earlier used V = E x S and the later V = S - Ac since they both use the same definitions.

These differences in understanding display the complexity of defining vulnerability. But what can be concluded is that vulnerability is not only (climate) hazard specific, but also depends on an individuals location (exposure) and personal characteristic (sensitivity) and can be reduced by adaptive capacity. Many researchers, therefore, explain vulnerability by V = E + S - Ac (Ahmed et al., 2023; Gamble et al., 2016; Turner et al., 2003; Yu et al., 2021).

In other words, a hazard is considered an independent and unchangeable variable, such as an earthquake or weather conditions. This hazard causes a potential impact on a system, depending on its exposure to the hazard and the predefined sensitivity. By enhancing adaptive capacity, the system’s potential impact is reduced. The expansion of adaptive capacity can eventually lead to the development of resilience. However, resilience can only be reached if adaptive capacity is distributed equitably around the system, and this is where climate justice comes into play, as will be explained in section 2.1.2.

Nonetheless, as also visible in Fig. 2.1, the development of resilience does not affect the overall vulnerability of the system since some underlying conditions contributing to exposure and sensitivity can not be scraped. Resilience only mitigates the potential impact.

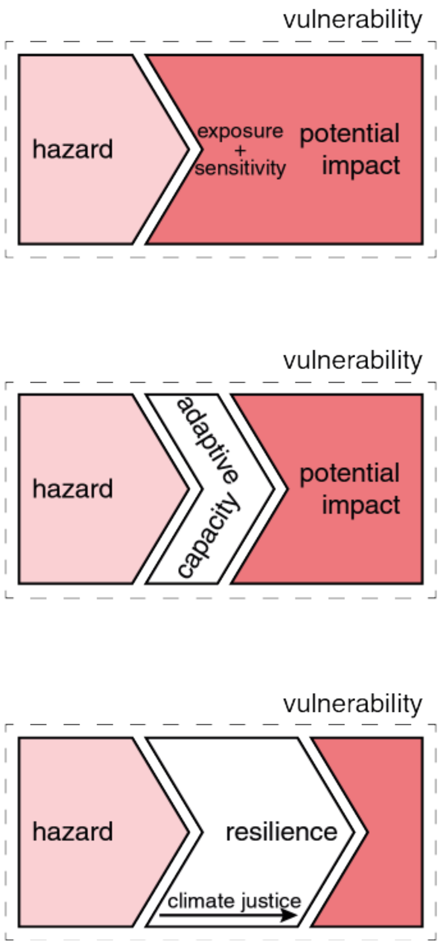



Figure 2.1: Explanation of the interaction between hazard, potential impact and adaptive capacity

### 2.1.2 Room for Justice within Vulnerability

As stated in the previous section, a strong distribution of adaptive capacity can ultimately lead to resilience: “[t]he capacity [...] to cope with a hazardous event or trend or disturbance; responding or reorganizing [...] [and] maintaining the capacity for adaptation, learning, and transformation" (IPCC, 2022a, 2920 f.).

Key components of becoming resilient are resource availability, practical knowledge, and the ability to maintain stability (Davoudi, 2012; Doff, 2017; Magis, 2010; Matarrita-Cascante et al., 2016). The exact needs, however, vary across scales: At the household level, it involves maintaining financial stability and accessing essential resources. Communities focus on social cohesion, while cities prioritize disaster-ready infrastructure (Brown & Westaway, 2011; Campbell et al., 2024; Turner et al., 2003).

Nevertheless, a system is only as resilient as its weakest link: If resources and opportunities are not equitably divided in society, the system as a whole cannot be seen as resilient but rather as strongly segregated into have’s and have-not’s (Gamble et al., 2016). A concept that emphasizes this equal and fair distribution is (climate) justice.

Climate justice is commonly defined as the fair distribution of the burdens, benefits, and impacts of climate change (IPCC, 2022a; Samen Klimaatbestendig, 2023), but also refers to the equal accessibility of resources (Gamble et al., 2016). Currently, it is often seen that those least responsible for climate change, and with the least capacities, often bear its greatest impacts (Rocha et al., 2024).

Social and spatial inequalities, reflecting in a lack of resources and opportunities, often exemplify vulnerability. For example, buildings with poor foundations are more prone to collapse during earthquakes. Households suffering from energy poverty are stronger affected by extreme colds if there is no money for heating systems or alternative heat (cf. Ahmed et al., 2023; IPCC, 2022e)

Nevertheless, addressing climate justice takes more than providing equal access to resources, opportunities (distributive justice) (IPCC, 2022c). Sen (2008) compares this to giving a disabled and an able-bodied person the same income and expecting them to have the same opportunities. Hence, it is also crucial be aware of recognitional justice: identifying who is vulnerable and where they are located, taking into account historical injustices (e.g. the placement of marginalized groups in neglected neighborhoods) and future risks (UN, 2022). This is related to recognizing that climate justice has a strong reciprocal relationship to other social and spatial injustices (Rocha et al., 2024). Lastly, procedural justice, ensuring fair and accessible processes for change, is a key element of reducing climate injustice. This includes providing critical information and warnings in languages and formats that are understandable to diverse populations (Samen Klimaatbestendig, 2023; UN, 2022).

By integrating the three perspectives of justice, individuals will be given the opportunity to use the available resources to adapt to climate change in a way that is suitable for their own individual characteristics (cf. Brotzman, 2017; Burchardt, 2015; Harvard University Press, 2011). By focusing on an outcome-focused approach, rather than a resource-focused (Melin et al., 2021), there will be room for justice within a vulnerable system.

### 2.1.3 The Dimensions of Vulnerability

The literature on vulnerability often focuses on disaster risk management, addressing single climate events such as floods, earthquakes, or pandemics. Research tends to treat these events as isolated occurrences. However, there is increasing evidence that natural disasters occur in patterns and will happen more frequently (Sauter et al., 2023). This calls for a different, more holistic approach to defining vulnerability and its full complexity (Eklund et al., 2023).

As stated in the previous chapter, a more human-centered approach evolved with the shift to the vulnerability paradigm in the 1990s. Within the current literature to focus of the human perspective, is strongly directed towards the economic and social traits of a community. The advantage of this rather simplified assessment is the availability of sufficient and straightforward variables to measure (Eklund et al., 2023). However, by focusing solely on the socioeconomic status of communities, key variables such as cultural factors and spatial contributions are overlooked. A broader insight into individual traits gives a better understanding of the population's needs. This enables the creation of targeted interventions, instead of offering a one-size-fits-all approach (cf. Gonçalves et al., 2024).

Additionally, political dynamics must be included, as political decisions not only influence the approach (focus on climate mitigation or adaptation), but also the access to resources, such as subsidies (Eklund et al., 2023).

The multidimensional aspect plays an essential role in this research. It underscores the complexity of vulnerability and emphasizes that there is no single, straightforward solution. Instead, since climate hazards are unpredictable events, the response should be a strategy that addresses multiple scales and aspects simultaneously.

Following Eklund et al. (2023), multidimensionality in this research is defined by both scale (individual & household, street, and neighborhood) and domain (social, physical, and political). These dimensions are interconnected with the main vulnerability concepts of exposure, sensitivity, and adaptive capacity. The understanding of these three axes that define vulnerability, as shown in the Multidimensionality framework (Fig. 3.2), will be used throughout this research as a lens for assessing and interpreting the results. For a clear understanding, this section will explain the different components one by one.

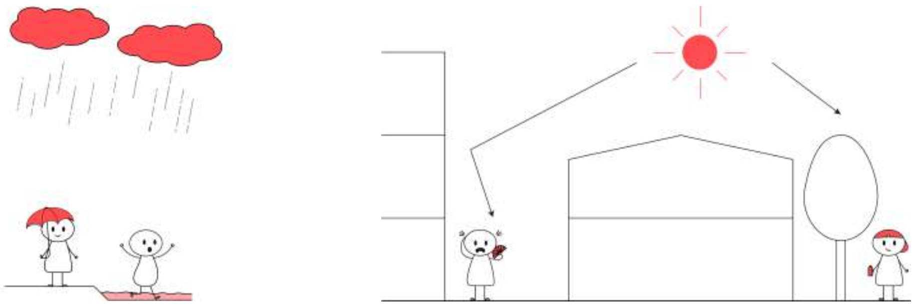
**Exposure**

The IPCC (2022a, p. 2908) defines exposure as "the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected". These encounters with hazards can happen once or repeatedly over time, as well as in a single location or spread over a broader geographic region (Gamble et al., 2016).

Based on this definition, exposure can be interpreted as a given and static component: a system is exposed or not. This works for many hazards: the ground is shaking, or not, and the streets are flooded, or not (Fig. 2.2a). However, analyzing exposure to heat is more complicated since heat does not have a clear boundary and depends on factors beyond the sun's intensity (Fig. 2.2b).

To include 'contributing variables' to exposure, this research defines exposure as the presence of a system (humans, built environment, ecosystems, or infrastructures) in heat-prone areas. Heat-prone areas are those with higher Urban Heat Islands (UHI), as explained in section 2.2.2. In urban areas, characteristics of the built environment, such as density or material usage, can cause a temperature increase of up to seven degrees compared to more rural areas. Infrastructures such as waterways and greenery can reduce these local temperatures

(Kleerekoper et al., 2012; Rocha et al., 2024).



(a) Exposure to flooding

(b) Exposure to heat

Figure 2.2: Examples of exposure to different hazards

**Sensitivity**

The IPCC (2022a, p. 2922) defines sensitivity as "[t]he degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by increased coastal flooding due to sea level rise)".

Since it refers to a 'degree', it is conceptualized as a gradual element that can intensify when multiple factors accumulate (cf. Eklund et al., 2023). However, this definition does not include the likelihood of being affected, thus overlooking the fact that sensitivity is subject to change over time (Gamble et al., 2016; IPCC, 2022a): For example, ageing gradually alters vulnerability, making a person initially less sensitive during adolescence and more sensitive as they reach old age. Sudden life events such as childbirth, illness, or physical accidents, can trigger abrupt changes that influence other variables, such as employment and income (Chambers, 1983).

It is anticipated that the sensitivity of the population will rise sharply in the coming years, not only due to an ageing population and the health problems associated with ageing but also as a result of increasing numbers of individuals suffering from conditions like obesity and type II diabetes (Martín & Paneque, 2022).

In this research, sensitivity is framed as the social dimension of heat vulnerability, encompassing variables such as age, gender, socioeconomic status, education, income, and employment (for example Flanagan et al., 2011; Gamble et al., 2016; IPCC, 2022c; Rocha et al., 2024). Some authors, including Ahmed et al. (2023), Tapia et al. (2017), and Yu et al. (2021), also add physical elements, such as spatial configuration, to this concept. However, since many of these physical elements also influence urban heat, they are categorized as exposure, as shown in section 2.2.2.

Many of these sensitivity variables, such as age or migration background, cannot be changed (Martín & Paneque, 2022). The inherent unchangeability of these factors makes it challenging to reduce heat vulnerability through sensitivity alone. However, enhancing adaptive capacity offers sensitive individuals the ability to adapt to future hazards.

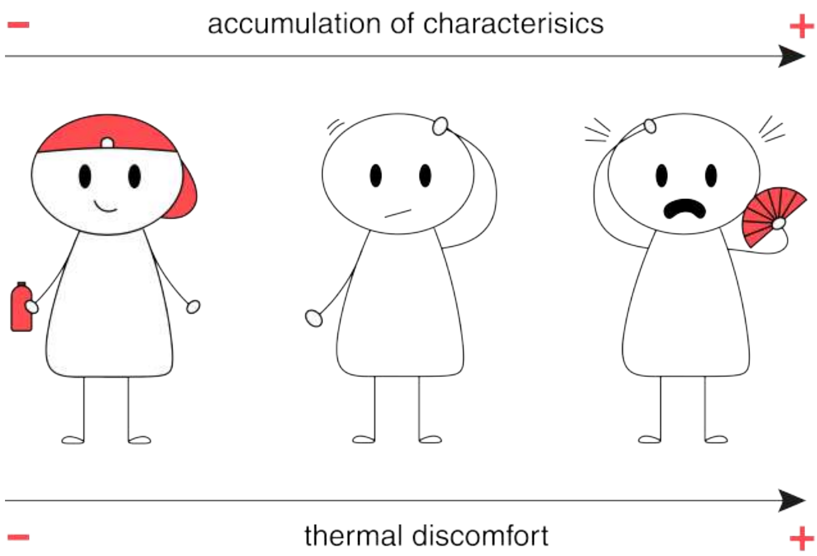



Figure 2.3: Sensitivity: an increase of thermal discomfort due to the accumulation of multiple factors

### Adaptive capacity

Governments implement mitigation and adaptation strategies to address climate change. In its broadest sense, mitigation focuses on reducing greenhouse gas emissions to prevent the occurrence of climate hazards. In contrast, adaptation involves proactive measures aimed at adjusting to and minimizing the harm caused by the expected or actual impacts of climate change (IPCC, 2022a).

In the disaster literature, adaptive capacity is defined as “the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences” (IPCC, 2022a, p. 2899), which is crucial for reducing vulnerability (Wu et al., 2022). It can have various forms, such as financial resources, access to volunteers, tools, materials, social networks, and supportive policies, and is influenced by both institutional and built infrastructures as well as demographic dynamics (IPCC, 2022c).

There is often confusion between the concepts of sensitivity and adaptive capacity, as both influence how a system responds to stressors. Some researchers, such as Tapia et al. (2017), distinguish between the two by defining sensitivity as a variable positively correlated with vulnerability, while adaptive capacity is considered a negative correlate. For example, a low education level increases a person’s vulnerability, making education a sensitivity indicator. Similarly, higher education is associated with lower vulnerability, thus serving as an indicator of adaptive capacity. While this distinction is useful in some cases, particularly regarding knowledge, it does not hold when considering variables such as age or health. They only indicate a higher likelihood that individuals with good health conditions, within certain age ranges, have more access to resources.

Yu et al. (2021), on the other hand, views adaptive capacity as a dynamic factor that can be modified in the short term. In this view, age, health conditions, and education levels fall under sensitivity rather than adaptive capacity.

This debate, combined with the challenge of quantifying adaptive capacity, related to personal experiences and unconscious actions, complicates the assessment of this concept (Guardaro et al., 2022).

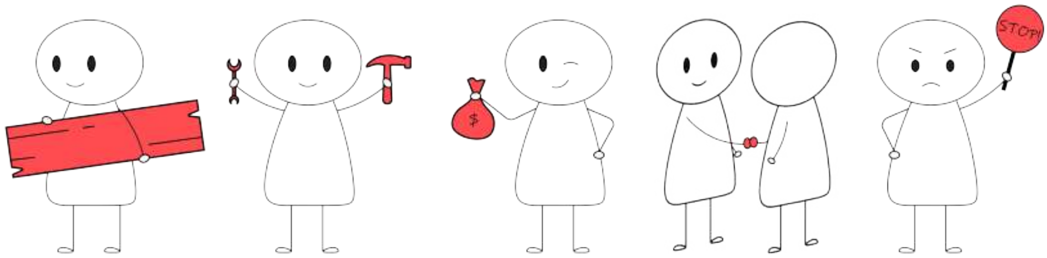
Nonetheless, there is some agreement on key variables, such as access to and possession of resources. These include not only physical resources, like materials and tools, but also social capital, community networks, technical skills, and attitudes (Ahmed et al., 2023; Guardaro et al., 2022; Yu et al., 2021) (Fig. 2.4). City-level responses, such as the implementation of green infrastructure, early warning systems, and policies, are also essential components of adaptive capacity (IPCC, 2022d; Marzi et al., 2018). Therefore, adaptive capacity can be understood as both a bottom-up and top-down process (Marzi et al., 2019).

There is a strong connection between the accumulation of sensitivities and the availability of resources, such as the quality of infrastructure, accessible health care, socioeconomic status, and social capital (Gamble et al., 2016). The mismatch between those with higher sensitivity and suitable resources can worsen the consequences of climate events, such as heat waves. Even if there is access to the resources, this does not mean that they are what the individuals need (Martín & Paneque, 2022). As discussed in section 2.1.2, climate justice plays an important role in this. A common mismatch is the provision of subsidies for building adaptations, such as insulating the building. Many subsidies can only be requested by the homeowner, causing the renters to depend on their landlord. Another example is the upfront payment for sustainable purchases, with in the end only a part of the costs are covered by the subsidies (Rijksdienst voor Ondernemend Nederland, 2021).

Nonetheless, adaptive capacity is not only about the available resources but also about the ability to use them. A theory currently gaining more significance is the 'capability approach', defined by Nussbaum and Sen.

This approach does not focus on, for example, having a low income or limited resources; it emphasizes being capability-deprived (freedom-poor instead of resource-poor). Capabilities are the opportunities and everything a person needs to, through choice, be able to function (beings and doings; active realization of capabilities) (Brotzman, 2017). It integrates equality and human rights concerns while taking into account the variation in needs of the individual (Burchardt, 2015).

In this research, adaptive capacity is approached similarly to the capability approach by focusing on the diversity of individuals and their personal needs. By targeting resources and help, strategies can be more sufficient and equitable.




(a) Materials (b) Tools (c) Economic capital (d) Social capital (e) Personal attitude

Figure 2.4: An example of different forms of adaptive capacity

### Scale

Scale plays an important role in defining vulnerability (Eklund et al., 2023): Sensitivity is mostly defined at the individual or household scale. Exposure and adaptive capacity, on the other hand, vary per scale. Exposure on a household scale is determined by dwelling characteristics, such as typology, energy label or floor level. On a neighborhood scale, it can refer to water management or green infrastructures (Ahmed et al., 2023; IPCC, 2022c).

When only focusing on one scale, important variables connected to vulnerability might be forgotten. Therefore, the applied scales in this research are: individual/ household, street, and neighborhood (buurt in Dutch).

### Domain

Essential variables that can determine vulnerability can furthermore be divided into multiple domains: social, spatial and political (cf. Eklund et al., 2023).

There is an overlap between sensitivity and the social domain, as well as exposure and the physical domain. Yet, the distinction of domains is foremost important when analyzing adaptive capacity since this can refer to all three domains.

**Social :** The social domain describes the circumstances affecting both individuals and the population as a whole. This includes health factors, social networks, demographic trends, population distribution, and housing conditions (Eklund et al., 2023).

Furthermore, it is also linked to economic capital, which influences how one deals with problems; Factors such as income, employment, and resource access influence adaptive capacity and social equity.

At the same time, individuals' economic capital can be impacted both during and after hazards (Eklund et al., 2023; Marzi et al., 2019): Depending on the occurring stressor, the damages might differ; pandemics may lead to financial difficulties for businesses and individuals, while flooding primarily results in property damage. Economic losses are often used when emphasizing the impact of climate hazards. However, the emotional losses are usually neglected, perhaps since this is harder to quantify. Nonetheless, the loss of a home can have a significant impact on a person's well-being.

**Physical :** The physical dimension discussed in this research addresses the built environment including green, blue and gray infrastructures. Especially when talking about urban heat, the green infrastructure plays a crucial role in reducing the impact and exposure (Eklund et al., 2023; Marzi et al., 2019). At the same time, a collapse of the energy and water supply-system can have fatal consequences during heat waves (Klinenberg, 2018).

**Political :** Strong institutions and effective governance are vital in successfully implementing emergency response plans, climate adaptation strategies, and policies addressing vulnerability. Political structures play an important role when addressing inequalities; It can empower citizens, and distribute resources, money, and benefits of urban planning (Das et al., 2020; Eklund et al., 2023; IPCC, 2022c; Marzi et al., 2019).

## 2.2 Warm, Warmer, Cities: Understanding Urban Heat

This research will focus on the climate driver of temperature rise, which contributes to heatwaves (Zscheischler et al., 2020). Due to global warming, every year the temperatures rise a little more, leading to heat-related records, such as the warmest June or the driest summer, being broken over and over again. As happened in 2024: 2024 became the warmest year on record since 1850. These high temperatures even exceeded the Paris Agreement's target of a 1.5 °C increase above pre-industrial levels for the first time. With the current climate change prognoses, global temperatures are expected to continue rising (C3S, 2025), gradually shifting the Dutch climate toward conditions more typical of Southern Europe.

Compared to other climate hazards, heat is harder to assess because it lacks an immediate, visible impact. While floods or earthquakes cause clear physical damage, the effects of heat unfold more subtly and depend heavily on individual circumstances, such as age, health, and housing quality. Poorly insulated homes or densely built neighborhoods, for example, can significantly increase vulnerability. These differences are amplified by urban morphology, as seen in the Urban Heat Island (UHI) effect, where urban areas retain more heat than their greener suburban areas. Adding to the complexity, researchers use varied methods to measure heat exposure—not just air temperature, but also factors like humidity, wind speed, and solar radiation influence how heat is felt (cf. Ahmed et al., 2023; C3S, 2025; Guardaro et al., 2022). This subjectivity has contributed to heat being a relatively underexplored risk in climate adaptation, despite its growing urgency.

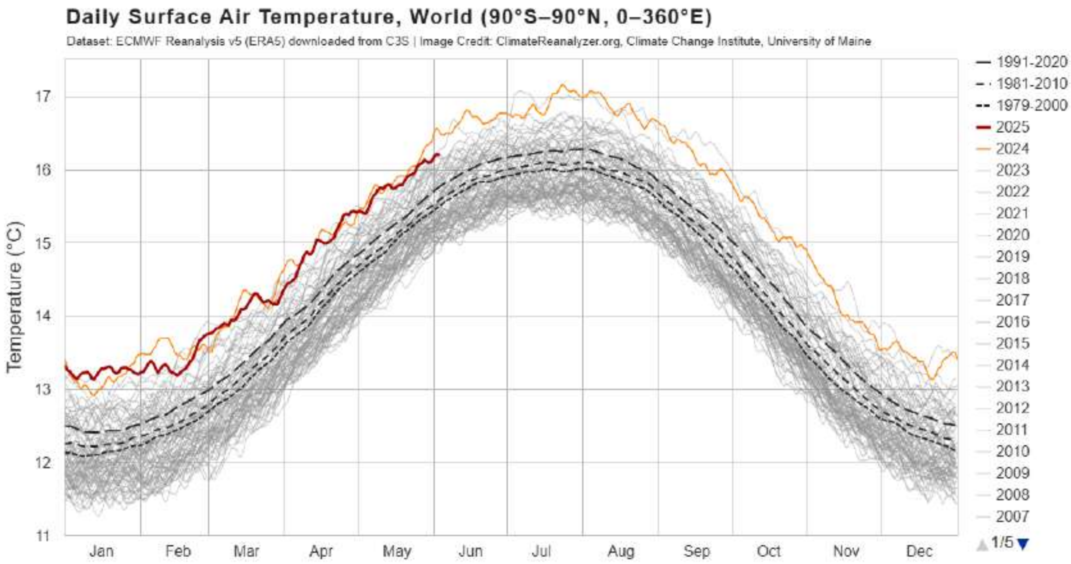



Figure 2.5: Daily Surface Air Temperature in the World (Last update on June 3rd, 2025 C3S, 2018)

### 2.2.1 When warmth turns into heat waves...

Heat waves are considered one of the deadliest hazards in developed countries (Martín & Paneque, 2022; Rocha et al., 2024). They not only cost human lives, but also adversely affect multiple sectors, such as energy, transport, agriculture, and the built environment (Martín & Paneque, 2022).

The threshold for heat waves is country-dependent but generally refers to a sequence of multiple warm days with the minimum and maximum temperature higher than the yearly $95^{th}$ percentile for at least three consecutive days. The heat wave ends as soon as one of these indicators drops below this threshold (Sauter et al., 2023; Tapia et al., 2017).

In the Netherlands, the KNMI [Royal Netherlands Meteorological Institute] defines heat waves as a "succession of at least five summer days in De Bilt (maximum temperature 25.0℃ or higher), of which at least three are tropical (maximum temperature 30.0℃ or higher)". Based on this definition, in the last 50 years, there have been 23 heatwaves in the Netherlands (Instituut [KNMI], 2024).

With a shift towards a warmer climate, predictions show that we can expect longer and stronger heat waves in the future, along with unusual droughts (IPCC, 2022b; Martín & Paneque, 2022; Rocha et al., 2024; Tapia et al., 2017). Also in the Netherlands, the KNMI predicts similar occurrences with increasing deadly consequences (Ahmed et al., 2023; van der Hoeven & Wandl, 2018).

### 2.2.2 ... and cities become challenging: Urban Heat Island

Urban areas are considerably more vulnerable to heat than rural regions due to a combination of spatial and environmental factors (Ahmed et al., 2023; Guardaro et al., 2022; Kleerekoper et al., 2012; Tapia et al., 2017). The built environment tends to accumulate and retain heat, resulting in temperature differences of up to 7–10 °C between urban and rural areas (Endreny, 2024; Kleerekoper et al., 2012; Rocha et al., 2024; van der Hoeven & Wandl, 2018; Yang et al., 2023). While such differences can be beneficial in colder seasons, by lowering heating demand, improving outdoor comfort, and reducing ice hazards, the impacts become far more problematic during extreme heat events. Prolonged periods of high temperatures, such as during heatwaves, can create dangerous conditions for urban populations (Ahmed et al., 2023; Martín & Paneque, 2022; Stewart & Oke, 2012; van der Hoeven & Wandl, 2018). With ongoing urbanization and population growth, addressing urban heat will become an increasingly urgent challenge (Yang et al., 2023).

A key indicator of urban heat exposure is the Urban Heat Island (UHI) effect, which describes the phenomenon where urban areas experience significantly higher air temperatures than their rural surroundings, often by as much as 10 °C. This effect is driven by several interrelated factors tied to the physical form and function of cities:

First, urban surface materials play a significant role. Asphalt, concrete, and building materials absorb and store more solar radiation than natural surfaces such as grass or soil. These materials heat up quickly during the day and release stored heat slowly at night, leading to prolonged periods of elevated temperatures. Tall buildings and dense construction patterns reduce sky exposure, trapping heat within street canyons. Air pollution in urban areas can further intensify this effect by absorbing and re-emitting thermal radiation back toward the surface.

Second, reduced vegetation and limited evapotranspiration contribute to the overheating of cities. Natural landscapes like parks and trees allow moisture release through evaporation, which cools the surrounding air. In contrast, the dominance of impervious surfaces in urban environments limits this natural cooling mechanism, leading to higher retained heat levels in the urban atmosphere.

Third, human activities such as transportation, industrial operations, and air conditioning introduce additional anthropogenic heat into the urban microclimate. At the same time, the compact layout of cities—with tall, closely spaced buildings—disrupts natural wind flow, reducing the ability of hot air to dissipate and further exacerbating heat build-up (Ahmed et al., 2023; Endreny, 2024; IPCC, 2022c; Kleerekoper et al., 2012; Rocha et al., 2024; Stewart & Oke, 2012; Yang et al., 2023).

### 2.2.3 Survival of the fittest: Heat-related Implications

As shown in the overview created by the HVA (2019), the impacts of heat waves are diverse. The consequences range from health issues and overloaded healthcare systems to damage to nature, possible wildfires, reduced livability and comfort, impacts on the water system, and defects in infrastructure such as bridges and rails.

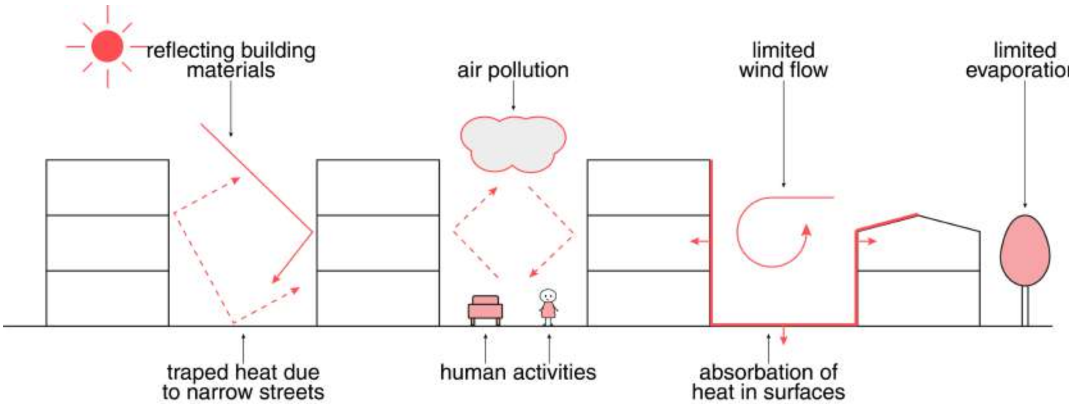
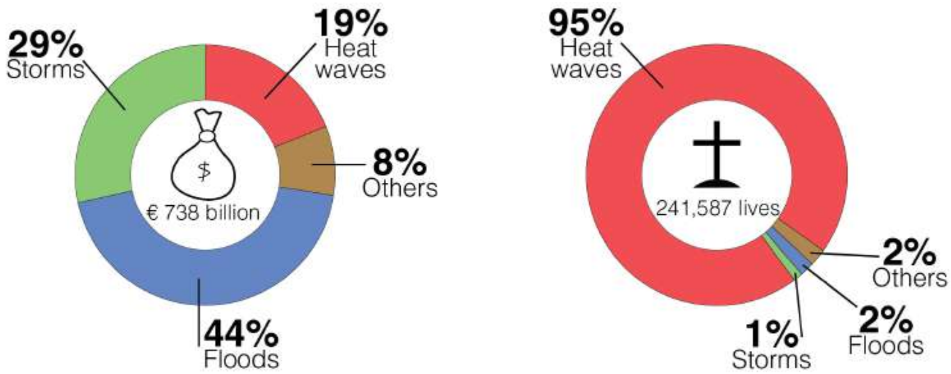



Figure 2.6: UHI explained; image adapted from Kleerekoper et al. (2012, p. 31)

### Infrastructural Consequences

A study conducted by the EEA (2024) showed that between 1980 and 2023, climatological heat wave events globally caused 19% of the total €738 billion in economic losses due to climate events (Fig. 2.7).

Focusing on the Netherlands, the NKWK (2020) projected climate-related losses for the period between 2018 and 2050. In The Hague alone, heat stress is expected to result in €203 million in damages—€62.7 million of which is linked to reduced labor productivity. These projections, however, do not yet include losses due to infrastructure failure.




(a) Total economic loss of € 738 billion

(b) 241,587 climate-related fatalities

Figure 2.7: Climate-related impact in Europe between 1980 and 2023 (based on EEA, 2024).

High temperatures can cause rails to expand and buckle, form potholes in asphalt, and lead to the thermal expansion of steel in bridges, making them temporarily inoperable (HVA, 2019). The consequences are not limited to economic costs for repairing the infrastructure: access routes may be blocked, emergency services delayed, and accidents caused. In more extreme cases, strain on electricity grids can lead to blackouts, and heat-related pressure on water systems may result in failures with fatal outcomes (HVA, 2019; IPCC, 2022c; Klinenberg, 2018; Martín

& Paneque, 2022).

#### Health Impacts of Heat Waves

In addition to economic and infrastructural costs, heat waves present serious public health challenges. High temperatures can cause a range of health problems, including heat rash, cramps, exhaustion, dehydration, and heat stroke. More critically, they can exacerbate chronic conditions such as respiratory or cardiovascular disease, diabetes, and kidney disorders (IPCC, 2022d; Lenzholzer, 2015; Wu et al., 2022; Yu et al., 2021). Vulnerable groups—such as the elderly, young children, pregnant women, and people with pre-existing health conditions—are particularly at risk (Gamble et al., 2016; Kleerekoper et al., 2012; Tapia et al., 2017). Furthermore, heat waves can exacerbate air pollution, increasing smog and ground-level ozone, which in turn further impact public health (Ahmed et al., 2023).

Social and environmental factors, such as poor housing insulation, lack of cooling options, and urban heat island effects intensify the physiological impacts of heat. The risks escalate when individuals are exposed to prolonged heat without adequate coping strategies. Heat can impair cognitive function, disturb sleep, and, in extreme cases, lead to unconsciousness or death. Symptoms include dizziness, nausea, headaches, concentration loss, and excessive sweating (Kluck et al., 2020; RIVM, 2023).

Statistical evidence further illustrates the severity of the issue. According to the EEA (2024), heat waves are the deadliest type of climate hazard, responsible for 95% of the 241,587 climate-related deaths in Europe between 1980 and 2023. In 2022 alone, over 60,000 people in Europe died as a result of extreme heat (Endreny, 2024; Rocha et al., 2024), with children and older adults making up the majority.

Notably, countries in the Northern Hemisphere are particularly vulnerable, as populations are generally less physiologically adapted to heat, and housing is often optimized for cold conditions. Furthermore, many people at risk, such as socially isolated individuals, homeless people, or those on medications affecting thermo-regulation, are often overlooked in planning and response efforts (Martín & Paneque, 2022; RIVM, 2023; Yu et al., 2021).

Understanding these risks and how they intersect with personal, medical, and socio-economic vulnerabilities is essential for developing targeted adaptation strategies. As outlined in section 2.1.3, sensitivity to heat is rarely the result of a single factor but rather the accumulation of multiple characteristics that, combined, determine individual vulnerability.

### 2.2.4 Reducing Heat-Discomfort by increasing Capacities

To mitigate the Urban Heat Island (UHI) effect, the most common strategies are the implementation of blue and green infrastructures. van Oorschot et al. (2021)

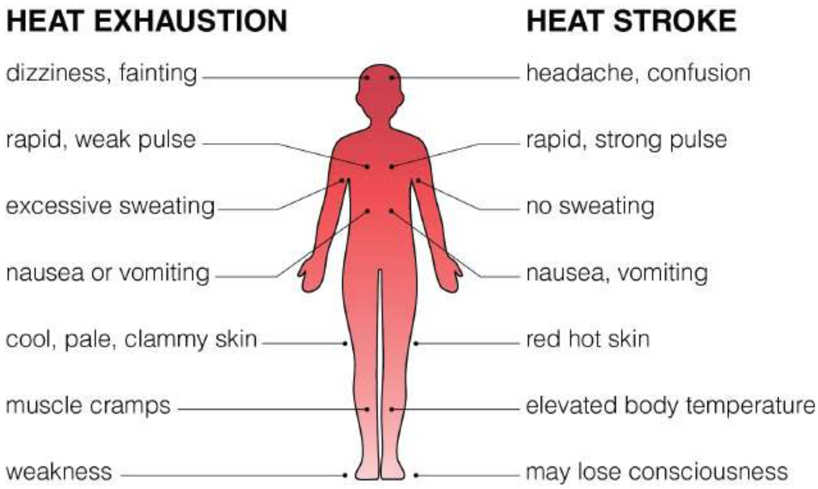



Figure 2.8: Health symptoms of heat exhaustion and heat stroke

have demonstrated that grasslands reduce the urban temperature by 16%, structures such as fruit farms, graveyards, or sport fields by 29%, and tree planting has caused a reduction of the UHI effect by nearly 35%.

Nevertheless, addressing the UHI effect through spatial development can pose challenges related to social equity. Without careful planning, such interventions may unintentionally deepen existing inequalities. It is often observed that marginalized neighborhoods are more vulnerable to heat due to factors such as a higher concentration of social housing, impervious surfaces like cobbled streets, and limited financial resources for adaptation measures. This leads to the fact that the poorest neighborhoods are often the hottest neighborhoods (Endreny, 2024; Guardaro et al., 2022; IPCC, 2022c; Rocha et al., 2024; Samen Klimaatbestendig, 2023). The elevated temperatures lead to higher cooling costs, an additional financial burden for people already struggling, which can further result in increased inequalities in life expectancy and income (Diekmann et al., 2023; Samen Klimaatbestendig, 2023). This shows that environmental inequalities are strongly related to other inequalities, such as housing, income, gender and opportunity inequality (Rocha et al., 2024).

Adaptation to heat can be both in the short term (often referred to as coping capacity) and in the long term (through structural adaptation or mitigation) (Eklund et al., 2023). During an acute heat wave, it is important to stay hydrated and, if possible, stay inside, especially during peak heat hours (Guardaro et al., 2022). However, one person's capacity can increase discomfort for others. For example, extensive use of air conditioners can increase outdoor temperatures (Endreny, 2024; Yang et al., 2023). The high energy demand can also lead to a collapse of the energy infrastructures (Ahmed et al., 2023; IPCC, 2022c). This was also visible during a heat wave in Chicago in 1995, where the collapse of energy and water infrastructure significantly increased the mortality rates (Klinenberg, 2018).

Similar to short vs. long-term adaptation, the reduction of heat can be seen in four layers. A sustainable strategy is to start at the top, by providing cool environments (Alders, 2025; Meijaard et al., 2022). The first two layers can be seen as preventing heat, while the last one is a response to it. Passive cooling can be seen both as prevention (like thermal mass) and as a response (night cooling).

1. **Creating a cool environment:** Through the use of vegetation, conscious materials, and positioning of buildings for shade and air movement.
2. **Heat protection:** With sun protection, solar control glass, and thermal insulation
3. **Passive cooling:** Through natural ventilation, night cooling, and thermal mass
4. **Energy-efficient active cooling systems:** efficient air conditioning and ventilation systems with low energy consumption

## 2.3 Summary

To conclude the conceptual background, it can be said that the concept of vulnerability is controversial in its definition and is context-sensitive (Das et al., 2020; Eklund et al., 2023; Flanagan et al., 2011). In this thesis, it is implemented by the equation $Vulnerability = Hazard * (Exposure + Sensitivity - Adaptive\,Capacity)$ (cf Ahmed et al., 2023; IPCC, 2022b).

Heat waves, as a hazard, are used as the entry point in the contextual framework. Therefore, exposure to heat waves (heat-prone areas) is defined by the physical characteristics that contribute to the UHI, such as materials, green-blue infrastructures and urban morphology (IPCC, 2022d; Kleerekoper et al., 2012; Rocha et al., 2024). However, not all residents in the same area experience heat similarly. The social factors specify an individual's sensitivity. This research emphasizes that sensitivity should not be concluded based on a single variable, such as age or SES. Instead, sensitivity is a spectrum defined by the accumulation of multiple indicators. Not all elderly are equally sensitive; it also depends on their health, social context, gender, etc.

Lastly, having adaptive capacity - the ability to adjust and create opportunities through resources - can reduce vulnerability. These resources can refer to materials, tools, skills, social capital and behavior (Ahmed et al., 2023; Guardaro et al., 2022; Yu et al., 2021).

However, following the principles of adaptive capacity, access to resources is not enough: Individuals need conditions that can enable themselves to be able to use the resources. These enabling conditions are subject to the diversity of individuals.

This awareness of the enabling conditions is often lacking in policies. The strong focus on simply providing resources (distributive justice) contributes to the growing climate injustice. It is not only about recognizing that multiple social factors contribute to vulnerability; it is also about recognizing that this diversity also asks for diverse implementations.

Only when fully integrating diversity into climate justice can we enable a community's climate resilience since the system as a whole is not resilient as long as there are still parts left that are not able to adapt. This, however, does not mean that resilience reduces vulnerability, it solely reduces the potential impact of a hazard on the system.

# 3 Research Approach

## 3.1 Frameworks

### 3.1.1 Conceptual Framework

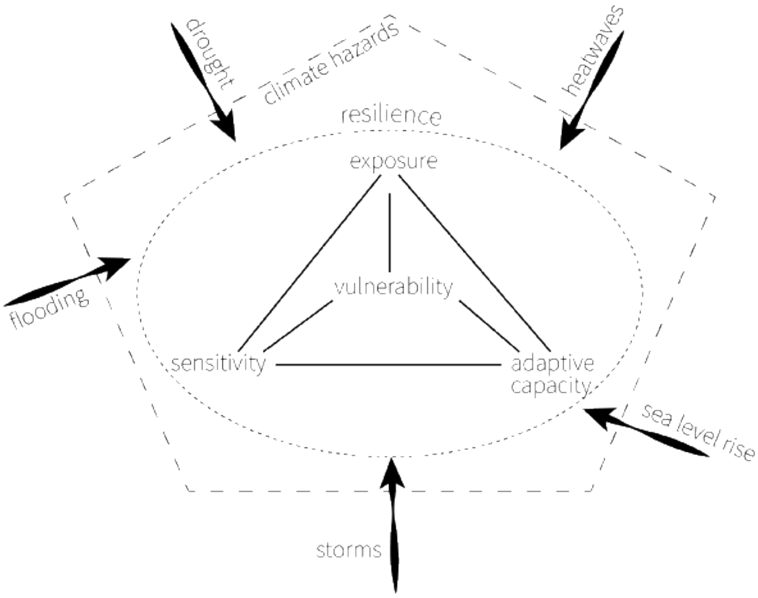



Figure 3.1: Conceptual framework

Based on the starting point that climate vulnerability is hazard-specific and is determined by exposure, sensitivity, and adaptive capacity, the conceptual framework guiding this research was developed.

Climate hazards impact a system. Depending on the location, these climate hazards can change. Resilient strategies can be implemented to protect the system and reduce the impact; however, some impact will always remain, leaving specific systems vulnerable. Vulnerability represents the interplay between sensitivity, exposure, and adaptive capacity.

The present research enters the framework through the hazard heat wave, analyses its effect on exposure and sensitivity and concludes with strategies to enhance adaptive capacity.

The emphasis on adaptive capacity is because, within exposure and sensitivity, many variables cannot be altered. However, empowering citizens to improve their adaptive capacity benefits everyone, regardless of their exposure or sensitivity. Furthermore, providing citizens with the means to empower themselves also contributes to climate justice.

### 3.1.2 Multidimensionality Framework

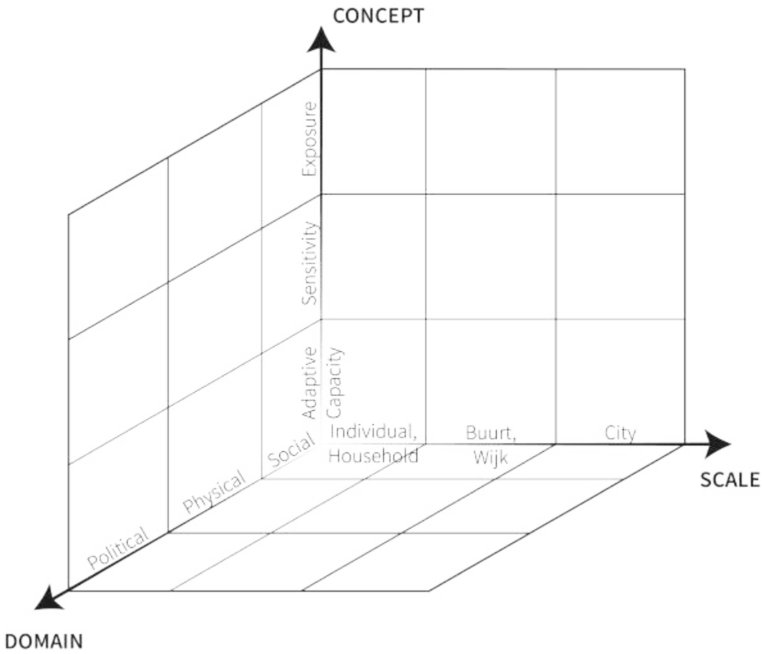



Figure 3.2: Multidimensional perspective: The relation between concept, scale, and domain (inspired by Eklund et al., 2023)

The literature on vulnerability often focuses on disaster risk management, addressing single incidents such as floods, earthquakes, or pandemics. Research tends to treat these events as isolated occurrences. However, there is increasing evidence that natural disasters occur in patterns and will happen more frequently (Sauter et al., 2023). This calls for a different, holistic approach to defining vulnerability and its full complexity (Eklund et al., 2023).

As stated in the previous chapter, a more human-centred approach evolved with the shift to the vulnerability paradigm in the 1990s. Current literature continues to prioritize the human perspective, often focusing on the economic and social traits of a community. The advantage of this simplified assessment is the availability of sufficient data to measure these factors (Eklund et al., 2023). However, by focusing solely on the socioeconomic status of communities, important variables are overlooked, such as cultural factors and spatial contributions. Furthermore, environmental and political dimensions must be included to create a holistic perspective of climate vulnerability (Eklund et al., 2023, p. 5).

The multidimensional aspect plays an important role in this research. It underscores the complexity of heat hazards, and emphasizes that there is no single, straightforward solution. Rather, since heat is an unpredictable stressor, the response should be a strategy that addresses multiple scales simultaneously.

Following Eklund et al. (2023), multidimensionality in this research is defined by both scale (individual & household, local administrative boundaries and national structures) and domain (social, economic, political and environmental). These dimensions are interconnected with the main vulnerability concepts of hazard, exposure, sensitivity, and adaptive capacity. These relationships are visualized in Fig. 3.2.

Maintaining these different dimensions helps structure the results from existing literature as well as current policies. Any potential overlap or gaps can inform further recommendations and policy suggestions.

## 3.2 Research Design

The research design of this study is structured into three interconnected phases: (1) establishing the theoretical foundation, (2) displaying the current heat vulnerability in The Hague, and (3) proposing improvements to existing adaptation strategies and developing an adaptation toolkit. Every phase is concluded by answering a sub-research question.

### Phase 1: Literature Review

The first phase involved a thorough literature review to develop a multidimensional framework for comprehensively analysing heat vulnerability. This framework, see Fig. 3.2, connects the three concepts (exposure, sensitivity, and adaptive capacity) to scales (households, neighborhood, and city) and domains (social, political, and physical). Together, these elements form the foundation for assessing and addressing heat vulnerability.

Besides the conceptual framework and the multidimensional framework, this phase also resulted in a vulnerability matrix, Sec. 4.1. This overview of the contributing variables to vulnerability and how literature relates them, helped to answer the first sub-research question: *Which factors contribute to individuals' exposure and sensitivity to urban heat?*

### Phase 2: Heat Vulnerability in The Hague

A mixed-methods process was employed in the second phase to map the current heat vulnerability situation in The Hague. Using an explanatory research approach (Plano-Clark et al., 2008), the accumulation of vulnerabilities was calculated by applying a Principal Component Analysis (PCA). This led to the selection of a focus neighborhood, which was further analyzed by fieldwork. The second phase concluded with answering the research question: *What patterns emerge when analyzing heat vulnerability in The Hague?*

### Phase 3: Developing Adaptation Toolkit

Using a triangulation research design (Plano-Clark et al., 2008), the third phase combines the findings from the previous stages to answer the last research question: *How can existing heat adaptation strategies be improved?* A user-centered toolkit was created based on exposure, sensitivity, and adaptive capacity analyses. This toolkit provides well-informed and tailored suggestions for heat adaptation in The Hague by targeting the most vulnerable communities.

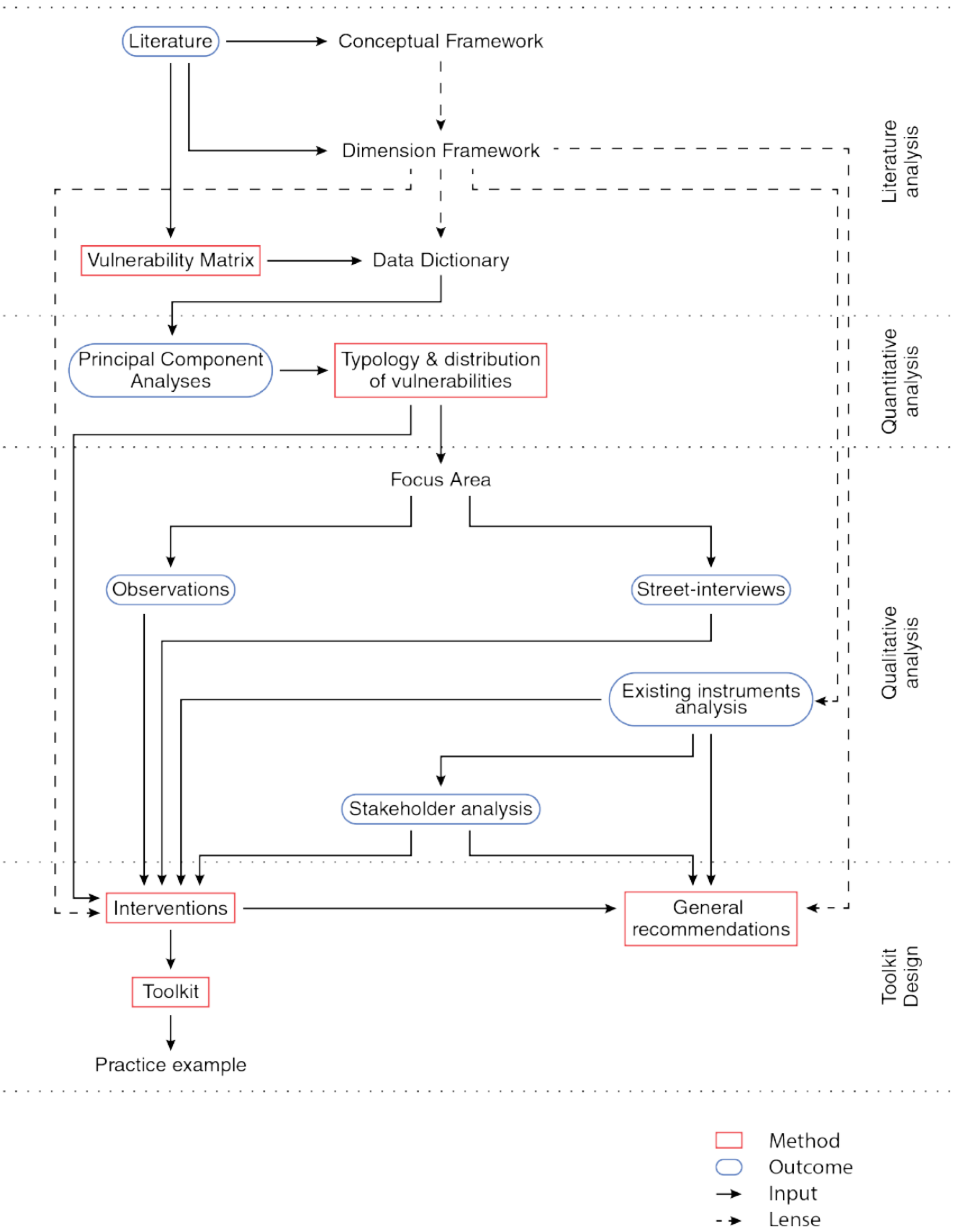



Figure 3.3: Method flowchart

## 3.3 Methods

This research combines a literature review, quantitative analysis (PCA), and qualitative methods (governance analysis, interviews, and observations). By triangulating the results, the research was enriched with in-depth understanding: The qualitative methods justify and validate the quantitative results while also providing insights into the spatial and contextual dimensions of the results.

Throughout the development of this thesis, the Artificial Intelligence (AI) tool ChatGPT was used to support the writing process and to assist with troubleshooting code issues in R Studio, particularly related to the Principal Component Analysis (PCA). All output generated with the help of AI was carefully reviewed, validated, and critically assessed by the author. AI tools were used solely to improve clarity and efficiency and did not replace any part of the analytical thinking or execution.

The following section explains how these methods contribute to answering the research question.

### 3.3.1 Literature Review

A comprehensive literature analysis, as presented in the literature review, formed the foundation of this study. The literature not only provided insights into relevant theories but also identified key variables contributing to vulnerability. The variables mentioned in 20 papers were gathered together in a Vulnerability Matrix, which not only visualizes the literary awareness of the variables but also shows their mutual coherence based on existing research. Besides serving as a summary of the literature, this matrix also functions as a foundational tool for guiding the selection of variables in the quantitative analysis.

### 3.3.2 Principal Component Analysis

Measuring vulnerability is a key step in understanding its complexity (Eklund et al., 2023; IPCC, 2022e; Yu et al., 2021). While much of the existing research has focused on socioeconomic or demographic indicators, the interaction between social and physical factors has often been overlooked (Eklund et al., 2023; Yu et al., 2021). To address this gap, a Principal Component Analysis (PCA) was conducted on a buurt scale. The individual steps for the PCA preparation are highlighted in Fig. 3.4.

PCA is a commonly used method for data reduction. This is especially valuable when analysing vulnerability, where many variables play a crucial role (Ewing & Park, 2020; Robinson et al., 2019; Yu et al., 2021). It seeks patterns in the given variables and creates new components that cluster the original variables, without losing significant details (Ewing & Park, 2020). The extraction of key components simplifies the comparison of vulnerability among different areas (Robinson et al., 2019)

Mapping the spatial distribution of vulnerability, particularly where factors amplify one another, supports planners and policymakers in developing place-based approaches (Flanagan et al., 2011). A granular data scale enables the display of local diversities in vulnerability, which is essential for developing tailored adaptation strategies (Eklund et al., 2023).

This mapping approach is consistent with methods used in established vulnerability indexes, such as the World Risk Index, Social Vulnerability Index (US), INFORM (EU), and the Disadvantaged Index (NL). These indices overlay multiple maps to highlight hotspots of climate and economic risks (Eklund et al., 2023; Phlippen & Vendel, 2024).

**1) Data collection**
Prior to the PCA, a database was created based on the vulnerability matrix: For every variable mentioned, data or a proxy was collected. The available data was organized in a data dictionary as presented in Appendix A.4. Since a more granular scale was preferred, the scales 100x100, Postcode5, and Buurt were considered during the data search. Due to missing values and data, the final data collection contained 54 variables on a 'Buurt' scale retrieved from the databases Centraal Bureau voor de Statistiek (CBS, 2024), Gemeente Den Haag (2023), and Klimaateffectatlas (2024).

**2) Data selection**
The second step of preparing the data was selecting suitable data for the analysis. As visible in Fig. 3.4, first four neighbourhoods (buurten) (Oostduinen, Vliegeniersbuurt, Tedingerbroek, De Rivieren) and eight variables (Energylabel B, C, D, E, F, G, green rooftop surfaces and significantly warmer areas) had to be removed due to the high amount of missing values.

Next, Bartlett's Test of Sphericity was used to create a correlation matrix. The test "indicates whether the data are sufficiently correlated" (Ewing & Park, 2020, p. 103), or if the correlation is too high and therefore the variables are (almost) identical. This led to the removal of another four variables.

In the end, the data structure was left with 42 variables containing information about 110 buurts that are suitable for the PCA. However, before being able to run the analysis, the data first had to be standardized.

**3) Performing the PCA**
The mathematical calculations of the PCA are done in R. After running the PCA, a set of components was returned. The components with an eigenvalue below one were removed since they explain less variance than a single original variable in the dataset (Ewing & Park, 2020). This led to a selection of 6 components.

To improve interpretability and reduce noise, cosine squared (COS2) was used to indicate the quality of the representation of the variables in a single component. Based on this, it was decided to only keep the first four components.

**4) Interpretation of the results**
In each component, the variables are represented with loadings. Loadings represent the strength and direction (positive or negative) of the relationship between a variable and a component (Jolliffe, 1986 in Robinson et al., 2019). Based on the patterns of the highest absolute loadings, a profile of the neighborhoods and their residents can be formulated.

The first component has the highest representation of the data since the PCA follows the principle of maximum variance: “the first component (PC1) should represent as much of the variance of all original variables as possible. Each subsequent component should then account for the maximum amount of variance not explained by any preceding components." (Ewing & Park, 2020, p. 99). This is also visible when looking at COS2, where the quality of the representation declines with every component.

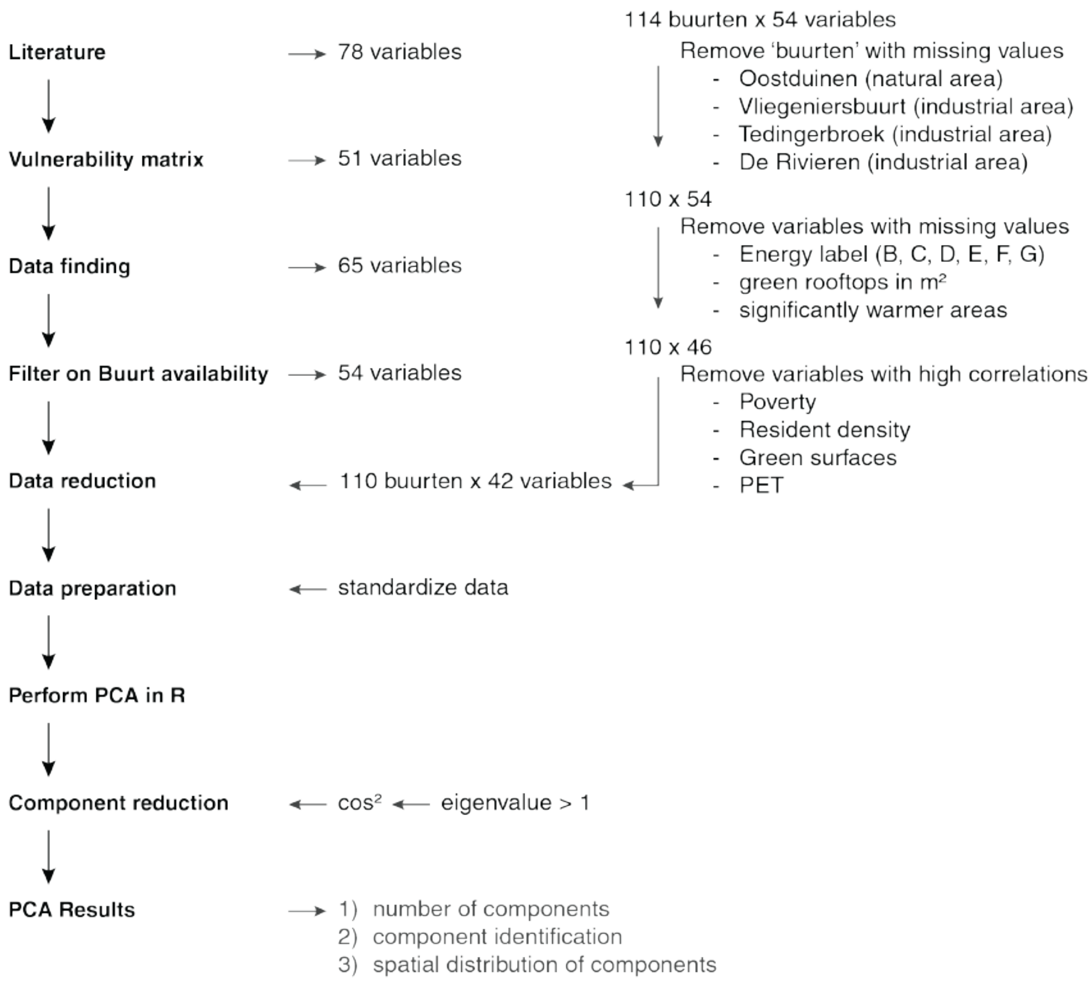



Figure 3.4: Steps for data analysis

### 3.3.3 Contextual Inquiry

**Observations**

Field observations were conducted in the Schildersbuurt-West neighborhood. These observations aimed to contextualize the abstract PCA results and verify their alignment with on-the-ground conditions by focusing on: How wide are the streets, and how are the walkways used? What is the quality of the existing urban green? What potentials are there to improve temperature comfort for residents?

**Street-Interviews**

Randomized street interviews were conducted during field observations to collect subjective information about how residents experience and cope with heat. Participants were asked about their comfort during heat waves and potential coping strategies.

To be able to conduct interviews, the creation of a Data Management Plan was obligatory. This helped to understand potential risks to participants. The Human Research Ethics Committee of the TU Delft approved this. The Data Management Plan is included in Appendix A.1.

### 3.3.4 Heat Governance Analysis

**Analysis of existing instruments**

An analysis of existing adaptation instruments in the Netherlands was conducted, based on the provided information on www.klimaatadaptatienederland.nl (Services [Sticthing CAS], n.d.). This analysis provides information about the kind of tools that already exist, who they target, which climate topic they address, and which specific interventions are proposed to adapt to (urban) heat.

The website displays 107 different instruments, which, in the first run, were categorized based on their focus on sensitivity, exposure, or adaptive capacity, as well as their focus scale, domain, and the specific climate problem. Twenty-seven tools were selected for further investigation to inform the development of the adaptation toolkit.

**Stakeholder Analysis**

A stakeholder analysis was conducted based on users of the existing tools, who the tools are targeted at, and which further stakeholders were mentioned in the existing tools. This information provides information for the toolkit about who the active stakeholders are that can contribute to helping vulnerable residents.

### 3.3.5 Toolkit Design

The final output of this research is the design of a heat adaptation toolkit, titled *Beat the Heat*. This toolkit aims to translate complex research findings into a clear, actionable, and user-friendly tool that communicates the diversity of heat vulnerability and promotes tailored adaptation strategies. It combines both a summary of existing adaptation tools and newly developed insights based on the PCA results.

The toolkit was developed iteratively: First, a broad collection of interventions was assembled, drawn from literature, municipal documents, and existing climate adaptation toolkits. These were categorized and complemented with new measures aligned with the vulnerability typologies identified in The Hague. This formed the basis for a structured intervention table, later translated into a card format and envisioned as an interactive website. This design process emphasizes the importance of accessibility and customization in fostering adaptation, both at the individual and institutional levels.

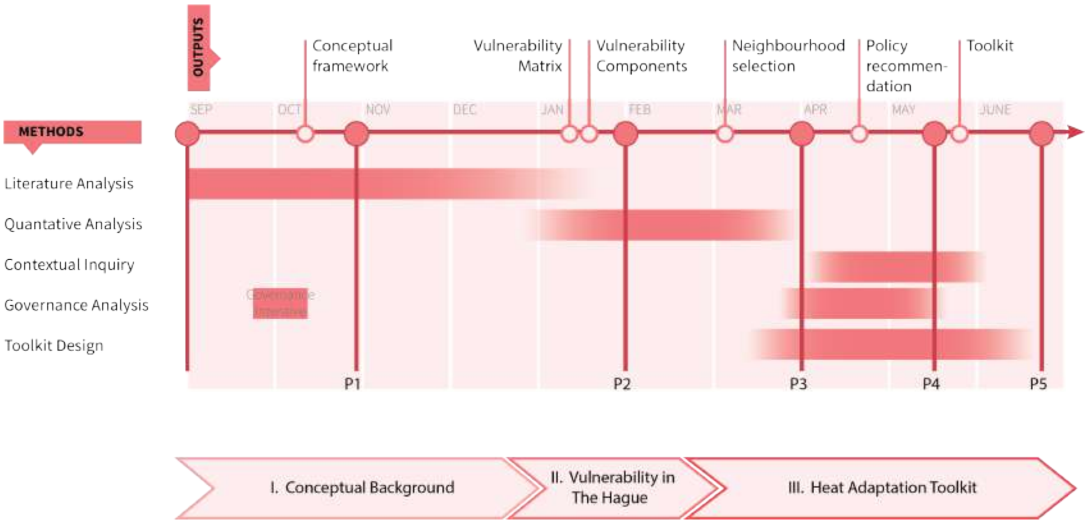
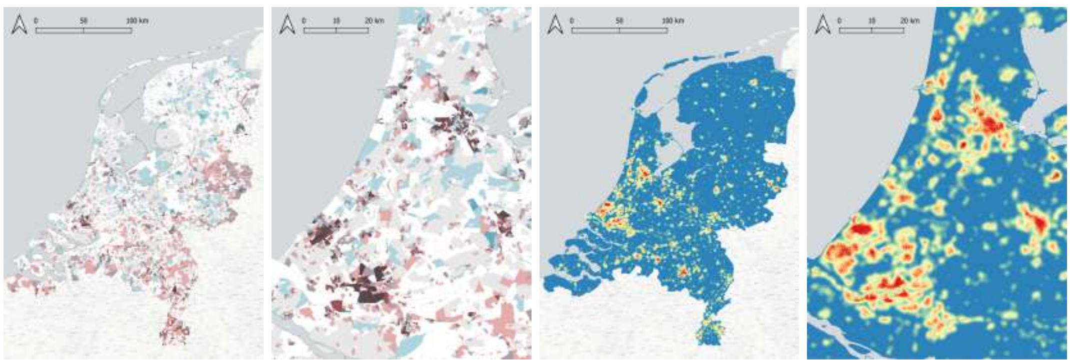



Figure 3.5: Timeline of the research

## 3.4 Case Study: The Hague



(a) The Netherlands (b) Randstad (c) The Netherlands (d) Randstad

Figure 3.6: Social Vulnerability Heat (a, b) and Urban Heat Islands (c, d) (Klimaateffectatlas, 2024)

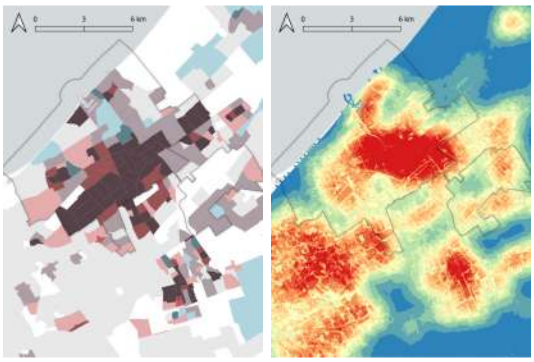
For the case study selection, easy accessibility was a crucial factor to facilitate frequent site visits. Therefore, the location needed to be in the Netherlands. This also ensured easier access to data and policy documents. The specific location was chosen using two key maps: the Urban Heat Island (UHI) map (Fig. 3.6c, 3.6d), indicating heat exposure, and the Social Vulnerability to Heat (SVH) map (original: Sociale kwetsbaarheid hitte) (Fig. 3.6a, 3.6b).

The SVH map illustrates the spatial distribution of households living in poverty and the elderly with health issues, two key indicators of heat sensitivity (Klimaateffectatlas, 2024). However, as demonstrated in this research, more variables indicate one's sensitivity. Additionally, the spatial dimension of exposure is lacking in this map. Therefore, the SVH does not say anything about heat vulnerability. If policymakers only focused on this map, crucial information would not be considered. This, eventually, might lead to uninformed and mismatched policies and strategies. The PCA conducted in this research fills this gap.

The SVH map of the Netherlands (Fig. 3.6a) shows that social vulnerability is primarily concentrated in the east, south, and west of the Netherlands, whereas spatial exposure to UHI (Fig. 3.6c) is more in the north-east of the country. When comparing the UHI and SVH maps, neighborhoods in the east and southeast of the Netherlands appear more socially vulnerable to heatwaves than spatially vulnerable. Although they score high on the SVH, these areas have fewer heat islands. This contrast is due to the large number of elderly people living in these areas (Klimaateffectatlas, 2024).

The overlap between heat islands and high social vulnerability is much more pronounced in the Randstad. Major clusters include Amsterdam, The Hague, Rotterdam, Utrecht, and Eindhoven. In particular, Rotterdam stands out on the SVH map. However, zooming in on the SVH map can explain this by the larger administrative boundaries in the area, which create a somewhat distorted representation.

With this in mind, The Hague was selected as the starting point for the PCA, given its high spatial (Fig. 3.7b) and social (Fig. 3.7a) vulnerability to heat.



(a) Social vulnerability Heat (b) Heat Island Effect

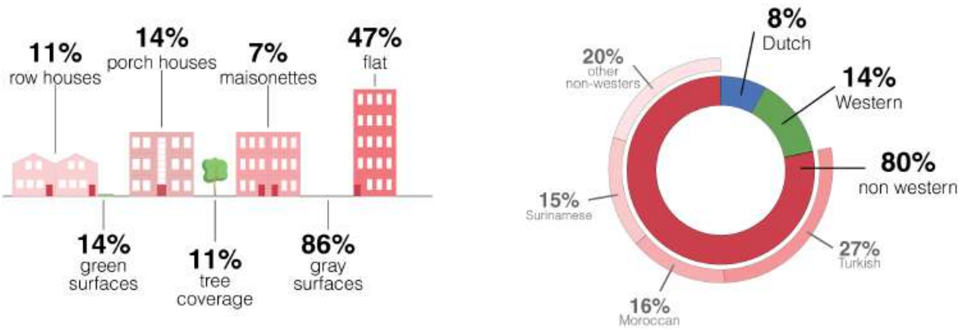
Figure 3.7: Heat vulnerability in The Hague

## Focus area: Schildersbuurt-West

Schildersbuurt-West, located in The Hague, was selected for further analysis based on the results of the quantitative study. It is one of the three sub-neighborhoods that make up the Schilderswijk, an area widely recognized for its high levels of poverty and social challenges. As such, it is often referred to as a krachtwijk ('problem neighborhood' [1]). The neighborhood is characterized by a very high degree of ethnic diversity: 91.7% of the residents have a migration background, with significant communities from Turkey (26.8%), Morocco (16.4%), and Suriname (15.3%). Only 8.3% of residents have a native Dutch background.

The housing stock mainly consists of flats (46.9%) and porch houses (14%), with a relatively low share of single-family homes (11.2%) and maisonettes (6.7%). Over half of the housing is owned by housing corporations (54.1%), while 21.4% is private rental. The area is densely built, with limited green space—only 14% of the surface area is green, and 11% is tree-covered (Gemeente Den Haag, 2023).

The neighborhood underwent significant urban renewal from the 1970s through the 1990s. Large-scale redevelopment projects replaced much of the old housing stock with new social housing. The first major project, near Oranjeplein, began in 1973 and marked the start of a transformative period in which old buildings were mainly demolished rather than renovated. (Gemeente Den Haag, n.d.).




(a) House and surface typologies in the Schildersbuurt

(b) Nationalities in the Schildersbuurt

Figure 3.8: Data of the Schildersbuurt

[1] Problem neighborhood is an often-used term to indicate neighborhoods with high socio-economic problems. However, its use is highly debated, since it stigmatizes the population living in these areas as problematic. In this thesis, it is still referred to as 'problem neighborhood' as a reference to the areas facing socio-economic difficulties.

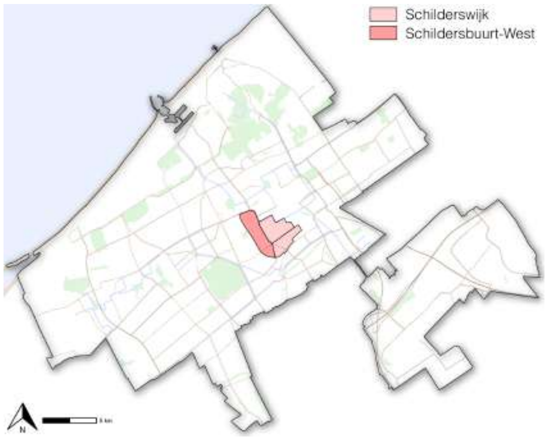



Figure 3.9: Location of Schildersbuurt-West in The Hague

## 3.5 Research Quality

The quality of this research is evaluated using the framework proposed by Prochner and Godin (2022), which outlines several key dimensions of research quality.

**Traceability** plays a central role, with each research process step carefully documented. This transparency helps clarify how decisions were made and allows others to follow or replicate the methods for consistent results. **Interconnectivity** is addressed by investigating cause-and-effect relationships between variables, supported by a triangulated research design (Plano-Clark et al., 2008), which strengthens the validity of the findings.

**Applicability** is reflected in the aim to provide frameworks and insights that can inform the understanding of heat vulnerability beyond this specific case, particularly in settings with similar social and political dynamics. To safeguard the integrity of the analysis, steps are taken to acknowledge and minimize potential biases. Finally, **reasonableness** is upheld by using reliable methods and aligning with established research standards, resulting in a process that is both repeatable and trustworthy.

# 4 Research Results

## 4.1 Vulnerability Matrix

As shown in the Literature Review, the exact definition of vulnerability differs between research fields, as well as between researchers. However, in the end, it is not the exact definition that matters, but the variables included when addressing the topic.

A literature review was conducted to develop a comprehensive understanding of the variables contributing to heat vulnerability. As shown in Table 4.1, the indicators are grouped by domain (social and physical) and by concept (exposure, sensitivity, and adaptive capacity). Social indicators relate to sensitivity and adaptive capacity—roughly framed as who you are and what you have (access to). The physical domain includes all three concepts: sensitivity refers to where you live (on the building scale), exposure concerns the characteristics of the surrounding area (street and neighborhood scale), and adaptive capacity includes access to public facilities and infrastructure.

This chapter explains how a collection of different variables shapes the basis of a multidimensional understanding of heat-vulnerability.

Table 4.1: Overview of the heat-vulnerability indicators according to literature, categorized by domain (So - social, Ph - physical) and concepts (E - exposure, S - sensitivity, and Ac - adaptive capacity). This table includes both variables used for the quantitative analysis (**bold**) as well as variables for which no proxies were found (*italic*). The references indicate papers that mentioned the relative variable related to heat-vulnerability.

| | | variable | reference |
|---|---|---|---|
| So | S | **children (0-15 years)** | IPCC, 2022; Gamble et al., 2016; OHCHR, 2022; Flanagan et al., 2011; World Bank, 2023; Yu et al., 2021; Eklund et al., 2023; Conglaves et al., 2022; Cole et al., 2021 |
| So | S | **elderly (65+ years)** | IPCC, 2022; Ahmed et al., 2023; Martín & Paneque, 2022; Gamble et al., 2016, World Bank, 2023; Yu et al., 2021; Eklund et al., 2023; Rocha et al., 2023; Flanagan et al., 2011 |
| So | S | **amount of women** | Conglaves et al., 2022; IPCC, 2022; Ahmed et al., 2023; Gamble et al., 2016; OHCHR, 2022; World Bank, 2023; Yu et al., 2021; Tapia et al., 2017 |
| So | S | *educational level* | IPCC, 2022; Ahmed et al., 2023; Yu et al., 2021; Eklund et al., 2023; Tapia et al., 2017 |
| So | Ac | *knowledge* | Flanagan et al., 2011; Tapia et al., 2017 |
| So | S | **migration background (proxy: first and second degree EU and non-EU migrants)** | Ahmed et al., 2023; Conglaves et al., 2022; Eklund et al., 2023; Flanagan et al., 2011; Gamble et al., 2016; IPCC, 2022; OHCHR, 2022; Rocha et al., 2023; Tapia et al., 2017; World Bank, 2023; Yu et al., 2021 |
| So | S | *cultural impacts* | Conglaves et al., 2022; OHCHR, 2022; World Bank, 2023 |
| So | Ac | *language* | Gamble et al., 2016; Flanagan et al., 2011; Yu et al., 2021; Tapia et al., 2017; IPCC, 2022 |
| So | S | *length of residence* | IPCC, 2022 |
| So | Ac | *religion* | OHCHR, 2022 |
| So | S | **longterm health issues** | Conglaves et al., 2022; IPCC, 2022; Gamble et al., 2016; Yu et al., 2021; Martín & Paneque, 2022; Van der Hoeven & Wandl, 2018) |
| So | S | **physical disabilities** | IPCC, 2022; Cole et al., 2021; Ahmed et al., 2023; Gamble et a., 2016 OHCHR, 2022; Flanagan et a., 2011; World Bank, 2023; Tapia et a., 2017 |
| So | S | **mental health issues** | IPCC, 2022; Gamble et al., 2016; Yu et al., 2021 |
| So | S | **severe overweight** | IPCC, 2022 |
| So | S | **low-income households** | Ahmed et al., 2023; Cole et al., 2021; Conglaves et al., 2022; Eklund et al., 2023; Flanagan et al., 2011; Gable et al., 2016; IPCC, 2022; Rocha et al., 2023; Saja et al., 2018; Samen Klimaatbestendig, 2023; Tapia et al., 2017; World Bank, 2023; Yu et a., 2021; OHCHR, 2022 |
| So | S | *poverty* | Eklund et al., 2023; IPCC 2022; Tapia et al., 2017; Rocha et al., 2023; IPCC, 2022; OHCHR, 2022 |
| So | S | **energypoor households** | IPCC, 2022; Ahmed et al., 2023 |
| So | S | *energy consumption* | Ahmed et al., 2023 |
| So | S | **unemployment (proxy: ww-benefits)** | Conglaves et al., 2022; IPCC, 2022; Saja et al., 2018; Gamble et al., 2016; Yu et al., 2021; Elkund et al., 2023; IPCC, 2022; Tapia et al., 2017; Rocha et al., 2023 |
| So | Ac | *access to resources* | Rocha et al., 2023; IPCC, 2022; World Bank, 2023; Eklund et al., 2023; Tapia et al; Yu et al., 2021 |
| So | Ac | **low personal resilience** | - |
| So | Ac | **socially lonely** | Yu et a., 2021; IPCC, 2022; Ahmed et al., 2023; World Bank, 2023; Tapia et al., 2017 |
| So | Ac | *participation* | Samen Klimaatbestendig, 2023; Eklund et al., 2023; Tapia et al., 2017 |
| So | Ac | *social cohesion* | Yu et al., 2021; Tapia et al., 2017; IPCC, 2022 |
| So | S | **single-parent households** | Flanagan et al., 2011 |
| So | S | **one-person households** | IPCC, 2022; Cole et al., 2021; Flanagan et a., 2011; Tapia et al., 2017 |
| Ph | S | **corporation-rent properties** | IPCC, 2022; Samen Klimaatbetending, 2023; World Bank, 2023; Tapia et al., 2017; Rocha et al., 2023 |
| Ph | S | **private-rent properties** | Tapia et al., 2017; Rocha et al., 2023; IPCC, 2022 |
| Ph | S | **multifamily dwellings** | Ahmed et al., 2023; Flanagan et al., 2011; Tapia et al., 2017; Rocha et al., 2023 |
| Ph | S | *building year* | IPCC, 2022 |
| Ph | E | **building quality** | Conglaves et al., 2022; Tapia et al., 2017 |
| Ph | E | *energy label* | Flanagan et al., 2011; IPCC, 2022; Rocha et al., 2023, Yu et al; Van der Hoeven & Wandl, 2018 |
| Ph | E | *high population density* | Ahmed et al., 2023; Flanagan et al., 2011; Yu et al., 2021; Eklund et al., 2023; Tapia et al., 2017 |
| Ph | E | **urban human activities** | IPCC, 2022; Ahmed et al., 2023; Flanagan et al., 2011; Kleerekoper et al., 2012; Eklund et al., 2023; Tapia et al., 2023 |
| Ph | E | *qualtiy of the built environment* | Conglaves et al., 2022; Tapia et al., 2017; Ahmed et al., 2023; Yu et al., 2021 |
| Ph | E | *UHI* | Ahmed et al., 2023; Cole et al., 2021; Eklund et al., 2023; Flanagan et al., 2011; Gable et al., 2016; IPCC, 2022; Rocha et al., 2023; Saja et al., 2018; Samen Klimaatbestendig, 2023; Tapia et al., 2017; World Bank, 2023; Yu et a., 2021; OHCHR, 2022 |
| Ph | E | **gray surfaces** | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012; Yu et al., 2021; Samen Klimaatbestendig, 2023 |
| Ph | E | *air pollution* | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012; Ahmed et al., 2023 |
| Ph | E | **green infrastructure (proxies: low green surfaces, surfaces covered by trees, watersurfaces** | IPCC, 2022; Ahmed et al., 2023; Flanagan et al., 2011; Kleerekoper et al., 2012; Eklund et al., 2023; Rocha et al., 2023; Van der Hoeven & Wandl, 2017 |
| Ph | E | **pathway surfaces in shades** | IPCC, 2022; Ahmed et al., 2023; Kleerekoper et al., 2012; Van der Hoeven & Wandl, 2017 |
| Ph | Ac | **physical infrastructure (proxy: average distance from dwellings to nearest GP, hospital, 'huisartsenpost', pharmacy, supermarket, and library** | IPCC, 2022 |

The variables of Tab. 4.1 were transformed into a matrix: Figure 4.1 has two identical axes perpendicular to each other. The variables with a gray background were mentioned in the literature, but were not used in the quantitative analysis due to a lack of data or a proxy.

Along the diagonal line, where the same variables of the two axes meet, the matrix is split into two sides. The upper half of the matrix shows the number of sources that mention a connection between two variables. The number one indicates a single mention in literature, and three indicates a connection is mentioned in three different papers.

The number of connections between variables was less than anticipated. There were several correlations, both positive or negative, that were to be expected, but not mentioned. Examples are the correlation between migration background and cultural aspects, income and health in relation to adaptive capacity, or the influence of renting a house. Therefore, expected connections were added to the matrix as a hypothesis (H).

The lower half of the matrix visualizes results based on a correlation test. The data used for this is the same as for the PCA: information about The Hague. A lower score, a darker blue color, means a negative correlation: An increase in variable A leads to a decrease in variable B. For example, there is a negative correlation between adults with low personal resilience and being a second-degree EU migrant, meaning that second-degree EU migrants often have higher personal resilience.

On the other hand, a higher score, a darker red color, stands for a positive correlation: An increase in variable A leads to an increase in variable B. For example, a high positive correlation exists between women and single-parent households.

The factors mentioned most in the papers are income, age, gender, migration background, and health issues. However, except for the migration background, these factors are not often connected to other variables, especially not to physical variables. The physical variables are mentioned a couple of times, mainly in relation to their contribution to UHI, rather than their connection to sensitivity.

Looking at the variables related to sensitivity, it becomes clear that the literature strongly focuses on economic capital, including household income, (energy) poverty, and occupation status, combined with migration background. This correlation is also present in the correlation matrix, based on quantitative data in The Hague. Furthermore, economic capital is also often analyzed in combination with housing typology and quality, where lower-income households often live in smaller or lower-quality housing.

Specific tools that increase adaptive capacity are not often mentioned in the read papers; instead, they focus more generally on factors such as access to resources, social cohesion, and participation. Access to resources negatively correlates with age, migration background, and poverty. Due to its broad concept, the qualitative analysis could not confirm this since there was no data or proxy for 'access to resources'. Based on the literary mentions, it becomes apparent in the matrix that adaptive capacity is mainly researched in combination with sensitivity variables. Yet, when looking at residents feeling lonely or resilient, the quantitative analysis shows a strong connection towards elements indicating the building quality.

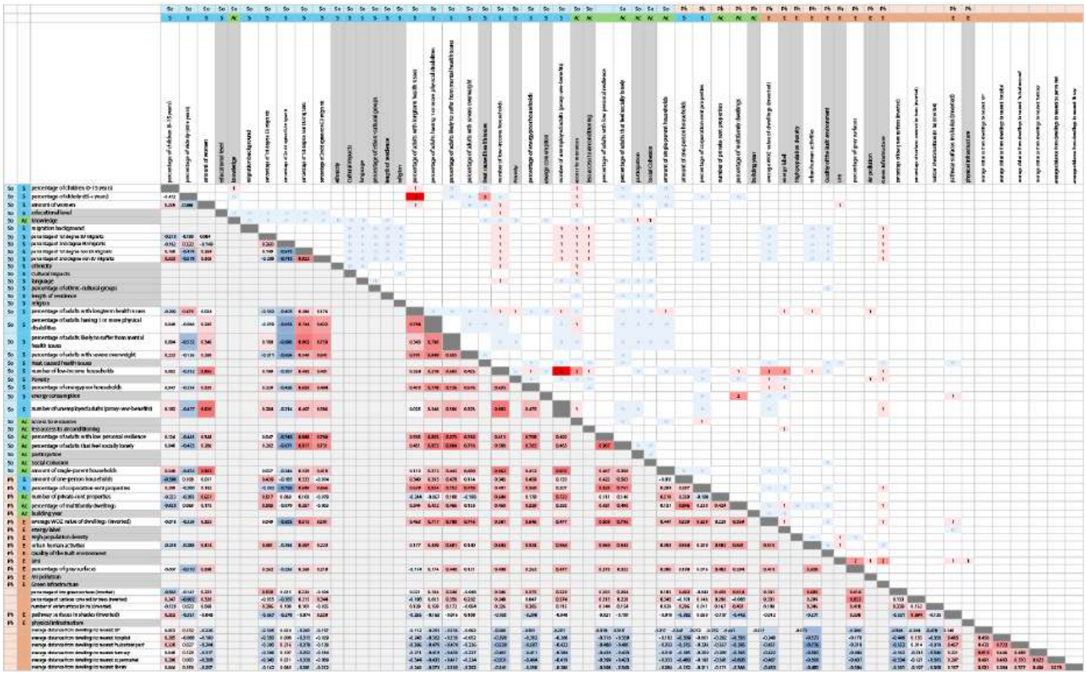


Figure 4.1: Vulnerability Matrix (see also App. A.3 for a bigger version)

## 4.2 Quantitative results

### 4.2.1 Principal Component Analysis

The Principal Component Analysis, conducted in R, resulted in six components with eigenvalues greater than one. Based on the cumulative explained variance, the number of components selected for further analysis was limited to four. This chapter describes the profiles represented by these four principal components and their spatial distribution within The Hague. The full statistical results are in Appendix A.7.

Figure 4.2 summarizes each component's loadings. Each circle represents the relationship between a variable (left axis) and a principal component (top axis): red circles indicate positive correlations, blue circles indicate negative correlations. The size of the circle reflects the strength of the loading, with larger circles representing higher absolute values. Based on this information, profiles of the vulnerabilities in The Hague can be sketched. A summary is presented in Tab. 4.2.1 together with the most dominant neighborhoods of each group. In the following sections, each principal component is described individually.

Table 4.2: Most significant positive and negative indicators per component, with the neighborhoods where they are the most dominant.

| **Group** | **characteristics** | **neighborhood** |
|---|---|---|
| 1 (+) | non-EU migrants, mental and physical health issues, low socio-economic status, single parents, one-person households, low social adaptive capacity, corporation-rent properties, multi-family dwellings, high UHI | Schildersbuurt-West, Schildersbuurt-Noord, Schildersbuurt-Oost |
| 1 (-) | elderly, second-degree EU migrants, long distances to public (health) facilities | Bosweide, Ockenburgh, Vlietzoom-Oost |
| 2 (+) | children, second-degree non-EU migrants, adults with severe over-weight, corporation-rent properties, lack of shading, long distances to public (health) facilities | De Reef, Rietbuurt, De Venen |
| 2 (-) | EU migrants, one-person households, private-rent properties, row houses, sufficient green and blue surfaces, | Haagse Bos, Zorgvliet, Voorhout |
| 3 (+) | children, women, unemployed adults, single-parents, private-rent properties, high UHI | Valkenboskwartier, Leyenburg, Laakkwartier-Oost |
| 3 (-) | elderly, physical health issues, one-person households, corporation-rent properties | Zuiderpark, Haagse Bos, De Uithof |
| 4 (+) | women, unemployed adults, low-income households, single-parent households | Leyenburg, Kraayenstein & Vroondaal, Houtwijk |
| 4 (-) | lack of trees and shades, lots of gray surfaces | Kerketuinen/Zichtenburg, Rivierenbuurt-Zuid, Binckhorsst |

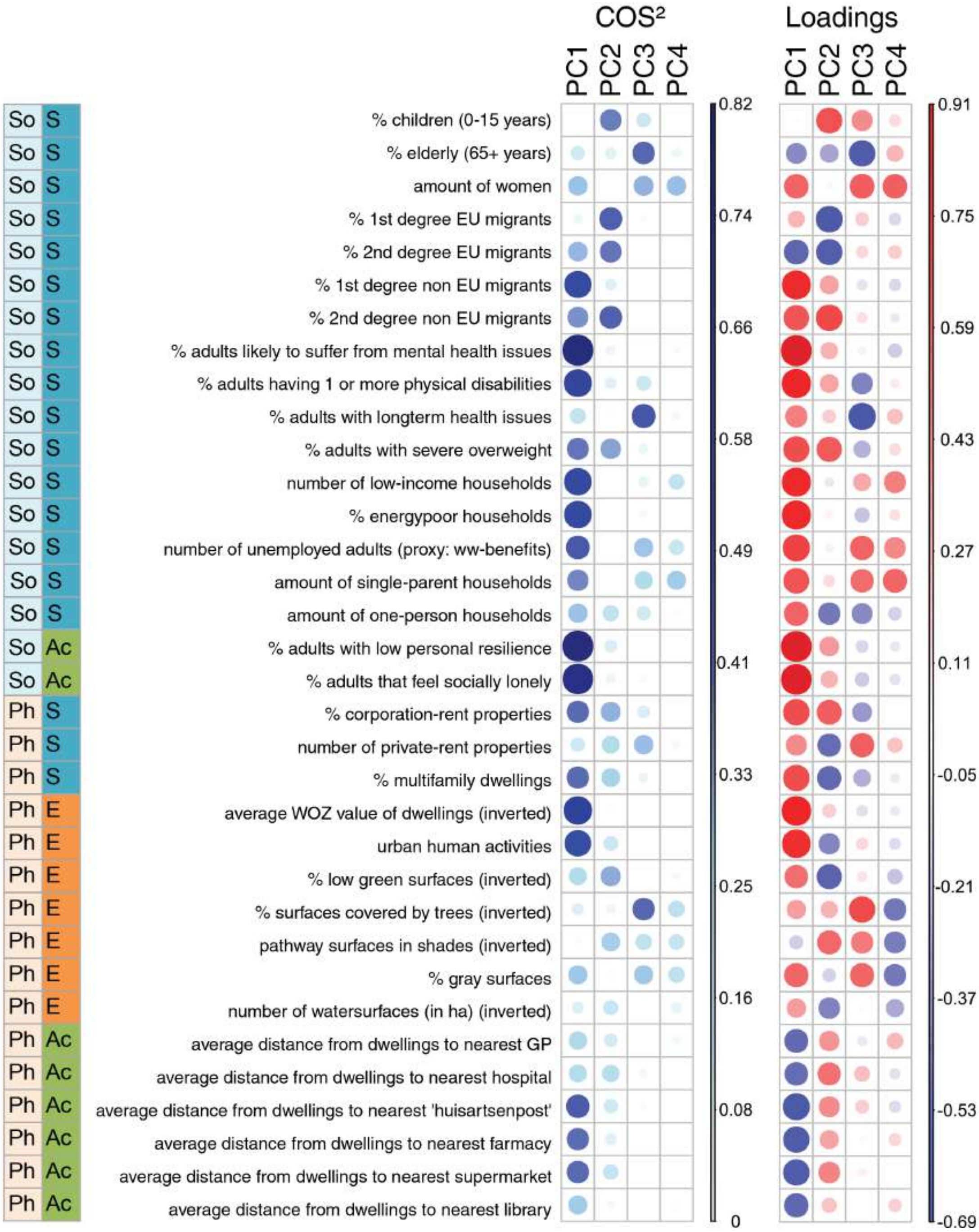



Figure 4.2: quality of representation (COS²) and variable loadings and per component. The variables are categorized into sensitivity (S), Adaptive capacity (Ac), Exposure (E), as well as social (SO) and physical (Ph)

### Group 1: Socio-spatial Vulnerability in Urban Areas

The spatial distribution of PC1 is clustered around the city center and in the southwest of The Hague. The pattern strongly overlaps with the 'problem neighborhoods' designated in The Hague. Neighborhoods with the highest scores on PC1 include Schilderstbuurt (north, east, and west), Transvaalkwartier north, and Moerwijk west.

The first principal component reflects a clear combination of social and spatial vulnerabilities. As illustrated in Fig. 4.2, this component is associated with a high concentration of non-EU migrants (Fig. 4.6b, 4.13a), adults with health issues (Fig. 4.8a, 4.4b), and households experiencing poverty (Fig. 4.13d, 4.13e). These social conditions are accompanied by poor housing quality (Fig. 4.4d), predominantly multi-family dwellings (Fig. 4.13h) owned by corporations (Fig. 4.13g) and rented by single-adult households, either with (Fig. 4.11b) or without children (Fig. 4.13f). In addition, high urban density (Fig. 4.14a) correlates with limited green infrastructure development (Fig. 4.12b, 4.14b). The buildings, nonetheless, may cast a significant amount of shade in this dense urban area.

Contrarily, areas characterized by PC1 tend to have a relatively lower number of elderly (Fig. 4.8b) and second-degree European migrants[1] (Fig. 4.6c). The negative correlation with average distances to facilities suggests better access to healthcare services and other public amenities, such as supermarkets and libraries (Fig. 4.14e, 4.14d).

Individual adaptive capacity, here represented by adults with low personal resilience (Fig. 4.4a) and individuals reporting feelings of loneliness (Fig. 4.4c), is significantly lower in these areas compared to the other components.

[1] First-degree migrants are those born in a country other than the Netherlands who have moved to the Netherlands. Second-degree migrants are born in the Netherlands, but at least one of their parents was born in a different country (CBS, 2024).

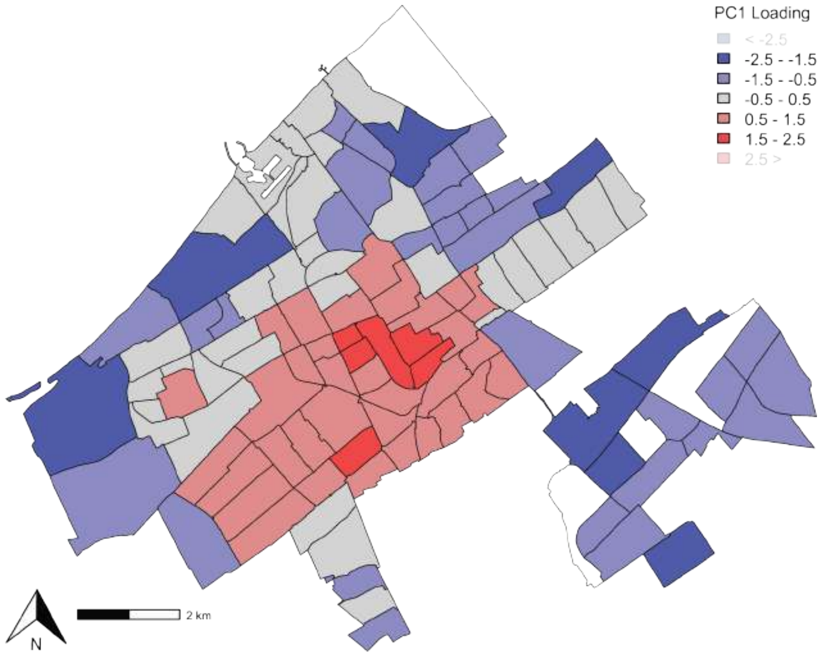
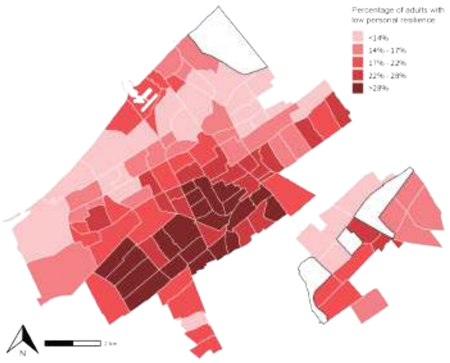
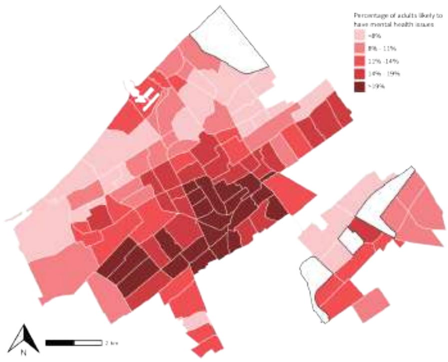


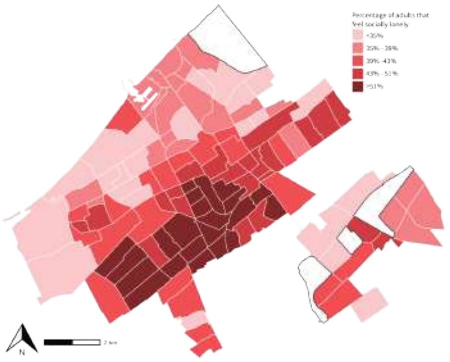

Figure 4.3: Representation of PC1 in the neighborhoods of The Hague



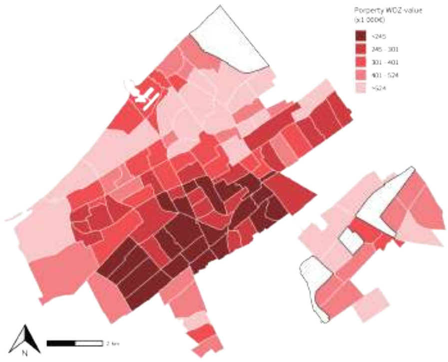
(a) percentage of adults with low personal resilience



(b) percentage of adults likely to suffer from mental health issues



(c) percentage of adults that feel socially lonely



(d) average WOZ value of dwellings (inverted)

Figure 4.4: Variables with highest absolute value PC1

### Group 2: Social Vulnerability in Suburban Family Neighborhoods

PC2 is concentrated in the outer rings of the city of The Hague. The areas most strongly associated are located in Ypenburg and Leidscheveen. These areas are separated from the rest of The Hague by the highway and the cities Rijkswijk and Voorburg.

PC2 primarily captures the social dimension of vulnerability, characterized by a high presence of children (Fig. 4.6d), adults with severe overweight (Fig. 4.13c), and second-degree non-EU migrants (Fig. 4.6b). Yet, PC2 has a strong negative correlation, so the absence of, both first- and second-degree EU migrants. Although the social adaptive capacity, measured by personal resilience (Fig. 4.4a) and feelings of loneliness (Fig. 4.4c), in these areas remains relatively low, it is notably better compared to PC1.

On the physical scale, the negative loadings associated with multifamily dwellings (Fig. 4.13h) suggest an urban morphology dominated by row houses, consistent with the lower presence of one-person households (Fig. 4.13f). These dwellings are mostly owned by corporations (Fig. 4.13g).

The suburban locations provide greater opportunities for the development of green and blue infrastructure (Fig. 4.14b, 4.14c), which can help mitigate urban heat island (UHI) effects. However, despite the available space, the number of trees is relatively low, as indicated by the positive correlation with surfaces covered by trees (Fig. 4.12b). The combination of low urban density (Fig. 4.14a) and the limited trees present results in insufficient shaded pathways. However, the consequence of the suburban location and low urban density is an increased distance to (health) facilities (Fig. 4.14f, 4.14g, 4.14h).

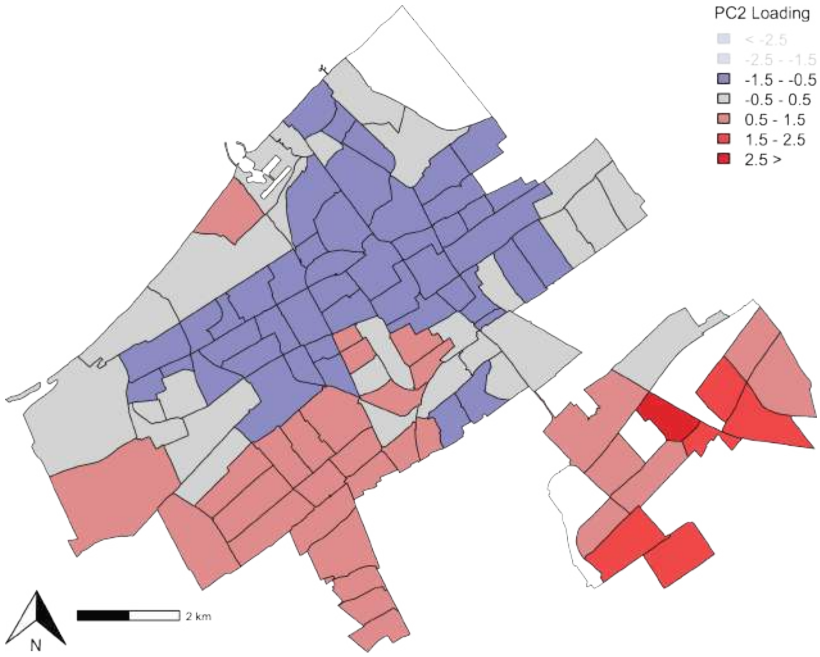
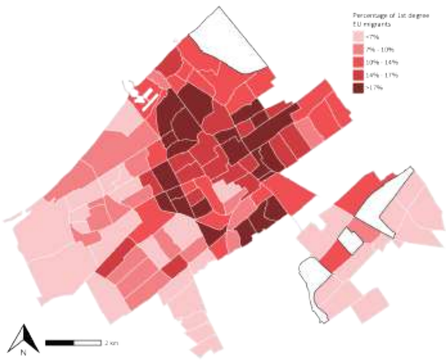
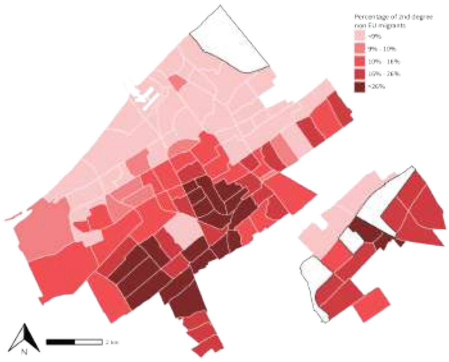


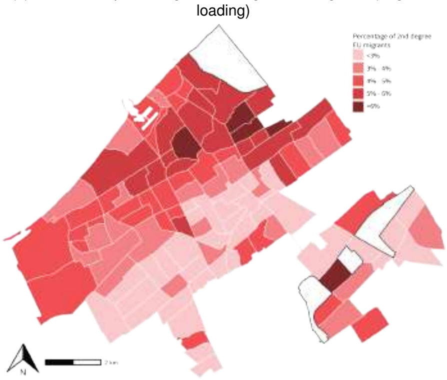

Figure 4.5: Representation of PC2 in the neighborhoods of The Hague



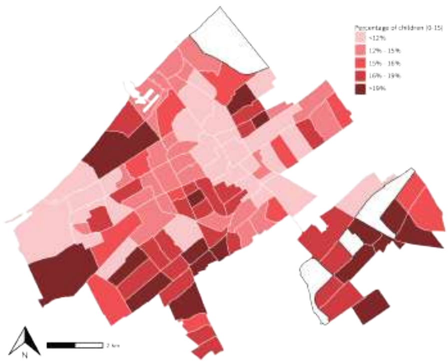
(a) Absence of percentage of 1st degree EU migrants (negative loading)



(b) percentage of 2nd degree non EU migrants



(c) Absence of percentage of 2nd degree EU migrants (negative loading)



(d) percentage of children (0-15 years)

Figure 4.6: Variables with highest absolute value PC2

### Group 3: Social Vulnerabilities among Single Mothers in Mixed Urban Contexts

In terms of spatial distribution, PC3 differs from the earlier components. While PC1 and PC2 align closely with existing segregation patterns in the city, PC3 is observed across wealthier and less affluent neighborhoods. There is a slight clustering toward central areas of The Hague and suburban locations such as Ypenburg, Leidscheveen, and Wateringse Veld.

PC3 presents a distinct social pattern of single-parent households (Fig. 4.11b), predominantly mothers (Fig. 4.9b), with young children (Fig. 4.6d). There is a high presence of unemployed adults (Fig. 4.9a), which correlates with low-income households (Fig. 4.13d). These households display relatively good health outcomes, as indicated by the strong negative correlation with long-term health issues (Fig. 4.8a), and demonstrate somewhat stronger social capital (Fig. 4.4a, Fig. 4.4c) compared to PC1 and PC2.

The physical environment is characterized by row houses within the private rental sector, combined with a low tree density (Fig. 4.12b) and limited shaded pathways.

The negative loadings of PC3 highlight another group: elderly residents (Fig. 4.8b) with long-term health issues (Fig. 4.8a), higher feelings of loneliness (Fig. 4.4c), and a concentration in multi-family corporation-owned dwellings (Fig. 4.13g). To a lesser extent, physical disabilities (Fig. 4.13b), severe overweight (Fig. 4.13c), and single-person households (Fig. 4.13f) are also present in these areas.

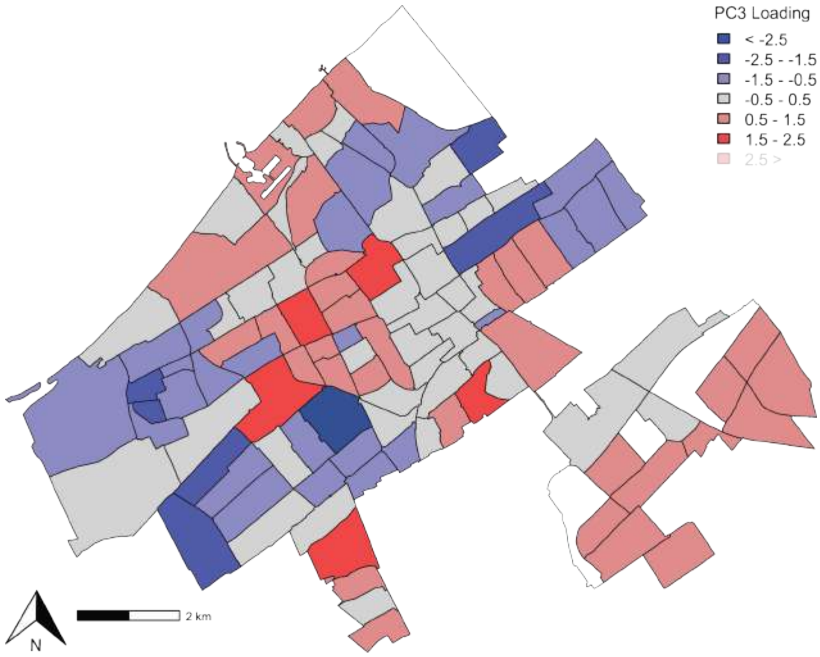
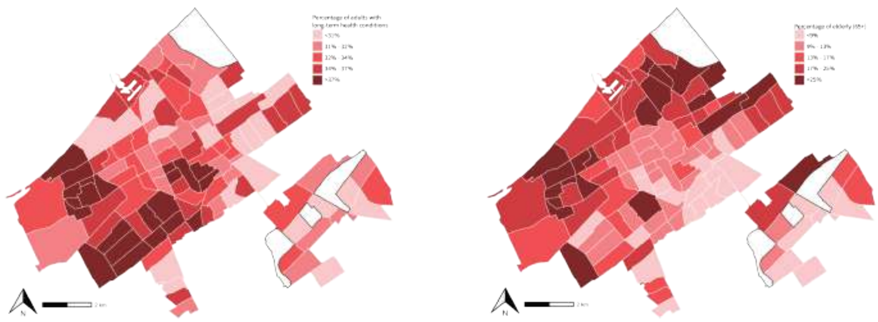


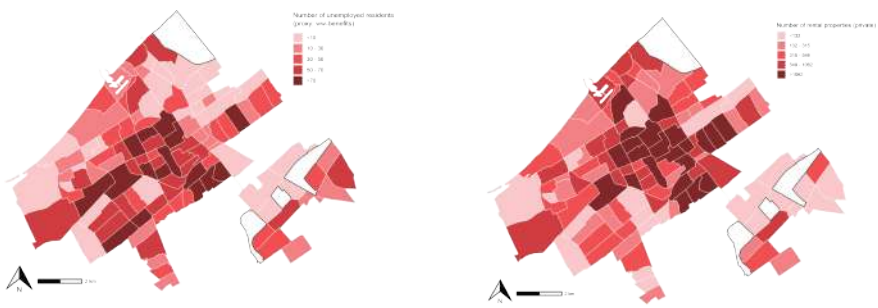

Figure 4.7: Representation of PC3 in the neighborhoods of The Hague



(a) Absence of percentage of adults with long-term health issues (negative loading)

(b) Absence of percentage of percentage of elderly (65+ years) (negative loading)

Figure 4.8: Variables with highest absolute value PC3



(a) Number of unemployed adults, based on the proxy of WW-benefit (unemployment benefit)

(b) Number of dwellings within the private rent sector

Figure 4.9: Variables with highest absolute value PC3

### Group 4: Socioeconomically Fragile Families in Green, Low-Density Areas

Like PC3, PC4 is dispersed across the city, but the two components appear to be spatially somewhat inverted relative to each other. This is due to the reduced UHI effect of this group, visible in neighborhoods such as Leyenburg, Kraayenstein & Vroondaal, and Houtwijk, located in the northern and western parts of The Hague.

PC4 also highlights social vulnerabilities related to female single-parent households with children, similar to PC3. However, in PC4, socioeconomic challenges are more severe. The positive correlation with low-income households (Fig. 4.13d) is stronger, and there is a higher incidence of households experiencing energy poverty (Fig. 4.13e).

Greater differences between PC3 and PC4 emerge in relation to urban heat island (UHI) variables. In neighborhoods with high PC4 scores, urban density is lower (Fig. 4.14a), providing more space for green and blue infrastructure as well as trees (Fig. 4.14b, 4.14c, 4.12b). Among all components, PC4 shows the strongest negative correlation with urban density and the strongest positive presence of natural elements. The relatively low UHI intensity is reflected in the spatial distribution of PC4 in the more natural areas of the city.

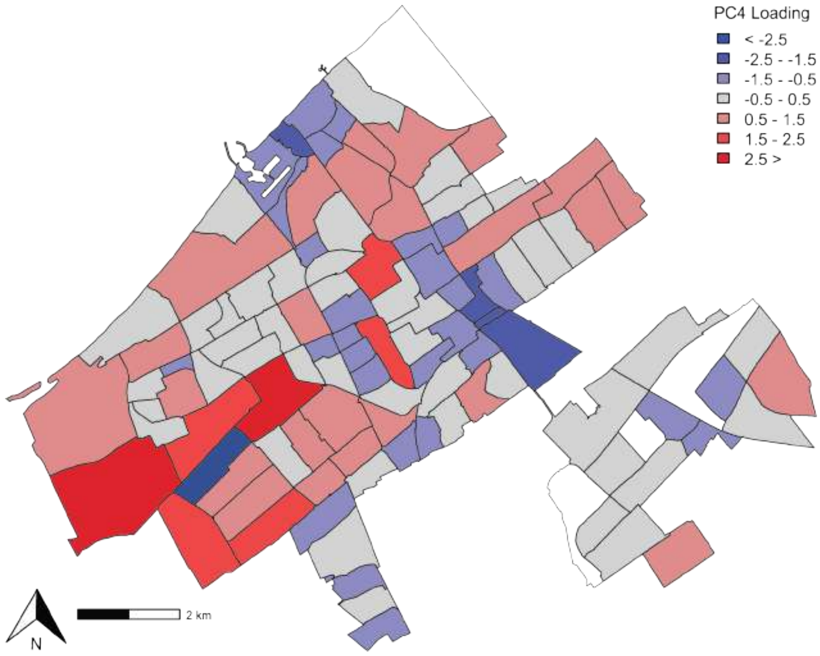
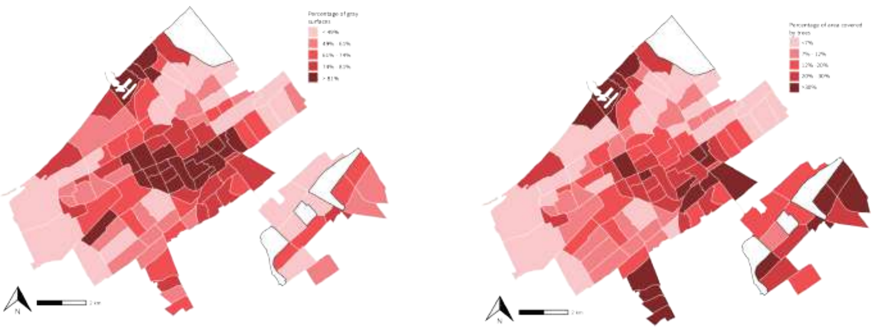



Figure 4.10: Representation of PC4 in the neighborhoods of The Hague

(a) amount of women

(b) amount of single-parent households

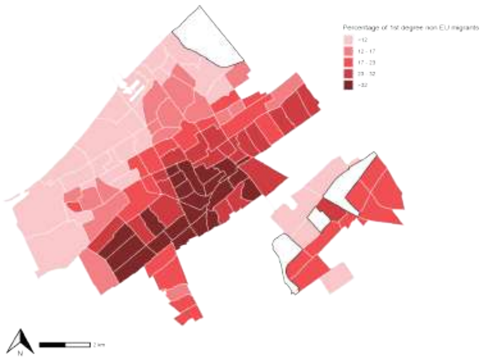
Figure 4.11: Variables with highest absolute value PC4



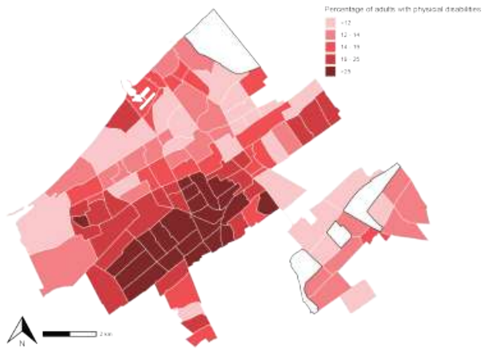
(a) Absence of percentage of gray surfaces (negative loading)

(b) Absence of percentage of surfaces covered by trees

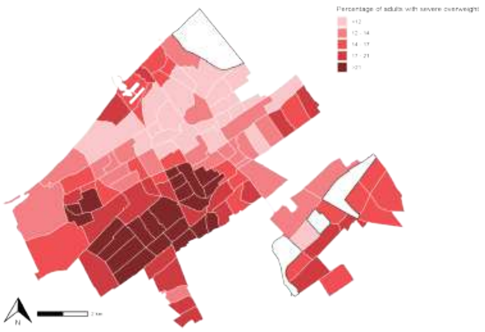
Figure 4.12: Variables with highest absolute value PC4



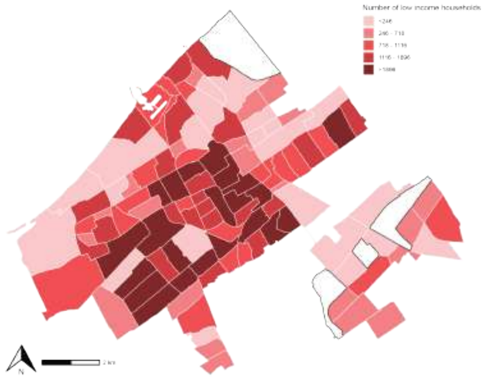
(a) Percentage of first degree non European migrants



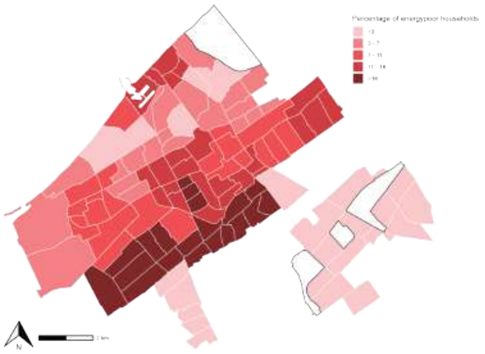
(b) percentage of adults with one or more physical disabilities



(c) percentage of adults suffering from severe overweight

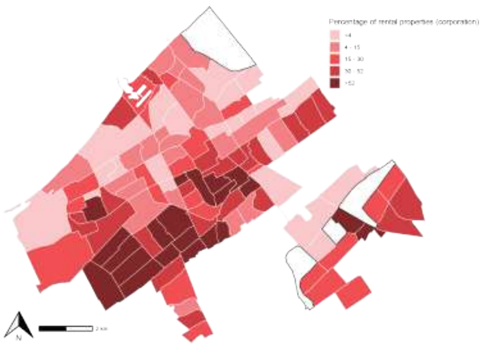


(d) number of low-income households

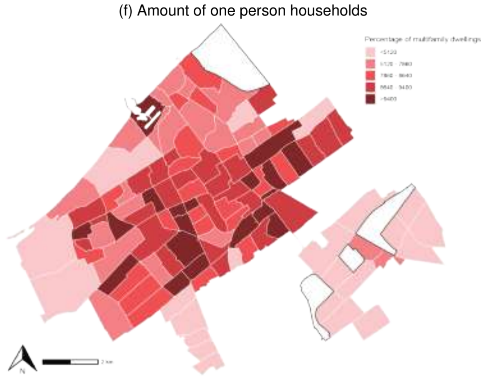


(e) Percentage of households suffering from energypoverty

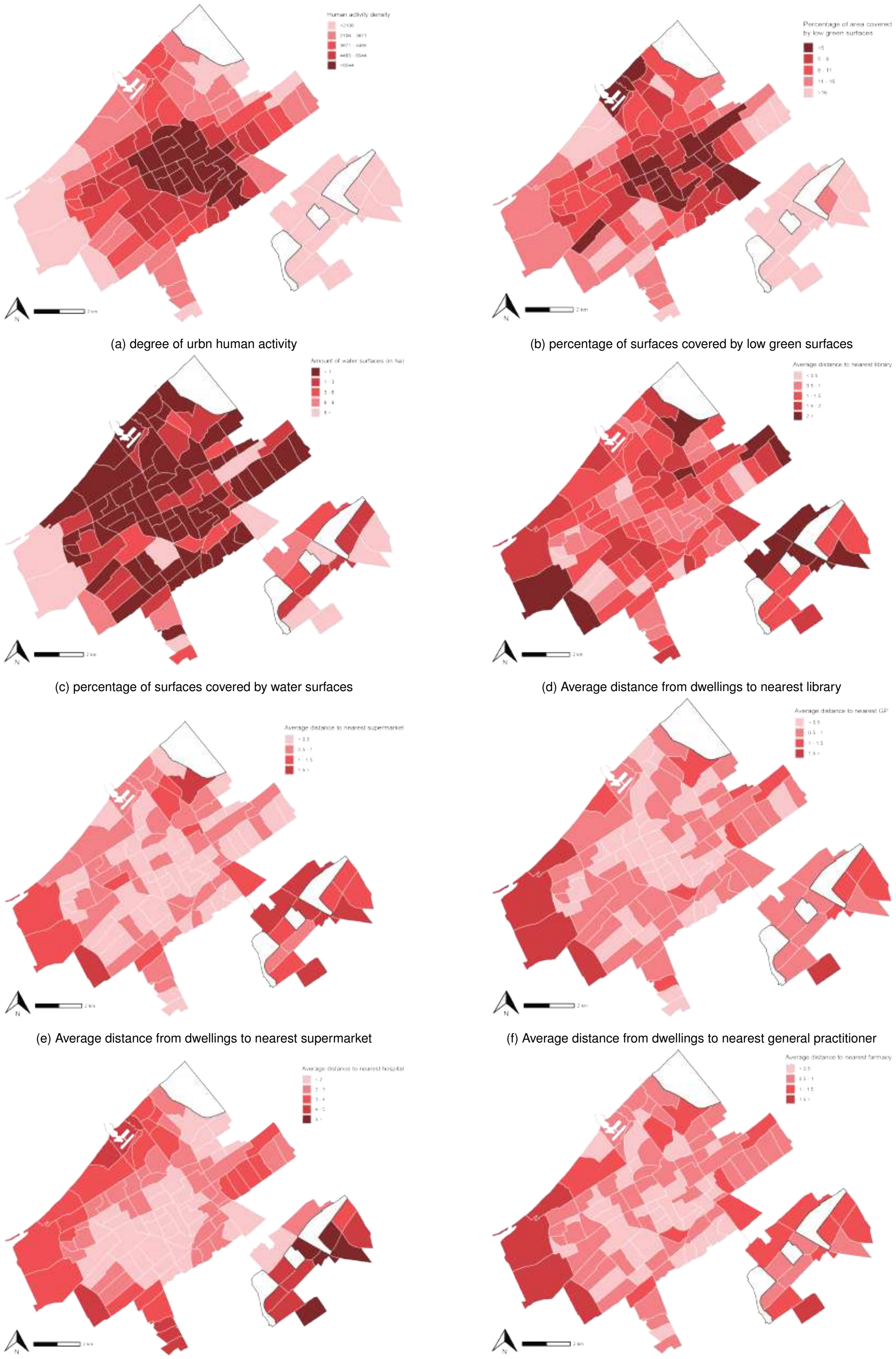
(f) Amount of one person households



(g) percentage of dwellings rented by corporations



(h) Percentage of multi family dwellings



(a) degree of urbn human activity

(b) percentage of surfaces covered by low green surfaces

(c) percentage of surfaces covered by water surfaces

(d) Average distance from dwellings to nearest library

(e) Average distance from dwellings to nearest supermarket

(f) Average distance from dwellings to nearest general practitioner

(g) Average distance from dwellings to nearest hospital

(h) Average distance from dwellings to nearest pharmacy

Figure 4.14: Variables used for PCA

### 4.2.2 Overall vulnerability distribution

To create an understanding of the most and least heat-vulnerable neighborhoods of The Hague, the principal components can be accumulated. However, due to the varying levels of variance explained by each component, with PC1 explaining the most and PC4 the least, this accumulation should be weighted according to the explained variance [2], indicated in Tab. A.1.

The weighted summary (Fig. 4.15) reveals that the PCA results align closely with the spatial distribution of The Hague's 'problem neighborhoods' (Fig. 4.16), particularly in the southwest of the city. As shown in Tab. 4.1, the most heat-vulnerable neighborhoods include Schildersbuurt-West, Schildersbuurt-Noord, Schildersbuurt-Oost, Dreven en Gaarden, and Leyenburg. It is notable, however, that Leyenburg is not originally part of the 'problem neighborhoods', but is located directly next to them.

On the other end of the spectrum, the five least vulnerable neighborhoods are Duttendel, Haagse Bos, van Stolkpark/Scheveningse Bosjes, Westbroekpark, and Zorgvliet. All of these areas are considered among the wealthiest in The Hague.

Table 4.1: Top five most and least vulnerable neighborhoods of The Hague based on a weighted sum.

| Buurt | PC1 | PC2 | PC3 | PC4 | weighted sum |
|---|---|---|---|---|---|
| Schildersbuurt-West | 2.212 | 0.3600 | 0.829 | 1.527 | **1.515** |
| Schildersbuurt-Noord | 2.071 | 1.001 | -0.369 | 0.239 | **1.284** |
| Schildersbuurt-Oost | 1.902 | 1.134 | -0.367 | -0.504 | **1.123** |
| Dreven en Gaarden | 1.182 | 1.207 | -0.183 | 2.011 | **1.036** |
| Leyenburg | 1.032 | -0.773 | 1.834 | 3.394 | **0.968** |
| Duttendel | -1.669 | -0.368 | -0.682 | 0.700 | **-1.003** |
| Haagse Bos | -0.654 | -1.465 | -2.424 | 0.625 | **-1.016** |
| van Stolkpark/ Scheveningse Bosjes | -1.261 | -1.060 | -1.344 | 0.806 | **-1.046** |
| Westbroekpark | -1.410 | -0.562 | -1.480 | 0.640 | **-1.051** |
| Zorgvliet | -1.259 | -1.434 | -1.093 | 0.195 | **-1.142** |

[2] The formula used for the weighted summary is $\sum$ [PC loading * (Variance explained of the PC / cumulative variance of the PC's)].

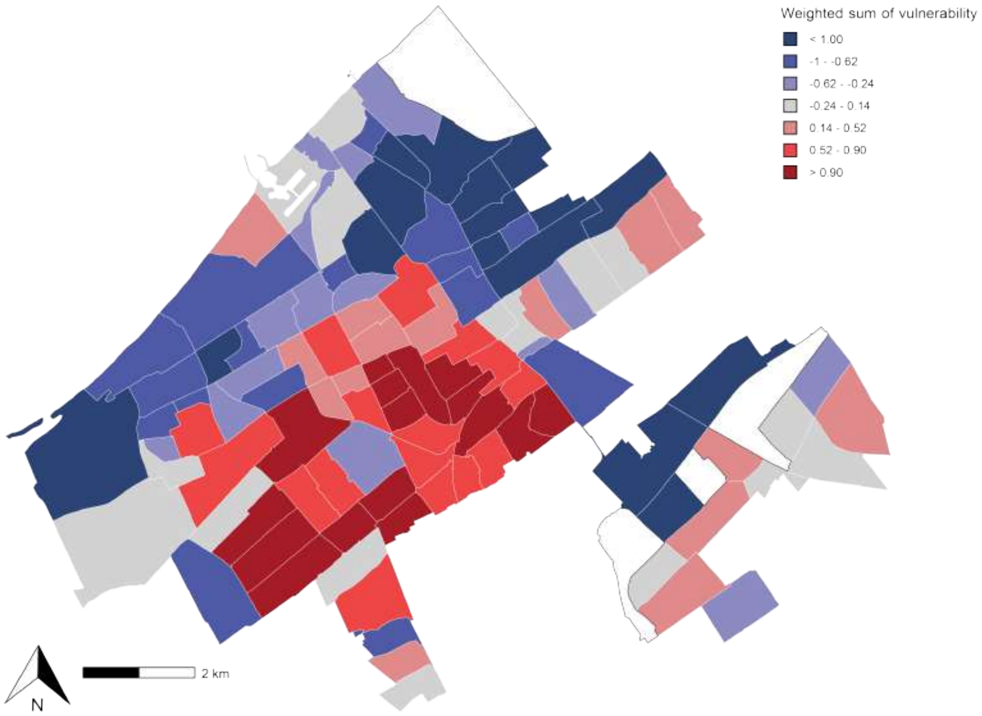



Figure 4.15: Spatial distribution of the weighted summary of heat vulnerability

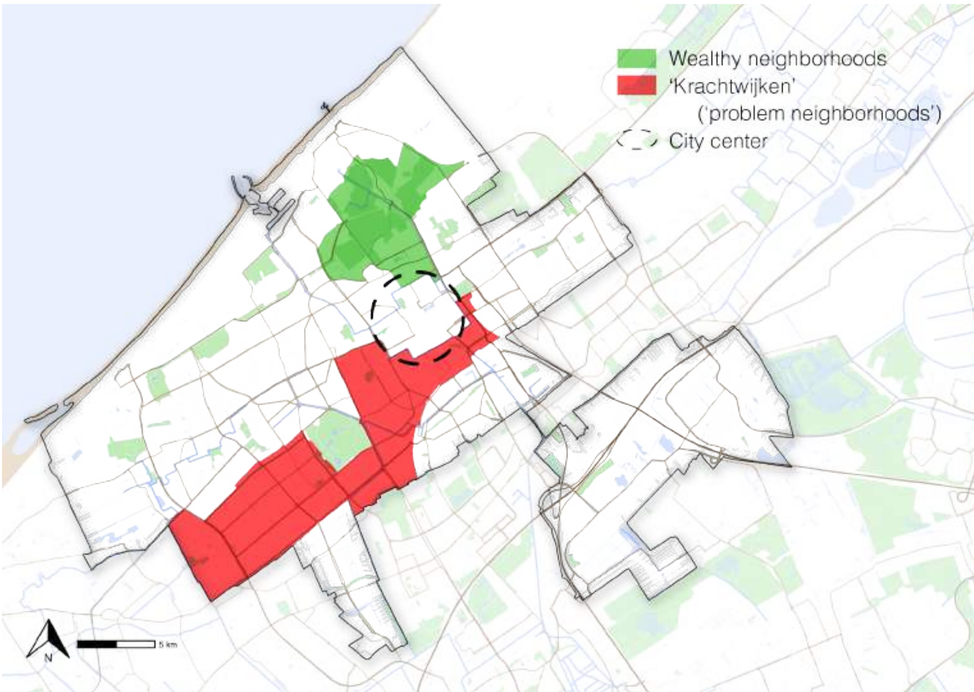



Figure 4.16: Indication of the wealthy neighborhoods in the north (green) and the Krachtwijken in The Hague south west (red)

## 4.3 Qualitative Results

### 4.3.1 Observations in the Neighborhood

When walking through the Schildersbuurt-West, one can feel the effect of the UHI: The differences in temperatures between streets with and without trees and the open and fully paved street corners where no escape from the heat is possible. The neighborhood is facing significant challenges regarding urban heat.

Public spaces such as parks, squares, and sidewalks are generally spacious but underutilized in terms of greenery and shade. Trees are often placed on the south side of the street, leading them to stand in the shade of the buildings, instead of casting shade on them. Additionally, many play areas lack sufficient shade cover. This is not just problematic for the children playing there, but also for the parents watching them.

Additionally, the PCA showed a high presence of gray surfaces. The fieldwork observations show that the sidewalks take up a very high percentage of the gray surfaces: The sidewalks and street corners are very wide, lacking trees and other green structures. In fact, 86% of the neighborhood is indicated as gray surfaces (Gemeente Den Haag, 2023), leaving a lot of potential for green infrastructure.

Socially, the neighborhood shows signs of casual familiarity: residents often engage in brief street interactions, especially among women and the elderly. Cultural dynamics, particularly the prominence of cars as status symbols, must be taken into account in any design intervention. Removing parking spaces without community support could lead to resistance.

Overall, any spatial strategy should be community-sensitive, leverage existing social networks, and focus on creating more inclusive, shaded, and socially vibrant public spaces.

Sportpark De Verademing
Brouwerij De Prael Den Haag
HMC Westeinde
Zamenhofstraat
Den Haag, Monstersestraat
Van Goghstraat
Ruzenburgstraat
Schapenlaan
Zoutkeetsingel
Jacobastraat
Honselersdijkstraat
's-Gravenzandelaan
Wateringsestraat
Monstersestraat
Prinsegracht
Stichting Islamitisch Centrum 's-Gravenhage
Karwei bouwmarkt Den Haag-Haagse Markt
Engelenburgstraat
Bakhuizenstraat
De Vliegerstraat
Hobbemastraat
Hobbemaplein
Schilderstraat
Honthorststraat
De Heemstraat
De Haagse Markt
RK Parochie
Scheeperstraat
Natalstraat
Ellekomstraat
De la Reyweg
Velpsestraat
Nunspeetlaan
Hulshorststraat
Staverdenstraat
Uddelstraat
Sporthal Transvaal
Soestdijksekade
Hondiusstraat
Fischerstraat
Wesselsstraat
Wolmaransstraat


Lage Nieuwstraat
Gedempte Burgwal
Amsterdamse Veerkade
Stille Veerkade
Wagenstraat
Dunne Bierkade
Groenewegje
Repelaerstraat
Van der Duynstraat
Paviljoensgracht
Den Haag
Paulus Potterstraat
Rembrandtstraat
Hoefkade
Van der Helststraat
Gerard Doustraat
Maria Sterre
H. Willibrord
Abraham van Beyerenstraat
Wouwermanstraat
Ferdinand Bolstraat
Gabriël Metsustraat
Kraijcek playground
Vermeerpark
Mijtensstraat
Parallelweg
Groenteweg
Spoorslag
Waldorpstraat
Boulderhal Walhalla
Slachthuislaan
Stationsweg

### 4.3.2 Conversations on the Sidewalk

To explore how residents of Schildersbuurt-West experience and respond to heat, a series of informal conversations were held with individuals in public spaces such as parks, religious institutions, and community hubs. These brief interviews offer insight into both personal behavioral adaptations and the (potential) role of local institutions in heat resilience.

Across the conversations with residents, a few key themes emerged: residents often adapt in small, personal ways—through clothing, diet, hydration, or seeking cooler spaces. Yet, there's a clear reliance on informal networks and public spaces, especially when home environments lack adequate cooling.

Institutions such as the library, which has strong municipal links and a community-oriented approach, demonstrate how public spaces can support resilience. However, the church and mosque show that without sufficient resources or openness, their role remains limited. Meanwhile, trust in the municipality is generally low; residents expressed skepticism about its responsiveness and support for local adaptation needs.

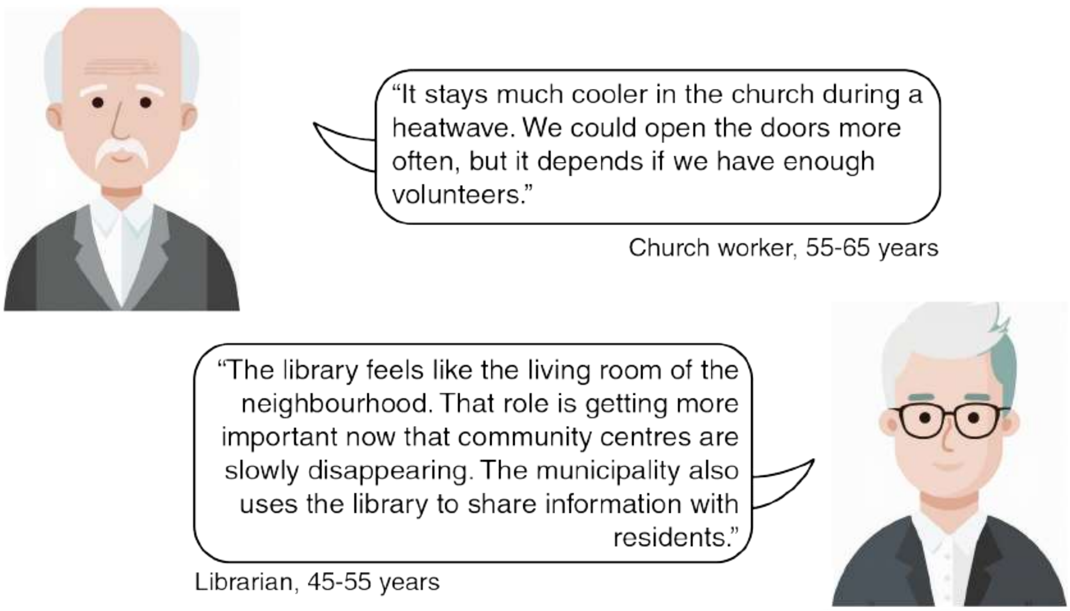



Figure 4.17: Summary of street interviews 1

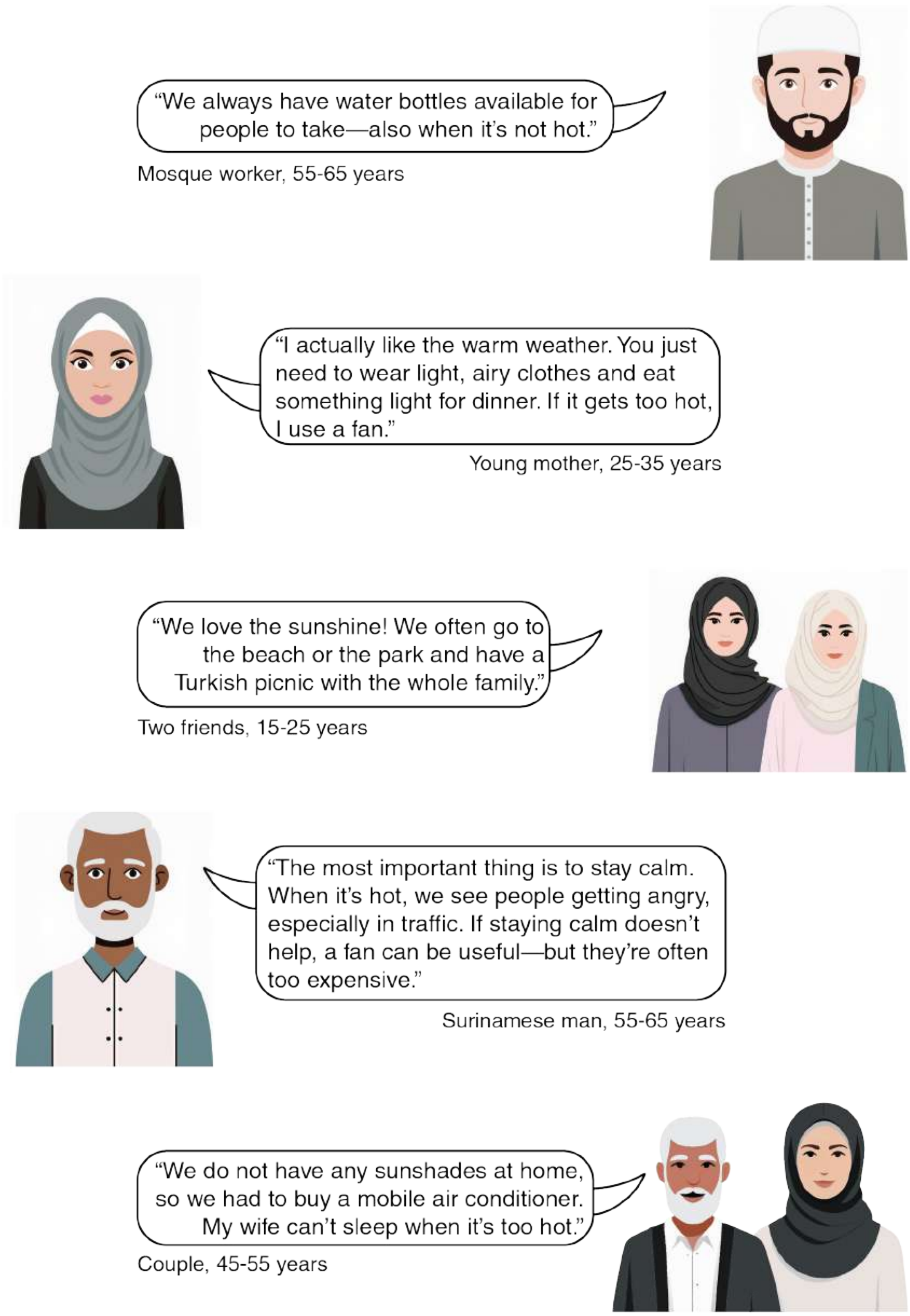



Figure 4.18: Summary of street interviews 2

### 4.3.3 Analysis of existing instruments

#### Klimaatadaptatie Nederland

The website www.klimaatadaptatienederland.nl has a collection of 107 Dutch climate adaptation strategies. Most of the instruments have multiple focus points, but 22 focus on droughts, 31 on biodiversity, 38 on floods, and the majority, 54, on heat. The high number of instruments focusing on heat can be linked to the fact that many tools prioritize the implementation of greenery in the built environment, which is beneficial for both heat and water management, as well as biodiversity. This is also reflected in the high number of tools addressing physical (50) exposure (41) on both the street (44) and neighborhood (36) level. The number of instruments addressing sensitivity (9), behavior (5), or the social (6) dimension is limited. Based on a pre-selection, 27 tools out of the 57 addressing heat were further investigated.

Tools addressing heat on the physical exposure level mainly focus on implementing different types of green infrastructures, such as designing green streets, facades, or rooftops. Examples are Effectief Klimaatgroen (Kleerekoper et al., 2024), Handreiking natuurinclusief bouwen voor gezonde bewoners (Mereboer & Postma, 2023), and Maatregelen klimaatadaptatie en natuurinclusief bouwen en renoveren (Rijksdienst voor Ondernemend Nederland [RVO], 2024). This also leads to the municipality and urban developers being the main stakeholders in the existing adaptation instruments, followed by project developers, housing corporations, and policymakers.

Only five adaptation tools specifically address behavioral changes, of which only one is created to inform residents: Effectiviteit van klimaatadaptieve maatregelen (RIONED, 2019). Yet, this tool, an extensive table that shows the effect of different interventions on reducing heat, drought, or flooding, is not accessible for the general public due to its abstract visualisation.

The instruments Klimaatadaptatie en natuurinclusief bouwen en renoveren (RVO, 2024) and Huisje Boompje Beter (Atelier Groenblauw, n.d.) have more user-friendly interfaces showing interventions. However, the first includes only a few measurements residents can do, and the rest are projects on a bigger scale for developers and municipalities. The latter interface, Huisje Boompje Beter, displays many options for climate adaptation, but only for gardens. Therefore, the target group is limited to residents with gardens and explicitly excludes those with balconies.

#### Nationaal Hitteplan

After a severely increased mortality rate in 2005 and 2006 due to heatwaves, the KNMI and the RIVM decided in 2007 to launch the Nationaal Hitteplan (national heatplan) (KNMI, 2007) together with the Nederlandse Rode Kruis, GGD GHOR Nederland(Gemeentelijke / Gemeenschappelijke GezondheidsDienst – Geneeskundige

HulpverleningsOrganisatie in de Regio). The heatplan is a warning system in the form of a communication plan (Klimaatadaptatiestrategie [NAS], 2019): When the KNMI predicts a period of at least 4 warm days, they contact the RIVM. Since a heatwave is a phenomenon that can only be pointed out after it happened, the national heat plan is based on weather predictions: temperatures during the day and night, perceived temperature and humidity (RIVM, 2023). Together the KNMI and the RIVM decide whether the set of the warning system. This is done by sending an email with information to approximately 70 organizations, including healthcare organizations, caregivers, and national industry and interest groups.

Due to local temperature differences across the country, it has been possible since 2015 to activate the warning system per province. Since the start of the warning system, it has been activated yearly, with 17 activations in the year 2022 (RIVM, 2023).


(a) Heat and health - recognize the symptoms, know what to do (infographic created by RIVM, 2024)


(b) National Heat plan - prevent health problems due to hot weather (infographic created by RIVM, 2024)


(c) National Heat plan - take care of each other in the heat (infographic created by RIVM, 2024)

Figure 4.19: Infrographics as part of the National Heat Plan of the RIVM (2024)

### Haags Hitteplan

As a reaction to the National Heatplan, The Hague published in 2022 their own heat plan, 'Haags Hitteplan', as one of the first cities in the Netherlands. With a focus on elderly living on their own, chronically ill, and homeless people, this action plan addresses local stakeholders in the Hague. The mention of homeless people is a new contribution to the national health plan. In 2021, a list of local stakeholders was included, of which 17 organizations focus on the elderly and chronically ill, and nine organizations on homeless people and residents with mental problems (Gemeente Den Haag, 2021).

Additionally, de Wijs (2022) wrote a letter to the municipal council, which stated that there should also be a focus on the elderly living in healthcare centers. The letter predominantly mentions the need for subsidies for these facilities to reduce UHI by implementing more green infrastructure (on the ground and on the rooftops) and insulating buildings.

**Klimaatweek Den Haag**

To raise awareness about climate change, the Ministry of Climate and Green Growth (Ministerie van Klimaat en Groene Groei) organizes the annual ‘Climate Week’ (Klimaatweek). In 2024, this event occurred from November $11^{th}$ to $17^{th}$.

During this period, municipalities around the country organize various events to enhance public understanding of reducing greenhouse gas emissions, improving green energy infrastructure, and encouraging citizens to take action against climate change.

The organization’s website highlights the importance of this initiative, stating that global warming is causing more frequent extreme weather events. However, this specific issue was notably absent from the activities organized during the events (Nationale Klimaatweek [NKW], 2024).

The Hague was among the participating municipalities and hosted 35 events. The majority focused on reducing energy consumption and promoting general awareness of climate change. Eight events provided information about implementing greenery, and only three addressed the issue of heat problems (Duurzame stad Den Haag, 2024). These events are analyzed in Appendix A.5.

Overall, it can be observed that the events were relatively low-key, with a few targeted expert discussions. However, almost one-third of the events were scheduled between 09:00 and 12:00, making it impossible for working people to join. Furthermore, advance registration was required for 26 of the events, which reduced accessibility, particularly if events reached full capacity.

Event locations also lacked spatial diversity: As shown in Fig. 4.20, the activities were concentrated in the city center and the ‘problem neighborhoods’, while many other parts had no access to activities. This uneven distribution raises concerns about accessibility and inclusivity.

In conclusion, this analysis highlights the importance of carefully considering scheduling, registration requirements, and event locations when organizing public events.

### 4.3.4 Stakeholder Analysis

The previous section showed that in the process of climate adaptation, a high variance of projects and strategies exist. Based on the analysis of the existing instruments from Stichting CAS (n.d.), the Nationaal Hitteplan (RIVM, 2023) and a guide to the heatplan (Handreiking Lokaal Hitteplan; NAS, 2019), an analysis of the mentioned stakeholders has been executed.

The stakeholders can be divided into four groups: those who spread Information, those who adapt the Built Environment, those related to Local Executive Organ-

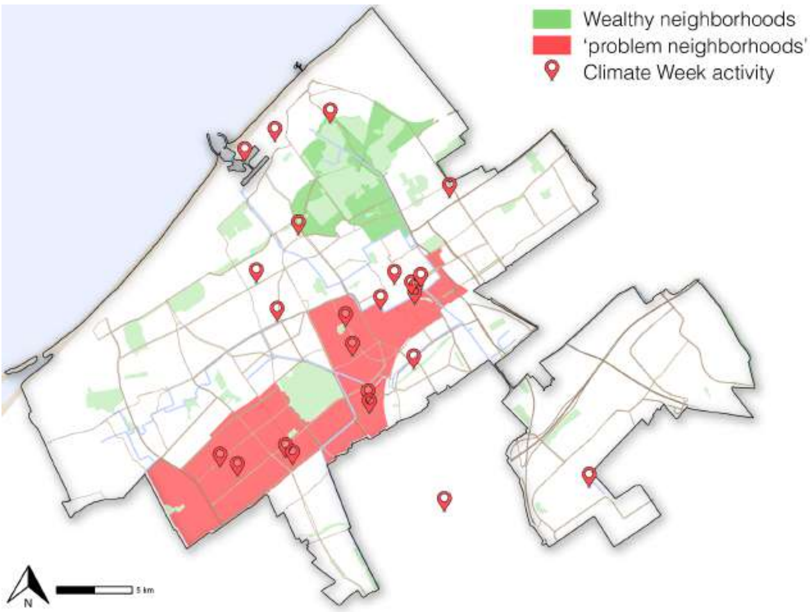



Figure 4.20: Location of Haagse Klimaatweek 2024

isations, and the Additional Assistance. As is also be in Fig. 4.21, there are two moments of information: the RIVM and KNMI informing and debating wether or not the National Heatplan should be activated, and the moment of activation, when local executive organizations are informed.

As discovered before, the instruments displayed in Sticthing CAS (n.d.) mainly focus on reducing exposure by improving the green infrastructures. As a result, many of the mentioned stakeholders, such as project developers and urban planners, can be primarily categorized as part of the Built Environment.

As the heatplan is a warning system, many stakeholders spread information to larger institutions and healthcare institutions (RIVM, 2023). These later institutions can be divided into larger institutions that spread information, such as the GGD (Gemeentelijke Gezondheids Dienst) or the LHV (Landelijke Huisartsen Vereniging), and local executive organisations like nursing homes, caregivers, or schools (NAS, 2019). Additionally, as the NAS (2019) shows, an essential part of the heatplan is having additional assistance, such as volunteers and social organizations.

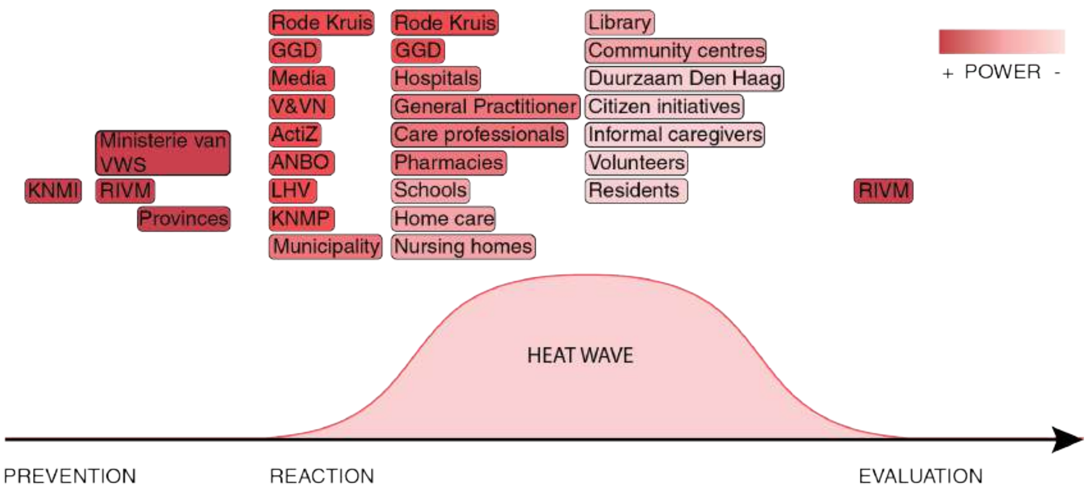



Figure 4.21: Activation of stakeholders


Figure 4.22: Stakeholders for heat wave adaptation

Figure 4.21 illustrates when different stakeholders become involved during a period of heatwaves. Stakeholders categorized in the Built Environment were removed from this figure, since adapting the physical realm is unrelated to an acute hazard, but rather a long-term adaptation strategy.

When categorizing stakeholders by power, it becomes clear that the most powerful and top-down stakeholders mainly influence the situation before the heatwave starts, as their main task is to spread information. As the heat wave approaches, the more local bottom-up stakeholders become of greater importance, especially during the heat wave. These stakeholders are in direct contact with the vulnerable groups and can therefore have a more hands-on approach.

Some stakeholders, such as the Municipal Health Service (GGD) or the Dutch Red Cross, change their roles over time: their primary function is to provide information before the heatwave starts. However, once the temperatures rise, they start distributing volunteers for more local help.

### 4.3.5 Conclusion of the qualitative results

The qualitative analysis highlights several important insights into heat vulnerability and adaptation strategies. The Vulnerability Matrix visualizes a clear research gap: although many studies identify variables contributing to vulnerability, few examine how these variables interact, particularly across dimensions such as exposure, sensitivity, and adaptive capacity. This finding emphasizes the need for a more integrated approach to understanding vulnerability.

Field observations reveal substantial opportunities for spatial improvements. Many areas are dominated by hard surfaces, which could be replaced by greenery to improve heat resilience, particularly along walkways and street corners. Furthermore, public spaces often lack adequate shade. In parallel, street interviews show that residents are making small-scale behavioral adjustments—such as changing clothing, staying hydrated, modifying diets, or seeking cooler locations—yet structural support for these behaviors remains limited.

Existing adaptation resources, such as Sticthing CAS (n.d.), offer a wide range of strategies but are primarily oriented toward large-scale stakeholders and infrastructural interventions, with limited attention to behavioral adaptations or reducing sensitivity. Similarly, public warning systems like the Nationaal Hitteplan (RIVM, 2023) and Haags Hitteplan (Gemeente Den Haag, 2021) are focused mainly on institutional coordination and the distribution of information, rather than actively enabling citizens to implement proactive coping strategies. As a result, while institutions are informed of upcoming heat events, coping measures often remain scattered across organizations, missing the opportunity to reinforce and strengthen each other's efforts.

The stakeholder analysis further emphasizes this, identifying four key groups involved in heatwave adaptation and response: information providers, Built Environment actors, Local Executive Organizations, and providers of Additional Assistance. Built environment stakeholders are engaged year-round, pursuing the long-term goal of reducing the UHI effect. In contrast, information providers have two primary phases of activity: preparing communications in advance of the National Heat Plan's activation and, when the Heatplan is activated, informing organizations.

As temperatures rise, additional support networks are mobilized to help vulnerable groups directly. This phased response illustrates a shift from a top-down warning system to increasingly bottom-up, community-centered assistance as heat waves intensify.

# 5 Design Results

## 5.1 Beat the Heat: From Data to Design

A heat adaptation toolkit, called *Beat the Heat*, was developed to translate the research findings and turn them into a practical and actionable outcome. It includes actionable strategies to increase adaptive capacity towards urban heat. The evidence-based strategies across different spatial and social settings, aim to support both residents and municipalities in mitigating Urban Heat Island (UHI) effects and enhancing personal comfort during heatwaves.

Existing adaptation tools often target a narrow audience, either municipal policymakers or private homeowners, and focus on a specific scale (e.g. large green infrastructure or small household actions). However, building urban heat resilience demands a multidimensional and multi-scalar approach. Beat the Heat addresses this gap by integrating social and spatial responses into one tool, enabling collaboration between residents and institutions.

The toolkit currently exists as a detailed intervention table but is designed to be adaptable into different formats: a website for wide accessibility, or a physical card set to support in-person dialogues. This flexibility enhances the tool's relevance for a range of actors, including municipalities, housing corporations, community organizations, and citizens.

A central feature is the ability to customize: users can filter interventions based on user type (resident or institution), target group, spatial scale, domain of application, expected costs, cooling effect, and whether the measure is preventive or responsive. In this way, users are empowered to select the measures most relevant to their specific situation and capacities.

### 5.1.1 Adaptation Starts with Customization

#### From Vulnerability to Agency

The toolkit contains a collection of 65 interventions, designed to support heat adaptation. Collected in a comprehensive table, each intervention is described with clear and practical details: scale of application, cooling effect, estimated cost, responsible actors, relevant target groups, and type of action (prevention or response). This information helps the user, whether institutions or citizens, to select measures that are most relevant to their needs and context.

The PCA revealed that there are various vulnerability typologies, each with their own needs and agencies. These needs can be stilled with different interventions, executed by both the municipality and the residents themselves.

Table A.8 shows an example of how different tools can help specific sensitivity or exposure indicators to reduce the overall vulnerability of residents linked to vulnerability Group 1 (socio-spatial vulnerability in urban areas). An example of the most prominent interventions are:

- Municipal strategies can play a crucial role in supporting residents. First, the city could introduce new regulations that enable renters, not just home-owners, to make heat-adaptive modifications to their homes. This should be accompanied by financial support, such as subsidies specifically available to (social) renters, given that rental housing is predominant in Group 1 areas. Another key intervention would be the creation of cool hubs: public spaces where residents can take refuge during extreme heat. These hubs are vital in areas where homes lack adequate insulation or cooling options, and where residents may not be able to afford air conditioning or fans. Lastly, municipalities could organize community-based workshops on heat adaptation. If offered in an accessible and engaging format, these events could not only raise awareness but also help strengthen social networks, which is crucial in neighborhoods with high social isolation

- Residents themselves also have agency in reducing their vulnerability. One accessible measure is using indoor sun-blocking solutions, such as curtains, foil, or DIY methods, to keep sunlight out. Since outdoor shading options are often too expensive or restricted in social housing, focusing on indoor measures is a practical alternative. Additionally, joining local WhatsApp groups or community platforms can be a simple yet powerful step toward building supportive networks. These connections make it easier to exchange tips, ask for help during heatwaves, and foster a sense of solidarity, particularly important in areas where many people live alone or lack strong social ties.

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| Women | - | - | - | - | - |
| First and second degree non-EU migrants | Provide information in different languages | 58 | Inform | - | - |
| | Organize heat consultation hours | 59 | Involve | | |
| | Make use of religious institutes to reach communities | 65 | Collaborate | | |
| Adults with health issues | Organize social activities | 66 | Involve | Join WhatsApp groups | 61 |
| | Have volunteers who do social check-ins | 62 | Involve | Be careful with medication | 15 |
| | Expand subsidies | 33, 35 | Inform | Stay hydrated | 9 |
| | Organize sport events during cooler times | 66 | Involve | Cool (and dry) your body | 10, 14 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| Socio-economic low households | Expand subsidies | 33, 35 | Inform | Get creative: cooling does not have to be expensive | 19, 28 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| | Organize workshops and information sessions for affordable adaptations | 63 | Involve | | |
| | Create a public cool hub | 51 | Collaborate | | |
| Unemployed adults | Create new jobs, e.g., watering public green spaces | - | Empower | Sign up as a volunteer | 62 |
| Single-parent households | Organize activities for children away from their homes | 56 | Involve | - | - |
| One-person households | Organize social activities | 63, 66 | Involve | Join WhatsApp groups | 61 |
| | Have volunteers who do social check-ins | 62 | Involve | | |
| Low social adaptive capacity | Organize social activities | 63, 66 | Involve | Join WhatsApp groups | 61 |
| | Create a public cool hub | 51 | Collaborate | | |
| | Have volunteers who do social check-ins | 62 | Involve | | |
| Corporation-rent properties | Create regulations for housing corporations (e.g. sun shading) | 20, 33 | Inform | Have a residents' committee that fights for solutions | - |
| | | | | Use removable cooling alternatives | 28 |
| Multi-family dwelling | Create regulations that enable adaptation (e.g. sun shading) | 20, 33 | Inform | Add plants and shading to your balcony | 36, 37 |
| | Expand subsidies | 33, 35 | Inform | Cross-ventilate | 17, 25 |
| | Inform residents what to do with their balcony | 51, 63 | Inform | Add shading to your windows | 22, 24, 28 |
| | Create alternative outdoor spaces if no balcony | 52, 53 | Collaborate | | |
| High urban heat | Add greenery and trees | 28, 40 | Collaborate | Add plants to your balcony | 37 |
| | | | | Adopt a tree | 41 |
| | | | | Replace garden tiles with grass | 38 |

### The Five Categories of Interventions

To improve the clarity and usability of the toolkit, the interventions have been grouped into five categories. These categories help users quickly navigate the toolkit and select interventions that suit their context, needs, and capabilities. The categories reflect both spatial scales and social practices. Below the explanation of the categories, tab. 5.1.1 shows a few examples of the intervention table. The whole table is enclosed in Appendix A.9.

**1) It starts with your behavior -** This category includes low-threshold, everyday behavioral measures that individuals can implement without needing external support or significant resources. Examples include avoiding house chores during peak hours or staying hydrated. These actions may seem small, but they can have substantial health and well-being impacts.

**2) Keep your house cool -** These measures focus on reducing indoor temperatures through relatively simple or structural interventions at the household level. Examples include installing outdoor or indoor shading, or keeping windows closed during the day. Importantly, this category also includes governance tools that enable adaptation. For example, expanding municipal subsidies for renters.

**3) Balcony and garden -** Many existing tools address how gardens can be transformed to reduce the UHI locally. These tools ignore the fact that many people, especially in dense urban areas, do not have their own garden. Therefore, this category also includes interventions for balconies, including shade structures or placing potted plants.

**4) An adaptive street -** This category addresses public spaces at the street level. Interventions here include the planting of street trees, the installation of shading structures, or the redesign of paved surfaces. Municipalities or housing associations typically initiate these measures, but citizen input and co-creation are crucial for ensuring appropriate and equitable implementation.

**5) A cool neighborhood -** On a neighborhood scale, this category involves community-wide or institutional interventions. These include opening public buildings as cool hubs, improving park accessibility, organizing heat awareness activities, and promoting neighborhood awareness campaigns. These interventions require cross-sector collaboration and are especially relevant for municipalities, public health agencies, and community organizations.

| # | Title | Description | Scale | Domain | Cooling effect | Costs | Responsibility | Additional stakeholder | Target group | Prevention/response |
|---|---|---|---|---|---|---|---|---|---|---|
| **IT STARTS WITH YOUR BEHAVIOUR** | | | | | | | | | | |
| 6 | **Cook outside or eat salad** | Cooking adds heat and moisture. Cook briefly, outside if possible, or eat a cold meal like salad. | behavior | social | 1 | 0 | resident | | all, adults, elderly, migration background, women | prevention |
| **KEEP YOUR HOUSE COOL** | | | | | | | | | | |
| 19 | **Upgrade your fan** | Place a frozen water bottle or ice cubes in front of a fan for an extra cooling effect. | house | physical | 2 | 2 | resident | | all, children, elderly, health issues, low SES | response |
| **BALCONY & GARDEN** | | | | | | | | | | |
| 36 | **Add shading to your balcony** | Create shade on your balcony using a parasol, sun tarp, or canvas to prevent heat from entering your home. | balcony, garden | physical | 2 | 2 | resident | house owner/ VVE, housing corporation | all, elderly, health issues | prevention |
| **AN ADAPTIVE STREET** | | | | | | | | | | |
| 43 | **From parking to park** | Convert parking spots into small green areas. | street | physical | 2 | 2 | municipa | urban planner | all | prevention |
| **A COOL NEIGHBORHOOD** | | | | | | | | | | |
| 49 | **Consider street orientation** | Design streets with shade elements on the sunny (usually north) side. | neighborhc | physical | 3 | 2 | municipa | urban planner | all | prevention |

### 5.1.2 Making Adaptation Tangible: Intervention Cards

To increase usability and recognition, each intervention can be represented as a visual card (see Fig. 5.1). These intervention cards simplify the complex information from the spreadsheet into a clear and visually appealing format that can be used in physical or digital settings. Each card contains an image, the intervention name, a brief description, and intuitive icons representing cost and cooling effect.

This format allows the toolkit to be used in various contexts, such as community workshops or neighborhood planning meetings. It also facilitates hands-on engagement: cards can be sorted, grouped, or prioritized collaboratively during participatory sessions. For example, municipalities could use the cards to initiate dialogue with residents, co-design neighborhood strategies, or visualize trade-offs between different adaptation paths.

Additionally, the cards can help bridge communication gaps. Rather than presenting abstract policy measures, the cards make adaptation more personal and immediate. They invite reflection: What can I do in my own home? What should we ask from our housing corporation? What can our neighborhood accomplish together?

Below, four examples of the intervention cards are provided.

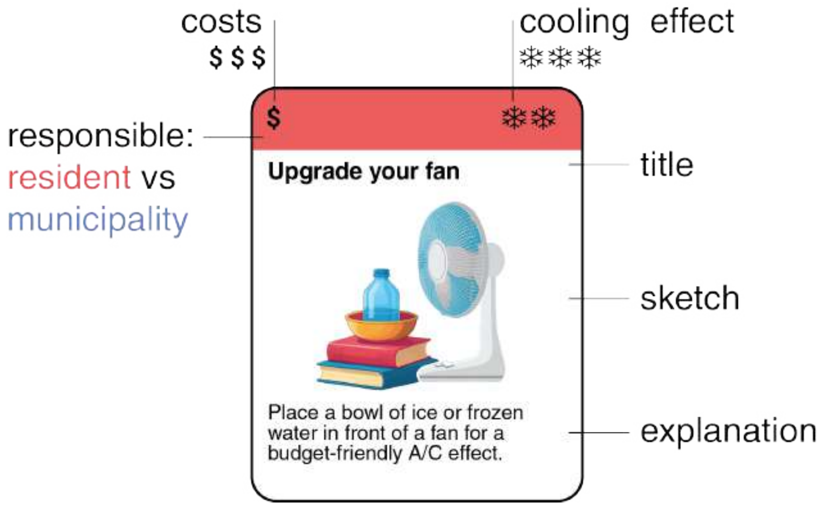



Figure 5.1: Pattern explanation

**Cool Down at the Library**


Library Transvaalkwartier has A/C and fun indoor activities—perfect for hot days.

The role of libraries is becoming increasingly important (Klinenberg, 2018). During a street interview, a librarian explained that libraries in The Hague often function as the "living rooms" of the neighborhood. A notable advantage is that libraries tend to be cooler due to air conditioning. By offering a variety of activities, libraries attract more residents to these spaces. For instance, the Transvaalkwartier Library currently hosts Dutch language classes, digital support sessions, and bureaucratic consultation hours.

**Hydrate at the Mosque**

Mosque El Islam hands out water bottles during hot weather.

The Schildersbuurt area has a high concentration of Turkish and Moroccan residents (see sec. 3.4). This demographic composition is also reflected in the large number of mosques in the area. Observations showed that many residents attend the mosque for Dhuhr (noon) and Asr (late afternoon) prayers—times. At these moments, outdoor temperatures are at their peak. Providing free water bottles at these locations helps residents stay hydrated after prayer. During a conversation, Mosque El Islam mentioned in a small interview that they already offer this service.

$ $

**Plant trees**

Plant trees in the streets to block sun and reduce heat.

Trees offer a wide range of benefits in urban environments: they provide shade, lower temperatures, and contribute to cooling through evaporation. In Schildersbuurt, the wide sidewalks provide plenty space to remove paving stones and plant new trees. Given the current lack of greenery in many streets, this presents a clear opportunity to improve thermal comfort and enhance the streetscape.

$

**Adopt a Tree**

Turn a tree bed into a mini garden—it keeps streets cooler and greener.

While tree planting is typically the responsibility of the municipality (indicated by the blue card in the toolkit), residents can contribute by adopting a tree and transforming its base into a small urban garden with plants and flowers. Although this intervention doesn't directly lower temperatures, it promotes biodiversity, improves water infiltration, and when done collectively, it fosters social cohesion. Additionally, it discourages people from parking bikes against the trees, a common issue in the neighborhood.

#### Multi-approach: From Individuals to Institutions

The interventions provided can be categorized into preventive and response measures, as explained in section 2.2.4. Figure 5.2 shows how this categorization works, based on a selection of interventions. Additionally, the axis of ‘scale’ is added, indicating that both response and prevention can happen throughout the scales. There appears to be a slight tendency for the interventions at a higher scale to focus more on prevention. By the blue color of the interventions, it can be concluded that municipal efforts target big-scale prevention strategies. Behavior changes, on the other hand, are mainly about responding to heat.

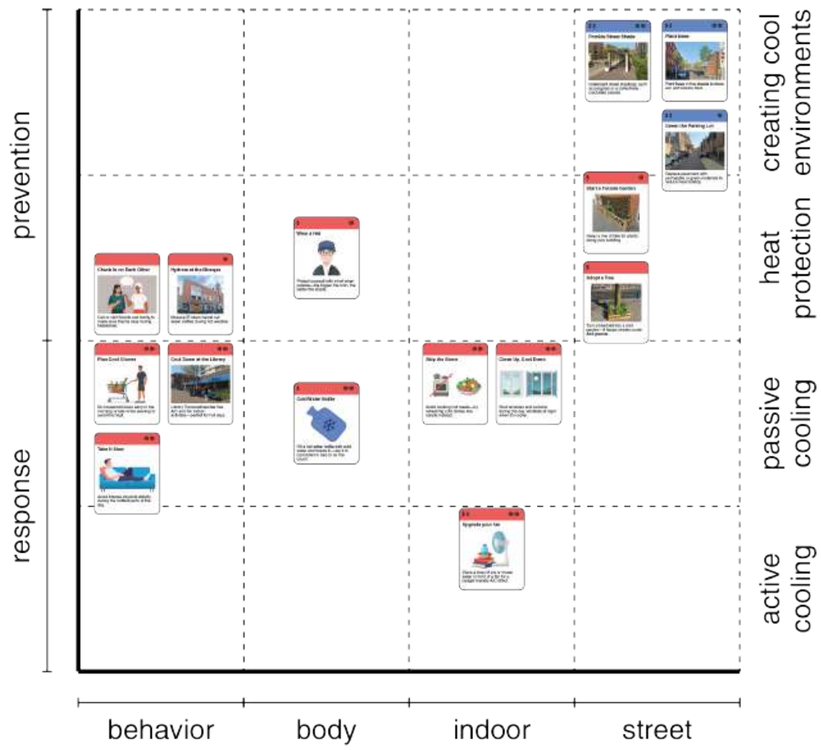



Figure 5.2: Patternfield: response/ prevention vs scale

### 5.1.3 From Table to Tool: Website Prototype

The toolkit’s next step is digital transformation. A prototype interface (see Fig. 5.3) demonstrates how the toolkit could be used online. Structured like a familiar webshop, users can easily filter interventions by category: Application scale and domain, the cooling effect, expected costs, stakeholders involved, potential target groups, and whether it focuses on prevention or response. This increases accessibility and helps users quickly find measures that suit their needs.

In addition to interventions, the website can include downloadable resources such as infographics or postcards. Furthermore, residents can find an interactive map with local resources that can help during heat waves. This includes mapping where cold indoor spaces are, public spaces with greenery and shade, public water tap points, and public sunscreen dispensers. Figure 5.3 shows a user journey of the website.

Importantly, this online tool can be accessed not only from home, but also in community hubs like libraries. With the support of librarians or volunteers, even digitally inexperienced residents can navigate the toolkit and print out relevant interventions for their household or neighborhood.

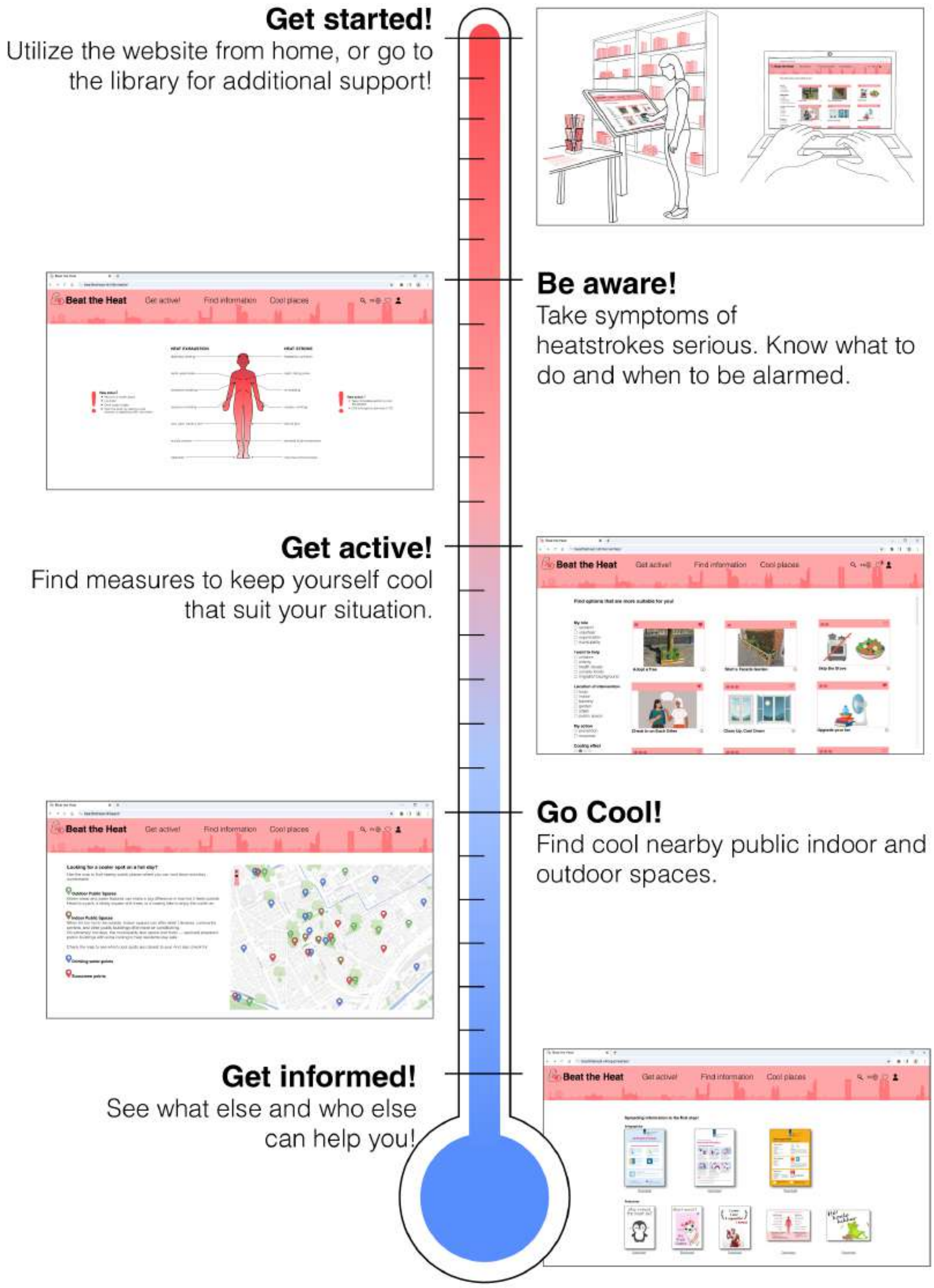



Figure 5.3: User Journey of the website

## 5.2 A Day in the Life: Personalising the Problem

To demonstrate how the toolkit can be implemented in a resident's everyday life, a small 'day in the life' story was created.

### 5.2.1 Meet Meryem

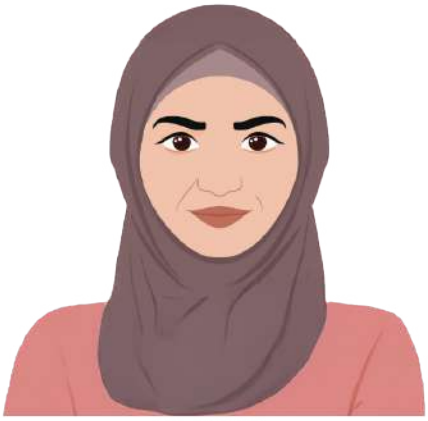
Meryem is in her early 50s and has lived in the Netherlands since the early 1990s. Originally from Morocco, she built a meaningful life in The Hague, raising a family and becoming deeply rooted in the Schildersbuurt community. Over the past three decades, she has become a well-known and respected figure in her neighborhood. As a member of the local community association, she is a trusted voice among residents and an active advocate for better living conditions.

Meryem lives on Netscherstraat with her husband in a small social housing apartment managed by the local housing corporation. It's a modest three-story walk-up, with six households sharing the entrance. Like most buildings in the area, it's a post-war multifamily block with little insulation and no outdoor sun protection. There's no balcony, and the narrow windows don't allow much airflow. With the rising number of heat waves, indoor temperatures often become unbearable, reaching over 30 degrees in the summer. Many neighbors, including Meryem, have used energy-intensive air conditioning to get through the hottest days.

The layout of the Netscherstraat also does not allow for lower temperatures either: the one-way street has parking on both sides and wide sidewalks. The handful of small trees offer minimal shade and cooling, and the extensive gray paving retains heat well into the evening.

But Meryem is not one to sit back and wait. She wants to help improve her street, not just for herself, but also for her neighbors. She recently heard about the 'Beat the Heat' toolkit and felt inspired. It gave her ideas on what she could do to make her apartment cooler and how to take small steps together with others in the community.

She's now thinking about how to green her street, share tips with neighbors, and talk to the housing corporation about better heat solutions. For Meryem, adapting to the heat is not just a personal challenge; she wants to tackle it with others.



**MERYEM**

45-55 years

living in the Hague since the 90's

**SCHILDERSBUURT-WEST**

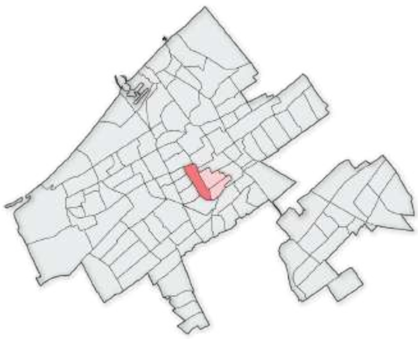
district type: renovated

85.71% gray surface

**EXPOSURE**

access to green spaces

indoor comfort



**SENSITIVITY**

economic capital

health

**ADAPTIVE CAPACITY**

social capital

access to public facilities

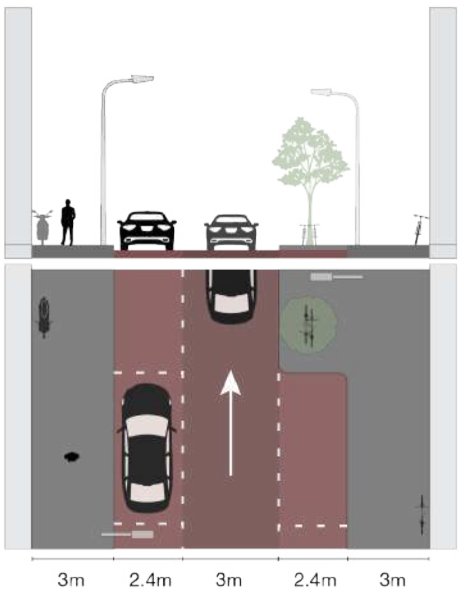



Figure 5.4: This is Meryem

## 5.2.2 Small Changes, Big Impact

Based on the interventions she found in the toolkit, Meryem has made several small but effective changes to her daily routine to better cope with extreme heat. Each morning, she opens all her windows widely to let in the cooler outside air. Because she doesn't feel safe leaving them open overnight, this early routine has become essential.

To avoid going out in the heat, she now does her groceries in the morning, when the temperature is still manageable. Her daughter, who lives nearby, checks in regularly, sometimes with a call, sometimes by stopping by, giving Meryem a sense of support on hotter days. As the afternoon heat sets in, she heads to the local library, where she knows the air conditioning offers a reliable escape. She participates in a Dutch language class there and often stays afterward to drink tea and chat with others.

In the late afternoon, she walks to the mosque to pray, taking a bottle of water provided by the mosque to stay hydrated. The building itself also offers a relatively cool indoor environment. Back at home, she avoids using the stove by preparing a light salad, which not only prevents extra heat indoors but also feels easier to eat in hot weather.

After dinner, she rests and cools herself with a frozen water bottle placed in front of a fan, a low-cost trick she found helpful. Finally, before going to bed, she uses a cold pack from the freezer to lower her body temperature and fall asleep more easily. These simple adaptations, tailored to her lifestyle and environment, help her stay comfortable and safe during periods of extreme heat.

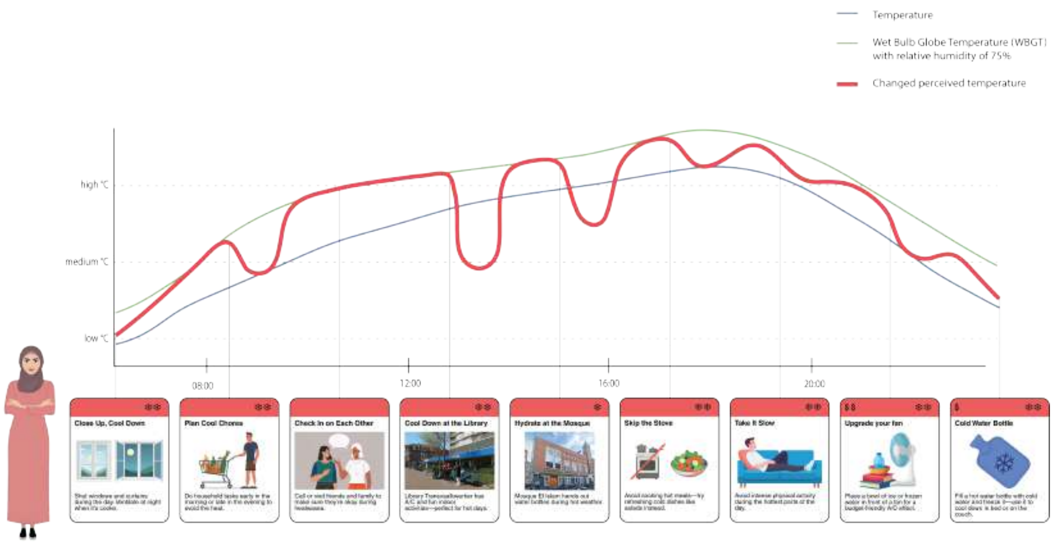



Figure 5.5: timeline of implementation of the interventions. After applying measures to the daily routine, the red line indicates the new perceived temperature.

### 5.2.3 A Cooler Street, a Warmer Heart

The measures Meryem uses are not limited to actions inside her home or changes in her daily routine. The tool showed Meryem what spatial changes are possible within her street. With a group of other concerned neighbors, Meryem advocated for change to reduce the temperatures in their street: The municipality has planted new trees and replaced some paved parking areas with permeable pavement. They also installed a pergola with climbing plants to provide shaded walkways for pedestrians.

Inspired by these changes, some neighbors gathered to maintain small green patches around the base of the new trees and add plants along the building facades. These collective efforts not only help to cool the street but also make the area more pleasant and lively. A side-effect is the new sense of connection among neighbors: working together has helped people get to know each other better. Now, during heatwaves, Meryem and her neighbors know who might need extra care, strengthening both environmental resilience and social cohesion in the neighborhood.


Figure 5.6: Spatial visualization of implementation of the interventions in the Netscherstraat, Schildersbuurt

# 6 Discussion and Conclusion

## 6.1 Discussion

This study explored how a multidimensional approach to climate vulnerability, focusing specifically on urban heat, can improve tailored adaptation strategies. The research was motivated by the observation that the warmest neighborhoods in cities often overlap with areas experiencing high concentrations of poverty (Endreny, 2024; Guardaro et al., 2022; Rocha et al., 2024). Despite this, current interventions mainly emphasize physical solutions, such as green-blue infrastructure (Sticthing CAS, n.d.), with limited attention to the integration of social and spatial dimensions or the inclusion of diverse actors across different scales. As a result, heat adaptation strategies often overlook the complex and unequal ways in which people and places experience vulnerability.

This pattern is visible in the literature. While there is growing recognition that (heat) vulnerability is not merely based on exposure but also on sensitivity and adaptive capacity (Eklund et al., 2023; IPCC, 2022c), only a few studies combine both social and spatial variables (e.g., Ahmed et al., 2023; Guardaro et al., 2022; Mashhoodi, 2021).

leading to a lack of a fully holistic application of these elements, particularly within the context of urban heat (Ahmed et al., 2023). Studies that do combine the three components often address climate hazards broadly, with heatwaves treated as just one example among others (e.g., Flanagan et al., 2011; Gamble et al., 2016; Yu et al., 2021). This somewhat generic approach risks ignoring hazard-specific dynamics of vulnerability.

This thesis addresses that gap by using a multidimensional framework, integrating the vulnerability concepts along social, spatial, and political domains, and scales from the individual to the neighborhood. A mixed-methods approach allowed for both pattern identification and contextualization: the principal component analysis (PCA) revealed patterns and typologies of local vulnerabilities, while the interviews and observations provided contextual information. Based on the existing instrument analysis and the stakeholder analysis, gaps in current strategies could be defined. These insights contributed to the design of a more tailored heat adaptation toolkit.

#### Factors contributing to exposure and sensitivity to heat

The first sub-research question, “Which factors contribute to individuals’ exposure and sensitivity to urban heat?”, was explored through a critical analysis of literature by using the IPCC (2022b) vulnerability framework. The literature review revealed that distinguishing different hazards is crucial when analyzing climate vulnerabilities: while some factors, such as poor housing quality or low income, are broadly relevant across climate hazards, others are more specific to heat. For example, age, chronic health conditions, and social isolation particularly increase sensitivity in extreme temperatures.

Studies focusing on heat often emphasize exposure via urban form and materials (e.g., Kleerekoper et al., 2012), but pay less attention to how these spatial features intersect with structural inequalities such as income disparity, migration background, or access to healthcare (Mashhoodi, 2021; Rocha et al., 2024). This research contributes by explicitly showing how social and spatial characteristics interact to shape differentiated vulnerability profiles. Therefore, sensitivity was conceptualized as a combination of fixed traits (for example, gender, migration background) and dynamic traits (for example, income, health), while exposure was defined by physical and environmental conditions that contribute to the UHI effect (e.g., building quality, green cover, and urban density).

### Socio-spatial typologies and patterns of heat vulnerability in The Hague

The second sub-research question, "What patterns emerge when analyzing heat vulnerability in The Hague?", was addressed through a Principal Component Analysis (PCA) conducted at the neighborhood level (Dutch: buurten). The PCA was based on social and physical indicators identified in response to the first sub-research question. The analysis revealed four distinct neighborhood types, which can be grouped into two broader categories of heat vulnerability.

The first category (Group 1 and Group 2) consists of neighborhoods with high concentrations of residents with non-European migration backgrounds, limited resilience, poor health conditions, and substandard social housing. These neighborhoods, primarily located in the central and southwestern parts of The Hague, correspond to socio-spatially vulnerable urban areas (Group 1) and socially vulnerable suburban family neighborhoods (Group 2). This spatial distribution aligns with historically labeled 'problem neighborhoods', many of which were developed during the post–World War II reconstruction period. In these peat-land areas, affordable social housing attracted low-income migrant workers.

The second category (Group 3 and Group 4) includes socially vulnerable populations such as low-income residents, women, single parents, and the unemployed. These groups are represented in socially fragile neighborhoods and include social vulnerabilities among single mothers in mixed urban contexts (Group 3), and socioeconomically fragile families in green, low-density areas (Group 4). Unlike the first category, these neighborhoods are more spatially dispersed across the city.

The PCA results underscore the increased vulnerability of women to heatwaves, a finding well-supported in the literature (Ahmed et al., 2023; IPCC, 2022b; Tapia et al., 2017; Yu et al., 2021). However, the vulnerability of single-parent households, particularly single mothers, has received far less literary attention (cf. Flanagan et al., 2011). This study highlights the need for greater focus on this group, as the PCA results indicate their heightened sensitivity to heat stress. The typology of heat-vulnerable neighborhoods shows that a one-size-fits-all approach to climate adaptation is unlikely to be effective. Moreover, the spatial patterns identified—spanning neighborhoods in the northwest, east, and southeast of The Hague—highlight the need to expand beyond the traditional 'problem neighborhoods'. Focusing adaptation strategies solely on these historically defined areas risks neglecting highly vulnerable neighborhoods that are not officially labeled as problematic, such as Leyenburg or Laakkwartier-Oost. Research of van Oorschot et al. (2021) also showed that the focus area for green infrastructural changes should not be limited to the 'problem neighborhoods', but should spatially be spread in patterns similarly to the weighted vulnerability distribution, as shown in Fig. 4.15.

The expansion of the area of concern may be related to the broader perspective of what contributes to the problem. Conventional 'problem neighborhoods' are typically identified based on indicators such as low income, limited education, unemployment, and sometimes migration background. However, this research demonstrates that these indicators alone do not capture the full complexity of climate-related vulnerability. A more nuanced, multidimensional perspective is essential for developing targeted and equitable adaptation strategies.

Based on the PCA results, Schildersbuurt-West was identified as the most heat-vulnerable neighborhood in The Hague based on both sensitivity and exposure. The neighborhood combines high social sensitivity (e.g., poverty, health issues, migration status) with significant physical exposure (e.g., limited greenery, poor housing conditions).

Fieldwork confirmed a high proportion of grey surface area, dominated by wide sidewalks and open street corners. Due to the limited presence of both green and grey shading, indoor temperatures in the surrounding dwellings are expected to rise significantly during heatwaves. Although a few trees are present, they are mainly positioned on the south side of the streets, which is less effective for shading building façades. Observations also revealed that only one dwelling had outdoor sun protection. This likely reflects the high concentration of social housing in the area and the limited investment by housing corporations in shading measures.

**Gaps in current strategies and potential for improvement**

The third sub-question, "How can existing heat adaptation strategies be improved?", was addressed by analyzing existing climate adaptation tools and policy documents using the multidimensional framework.

Most current strategies remain one-dimensional, focusing primarily on reducing exposure through physical interventions, such as implementing green-blue infrastructures. Behavioral adaptation is barely addressed, typically limited to five general heat-health tips shared by public health care agencies (Gemeente Den Haag, 2021): 1) drink enough, 2) cool your body, 3) cool your house, 4) take care of each other, and 5) be alert with your medications. Street interviews revealed that residents already take actions like changing clothing and adjusting diets, but are often unaware of other effective options. A better and accessible communication of these possibilities is therefore essential.

Moreover, the divide between municipal strategies and resident-level adaptation limits the potential for comprehensive and inclusive responses. The lack of integrated planning among stakeholders, particularly during heat waves, hinders the city's ability to support vulnerable groups effectively. A key takeaway is the need to integrate physical interventions with social and behavioral strategies, while recognizing the diversity of vulnerabilities and capacities. This recognition, together with a multidimensional integration of social inequalities, spatial opportunities, and political regulations, will enable targeted and equitable actions that will enhance climate justice (cf. Mashhoodi, 2021; Rocha et al., 2024).

### 6.1.1 General recommendations

**Recommendation 1: Empower citizens and bottom-up projects.**

Based on the stakeholder analysis (sec. 4.3.4) that showed the importance of bottom-up support, it is recommended that governments empower these support systems. This can be done in multiple ways, such as giving credit and awareness, broadening their possibilities by (temporarily) easing regulations, or giving initiatives money so they expand their help range.

**Recommendation 2: Acknowledge diversity**

The PCA showed how different vulnerabilities can be. Providing only a single or limited number of strategies to help residents can increase current inequalities. By acknowledging the diversity of residents, the targeted measures can empower those who need it to adapt to the increasing temperatures in a way that is most suitable and effective for them. This is possible for existing policies that are not yet inclusive, as well as creating new ones specifically targeted at this diversity in vulnerability.

Part of acknowledging diversity and creating targeted measures is communication: Communicating support should happen in different languages, both spoken languages and formalities, and through various media typologies (Gonçalves et al., 2024). This plays an important role, especially in areas where the migration backgrounds are high and diverse, such as in the Schildersbuurt-West. However, currently, this is not happening enough. For example, when visiting the Transvaalkwartier Library, the information pamphlets were provided in Dutch.

**Recommendation 3: Data Availability**

It is recommended that the municipality and the government collect more data relevant to climate hazards. For example, in the context of urban heat, it is also interesting to see how many households have access to private outdoor spaces, such as balconies. This can help with further research and help policymakers adapt the (recommended) policies.

Furthermore, it would help future research by making more data available on a smaller scale. Additionally, it is beneficial if similar data is provided in the same structure (percentages or numbers) so that missing data on one scale can be transferred to a different scale. For example, the amount of corporation-rented properties per area, on the 100x100m scale, was available in numbers, but it had a high percentage of missing values. For those areas, the goal was to fill the gaps with information on the Buurt level. However, this was impossible since the data typology on the Buurt scale was a percentage. Ultimately, this led the quantitative analysis to be on a higher level than preferred.

### 6.1.2 Research limitations

Several limitations have influenced the scope and outcomes of this research. First, the analysis was constrained by data availability. Certain variables that were initially considered valuable, such as specific, localized information on the urban heat island (UHI) effect, had to be excluded due to incompatible spatial scales, missing values, or lack of public access. Additionally, using third-party datasets meant that the existing data classifications shaped the research. This was particularly defining in the case of gender. The available data only recognized two categories, male and female. As a result, the analysis could not capture the full spectrum of gendered experiences related to heat vulnerability.

Secondly, the toolkit is grounded in a single case study, which raises questions regarding its generalization to other contexts. While it may be applicable in similarly temperate urban environments where adaptation to heat is still limited, its relevance reduces in warmer regions, such as Southern Europe, where both the population and infrastructure are already more used to higher temperatures.

Furthermore, the timing of the fieldwork, which took place in spring, might have affected the quality of responses. When conducting the fieldwork, it was the first time of the year that temperatures rose above 20 degrees Celsius. The pleasant weather may have reduced the perceived urgency of the topic, making it more difficult for participants to recall their experiences or coping mechanisms during previous heat waves.

Lastly, since the focus was primarily on the quantitative analysis, limited time was left for in-depth qualitative contextualization of the results. It is suggested that fieldwork in future research would help validate both the research and the design results by conducting more interviews and testing the interface of the toolkit.

### 6.1.3 Future Research Opportunities

To build on the findings of this research, there are several recommendations for future investigation. Firstly, it would be valuable to replicate the Principal Component Analysis (PCA) conducted in The Hague at a more granular level, such as the Postcode 6 scale. This more detailed resolution could provide more nuanced insights into the spatial distribution of heat-related vulnerabilities. It would reduce the limitations caused by administrative boundaries such as buurten or wijken.

Expanding the scope to a national level would further enhance the relevance of the analysis, particularly by revealing potential differences in vulnerability patterns between urban and rural contexts. For example, while access to green space is generally less problematic in rural areas, these regions may face different challenges, such as a higher proportion of elderly residents.

Additionally, applying the developed multidimensional framework and PCA methodology in other cities would help assess the generalizability and robustness of the identified vulnerability typologies. Such comparative studies could uncover regional differences in climate vulnerability and support the development of more tailored, context-sensitive adaptation strategies.

Moreover, future research should aim to integrate data on indoor temperatures, which are often overlooked despite their significance. While studies such as van der Hoeven and Wandl (2018) have addressed this in their focus on UHI, it is rarely combined with heat inequalities. Rocha et al. (2024) also emphasize indoor temperature as a factor in understanding environmental injustice, particularly given its close links to socioeconomic status, including income, employment conditions, and migration background.

## 6.2 Conclusion

This thesis demonstrated that urban heat vulnerability in The Hague is both multidimensional and multiscalar. By combining spatial and social data, PCA analysis, and fieldwork, it provided a more nuanced understanding of who is vulnerable, where these vulnerabilities are located, and how they can be addressed. The insights presented here underscore the importance of adaptive strategies that are not only effective but also targeted, equitable, and inclusive. The core focus of this research was "How can a multidimensional approach to urban heat improve tailored adaptation strategies?".

To answer this, the research employed a multidimensional framework that integrates the three main concepts of vulnerability (sensitivity, exposure, and adaptive capacity), across different scales (individual/ household, street, and neighborhood), and domains (social, spatial, and political). This approach is essential for capturing the complexity and inequality underlying heat vulnerability in cities like The Hague, which have highly diverse urban areas and population groups. The key findings of this research indicate that:

**The most socio-spatial vulnerable neighborhoods are also the warmest -** The quantitative analysis reveals strong correlations between sensitivity indicators such as income, gender, and health status, and exposure-related variables like housing quality and access to green space. Combined with the PCA results, these linkages conclude that neighborhoods with the highest vulnerability clusters also experience the highest temperatures. This phenomenon is not unique to The Hague; similar correlations between vulnerability and intensified urban heat island (UHI) effects have been documented in other contexts as well (e.g. Endreny, 2024; Guardaro et al., 2022; IPCC, 2022d; Rocha et al., 2024).

**Vulnerability extends beyond traditional 'problem neighborhoods' -** The PCA results identified patterns of heat vulnerability that extend beyond the boundaries of traditionally recognized 'problem neighborhoods'. This broader distribution is a result of incorporating a wider range of variables into the analysis. Consequently, when formulating adaptation strategies, municipalities should avoid relying solely on outdated categorizations and instead carry out topic-specific analyses to identify which neighborhoods truly require focused intervention.

**Current adaptation strategies remain one-dimensional -** Most existing heat adaptation efforts prioritize green-blue infrastructure interventions led by municipalities, given their well-documented effectiveness in mitigating urban heat. However, this approach often overlooks the uneven distribution of such infrastructure and fails to address residents' specific needs and capacities. More attention should be given to supporting local, community-based adaptation measures that empower residents to respond to increasing temperatures with the available resources.

The complexity of (heat) vulnerability, as indicated by the key findings, requires a multidimensional approach to lead to a comprehensive and tailored heat adaptation strategy. This requires an integration on three levels:

1. Integration of spatial and social, qualitative and quantitative, insights, to understand vulnerability holistically;
2. Integration across scales, from household to city-level design;
3. Integration of stakeholders, enabling cooperation between residents, civil society, and municipal actors.

This research highlights that climate justice in urban heat adaptation is not just about planting more trees, but equity, capacity, and inclusion. While further research and long-term monitoring are needed, the presented approach offers a promising step towards more resilient urban futures, focusing on **More than Just Vulnerability**.

## 6.3 Reflection

### 6.3.1 Ethical Considerations

**Challenges in defining vulnerability -** Creating a comprehensive definition of vulnerability is challenging since vulnerability is also a personal experience that cannot be fully generalised. Recognising that different people may experience vulnerability in unique ways is important, and an overly broad definition may fail to capture these nuances. This research must remain flexible and acknowledge the limitations of any one-size-fits-all approach to defining vulnerability.

**Avoiding stereotypes -** A key ethical concern is ensuring the research does not reinforce or create new negative stereotypes about vulnerable populations. The research must remain objective and avoid framing vulnerability in a way that stigmatises groups based on existing socio-economic or environmental conditions.

**Potential sensitivity towards vulnerability labels -** Expanding the definition of vulnerability to include new groups, such as wealthier individuals exposed to climate risks, may lead to discomfort. Since "being vulnerable" often carries negative connotations, some people might feel offended or resistant to being categorised as vulnerable. Open communication about the purpose and meaning of vulnerability in climate change will be essential.

**Limits to expanding vulnerability -** There is an ethical challenge in determining how far the concept of vulnerability can be expanded. Including too many types of vulnerabilities may dilute the focus of the research, making it harder to prioritise the most pressing needs. A balance between broad inclusion and practical policy relevance must be established to ensure that the expanded definition remains meaningful and actionable.

**Statistically invisible neighborhoods -** Building quantitative research on existing data is limited by the scale of the available data. Generally, smaller data clusters are preferred, as data from a 'buurt' more accurately represents the residents than from a 'wijk'. The usage of 'wijk' data could lead to incorrect assumptions if one part of a 'buurt' is very wealthy while another part experiences poverty; the more affluent area may overshadow the issues in the poorer area, making them statistically invisible when relying solely on quantitative data.

### 6.3.2 Research reflection

**What is the value of evidence-based urbanism?**
In my personal opinion, evidence-based urbanism is critical. The influence an urban designer can have on society is significant. As an urbanist, you develop

designs, visions, and perspectives for other people's environment, which makes it essential to truly understand who those people are.

During my bachelor's in architecture, I felt that this aspect was underappreciated. We were often expected to design something that, as long as it looked visually appealing and came with some justification, it was considered good. In that context, function followed form, and form was largely subjective.

However, conducting your own research to inform design makes the process more objective, meaningful, and attuned to actual users. A clear example of this in my thesis is the heat vulnerability map. The PCA revealed that more neighborhoods can be considered vulnerable than those currently labeled as Krachtwijken in The Hague. This insight could not have emerged without a data-driven approach.

**How is your personal development throughout this project reflected in this research?**

At the beginning of the year, I struggled to find a clear narrative. While heat vulnerability is already a focused topic, I wasn't yet familiar with it, and I had no idea where the literature review would take me. This uncertainty led me to create the vulnerability matrix, an overview of the variables mentioned in the literature. As the process developed, I became more confident in the topic and found room to challenge myself by learning new skills.

Looking back, I recognize a repeating pattern: in every graduation project — whether BSc Architecture, MSc Sociology, or now MSc Urbanism — I consciously push myself to grow by learning new methods and softwares. In this thesis, I taught myself to use R, perform a PCA, and apply Atlas.ti for literature analysis. To interpret the results meaningfully, I stepped out of my comfort zone and actively sought help from teachers and PhD candidates, which I found both helpful and inspiring.

In the end, this research truly reflects who I am, both as a person and a 'researcher': someone who values evidence-based thinking, embraces new tools and perspectives, and strives to empower those in vulnerable positions. The question "Who am I, as a student, to do or say this?" crossed my mind often. But the motivation and passion I developed for this topic helped me push through and commit to making a contribution, however small, to a more just and climate-adaptive urban future.

**What is the relation between your graduation project topic, your master track (A, U, BT, LA, MBE), and your master programme (MSc AUBS)?**

This graduation project is strongly rooted in the urbanism track through its place-based analytical approach, spatial analysis, and focus on local spatial adaptations. It adopts a research-based perspective emphasizing governance and stakeholder analysis in line with the Planning Complex Cities studio.

However, this thesis goes beyond conventional urbanism by emphasizing the social dimension of urban environments, an aspect currently underrepresented in the Urbanism track. Typically, urbanism projects aim to change the built environment to cause behavioral shifts. Yet, behavior is not easily altered through physical design alone. As with ants navigating around obstacles, people often adapt their paths rather than their behavior. Lasting change requires addressing underlying purposes and motivations. Thus, this thesis integrates both spatial and social interventions. The intervention cards, inspired by the idea of a pattern language, translate complex research findings into an understandable format that communicates to both policy and local actors, bridging the gap between analytical output and practical application.

**How did your research influence your design/recommendations, and how did the design/recommendations influence your research?**
The transition from research to design followed a relatively linear trajectory, as the findings directly informed the intervention toolkit. Nevertheless, developing the toolkit also prompted new questions that enriched the research process, making it iterative. For example, questions regarding existing adaptation tools led to an analysis of current instruments. Questions about the toolkit's target audience triggered a stakeholder analysis. Additionally, street observations and interviews created a basis for residents to identify themselves with the toolkit. In this way, the evolving concept of the toolkit shaped and expanded the research content throughout the process.

**How do you assess the value of your way of working (your approach, your used methods, used methodology)?**
The applied multidimensional framework served as a continuous guiding lens throughout the research process, ensuring that social, spatial, and political dimensions were considered at each stage. This structured approach, altered from existing literature, helped to critically assess whether all relevant aspects of vulnerability were being addressed.

The primary method used in this research was the Principal Component Analysis (PCA), an often-used method in vulnerability research, which allowed for classification and spatial identification of heat-vulnerable areas. At first, this was very challenging since it is not often applied within the field of urbanism. But by combining this quantitative technique with qualitative methods such as interviews and observations, the abstract results were contextualized with further local insights and real-life experiences.

**How do you assess your graduation project's academic and societal value, scope, and implications, including ethical aspects?**
Academically, the project contributes to an underexplored area: the integration of multidimensionality in the analysis of climate vulnerability. The developed framework offers a foundation for future research, encouraging more holistic vulnerability assessments. Societal, the project acknowledges urban residents' diverse needs and capacities, challenging the one-size-fits-all nature of many current

adaptation strategies. The project promotes equity and empowerment by advocating for tailored, inclusive responses. For a detailed scientific and societal relevance description, see Sec. 1.3.

Since vulnerability is a sensitive topic, many ethical considerations crossed my mind during the research. See Sec. 6.3.1 for a summary of the most significant ones. While analyzing the in-depth diversity of residents, it was crucial not to see the vulnerable groups as subjects of analysis but as active actors who can work on their own resilience. Therefore, principles of justice and capacity building became key.

**How do you assess the value of the transferability of your project results?**
While the core multidimensional framework and the variables mentioned in the data dictionary are transferable, the used data sources and local indicators limit direct replication in other contexts. Variables may need to be adjusted to locally available data and relevant proxies. Furthermore, in other contexts, there might be additional variables that are crucial for analyzing heat vulnerability.

The interpretation of the quantitative results might also vary in different urban and political contexts. A simple example is the usage of the wide sidewalks: In some countries, these might be used for markets and meeting others, whereas the sidewalks in the Schildersbuurt mainly function as a transition zone, and therefore can more easily be adjusted.

Despite this, the idea of the toolkit is valuable as a conceptual and methodological starting point. It includes general and context-specific interventions, allowing other municipalities to adapt the toolkit by modifying local references (e.g., identifying similar institutions or public spaces). Therefore, although the vulnerability typologies are context-specific, the process and structure of the toolkit apply to diverse urban settings. Nonetheless, the empowerment of citizens is again context-specific, since in some less democratic countries, this might not be tolerated.

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# A Appendix

## A.1 Data Management Plan

**Master Thesis - More than Just Heat Vulnerability: A Multidimensional Approach to Urban Climate Resilience**

**0. Administrative questions**

**1. Name of data management support staff consulted during the preparation of this plan.**

The DMP has been shared with my thesis supervisor, Juliana Goncalves, via DMPonline and reviewed by her in March 2025.
My faculty data steward, Janine Strandberg, has reviewed this DMP on April first, 2025.
A privacy officer of the TU Delft was contacted on April 18th, 2025, for questions about the anonymity of street-interview participants but no problems were indicated.
The HREC was approved on May first, 2025.

**2. Date of consultation with support staff.**

2025-04-01

**I. Data description and collection or re-use of existing data**

**3. Provide a general description of the type of data you will be working with, including any re-used data:**

| Type of data | File format(s) | How will data be collected (for re-used data: source and terms of use)? | Purpose of processing | Storage location | Who will have access to the data |
|---|---|---|---|---|---|
| anonymised data from DenHaag Databank: health issues or disabilities, (energy-)poverty, energy labels, Urban Heat Island characteristics. This data is combined on the 'buurt'-scale. | .xlsx | Dataset from Den Haag Databank. Access to the open data is public. | Quantitative Analysis: To quantify the relation between the several variables and how they amplify a person's vulnerability | TU Delft OneDrive | Master student (Milou Mulder) + Supervisors (Juliana Goncalves and Marjolein van Esch) |
| anonymised data from CBS: age, gender, urban density, household constellation, social benefits, homeownership, migration background, building age, distances to healthcare facilities. This data is combined on the 'buurt'-scale. | .xlsx, .shp | Dataset from CBS (Kerncijfers wijkenen en buurten 2023 - second version). Access to the open data is public. | Quantitative Analysis: To quantify the relation between the several variables and how they amplify a person's vulnerability | TUDelft OneDrive | same as above |
| Personally identifiable information (PII): participants' name, email, company name, mobile number | .pdf .xlsx | Contact information for participants taking part in expert interviews received from a professional network. Informed consent forms are signed digitally or on paper (depending on whether the interview is online via Teams or on sight) and contain participants' name + email. Paper forms are scanned ASAP after the events, after which papers are destroyed. | For administrative purposes: obtaining informed consent and communicating with participants | TU Delft OneDrive | Same as above |

Created using DMPonline. Last modified 05 May 2025 3 of 9

**Plan Overview**

*A Data Management Plan created using DMPonline*

**Title:** Master Thesis - More than Just Heat Vulnerability: A Multidimensional Approach to Urban Climate Resilience

**Creator:**Milou Mulder

**Principal Investigator:** Milou Mulder

**Data Manager:** Milou Mulder

**Contributor:** Marjolein van Esch, Juliana Goncalves, Milou Mulder

**Affiliation:** Delft University of Technology

**Funder:** Delft University of Technology

**Template:** TU Delft Data Management Plan template (2021)

**Project abstract:**

With the increase of climate effects on society, climate injustice also increases. One of the causes is the incomprehensive definition of climate vulnerability. In literature, climate vulnerability is often defined by age, gender and socioeconomic status. However, the variables are often considered separately and the spatial dimension, such as building typology, access to infrastructure, heating typology, etc. is not included. By combining the social and spatial dimensions that contribute to climate vulnerability, this research aims to create a (more) holistic understanding of the complexity. In the end, it will answer the following research question: How can a multidimensional approach to climate vulnerability in
the context of The Hague improve tailored resilience strategies?

An extensive literature review is used to define important concepts and their variables. These variables will form the basis of the quantitative analysis Principle Component Analysis (PCA). The quantitative input will be collected from CBS and KlimaateffectAtlas. To contextualize this data, the following methods will be used:

- Policy Analysis: What are the current policies from the municipality in The Hague to address climate vulnerability?
- Mapping: Based on the Principle Component Analysis (PCA), how are the various vulnerabilities divided over the city?
- Observations: Do the quantitative results of the PCA align with the spatial context of the areas, or coes it give a distorted image?
- Expert interviews: How do experts working with vulnerable people, see the current situation and future solutions to reduce vulnerability?
- stakeholder analysis
- Street interviews: How do randomly selected people perceive and deal with heat and flooding?
- Media analysis
- Pattern Language: How can different adaptation strategies strengthen each other?

**ID:** 164551

**Start date:** 02-09-2024

**End date:** 16-06-2025

**Last modified:** 05-05-2025

| | | | | | |
|---|---|---|---|---|---|
| Audio recordings of interviews with experts | .mp3 | Interviews with experts are conducted. Audio recordings are made on an external device before being moved to OneDrive. Recordings are deleted after transcription. | Capturing expert views on the exposure, sensitivity and adaptive capacity of vulnerable citizens and neighbourhoods | External recording device (temporary storage) + TU Delft OneDrive (primary storage) | Same as above |
| Pseudonymized transcriptions of interviews | .xdoc, .pdf | Pseudonymized transcriptions are created manually based on audio recordings. Participants are asked to review the transcriptions of their interview before the transcript is finalized. | Privacy-preserving data from participants (experts) | TU Delft OneDrive | Same as above |
| Pseudonymized data on experiences during heat waves | .txt | Small and informal street interviews will be conducted by randomly selecting people on the streets They will be asked the following questions: What do you do during heat waves; Where do you go to? Do you change your behaviour during heat waves? Does it become very warm in your house during heatwaves? And if so, what do you do to decrease the indoor temperature? The only data that will be known from the participants is their gender, the neighbourhood where the conversation took place and age range. | To justify and contextualize the results of the previous quantitative analysis | TU Delft OneDrive | Same as above |
| Pseudonymized pictures of the neighbourhood | .png | During fieldwork, pictures of the neighbourhood will be taken. The focus is on the public space. However, it is possible that people are visible in the background. Any faces will be blurred. | contextualizing the results of the previous quantitative analysis | Project Storage at TU Delft | Same as above |
| Informed consent form | .pdf | Before the interviews, experts are presented with an informed consent forms and asked to sign it. | To obtain permission for interview and usage of results in the report. | TU Delft OneDrive | same as above |
| Oral consent | - | Residents spoken to during street interviews will be informed about the research, and they will be asked about their oral consent | To obtain permission for interview and usage of results in the report. | TU Delft OneDrive | same as above |
| Notes from observations | .xdoc | Notes will be written during observations in the neighbourhoods | Collecting local information about several neighbourhoods regarding heat, flooding, and general climate vulnerability | TU Delft OneDrive | same as above |

**4. How much data storage will you require during the project lifetime?**

- < 250 GB

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## II. Documentation and data quality

**5. What documentation will accompany data?**

- Data dictionary explaining the variables used
- Methodology of data collection

The thesis will contain a chapter where the used methods are explained in detail. This will include the amount of interviews and the format and questions of the expert interviews. Furthermore, a data dictionary explaining variable names, measurement units, allowed values and definitions of values in the dataset is added in the appendix.

## III. Storage and backup during research process

**6. Where will the data (and code, if applicable) be stored and backed-up during the project lifetime?**

- Another storage system - please explain below, including provided security measures
- OneDrive

External recording device: Used as a temporary storage location for recorded expert interviews. The recordings will be deleted from the device as soon as they are moved to the OneDrive.
Digitally signed consent forms will be stored in a separate folder from the research data.

## IV. Legal and ethical requirements, codes of conduct

**7. Does your research involve human subjects or 3rd party datasets collected from human participants?**

- Yes

Open source, 3rd party datasets, collected published by CBS and DenHaag Databank are used for quantitative analysis. These data were already anonymized prior publications by the corresponding databank.

**8A. Will you work with personal data? (information about an identified or identifiable natural person)**

***If you are not sure which option to select, first ask yourFaculty Data Steward for advice. You can also check with the privacy website . If you would like to contact the privacy team: privacy-tud@tudelft.nl, please bring your DMP.***

- Yes

Personal data used for expert interviews, such as name, email address, and audio recordings, are necessary but will be pseudonymized.
The open data from the third parties, CBS and DenHaag Databank, are already anonymized.

**8B. Will you work with any other types of confidential or classified data or code as listed below? (tick all that apply)**

***If you are not sure which option to select, ask yourFaculty Data Steward for advice.***

- No, I will not work with any confidential or classified data/code

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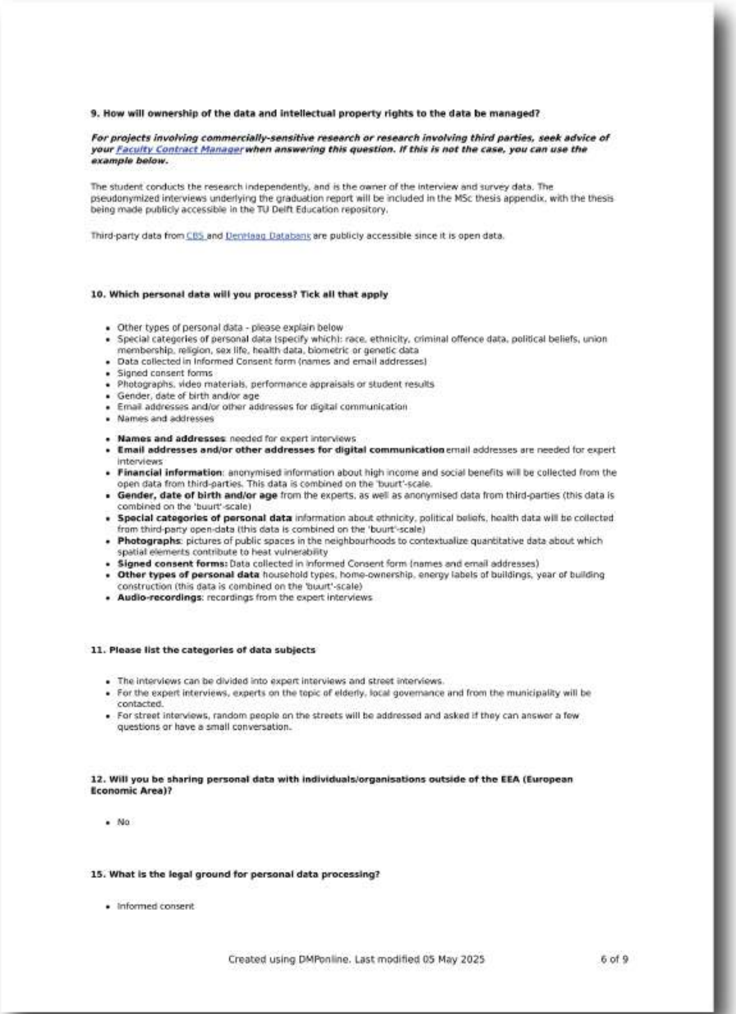

**9. How will ownership of the data and intellectual property rights to the data be managed?**

***For projects involving commercially-sensitive research or research involving third parties, seek advice of your Faculty Contract Manager when answering this question. If this is not the case, you can use the example below.***

The student conducts the research independently, and is the owner of the interview and survey data. The pseudonymized interviews underlying the graduation report will be included in the MSc thesis appendix, with the thesis being made publicly accessible in the TU Delft Education repository.

Third-party data from CBS and DenHaag Databank are publicly accessible since it is open data.

**10. Which personal data will you process? Tick all that apply**

- Other types of personal data - please explain below
- Special categories of personal data (specify which): race, ethnicity, criminal offence data, political beliefs, union membership, religion, sex life, health data, biometric or genetic data
- Data collected in Informed Consent form (names and email addresses)
- Signed consent forms
- Photographs, video materials, performance appraisals or student results
- Gender, date of birth and/or age
- Email addresses and/or other addresses for digital communication
- Names and addresses

- **Names and addresses**: needed for expert interviews
- **Email addresses and/or other addresses for digital communication** email addresses are needed for expert interviews
- **Financial information**: anonymised information about high income and social benefits will be collected from the open data from third-parties. This data is combined on the 'buurt'-scale.
- **Gender, date of birth and/or age** from the experts, as well as anonymised data from third-parties (this data is combined on the 'buurt'-scale)
- **Special categories of personal data** information about ethnicity, political beliefs, health data will be collected from third-party open-data (this data is combined on the 'buurt'-scale)
- **Photographs**: pictures of public spaces in the neighbourhoods to contextualize quantitative data about which spatial elements contribute to heat vulnerability
- **Signed consent forms:** Data collected in Informed Consent form (names and email addresses)
- **Other types of personal data** household types, home-ownership, energy labels of buildings, year of building construction (this data is combined on the 'buurt'-scale)
- **Audio-recordings**: recordings from the expert interviews

**11. Please list the categories of data subjects**

- The interviews can be divided into expert interviews and street interviews.
- For the expert interviews, experts on the topic of elderly, local governance and from the municipality will be contacted.
- For street interviews, random people on the streets will be addressed and asked if they can answer a few questions or have a small conversation.

**12. Will you be sharing personal data with individuals/organisations outside of the EEA (European Economic Area)?**

- No

**15. What is the legal ground for personal data processing?**

- Informed consent

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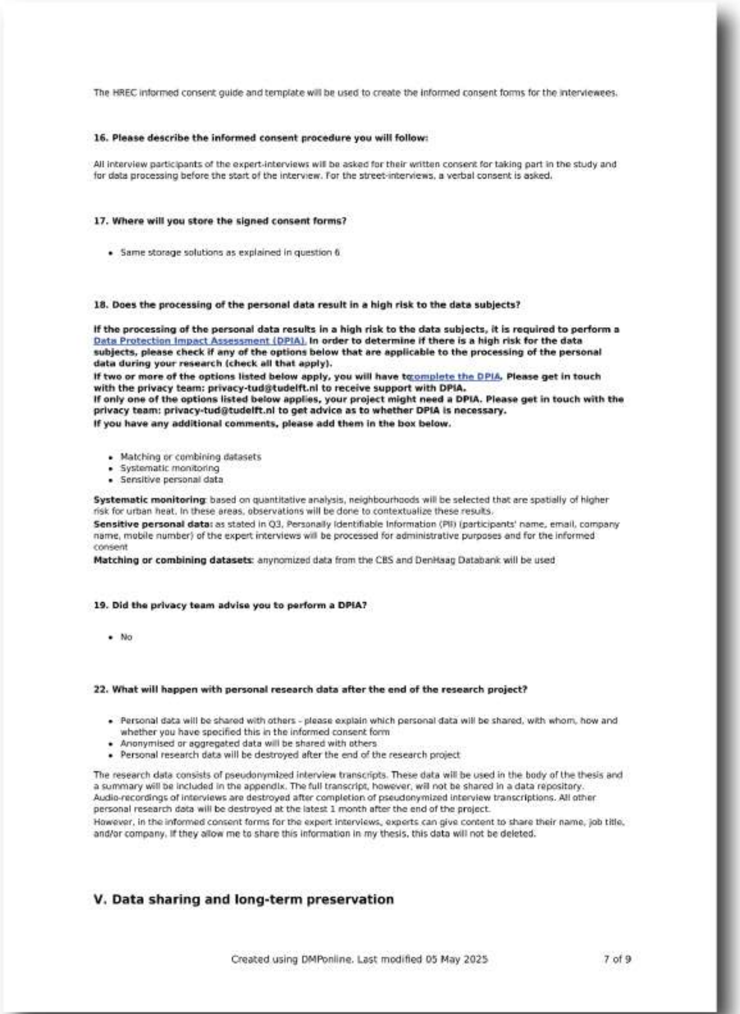

The HREC informed consent guide and template will be used to create the informed consent forms for the interviewees.

**16. Please describe the informed consent procedure you will follow:**

All interview participants of the expert-interviews will be asked for their written consent for taking part in the study and for data processing before the start of the interview. For the street-interviews, a verbal consent is asked.

**17. Where will you store the signed consent forms?**

- Same storage solutions as explained in question 6

**18. Does the processing of the personal data result in a high risk to the data subjects?**

**If the processing of the personal data results in a high risk to the data subjects, it is required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data during your research (check all that apply).**
**If two or more of the options listed below apply, you will have tocomplete the DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to receive support with DPIA.**
**If only one of the options listed below applies, your project might need a DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to get advice as to whether DPIA is necessary.**
**If you have any additional comments, please add them in the box below.**

- Matching or combining datasets
- Systematic monitoring
- Sensitive personal data

**Systematic monitoring**: based on quantitative analysis, neighbourhoods will be selected that are spatially of higher risk for urban heat. In these areas, observations will be done to contextualize these results.
**Sensitive personal data:** as stated in Q3, Personally Identifiable Information (PII) (participants' name, email, company name, mobile number) of the expert interviews will be processed for administrative purposes and for the informed consent
**Matching or combining datasets**: anynomized data from the CBS and DenHaag Databank will be used

**19. Did the privacy team advise you to perform a DPIA?**

- No

**22. What will happen with personal research data after the end of the research project?**

- Personal data will be shared with others - please explain which personal data will be shared, with whom, how and whether you have specified this in the informed consent form
- Anonymised or aggregated data will be shared with others
- Personal research data will be destroyed after the end of the research project

The research data consists of pseudonymized interview transcripts. These data will be used in the body of the thesis and a summary will be included in the appendix. The full transcript, however, will not be shared in a data repository. Audio-recordings of interviews are destroyed after completion of pseudonymized interview transcriptions. All other personal research data will be destroyed at the latest 1 month after the end of the project.
However, in the informed consent forms for the expert interviews, experts can give content to share their name, job title, and/or company. If they allow me to share this information in my thesis, this data will not be deleted.

**V. Data sharing and long-term preservation**

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**27. Apart from personal data mentioned in question 22, will any other data be publicly shared?**

- I do not work with any data other than personal data

**29. How will you share research data (and code), including the one mentioned in question 22?**

- My data will be shared in a different way - please explain below

Pseudonymized data collected during the project will be included in the body and appendix of the MSc thesis, made available in the TU Delft Educational repository.

**30. How much of your data will be shared in a research data repository?**

- < 100 GB

**31. When will the data (or code) be shared?**

- At the end of the research project

**32. Under what licence will be the data/code released?**

- Other - Please explain

Research data are only shared within the MSc thesis, which is automatically placed under copyright in the Education repository.

## VI. Data management responsibilities and resources

**33. Is TU Delft the lead institution for this project?**

- Yes, the only institution involved

**34. If you leave TU Delft (or are unavailable), who is going to be responsible for the data resulting from this project?**

Thesis supervisor, Juliana Goncalves of Section Spatial Planning and Strategy, department: j.e.goncalves@tudelft.nl

**35. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?**

Research data are only shared within the MSc thesis: no additional resources are required.



## Planned Research Outputs

### Instrument - "Climate Adaptation Toolkit"

This toolkit can help people to find suitable adaptation strategies

### Report - "Multidimensionality of Climate Vulnerability: A holistic approach to a more just adaptation transition"

Master Thesis

### Planned research output details

| Title | DOI | Type | Release date | Access level | Repository(ies) | File size | License | Metadata standard(s) | May contain sensitive data? | May contain PII? |
|---|---|---|---|---|---|---|---|---|---|---|
| Climate Adaptation Toolkit | | Instrument | Unspecified | Open | None specified | | None specified | None specified | No | No |
| Multidimensionality of Climate Vulnerability: A ho ... | | Report | Unspecified | Open | None specified | | None specified | None specified | Yes | No |

## A.2 HREC approval

Date 01-May-2025
Correspondence hrec@tudelft.nl

TU Delft

Human Research Ethics
Committee TU Delft
(http://hrec.tudelft.nl)

Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft

Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

*Ethics Approval Application: More than Just Vulnerability: A Multidimensional Approach to Urban Climate Resilience*
*Applicant: Mulder, Milou*

Dear Milou Mulder,

It is a pleasure to inform you that your application mentioned above has been approved.

Thank you very much for your submission to the HREC. Your submission has been conditionally approved. Please remember that this approval is conditional on ensuring the following conditions are met.

1. Please refrain from approaching minors.
2. Street interviews are generally a bit riskier, so please exercise extra caution to ensure that your participants feel safe and comfortable.

In addition to any specific conditions or notes, the HREC provides the following standard advice to all applicants:
• In light of recent tax changes, we advise you to confirm any proposed remuneration of research subjects with your faculty contract manager before proceeding.
• Please make sure when you carry out your research that you confirm contemporary COVID protocols with your faculty HSE advisor and that ongoing COVID risks and precautions are flagged in the informed consent, with particular attention to this where there are physically vulnerable (e.g., elderly or with underlying conditions) participants involved.
• Our default advice is not to publish transcripts or transcript summaries but to retain these privately for specific purposes/checking, and if they are to be made public, then only if fully anonymised and the transcript/summary itself approved by participants for a specific purpose.
• Where there are collaborating (including funding) partners, appropriate formal agreements, including clarity on responsibilities, including data ownership, responsibilities and access, should be in place, and relevant aspects of such agreements (such as access to raw or other data) are clear in the Informed Consent.
Please update the ICF to communicate to the participants that transcripts will be shared for review.

Good luck with your research!

Sincerely,

Dr. C. Shelley-Egan
Chair HREC
Faculty of Technology, Policy and Management

# A.3 Vulnerability Matrix

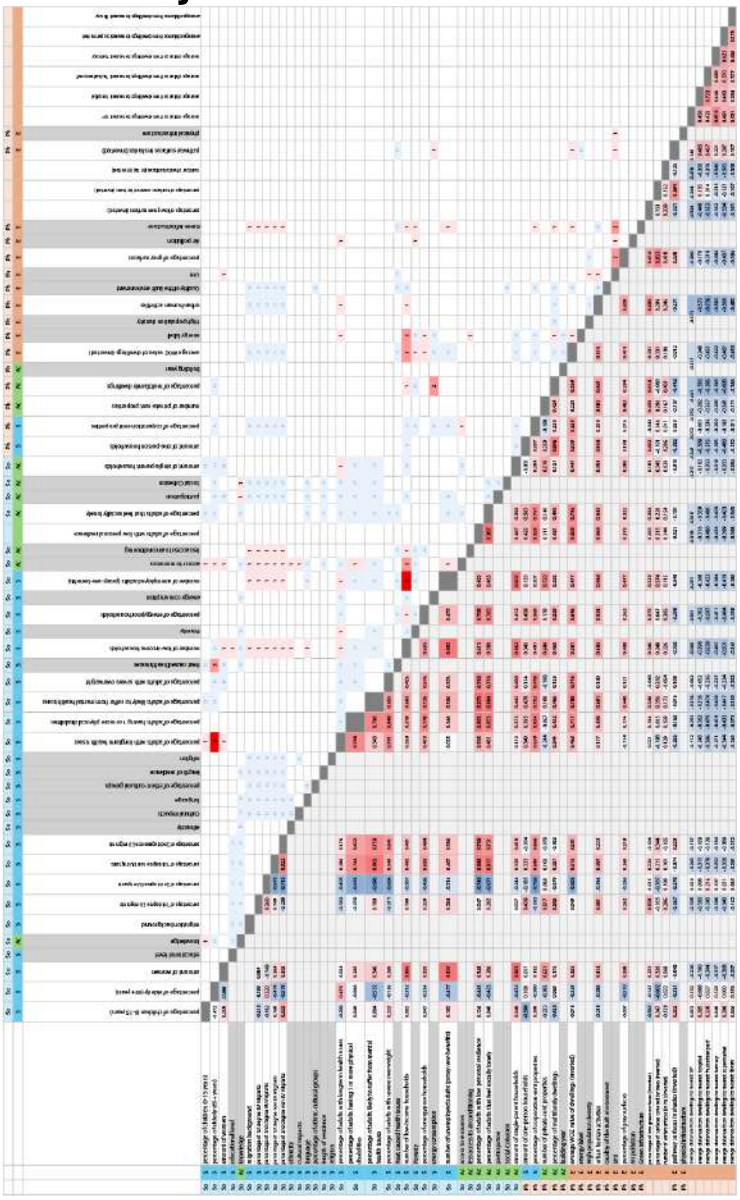

Figure A.1: Vulnerability Matrix

# A.4 Data Dictionary

The data dictionary is created to give an overview of the quantitative data available for the needed variables. The data is extracted from CBS (2024), Gemeente Den Haag (2023), and Klimaateffectatlas (2024).

The variables mentioned in the vulnerability matrix, that do not have a suitable proxy are not enclosed in the data dictionary.

| Group | Indicator | Discription | Data unit | Code | affect | Concept | Scale | domain | Year | Scale | Missing data | | | Source | OG code | References | reason for exclosure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | variable | description of what the variable indicates | unit of data (numbers, percentages...) | used code in database | does it increase (+) or decrease (-) the overall vulnerability? | Exposure (E), Sensitivity (S) or Adaptive Capacity (Ac) | Household (H), Neighbourhood (N), City (C) | Social (So), Physical (Ph), Political (Po) | year in which the data is collected | original scale of data | 100x100 | PC6 | buurt | source of the data | | references that mentioned the importance of this variable | |
| A. INDIVIDUAL CHARACTERISTICS | | | | | | | | | | | | | | | | | |
| age | **children ( < 15 y)** | amount of residents aged < 15 | num & perc | perc_age_0_15 | + | S | H | So | 2023 | PC6, buurt | 20% | 4% | 4% | (CBS, 2024) | aantal_inwoners_0_tot_15_jaar | IPCC, 2022; Gamble et al., 2016; OHCHR, 2022; Glanagan et al., 2011; World Bank, 2023; Yu et al., 2021; Eklund et al., 2023; Conglaves et al., 2022; Cole et al., 2021 | |
| | **elderly ( > 65 y)** | amount of residents aged 65 < | num & perc | perc_age_65_plus | + | S | H | So | 2023 | PC6, buurt | 24% | 3% | 4% | (CBS, 2024) | aantal_inwoners_65_jaar_en_ouder | IPCC, 2022; Ahmed et al., 2023; Martin & Paneque, 2022; Gamble et al., 2016; World Bank, 2023; Yu et al., 2021; Eklund et al., 2023; Rocha et al., 2023; Flanagan et al., 2011 | |
| gender | **women** | amount of women | num | num_women | + | S | H | So | 2023 | 100 x 100, PC6, buurt | 4% | 2% | 0% | (CBS, 2024) | aantal_vrouwen | Conglaves et al., 2022; IPCC, 2022; Ahmed et al., 2023; Gamble et al., 2016; OHCHR, 2022; World Bank, 2023; Yu et al., 2021; Tapia et al., 2017 | |
| migration status | **second/ third degree migrant (EU)** | percentage of residents born in NL with at least 1 parent born in the EU | perc | perc_2nd_degr_EU | + | S | H | So | 2023 | PC6, buurt | 60% | 10% | 4% | (CBS, 2024) | percentage_geb_nederland_herkomst_overig_europa | Ahmed et al., 2023; Conglaves et al., 2022; Eklund et al., 2023; Flanagan et a., 2011; Gamble et a., 2016; IPCC, 2022; OHCHR, 2022; Rocha et al., 2023; Tapia et al., 2017; World Bank, 2023; Yu et al., 2021 | |
| | **second/ third degree migrant (non EU)** | percentage of residents born in NL with at least 1 parent born outside of EU | perc | perc_2nd_degr_non EU | + | S | H | So | 2023 | PC6, buurt | 13% | 4% | 4% | (CBS, 2024) | percentage_geb_nederland_herkomst_buiten_europa | | |
| | **first degree migrant** | percentage of residents born EU | perc | perc_1st_degr_EU | + | S | H | So | 2023 | PC6, buurt | 37% | 5% | 4% | (CBS, 2024) | percentage_geb_buiten_nederland_herkomst_europa | | |
| | **first degree migrant** | percentage of residents born non-EU | perc | perc_1st_degr_non EU | + | S | H | So | 2023 | PC6, buurt | 20% | 3% | 4% | (CBS, 2024) | percentage_geb_buiten_nederland_herkmst_buiten_europa | | |
| health issues | **mental health issues** | %people aged 18 years and older at high risk of an anxiety disorder or depression | perc | perc_health_mental | + | S | H | So | 2022 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder met een hoog risico op een angststoornis of depressie [2022, buurt] | IPCC, 2022; Gamble et al., 2016; Yu et al., 2021 | |
| | **physical disabilites** | % persons aged 18 years and older with one or more physical disabilities | perc | perc_health_physical | + | S | H | So | 2020 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder met één of meer lichamelijke beperkingen [2020, buurt] | IPCC, 2022; Cole et al., 2021; Ahmed et al., 2023; Gamble et a., 2016 OHCHR, 2022; Flanagan et a., 2011; World Bank, 2023; Tapia et a., 2017 | |
| | **longterm health issues** | % persons aged 18+ with one or more long-term illnesses/conditions | perc | perc_health_longterm | + | S | H | So | 2022 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder met één of meer langdurige ziekten/aandoeningen [2022, buurt] | Conglaves et al., 2022; IPCC, 2022; Gamble et al., 2016; Yu et al., 2021; Martin & Paneque, 2022; Van der Hoeven & Wandl, 2018) | |
| | **severe overweight** | % persons aged 18 and over with severe overweight | perc | perc_health_overweight | + | S | H | So | 2022 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder met ernstig overgewicht [2022, buurt] | IPCC, 2022 | |

| Group | Indicator | Discription | Data unit | Code | affect | Concept | Scale | domain | Year | Scale | Missing data | | | Source | OG code | References | reason for exclosure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Socio economic status | **low income households** | amount of low income households | num | perc_ses_low_income | + | S | H | So | 2021 | buurt | NA | NA | 6% | (Den Haag Cijfers, 2025) | part. huishoudens met een laag inkomen [huishoudens] | Ahmed et al., 2023; Cole et al., 2021; Conglaves et al., 2022; Eklund et al., 2023; Flanagan et al., 2011; Gable et al., 2016; IPCC, 2022; Rocha et al., 2023; Saja et al., 2018; Samen Klimaatbestendig, 2023; Tapia et al., 2017; World Bank, 2023; Yu et a., 2021; OHCHR, 2022 | |
| | **poverty households** | households living in poverty | num | num_ses_poverty | + | S | H | So | 2024 | buurt | NA | NA | 0% | (Den Haag Cijfers, 2025) | Aantal doelgroephuishoudens [2021, buurt] | Eklund et al., 2023; IPCC 2022; Tapia et al., 2017; Rocha et al., 2023; IPCC, 2022; OHCHR, 2022 | high correlation |
| | **energypoor households** | % of energypoor households | perc | perc_ses_energypoverty | + | S | H | So | 2022 | wijk | NA | NA | 22% | (Den Haag Cijfers, 2025) | % energiearme huishoudens | IPCC, 2022; Ahmed et al., 2023 | |
| | **unemployment** | amount of individuals with ww benefits (Werkloosheidswet) | num | num_unemployment | + | S | H | So | 2023 | buurt | NA | NA | 4% | (CBS, 2024) | aantal_personen_met_een_ww_uitkering_totaal | Conglaves et al., 2022; IPCC, 2022; Saja et al., 2018; Gamble et al., 2016; Yu et al., 2021; Eklund et al., 2023; IPCC, 2022; Tapia et al., 2017; Rocha et al., 2023 | |
| Social capital | **low personal resilience** | % of persons aged 18 years and older who indicate that they have (very) low resilience | perc | perc_social_low personal resilience | + | Ac | H | So | 2022 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder dat aangeeft een (zeer) lage veerkracht te hebben [2022, buurt] | | |
| | **socially lonely** | % of people aged 18 and over who feel socially lonely | perc | perc_social_socially lonely | + | Ac | H | So | 2022 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | % personen van 18 jaar en ouder dat zich sociaal eenzaam voelt [2022, buurt] | Yu et a., 2021; IPCC, 2022; Ahmed et al., 2023; World Bank, 2023; Tapia et al., 2017 | |
| **C HOUSE(HOLD) CHARACTERISTICS** | | | | | | | | | | | | | | | | | |
| Household constilation | **single parent households** | amount of single parents with at least one home-living child | num | num_household_single parent | + | S | H | So | 2023 | PC5, Buurt | 60% | 9% | 5% | (CBS, 2024), (Den Haag Cijfers, 2024) | aantal_eenouderhuishoudens | Flanagan et al., 2011 | |
| | **single person household** | amount of households existing of 1 person | num, perc | num_household_one person | + | S | H | So | 2023 | PC5, buurt | 24% | 3% | 3% | (CBS, 2024) | aantal_eenpersoonshuishoudens | IPCC, 2022; Cole et al., 2021; Flanagan et a., 2011; Tapia et al., 2017 | |
| house ownership | **housing corporation** | amount of rental properties owned by housing corporations (incl social housing) | num, perc | perc_rent_corporation | + | S | H | Ph | 2023 | buurt | 70% | 35% | 4% | (CBS, 2024) | aantal_huurwoningen_in_bezit_woningcorporaties | IPCC, 2022; Samen Klimaatbetending, 2023; World Bank, 2023; Tapia et al., 2017; Rocha et al., 2023 | |
| | **Private rent** | amount of private rental properties | num | num_rent_private | + | S | H | Ph | 2024 | buurt | NA | NA | 3% | (Den Haag Cijfers, 2025) | Particuliere huurwoningen [2024, buurt] | Tapia et al., 2017; Rocha et al., 2023; IPCC, 2022 | |
| **D BUILDING CHARACTERISTICS** | | | | | | | | | | | | | | | | | |
| building typology | **amount of multi-family dwelling** | multi-family dwellings (flatgebouw) often lack of adaptive capacity due to regulations or possibilities | num, perc | perc_dwelling_multifamily | + | S | N | Ph | 2023 | PC5, buurt | 30% | 6% | 4% | (CBS, 2024) | percentage_meergezinswoning | Ahmed et al., 2023; Flanagan et al., 2011; Tapia et al., 2017; Rocha et al., 2023 | |
| building year | **dwellings built before 1945** | amount of dwellings built before 1945 | num, perc | perc_dwelling_before_1945 | + | S | H | Ph | 2023 | buurt | 59% | 40% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_voor_1945 | IPCC, 2022 | low data relevance |
| | **dwellings built 1945-1959** | amount of dwellings built 1945-1959 | num, perc | perc_dwelling_45-59 | + | S | H | Ph | 2023 | buurt | 81% | 64% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_45_tot_65 | | low data relevance |

| Group | Indicator | Discription | Data unit | Code | affect | Concept | Scale | domain | Year | Scale | Missing data | | | Source | OG code | References | reason for exclosure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **dwellings built 1960-1970** | amount of dwellings built 1960-1970 | num, perc | perc_dwelling_60-70 | + | S | H | Ph | 2023 | buurt | 94% | 84% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_65_tot_75 | | low data relevance |
| | **dwellings built 1971-1980** | amount of dwellings built 1971-1980 | num, perc | perc_dwelling_71-80 | + | S | H | Ph | 2023 | buurt | 90% | 74% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_75_tot_85 | | low data relevance |
| | **dwellings built 1981-1990** | amount of dwellings built 1981-1990 | num, perc | perc_dwelling_81-90 | + | S | H | Ph | 2023 | buurt | 88% | 67% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_85_tot_95 | | low data relevance |
| | **dwellings built 1991-2000** | amount of dwellings built 1991-2000 | num, perc | perc_dwelling_91-00 | + | S | H | Ph | 2023 | buurt | 80% | 64% | 3% | (CBS, 2024) | aantal_woningen_bouwjaar_95_tot_05 | | low data relevance |
| WOZ-value | **average WOZ-value** | average WOZ-value of dwellings | num x 1 000 Euro) | num_dwelling_WOZ | - | Ac | H | Ph | 2023 | 100 x 100, PC5, buurt | 9% | 3% | 4% | (CBS, 2024) | gemiddelde_woz_waarde_woning | Conglaves et al., 2022; Tapia et al., 2017 | |
| energylabel | **Energylabel B** | amount of dwellings with an energylable of B | num | num_dwelling_energylabel_B | + | Ac | H | Ph | 2024 | buurt | NA | NA | 9% | (Den Haag Cijfers, 2025) | Energielabel B [2024, buurt] | Flanagan et al., 2011; IPCC, 2022; Rocha et al., 2023, Yu et al; Van der Hoeven & Wandl, 2018 | high NA |
| | **Energylabel C** | amount of dwellings with an energylable of C | num | num_dwelling_energylabel_C | + | Ac | H | Ph | 2024 | buurt | NA | NA | 11% | (Den Haag Cijfers, 2025) | Energielabel C [2024, buurt] | | high NA |
| | **Energylabel D** | amount of dwellings with an energylable of D | num | num_dwelling_energylabel_D | + | Ac | H | Ph | 2024 | buurt | NA | NA | 17% | (Den Haag Cijfers, 2025) | Energielabel D [2024, buurt] | | high NA |
| | **Energylabel E** | amount of dwellings with an energylable of E | num | num_dwelling_energylabel_E | + | Ac | H | Ph | 2024 | buurt | NA | NA | 19% | (Den Haag Cijfers, 2025) | Energielabel E [2024, buurt | | high NA |
| | **Energylabel F** | amount of dwellings with an energylable of F | num | num_dwelling_energylabel_F | + | Ac | H | Ph | 2024 | buurt | NA | NA | 20% | (Den Haag Cijfers, 2025) | Energielabel F [2024, buurt] | | high NA |
| | **Energylabel G** | amount of dwellings with an energylable of G | num | num_dwelling_energylabel_G | + | Ac | H | Ph | 2024 | buurt | NA | NA | 18% | (Den Haag Cijfers, 2025) | Energielabel G [2024, buurt] | | high NA |
| **E DENSITY** | | | | | | | | | | | | | | | | | |
| population density | **amount of residents in an area** | amount of residents (within 100x100?) | num | num_density_residents | + | E | H | Ph | 2023 | 100 x 100, PC5, buurt | 1% | 2% | 0% | (CBS, 2024) | aantal_inwoners | Ahmed et al., 2023; Flanagan et al., 2011; Yu et al., 2021; Eklund et al., 2023; Tapia et al., 2017 | high correlation |
| Urban Density | **Urban density** | degree of concentration of human activities within 1km | num | num_density_urban | + | E | N | Ph | 2023 | PC5, buurt | NA | 0% | 0% | (CBS, 2024) | omgevingsadressendichtheid | IPCC, 2022; Ahmed et al., 2023; Flanagan et al., 2011; Kleerekoper et al., 2012; Eklund et al., 2023; Tapia et al., 2023 | |
| **F Urban Heat Island Effect** | | | | | | | | | | | | | | | | | |
| Green / blue infrastructure | **distance to cooling areas** | distance to cooling areas | num | num_UHI_distance cooling area | - | E | H | Ph | 2024 | pand | NA | NA | NA | Klimaateffectatlas, 2025 | afstand tot koelte | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | high NA |
| | **Green (NDVI)** | Groen (NDVI) | Dimensieloos. 0 tot . | num_UHI_srf green | - | E | N | Ph | 2017 | 100x100 | - | NA | NA | (Van der Hoeven & Wandl, 2017) | Groen_NDVI | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |
| | **green rooftops (surfaces)** | surface size of green rooftops | num | num_UHI_green rooftops | - | E | H | Ph | 2019 | buurt | NA | NA | 19% | (Den Haag Cijfers, 2025) | Oppervlakte groene daken - 2019 - buurten | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | high NA |
| | **Green surface** | % of green surfaces | perc | perc_UHI_green srf | - | E | N | Ph | n.d. | buurt | NA | NA | - | Klimaateffectatlas, 2025 | PercentageGroen [nd; buurt] | IPCC, 2022; Ahmed et al., 2023; Flanagan et al., 2011; Kleerekoper et al., 2012; Eklund et al., 2023; Rocha et al., 2023; Van der Hoeven & Wandl, 2017 | high correlation |
| | **low green surface** | % of low green surfaces | perc | perc_UHI_low green srf | - | E | N | Ph | n.d. | buurt | NA | NA | 0% | Klimaateffectatlas, 2025 | PercentageLaagGroen [nd; buurt] | | |
| | **trees** | % of trees | perc | perc_UHI_trees | - | E | N | Ph | n.d. | buurt | NA | NA | 0% | Klimaateffectatlas, 2025 | PercentageBoom [nd; buurt] | | |
| | **watersurface** | amount of watersurface in ha | num | num_UHI_water | - | E | N | Ph | 2023 | buurt | NA | NA | 0% | (CBS, 2024) | oppervlakte_water_in_ha | | |
| heat | **warmer surfaces** | Surface area 'considerably warmer' [$m^2$] | num | num_UHI_warm areas | - | E | N | Ph | 2021 | wijk | NA | NA | 22% | (Den Haag Cijfers, 2025) | Oppervlakte gebied 'aanzienlijk warmer' [$m^2$] (1) [2021, wijk] | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | high NA |
| | **surface temperature (day)** | surface temperature, day (27 mei 2017) | Graden Celsius | num_UHU_srf temp day | + | E | N | Ph | 2017 | 100x100 | - | NA | NA | (Van der Hoeven & Wandl, 2017) | Opp_temp_d | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |

| Group | Indicator | Discription | Data unit | Code | affect | Concept | Scale | domain | Year | Scale | Missing data | | | Source | OG code | References | reason for exclosure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **surface temperature (night)** | surface temperature, night (26 mei 2017) | Graden Celsius | num_UHI_srf temp night | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Opp_temp_n | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |
| | **Net radiation** | Netto straling | W/m² | num_UHI_radiation | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Nto_string | Van der Hoeven & Wandl, 2017 | 100x100 only |
| | **Latent heat** | Latente warmte | W/m² | num_UHI_latent heat | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Lat_warmte | Van der Hoeven & Wandl, 2017 | 100x100 only |
| | **Sensible heat** | Voelbare warmte | W/m² | num_UHI_sensible heat | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Vlb_warmte | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |
| | **Ground heat flux** | Bodemwarmtestroom | W/m² | num_UHI_ground heat flux | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Bwstroom | Van der Hoeven & Wandl, 2017 | 100x100 only |
| | **Reflection by the city surface** | Reflectie door het stadsoppervlak | 0-1, 0 = geen reflectie, 1 = maximale reflectie | num_UHI_reflection | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Reflectie | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |
| | **Sky view factor** | Sky view factor | 0 = geen blootstelling aan het hemelgewelf, 250 = volledige blootstelling | num_UHI_sky view | - | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Skyviewfac | Van der Hoeven & Wandl, 2017 | 100x100 only |
| | average PET | average PET | num | num_UHI_PET | + | E | N | Ph | 2022 | buurt | NA | NA | 0% | Klimaateffectatlas, 2025 | PET_gem | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | |
| solar shading (public) | **Leaf Area Index (LAI)** | Leaf Area Index (LAI) | Dimensieloos. 0 tot 1. | num_UHI_leaf area index | - | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Blad_LAI | Van der Hoeven & Wandl, 2017 | 100x100 only |
| | **Shade (mid-July)** | Schaduw (midden juli) | Uur schaduw per hectare vanaf zonsopgang. | num_UHI_shade | - | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Schaduw | IPCC, 2022; Ahmed et al., 2023; Kleerekoper et al., 2012; Van der Hoeven & Wandl, 2017 | 100x100 only |
| | shade cycle and pathways | shades cycle and pathways | num | num_UHI_shade_pathway | - | E | N | Ph | 2024 | buurt | NA | NA | 0% | Klimaateffectatlas, 2025 | P_scha_fw | | |
| impervious paving | gray surface | % of gray surfaces | perc | perc_UHI_gray srf | + | E | N | Ph | n.d. | buurt | NA | NA | 0% | Klimaateffectatlas, 2025 | PercentageGrijs [nd; buurt] | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012; Yu et al., 2021; Samen Klimaatbestendig, 2023 | |
| | **Degree of hardening** | Mate van verharding | Dimensieloos. - 1 tot 1. | num_UHI_srf hardening | + | E | N | Ph | 2017 | 100x100 | – | NA | NA | (Van der Hoeven & Wandl, 2017) | Verharding | Van der Hoeven & Wandl, 2017; Kleerekoper et al., 2012 | 100x100 only |
| **G PUBLIC DOMAIN** | | | | | | | | | | | | | | | | | |
| health facilities | **General Practitioners** | average distance to nearest General Practitioners | km | dist_facilities_GP | + | Ac | N | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | huisartsenpraktijk_gemiddelde_afstand_in_km | IPCC, 2022 | |
| | **Hospitals** | average distance to nearest hospital | km | dist_facilities_hospitals | + | Ac | N | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | ziekenhuis_incl_buitenpolikliniek_gem_afst_in_km | | |
| | **Huisartsenpost** | average distance to nearest *huisartsenpost* | km | dist_facilities_huisartsenpost | + | Ac | H | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | huisartsenpost_gemiddelde_afstand_in_km | | |
| | **Farmacy** | average distance to nearest farmacist | km | dist_facilities_farmacy | + | Ac | H | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | apotheek_gemiddelde_afstand_in_km | | |
| public facilities | **Big supermarkets** | average distance to nearest supermarket | km | dist_facilities_supermarket | + | Ac | N | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | grote_supermarkt_gemiddelde_afstand_in_km | | |
| | **library** | average distance to nearest library | km | dist_facilities_library | + | Ac | H | Ph | 2023 | buurt | NA | NA | 2,6% | (CBS, 2024) | bibliotheek_gemiddelde_afstand_in_km | | |

## A.5 Haagse Klimaatweek

This table shows an analysis of the activities organized during the Haagse Klimaatweek in November 2024.

| activity | | | | date | | location | target group | | sustainablity | | | | | | | | accessibility | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **name** | **organisation** | **type** | **low key** | **day** | **time** | **neighborhood** | **individuals** | **building** | **green** | **heat** | **rain** | **sea level** | **waste** | **energy** | **gas** | **gene** | **costs** | **enrollment** | **spots** |
| Aftrap Klimaatweek bij de hofvijver | NA | NA | NA | 11-Nov | 09:00 - 09:30 | Centrum | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Workshop koken op inductie in de Schilderswijk | NA | food | yes | 11-Nov | 16:00 - 18:00 | Schilderswijk | all | NA | | | | | | | x | | 0 | mail, call | 15 |
| Workshop: Maak je tuin of balkon klimaatbestendig | Haagse Groen | information/ DIY | medium | 11-Nov | 11:30 - 13:00 | Bomen- en Bloemenbuurt | all | garden, balcony | x | x | x | | | | | | 0 | mail | full |
| Springtij in de Regio: leven in Den Haag met een stijgende zee | Gemeente Den Haag & Springtij en Deltares | lecture | no | 12-Nov | 18:00 - 22:00 | Scheveningen | all | NA | | | | x | | | | | 0 | website | 60 |
| Rondleiding en workshops bij The New Farm | The New Farm | information | medium | 12-Nov | 10:00 - 11:00 | Groente- en Fruitmarkt | all | NA | | | | | x | | | | 0 | mail | 25 |
| Workshop chocolade maken | De Haagsche Cacaofabriek | DIY | yes | 12-Nov | 11:00 - 12:00 | Groente- en Fruitmarkt | all | NA | NA | NA | NA | NA | NA | NA | NA | NA | 15 | mail | 20 |
| Workshop sokken maken | Sox2Sox | DIY | medium | 12-Nov | 11:00 - 12:00 | Groente- en Fruitmarkt | all | NA | NA | NA | NA | NA | NA | NA | NA | NA | 25 | mail | 6 |
| Rondleiding elektriciteitsnetwerk | gemeente Den Haag | information | yes | 12-Nov | 10:00 - 11:30; | Scheveningen | all | NA | | | | | | x | | | 0 | website | NA |
| Wat leer je van het weer door Reinier van den Berg | gemeente Den Haag en gemeente Rijswijk | lecture | no | 12-Nov | 15:30 - 17:30 | Rijswijk | all | all | | x | | | | x | | | 0 | website | NA |
| Praat mee over warmtenetten | Duurzaam Den Haag | lecture | no | 12-Nov | 16:30 - 19:00 | Bouwlust/ Vrederust | all | all | | | | | | x | x | | 0 | optional | NA |
| Masterclass transitiekunde | Energierijk Den Haag en gemeente Den Haag | lecture | no | 12-Nov | 14:00 - 17:00 | Centrum | experts only | NA | | | | | | x | | x | 0 | mail | NA |
| Klimaatkraam weekmarkt Leyweg | stichting Duurzaam Den Haag | information market | yes | 12-Nov | 09:00 - 17:00 | Morgenstond | all | NA | x | | | | | x | | x | 0 | NA | NA |
| Film: All that breathes | Filmhuis Den Haag, Movies that Matter en Humanity Hub | documentary | yes | 13-Nov | 19:00 | Centrum | all | NA | NA | NA | NA | NA | NA | NA | NA | NA | 12 | website | NA |
| Ontbijt en lezing door Shivant Jhagroe | LDE Centre for Sustainability | lecture | medium | 13-Nov | 09:00 - 10:30 | Centrum | english | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0 | website | NA |
| Bibliotheek Bomenbuurt: Spreekuur duurzame woning | Bibliotheek den Haag | information market | yes | 13-Nov | 13:00 - 17:00 | Bomen- en Bloemenbuurt | all | NA | | | | | | x | | x | 0 | NA | NA |
| Duurzame Restaurantroutes Centrum | Horecaroute | food | no | 13-Nov | 18:30 | Centrum | all | NA | NA | NA | NA | NA | NA | NA | NA | NA | € 39 | website | 50 |
| Bespaartheater: Uw huis winterklaar | gemeente Den Haag | theater | yes | 13-Nov | 18:30 - 20:00 | Centrum | all | all | | | | | | x | x | x | 0 | website | NA |
| Bibliotheek Ypenburg: film Groenkijkers | Bibliotheek Ypenburg | documentary | yes | 13-Nov | 20:00 - 21:30 | Ypenburg | all | NA | | | | | | | | | 0 | website | ? |
| Moerwijk-Noord in gesprek over isoleren | Isoleren Moerwijk | information market | yes | 13-Nov | 12:00 - 14:00 | Moerwijk | all | all | | | | | | x | x | x | 0 | NA | NA |
| Bibliotheek Segbroek: workshop een groenere tuin of balkon | Haagse Groen | information/ DIY | medium | 14-Nov | 10:00 - 11:30 | Valkenboskwartier | all | garden, balcony | x | x | x | | | | | | 0 | mail, call | full |
| Bibliotheek Segbroek: film Groenkijkers | Bibliotheek den Haag | documentary | yes | 14-Nov | 12:00 - 13:00 | Valkenboskwartier | all | NA | | | | | | | | | 0 | mail, call | ? |
| Bibliotheek Bouwlust: tips voor meer groen en energiebesparen | Bibliotheek Bouwlust | lectrue | yes | 14-Nov | 09:30 - 11:00 | Bouwlust/ Vrederust | all | NA | x | | | | | x | x | x | 0 | location, mail, call | ? |
| Bibliotheek Escamp: kinder workshop plasticsoepcamp | Afvaljuf | DIY | yes | 14-Nov | 15:30 - 17:00 | Morgenstond | kids (>6y) | NA | | | | | x | | | | 0 | mail, call | ? |
| Duurzame Restaurantroute Scheveningen | Horecaroute | food | no | 14-Nov | 18:30 | Scheveningen | all | NA | | | | | | | | | € 39 | website | 50 |
| Klimaatkraam weekmarkt Stevinstraat | Green2live | information market | yes | 14-Nov | 09:00 - 17:00 | Belgisch Park | all | single houses | x | | x | | | x | | x | 0 | NA | NA |
| Haags Klimaatcafé XL | gemeente Den Haag | politics | no | 15-Nov | 12:30 - 17:00 | Zorgvliet | experts only | NA | | | | | | | | x | 0 | website | NA |
| Haags Stadmakersfestival | gemeente Den Haag | lecture | medium | 15-Nov | 09:00 - 18:00 | Centrum | all | NA | x | | | | x | x | | x | € | website | ? |
| The Hague Climate Drinks | Women and Climate | information market | medium | 15-Nov | 18:30 - 22:00 | Centrum | women | NA | | | | | | | | x | 0 | website | NA |
| Bibliotheek Benoordenhout: workshop voor kids | Afvaljuf | DIY | yes | 16-Nov | 11:00 - 12:30 | Benoordenhout | kids (>6y) | NA | | | | | x | | | | 0 | website | 12 |
| KliMAAT Festival Club Laak | Back on the rack | mini festival | yes | 16-Nov | 12:00 - 17:00 | Laakkwartier en Spoorwijk | all | NA | | | | | | | | x | 0 | NA | NA |
| Vegan pop-up diner | ùmammie | food | no | 16-Nov | 18:30 - 21:00 | Laakkwartier en Spoorwijk | all | NA | | | | | | | | x | 36 | website | ? |
| Kids-college en flitsexcursie: Briljante Planten | Geert-Jan Roebers | information/ DIY | yes | 16-Nov | 09:00 - 10:30 | Bomen- en Bloemenbuurt | kids (8-12 y) | NA | x | | | | | | | | 0 | location, mail | ? |
| Klimaatkraam Haagse Markt | Stichting Duurzaam Den Haag | information market | yes | 16-Nov | 09:00 - 17:00 | Schilderswijk | all | NA | x | | | | | x | x | x | 0 | NA | NA |
| Bibliotheek Ypenburg gaat duurzaam | Bibliotheek Ypenburg | DIY | medium | 16-Nov | 11:00 - 17:00 | Schilderswijk | all | NA | | | | | x | | | x | 0 | NA | NA |
| Just Peace film: Yumi - The Whole World | JUST PEACE | documentary | medium | 16-Nov | 19:00 - 22:00 | Centrum | all | NA | | | | | | | | | ? | website | ? |

## A.6 Existing Instruments Analysis

Kennisportaal Klimaatadaptatie. (n.d.). https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/

| | | | concept | | | scale | | | | | domain | | | climate problem | | | | infrastr. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| name | description | target group | sensitivity | exposure | adaptive capacity | behavior | house (hold) | street | neighborhood | city | social | physical | political | heat | drought | flood | biodiversity | green | blue | costs | source |
| | | number of instruments focusing on the respective category: | 10 | 61 | 21 | 6 | 46 | 66 | 60 | 39 | 14 | 85 | 13 | 54 | 22 | 38 | 31 | 38 | 15 | 30 | |
| | | percentage of heat-focused instruments focusing on the respective category: | 17% | 76% | 28% | 9% | 56% | 81% | 67% | 43% | 11% | 93% | 15% | #### | 41% | 61% | 44% | 44% | 19% | 17% | |
| Beleidsmixer | This toolkit provides an overview of ways to encourage climate adaptation on private property, focusing on adding greenery and managing (rain)water, with financial support options from municipalities or governments. | government professionals | | x | x | | x | | | | | | x | x | | x | x | x | | | Albantie Financiële Prikkels. (2021). Beleidsmixer. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/beleidsmixer/ |
| Beoordelingskader kwaliteit DPRA-stresstesten | This tool helps institutions (DPRA work regions) decide which stress tests to carry out or update for the 2025 DPRA stress test. | provinces, waterboards, municipalities | | x | | | | | | x | | x | x | x | x | x | | | | | Deltaprogramma Ruimtelijke Adaptatie. (2024). Beoordelingskader kwaliteit DPRA-stresstesten. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/beoordelingskader-kwaliteit-dpra-stresstesten/ |
| bomentabel | Shows the contribution of 359 tree species to climate adaptation, biodiversity, air quality, and heat stress reduction through shade and evaporation. | municipalities, urban designers, project developers | | x | | | | x | x | | | x | x | x | | | x | x | | | Wageningen University & Research & Hogeschool van Amsterdam (HvA). (2024). Bomentabel. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/bomentabel/ |
| effectief klimaatgroen | Offers practical tools for designing new and existing areas with cooling greenery, tailored to different neighborhood types. | urban designers, project developers | | x | x | | | x | x | | | x | | x | | | | x | | | Kleerekoper, L., Hiemstra, J. A., van der Poel, J., Erwin, S., Zhang, X., Kluck, J., & Jalalfahim, M. (2024). Effectief Klimaatgroen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/effectief-klimaatgroen/ |
| Coolkit | A toolkit that helps designers add more greenery and shading in different types of neighborhoods. | urban designers, project developers | | x | x | | | x | x | | | x | | x | | | x | x | | | Kluck, J., Kleerekoper, L., Klok, L., Solcerova, A., Loeve, R., Erwin, S., Liu, C., Webster, N., Lopes, M., & Rajaei, S., KuiperCompagnons. (2020). Coolkit. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/coolkit/ |
| Cool Towns Heat Stress Measurement Protocol | A measurement protocol to carry out a Thermal Comfort Assessment (TCA) at street level, supporting climate-adaptive design. | urban designers, project developers | | x | | | | x | | | | x | | x | | | | x | | | Hogeschool van Amsterdam. (2020). Cool Towns Heat Stress Measurement Protocol. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/heat-stress-measurement-protocol/ |
| Effact checker | Provides answers to frequently asked practical questions regarding heat adaptation measures. | everybody | | | | | | | | | | | | x | | | | | | | Hogeschool van Amsterdam. (n.d.). Effact checker. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/effact-checker/ |
| Effectiviteit van klimaatadaptieve maatregelen | Offers a clear overview of the impact of various climate adaptation interventions. | everybody | | x | x | x | x | x | x | | | x | | x | x | x | | x | x | | Stichting RIONED. (2019). Effectiviteit van klimaatadaptieve maatregelen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/effectiviteit/ |
| Factsheet Multifunctionele Daken | Shows the performance and possibilities of green-blue roofs as a climate adaptation measure. | municipalities, project developers, residents | | | | | x | | | | x | x | | x | | | x | x | | | Nationaal Dakenplan. (2023). Factsheet Multifunctionele Daken. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/factsheet-multifunctionele-daken/ |
| Factsheets Groen in de stad | Includes multiple fact sheets highlighting the climate, health, and environmental benefits of trees and green infrastructure. | municipalities, urban designers, project developers | | x | | | x | x | | | | x | | x | | | x | x | | | Wageningen University & Research. (2023). Factsheets Groen in de stad. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/factsheets-groen-stad/ |
| Factsheets Hitte in de woning | Shows the impact of heat in houses and offers practical solutions for heat adaptation in existing buildings. | provinces, municipalities, GGD, housing corporations | x | x | x | x | x | x | | | | x | | x | | | | | | | Hogeschool van Amsterdam, TAUW, Stichting W/E adviseurs, Groene Huisvesters, & Klimaatverbond Nederland. (2024). Factsheets Hitte in de woning. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/factsheets-hitte-woning/ |
| Fotobank Natuurlijke Alliantie | A visual collection showing the effects of climate change and examples of climate adaptation in spatial planning. | everybody | | x | x | | x | x | x | | | x | | x | x | x | x | | | | Natuurlijke Alliantie. (n.d.). Fotobank Natuurlijke Alliantie. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/fotobank-natuurlijke-alliantie/ |
| Framework for Climate Adaptive Buildings. Deel 3: Strategie en maatregelen | Gives a basic overview of climate risks and adaptation options for buildings and the built environment. | municipality, housing corporations, project developer, financiers | | x | x | | x | x | x | | | x | | x | x | x | | | | | Bakker, A., Kadijk, J., Prijden, R., an der Velde, R., & Verbrugge, A. (2024). Framework Climate Adaptive Buildings. Deel 3: Strategie en maatregelen. Klimaatadaptatie. https://www.dgbc.nl/whitepapers/framework-climate-adaptive-buildings/ |
| Gidsmodellen | Presents climate adaptation strategies tailored to 11 different Dutch landscape types. | municipalities, urban designers, project developers | | | | | | | | x | | x | | x | x | x | | | | | Grond RR. (n.d.). Gidsmodellen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/gidsmodellen/ |
| Groenblauwe Netwerken | An overview of real-life case studies featuring green-blue infrastructure projects. | professionals | | x | | | | x | x | | | x | | x | | x | x | x | x | | Atelier Groenblauw, Deltares, Hanzehogeschool Groningen, Hogeschool van Amsterdam and Stichting CAS. (2023). Groenblauwe Netwerken. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/groenblauwe-netwerken/ |
| Handleiding De Levende Openbare Ruimte | A guide to adding green spaces for climate adaptation, similar to concepts like 'de levende tuin' or 'the living building' | municipalities, urban designers | | x | | | | x | x | x | | x | | x | | x | x | x | x | | Branchevereniging VHG. (n.d.). Handleiding De Levende Openbare Ruimte. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handleiding-levende-openbare-ruimte/ |
| Handreiking Duurzame bedrijventerreinen | Guidelines to make industrial areas and buildings—both new and existing—more sustainable, biodiverse, and climate resilient. | entrepreneurs | | x | x | | x | x | | | | x | | x | | | x | x | | | Provincie Overijssel, MKB Nederland Midden, VNO-NCW Midden. (2025). Handreiking Duurzame bedrijventerreinen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handreiking-duurzame-bedrijventerreinen/ |
| Handreiking Groen in en om de Stad | A framework for planning and maintaining green spaces from street to regional scale, including standards and requirements. | provinces, municipality, urban designers, housing corporations, project developer | | x | x | | x | x | x | x | | x | x | x | | | x | x | | | Arcadis, & Flux. (2024). Handreiking Groen in en om de Stad. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handreiking-groen-stad/ |

Kennisportaal Klimaatadaptatie. (n.d.). https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/

| | | | concept | | | scale | | | | | domain | | | climate problem | | | | infrastr. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **name** | **description** | **target group** | **sensitivity** | **exposure** | **adaptive capacity** | **behavior** | **house (hold)** | **street** | **neighborhood** | **city** | **social** | **physical** | **political** | **heat** | **drought** | **flood** | **biodiversity** | **green** | **blue** | **costs** | **source** |
| **Handreiking Hitte in Bestaande Woningen** | Tools and strategies to make existing homes more heat-resilient and comfortable during high temperatures. | municipality, housing corporations | x | x | | | x | x | x | | | x | | x | | | | | | | Nationaal Kennis- en innovatieprogramma Water en Klimaat (NKWK). (2023). Handreiking Hitte in Bestaande Woningen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handreiking-hitte-bestaande-woningen/ |
| **Handreiking Klimaatadaptief en Natuurinclusief Bouwen** | A general guide to support the inclusion of climate-adaptive construction and design in spatial policies and long-term planning. | policy maker | | x | x | | x | x | x | x | | x | x | x | x | x | | | | | Meijaard, S., van Hamel, A., Dekker, G., & Handgraaf, S. (2022). Handreiking Klimaatadaptief en Natuurinclusief Bouwen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handreiking-klimaatadaptief-bouwen/ |
| **Handreiking Klimaatbestendige Kinderboerderijen** | Offers practical steps to transform petting zoos into climate-resilient spaces, addressing layout, water use, and green elements. | petting zoo's | | x | x | | x | x | | | | x | | x | x | x | x | x | | | Gemeenten voor Duurzame Ontwikkeling. (2016). Handreiking Klimaatbestendige Kinderboerderijen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/kinderboerderij/ |
| **Handreiking Lokaal Hitteplan** | Provides a step-by-step approach to developing municipal heat plans, clarifying responsibilities and actions during heat events. | municipality, veiligheidsregio's, GGD | x | | x | x | x | x | x | x | | x | x | x | | | | | | | Nationale Klimaatadaptatiestrategie (NAS). (2019). Handreiking Lokaal Hitteplan. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/lokaal-hitteplan/ |
| **Handreiking Natuurinclusief bouwen voor gezonde bewoners** | Explains how green infrastructure, such as trees and parks, positively impacts public health and well-being. | municipality, policy maker, urban designers, project developer | x | | x | | x | x | x | | | x | | x | | | | x | | | Mereboer, P., & Postma, A. (2023). Handreiking Natuurinclusief bouwen voor gezonde bewoners. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/natuurinclusief-bouwen-gezonde-bewoners/ |
| **Handvat klimaatadaptatie in bebouwd gebied** | Provides practical (but sometimes limited) examples for builders and infrastructure managers on how to make the built environment more climate-resilient. | companies | | | | | x | x | x | x | | x | | x | | x | | x | | | Bouwend Nederland. (2019). Handvat klimaatadaptatie in bebouwd gebied. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/handvat-klimaatadaptatie-bebouwd-gebied/ |
| **Hoe vergroen je je omgeving?** | Contains brochures with green interventions tailored to different urban zones, including estimated impacts and costs. | municipality, urban designers | | x | | | x | x | x | x | | x | | x | | | x | x | | | Provincie Gelderland. (n.d.). Hoe vergroen je je omgeving?. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/vergroen-omgeving/ |
| **Huisje Boompje Beter** | A website offering practical tips for citizens to climate-proof their garden or balcony, focusing on reducing heat, improving water management, and boosting biodiversity. | residents | | x | x | | x | x | | | | x | | x | | x | x | x | | | Atelier Groenblauw. (n.d.). Huisje Boompje Beter. Klimaatadaptatie. https://www.huisjeboompjebeter.nl/ |
| **Kennisdocument Stedelijke Waterkwaliteit, Klimaat en Adaptatie** | Provides insight into how climate change can impact urban water quality, considering various perspectives and processes like pollution, heat, and drought. | waterboards | | x | | | | x | x | x | | x | | x | x | x | x | | x | | Arcadis, Deltares, RIVM, Royal HaskoningDHV, Stichting CAS, TAUW. (2023). Kennisdocument Stedelijke Waterkwaliteit, Klimaat en Adaptatie. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/kennisdocument-stedelijke-waterkwaliteit-klimaat/ |
| **Klimaatadaptatie-app** | An interactive app that helps select fitting climate adaptation measures based on local conditions and spatial characteristics. | municipality, policy maker, urban designers | | x | | | x | x | x | x | | x | | x | x | x | | | | | Bosch Slabbers, Deltares, KNMI, Sweco, Witteveen+Bos. (n.d.). Klimaatadaptatie-app. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/klimaatadaptatie-app/ |
| **Klimaateffectatlas** | An online knowledge hub mapping a wide range of climate and water-related effects, offering accessible data and tools for spatial planning. | everybody | x | x | x | | x | x | x | x | x | x | | x | x | x | x | x | x | | Stichting Climate Adaptation Services (CAS). (n.d.). Klimaateffectatlas. https://www.klimaateffectatlas.nl/nl/ |
| **Klimaatscenario's** | Gives insight into expected future climate conditions in the Netherlands based on various KNMI climate scenario models. | government professionals | | x | | | x | x | x | x | | x | | x | x | x | x | | | | KNMI. (2023). Klimaatscenario's. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/klimaatscenario/ |
| **Klimaatschadeschatter** | Provides projections of potential economic damage due to climate change, aimed at both residents and public institutions. | everybody | x | x | | | x | x | x | x | x | x | x | x | x | x | | | | | NKWK. (n.d.). Klimaatschadeschatter. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/schadeschatter/ |
| **Maatlat groene klimaatadaptieve gebouwde omgeving** | Offers a high-level overview of how climate adaptation can be integrated into urban development and the built environment. | government professionals, housing corporations, project developer, companies | | x | | | x | x | x | x | | x | | x | x | x | x | | | | Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, Ministerie van Infrastructuur en Waterstaat en Landbouw, Natuur en Voedselkwaliteit. (2023). Maatlat groene klimaatadaptieve gebouwde omgeving. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/maatlat-groene-klimaatadaptieve-gebouwde-omgeving/ |
| **Maatregelen klimaatadaptatie en natuurinclusiviteit in de gebouwde omgeving** | An overview showing the effects and associated costs of a wide variety of climate adaptation interventions. | government professionals, project developer, companies, citizens | | x | | | x | x | x | | | x | | x | | x | x | x | x | | Rijksdienst voor Ondernemend Nederland. (2024). Maatregelen klimaatadaptatie en natuurinclusief bouwen en renoveren. https://www.rvo.nl/onderwerpen/klimaatadaptatie-gebouwde-omgeving/maatregelen/bouwen-renoveren |
| **Menukaart Hitte en Handreiking Integraal Actieplan** | Supports municipalities in setting up a heat strategy, focusing on health impacts and adapting the built environment to high temperatures. | municipality | | x | | x | x | x | x | | | x | | x | | | | | | | ministerie van Volkshuisvesting en Ruimtelijke Ordening, Rijksdienst voor Ondernemend Nederland. (2024). Menukaart Hitte en Handreiking Integraal Actieplan. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/menukaart-hitte/ |
| **Mindmap Hitte** | A visual mindmap showing the broad range of heat-related problems that affect different sectors during heatwaves. | government professionals, provinces, municipality, policy maker, GGD | x | x | | x | x | x | x | x | x | x | | x | | | | | | | Hogeschool van Amsterdam. (2019). Mindmap Hitte. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/mindmap-hitte/ |
| **Reinventing Multifunctionality** | A book combining theory and real-life examples of how climate adaptation is linked with other agendas like energy, mobility, and spatial quality. | Urban designers, project developers | | | | | | x | x | x | | x | | x | | x | x | | | | Rijksdienst voor Ondernemend Nederland. (2016). Reinventing Multifunctionality. Klimaatadapatatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/reinventing/ |

Kennisportaal Klimaatadaptatie. (n.d.). https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/

| | | | concept | | | scale | | | | | domain | | | climate problem | | | | infrastr. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **name** | **description** | **target group** | **sensitivity** | **exposure** | **adaptive capacity** | **behavior** | **house (hold)** | **street** | **neighborhood** | **city** | **social** | **physical** | **political** | **heat** | **drought** | **flood** | **biodiversity** | **green** | **blue** | **costs** | **source** |
| **NAS-adaptatietool** | Based on the NAS 'bollenschema', this tool allows you to visualize local climate trends and their effects. | government professionals, provinces, municipality, policy makers | x | x | | | x | x | x | x | x | x | | x | x | x | | | | | NAS. (2016). NAS-adaptatietool. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/nas-adaptatietool/ |
| **Ontwerprichtlijnen groen in de stad** | Practical design tips to integrate more greenery in urban public spaces to combat heat. | urban designers | | | | | | x | | | | x | | x | | | | x | | | Klemm, W.. (2018). Ontwerprichtlijnen groen in de stad. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/ontwerp-groen/ |
| **Praatplaat Klimaatbestendig Beekdallandschap** | A communication tool that supports discussions on nature-based solutions in stream valley areas. | waterboards, municipality, companies, financiers | | x | | | x | x | x | | | x | | x | x | x | | | | | stowa. (2019). Praatplaat Klimaatbestendig Beekdallandschap. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/praatplaat-klimaatbestendig-beekdallandschap/ |
| **Ritsen: klimaatadaptieve instrumenten voor bouwen** | Clarifies responsibilities at different spatial scales to support climate adaptation in area development. | municipality, urban designers | | | | | | x | x | x | | x | x | x | x | x | | | | | &Flux, Tauw and Samen Klimaatbestendig. (2020). Ritsen: klimaatadaptieve instrumenten voor bouwen. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/ritsen-klimaatadaptieve-instrumenten-bouwen/ |
| **Roadmap Cool Towns** | A step-by-step guide to help cities develop a targeted strategy for managing heat stress. | municipality, policy maker, GGD, housing corporations | x | x | | | x | x | x | x | x | x | | x | | | | | | | Interreg 2 Mers Seas Zeeën-programma. (2022). Roadmap Cool Towns. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/roadmap-cool-towns/ |
| **Toolbox Klimaatbestendige Stad** | Visualizes the effect and feasibility of various adaptation measures at street or neighborhood scale. | municipality, urban designers | | | | | | x | x | x | | x | | x | x | x | | x | x | | NKWK. (2020).Toolbox Klimaatbestendige Stad. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/toolbox-ks/ |
| **Voorbeeldenboek** | Illustrates how different street types can be redesigned for water management and heat mitigation. | municipality, urban designers | | x | | | | x | | | | x | | x | | x | | x | x | | Hogeschool van Amsterdam. (2017). Voorbeeldenboek. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/voorbeeldenboek/ |
| **Werkwijze klimaatadaptatie met natuur tussen stad en platteland** | Tool for visualizing challenges and opportunities for natural climate solutions at urban-rural interfaces. | provinces, waterboards, municipality | | x | | | | x | x | x | | x | | x | x | x | x | x | x | | Bureau Stroming, GreenSteps Duurzame Innovatie. (2023). Werkwijze klimaatadaptatie met natuur tussen stad en platteland. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/werkwijze-klimaatadaptatie-natuur-tussen-stad/ |
| **Woordenboek Hitte** | Provides clear definitions for key concepts and terms related to heat and heat stress. | government professionals | | | | | | | | | | | | x | | | | | | | Overheidsstichting Geonovum. (2023). Woordenboek Hitte. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/woordenboek-hitte/ |
| **BlueLabel** | Displays climate risk labels for individual buildings, helping inform adaptation priorities. | municipality | | x | | | x | | | | | x | | x | x | x | | | | € | Achmea, Nelen & Schuurmans, Royal HaskoningDHV. (n.d.). BlueLabel. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/bluelabel/ |
| **Buiten Ruimte Inrichtings Tool (BRIT)** | Game-based method that helps developers and citizens co-create climate-resilient public spaces. | urban designers, project developer | | | | | | x | x | | | x | | x | x | x | x | | | € | IMAGEN. (n.d.). Buiten Ruimte Inrichtings Tool (BRIT). Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/brit/ |
| **Hittestresstool** | A digital tool to simulate and evaluate how heat mitigation strategies perform in outdoor spaces. | municipality, urban designers | | x | | | | x | x | | | x | | x | | | | x | x | € | Nelen & Schuurmans. (2024). Hittestresstool. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/hittestresstool/ |
| **Lizard klimaatatlas** | Interactive tool to visualize how climate change is likely to affect specific areas, similar to the Klimaateffectatlas. | municipality | | x | | | | | x | x | | x | | x | x | x | | | | € | Nelen & Schuurmans. (2025). Lizard klimaatatlas. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/lizard-klimaatatlas/ |
| **NL Omgevingsscan** | Assesses an area's vulnerability to heat stress, water issues, air quality, and biodiversity, showing how climate-resilient it is. | companies | | x | | | | | x | x | | x | | x | | x | x | | | € | NL Greenlabel. (n.d.). NL Omgevingsscan. Klimaatadaptatie.https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/nl-omgevingsscan/ |
| **NL Terreinlabel** | A label (similar to NL Gebiedslabel) that monitors and embeds sustainability ambitions for locations like sports fields, schoolyards, and business parks. | government professionals, municipality, project developer, companies | | x | | | | x | | | | x | | x | | x | x | | | € | NL Greenlabel. (n.d.). NL Terreinlabel. Klimaatadaptatie.https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/nl-terreinlabel/ |
| **NL Tuinlabel** | Tool that scores how climate-proof your garden is and provides tips to improve it based on biodiversity, greenery, and water absorption. | municipality, citizens | | | | | x | | | | | x | | x | | x | x | | | € | NL Greenlabel. (n.d.). NL Tuinlabel. Klimaatadaptatie.https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/nl-tuinlabel/ |
| **Staat van je Straat** | A communication tool that collects and visualizes street-level adaptation data, helping inform and involve local residents. | municipality | | x | | | | x | | | | x | | x | x | x | | | | € | Sweco. (n.d.). Staat van je Straat. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/staat-straat/ |
| **Thermal walk** | Observation-based tool to document and compare actual and perceived heat in specific urban areas. | municipality, urban designers | | x | | | | x | x | | | | | x | | | | | | € | Hogeschool van Amsterdam. (n.d.). Thermal walk. Klimaatadaptatie. https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/thermal-walk/ |

# A.7 PCA statistical results

## Correlation Matrix

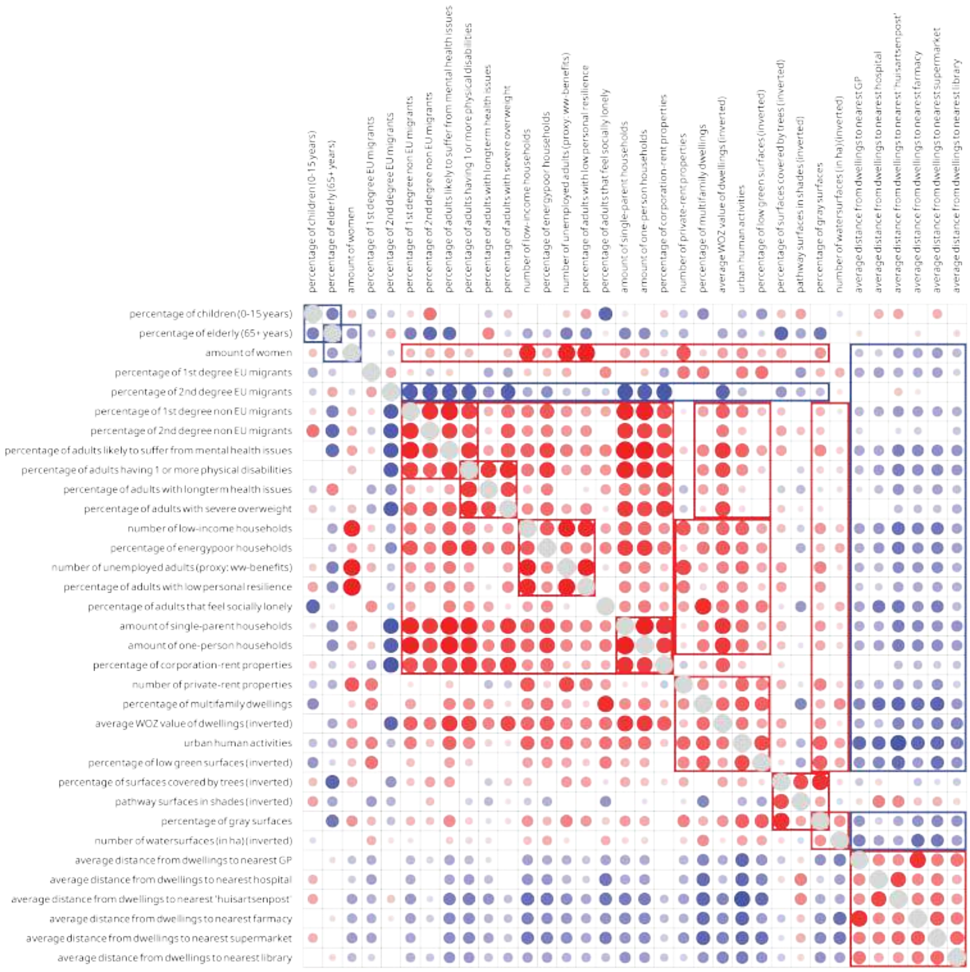


Figure A.2: Correlation matrix based on variables (calculated with R)

## Eigenvalue table with local and global PTV

Table A.1: Eigenvalue and variance Table

| Component | Eigenvalue | Explained Variance | Local PTV | Global PTV |
|---|---|---|---|---|
| 1 | 13.04431142 | 38.36562183 | 38.36562183 | 82.9051 |
| 2 | 5.625817705 | 16.54652266 | 16.54652266 | |
| 3 | 4.140782996 | 12.17877352 | 12.17877352 | |
| 4 | 2.218261979 | 6.524299937 | 6.524299937 | |
| 5 | 1.729992872 | 5.088214329 | | |
| 6 | 1.428568178 | 4.201671112 | | |
| 7 | 0.845008984 | | | |

## Screeplot

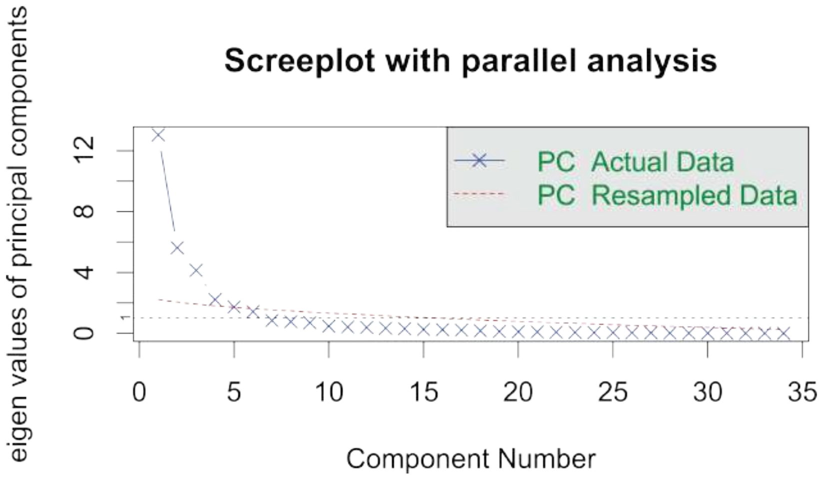


Figure A.3: Scree plot based on PCA with R

## COS2


Figure A.4: COS2 visualisation

# A.8 measures suitable for the Vulnerability Groups

## Tools for Vulnerability group 1: Socio-Spatial Vulnerability in Urban Areas

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| Women | - | - | - | - | - |
| First and second degree non-EU migrants | Provide information in different languages | 58 | Inform | - | - |
| | Organize heat consultation hours | 59 | Involve | | |
| | Make use of religious institutes to reach communities | 65 | Collaborate | | |
| Adults with mental health issues | Organize social activities | 66 | Involve | Join WhatsApp groups | 61 |
| | Have volunteers who do social check-ins | 62 | Involve | Be careful with medication | 15 |
| Adults with physical disabilities | Expand subsidies | 33, 35 | Inform | Always have something to drink close to you | 9 |
| | Have volunteers who do social check-ins | 62 | Involve | Be careful with medication | 15 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| Adults with severe overweight | Organize sport events during cooler times | 66 | Involve | Cool (and dry) your body | 10, 14 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | Be careful with medication | 15 |
| | | | | Stay hydrated | 9 |
| Low-income households | Expand subsidies | 33, 35 | Inform | Get creative: cooling does not have to be expensive | 19, 28 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| | Organize workshops and information sessions for affordable adaptations | 63 | Involve | | |
| | Create a public cool hub | 51 | Collaborate | | |
| Energypoor households | Expand subsidies | 33, 35 | Inform | Get creative: cooling does not have to be expensive | 19, 28 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| | Organize workshops and information sessions for affordable adaptations | 63 | Involve | | |
| | Create a public cool hub | 51 | Collaborate | | |
| Unemployed adults | Create new jobs, e.g., watering public green spaces | - | Empower | Sign up as a volunteer | 62 |
| Single-parent households | Organize activities for children away from their homes | 56 | Involve | - | - |

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| One-person households | Organize social activities | 63, 66 | Involve | Join WhatsApp groups | 61 |
| | Have volunteers who do social check-ins | 62 | Involve | | |
| Low personal resilience | Organize social activities | 63, 66 | Involve | Join WhatsApp groups | 61 |
| | Create a public cool hub | 51 | Collaborate | | |
| | Have volunteers who do social check-ins | 62 | Involve | | |
| Socially lonely | Organize social activities | 63, 66 | Involve | Join WhatsApp groups | 61 |
| | Have volunteers who do social check-ins | 62 | Involve | | |
| | Create a public cool hub | 51 | Collaborate | | |
| Corporation-rent properties | Create regulations for housing corporations (e.g. sun shading) | 20, 33 | Inform | Have a residents' committee that fights for solutions | - |
| | | | | Use removable cooling alternatives | 28 |
| Multi-family dwelling | Create regulations that enable adaptation (e.g. sun shading) | 20, 33 | Inform | Add plants and shading to your balcony | 36, 37 |
| | Expand subsidies | 33, 35 | Inform | Cross-ventilate | 17, 25 |
| | Inform residents what to do with their balcony | 51, 63 | Inform | Add shading to your windows | 22, 24, 28 |
| | Create alternative outdoor spaces if no balcony | 52, 53 | Collaborate | | |
| High urban heat | Add greenery and trees | 28, 40 | Collaborate | Add plants to your balcony | 37 |
| | | | | Adopt a tree | 41 |
| | | | | Replace garden tiles with grass | 38 |

## Tools for Vulnerability group 2: Social Vulnerability in Suburban Family Neighborhoods

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| Children | Educate children (books, coloring pages) | 7 | Collaborate | Watch out for sunburns | 7, 12, 13 |
| | Organize summer camps/activities | 56 | - | Make sure they drink enough water | 9 |
| | Provide enough shade on playgrounds | 47, 52 | Inform | | |
| 2nd degree non-EU migrants | Provide information in different languages | 58 | Involve | - | - |
| | Organize Dutch lessons | - | Involve | | |
| | Have walk-in-hours for help | 59 | Involve | | |
| | Make use of religious institutes to reach communities | 65 | Collaborate | | |
| Overweight | Organize sport events during cooler times | 66 | Involve | Cool (and dry) your body | 10 |
| | | | | Stay Hydrated | 9 |
| | | | | Be careful with medication | 15 |
| Corporation-rent properties | Create regulations for housing corporations (e.g. sun shading) | 20, 33 | Inform | Have a residents' committee that fights for solutions | - |
| | | | | Use removable cooling alternatives | 28 |
| Row houses | Subsidies and regulations | 20, 32 | Inform | Add plants to your balcony | 37 |
| | | | | Replace garden tiles with grass | 38 |
| No shades | Add trees, pergolas, shading fabrics | 29, 40, 47, 52 | Collaborate | Craft shading fabrics together | - |

## Tools for Vulnerability group 3: Social Vulnerabilities Among Single Mothers in Mixed Urban Contexts

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| Women | - | - | - | - | - |
| Children | Educate children (books, color papers) | 7 | Involve | Watch out for sunburns | 7, 12, 13 |
| | Organize summer camps/activities | 56 | Involve | Make sure they drink enough water | 9 |
| | Provide enough shade on playgrounds | 47, 52 | Collaborate | | |
| Unemployed adults | Create jobs, e.g. watering the plants | - | Empower | Sign up as a volunteer | 62 |
| Single-parent households | Organize activities for children | 56 | Involve | - | - |
| Private rent properties | Create regulations for private owners (e.g. sun shading) | 33 | Inform | - | - |
| | Subsidies available for renters | 33 | Inform | | |
| No trees | Add trees | 39, 40 | Collaborate | Plant trees in your garden | 39 |
| A lot of grey surfaces | Add greenery and trees | 39, 40 | Collaborate | Add plants to your balcony | 37 |
| | | | | Adopt a tree | 41 |

## Tools for Vulnerability group 4: Socioeconomically Fragile Families in Green, Low-Density Areas

| PCA Indicator | Municipality Action | # Int. | Collab. | Resident Action | # Int. |
|---|---|---|---|---|---|
| Women | - | - | - | - | - |
| Low-income households | Subsidies | 33, 35 | Inform | Get creative, cooling does not have to be expensive | 19, 28 |
| | Create opportunities for (passive) indoor cooling | 17, 20, 22, 24 | Inform | | |
| | Organize workshops and sessions for affordable tricks | 63 | Involve | | |
| | Create a cool hub | 51 | Collaborate | | |
| Single-parent households | Organize activities for children | 56 | Involve | - | - |

# A.9 Beat The Heat - Interventions

| | Title | Description | Scale | Domain | Cooling effect | Costs | Responsible stakeholder | Target group | Prevention/ response |
|---|---|---|---|---|---|---|---|---|---|
| | **IT STARTS WITH YOUR BEHAVIOUR** | | | | | | | | |
| 1 | **Go to cooler indoor places** | When it gets too hot at home, visit air-conditioned places like libraries, churches, or community centers. | behavior | social | 2 | 0 | community centers, libraries, municipality, volunteers | all, children, elderly, health issues, low SES, migration background, socially isolated | response |
| 2 | **Stay inside during peak heat** | Stay indoors or in the shade during the hottest hours of the day. | behavior | social | 2 | 0 | resident | all | response |
| 3 | **Take it slow** | Avoid intense physical ativities durng the hottest parts of the day and take enough breaks. | behavior | social | 2 | 0 | resident | all | response |
| 4 | **Plan house chores** | Do intense activities such as grocery shopping in the early morning or late afternoon when it's cooler. | behavior | social | 1 | 0 | resident, volunteers | all, elderly, health issues, women | prevention |
| 5 | **Eat light food** | Choose easy-to-digest, light meals such as cold dishes or salads. | behavior | social | 1 | 0 | resident | all | prevention |
| 6 | **Cook outside or eat salad** | Cooking adds heat and moisture. Cook briefly, outside if possible, or eat a cold meal like salad. | behavior | social | 1 | 0 | resident | all, adults, elderly, migration background, women | prevention |
| 7 | **Educate children** | Use playful methods such as books and coloring pages to educate children about heatwaves and what actions to take. | behavior | social | 0 | 0 | community centers, libraries, resident, schools, volunteers | children, adults | prevention |
| 8 | **Care for each other** | Check in on friends and neighbors during hot days, especially vulnerable people. | behavior | social | 0 | 0 | resident, volunteers | all, elderly, health issues, socially isolated | response |
| 9 | **Stay hydrated** | Drink at least 1.5 liters of water daily. Always have a bottle of water close to you. | body | social | 1 | 0 | resident | all, children, elderly, health issues | response |
| 10 | **Cool your body** | Cool your feet, palms, and neck with a wet towel; take a lukewarm shower or use a spray bottle; put a washcloth in the freezer and use it later. | body | social | 2 | 1 | all, resident | all, children, elderly, health issues | response |
| 11 | **Cool water bottle** | Fill a bottle with water and put it in the fridge or freezer to use as a cooling bottle instead of a hot water bottle. | body | physical | 2 | 1 | resident | all, children, elderly, health issues | response |
| 12 | **Adjust your clothes** | Wear loose, breathable clothes. Long sleeves can block sun exposure while staying cool. | body | social | 2 | 1 | resident | all | prevention |
| 13 | **Wear a hat** | Protect your head from the sun with a wide-brimmed hat. | body | social | 1 | 1 | resident | all | prevention |
| 14 | **Use cooling fabrics and packs** | Use cooling scarves, arm coolers, cushions, or towels. | body | physical | 1 | 2 | resident | all, children, elderly, health issues | response |
| | **KEEP YOUR HOUSE COOL** | | | | | | | | |
| 15 | **Air conditioner** | Use an A/C unit to cool indoor spaces. | house | physical | 3 | 2 | resident | all, elderly, health issues | response |

| | Title | Description | Scale | Domain | Cooling effect | Costs | Responsible stakeholder | Target group | Prevention/ response |
|---|---|---|---|---|---|---|---|---|---|
| 16 | **Open windows and doors in the morning or night** | Open windows and doors when it's still cool outside. For extra effect, hang wet sheets in front of the windows. | house | physical | 2 | 0 | resident | all, elderly, health issues | prevention |
| 17 | **Keep doors and windows closed during the day** | Once the temperature rises outside, keep windows and doors closed to trap cooler air inside. | house | physical | 2 | 0 | resident | all, elderly, health issues | prevention |
| 18 | **Upgrade your fan** | Place a frozen water bottle or ice cubes in front of a fan for an extra cooling effect. | house | physical | 2 | 2 | resident | all, children, elderly, health issues, low SES | response |
| 19 | **Support outdoor sun protection** | Help housing corporations install exterior shading devices. | house | political | 2 | 2 | house owner/ VVE, housing corporation, municipality, policy maker | all, adults, elderly, health issues | prevention |
| 20 | **Install green rooftops** | Add vegetation to rooftops to reduce building and air temperature. | house | physical | 2 | 2 | resident, house owner/ VVE, housing corporation, resident | all | prevention |
| 21 | **Add outside sun protection** | Install external sun protection (e.g., awnings, shutters) to block sunlight before it enters your home. | house | physical | 2 | 3 | house owner/ VVE, housing corporation, resident | all, elderly, health issues | prevention |
| 22 | **Insulate buildings** | Proper insulation helps keep heat out during summer. | house | physical | 2 | 3 | house owner/ VVE, housing corporation, resident | all | prevention |
| 23 | **Close curtains during the day** | Keep curtains closed during the day to block out the sun and reduce indoor temperatures. | house | physical | 1 | 0 | resident | all, elderly, health issues | prevention |
| 24 | **Cross-ventilate** | Open windows on opposite sides of your home in the morning for better airflow. | house | physical | 1 | 0 | resident | all, elderly, health issues | prevention |
| 25 | **Turn off electric devices** | Electrical appliances like lights, TVs, ovens, and dishwashers produce heat. Turn them off when not in use. | house | physical | 1 | 0 | resident | all, elderly, low SES | prevention |
| 26 | **Prevent moist air inside** | Moist air feels warmer. Dry clothes outside and limit steam-producing activities. | house | physical | 1 | 0 | resident | all, elderly, health issues | prevention |
| 27 | **Add indoor sun blockers** | Use blackout curtains or custom-cut cardboard to block sunlight from inside. | house | physical | 1 | 1 | resident | all, elderly, health issues | prevention |
| 28 | **Replace lights with LEDs** | Replace traditional bulbs with LED lights that emit less heat. | house | physical | 1 | 1 | resident | all | prevention |
| 29 | **Limit sun reflections** | Limit building surfaces to 20% sunlight reflection to reduce UHI and improve comfort. | house | political | 1 | 1 | house owner/ VVE, housing corporation, municipality, urban planner | all | prevention |
| 30 | **Green property boundaries** | Replace fences with hedges or climbing plants. | house | physical | 1 | 2 | house owner/ VVE, housing corporation, resident | all | prevention |

| Title | Description | Scale | Domain | Cooling effect | Costs | Responsible stakeholder | Target group | Prevention/ response |
|---|---|---|---|---|---|---|---|---|
| 31 **Green facades** | Use vertical gardens or climbing plants on walls to cool buildings. | house | physical | 1 | 3 | house owner/ VVE, housing corporation, urban planner | all | prevention |
| 32 **Regulations for house renters** | Enable renters to make home adjustments, such as allowing sun protection and offering subsidies. | house | political | 0 | 0 | house owner/ VVE, housing corporation, municipality, policy maker | all, adults, elderly, health issues | prevention |
| 33 **Burglar-proof windows** | Install secure windows that allow for safe night ventilation. | house | physical | 0 | 2 | resident, house owner/ VVE, housing corporation, resident | all | prevention |
| 34 **Small subsidies** | Offer small grants for items like fans or blackout curtains. | house | political | 0 | 2 | municipality | all, low SES | response |
| **BALCONY & GARDEN** | | | | | | | | |
| 35 **Add shading to your balcony** | Create shade on your balcony using a parasol, sun tarp, or canvas to prevent heat from entering your home. | balcony, garden | physical | 2 | 2 | house owner/ VVE, housing corporation, resident | all, elderly, health issues | prevention |
| 36 **Add plants to your balcony** | Plants help reduce heat on balconies; create a small balcony garden. | balcony, garden | physical | 1 | 1 | house owner/ VVE, resident | all, adults | prevention |
| 37 **Replace garden tiles with grass** | Swap garden tiles for grass or plants to reduce heat buildup. | garden | physical | 1 | 0 | house owner/ VVE, housing corporation, resident | all | prevention |
| 38 **Plant more trees** | Plant trees along streets to provide shade and reduce heat. | garden, neighbor hood | physical | 3 | 1 | house owner/ VVE, housing corporation, municipality, resident, urban planner | all | prevention |
| **AN ADAPTIVE STREET** | | | | | | | | |
| 39 **Green strips with trees** | Add tree-lined green strips along roads, possibly in a zigzag pattern. | street | physical | 3 | 2 | municipality, urban planner | all | prevention |
| 40 **Adopt a tree** | Adopt a tree, and plant plants and flowers in the tree bedding. | street | physical | 2 | 1 | resident, volunteers | all, adults, socially isolated | prevention |
| 41 **Create shading on streets and walkways** | Add shade structures like tarps, umbrellas, or pergolas to streets for comfort and heat reduction. | street | physical | 2 | 2 | municipality, urban planner | all | prevention |
| 42 **From parking to park** | Convert parking spots into small green areas. | street | physical | 2 | 2 | municipality, urban planner | all | prevention |
| 43 **Shaded pathways** | Ensure at least 40% shade coverage on busy walking routes using trees or coverings. | street | physical | 2 | 2 | municipality, urban planner | all | prevention |

| | Title | Description | Scale | Domain | Cooling effect | Costs | Resonsible stakeholder | Target group | Prevention/ response |
|---|---|---|---|---|---|---|---|---|---|
| 44 | **Green pergolas above sidewalks** | Install pergolas above sidewalks and plant climbing greenery. | street | physical | 2 | 3 | municipality, urban planner | all | prevention |
| 45 | **Micro gardens along facades** | Remove a row of pavement tiles along your facade to plant greenery. | street | physical | 1 | 1 | resident, volunteers | all, adults, socially isolated | prevention |
| 46 | **Give trees more space** | Expand tree beds to allow for healthier and cooler greenery. | street | physical | 1 | 1 | municipality, urban planner | all | prevention |
| 47 | **Permeable pavement** | Use permeable or green materials for streets and parking to reduce heat retention. | street | physical | 1 | 2 | house owner/ VVE, housing corporation, municipality, urban planner | all | prevention |
| 48 | **Provide shaded benches** | Place seating in shaded areas. | street | physical | 1 | 2 | municipality, urban planner | all | response |
| 49 | **Wet surfaces** | Add small fountains or water features to cool the air through evaporation. | street | physical | 1 | 2 | municipality, urban planner | all | prevention |
| 50 | **Fountains** | Install moving water features to naturally cool the surrounding air. | street | physical | 1 | 2 | municipality, urban planner | all | prevention |
| | **NEIGHBOURHOOD** | | | | | | | | |
| 51 | **Consider street orientation** | Design streets with shade elements on the sunny (usually north) side. | neighbor hood | physical | 3 | 2 | municipality, urban planner | all | prevention |
| 52 | **Adjust library opening hours** | Keep libraries open daily from 08:00–19:00 to offer cooling shelter. | neighbor hood | political | 2 | 1 | community centers, libraries, municipality, volunteers | all, children, elderly, health issues, low SES, migration background, socially isolated | response |
| 53 | **Create a cool hub** | Designate public buildings as "cool hubs" with sufficient air conditioning. | neighbor hood | physical | 2 | 2 | community centers, libraries, municipality, volunteers | all, children, elderly, health issues, low SES, migration background, socially isolated | response |
| 54 | **Shade busy public spaces** | Add trees or coverings to playgrounds and plazas. | neighbor hood | physical | 2 | 2 | municipality, urban planner | all | prevention |
| 55 | **Create mobile shade carts** | Use movable shade structures for markets, schoolyards, or events. | neighbor hood | physical | 2 | 2 | all | all | response |
| 56 | **3-30-300 principle** | Aim for: 3 trees visible from your home, 30% canopy in the neighborhood, and a green space within 300m. | neighbor hood | physical | 2 | 3 | municipality, urban planner | all | prevention |
| 57 | **Public drinking fountains** | Install water fountains in public spaces for easy hydration access. | neighbor hood | physical | 1 | 2 | municipality, urban planner | all, children, elderly, health issues | response |

| | Title | Description | Scale | Domain | Cooling effect | Costs | Resonsible stakeholder | Target group | Prevention/ response |
|---|---|---|---|---|---|---|---|---|---|
| 58 | **Summer holiday activities** | Organize indoor or shaded summer activities for children. | neighbor hood | social | 1 | 2 | community centers, libraries, municipality, schools, volunteers | children | prevention |
| 59 | **Wadis** | Replace pavement with green water retention areas that can double as play spaces. | neighbor hood | physical | 1 | 2 | housing corporation, municipality, urban planner | all | prevention |
| 60 | **Provide information in different languages** | Share heat-related information in various languages and formats (formal/informal, online/offline). | neighbor hood | social | 0 | 0 | community centers, GGD, GP, libraries, municipality, policy maker, schools | all, children, elderly, migration background | prevention |
| 61 | **Adjust green regulations** | Loosen rules to let citizens create more greenery on and around their property. | neighbor hood | political | 0 | 0 | municipality, policy maker | all | prevention |
| 62 | **WhatsApp Communities for vulnerable people** | Create WhatsApp groups that enable vulnerable residents to ask for support | neighbor hood | social | 0 | 0 | resident, volunteers | all, elderly, socially isolated | prevention |
| 63 | **Deploy social workers and volunteers** | Temporarily increase caretakers or volunteers to check on socially isolated or vulnerable residents. | neighbor hood | social | 0 | 1 | community centers, GGD, GP, libraries, municipality, volunteers | elderly, health issues, socially isolated | response |
| 64 | **Organize heat resilience workshops** | Host workshops on how to stay cool and adapt homes affordably. | neighbor hood | social | 0 | 1 | community centers, GGD, GP, libraries, municipality, volunteers | all | prevention |
| 65 | **Finance green initiatives** | Provide financial support for projects that increase green infrastructure. | neighbor hood | political | 0 | 2 | municipality | all | prevention |