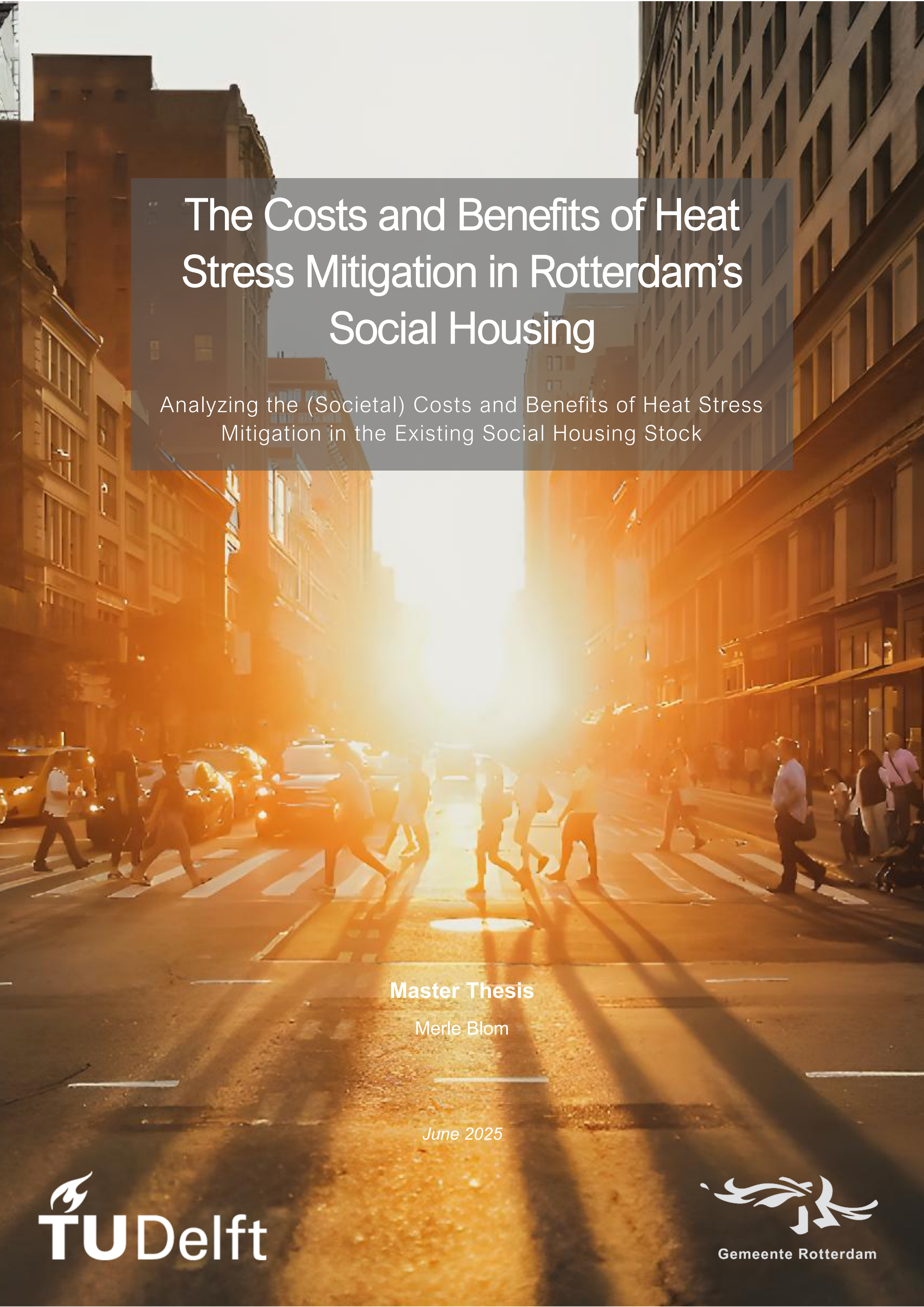

# The Costs and Benefits of Heat Stress Mitigation in Rotterdam's Social Housing

Analyzing the (Societal) Costs and Benefits of Heat Stress Mitigation in the Existing Social Housing Stock

**Master Thesis**

Merle Blom

*June 2025*

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# Abstract

Due to climate change, urban heat stress is becoming an increasing problem, affecting mostly vulnerable populations. Tenants of social housing are particularly vulnerable to the effects of extreme heat, due to inadequate social housing conditions and limited financial resources for cooling interventions. However, due to limited financial resources, housing corporations struggle to implement heat stress mitigation measures into their existing building stock. Therefore, this thesis examines how heat stress mitigation measures for the existing social housing stock can be both socially and financially viable. The formulated research question of this thesis is: ***What are the long-term costs and benefits of mitigating heat stress in the existing social housing stock?***

To answer this research question, a mixed method approach was adopted, in which the first part of the research encompassed a literature review, followed by an empirical case study on Rotterdam. The findings of the research reveal that if indoor heat stress in social housing remains unaddressed, it poses significant risks to the health, energy and financial sectors. Health impacts, such as heat-related mortality and hospitalizations, emerged as the most severe impact, both in human and economic terms. The climate risk assessment indicated that under the high climate scenario, the risk of heat stress in Rotterdam rises significantly. Furthermore, the areas identified as most vulnerable to heat stress socially and (bio)physically are Delfshaven, the Oude Noorden, and the upper south of Rotterdam. In terms of mitigation strategies, the research concluded that passive measures such as shading and natural ventilation are the most effective way to reduce indoor heat stress. Lastly, the societal cost-benefit analysis demonstrated that, under both low and high climate scenarios, the benefits of mitigation outweigh the implementation costs. However, these benefits are unevenly distributed. While housing corporations bear the costs, the benefits accrue to the health, energy, and financial sector. This creates a split incentive that challenges implementation. In conclusion, reducing heat stress in social housing is both societally and economically beneficial. However, while the societal advantages are evident, practical feasibility requires stronger financial support.

**Key words** – Heat stress, social housing, Urban Heat Island effect, climate adaptation, climate equity, societal cost-benefit analysis

# Preface

This thesis explores the long-term costs and benefits of mitigating heat stress in the existing social housing stock. It has been written as part of the graduation for the MSc Architecture, Urbanism and Building Sciences, for the Management in the Built Environment track at TU Delft. Over the past few months, I have been exploring this topic motivated by an interest in how social and environmental issues intersect in our cities.

The growing frequency and intensity of heatwaves in the Netherlands is no longer a distant climate scenario, it is a lived reality, particularly for those with limited means to adapt. When I moved to Rotterdam just before last summer, I experienced firsthand how hot a top-floor apartment can become during warm days. While I was able to afford basic cooling measures like fans and could have turned to air conditioning if needed, not everyone has that option. For many, especially in social housing, staying cool during extreme heat is not a matter of comfort but of vital importance. This experience highlighted how some people are more affected by climate risks and how socioeconomic status often determines who bears the brunt of these impacts. It also deepened my interest in how climate resilience can be achieved more equitably. This thesis topic stems from this, focusing on how the social housing sector can address heat stress in a way that is both equitable and financially feasible.

Writing this thesis has been both an educational and fulfilling process, which I would not have been able to complete without the support and encouragement of several people. First, I would like to express my gratitude to my thesis supervisors Audrey Esteban, Marietta Haffner and Zac Taylor, for their guidance throughout my thesis. Their feedback, suggestions and great knowledge of the topic have helped me a lot during the research. From helping me sharpen the research question to providing constructive input, their mentorship has been incredibly valuable. I have learned a lot from their expertise and am very thankful for their time, encouragement and insights.

In addition, I would like to thank my internship supervisors at the Municipality of Rotterdam, Tineke Keuzenkamp and Tara van Iersel, for their involvement and support during the research. Their practical insights were extremely helpful and played an important role in the empirical part of my thesis. I am grateful for their help in connecting me with stakeholders involved in heat stress mitigation in Rotterdam, which allowed me to gain a broader perspective and gather insightful information for the research.

Furthermore, I would like to thank everyone who contributed to this research. I appreciate the time they took to speak with me and the thoughtful conversations that contributed to the research. I am especially grateful to the interviewees for their time and for sharing their insights and experiences. Lastly, I would like to thank my family and friends for their support, encouragement, perspective and the occasional distraction when I needed it most. Your patience and understanding helped me stay motivated throughout this process.

Enjoy reading my thesis!

Merle Blom

*Rotterdam, June 2025*

# Executive summary

## Introduction

Due to climate change, global temperatures are rising, leading to more frequent and severe heatwaves (IPCC, 2007; KNMI, 2023). These heatwaves and the overall rise in temperatures pose risks to the population's health, energy systems, economic sector, and infrastructure (Runhaar et al., 2012; IPCC, 2023; Hayhoe et al., 2010; Santamouris, 2019). Urban areas face even more risks, due to the Urban Heat Island (UHI) effect caused by the dense urban infrastructure (Santamouris, 2019).

In the Netherlands, social housing tenants are at great risk for heat stress, as the social housing dwellings are often older and heat retaining. Moreover, low-incomer tenants often lack the resources to take measures against heat themselves (Reckien et al., 2017). Zuurbier et al. (2024) even state that *"the poorest neighborhoods are usually the warmest neighborhoods"*. Consequently, health issues, rising energy costs for cooling and deepening social inequalities are expected to increase without mitigation interventions. Thus, housing corporations are under pressure to enhance heat resilience, but face budget constraints that limit their capacity to take measures. These combined challenges of climate change, social vulnerability and financial constraints emphasize the demand for socially responsible and financially feasible strategies for heat stress resilience in the social housing sector.

While environmental and health impacts of heat stress are increasingly recognized, significant gaps remain regarding the economic feasibility and the social outcomes of heat mitigation measures in social housing. Additionally, the absence of regulatory requirements of heat stress within existing dwellings leaves a large portion of the urban population exposed to (future) risks. To address these gaps, this thesis explores the following research question:

***"What are the long-term costs and benefits of mitigating heat stress in the existing social housing stock?"***

To answer this research question, the following sub-questions have been developed:

> **SQ1**: *"What risks and costs could arise if heat stress is not addressed in the existing social housing stock?"*
>
> **SQ2**: "*What areas are most vulnerable to the risks of heat stress?"*
>
> **SQ3**: *"What measures can be taken to mitigate heat stress in existing properties of housing corporations and what are the costs of implementing these measures?"*
>
> **SQ4**: *"How do the economic and social benefits of implementing heat stress mitigation measures into social housing demonstrate the value of the costs of the mitigation measures?"*

Drawn from the insights of the literature, the heat stress impact frameworks and guided by the research questions, a conceptual model for the research was developed in Figure 0.1.

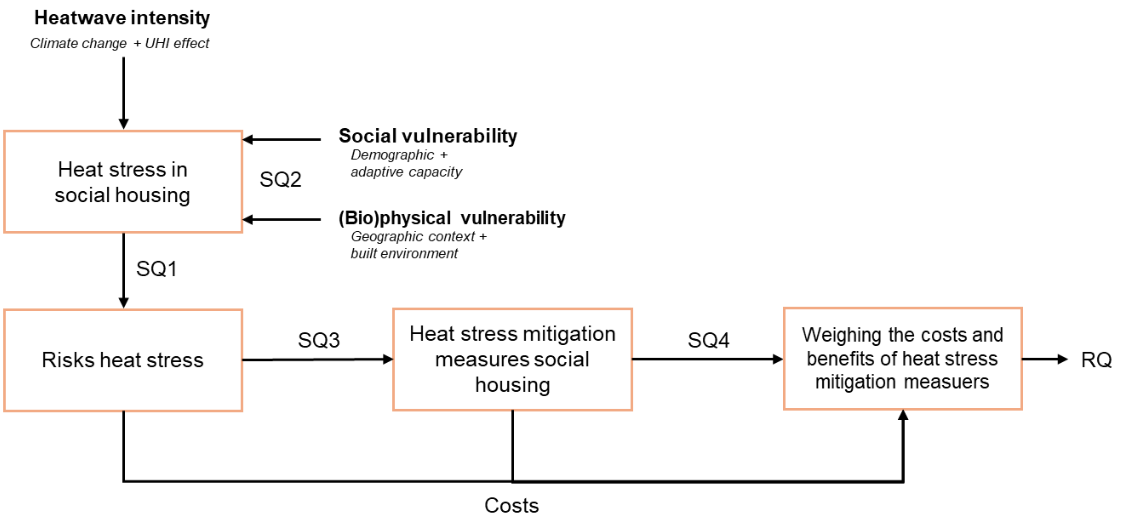


*Figure 0.1: Conceptual model (Own work)*

Through answering the sub-questions, this research aims to evaluate the long-term financial and social impact of implementing heat stress mitigation measures in existing dwellings of housing corporations. By analyzing the effectiveness, investment costs and maintenance costs of the measures, alongside the benefits, such as tenant health, the research aims to guide housing corporations in their heat stress mitigation strategy and explore how municipal and national policies could support these efforts.

The research will follow a mixed method approach, combining both qualitative and quantitative techniques. First, a literature review has been conducted to establish the theoretical foundation of the research. Thereafter, for the empirical part of the research a case study has been conducted. Rotterdam was selected for the case study, because of its exposure to high urban temperatures caused by the Urban Heat Island (UHI) effect and large share of social housing. These factors make Rotterdam a relevant case for researching the challenges and opportunities related to heat stress mitigation in the social housing sector. Consequently, to assess the economic and societal costs and benefits of indoor heat stress mitigation in Rotterdam, a social cost-benefit analysis was conducted. This method was chosen to assess the costs and benefits of heat stress, as it monetizes both the costs and benefits, allowing for a comprehensive and objective comparison.

## Findings

This research explored the long-term costs and benefits of mitigating heat stress in the existing social housing stock through four sub-questions. The first sub-question examined the potential consequences of inaction, revealing that if indoor heat stress is not mitigated it poses growing risks to the population's health, the energy sector and the financial sector. A climate risk assessment of Rotterdam found that while the city currently faces a medium risk of heat stress, this could rise to a high risk under the high-emission scenario. Moreover, the future costs of the risks of indoor heat stress for the low and high climate scenarios in Rotterdam were estimated for the health, energy and financial sectors. These findings showed that the costs of unaddressed heat stress fall mostly in the health and energy sector, consisting of the heat-related hospitalizations and mortalities and the costs for cooling.

The second sub-question identified the most vulnerable areas to heat stress in Rotterdam by mapping the social and (bio)physical vulnerability. The neighborhoods that emerged as highly vulnerable and in most need of mitigation were Delfshaven, Oude Noorden and several neighborhoods in the upper south of Rotterdam. The findings also confirmed climate inequity, showing that social housing tenants are disproportionately exposed to heat stress and are dependent on housing corporations for mitigation interventions.

The third sub-question focused on identifying effective and feasible mitigation strategies. Shading, ventilation and installations (e.g., air conditioners) were found to be the most effective measures. However, housing corporations indicated they strongly favor passive mitigation measures, such as shading and ventilation. Expert interviews revealed that around 15.000 dwellings in Rotterdam's social housing stock are considered highly vulnerable to heat stress. Nevertheless, mitigating heat stress in these dwellings is complicated by the financial capacity of the housing corporations, due to the absence of an incentive for the corporations.

Sub-question four assessed the societal and financial value of these measures through a social cost-benefit analysis. The societal cost-benefit analysis showed that under both the low and high climate scenarios, the benefits of mitigation outweigh the costs. However, there is a split incentive in these costs and benefits. The benefits of heat stress mitigation lie with the health, energy and financial sectors, through for example less hospitalizations and a reduced energy demand, while the costs of mitigation lie with the housing corporations.

In conclusion, the findings show that mitigating heat stress in the existing social housing stock in Rotterdam is socially and economically beneficial in the long term. However, the misalignment of the costs and benefits poses challenges for implementation. Therefore, policy interventions, such as implementing legal standards for thermal comfort in the existing building stock or integrating heat stress mitigation into the *woningwaarderingsstelsel* (housing valuation system) are suggested to support financially viable and equitable heat resilience in the social housing sector. Concurrently, indoor heat stress is one of many interconnected environmental and social challenges disproportionately impacting vulnerable urban populations, highlighting the need to align mitigation efforts with broader climate resilience and social equity initiatives in social housing.

## Discussion

The research indicated that indoor heat stress poses significant risks to the health, energy, and financial sectors, particularly affecting vulnerable populations in social housing. The findings showed that there is a connection between social vulnerability and exposure to heat stress, supporting previously conducted studies that show low-income populations are disproportionately impacted by heat. Furthermore, the findings of the societal cost-benefit analysis show that the long-term societal benefits of implementing heat stress mitigation measures outweigh the associated costs. However, the investment costs are now borne by the housing corporations, while the benefits fall across several sectors. This creates a split incentive that discourages action from being taken, especially in the absence of legal requirements or effective subsidies. Therefore, this research underscores the need for policies regarding the existing social housing stock and provides insights to inform heat stress mitigation strategies.

Nevertheless, while providing valuable insights, the research also faced several limitations. For the qualitative part of the thesis, a limited number of expert interviews were conducted, which might have limited the diversity of perspectives. In the qualitative part of the research, estimates were used in parts of the societal cost-benefit analysis, due to the limited amount of data available.

## Recommendations for practical implementation

This thesis provides practical insights for stakeholders involved in mitigating heat stress in the existing social housing stock. For housing corporations, the research presents the potential risks of inaction and informs investment decisions by indicating the effectiveness and costs of various mitigation measures. For the Municipality of Rotterdam, the research findings can be used to allocate resources more efficiently through the results of the vulnerability maps. Moreover, the findings of the societal cost-benefit analysis can be used to develop subsidies. On a national level, the findings indicate the importance of addressing the policy gap for heat stress in existing dwellings or suggest integrating mitigation measures into the *woningwaarderingsstelsel* (housing valuation system) to improve financial feasibility.

Additionally, the research identifies opportunities for involving other stakeholders, such as healthcare insurance providers and energy network providers, who may benefit from reduced health impacts and lower peak energy demands. Overall, the research aims to provide a strategic framework for advancing heat stress mitigation in social housing from both a financial and social perspective.

## Recommendations for future research

During the writing of the thesis several opportunities for future research arose. These recommendations include conducting a societal cost-benefit analysis of outdoor heat stress mitigation and comparing it to the findings of indoor heat stress to determine the most effective investment strategy. Additionally, future research could focus on heat stress mitigation on a neighborhood-level, to better understand localized vulnerabilities and address mitigation strategies accordingly. Moreover, expanding the scope of the analyzed benefits, such as mental health impacts and social wellbeing, could provide a more comprehensive understanding of the benefits of heat stress mitigation. Lastly, exploring innovative financial models and stakeholder cost-sharing mechanisms could support a more feasible implementation of heat resilience measures, as the societal benefits do not accrue to the housing corporations.

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# 1. Introduction

## 1.1 Problem statement

Climate change leads to rising global temperatures, impacting natural environments, economies and societies. As temperatures rise and weather patterns shift, more severe climate-related events will occur (IPCC, 2007). Over the past three decades, the frequency and intensity of these climate-related events, such as floods and heatwaves, have increased substantially, resulting in disruptive effects on human well-being, the economy and the built environment (Rędzińska & Piotrkowska, 2020; Wamsler et al., 2013). Though climate change affects every part of the world, cities face additional risks, as they are densely populated. The rapid speed of urbanization has intensified these challenges, turning cities into focus points for both the consequences of climate change and the urgent need for adaptation (Wamsler et al., 2013).

According to the International Panel on Climate Change (IPCC) (2007), climate models project significant global temperature increases throughout the 21st century, primarily driven by human-caused greenhouse gas emissions. If these emissions continue to increase, even more severe warming is anticipated later in this century, as indicated in Figure 1.1, showing the estimated climate scenarios of the average temperature in the Netherlands. As a result of this warming, there will be more intense and frequent heatwaves and fewer cold events (IPCC, 2007; KNMI, 2023).

Consequently, these temperature increases and heatwaves lead to exacerbated health risks (Runhaar et al., 2012), strained infrastructure (IPCC, 2023), and an increased energy demand (Hayhoe et al., 2010, Santamouris, 2019), disproportionately impacting vulnerable populations (Elmarakby & Elkadi, 2024). Moreover, the consequences of the temperature increases will be more intense in urban areas due to the Urban Heat Island (UHI) effect (Santamouris, 2019).

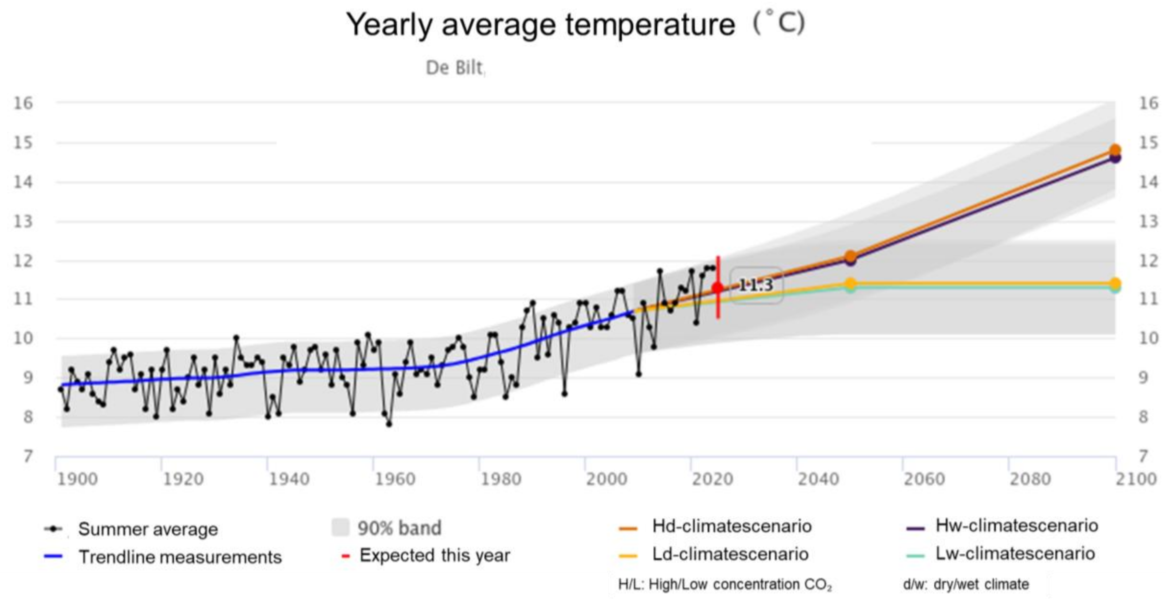



*Figure 1.1: Summer average maximum temperature the Netherlands (KNMI, 2025)*

Thus, climate change and the UHI effect pose a critical challenge to Dutch urban areas, where rising temperatures and more frequent heatwaves increase heat related risks. However, extreme heat remains underexposed in municipal climate policies compared to issues like heating in the winter, flooding and drought (Didde, 2024; De Vries et al., 2020). Moreover, within Dutch urban areas social housing tenants are especially vulnerable, as a large part of the social housing stock consists of older, poorly insulated buildings that retain heat (Sneep, 2024). Furthermore, lower-income tenants that live in social housing often lack resources for cooling measures (Reckien et al., 2017). Housing corporations, providers of social housing in the Netherlands, are thus obliged to improve heat resilience in the social housing stock, but the corporations often lack financial means to implement mitigation measures. Without adequate resources to improve heat resilience within the dwellings, the corporations struggle to improve the living conditions of tenants, leaving at-risk populations increasingly vulnerable to the effects of urban heat stress. This underscores the need for socially and environmentally sustainable and financially viable strategies to enhance heat resilience in social housing.

# 1.2 Literature research heat stress

## *1.2.1 Heat in urban areas*

As global temperatures are rising, the frequency, intensity and duration of heatwaves is increasing, resulting in heat stress becoming a pressing issue in urban areas. Heatwaves are defined as prolonged periods of high temperatures that are higher than the ordinary seasonal averages and are caused by the existence of high pressure systems that increase the air and surface temperatures in an area (Li & Bou-Zeid, 2013). In the Netherlands heatwaves are described by the KNMI (2023) as periods of at least five days above 25°C, including three days over 30°C. This trend of more frequent and severe heatwaves has become increasingly visible in the Netherlands, highlighting the urgent need for effective heat mitigation measures (KNMI, 2023).

Urban areas are more vulnerable to the effects of increasing temperatures than suburban areas, due to the UHI (Urban Heat Island) effect (Li & Bou-Zeid, 2013). The UHI effect refers to the phenomenon where city temperatures are significantly higher than those of surrounding suburban and rural areas (Santamouris, 2019). The UHI effect is driven by various factors, including the thermal characteristics of urban materials, heat emissions from human activities, the urban greenhouse effect, reduced evaporative surfaces, restricted airflow and increased heat absorption from impervious surfaces, leading to less nighttime cooling (Santamouris, 2019; Li et al., 2020).

Furthermore, research by Li & Bou-Zeid (2013) concluded that heatwaves also synergistically interact with UHI's. This amplifies the temperature difference between urban and rural areas. Urban areas are already exposed to higher temperatures due to the UHI effect, making the combined impact of heatwaves and UHI further worsening local climate conditions in cities. Therefore, compared to suburban areas, cities are more vulnerable to heat-related health problems, infrastructure problems, and a higher energy demand (Li & Bou-Zeid, 2013; Hayhoe et al., 2010). To mitigate the effects of heat stress on urban residents and infrastructure, addressing these issues has been a focus area of urban heat research (Santamouris, 2019).

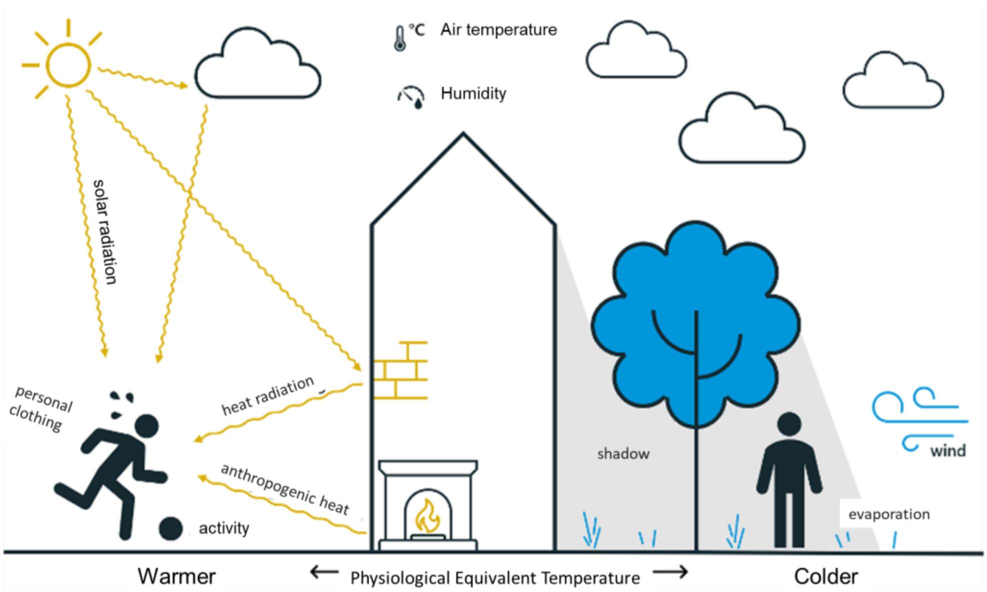



*Figure 1.2: Physiological Equivalent Temperature (Klimaateffectatlas, n.d.)*

Heat stress is usually measured in Physiological Equivalent Temperature (PET) compared to just the air or surface temperature, as the PET provides a more accurate representation of how heat is experienced by individuals in different environments (Figure 1.2). While air and surface temperatures indicate how warm the air or surface is, PET considers multiple factors, including wind speed, humidity, solar radiation and heat emitted by surfaces, which significantly influence perceived temperature (Klimaateffectenatlas, n.d.). Consequently, PET better reflects the heat stress experienced by people through integrating both the meteorological conditions and the characteristics of the built environment.

### 1.2.2 Heat stress on different levels

Besides climate change rising global temperatures, urban heat stress is also impacted by local conditions at three levels: the area, the building, and the user level (Van der Strate et al., 2022). Understanding how factors on these levels have an impact on heat stress can provide insights into how heat stress emerges and how it can be mitigated. First, there is heat stress on an area level, which is influenced by the environmental or broader urban context. This can include factors like UHI's, the presence of green spaces, the building density, and the overall climate conditions in an area (Ahmed et al., 2023). Hence, it focuses on the external environmental conditions that contribute to heat stress in a certain area.

Then there is heat stress on a building level, which refers to the specific characteristics of a building that contribute to heat stress. This can include factors such as the building's insulation, roofing materials, windows, ventilation, and shading (Nationaal Kennis- en innovatieprogramma Water en Klimaat, 2023). The building's design, construction and exposure to sunlight all influence how heat is absorbed, stored, or released within the building. Lastly, at the user level, the influence of heat stress factors refers to how the actions and habits of the building's tenants can either exacerbate or mitigate heat stress. This includes factors such as how residents manage indoor temperatures through ventilation or shading, and how they adapt to high temperatures (Willems & Nonner, 2021).

### 1.2.3 Heat stress in dwellings

As mentioned in the previous section, several factors influence indoor temperatures and contribute to excess heat within a building. In dwellings, prolonged exposure to high indoor temperatures can cause thermal discomfort, a condition linked to the 'Sick Building Syndrome'. The 'Sick Building Syndrome' refers to circumstances in which tenants have unidentified health or comfort problems that appear to be related to their time spent indoors (Joshi, 2008). Moreover, without adequate ventilation and cooling, indoor heat can also lead to an increase in indoor air pollutants, which could cause more health symptoms, further affecting the tenant's health and well-being (Niza et al., 2023). Therefore, understanding the influences that contribute to heat stress in dwellings is essential, as they determine how these factors can be mitigated. By recognizing the factors contributing to heat stress, more effective strategies can be implemented to enhance thermal comfort and resilience within buildings.

Foremost, solar radiation is a primary driver of heat gain within dwellings. The extent to which a dwelling is exposed to direct sunlight depends on multiple factors, such as building orientation, window placement, shading from surrounding structures, and dwelling type (De Vries et al., 2020). Dwellings with large south- or west-facing windows, for example, tend to experience higher indoor temperatures due to more sun exposure. The type and percentage of glazing also plays an important role, as solar radiation enters the dwelling through windows (Taylor et al., 2014).

Furthermore, ventilation has an influence on indoor temperatures, because it permits heat to move out and allows fresh air to flow in. The effectiveness of ventilation depends on factors such as window placement, resident behavior towards ventilation, the possibility of cross-ventilation, and external conditions, like wind patterns and air quality. For instance, tenants in dwellings in areas that are noisy or have high concentrations of air pollutants are less likely to open windows, leaving them more susceptible to heat stress (Taylor et al., 2014; De Vries et al., 2020).

The presence of greenery in the immediate surroundings of a dwelling can also lower the temperature within the dwelling. Greenery, like trees, can help mitigate the urban heat island effect by providing shade and cooling through evapotranspiration. Moreover, trees and green roofs can reduce solar radiation reaching the building facade, leading to lower indoor temperatures (Taylor et al., 2014).

To assess and regulate the extent to which dwellings are susceptible to overheating by these factors, the Dutch government introduced the TO-July requirement in 2021 (Rijksdienst voor Ondernemend Nederland, 2017). The TO-July requirement, which currently only applies to newly constructed dwellings, aims to minimize the risk of overheating and improve thermal comfort (Nationaal Kennis- en Innovatieprogramma Water en Klimaat, 2023). The TO-July value is an indicator that reflects the risk of excessive indoor heat, calculated based on a dwelling's cooling demand in July. The higher the TO-July value, the greater the risk of overheating, with the maximum allowable value set at 1,20 (Kluck et al., 2023). The value of the TO-July is derived from an energy performance calculation following the NTA8800 method, which calculates the required thermal comfort through passive or active cooling strategies (Rijksdienst voor Ondernemend Nederland, 2017; De Vries et al., 2020). If a dwelling exceeds the limit of 1,2, additional measures, such as shading, ventilation, or cooling, must be implemented to adhere to the requirements (Rijksdienst voor Ondernemend Nederland, 2017). Thus, by obligating dwellings to stay under a threshold for overheating, the TO-July requirement reduces the risk of excessive indoor heat. Furthermore, the GTO (Weighted Temperature Exceedance) method can be used to determine the risk of overheating in more detail. However, this method has not been adopted in regulatory frameworks yet (Kluck et al., 2023).

### *1.2.4 Health risks heat stress*

After understanding which factors influence heat stress, this section focuses on the risks that heat poses to the population's health, particularly for vulnerable people (Section 1.2.6). As temperatures increase, the natural cooling mechanisms of some people are not equipped to deal with overheating, especially during extended exposure to high temperatures. Without mitigation, heat stress can lead to several health-related consequences, including increased mortality, illnesses and distress (Runhaar et al., 2012).

#### *Heat related mortality*

Mortality is the most severe risk as a consequence of heat stress. In a study by Huynen et al. (2001), it is shown that heatwaves lead to an increase in mortalities, particularly among the elderly and people with pre-existing health issues (Elmarakby & Elkadi, 2024; Dong et al., 2020; Arsad et al., 2022; Amengual et al., 2014). For example, in the Netherlands, the heatwave of the summer of 2003 saw an estimated excess of 1.000 deaths (Garssen et al., 2005). In Figure 1.3 this relation between the average daily temperature and excess mortality in the Netherlands is shown (Huynen et al., 2001).

Moreover, in Figure 1.4, research by CBS and the Ministry of Infrastructure and Water Management that was conducted in 2019 predict that the rising temperatures in combination with the aging population will cause an even larger surge in mortality rates in the future (Visser & Oosterholt, n.d.). In addition to a higher risk of mortality and illness burden during heatwaves, there also is a higher risk of mortality and disease associated with higher temperature throughout the year (Hall et al., 2021).

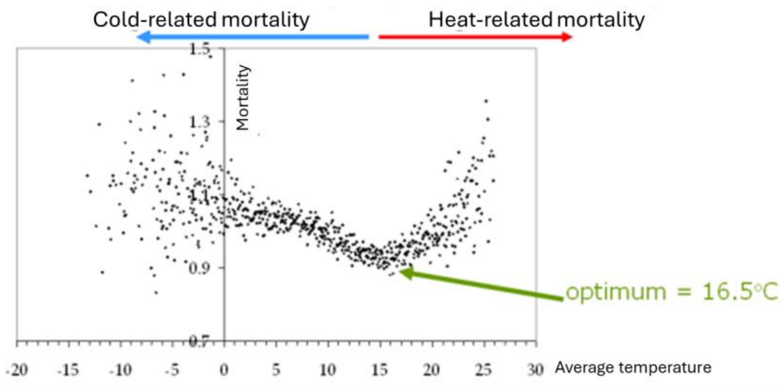



*Figure 1.3: Relation between excess mortality and daily temperatures in the Netherlands (Huynen et al., 2001)*

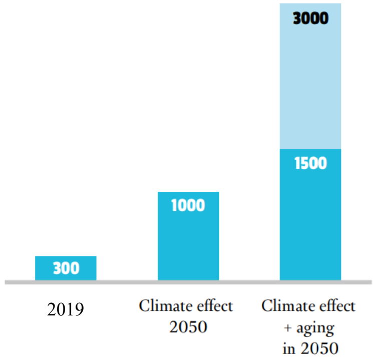



*Figure 1.4: Projected number of heat casualties in 2019 and in 2050 with unchanged policies (Visser & Oosterholt, n.d.)*

However, the study by Huynen et al. (2001) also showed the possibility of a 'harvesting' effect in which people with pre-existing health issues are among the people that were likely to pass away regardless of the high temperatures, though these results on forward displacement were not conclusive. The research concluded that mortality decreased after certain heatwaves, but not after others (Huynen et al., 2001).

Nevertheless, these findings still highlight the importance of mitigating the impact of heat stress, particularly for vulnerable populations such as the elderly and those with pre-existing health conditions. Especially as climate projections predict even warmer summers and more frequent heatwaves in the future and the threat of heat stress and heat related mortalities is likely to increase (Van den Hurk et al., 2006). Moreover, research by Betgen et al. (2024) from the RIVM (National Institute for Public Health and the Environment) concluded that the overall impact of high temperatures on people is high, with more than 100.000 people affected by heat annually. Additionally, between 1991 and 2020, climate change was responsible for 31% of temperature-related deaths, highlighting the growing threat of heat-related mortality due to rising temperatures (Betgen et al., 2024).

### *Heat related illnesses*

Besides the fact that heat stress can lead to mortality, it can also instigate heat-related illnesses. Exposure to heat can strain various systems in the body, particularly those responsible for maintaining temperature regulation, like the cardiovascular system. Consequently, the cardiovascular system is significantly impacted by heat. When the body is exposed to heat, the blood flow to the skin increases to release extra heat. This increase in circulation reduces the return of blood to the heart, resulting in the heart accelerating its contraction rate (Adolph, 1947). When people are exposed to extreme heat, their body's regulatory mechanisms can fail, particularly among vulnerable groups (Daanen, 2010).

Heat-related illnesses range from mild to severe and can occur independently or in combination with one another. Common heat-related illnesses include heat rash, heat cramps, heat exhaustion and heatstroke (Howe & Boden, 2007). The milder forms of heat-related illnesses are heat rash and heat cramps. Heat rash is caused by blocked sweat glands causing blisters, while heat cramps can be caused by an electrolyte balance due to low salt levels. Furthermore, heat exhaustion, a more severe heat related illness, can be caused by physical activity in high temperatures (Howe & Boden, 2007).

The most severe illness caused by heat stress is heat stroke, this can happen when the body fails to regulate its temperature under extreme heat. Symptoms of heat strokes include heat exhaustion, high body temperature, confusion, seizures, and unconsciousness (Howe & Boden, 2007). Additionally, heat strokes can even lead to more severe complications such as organ failure (Bouchama et al., 2007). In addition to the physical effects, heat can also aggravate mental health illnesses, due to heightening physical discomfort, disrupted sleep and increased irritability, which affect people's emotional state (IPCC, 2023).

As a result of an increase in heat related illnesses, heat can lead to a strain on urban healthcare systems. During heatwaves, hospitals and emergency services often experience a surge in emergency cases and hospital admissions, limiting their ability to provide treatment for everyone one time (Oppenheimer et al., 2014; Reid et al., 2009; Bouchama et al., 2007). Research by van Loenhout et al. (2018) shows that even moderate temperature increases, starting from 21 °C, can lead to a rise in hospital visits for heat-related illnesses, highlighting the vulnerability of healthcare systems even with moderately high temperatures. Consequently, these impacts on the population's health and healthcare stress the need for heat stress mitigation strategies to protect vulnerable populations from the increasing risks of extreme heat.

#### *Heat related distress*

Heat not only poses risks of illnesses, like heatstroke or heat exhaustion, but it also disrupts physiological processes and reduces human functioning. Heat stress can for example disrupt sleep, as high temperatures can reduce the time of sleep and impair REM sleep (Buguet, 2007). This is especially visible in older people and people in urban areas, where the limited nighttime cooling exacerbates this issue. Besides, disrupted sleep during heatwaves can worsen pre-existing health conditions like heart failure or COPD, and thus result in health risks (Daanen, 2010).

Moreover, heat stress negatively affects both cognitive and physical performance, decreasing labor productivity by slowing reaction times, increasing errors and reducing movement efficiency. These impairments are particularly concerning for sectors that require coordination and physical labor. In the manual labor sectors, the reduced cognitive and physical functions can for instance directly impact productivity and safety (Hancock et al., 2007; Oppenheimer et al., 2014). Research by NKWK - Klimaatbestendige Stad (2020) supports this statement, indicating how rising temperatures lead to declining work efficiency, disrupting economic welfares and worker well-being.

### 1.2.5 Other risks of heat stress

In addition to health risks, heat also has other risks that could arise. One concern is that the high temperatures lead to an increased electricity usage for cooling, resulting in a peak in electricity consumption (Hayhoe et al., 2010, Santamouris, 2019). The risk that arises therefore is that the energy infrastructure might not be able to handle this increased energy demand (Hayhoe et al., 2010). Next to affecting the energy infrastructure, extreme heat can also lead to significant disruptions in other critical urban infrastructures, including transportation, water, bridges and roads (IPCC, 2023; Hayhoe et al., 2010; Oppenheimer et al., 2014). These disruptions can result in economic losses and hinder access to essential services (IPCC, 2023).

High temperatures also contribute to higher concentrations of air pollutants, which can aggravate respiratory conditions (Kalisa et al., 2018; Santamouris, 2019; Betgen et al., 2024). Moreover, air pollutants, like airborne particulate matter (PM10), have been linked to increases in mortality rates (Fischer et al., 2003). Thus, this decrease in air quality is also directly associated with health risks. As temperatures continue to rise, the interplay between extreme heat and worsening air quality will aggravate one another.

Furthermore, rising temperatures can decrease the tap water quality, as this can lead to the warming of drinking water pipes, resulting in an increase of the risk of pathogen growth. This warming of the ground has made it difficult to maintain the maximum allowable tap water temperature of 25°C determined by the Drinking Water Law (Hitte - Rotterdams Weerwoord, 2023). This presents health risks, as elevated water temperatures create ideal conditions for bacteria to thrive, potentially leading to illnesses such as Legionnaires' disease.

### 1.2.6 Vulnerability

The term vulnerability refers to how exposed, sensitive and unable systems, people, communities, or populations are to certain events (Ahmed et al., 2023). In the context of heat stress, vulnerability highlights the extent to which individuals and urban environments are affected by rising temperatures and extreme heat events, like heatwaves. It reflects the interaction between exposure to heat, the sensitivity of populations, and their ability to adapt or mitigate its impacts. In Figure 1.5 the heatwave hazard vulnerability framework developed by Ahmed et al. (2023) is shown. In the framework, vulnerability is influenced by three interrelated factors: exposure, sensitivity and adaptive capacity.

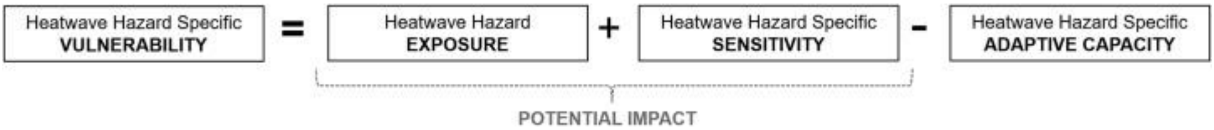



*Figure 1.5: Vulnerability framework* (Ahmed et al., 2023)

#### *Exposure*

Exposure to heat stress refers to populations in environments affected by high temperatures, such as urban areas experiencing heatwaves. This exposure can be measured through temperatures, such as land surface temperatures or PET (Ahmed et al., 2023). Since people spend most of their time indoors, indoor heat exposure plays an important role in determining the heat stress. Buildings without proper insulation, shading or ventilation can retain heat, making living conditions uncomfortable and potentially unhealthy (Betgen et al., 2024; Vellei et al., 2017). Moreover, within these dwellings those facing financial difficulties and the elderly are particularly vulnerable to indoor heat exposure, as they often lack access to cooling measures (Betgen et al., 2024).

Besides the dwelling, location plays a role in determining which populations are more vulnerable to heat stress. Areas that experience high temperatures and have limited access to cooling are more likely to face severe health impacts as warming intensifies (Samson et al., 2011). Within the Netherlands there are geographical temperature variations. The south and southeast of the Netherlands experience higher average temperatures and more frequent hot days compared to the cooler north (Betgen et al., 2024). Moreover, urban residents are exposed to higher temperatures, due to the dense urban infrastructure, urban paved materials and limited green spaces, exposing these residents to more heat (Santamouris, 2019).

#### *Sensitivity*

Sensitivity indicates how severely individuals or populations are impacted by heat stress. Sensitivity is determined by factors such as age, pre-existing health status and socioeconomic status. The first factor in determining the sensitivity is age, with elderly individuals and young children being particularly vulnerable to heat, due to their reduced ability to regulate their body temperature. Elderly people have a lower ability to sweat and respond to heat, on the other hand children have a higher body surface area relative to their mass, making them more susceptible to heat (Van Der Ree et al., 2022; Kovats & Hajat, 2008; Gamble et al., 2013).

Besides age, pre-existing health conditions, such as diabetes, cardiovascular diseases and obesity, increase susceptibility to heat stress, heightening the risk of severe heat-related illnesses or mortality (Basu & Ostro, 2008). Moreover, certain medications, alcohol, and drugs can further exacerbate heat sensitivity. Additionally, women are slightly more vulnerable to heat than men, due to lower sweat production and higher body fat (Betgen et al., 2024).

Socioeconomic factors also play a role in determining the sensitivity of a population or individual, as people with a lower income often lack access to cooling resources, such as air conditioning, making them less able to adapt and protect themselves during extreme heat events (Kovats & Hajat, 2008; Ostro et al., 2010). Moreover, chronic diseases and other pre-existing health conditions, like obesity and mental health illnesses, are more common among low-income populations (Kovats & Hajat, 2008).

### Adaptive capacity

Finally, the adaptive capacity refers to the ability to cope with or recover from heat-related impacts through resources, such as financial resources or social networks, which play a role in the experience of heat (Ahmed et al., 2023). People can for instance adapt their behavior by staying hydrated, seeking shade and adjusting daily routines, which can all help people cope with high temperatures better (Betgen et al., 2024). However, not everyone has the same ability to adapt to heat. Vulnerable people may struggle to take necessary measures, such as opening windows for night cooling, due to physical limitations, social isolation, or security concerns (Vellei et al., 2017). People that are unable to modify their behavior or environment during periods of head face a high risk, making them highly vulnerable to heat stress.

## 1.2.7 Heat stress in social housing in the Netherlands

Approximately one-third of the homes in the Netherlands are owned and managed by housing corporations, highlighting the significance of the social housing stock in the Dutch housing market. Only a very small portion of this social housing stock is new construction (Roders, 2015). This is why the existing social housing stock can play an important part in the implementation of climate mitigation measures to improve the climate adaptability of the Dutch housing stock. Moreover, the social housing stock in the Netherlands is primarily owned by a relatively small number of housing corporations (Roders, 2015), thus implementing climate adaptation measures in this sector provides an opportunity for comprehensive interventions.

Social housing tenants are often considered vulnerable, as a large portion of the social housing tenants are elderly people, people with a lower socioeconomic status and individuals with fragile health. As a result, they are more susceptible to extreme heat and face more risks. However, research has shown that climate adaptation actions remain scarce in the social housing sector, and awareness of climate adaptation among housing corporations is limited (Boezeman & De Vries, 2019).

One of the challenges in implementing climate adaptation in social housing is the low prioritization of these measures compared to other pressing concerns, like housing affordability requirements. Housing corporations often lack financial means to invest in climate adaptation beyond the minimum legal requirements (Roders & Straub, 2014). As a result, most implemented measures are reactive to legal requirements rather than proactive, with adaptation efforts often being initiated after extreme weather events (Boezeman & De Vries, 2019).

This low prioritization is especially visible in the mitigation of heat stress. Dutch housing corporations have not yet prioritized heat stress mitigation, largely due to a lack of awareness and urgency regarding the issue (Runhaar et al., 2012). Unlike flood risk management, which has gained more attention due to past incidents, heat stress remains a relatively overlooked climate adaptation challenge. A recent survey by *Samen Klimaatbestendig* (2023), involving 30 Dutch housing corporations, underscores this low awareness of heat stress. Despite the growing importance of heat stress mitigation, the survey reveals that only 20% of the participating housing corporations currently have a heat policy. Thus, this lack of awareness and intervention shows that there is a need for heat stress awareness among Dutch housing corporations.

Moreover, a split incentive poses an obstacle in taking mitigation measures for housing corporations. In the case of a split incentive, tenants rather than the building owner benefit primarily from the improvements of an intervention (MacAskill et al., 2019). This divided incentive may be one of the causes that the housing corporations are reluctant to implement heat stress mitigation measures as they do not benefit from the mitigation measures directly financially. Instead, they benefit indirectly through improving tenant living conditions and tenant satisfaction. Consequently, to ensure that housing corporations can effectively address heat stress in their properties, there is a need for more financial support and policy guidance.

## 1.3 Research gap

As shown in the previous sections, the increasing frequency and severity of heatwaves, exacerbated by the urban heat island effect, have significantly heightened the risks of heat stress in urban areas. Numerous studies have shown the effect of heat stress on urban areas, created by disproportionately high temperatures in cities, leading to increased health risks, an infrastructure strain and a higher energy demand (Li & Bou-Zeid, 2013; Hayhoe et al., 2010; Kovats & Hajat, 2008).

Despite the growing recognition of the need for heat resilience, the existing literature largely focuses on the environmental and health consequences of heat stress, resulting in a significant gap in the understanding of the economic and social dimensions of heat stress mitigation (Xing et al., 2008). Moreover, there is a gap in the awareness of the risks of heat stress among the housing corporations and heat stress mitigation measures that could reduce these heat risks are still scarcely implemented (Roders, 2015; Boezeman & De Vries, 2019). This shortcoming in the implementation of heat stress mitigation measures is largely due to the budget constraints faced by housing corporations (Roders, 2015). To encourage housing corporations to prioritize investments in heat stress mitigation, it is important that the corporations understand the costs and benefits of such measures. However, there is limited research addressing the economic feasibility and societal impacts of heat stress mitigation within the context of social housing. Furthermore, the existing literature does not provide adequate frameworks to guide housing corporations in making cost-effective and strategic decisions to heat resilience in their housing stock.

Moreover, there is a policy gap in the regulations for heat stress in existing dwellings. Recently, the TO-July requirement has been introduced in the Netherlands, as discussed in Section 1.2.3. However, this legal requirement only applies to newly built dwellings (Hoevers, 2021). There are currently no requirements the existing building stock must adhere to regarding heat, even though many of these dwellings are highly vulnerable to overheating. Thus, this represents a gap in current regulations and emphasizes the need for future policy interventions.

Consequently, this research aims to bridge this gap by assessing the social and economic implications of heat stress mitigation for social housing by evaluating both the financial and societal costs and benefits of implementing heat resilience strategies. Through this approach the goal is to not only address the environmental impact of heat stress, but to also consider the broader social and economic benefits.

## 1.4 Societal and scientific relevance

The societal relevance of this thesis lies in addressing the growing issue of urban heat stress, which is worsening due to climate change. For cities in the Netherlands implementing heat stress mitigation measures has become crucial, as the temperatures within the city are rising and putting the population at risk. This has also become increasingly important for the social housing stock, which encompasses one third of the Dutch housing stock (Scanlon et al., 2015). Moreover, a large part of this social housing stock is made up of older, inadequately insulated buildings without sufficient cooling capacities (Roders, 2015), highlighting the importance of the implementation of mitigation measures. This is confirmed by Zuurbier et al. (2024) who state that the poorest neighborhoods are usually the warmest neighborhoods.

Furthermore, research has shown that socioeconomic status and other demographic factors influence an individual's vulnerability to heat stress (Ahmed et al., 2023; Santamouris, 2019). Socially disadvantaged groups, who frequently live in social housing, face heightened risks from heat stress due to limited resources necessary to protect them against extreme temperatures (Mees et al., 2015). This underscores the importance of addressing heat stress as an issue causing urban inequity, as pre-existing inequalities are exacerbated by the impacts of climate change (Reckien et al., 2017). For individuals living in social housing, the combination of socioeconomic challenges and inadequate housing conditions intensifies their vulnerability to heat stress. Thus, the issue of heat stress in the social housing stock needs to be addressed to reduce social inequalities (Nationaal Kennis- en Innovatieprogramma Water en Klimaat, 2023).

The scientific relevance of this thesis lies in addressing the gap in research on heat stress mitigation for social housing, an issue that deals with both environmental and social challenges. While urban heat and climate adaptation are widely studied, there is limited research that considers the specific challenges and needs of social housing tenants, who are often disproportionately impacted by heat stress due to pre-existing socioeconomic inequalities and inadequate housing conditions. Moreover, housing corporations in the Netherlands currently have limited awareness and encounter major obstacles when it comes to implementing climate adaptation measures, including those related to heat stress (Roders, 2015). This thesis is thus scientifically relevant because it addresses these gaps by examining how cost-effective heat stress mitigation strategies can be implemented in social housing, integrating social equity considerations into climate adaptation research. Furthermore, the scientific relevance lies in bridging the gap between theoretical knowledge and practical application.

## 1.5 Research questions

The aim of this thesis was to evaluate the long-term costs and benefits of heat stress mitigation measures in the existing social housing stock in Rotterdam. In the thesis the financial implications have been evaluated, such as investment costs, maintenance costs and cost-effectiveness. Moreover, the benefits and the societal impacts were assessed, such as improved tenant health.

The challenges posed by climate change, along with its disproportionate impact on vulnerable populations, underscore the importance of the mitigation of heat within the social housing sector. Consequently, the research aims to help housing corporations to make informed decisions about heat resilience strategies, while balancing financial sustainability with social responsibility. Moreover, the municipality plays an important role in improving mitigating heat stress in the social housing stock by providing policy support and ensuring alignment with broader urban climate adaptation goals. By examining how municipalities can support housing corporations in achieving these objectives, the research also aims to contribute to a more coordinated and effective approach to heat stress mitigation.

Based on the research objective the following research question is proposed:

***“What are the long-term costs and benefits of mitigating heat stress in the existing social housing stock?”***

To answer the research questions the following sub-questions have been formulated:

**SQ1**: *“What risks and costs could arise if heat stress is not addressed in the existing social housing stock?”*

**SQ2**: “*What areas are most vulnerable to the risks of heat stress?”*

**SQ3**: *“What measures can be taken to mitigate heat stress in existing properties of housing* corporations *and what are the costs of implementing these measures?”*

**SQ4**: *“How do the economic and social benefits of implementing heat stress mitigation measures into social housing demonstrate the value of the costs of the mitigation measures?”*

# 2. Theoretical background

By drawing back on existing literature and theoretical frameworks, this chapter presents the theoretical background for understanding the impact of heat stress. In previous research, various theoretical frameworks and risk assessment approaches have been developed to analyze the impact of extreme heat events, focusing on hazard intensity, vulnerability, and resilience. In this chapter, the findings from the literature review and existing frameworks are integrated into one combined heat stress impact framework that forms the basis for the conceptual model.

## 2.1 Heat stress impact model

The IPCC (2014) has developed a central climate risk assessment framework, which defines risk as being influenced by hazard, vulnerability and exposure. Building on this foundation, Hatvani-Kovacs et al. (2016) have created an impact model for heat stress, as shown in Figure 2.1. This impact model conceptualizes heat stress impact as being influenced by two primary elements: heatwave intensity and population heat stress resilience. These two factors determine the overall level of risk associated with extreme heat events. Although adaptation and mitigation strategies are considered secondary processes in this framework, they play an important role in reducing long-term risk of heat stress (Hatvani-Kovacs et al., 2016).

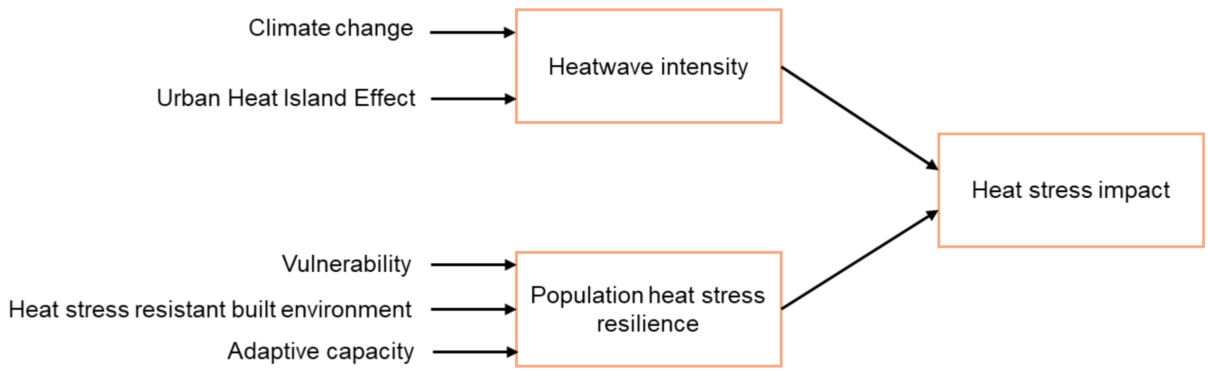



*Figure 2.1: Heat stress impact model (Adjusted from Hatvani-Kovacs et al., 2016)*

In the heat stress impact model, heatwave intensity plays a role in determining the severity of heat stress. As temperatures are rising due to the increasing climate change, the heat wave intensity is expected to intensify by making heatwaves more frequent, longer and more intense, which results in more severe heat stress conditions (IPCC, 2013). Additionally, the UHI effect makes urban environments experience higher temperatures than surrounding rural areas (Santamouris, 2014).

Furthermore, the population heat stress resilience reflects how well communities can handle and adjust to extreme heat. This resilience is determined by vulnerability, the heat stress-resistant built environment and adaptive capacity. Vulnerability, as discussed in section 1.2.5, refers to groups such as elderly and individuals with pre-existing health conditions who are more susceptible to heat stress. The role of the built environment in resilience is also emphasized in urban heat risk literature, where it is stated that urban infrastructure and housing design significantly impact heat exposure. Additionally, adaptive capacity refers to the ability of individuals and communities to implement effective heat adaptation strategies, including early warning systems and heat action plans (Hatvani-Kovacs et al., 2016).

## 2.2 Hazards of Place model

Another climate impact model that can be used for the risk assessment of heat stress, is the Hazards of Place (HOP) model (Figure 2.2). According to the HOP model, vulnerability arises from the dynamic interplay between social and physical systems (Cutter, 2024).

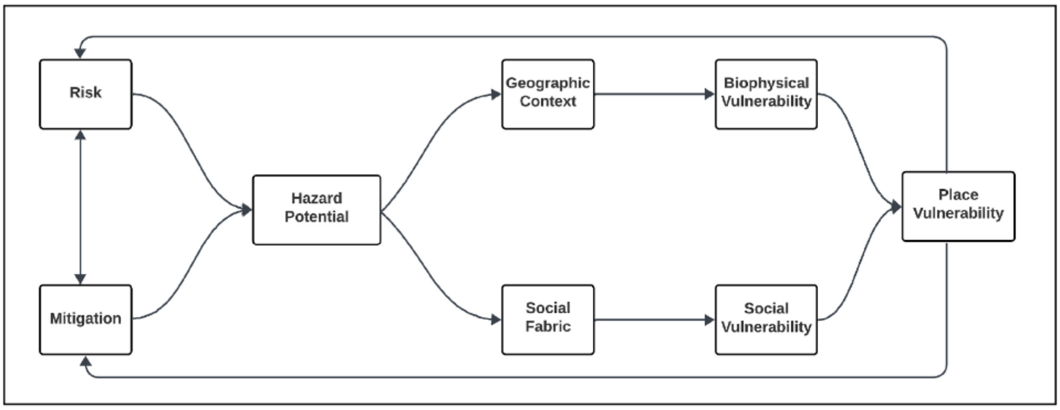



*Figure 2.2: Hazards of Place model (Cutter, 2024)*

The geographical context, such as the physical topography of an area, defines the degree of biophysical vulnerability and consequently the risk posed by environmental hazards. In the context of heat stress, heatwaves are the environmental hazard that could be faced, and the environmental temperature forms the physical component. At the same time, the social fabric influences how communities perceive and deal with these threats. The social fabric includes factors such as socioeconomic status and the presence of vulnerable populations (Cutter, 2024).

Previous vulnerability assessments have been effective in identifying physical hazards such as heatwaves and assessing risk based on the likelihood of such events occurring. However, indicators of social vulnerability, which are important for comprehending how various groups perceive environmental threats, have not been included in these assessments. Given the importance of equitable climate adaptation, it is essential to incorporate social vulnerability assessments into hazard mitigation and disaster risk management plans (Cutter, 2024).

## 2.3 Combined heat stress impact and risks model

The HOP model and the heat stress impact model are closely related, as both emphasize the interaction between physical and social factors in shaping vulnerability, risk and impact. According to the HOP model, vulnerability is determined by social and physical systems (Cutter, 2024). Similarly, the heat stress impact model considers both environmental and social components in determining the severity of heat stress. For instance, in the heat stress impact model, heatwave intensity, exacerbated by climate change and the urban heat island effect, defines the physical hazard, aligning with the HOP model's emphasis on geographical context and biophysical vulnerability. At the same time, the population's resilience to heat stress depends on social factors, such as economic status and the presence of vulnerable populations, which are important elements in the HOP model's framework of social vulnerability.

By combining the HOP model's emphasis on the interplay between social and physical systems with the heat stress impact model's focus on heatwave intensity and heat stress resilience and drawing back on other literature from the literature review, a comprehensive heat stress impact and risk framework was developed in Figure 2.3.

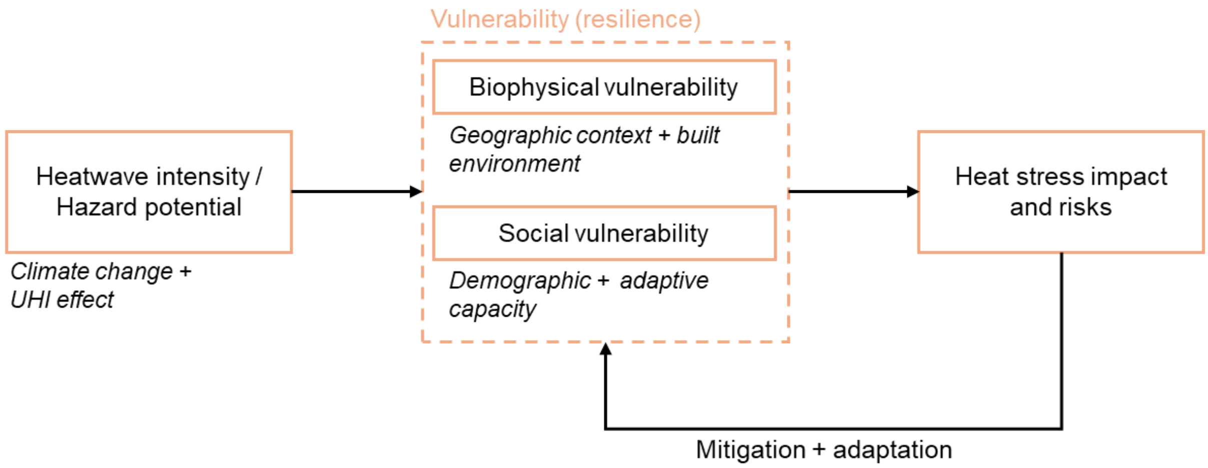
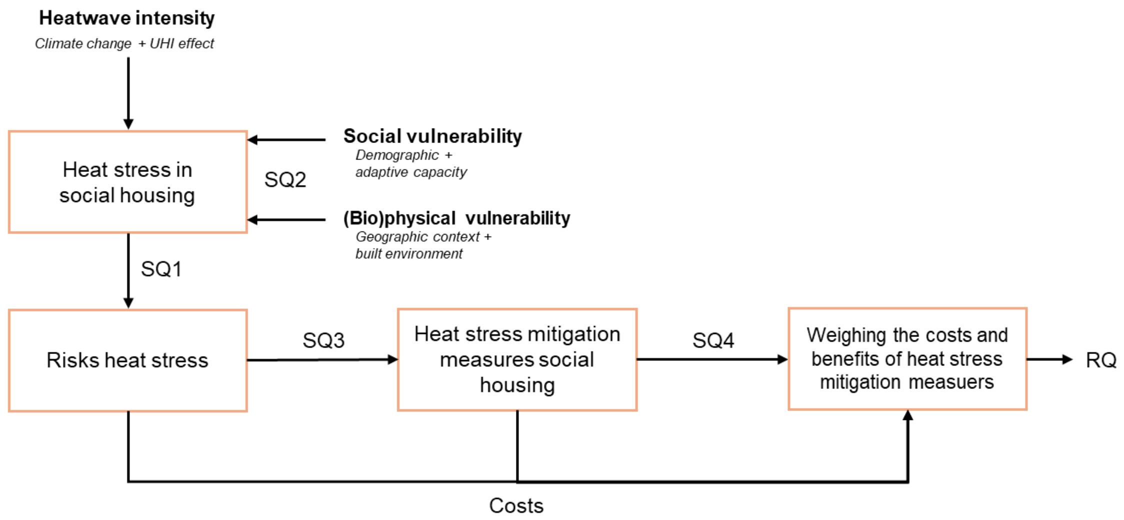



*Figure 2.3: Integrated heat stress impact and risk framework (Own figure)*

This integrated heat stress impact and risk framework illustrates how heat stress impact and risk are determined by the interaction between hazard, vulnerability and mitigation. Hazards, such as heatwaves, represent the environmental threat, while vulnerability is determined by social and physical factors that influence a neighborhood's sensitivity to heat stress. Mitigation and adaptation strategies, such as improved urban planning and building characteristics, can enhance resilience and reduce vulnerability. The risks of heat stress are highest when hazards are severe, vulnerability is high, and mitigation and adaptation measures are lacking. However, effective mitigation and adaptation strategies can significantly lower vulnerability, thereby reducing both the overall impact of heat stress and the associated risks. Hence, understanding the theoretical foundation of heat stress impact is necessary for developing effective policies and interventions to protect vulnerable populations.

## 2.4 Conceptual research framework

Building on insights from the integrated heat stress impact and risk framework and guided by the research questions, the conceptual research framework has been developed for this research to assess heat stress in social housing and explore effective mitigation strategies, as shown in Figure 2.4.




SQ1: "What risks and costs could arise if heat stress is not addressed in the current social housing stock?"

SQ2: *"What areas are most vulnerable to the risks of heat stress?"*

SQ2: *"What measures can be taken to mitigate heat stress in existing properties of housing associations and what are the costs of implementing these measures?"*

SQ3: *"How do the economic and social benefits of implementing heat stress mitigation measures into social housing demonstrate the value of the implementation costs for housing associations?"*

*Figure 2.4: Conceptual model (Own figure)*

The research framework begins with heat stress in social housing, where vulnerable populations are often disproportionately affected due to factors such as inadequate building quality, limited access to cooling measures and socioeconomic constraints. From there, the focus shifts to the risks associated with heat stress, analyzing what the impact is on urban areas and populations that are exposed to high temperatures and the costs that could arise if these risks are not mitigated. Then the heat stress mitigation measures for social housing and the associated costs of these mitigation measures are explored, which were later also used in weighing the costs against the benefits. Finally, the costs and benefits of mitigation measures were evaluated, weighing financial investments against long-term social and economic advantages. Overall, the framework aims to answer the research question and address whether the costs outweigh the benefits or the other way around.

# 3. Research design

## 3.1 Research scope

The scope of this research focuses on evaluating the long-term costs and benefits of heat stress mitigation measures at a building level within the existing social housing stock in Rotterdam. The research focuses on the existing housing stock and excludes the newly built properties, as the existing housing stock comprises a much larger percentage of the housing corporations' stock. Moreover, there already are heat stress requirements that newly built dwellings must adhere to, but no requirements yet for the existing stock. The research focuses on social housing, as people within social housing are highly vulnerable and often lack the ability to take measures against heat themselves. Exclusions from the scope include strategies on an area and behavioral level, which keeps the emphasis on the measures directly applicable to the buildings of the social housing stock. Consequently, the aim of the research is to identify heat stress mitigation measures on building-level, like insulation, shading, reflective surfaces and green roofs (Roders, 2015; *Hittekaart Gevoelstemperatuur - Klimaateffectatlas*, n.d.). The focus of the research lies in assessing the economic and social impacts of heat stress consequences and mitigation measures. Through a mid-term and long-term perspective both the initial and operational costs and sustained benefits over time will be analyzed.

## 3.2 Research approach

The research uses a mixed-method research approach using both qualitative and quantitative research techniques. This allows for a comprehensive analysis of the economic impacts, social effects, and practical considerations of implementing heat stress mitigation measures into social housing. Figure 3.1 gives an overview of the research design including the methods, data collection and analysis and the data output.

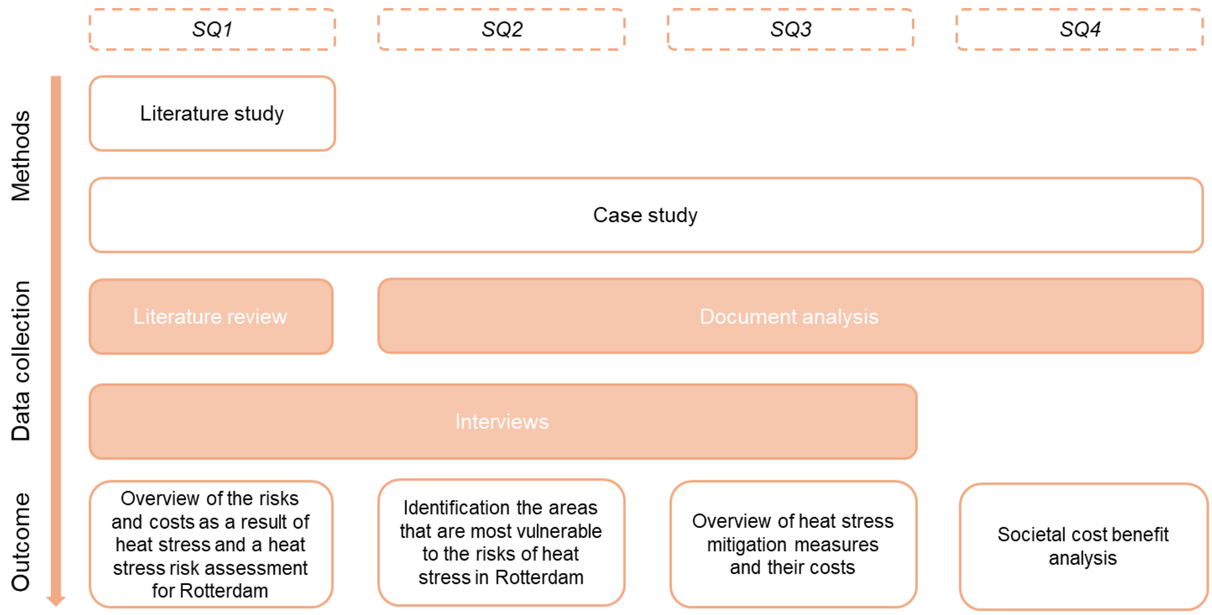



*Figure 3.1: Research design (Own figure)*

## 3.3 Methods

The research methods employed are a literature study and a case study, as shown in Figure 3.2. The literature study serves as the theoretical foundation of the research, focusing on analyzing the existing knowledge of heat stress in dwellings and its associated risks. The empirical component of this research is a case study, for which Rotterdam has been selected. Rotterdam is chosen for the case study as it is one of the most densely populated cities in the Netherlands, where the impacts of heat stress and the UHI effect are severe. Moreover, there is a high concentration of social housing in Rotterdam, which makes it a highly relevant location for examining the challenges and opportunities of implementing heat resilience strategies in social housing.

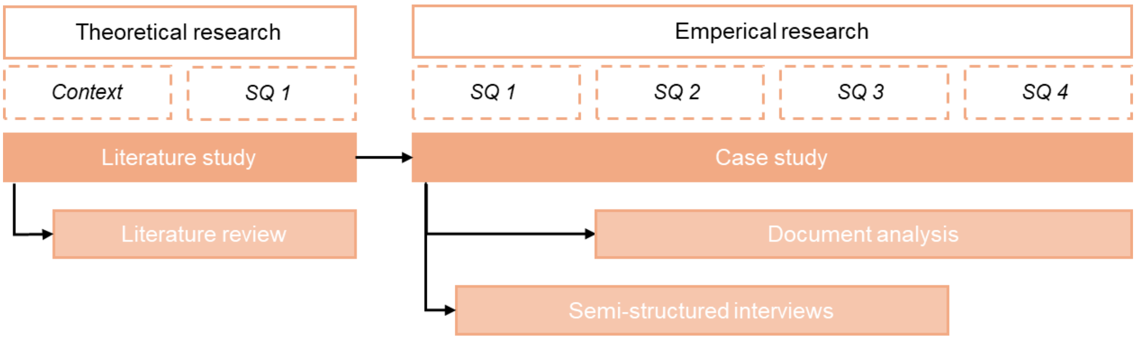



*Figure 3.2: Research methods (Own figure)*

### *3.3.1 Literature study*

The literature study forms the theoretical foundation of the research. The initial aim of the literature study was to examine the contextual background of the research and to locate the research gap. Furthermore, the literature study aimed to partly answer sub-question one, by reviewing existing knowledge on the factors influencing heat stress, the risks that could arise if heat stress is not addressed and identifying the people that are most vulnerable to the effects of heat stress. This theoretical background provides a foundation for the analysis of the case study of Rotterdam, during the empirical part of the research.

### *3.3.2 Case study: Rotterdam*

For the empirical part of the research, the case study serves to provide practical relevance by applying theoretical insights to a specific case. The case study chosen for this research is Rotterdam, a city with a high urban density, that is experiencing high temperatures during the summer due to the UHI effect and has a high percentage of social housing. The choice for the case study and an initial analysis of Rotterdam is further elaborated in Chapter 4.

## 3.4 Data collection and analysis

### *3.4.1 Literature review*

The first data collection method for the research is a literature review. The literature review serves as a qualitative data collection method to establish a theoretical foundation through integrating existing knowledge about heat stress. The literature review started with a general exploration of heat stress, followed by an analysis of its associated factors and risks. To answer sub-question one a qualitative literature review was conducted to analyze the risks of heat stress.

To find academic papers for the literature review, Scopus and Google Scolar were used. Search terms that were used to find academic papers on these search engines included among others the following terms: ‘heat stress’, ‘heat stress risks’, ‘heat stress in buildings’, ‘heat stress mitigation’, ‘Urban Heat Island effect’, ‘vulnerability’ and ‘climate adaptation in social housing’. The relevant articles were then selected by first looking at the titles, followed by reading the abstracts of the articles that seemed relevant. Then based on the abstracts, the articles that were relevant for the research were selected. Moreover, the snowballing effect was used to find even more relevant academic articles.

### 3.4.2 Document analysis

A document analysis was conducted as part of the research to systematically review and interpret relevant documents, to gain comprehension and develop empirical knowledge (Bowen, 2009). The data collected from the document analyses are both qualitative data and quantitative data. For sub-questions one, quantitative data was collected in the form of cost estimates for the risks of heat stress. For sub-question two, both quantitative and qualitative data were collected from documents, primarily through the examination of maps, to identify areas in Rotterdam that are most vulnerable to heat stress. For sub-question three, the document analysis focused on collecting qualitative and quantitative data to assess various heat stress mitigation measures by reviewing documents that detail their implementation, maintenance costs and effectiveness. For sub-question four, the cost estimation quantitative data collected were further analyzed through a societal cost benefit analysis.

### 3.4.3 Interviews

Furthermore, interviews with stakeholders involved in heat stress mitigation in Rotterdam were conducted, serving as a qualitative data collection method for sub-questions one to three. The interviews follow a semi-structured format, for which initial questions were prepared while leaving open the flexibility to discuss topics and insights that arose during the conversations. The goal of the in-depth interviews was to gain practical insights into the mitigation of heat stress in social housing within Rotterdam. Additionally, the interviews aimed to identify important factors, challenges and priorities that influence the implementation of mitigation measures. An example interview protocol is provided in Appendix 1 (in Dutch). The added interview protocol is the interview protocol for the housing corporations, for privacy reasons the other interview protocols are not shared in the appendix of this thesis.

A purposive sampling approach was used to select the interviewees, ensuring that participants had direct expertise and involvement in heat stress mitigation in Rotterdam. The interviewees that were selected for the research are three experts from the Municipality of Rotterdam, as the municipality is involved in policy development and urban climate resilience strategies. Furthermore, the interviewees include three representatives from three different housing corporations in Rotterdam. The perspectives of the housing corporations were valuable for the research, as the corporations are responsible for managing and maintaining the social housing stock. The last expert selected for the interviews is a neighborhood cooperative representative, who could provide more insight into the perspective of the people in the neighborhoods. An overview of the interviewees is shown in Figure 3.2.

| Interviewees |
| --- |
| *Municipality of Rotterdam* |
| Municipal representative 1 |
| Municipal representative 2 |
| Municipal representative 3 |
| *Housing Corporations Rotterdam* |
| Housing Corporation 1 |
| Housing Corporation 2 |
| Housing Corporation 3 |
| *Cooperatives* |
| Neighborhood cooperative representative |

*Figure 3.2: List of interviewees (own figure)*

The interviews were analyzed using Atlas.ti, a qualitative data analysis software. Both deductive and inductive codes were developed to analyze the interviews. The deductive codes derived from existing literature on heat stress and heat stress mitigation. In addition, inductive codes that arose during the analysis of the interviews were added, allowing for the identification of new themes and perspectives that emerged from the interviews. An overview of the codes and code-groups is shown in Figure 3.3.

| Theme | Code group | Code |
| --- | --- | --- |
| Risks of heat stress | Health risks | Heat-related mortality |
| | | Heat-related illnesses |
| | | Heat-related distress |
| | | Mental health issues |
| | | Concentration of air pollutants |
| | | Tap water quality |
| | Energy risks | Increased energy demand |
| | Economic risks | Loss of labor productivity |
| | Urban infrastructure risks | Strain on infrastructure |
| Heat stress vulnerability | Vulnerability | Biophysical vulnerability |
| | | Social vulnerability |
| | | Climate inequity |
| Heat stress mitigation measures and costs | Mitigation measures | Shading |
| | | Ventilation |
| | | Roof and facade additions |
| | | Installations |
| | | Insulation |
| | | Behavior |
| | | Challenges |
| | Costs | Impementation costs |
| | | Maintenance costs |
| | | Subsidies |
| Costs, benefits and policies | Societal cost-benefit analysis | Costs vs benefits |
| | Policy and governance | Lack of existing heat policies |
| | | Lack of awareness among associations |
| | | Policy enforcement |

*Figure 3.3: Interview codes (Own figure)*

## 3.5 Data outputs

This thesis' main objective is creating strategies for addressing heat stress in social housing. This involves identifying the risks of heat stress, vulnerable populations and locations, and effective mitigation strategies while evaluating their economic and societal impacts. Consequently, the research aims to equip policymakers and housing corporations with the tools and knowledge to implement informed heat stress mitigation measures. The data outputs of this research encompass deliverables that aim to address the research objectives. The findings of the thesis will be disseminated to the stakeholders involved in the mitigation of heat stress in Rotterdam. For the academic community, results will be shared in the TU Delft repository.

### 3.5.1 Risk assessment

For sub-question one, the deliverables consist of a qualitative literature overview of the risks associated with heat stress. This overview provides context for understanding the impact and scope of heat stress a growing urban challenge. Additionally, a climate risk assessment was conducted to analyze the impact of heat stress in Rotterdam under various climate scenarios and timescales. This assessment considered factors such as the climate vulnerability of the population of Rotterdam, the percentage of the population exposed to high temperatures and the likelihood of warm days. By comparing future climate projections, the analysis determined how risks may evolve over time under different climate scenarios. Lastly, the risks of heat stress were monetized by estimating the annual costs that excess heat is adding to the health, energy and financial sector for each of the climate scenarios. This included the burden on healthcare systems, increased energy demand for cooling and potential financial losses resulting from a decrease in productivity due to indoor heat.

### 3.5.2 Vulnerability assessment

For the second sub-question, the most vulnerable locations to heat stress in Rotterdam's were identified using GIS maps and neighborhood data that combine social vulnerability and (bio)physical vulnerability (heat exposure) data. By overlaying and combining these maps, the vulnerability assessment identified areas where social and (bio)physical vulnerability are both present, offering insights into the areas that require the most urgent mitigation against heat stress.

### 3.5.3 Overview of mitigation measures and costs

For sub-question three, the data output includes an overview of heat stress mitigation strategies, including their costs and effectiveness for existing social housing dwellings. Moreover, different variants were developed to explore the potential effectiveness and feasibility of various mitigation strategies. These outputs can provide an overview of the most effective and financially feasible solutions that can inform decision-making for policymakers and housing corporations in implementing fitting mitigation measures.

### 3.5.4 Societal cost-benefit analysis

Finally, for sub-question four, a societal cost-benefit analysis (SCBA) was conducted to weigh the costs of implementing heat stress mitigation measures against the anticipated benefits. The SCBA outlines the financial and societal impacts and aims to demonstrate how the mid-term and long-term economic and social benefits of heat stress mitigation weigh up against the associated costs for the implementation of the mitigation measures. The output of the costs of the risks of heat stress that was developed for sub-question one and the variants of heat stress mitigation measures that were developed for sub-question three were used as input for the SCBA.

The SCBA was chosen as a method as it evaluates measures from the perspective of societal welfare, aligning with this research. Moreover, the SCBA provides insight into whether the measures improve this societal welfare while taking into account the costs and benefits for all stakeholders, including the population and government (Romijn & Renes, 2013). The advantage of using a SCBA is that all the costs and benefits are all monetized and thus expressed in the same unit, ensuring that the effects, such as healthcare costs and energy usage costs can be compared equally. This makes a SCBA for an integrative comparison of all effects, allowing for a transparent assessment of whether the benefits justify the costs (Koopmans et al., 2016).

There are multiple other methods that could also be used for a cost assessment. However, for this research the other methods were less compatible. One of these other methods is the cost-effectiveness analysis (kosten-effectiviteitsanalyse), which focuses on the cost per unit of a single effect. However, it does not determine whether the effect outweighs the costs. Another method is the multi-criteria analysis, where quantified effects are weighted based on a hierarchy, but this method can lead to biased results (Koopmans et al., 2016). Furthermore, there is the Social Return on Investment (SROI) method, which emphasizes stakeholder involvement and social impact, but often lacks quantification and can include speculative assumptions, reducing the reliability of the findings. The Impact Analysis (IA) also is not a fitting method as it is incomplete, as the different effects are not weighed against one another (Koopmans et al., 2016).

Consequently, the SCBA is the most fitting method for this research, as it can be used to evaluate the financial and societal effects of mitigating heat stress thoroughly and transparently (Romijn & Renes, 2013). A SCBA includes social and societal factors, such as the population's health. To use these factors in a SCBA, the monetary value of these non-monetary factors are assessed through either market prices or assumed shadow prices (Bos et al., 2022). For the SCBA in this thesis, benefits such as improved tenant health and reduced energy costs were monetized, while also considering the implementation expenses and maintenance of the mitigation measures. By weighing these factors, the SCBA results aimed to guide municipalities and housing corporations in making informed decisions about the viability and effectiveness of heat stress mitigation strategies.

A comprehensive guideline to conduct a SCBA was developed in 2011 by the 'Centraal Planbureau' and 'Planbureau voor de Leefomgeving' (Figure 3.4). This guideline outlines the process for creating a SCBA and establishes a set of requirements and standards the SCBA is required to meet based on theories and best practices (Romijn & Renes, 2013).

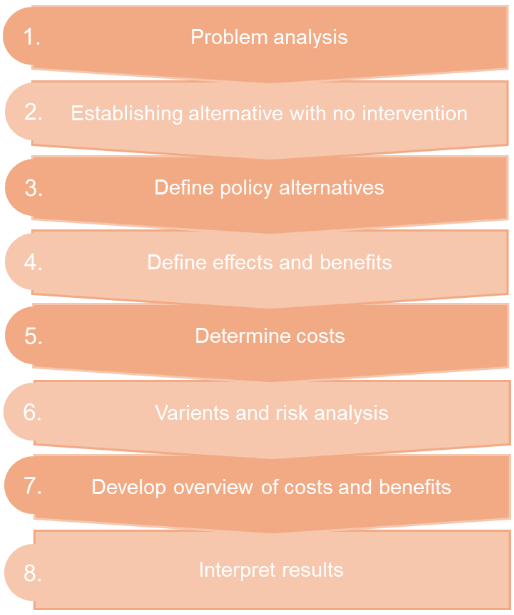



*Figure 3.4: Approach for a societal cost-benefit analysis (Romijn & Renes, 2013)*

The first three steps of the SCBA form the preparation phase. During the preparation phase, firstly the problem analysis is conducted. This consists of the problem statement addressing heat stress and the consequences of heat stress for social housing tenants. Furthermore, the alternative with no intervention was established showing what will happen if heat stress is not addressed (Romijn & Renes, 2013). This is followed by a description of the possible mitigation measures as a part of the defining of policy alternatives.

The preparation phase of the SCBA was followed by the central steps of the SCBA. The initial step of this phase involved defining the effects of heat stress and quantifying and monetizing these effects. In the next step the costs were determined. The last step is the development of an overview of the costs and benefits, who are calculated to a base year after which all cash values are discounted and added to one another (Romijn & Renes, 2013). Lastly, the results are presented, interpreted and conclusions are drawn from the SCBA.

## 3.6 Data plan and ethical considerations

### *3.6.1 Data plan*

In this thesis, data protection is ensured by applying the principles of data protection by design and default, as outlined in the General Data Protection Regulation (GDPR). Throughout the research process, safeguards were put in place to protect participants' fundamental rights. Sensitive information and personal data were anonymized, and the participants are only referred to by their organizations. By only gathering the information required to meet the goals of the research, data minimization principles were enforced (Hayes et al., 2021).

Additionally, secure storage platforms were used to safeguard collected data, and access was restricted to authorized people. The data of the research was stored in personal storage and TU Delft OneDrive. Before the data collection, explicit consent was obtained from the participants, ensuring they understood how their information is processed and stored. Through these measures the risks are mitigated, and participants' privacy and security are maintained. The extended Data Management Plan is added in Appendix 2.

### *3.6.2 Ethical considerations*

Ethical considerations play a role in ensuring the protection of human participants from harm during or after the research. This is important for protecting the interviewed participants who provide their time and information for the research, this was thus the primary concern during the entire research (Rauhala et al., 2021). Before conducting interviews, participants received an introductory email outlining the purpose of the research. Then participants were asked to sign a consent form before the interview began, to give their informed consent. The informed consent form is provided in Appendix 3 (in Dutch). The goal of the research, the requirements for participation, and any possible dangers are all covered in detail on this form. This guarantees that participants were fully informed about the research prior to providing their consent to participate (Hayes et al., 2021).

Moreover, before each interview, the participants were asked for explicit consent for recording the interview for transcription purposes. To protect the participants' identities, their statements were anonymized by referencing only their organizations. Consequently, this was put in place so that participants were well informed, their privacy is maintained, and any potential risks associated with their involvement in the research were minimized.

# 4. Case study: Rotterdam

In this chapter the case study of this thesis will be discussed. First, the case selection will be described, explaining why Rotterdam is a relevant case study for research about heat stress mitigation in social housing, including additional background information. Moreover, the stakeholders involved in heat stress mitigation will be discussed, including the housing corporations in Rotterdam, whose heat stress mitigation strategies will be described more in depth.

## 4.1 Case selection Rotterdam

For the case study selection, the following case selection criteria were determined:

- Exposure to high temperatures
- High percentage of social housing
- Data available

Based on these criteria, Rotterdam was chosen for the case study. Rotterdam fits the first criterion, as the city faces significant heat stress challenges due to its high urban density and Urban Heat Island effect. The UHI effect in Rotterdam can cause temperature variations of inner-city temperatures to be up to 8°C higher than those of nearby rural areas (Heusinkveld, 2013), shown in Figure 4.1.

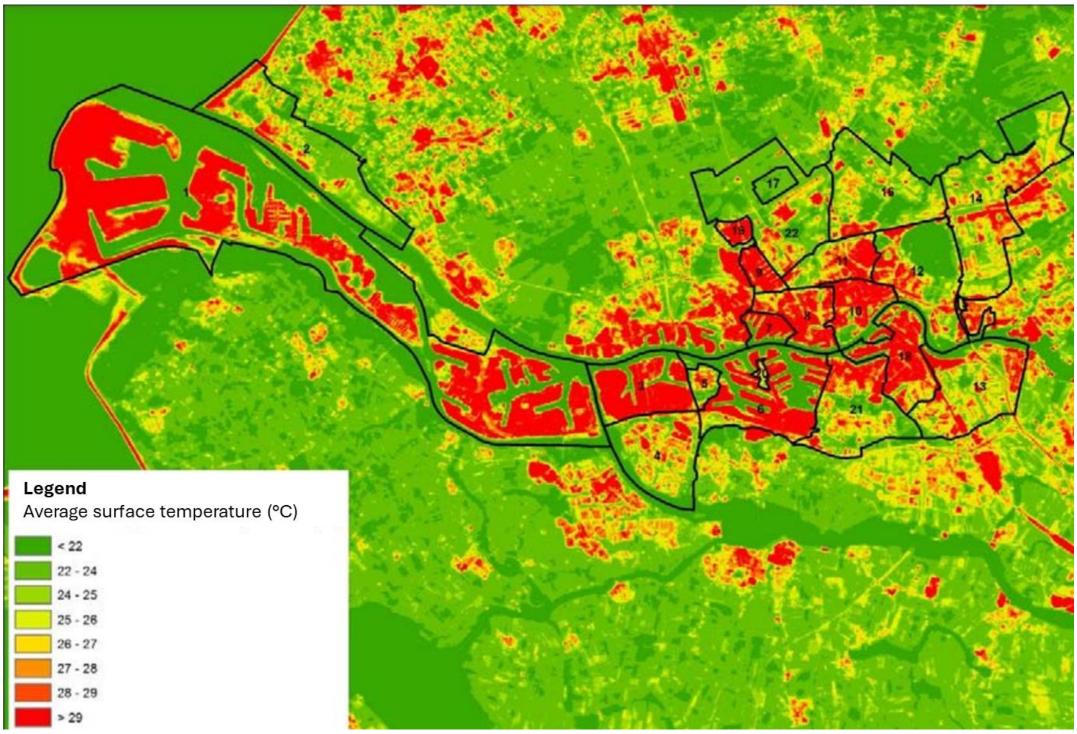



*Figure 4.1: Rotterdam surface temperatures (Gemeentewerken Rotterdam, 2011)*

Heat stress is particularly visible in densely populated areas in Rotterdam, like the Centre and Kop van Zuid (Gemeentewerken Rotterdam, 2011). Moreover, the high particulate matter concentrations and heat output from industrial sources in Rotterdam, such as power plants, further intensify the UHI effect (Daanen et al., 2010). This intensified heat puts the population at risk, as studies indicate that heat can lead to health risks, such as heat exhaustion, respiratory distress and increased mortality rates during heatwaves (Runhaar et al., 2012; Howe & Boden, 2007). With Rotterdam's Urban Vision 2030 focusing on urban densification, these conditions are expected to worsen. Thus, action needs to be taken to reduce the UHI effect and protect the public health (Gemeentewerken Rotterdam, 2011).

Furthermore, within Rotterdam around 70% of the population lives in dwellings that are unable to efficiently release heat, which poses more significant health risks. These poorly cooled homes create uncomfortable and potentially dangerous living conditions. This housing stock also includes around 70.000 elderly residents, who are especially vulnerable to heat-related risks (Sneep, 2024). The ‘Klimaatrechtvaardig Rotterdam’ department within the municipality of Rotterdam has developed a map indicating the percentage of residents per neighborhood that do not experience sufficient cooling in their dwelling during persistent periods of heat, shown in Figure 4.2 (Klimaatrechtvaardig Rotterdam, 2020).

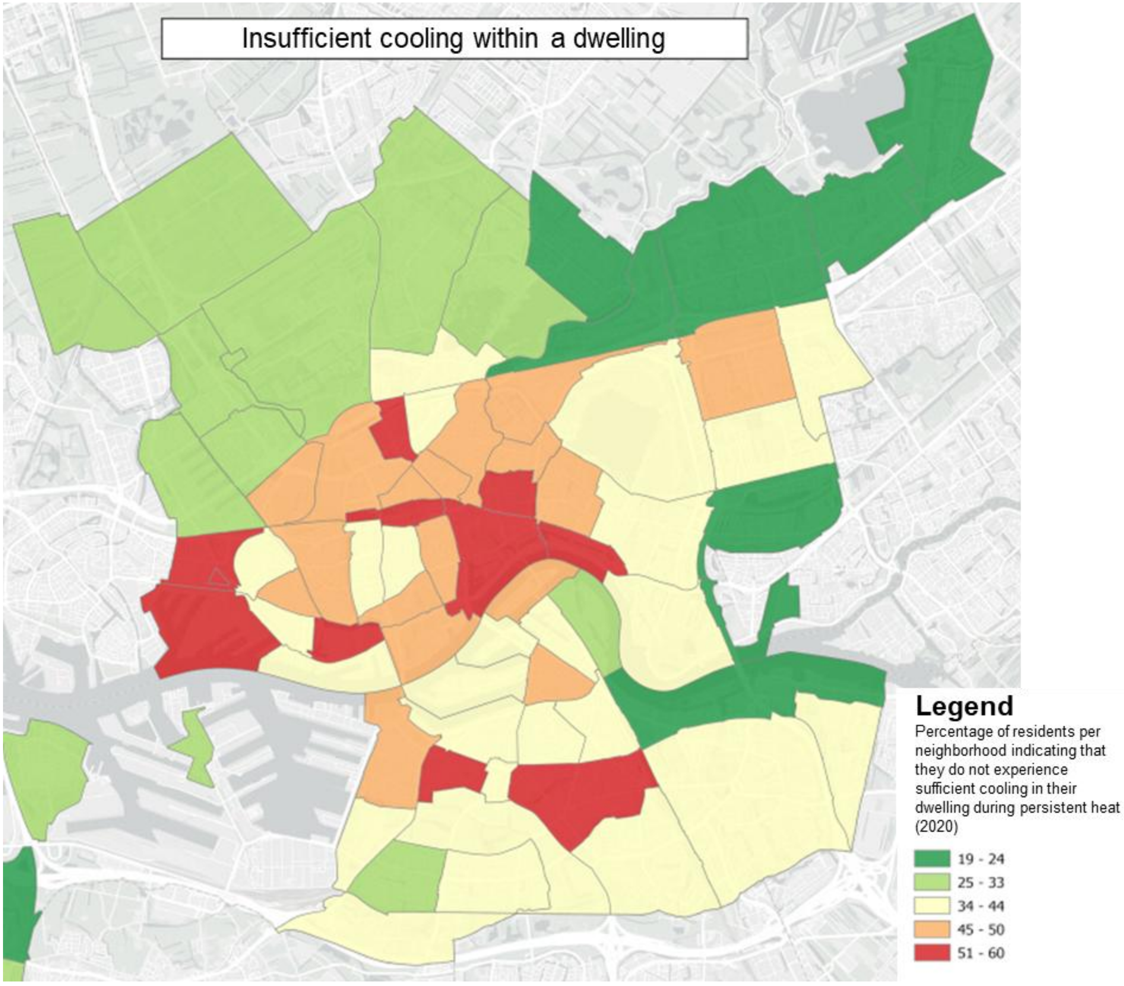



*Figure 4.2: Insufficient cooling within dwellings per neighborhood in Rotterdam (Klimaatrechtvaardig Rotterdam, 2020)*

Moreover, Rotterdam is a relevant case study for research about mitigating heat stress in social housing, as Rotterdam has the largest percentage of social housing in the Netherlands (CBS, 2023). The social housing tenants living in these dwellings face heightened indoor temperatures that can lead to severe discomfort and health risks (Santamouris, 2019; *Hittestress Vooral in Oude Woningen - Rotterdams Weerwoord*, 2021). This stresses that housing corporations must take action to mitigate heat stress in their housing stock, to ensure safer and more comfortable living conditions for their tenants.

The last criterion is also met, as there are a lot of available resources about heat and heat mitigation, including maps and policy documents. Furthermore, through the graduation internship company, the municipality of Rotterdam, there was close access to professionals with broad knowledge about heat stress in Rotterdam. The combination of the large data availability and possibility of engaging with experts make Rotterdam a suitable case study.

## 4.2 Stakeholders heat stress Rotterdam

Numerous stakeholders are involved in tackling heat stress in Rotterdam, who each have distinct roles, responsibilities and interests. This section explores the key stakeholders involved in heat stress mitigation in social housing in Rotterdam and analyzes their interests and role. In figure 4.2, a power interest matrix of the stakeholders involved in heat stress mitigation in Rotterdam is shown. The section is followed by an elaborate explanation of the roles and interests of the four key stakeholders involved in heat stress mitigation.

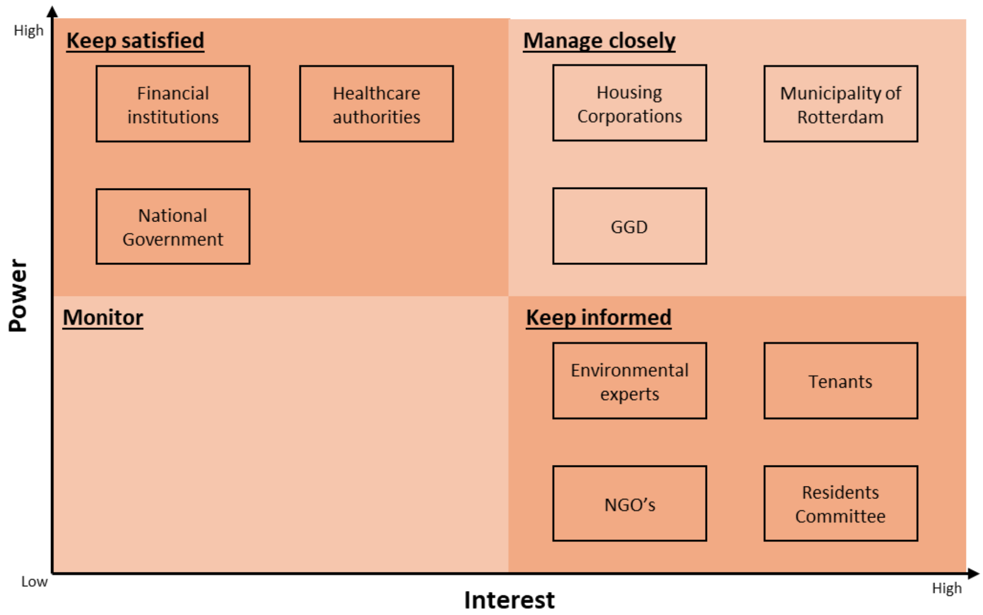



*Figure 4.2: Power interest matrix (Own work)*

### *4.2.1 Municipality*

Foremost, the municipality is a stakeholder with high power and interest in mitigating heat stress in Rotterdam, as they are responsible for urban planning and public health initiatives. Their primary interest lays in creating a livable and resilient city by integrating climate adaptation measures into urban development plans. Within the municipality of Rotterdam, a climate adaptation initiative has been created called the *Rotterdams WeerWoord*, which works together with Hoogheemraadschap van Schieland en de Krimpenerwaard, Waterschap Hollandse Delta, Hoogheemraadschap van Delfland, and Evides Waterbedrijf. The *Rotterdams WeerWoord* addresses challenges such as heavy rainfall, heat, drought, and flood risks. They have created a framework, the Urban Vision 2030 (Visser & Oosterholt, n.d.), in which they describe the goal of reducing the UHI effect, enhancing public well-being, and complying with local and international climate adaptation commitments (*Wat doen we - Rotterdams Weerwoord, n.d.)*.

### *4.2.2 Housing corporations*

Furthermore, housing corporations are an important stakeholder in the mitigation of heat stress in social housing in Rotterdam, as they are responsible for the implementation of building-level mitigation measures. Their interests include maintaining the quality of their properties, reducing long-term maintenance costs and ensuring tenant satisfaction. There are in total 14 housing corporations who are active in Rotterdam. Four of these housing corporations own by far the largest percentage of social housing dwellings in Rotterdam. These corporations are Woonstad Rotterdam, Havensteder, Hef Wonen and Woonbron (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, n.d.).

### 4.2.3 GGD

The GGD, another important stakeholder in the urban heat stress mitigation of Rotterdam, is focused on minimizing the public health impacts of heat stress, which includes heat-related illnesses, hospitalizations, and mortality. Their interest lies in safeguarding public health by promoting preventive measures, raising awareness of the risks associated with heat stress, and advocating for targeted interventions for at-risk groups such as the elderly, children, and individuals with chronic illnesses (*GGD-richtlijn Medische Milieukunde: Hitte en Gezondheid*, n.d.). Moreover, the GGD is the initiator of the *Rotterdam Heat Plan* and collaborates with local governments and healthcare institutions to develop a strategy of what needs to be done during heatwaves. The heat plan focuses on coordination, preventive measures and communication to ensure that residents receive information and the necessary care and support during periods of extreme heat (Ministerie van Infrastructuur en Waterstaat et al., 2019).

### 4.2.4 Tenants

Lastly, tenants are the stakeholders most affected by heat stress mitigation efforts, because they are directly impacted by the effects of extreme heat. The tenants' primary interest lies in maintaining a healthy and comfortable living environment, while minimizing energy costs associated with cooling.

## 4.3 Rotterdam's housing corporations and heat stress

In Rotterdam 14 housing corporations manage and own the city's social housing stock, of which four corporations own by far the largest percentage of the social housing dwellings (Ministerie van Volkshuisvesting en Ruimtelijke Ordening, n.d.). As climate change intensifies, Rotterdam's housing corporations play an increasingly important role in safeguarding the health and comfort of social housing tenants, ensuring their homes remain livable.

A large portion of the social housing stock in Rotterdam consists of older buildings that lack proper insulation and cooling capabilities, creating challenges for the housing corporations, who aim to ensure healthy and safe dwellings (Sneep, 2024). Thus, housing corporations are under pressure to implement heat stress mitigation measures to their dwellings that address the specific risks posed by heat stress. Without these measures, tenants are left vulnerable to heat-related health risks and rising cooling costs, which many cannot afford (Santamouris, 2019).

In response to these growing concerns, the Municipality of Rotterdam, together with housing corporations, has outlined a commitment to addressing heat stress in its *2024-2025 Prestatieafspraken* (performance agreements). These agreements describe collaborative initiatives to enhance neighborhood greenery and improve livability in Rotterdam's social housing stock (*Prestatieafspraken Woningcorporaties*, n.d.). As part of this commitment, the municipality is working on a localized heat plan, which will be updated annually. Moreover, in the period 2024-2026, subsidies will be made available for physical measures that contribute to mitigation of heat mitigation in buildings.

Additionally, the municipality and housing corporations stated that they are investigating if they can establish a heat standard for existing real estate together for the thermal discomfort (TO) levels in July. Furthermore, housing corporations are assessing which residential buildings and communal spaces are most at risk of overheating and identifying high-risk complexes, for which they can also request neighborhood passports from the municipality that provide neighborhood specific data (*Prestatieafspraken Woningcorporaties*, n.d.). These efforts reflect a comprehensive approach to tackle heat stress collaboratively with the corporations and the municipality, ensuring that Rotterdam's social housing stock remains safe in the face of rising temperatures.

The following sections will discuss the heat stress strategies discussed in the policy documents from the annual reports and the individual performance agreements of the four largest housing corporations in Rotterdam: Woonstad Rotterdam, Havensteder, Hef Wonen and Woonbron.

### 4.3.1 Woonstad Rotterdam

In its annual report of 2023 (Woonstad Rotterdam, n.d.) Woonstad Rotterdam recognizes the growing climate risks, among which heat stress. The corporation is working to identify effective, feasible and affordable solutions to mitigate climate risks, with the goal of improving residents' living conditions. Furthermore, in 2023, Woonstad Rotterdam launched a pilot project in which they implemented sun shading in two senior housing complexes. This initiative served as a test case for potential wider implementation (Woonstad Rotterdam, n.d.). The corporation gained many insights from this pilot project and states it is committed to further expanding sun shading initiatives, which they indicate in the individual section of the performance agreement report 2024-2025 (*Prestatieafspraken Woningcorporaties*, n.d.). The report emphasizes the importance of increasing the implementation of sun shading, including encouraging tenants to take measures themselves where possible. Additionally, Woonstad Rotterdam states in the performance agreements report that they want to continue to focus on resident communication, to ensure tenants are informed about ways to reduce indoor heat through their behavior (*Prestatieafspraken Woningcorporaties*, n.d.).

### 4.3.2 Havensteder

Havensteder recognizes that addressing heat stress is an important part of its sustainability goals in their annual report of 2023 (*Havensteder Jaarverslag*, n.d.). However, in the report, the corporation also indicates the financial challenges they are facing regarding the implementation of sustainability measures. Besides, in the performance agreements 2024-2025 (*Prestatieafspraken Woningcorporaties*, n.d.) Havensteder states that they will establish a policy framework and multi-year program for heat adaptation in 2024 and 2025, with a focus on senior housing complexes, to manage heat stress mitigation. Thus, Havensteder aims to develop effective and financially viable heat mitigation strategies.

### 4.3.3 Hef wonen

Hef wonen has mentioned little information about their heat strategy in their annual report of 2023. However, they state that they plan to reevaluate climate risks, including heat stress, in 2024, as part of its strategic risk reassessment (*Structuur & Verantwoording*, n.d.). Moreover, in the individual part of the 2024-2025 performance agreements report, Havensteder does not mention a dedicated heat mitigation strategy, unlike the other corporation in Rotterdam (*Prestatieafspraken Woningcorporaties*, n.d.).

### 4.3.4 Woonbron

Woonbron describes their heat stress mitigation strategy in its 2023 annual report (*Jaarverslag 2023: "Er Is Veel te Doen, in een Korte Tijd"*, 2024). Woonbron recognized the importance of heat stress mitigation, led by the statements of the *Rotterdams Weerwoord* about the importance of counteracting heat in dwellings. As a result, they developed their initial heat protocol in the summer of 2023, with plans to further expand this protocol in 2024. Furthermore, in the performance agreements 2024-2025 (*Prestatieafspraken Woningcorporaties*, n.d.) Woonbron emphasizes climate adaptation through local projects and the use of neighborhood passports to assess climate risks. The individual performance agreements of Woonbron do not specifically mention a heat strategy. However, it does mention the corporations focus on greening communal gardens to support climate resilience.

# 5. Risk assessment

Chapter 5 aims to answer the first sub-question: *"What risks and costs could arise if heat stress is not addressed in the existing social housing stock?"*. Building upon the literature review in sections 1.2.4 and 1.2.5, a qualitative literature review will be conducted in this chapter, to address the key risks associated with heat stress. This is followed by a risk assessment of heat stress in Rotterdam, exploring the arising risks extreme heat poses to the city of Rotterdam. The risk assessment will be conducted using the EU Missions' climate risk assessment methodology outlined by Smithers & Dworak (2023), along two different climate scenarios. Furthermore, the costs that could arise if heat stress is not addressed will be calculated and estimated for each of the risk sectors affected by heat stress. These costs will be estimated for Rotterdam and will be used as input for the societal cost-benefit analysis in Chapter 8.

## 5.1 Risks of heat stress

As outlined in the literature review in Section 1.2.4 & 1.2.5, various risks associated with heat stress have been identified. The risks pose threats among various sectors, including the health, financial, energy and urban infrastructure sectors. Figure 5.1 gives an overview of the risks associated with heat stress and the sectors they affect.

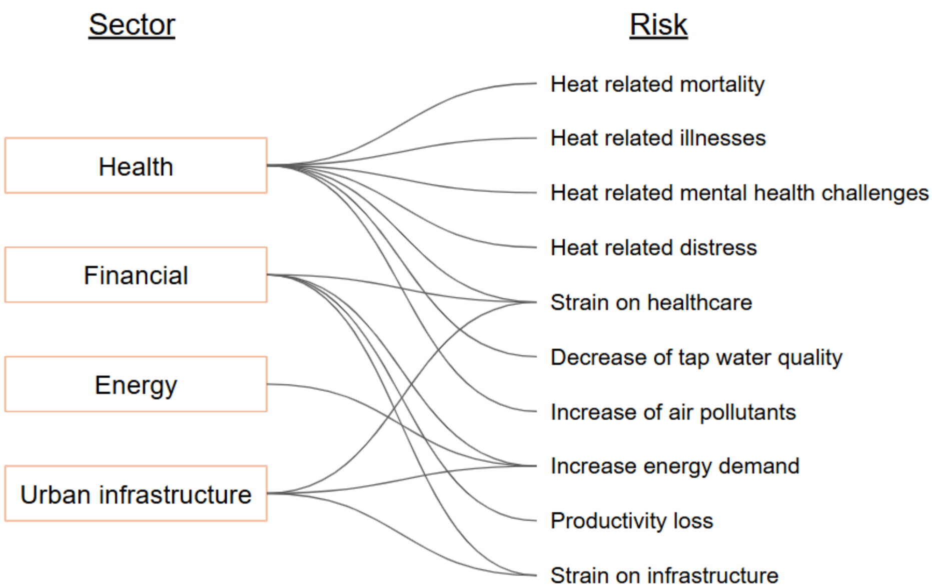



*Figure 5.1: Risks of heat stress by sector (Own figure)*

### *5.1.1 Qualitative literature review risks*

To systematically assess these risks, a qualitative literature review was conducted. This analysis identified the most frequently discussed risks and their relative impact. The findings, shown in Figure 5.2, categorize the impact of heat stress from positive to severe negative consequences, highlighting the potential impact of risks if heat stress is not addressed. The findings of the qualitative literature analysis indicate that while heat stress affects many parts of society, its most severe impact is on health-related risks, particularly the increase in mortality and illnesses during extreme heat.

| Risk | IPCC, 2023 | Huynen et al., 2001 | Elmarakby & Elkadi, 2024 | Santamouris, 2019 | Hayhoe et al., 2010 | Betgen et al., 2024 | Runhaar et al., 2012 | Oppenheimer et al., 2014 |
|---|---|---|---|---|---|---|---|---|
| Heat related mortality | - - | - - | - - | - - | | - - | - - | - - |
| Heat related illnessess | - - | | - - | - - | | - - | - - | - - |
| Heat related mental health issues | - | | | | | - | | |
| Heat related distress | | | | | | - | - | |
| Stain on healthcare | | | | | | - | | - |
| Decrease tap water quality | | | | | | - | | |
| Increase of air pollutants | | | | - - | | - | - | - |
| Increased energy consumption | - | | | - - | - - | - | | - |
| Productivity loss | | | | | | - | - | - |
| Stain on infrastructure | - | | | | - | - | | - |

**Impact of heat stress**
+ Positive impact O Neutral impact - Negative impact - - Severe negative impact

*Figure 5.2: Qualitative literature review risks heat stress (Own figure)*

### 5.1.2 Interview results health risks

The interviewed experts emphasize that heat stress can lead to distress, disrupted sleep, increased aggression and lower productivity. These physical and physiological strains of heat stress are mostly visible among vulnerable populations, such as the elderly, children and individuals with pre-existing health conditions. Furthermore, the experts mentioned that there is a noticeable rise in hospitalizations and mortalities during heatwaves, which stresses the severity of heat stress as a public health concern. That is why they underscore the importance of mitigation to protect the vulnerable population during periods of heat.

The Rotterdam heat plan was also discussed in relation to the health risks, as this is a strategy made by the municipal health department to raise awareness and prepare the population and organizations for extreme heat events. The plan is an extension of the national heat plan and was developed in response to the gaps in the national plan. The plan involves multiple stakeholders, such as local organizations, childcare providers and pharmacies. It was stated by the experts that the Rotterdam heat plan focuses on ensuring that these stakeholders are better prepared for heat events and that they aim to mitigate the risks associated with these heat events with the help of the heat plan. Through campaigns and communication, the plan aims to increase awareness and encourage proactive measures to mitigate the negative health impacts of heat stress.

## 5.2 Risk assessment heat stress in Rotterdam

### 5.2.1 Climate scenario’s

Given the significant risks associated with heat stress, it is important to understand how the risks may evolve under different climate conditions. Climate change is analyzed in scientific models using different scenarios defined by the IPCC (Intergovernmental Panel on Climate Change). These scenarios, known as the Shared Socioeconomic Pathways (SSPs), combine socioeconomic developments and climate policies to model possible future emission levels and climate effects (KNMI, 2023). The projections range from the low-emission scenario to the high-emission scenario, shown in Figure 5.3.

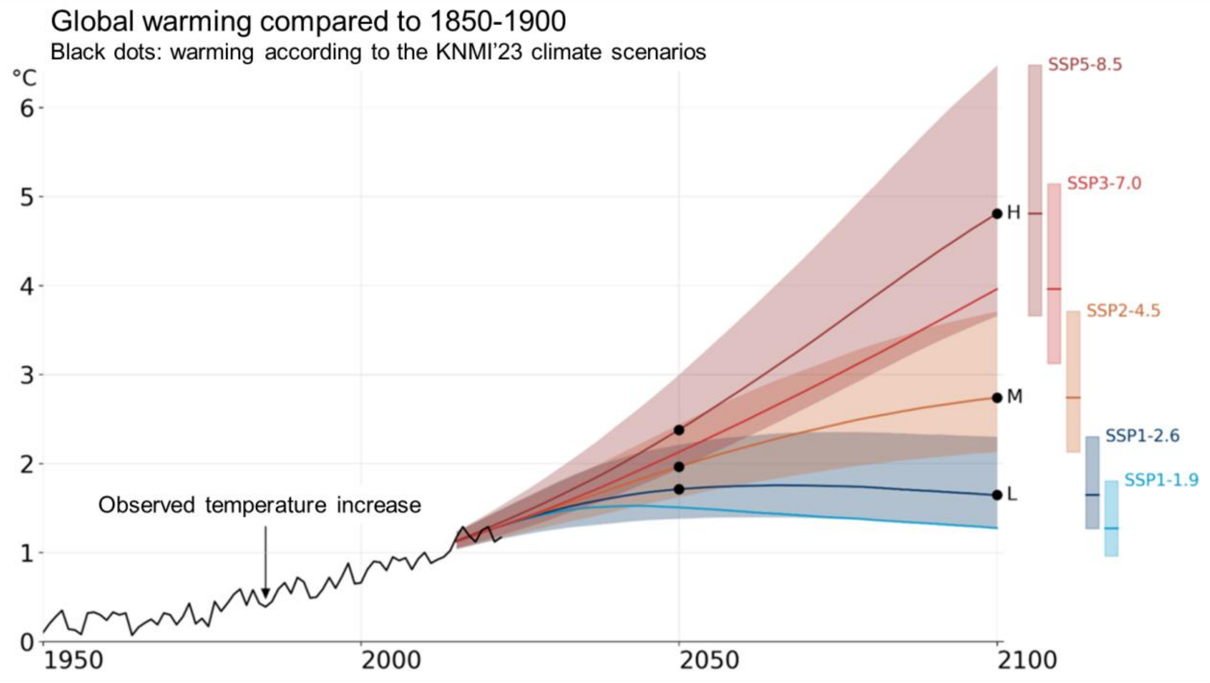



*Figure 5.3: Climate scenarios (KNMI, 2023)*

In the figure, five climate scenarios are defined, of which two are used for this research. The first scenario that is used for this research is the low-emission scenario SSP1-2.6, which aligns with the Paris Agreement and leads to approximately 1.7°C global warming by 2100. Furthermore, the high-emission scenario SSP5-8.5 is used in the research, which leads to a temperature increase of 2.4°C by 2050 and potentially 4.9°C by 2100 (KNMI, 2023; Smithers & Dworak, 2023; IPCC, 2023). Additionally, these scenarios are considered along three timeframes: current climate, mid-term (2050) and long-term (2100), allowing for an assessment of both mid-term and long-term climate-related risks. In Figure 5.4 the projections of the low and high emission scenario in the current, mid and long-term, are shown for the number of warm days in Rotterdam. These data are used for the risk assessment of heat stress in Rotterdam in the next section.

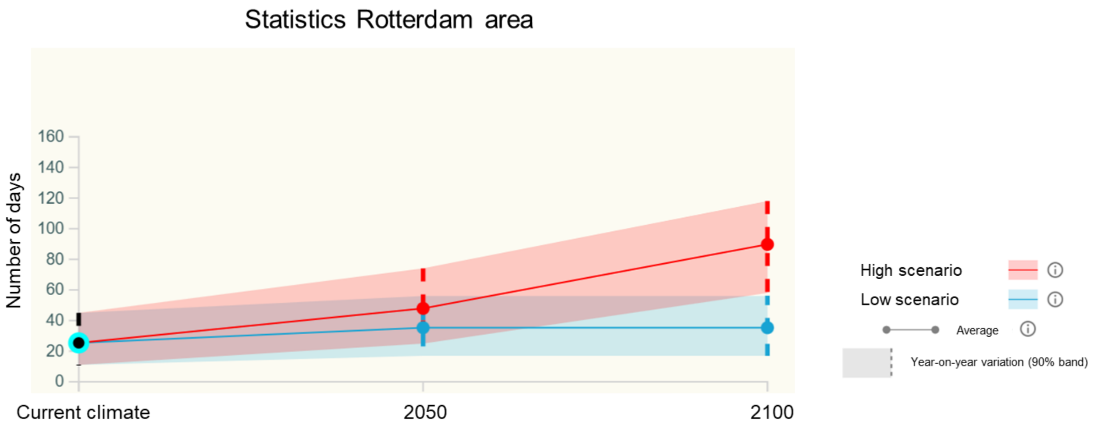



*Figure 5.4: High and low climate scenario Rotterdam for the number of days above 25°C (KNMI'23-KlimaatScenario's, 2023)*

## 5.2.2 Heat stress risk assessment Rotterdam

In this section a climate risk assessment of extreme heat in Rotterdam is conducted. Extreme heat poses significant risks to people and puts a stain on several urban infrastructures in Rotterdam. To identify the risk and impact of heat stress caused by climate change, a heat stress risk assessment of Rotterdam is conducted for the low and high climate scenario (SSP1-2.6 and SSP5-8.5) along the three earlier identified timeframes. For this climate risk assessment, the EU Missions guide to risk assessment document and excel tool are used (Smithers & Dworak, 2023). The risk assessment is based on the principles shown in Figure 5.5, in which the risk impact is determined by the impact rate and the likelihood rate of the hazard (which in this case is heat stress). Moreover, the impact rate is determined by the vulnerability and exposure rate.

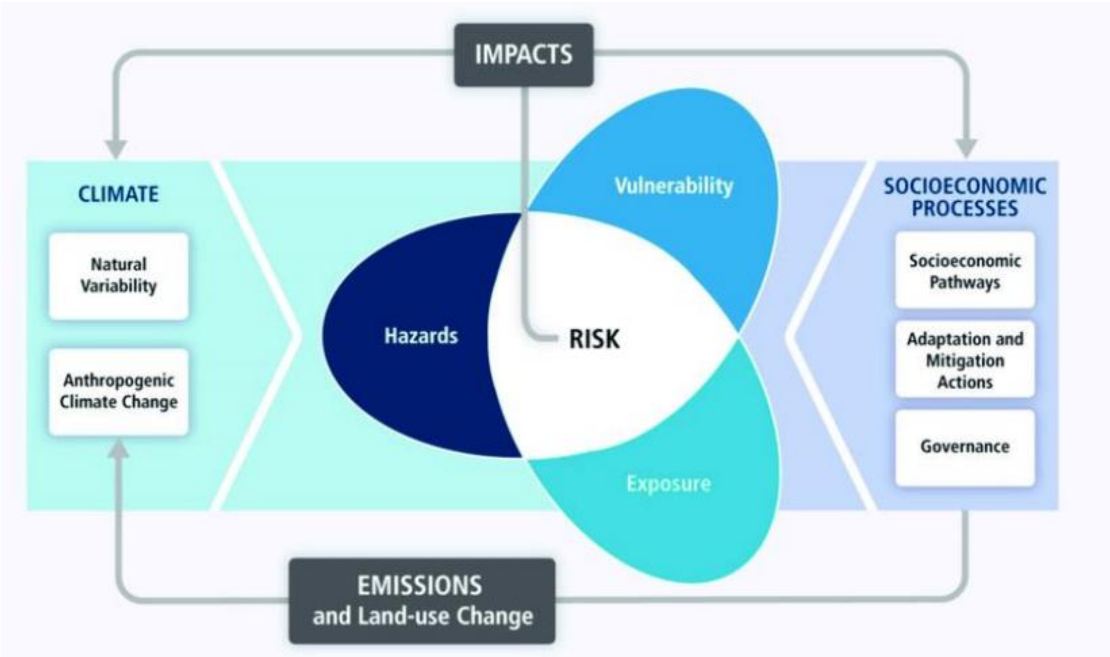



*Figure 5.5: Climate risk impact as a function of hazard, exposure and vulnerability (IPCC, 2014)*

First, the vulnerability to climate risk was determined for Rotterdam based on the framework developed for the Risk Data Hub (DRMKC - Risk Data Hub, 2023), which analyses various vulnerability factors across five dimensions: social, economic, political, environmental, and physical. These dimensions provide a comprehensive assessment of the area's vulnerability to disasters. At the NUTS3 level, the region of Groot-Rijnmond, which includes Rotterdam, was assigned a vulnerability score of 2,94 out of 10, with higher scores indicating greater vulnerability. For the climate risk assessment all the factors are given a score between 1-5, resulting in the overall climate vulnerability of Rotterdam being 1,47 out of 5. The Risk Data Hub shows that compared to the other areas in the EU, Rotterdam (Groot-Rijnmond) has a relatively low level of vulnerability to climate related disasters.

Furthermore, the exposure rate of Rotterdam to heat stress was determined. The exposure to extreme heat of Rotterdam was determined by the selected exposure indicator for extreme temperature by Maes et al. (2022), as the percentage of the population exposed to hot days. To determine the percentage of the population of Rotterdam that is exposed to hot days, data from the OECD were used (OECD, 2022).

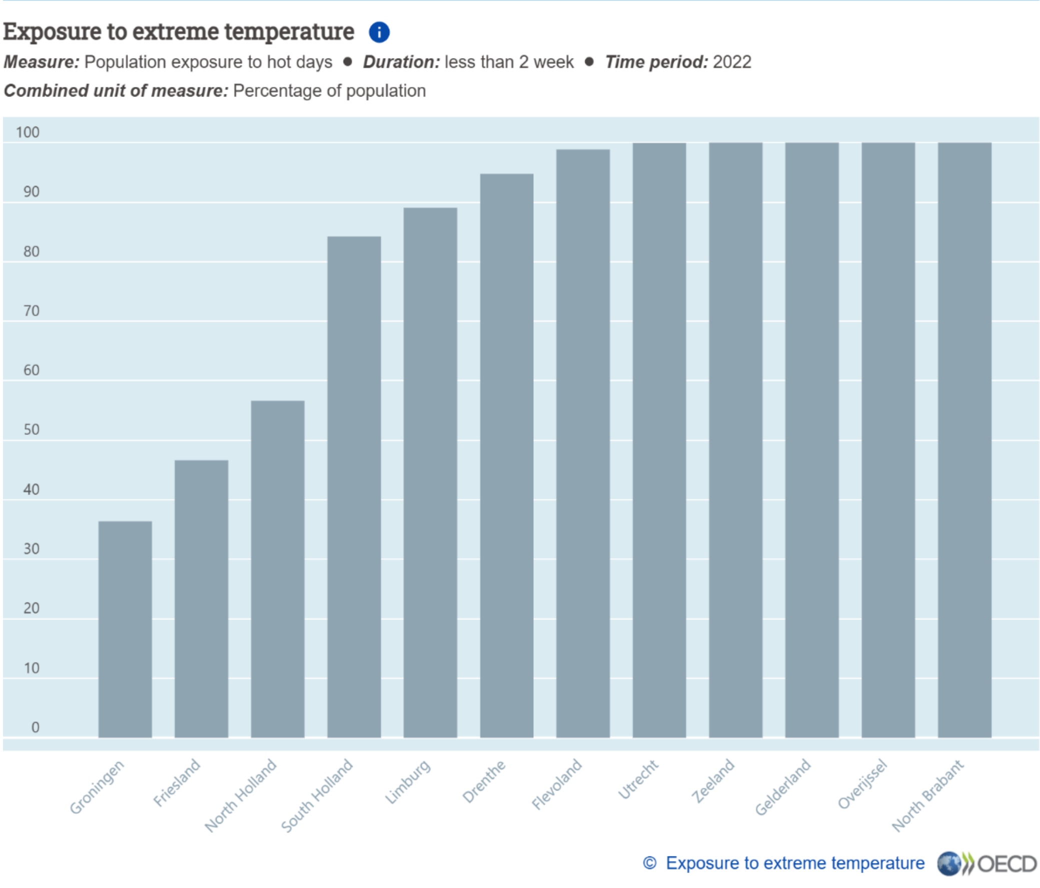



*Figure 5.6: Percentage of the population exposed to hot days in the provinces of the Netherlands (OECD, 2022)*

As shown in Figure 5.6, the percentage of the population exposed to hot days is determined for the provinces of the Netherlands, this was the smallest scale these data were available for. Therefore, the data of the province of South Holland were used to determine the percentage of the population exposed to hot days, as Rotterdam is a part of the province of South Holland. The exposure of South Holland is indicated as 84,24% of the population exposed to hot days. The exposure rating is determined based on the indications in Figure 5.7, resulting in the exposure rating of South Holland being a 5.

| Exposure rating | Definition of ratings | |
|---|---|---|
| **1** | **Low** | 0-20% of population exposed to hot days |
| **2** | **Low-medium** | 20-40% of population exposed to hot days |
| **3** | **Medium** | 40-60% of population exposed to hot days |
| **4** | **Medium-high** | 60-80% of population exposed to hot days |
| **5** | **High** | 80-100% of population exposed to hot days |

*Figure 5.7: Exposure ratings (Own figure, based on the exposure indicator determined by Maes et al. (2022))*

Together, the vulnerability and exposure rating determine the impact rating, as shown in Figure 5.8. As data on vulnerability and exposure were only available for the current time frame, this rating for impact was used in all the scenarios.

| Vulnerability rating | Exposure rating | Impact rating |
|---|---|---|
| *Determined for each receptor in relation to each relevant hazard by combining the ratings of sensitivity and adaptive capacity* | *Use the drop down list to enter the exposure rating* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* |
| 1,47 | 5 | 3,235 |

*Figure 5.8: Impact rating of extreme heat in Rotterdam (Own figure using the excel table from Smithers & Dworak (2023))*

To determine the risk ratings, the impact rating is combined with the likelihood ratings over the three predetermined timeframes and scenarios using the excel risk assessment document developed by EU Missions (Smithers & Dworak, 2023). In this excel document, the likelihood is determined based on the number of hot days (days above 25 degrees). The KNMI (2023) has made predictions for the number of hot days in the Netherlands. The number of expected hot days for the low and high climate scenario are retrieved from Figure 5.4 from *KNMI'23-KlimaatScenario's* (2023). The number of hot days is shown in Figure 5.9 for each timeframe.

| Hazard | Unit of measurement | Near term (2021-2040) | | Medium term (2041-2060) | | Long term (2081-2100) | |
|---|---|---|---|---|---|---|---|
| | | *Low Scenario (SSP1-2.6)* | *High Scenario (SSP5-8.5)* | *Low Scenario (SSP1-2.6)* | *High Scenario (SSP5-8.5)* | *Low Scenario (SSP1-2.6* | *High Scenario (SSP5-8.5)* |
| Heat stress | Number of days above 25 degrees | 25 | 25 | 35 | 48 | 35 | 90 |

*Figure 5.9: Number of days above 25 degrees in Rotterdam (Own figure using data from KNMI (2023) and the excel table from Smithers & Dworak (2023))*

| Likelihood rating | Definition of ratings | |
|---|---|---|
| **1** | **Low** | 1-20 days max. temp. above 25°C |
| **2** | **Low-medium** | 20-40 days max. temp. above 25°C |
| **3** | **Medium** | 40-60 days max. temp. above 25°C |
| **4** | **Medium-high** | 60-80 days max. temp. above 25°C |
| **5** | **High** | >80 days max. temp. above 25°C |

*Figure 5.10: (Own figure, scoring based on climate predictions of KNMI'23-KlimaatScenario's (2023))*

Thereafter, the likelihood ratings were derived using the rating indications as shown in Figure 5.10. After which all the ratings were added into the excel table by Smithers & Dworak (2023), added in full in Appendix 4. Consequently, combining the likelihood and impact to extreme heat of each timeframe and scenario presented the risks ratings of the scenarios in Figure 5.11.

| Timeframe | Scenario | Risk rating |
|---|---|---|
| Near term (current climate) | Low Scenario (SSP1-2.6) | **2,6** |
| Near term (current climate) | High Scenario (SSP5-8.5) | **2,6** |
| Medium term (2050) | Low Scenario (SSP1-2.6) | **2,6** |
| Medium term (2050) | High Scenario (SSP5-8.5) | **3,1** |
| Long term (2050) | Low Scenario (SSP1-2.6) | **2,6** |
| Long term (2050) | High Scenario (SSP5-8.5) | **4,1** |

| Risk rating | Definition of ratings |
|---|---|
| 1 | **Very low risk** |
| 2 | **Low risk** |
| 3 | **Medium risk** |
| 4 | **High risk** |
| 5 | **Very high risk** |

*Figure 5.11: Left: Risk ratings (Own figure), Right: Definition of risk ratings (Smithers & Dworak, 2023)*

To conclude, the risk ratings of the low-emission scenario remain consistent along the three timeframes, because the temperature is expected to remain stable in this scenario. Nevertheless, the high-emission scenario shows that the risk of heat stress in Rotterdam is expected to increase over time, with the expectation of a high to very high risk to heat stress in Rotterdam by the end of this decade.

## 5.3 Economic impact risks

In Section 5.1 the risks of heat stress were determined and assessed. In this section the financial impact of the risks caused by indoor heat is determined for Rotterdam. The costs are determined per sector and are estimated only for the sectors that are impacted by indoor heat stress, as the research focuses on the costs and benefits of heat stress mitigation for the existing social housing stock. That is why the costs of the urban infrastructure sector is not included in this research. Figure 5.12 gives an illustration of which sectors are impacted by heat in general and the sectors impacted by indoor heat are indicated in orange.

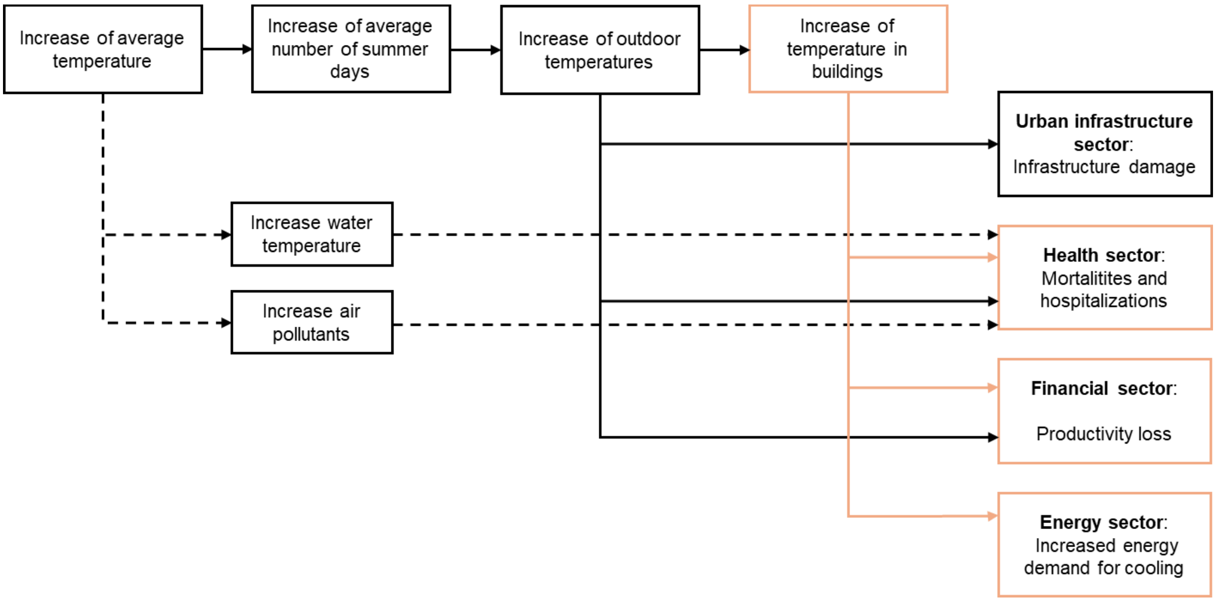



*Figure 5.12: Impacted sectors by high temperatures in buildings (Own figure, adapted from Stone et al., 2015)*

The financial impact of the risks is calculated for both low and high climate scenarios, and for the mid-term (2050) and long-term (2100) timeframes. The costs of the risks that are determined per sector also represent the potential benefits of implementing effective heat stress mitigation measures. In other words, if heat stress is adequately addressed in the existing social housings stock, these are the avoided costs and therefore can be interpreted as the monetized benefits in the societal cost-benefit analysis. The total cumulative benefits, alongside the corresponding mitigation costs, are further analyzed in Chapter 8, where the societal cost-benefit analysis is conducted.

### *5.3.1 Health sector*

As outlined in Chapter 1, extreme heat events can have severe health consequences, particularly for vulnerable populations such as the elderly, individuals with pre-existing conditions, and those living in urban areas with limited access to cooling. These impacts place a significant strain on the healthcare sector. This section aims to monetize the direct health impacts sustained by the health sector in Rotterdam as a result of extreme heat. The direct health impacts are monetized by estimating the heat-related mortalities and hospitalizations due to heat. Other health impacts, such as mental health issues and reduced sleep quality, are not included in the calculations, as no data was available for these impacts. It is important to note that there is great uncertainty in the estimation of the health-related costs, since a monetary value is being given to human life (Stone et al., 2013).

To estimate the economic impact of heat-related mortality in Rotterdam a formula by NKWK - Klimaatbestendige Stad (2020) is used. However, values in this formula have been adapted to fit more recent studies. The formula by NKWK - Klimaatbestendige Stad (2020) estimated that every heat-related mortality corresponds to €400.000. This estimation assumes that a heat-related death corresponds to a loss of 10 years of life (Stone et al., 2013) and that each year of life lost costs €40.000 (Hurley et al., 2005). However, a more recent study by NEEDS (2007) estimated the value of a year of life at €20.000 and this estimation was used by Smeets (2012) in research about air pollution for the 'Planbureau voor de Leefomgeving'. Consequently, an average of these estimations of €30.000 is used in the formula for this research. Moreover, Stone et al. (2013) estimated that the average years of life lost due to heat corresponds to 10 years of life lost. On the other hand, more recent studies suggest a lower average years of life lost to heat, as most people that pass away from heat are often elderly people or people with pre-existing health conditions. Since more recent studies suggest a lower average for the years of life lost due to heat this estimation is lowered in the formula used in this research. A study by Chiabai et al. (2018) estimated that the average years of life lost due to heat in Madrid was 4,7 years. Another study by Ritchie (2024) estimated the average years of life lost due to heat as 6 months to a few years. For the Netherlands in specific, no numbers have been estimated yet for the years of life lost due to heat. Therefore, for this research the average years of life loss is lowered to 5 years based on the recent estimates from abroad. Thus, the costs per mortality due to heat come down to €30.000 * 5 = €150.000 per mortality.

In the formula below the costs of mortalities due to heat per year in Rotterdam is given based on the adjust formula by NKWK - Klimaatbestendige Stad (2020):

**$C_{mortality}$ = yearly mortality rate due to heat * 150.000 * ($n_{municipality}$ / $n_{Netherlands}$)**

$C_{mortality}$ = Total cost of heat-related mortality per year in Municipality

$n_{municipality}$ = Number of inhabitants municipality (664.311 for Rotterdam)

$n_{Netherlands}$ = Number of inhabitants Netherlands (18.071.052)

The heat-related mortalities for the low and high climate scenarios and for the mid- and long-term derived from the estimations by the RIVM in Figure 5.13 (Staatsen et al., 2024). The data that are used for this research are the data from only the dark red part of the graphic. The data in the light red parts indicate the expected mortality rates including the expected population increase and aging. However, as these estimations are still uncertain these are not used for this research.

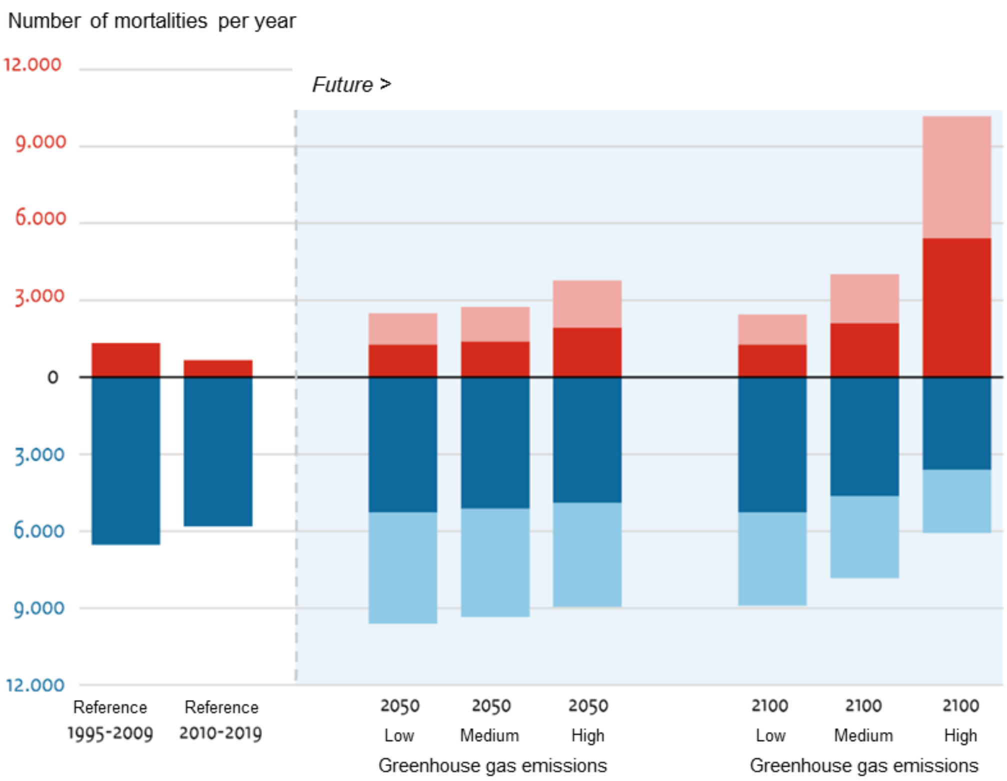



*Figure 5.13: Expected number of mortalities per year, related to cold and heat (Staatsen et al., 2024)*

Consequently, using the formula, the yearly costs of heat-related mortality are given for the low and high climate scenarios and for the mid- and long-term timeframes in Figure 5.14.

| Scenario | Timeframe | Yearly mortality | $C_{mortality}$ |
|---|---|---|---|
| Current time | | 660 | € 3.639.345 |
| Low scenario | Mid-term (2050) | 1200 | € 6.616.991 |
| High scenario | Mid-term (2050) | 1800 | € 9.925.486 |
| Low scenario | Long-term(2100) | 1200 | € 6.616.991 |
| High scenario | Long-term(2100) | 5400 | € 29.776.457 |

*Figure 5.14: Total cost of heat-related mortality per year in Rotterdam across scenarios (Own figure)*

Furthermore, the hospitalizations resulting from heat related illnesses are calculated. In these calculations, the number of hospitalizations is estimated at 1,079 per 100.000 inhabitants on a tropical day (above 30°C) (NKWK - Klimaatbestendige Stad, 2020). Moreover, the costs for one hospitalization are estimated at €5.000 (Stone et al., 2013). The following formula by NKWK - Klimaatbestendige Stad (2020) was used for the hospitalization costs of heat:

$$\mathbf{C_{hospitalization} = Z * \text{number of tropical days (above 30°C)}}$$

$$\mathbf{Z = 5000 \times 1{,}079 * n_{municipality} / 100.000}$$

$C_{hospitalization}$ = Total costs of hospitalizations due to heat per year in Rotterdam

Z = Costs in Euros for a municipality from extra hospital admissions due to heat of 1 tropical day, per 100.000 inhabitants

$n_{municipality}$ = Number of inhabitants Rotterdam (664.311)

The hospitalization costs were determined for the different scenarios and timeframes. In Figure 5.15, the estimated costs of the hospitalizations due to extreme heat per year in Rotterdam are indicated.

| Scenario | Timeframe | Number of tropical days (KNMI) | Z | $C_{hospitalization}$ |
|---|---|---|---|---|
| Current time | | 9 | € 35.840 | € 322.556 |
| Low scenario | Mid-term (2050) | 9 | € 35.840 | € 322.556 |
| High scenario | Mid-term (2050) | 14 | € 35.840 | € 501.754 |
| Low scenario | Long-term(2100) | 9 | € 35.840 | € 322.556 |
| High scenario | Long-term(2100) | 39 | € 35.840 | € 1.397.744 |

*Figure 5.15: Total cost of hospitalization due to extreme heat per year in Rotterdam across scenarios (Own figure)*

After determining the mortality and hospitalization costs due to heat stress, these two costs were combined, resulting in the total yearly costs of heat stress for the health sector. Figure 5.16 gives an overview of these estimated costs in the health sector for the different scenarios.

$$\mathbf{C_{health\ sector} = C_{mortality} + C_{hospitalization}}$$

| Scenario | Timeframe | Mortality | Hospitalization | $C_{health\ sector}$ |
|---|---|---|---|---|
| Current timeframe | | € 3.676.106 | € 322.556 | **€ 3.998.662** |
| Low scenario | Mid-term (2050) | € 6.616.991 | € 322.556 | **€ 6.939.547** |
| High scenario | Mid-term (2050) | € 9.925.486 | € 501.754 | **€ 10.427.240** |
| Low scenario | Long-term (2100) | € 6.616.991 | € 322.556 | **€ 6.939.547** |
| High scenario | Long-term (2100) | € 29.776.457 | € 1.397.744 | **€ 31.174.201** |

*Figure 5.16: Costs per year due to heat in the health sector (Own figure)*

## 5.3.2 Energy sector

Furthermore, the costs of the increased energy demand for cooling were calculated. The formula for the energy costs for cooling is based on estimates made by Martien Visser, who determined that the energy usage increases with 6 million kWh per degree Celsius above 20°C (Zuil, 2019). Based on this principle, the following formula was developed to determine the energy demand for cooling:

**kWh energy demand for cooling in NL = ((days above 20°C in the year / 24 hours) * average amount of hours the temperature is above 20 degrees on these days * (average temp - 20) / 2) * 6.000.000**

Thereafter, the costs due to heat for the energy sector in Rotterdam were determined using the formula:

**$C_{energy\ sector}$ = (kWh energy demand for cooling * energy price per kWh) * ($n_{municipality}$ / $n_{Netherlands}$)**

$C_{energy\ sector}$ = Energy costs for cooling

The costs were calculated for the low and high climate scenarios and for the mid- and long-term timeframe. In Figure 5.17 an overview of the estimated energy costs for cooling per year is given. The data for the calculations for the number days above 25 °C derived from data by *KNMI'23-KlimaatScenario's*. (2023) and the data for the average maximum summer temperature derived from the 'climate dashboard' by the KNMI (2025). For the calculations an energy price of €0,30 per kWh was used.

| Scenario | Timeframe | Days above 20 degrees (Klimaateffectenatlas) | Average max summer temp (KNMI) | Hours above 20 degrees | kWh energy for cooling | $C_{energy\ sector}$ |
|---|---|---|---|---|---|---|
| Low scenario | Mid-term (2050) | 105 | 23,4 | 6 | 267750000 | € **2.952.832** |
| High scenario | Mid-term (2050) | 121 | 24,5 | 7 | 476437500 | € **5.254.304** |
| Low scenario | Long-term(2100) | 105 | 23,4 | 6 | 267750000 | € **2.952.832** |
| High scenario | Long-term(2100) | 159 | 27,7 | 10 | 1530375000 | € **16.877.461** |

*Figure 5.17: Costs of the increased energy demand due to heat (Own figure)*

## 5.3.3 Financial sector

To determine the costs of heat stress in the financial sector, the reduced labor productivity of indoor workers are estimated. To calculate the loss of indoor labor productivity, Stone et al. (2013) developed a formula based on data from Seppänen et al. (2004) who stated that indoor productivity decreases with 2% per degree after 25°C.

**$C_{financial\ sector}$ = P * number of days above 25 °C * ($n_{municipality}$ / $n_{Netherlands}$)**

**P = ((469817 *103)/180000) * T * 2 – 50**

$C_{financial\ sector}$ = Total cost of productivity loss in buildings in Rotterdam per year

P = Productivity loss per day due to heat in NL (Euro)

T = Daily average summer temperature

To determine the costs of the reduced indoor labor productivity, the daily average temperature and the number of days above 25 °C derived from the climate predictions data by *KNMI'23-KlimaatScenario's (2023)*. These were calculated per scenario in the excel table of which the results are shown in Figure 5.18.

| Scenario | Timeframe | Days above 25 °C | T daily summer temperature | Loss of productivity in € per day | Loss of productivity in € per year in nl | $C_{financial\ sector}$ |
|---|---|---|---|---|---|---|
| Low scenario | Mid-term (2050) | 35 | 18,4 | € 98.883 | € 3.460.906 | € **127.227** |
| High scenario | Mid-term (2050) | 48 | 19,5 | € 104.797 | € 5.030.280 | € **184.918** |
| Low scenario | Long-term(2100) | 35 | 18,4 | € 98.883 | € 3.460.906 | € **127.227** |
| High scenario | Long-term(2100) | 90 | 22,6 | € 121.466 | € 10.931.900 | € **401.868** |

*Figure 5.18: Costs of reduced labor productivity due to heat (Own figure)*

## *5.3.4 Total costs of the risks*

After determining the financial impact of indoor heat stress in Rotterdam across the health, energy and financial sector, the combined costs per year per scenario were calculated, as shown in Figure 5.19 & 5.20. The results show that the health sector accounts for the largest share of the costs, followed by the energy sector, with the financial sector contributing a smaller portion. These findings highlight that unaddressed heat stress in the existing social housing stock leads to high costs, particularly in scenarios with higher future temperatures.

| Scenario | Timeframe | $C_{health\ sector}$ | $C_{energy\ sector}$ | $C_{financial\ sector}$ | $C_{total}$ |
|---|---|---|---|---|---|
| Current timeframe | | € 3.998.662 | € 2.952.832 | € 127.227 | **€ 7.078.721** |
| Low scenario | Mid-term (2050) | € 6.939.547 | € 2.952.832 | € 127.227 | **€ 10.019.605** |
| High scenario | Mid-term (2050) | € 10.427.240 | € 5.254.304 | € 184.918 | **€ 15.866.462** |
| Low scenario | Long-term (2100) | € 6.939.547 | € 2.952.832 | € 127.227 | **€ 10.019.605** |
| High scenario | Long-term (2100) | € 31.174.201 | € 16.877.461 | € 401.868 | **€ 48.453.531** |

*Figure 5.19: Total costs of risks due to heat (Own figure)*


*Figure 5.20: Total costs of risks due to heat per scenario and sector (Own figure)*

In response to sub-question one, the risks and costs that could arise if heat stress is not addressed include increased health-related expenses, higher energy demand for cooling, and economic impacts such as reduced productivity and property value, with the most significant burden falling on the health sector.

These estimated costs also represent the **p**otential benefits of mitigation, as they are the avoided risks if heat stress is effectively addressed. In this way, the quantified risks serve as the basis for valuing the societal benefits of indoor heat stress mitigation. These benefits are further evaluated in Chapter 8 through a societal cost-benefit analysis over time.

# 6. Vulnerability analysis

Following the heat stress risk assessment, this chapter focuses on the spatial distribution of heat stress vulnerability across neighborhoods in Rotterdam. The thereby associated sub-question that Chapter 6 aims to answer is: "*What areas are most vulnerable to the risks of heat stress?".* The chapter aims to identify the neighborhoods that are most susceptible to heat stress risks based on the social and (bio)physical vulnerability, to locate which areas are in most urgent need for mitigation.

## 6.1 Vulnerable locations

This section integrates data from both the social and (bio)physical vulnerability, to identify the areas in Rotterdam that are most vulnerable to heat stress. Data on environmental hazards have been combined with socioeconomic and demographic characteristics to create a thorough vulnerability map, resulting in an overview of the areas that require heat stress mitigation in the social housing stock the most urgently.

The *Rotterdams Weerwoord* has already developed a preliminary map to assess the areas in Rotterdam in need of heat stress mitigation. However, this map is based solely on the physiological aspects of heat stress, considering factors such as temperature levels, proximity to cool areas, and the impact of air quality and noise pollution when windows are opened (*Hitte - Rotterdams Weerwoord*, 2023). While these elements provide valuable insight into the physical burden of heat stress, they do not consider the social factors that play a role in determining vulnerability and are highly relevant to this research. Consequently, a more comprehensive identification map has been created for this research that incorporates both the geographic and social dimensions of Rotterdam's neighborhoods.

For this research, the Hazards of Place model, previously discussed in Section 2.2, was utilized to assess the overall vulnerability across Rotterdam's neighborhoods, integrating both social and (bio)physical aspects to create a more comprehensive vulnerability map. The first step was to identify social vulnerability by combining data of demographic and socioeconomic factors, resulting in the social vulnerability map. Thereafter, to assess the (bio)physical vulnerability, the PET map was used to determine the heat stress per neighborhood. Then the social and (bio)physical vulnerability maps were combined to develop a comprehensive place vulnerability map. This final map identified locations where high social vulnerability overlaps with extreme heat exposure, outlining the neighborhoods most in need of heat stress mitigation interventions. Given that the objective of this research is to determine which areas require targeted heat stress mitigation measures in social housing, this approach ensures that mitigation efforts are directed toward the communities most at risk.

### *6.1.1 Social vulnerability*

To identify areas with high social vulnerability to heat, a social vulnerability map was developed based on the vulnerability framework by Ahmed et al. (2023), discussed in Section 1.2.6. The framework defines climate vulnerability as a combination of three interrelated factors: exposure, sensitivity and adaptive capacity. To develop a map that combines these three factors, three different data sources were used.

The first data source used for the map was the percentage of people that are 65+ with fragile health (RIVM, 2022). This indicator was chosen to reflect the sensitivity, as a higher age and the presence of pre-existing health conditions are determinants of a high sensitivity to heat stress. Furthermore, data on the average socioeconomic status per neighborhood (CBS StatLine, 2023) were used. These data reflect both a high sensitivity, due to the link between a lower socioeconomic statuses and health risks, and a lower adaptive capacity, as these households often lack the financial resources to implement heat stress mitigation measures themselves.

Lastly, the percentage of social rental homes (CBS, 2023) is included to represent the exposure factor in the framework. This map was included as social housing dwellings are often poorly insulated and heat retaining (Sneep, 2024), making tenants more exposed to indoor heat. The combination of these three data sources reflecting sensitivity, adaptive capacity and exposure, formed the basis of the social vulnerability map presented in Figure 6.1.

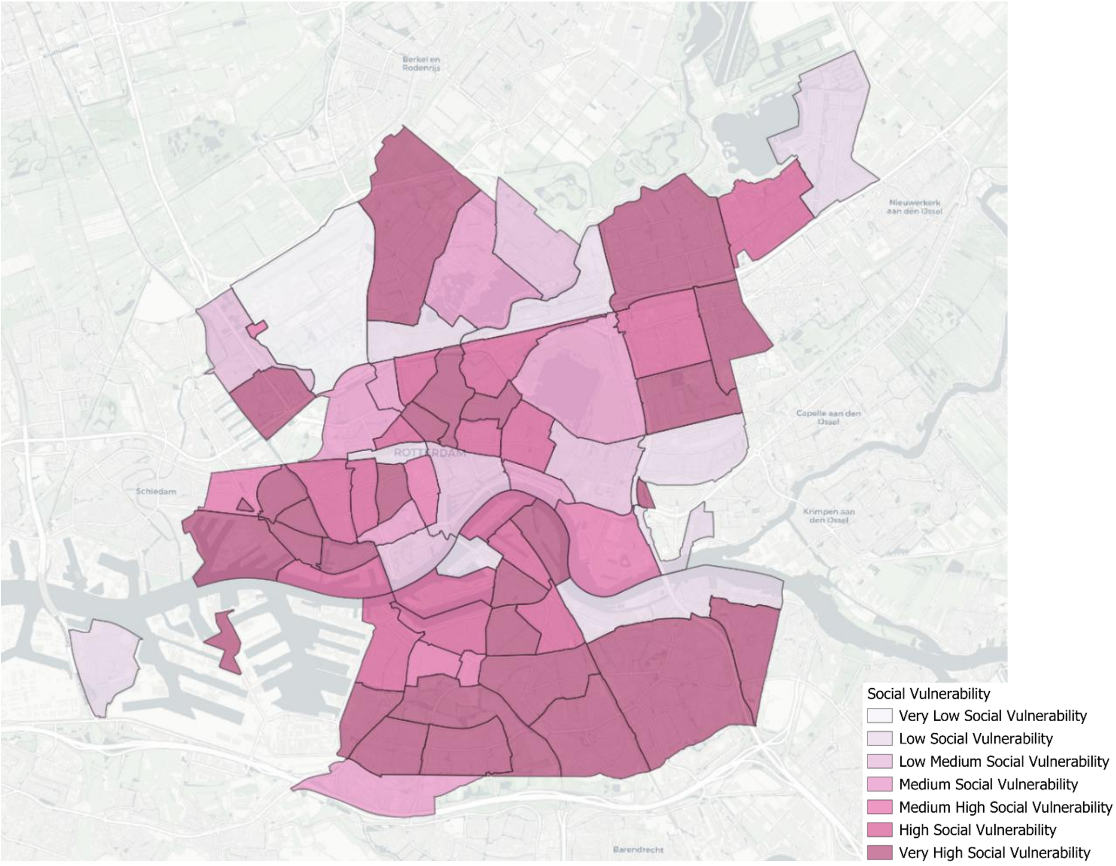



*Figure 6.1: Social vulnerability per neighborhood in Rotterdam, based on percentage of 65+ people with fragile health, socioeconomic status and the percentage of social rental homes (Own figure using data by RIVM (2022), CBS StatLine (2023) & CBS (2023))*

As shown in Figure 6.1, many neighborhoods in Rotterdam have a high social vulnerability to heat stress. This is particularly visible in the south and west of Rotterdam and was also evident in the three separate maps, reflecting that these areas face overlapping risk factors. Consequently, the south and west of Rotterdam are the most socially vulnerable areas in Rotterdam.

### 6.1.2 (Bio)physical and social vulnerability

After creating the social vulnerability map, the (bio)physical vulnerability serves as the second input for the thorough place vulnerability map. To assess the (bio)physical vulnerability, a PET (Physiological Equivalent Temperature) map by Nelen & Schuurmans (2024) was used on a neighborhood level. Then, the PET map and the social vulnerability map were combined to determine the locations with the highest heat stress and the highest social vulnerability. Figure 6.2 shows the map that was developed, in which social vulnerability and PET are placed on two axes as shown in the legend. In this way it is visible which areas are most affected by heat stress and which ones are most socially vulnerable separately, but it also shows the locations where these two elements are both indicated.

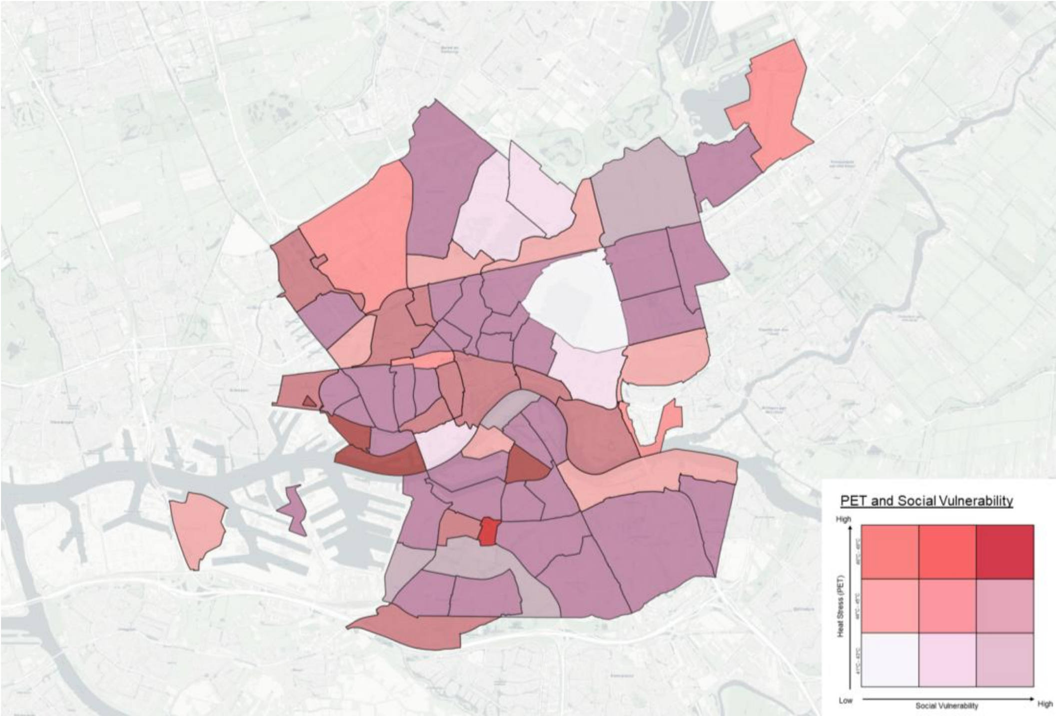



*Figure 6.2: Place vulnerability map Rotterdam (Own figure using data by Nelen & Schuurmans (2024), RIVM (2022), CBS Statline (2023) & CBS (2023))*

Resulting from Figure 6.2, the darker purple and red neighborhoods are highly affected by heat stress and highly socially vulnerable. The map indicates that there are many neighborhoods in Rotterdam that have a dark purple and red color and therefore are socially and (bio)physically vulnerable. Thus, to be able to find the most vulnerable locations, the place vulnerability map is also laid over a UHI effect map (Atlas Natuurlijk Kapitaal, 2017), resulting in the map shown in Figure 6.3.

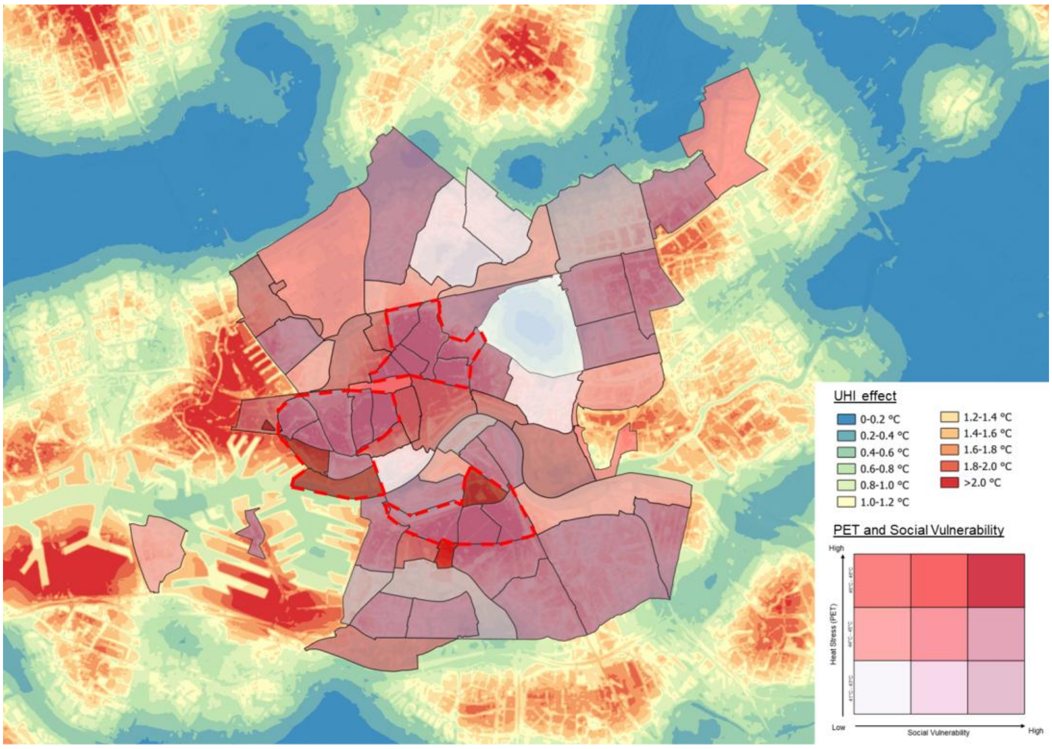



*Figure 6.3: (Bio)physical and Social Vulnerability per neighborhood in Rotterdam (Own figure using data by Atlas Natuurlijk Kapitaal (2017), Nelen & Schuurmans (2024), CBS StatLine (2023), CBS (2023) and RIVM (2022))*

Concluding from Figure 6.3, there are three areas that are both socially vulnerable and experience a lot of heat stress (biophysical vulnerability). The first location that is indicated is the Oude Noorden, an area just above Rotterdam Central railway station. The second location that is indicated to be vulnerable is an area in the west of Rotterdam, which is Delfshaven. The last location is an area in the south of Rotterdam, consisting of the neighborhoods Tarwewijk, Afrikaanderwijk, Bloemhof and Hillesluis. These areas are thus in urgent need for heat stress mitigation.

## 6.2 Interview results vulnerability

Resulting from the interviews regarding the topic of vulnerability, the experts stated that it is important to consider vulnerability to heat from not only a technical perspective, but also from a human perspective, thereby supporting the approach of looking at vulnerability to heat from both a social and (bio)physical perspective. The experts confirmed that social vulnerability to heat is determined by different factors. They first confirmed that social vulnerability is linked to socioeconomic status, as people with a lower socioeconomic status have fewer financial means to take measures and are often more likely to suffer from pre-existing health conditions such as obesity and cardiovascular diseases. Furthermore, the housing quality in the social housing sector is often lower with poor insulation, making these dwellings extra vulnerable for heat. Additionally, vulnerable individuals are often at home during periods of heat, making their indoor environment determinant for their exposure to heat.

Another important insight shared by one of the experts is that for many social housing residents, climate concerns are not at the top of their list, as some of these residents might have bigger struggles, for instance financially. This gave an insight into the broader context of the challenges social housing tenants are facing. One of the experts stated the following regarding this: “being concerned with climate is also a kind of privilege” emphasizing that climate adaptation efforts might be relative to the realities and priorities of vulnerable populations.

# 7. Heat stress mitigation measures

Chapter 7 addresses the possible mitigation measures for the existing properties of housing corporations. The chapter aims to answer sub-question three: *“What measures can be taken to mitigate heat stress in existing properties of housing* corporations *and what are the costs of implementing these measures?”.* In this chapter various mitigation measures to mitigate heat stress will be explored and assessed on their effectiveness, implementation costs, maintenance costs and lifespan. Using data from the document analysis, an overview of the mitigation measures will be developed. Moreover, variants of mitigation strategies will be developed based on findings of the expert interviews. The results of this chapter will also serve as an input for the societal cost-benefit analysis in Chapter 8.

## 7.1 Mitigation measures

### *7.1.1 Shading*

An effective way to minimize indoor heat is by preventing solar radiation from reaching the windows. Therefore, outdoor shading can be highly effective, as this can reflect sunlight before it enters the building (van Hooff et al., 2014; Porritt et al. 2012). Previous studies support this statement and show that the use of shading devices can significantly reduce indoor temperatures (Van der Strate et al, 2022). Movable shading, such outdoor blinds and awnings, are the most effective as they provide flexibility and can be used only when the sun enters the dwelling. However, this type of shading requires active operation and is vulnerable to wind (Salcedo Rahola et al., 2009). The effectiveness of shading thus also relies on the tenant’s usage (Nationaal Kennis- en innovatieprogramma Water en Klimaat, 2023). Moreover, the implementation of outdoor shading can be challenging, as this is sometimes prohibited due to protected city views or other regulations (Corpel et al., 2024).

Instead of outdoor shading, it is also possible to implement indoor shading, such as curtains and blinds. However, studies have shown that using indoor shading is far less effective than using outdoor shading, as the indoor shading materials absorb solar radiation and reflect heat into the building (Le Grand et al., 2014; De Vries et al., 2020). Even though using outdoor shading is more effective, the use of indoor shading has still proven to be more effective than not using shading at all.

Solar reflective glazing or reflective window foils are other effective measures to reduce indoor heat (Hoevers, 2021). These measures lower solar radiation transmission through windows, which results in reduced indoor temperatures. If regular windows are replaced by windows with a lower g-value, the heat gain of the building will be reduced. However, these measures could also contribute to a decrease in daylight entering a building and reduce the solar heat gain in the winter (Hoevers, 2021).

### *7.1.2 Ventilation*

Natural ventilation is another effective passive mitigation strategy to reduce indoor temperatures, which relies on windows openings or ventilation rosters to facilitate airflow. Ventilation allows fresh air to enter the dwelling and the heat to dissipate, particularly when outdoor temperatures are lower than indoor ones (van Hooff et al., 2014). The effectiveness of ventilation depends on building design, external conditions and the proper use of ventilation openings (Salcedo Rahola et al., 2009). Nevertheless, natural ventilation has several limitations that need to be addressed to be useful for lowering indoor heat. The limitations when opening windows are the dependency on tenant usage and the possibility of air pollution, noise and mosquitoes being introduced into the dwellings (De Vries et al., 2020). Measures such as insect screens and ventilation grill with a filter can help mitigate these issues. Additionally, safety concerns can prevent people from opening their windows at night (De Vries et al., 2020; Willems & Nonner, 2021). As areas with high percentages of social housing often have higher crime rates, this could present an issue for social housing (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022).

### 7.1.3 Roof and facade additions

Furthermore, adjustments to roofs and facades can serve as heat stress mitigation measures. Various approaches, including green roofs, green facades, cool roofs and reflective coatings, are explored as measures to reduce heat absorption and improve thermal comfort in buildings. While these measures offer several environmental and aesthetic benefits, their effectiveness in lowering indoor temperatures varies depending on building insulation and implementation.

Firstly, green roofs are a mitigation measure, which have the potential to cool down the dwelling by lowering the albedo (solar reflectance), adding additional thermal insulation from the soil layer, enhancing convective heat transfer and evapotranspiration (van Hooff et al., 2014; Salcedo Rahola et al., 2009). The most substantial cooling effect of green roofs comes from evapotranspiration, which is the combined process of evaporation from the soil and transpiration from plants, which can reduce heat flux through the roof by 12% in dry conditions and up to 25% when soil moisture is at maximum capacity (van Hooff et al., 2014; Lazzarin et al. 2005). However, green roofs also have several limitations, as they require regular maintenance, can be expensive to install and may not be structurally feasible for lightweight buildings (Salcedo Rahola et al., 2009). Additionally, studies have found only minimal effects on the reduction of indoor temperature when green roofs are applied, as it mostly reduces the external surface temperature of buildings rather than lowering indoor temperatures (Nationaal Kennis- en Innovatieprogramma Water en Klimaat, 2023; Van der Strate et al, 2022).

Furthermore, vegetation can be implemented on the facade to cool down a dwelling. Green facades can provide cooling benefits through shading and evapotranspiration, thereby lowering temperatures on the building surface and in the surrounding environment. Various systems can be used to implement green facades, including climbing plants growing directly on walls, plants supported by trellises and substrate-based vertical gardens. Nevertheless, green facades require high maintenance and structural support, which can influence their feasibility and cost-effectiveness (Deltaprogramma, n.d.).

Another heat stress mitigation strategy is the implementation of cool roofs or reflective coatings. These mitigation strategies focus on increasing solar reflectance (albedo) to reduce heat absorption of the surfaces exposed to solar radiation (Fox et al., 2018). Using high-albedo (light-colored) materials for roofs and facades can lead to a decrease in surface temperatures, reducing indoor heat (Climate ADAPT, 2024). Moreover, compared to green roofs, changing the absorption coefficient of surfaces is more cost-effective, requires lower maintenance and does not add extra weight to the structure. Reflective coatings and paints, however, may need periodic cleaning to maintain their effectiveness (Salcedo Rahola et al., 2009).

### 7.1.4 Installations

Besides the earlier-mentioned passive mitigation measures, various mechanical installations, such as air conditioners, fans and heat pumps, can also offer effective solutions to mitigate indoor heat stress. The first heat lowering installation that could be implemented is an air conditioner, which is a highly effective heat mitigation installation that could be used to lower indoor temperatures by providing the dwelling with cool air and withdrawing warm air. Research by Corpel et al. (2024) showed that it is the most effective mitigation measure perceived by tenants. However, despite its effectiveness, air conditioners come with many limitations. Air conditioners consume a large amount of energy when used, contributing to the increased energy demand. Moreover, they require the use of an outdoor unit to get rid of the excess heat, which in return causes additional warming of the urban environment, causes noise disturbance and impacts the aesthetics of the outdoor environment (Jin et al. 2020).

Heat pumps are an effective and more energy-efficient mitigation measure for cooling down dwellings. They are a type of cooling system that transfers heat, and they are more energy efficient than traditional air conditioners. Heat pumps are even more efficient with a geothermal energy storage using ATES, as this allows for storing cool water in summer and warm water in winter (Salcedo Rahola et al., 2009; Deltaprogramma, n.d.). Even though the initial investment costs of heat pumps are high, they offer long term energy savings and are a far more sustainable solution than air conditioners.

Furthermore, fans are a measure that can be used for heat stress mitigation. Fans increase circulation and enhance the body's ability to cool down through evaporation (De Vries et al., 2020; Morris et al. 2021). However, their effectiveness depends on humidity and temperature. Moreover, above a certain temperature, fans can become counterproductive, potentially increasing heat stress instead of lowering it (Morris et al. 2021).

### 7.1.5 Insulation

Another heat stress mitigation measure is insulation, which can have both positive and negative effects on heat within dwellings. Good roof insulation can help reduce indoor temperatures by keeping the heat outside of the dwelling for a longer time (Nationaal Kennis- en innovatieprogramma Water en Klimaat, 2023). However, insulation can also contribute to heat retention and therefore work counter effectively. This is often experienced in well-insulated buildings where indoor heat can be trapped during warm days, leading to high indoor temperatures (van Hoof et al., 2014). Concerns that have arisen are that highly insulated renovated dwellings may worsen heat stress due to the extra insulation and limited ventilation (Groene Huisversters, n.d.). Research from the Technical University of Eindhoven supports these statements, as the measured result from their research shows that highly insulated dwellings experience higher temperatures (van Hooff et al., 2014).

## 7.2 Costs of the mitigation measures

In this section, the effectiveness and costs of the mitigation measures discussed in the previous section are addressed. The mitigation measures are assessed on their effectiveness, implementation costs, maintenance costs and lifespan. A simplified overview of the mitigation measures is presented in Figure 7.1, developed through a document analysis of various existing studies and reports on heat stress mitigation measures. The full mitigation measures table including the references is added in Appendix 5.

| Mitigation measure | Effectiveness measure | Cost of implementation / dwelling | Cost of maintenance / year / dwelling | Lifespan |
|---|---|---|---|---|
| Outdoor shading | Very positive effect | €2.000 - €5.000 | €50 - €100 | 15 years |
| Indoor shading (blinds) | Positive effect | €2.000 - €5.000 | 0 - €50 | 20 years |
| Indoor shading (curtains) | Neutral - little effect | €50 - €500 | 0 - €50 | 20 years |
| Reflective window foils | Positive effect | €500 - €1000 | 0 | 10 years |
| Solar reflective glazing | Very positive effect | €3500<br>+- €100 for addition to tilt and turn windows | 0 | 40 years |
| Natural ventilation (tilt and turn window) | Very positive effect | € 4.000 | € 45 | 50 years |
| Natural ventilation (ventilation rosters) | Very positive effect | €1000 - €2500 | 0 - €50 | 50 years |
| Green roof | Little - positive effect | €80 / m2<br>€2.500 - €5.000 | €100 - €500 | 50 years |
| Green facade | Neutral - little effect | €300 / m2<br>€500 | €100 - €500 | 40 years |
| Cool / reflective roof | Positive effect | €100 / m2 | 0 - €50 | 50 years |
| Air conditioner | Positive - very positive effect | €1.000 - €5.000 | €100 - €500 | 10 - 15 years |
| Heat pump with ATES | Very positive effect | € 28.000 | €100 - €500 | 15 - 20 years |

*Figure 7.1: Costs and effectiveness of the heat stress mitigation measures (Own figure)*

The findings presented in Figure 7.1 indicate that the passive cooling strategies are generally the most cost-effective approaches for mitigating heat stress in the existing housing stock of corporations and are also the most sustainable. Measures such as ventilation rosters and external shading offer long-term benefits with relatively low maintenance costs. In contrast, active cooling methods, such as air conditioners are seen as less appropriate cooling measures. This is since they provide immediate relief, but are associated with high energy consumption and long-term financial and environmental burdens. Given the financial constraints of housing corporations, investing in durable, low-maintenance mitigation measures that are effective and affordable are preferred.

## 7.3 Results of interviews with Rotterdam housing corporations

Interviews with housing corporations in Rotterdam revealed a growing awareness of the need to address heat stress within their housing stock. The corporations all acknowledge that heat stress is becoming a problem that poses serious risks and are all driven to make an adaptation strategy for their stock. Several corporations have also noticed an increase in tenant complaints related to indoor heat. However, the perception of heat among the social housing tenants is complex and diffuse, according to the corporations. While some tenants report severe discomfort and claim their homes are unlivable during heatwaves, other tenants who come from warmer climates are often more accustomed to high temperatures. Despite the growing awareness, partly due to media attention, the overall number of heat-related complaints has remained limited, which could be attributed to the different heat perceptions or language barriers. Besides, these complaints were not able to be linked to specific housing types or locations. Consequently, in response to the increasing presence of heat stress, the corporations have begun integrating heat stress mitigation into their climate adaptation strategies.

Together, the four corporations have mapped and analyzed the heat status of all the dwellings in their combined housing stock, to identify which dwellings are in most urgent need for mitigation. The corporations focused on three criteria in this assessment, which include a TO-July above 4,8, the presence of sun shading and a roof insulation rate below 2,5. This assessment resulted in the identification of approximately 15.000 dwellings that are in urgent need of mitigation. Moreover, the corporations expressed a preference for using passive mitigation measures during the interviews, such as shading and ventilation, as these measures are effective and do not rely on active cooling systems that require energy.

Nevertheless, the implementation of heat mitigation measures comes with challenges. The primary concern that corporations addressed were the financial challenges, due to their limited financial capacity and the fact that there is no incentive for the corporations in mitigating heat stress. Housing corporations operate under tight budgets and are already required to comply with many regulatory obligations. Since there are no legal requirements for the mitigation of heat stress in the existing building stock in the Netherlands yet, heat mitigation remains a lower priority. Another insight presented during the interviews was that the financial challenges of the measures do not necessarily lie with the investment costs, but that the maintenance costs often pose the most financial challenges.

To tackle the financial challenges that the corporations face, the municipality of Rotterdam has provided a subsidy for the corporations for the implementation of sun shading. However, this subsidy only covers a small fraction of the investment costs. To create a larger incentive for the corporations, one of the experts provided a valuable insight, suggesting that incorporating heat mitigation into the *woningwaarderingssysteem* (housing valuation system) could provide a more structural financial incentive. This could potentially make the investments more viable, as it would then be considered a housing improvement that would be reflected in the rental price.

The corporations also addressed the importance of integrating heat mitigation and awareness into renovation projects, particularly for projects where additional insulation is implemented. One of the corporations had faced a case where indoor temperatures increased after renovation, which gave them insights into how to tackle future projects. This has led some corporations to include heat in their renovation strategies to remain below a TO-July of 4,8 when renovating.

Furthermore, challenges for the implementation of measures have been addressed by the corporations, since each housing complex requires a unique approach. This is due to the differences in the building design and structural challenges. Moreover, some buildings may carry a 'beschermd stadszicht' (protected city view) status, which legally restricts visible modifications to the exterior.

Consequently, while the housing corporations in Rotterdam are increasingly acknowledging and addressing heat stress, they face many challenges due to financial limitations, the absence of legal obligations and the complexity of implementing customized solutions. These challenges show the need for policy and financial support to facilitate effective heat stress mitigation across the social housing sector in Rotterdam.

## 7.4 Variants of mitigation strategies

In this section, possible variants of mitigation strategies are developed for the SCBA, to compare the costs and benefits of different mitigation strategies. The housing corporation representatives stated that they have listed 15.000 dwellings as in most urgent need of mitigation among the four largest housing corporations in Rotterdam. This number was used as a working assumption for this research. However, it is important to note that this number has not been independently verified. Due to privacy considerations, it was not possible to access or check the underlying dwelling-level data. Therefore, the analysis relies on the assumption that the estimate provided during interviews is accurate and representative.

Furthermore, the interviews revealed that corporations prefer to use passive mitigation measures and have limited financial means. Consequently, the variants were based on the implementation of passive mitigation measures that are cost effective. In Figure 7.2 the different variants, including the costs of the different measures, are shown. Thereafter, these variants serve as the cost input for the SCBA to determine the costs of the implementation over time in Chapter 8.

| **Variant 1** | | |
|---|---|---|
| 90% Shading | 13500 | Number of dwellings |
| 10% Solar reflective foils | 1500 | Number of dwellings |
| **Variant 2** | | |
| 50% Tilt and turn windows | 7500 | Number of dwellings |
| 50% Ventilations rosters | 7500 | Number of dwellings |
| **Variant 3** | | |
| 45% Shading | 6750 | Number of dwellings |
| 5% Solar reflective foils | 750 | Number of dwellings |
| 50% Tilt and turn windows + solar glazing | 7500 | Number of dwellings |
| 50% Ventilations rosters | 7500 | Number of dwellings |

| **Investment costs of the measures** | | | |
|---|---|---|---|
| Shading | € | 3.500 | € / dwelling / 15 years |
| Solar reflective foils | € | 750 | € / dwelling / 10 years |
| Tilt and turn windows | € | 4.000 | € / dwelling / 50 years |
| Extra costs for solar glazing | € | 100 | € / dwelling / 40 years |
| Ventilation rosters | € | 1.750 | € / dwelling / 50 years |
| **Maintenance cost of measure** | | | |
| Shading | € | 50 | € / dwelling / year |
| Solar reflective foils | € | - | € / dwelling / year |
| Tilt and turn windows | € | 45 | € / dwelling / year |
| Ventilation rosters | € | 25 | € / dwelling / year |

*Figure 7.2: Mitigation variants (Own figure)*

For the first mitigation variant, the aim is to limit solar radiation from entering the dwellings. For this variant the mitigation measures that are implemented are shading and reflective window foils, which are both highly effective for lowering indoor temperatures. However, even though shades are the most effective measure, because of its flexibility, there are some challenges for the implementation. That is that shades cannot be implemented to every existing dwelling, due to structural challenges, unreachability of some spots and the protected city view status of some buildings. For these dwellings, solar reflective foils are implemented. The limitation of the window foils on the other side is that they also restrict sunlight from entering the building during times that sunlight is wanted, like in the winter. For this reason, mitigation variant 1 consists of flexible outdoor shades for 90% and window foils for 10% (Figure 7.2).

The second mitigation variant focuses on increasing the ventilation in the dwelling. For this strategy the mitigation measures that are implemented are tilt and turn windows and ventilation roster. As explained by the interviewed experts and the literature, ventilation is dependent on the tenant's usage. One of the conclusions was that tenants have many reasons for not wanting to open their windows to ventilate their homes during the night. The reasons for this varied from the fear of break-ins to the fear of cats escaping. Due to these reasons, this mitigation variant implements the ventilation rosters for 50% and tilt and turn windows for 50%, as shown in Figure 7.2.

For variant three, there is a combined approach, including both shading and ventilation. For 50% of the dwellings tilt and turn windows are installed, which are combined with solar reflective glazing to tackle the two strategies at once. Moreover, the other 50% of the dwellings receive ventilation rosters, which are combined with shades in the same percentages used in variant one. As this is implemented in only 50% of the dwellings this results in the fact that 45% of the dwellings receive shading and 5% receive window foils. Consequently, these dwellings receive both improved shading and ventilation for optimal cooling.

# 8. Societal cost-benefit analysis

In this chapter, a societal cost-benefit analysis will be conducted following the SCBA guidelines (Figure 3.4) developed by 'Centraal Planbureau' and 'Planbureau voor de Leefomgeving' (Romijn & Renes, 2013). Chapter 8 aims to answer the question: *"How do the economic and social benefits of implementing heat stress mitigation measures into social housing demonstrate the value of the implementation costs?".* The SCBA will be developed using the findings of the avoided costs of heat stress (Section 5.3) and the heat stress mitigation costs for the existing social housing stock in Rotterdam (Section 7.2 & 7.4). Consequently, the societal cost-benefit analysis (SCBA) is conducted to analyze and compare the avoided costs of the risks (benefits if heat stress is addressed) and the costs of several variants of heat stress mitigation measures strategies.

## 8.1 Preparation of a SCBA

### *8.1.1 Problem analysis*

The first step of a SCBA includes an analysis of the problem. The problem stated for this research is that heat stress in the existing social housing stock in Rotterdam is an increasing concern due to rising temperatures from climate change and the UHI. Many social housing dwellings lack adequate insulation, ventilation and shading, leading to excessive indoor heat. This particularly affects vulnerable populations, such as the elderly, people with a lower socioeconomic status and people with pre-existing health conditions. Without intervention, indoor heat stress will worsen, increasing the risks associated with heat stress. Addressing this issue requires collaboration between housing corporations, the municipality and tenants to develop an integral heat stress mitigation strategy for the existing social housing stock.

### *8.1.2 Establishing alternative with no intervention*

A SCBA provides valuable insights for decision-making by evaluating the economic and social impacts of a proposed measure (Romijn & Renes, 2013). The effect of a measure is determined by comparing the scenario where the measure is implemented and one where it is not, this is referred to as the *nulalternatief* (alternative with no intervention). In the case of climate adaptation measures, the *nulalternatief* represents the situation where no additional policies or interventions are implemented. For heat stress, it is estimated that global temperatures will continue to rise, as mentioned in section 1.1, leading to worsening heat stress over time. Without intervention, temperatures in dwellings are going to rise, exacerbating the risks of heat stress.

The financial costs that result from the *nulaterlatief*, but can be mitigated through intervention, represent the avoided costs and thus the benefits. These avoided costs serve as the benefits of the SCBA. The avoided costs are estimated in Chapter 5.3 and include the heat-related health expenses, the excess energy consumption for cooling and the decreased indoor labor efficiency due to heat. The time horizon for the *nulalternatief* is set from 2025 to 2100, this timeframe aligns with the projections used in most climate prediction models and was also used in Section 5.2.

### *8.1.3 Defining policy alternatives / measures*

In a SCBA the policy alternative refers to measures that are expected to contribute to the reduction of a problem, which in this case are heat stress mitigation measures in the existing housing stock of housing corporations (Romijn & Renes, 2013). In Section 7.4, several mitigation variants were developed that represent the policy alternatives (Figure 8.1). These variants were used to estimate the costs of the measures and varied from a variant with minimal intervention to one including multiple mitigation measures. By comparing different alternatives, the SCBA aims to determine which approach delivers the greatest societal value relative to its costs.

| Variant 1 | Variant 2 | Variant 3 |
|---|---|---|
| Shading | Tilt and turn windows | Shading |
| Solar reflective foils | Ventilation rosters | Solar reflective foils |
| | | Tilt and turn windows + solar reflective glazing |
| | | Ventilation rosters |

*Figure 8.1: Mitigation measure variants (Own figure)*

Since a SCBA partly relies on assumptions, it is important to account for uncertainties. This involves identifying uncertainties and analyzing their potential impact on costs and benefits and integrating these insights into the SCBA (Romijn & Renes, 2013). For this SCBA, the several variants of heat stress mitigation strategies developed in Chapter 7 reflect the possible variation in cost estimates. Additionally, to account for the uncertainties related to climate change two climate scenarios, defined in Chapter 5, were used to test the SCBA along the low and high climate scenario. This allows the SCBA to reflect a range of possible future conditions.

## 8.2 Determining benefits and costs

### *8.2.1 Determining benefits*

After the benefits and costs of indoor heat stress in existing buildings of housing corporations were determined, the next step was to quantify and monetize these benefits and costs. For the benefits, this began with identifying the sectors or domains that were directly impacted by the interventions alongside the indirect effects in other sectors (Romijn & Renes, 2013). For heat stress within the existing building stock of corporations, the effects were identified for the health, energy and financial sector. Chapter 5 shows how these benefits were identified and monetized. Figure 8.2 gives an overview of the results of the calculations of Chapter 5.

| Scenario | Timeframe | $C_{health\ sector}$ | $C_{energy\ sector}$ | $C_{financial\ sector}$ | $C_{total}$ |
|---|---|---|---|---|---|
| Current timeframe | | € 3.998.662 | € 2.952.832 | € 127.227 | **€ 7.078.721** |
| Low scenario | Mid-term (2050) | € 6.939.547 | € 2.952.832 | € 127.227 | **€ 10.019.605** |
| High scenario | Mid-term (2050) | € 10.427.240 | € 5.254.304 | € 184.918 | **€ 15.866.462** |
| Low scenario | Long-term (2100) | € 6.939.547 | € 2.952.832 | € 127.227 | **€ 10.019.605** |
| High scenario | Long-term (2100) | € 31.174.201 | € 16.877.461 | € 401.868 | **€ 48.453.531** |

*Figure 8.2: Total costs of indoor heat stress per year in Rotterdam (Own figure)*

### *8.2.2 Determining mitigation costs*

To determine the costs, the resources needed for the implementation of heat stress mitigation measures for the different variants needed to be determined. These costs included all the costs compared to the *nulaternatief* and included the implementation, maintenance and replacement costs (Romijn & Renes, 2013). The costs of the implementation, maintenance and replacement of the mitigation variants have been determined in Chapter 7. Figure 8.3 gives an overview of the costs of the measures per variant.

| | | Implementation | Maintenance | Replacement |
|---|---|---|---|---|
| Variant 1 | 90% Shading | € 3.500 / dwelling | € 50 / year | 15 years |
| | 10% Solar reflective foils | € 750 / dwelling | - | 10 years |
| Variant 2 | 50% Tilt and turn windows | € 4.000 / dwelling | € 45 / year | 50 years |
| | 50% Ventilation rosters | € 1.750 / dwelling | € 25 / year | 50 years |

| | | Implementation | Maintenance | Replacement |
|---|---|---|---|---|
| Variant 3 | 45% Shading | € 3.500 / dwelling | € 50 / year | 15 years |
| | 5% Solar reflective foils | € 750 / dwelling | - | 10 years |
| | 50% Tilt and turn windows + solar glazing | € 4.100 / dwelling | € 45 / year | 40 years |
| | 50% Ventilations rosters | € 750 / dwelling | - | 10 years |

*Figure 8.3: Costs of the mitigation measures per variant (Own figure)*

# 8.3 Developing a SCBA

## 8.3.1 Discount rate

In a SCBA, the timing of the costs and the benefits often occur at different points in time. To be able to assess and compare these values with one another, a discount rate is used to convert these future costs and benefits. The discount rate is used to calculate the future value of the costs and benefits, in which the future value of money is estimated to be lower due to inflation and the fact that people place less value to future money (Romijn & Renes, 2013). For this research a discount rate of 2,25% was used, as this was determined in the most recent SCBA guidelines (Rijksoverheid, 2020). The discount rate was calculated according to the following formula (Romijn & Renes, 2013).:

Present value = cash flow in a future year / (1+discount rate) $^{\text{year}}$

Once the future values were discounted, the Net Present Value (NPV) was calculated by summing up the discounted cash flow over the years. For this research the NPV was calculated for two future timeframes, the mid-term (until 2050) and long-term (until 2100), allowing for an assessment of the societal value of heat stress mitigation over time. Moreover, the NPV was calculated for the low scenario and the high scenario, as it is still uncertain how climate change will evolve over time. The NPV's can give an indication about whether the present value of the expected benefits outweighs the expected costs (Romijn & Renes, 2013). In the following sections the discounted NPV's of the benefits and the costs are calculated for the low and high scenarios and for up until 2050 and 2100.

## 8.3.2 Benefits SCBA

The benefits of heat stress have previously been determined for the health, financial and energy sector. In this section the NPV of the benefits for the low and high climate scenarios are calculated for both the mid-term and long-term. To calculate the NPV's, first the expected benefits for each scenario and timeframe were determined in Section 5.3. In this section the expected benefits were only calculated for the individual year of 2025, 2050 and 2100. To determine the estimates for the years in between interpolation was applied, assuming that the growth over these years is consistent. After determining the yearly benefits, a discount rate of 2,25% was applied to determine the current value of money for the future benefits. The discounted yearly benefits were then added to one another up until 2050 and 2100, to calculate the total NPV for each timeframe. The extended NPV calculations of the benefits that were conducted in excel are added in Appendix 6.

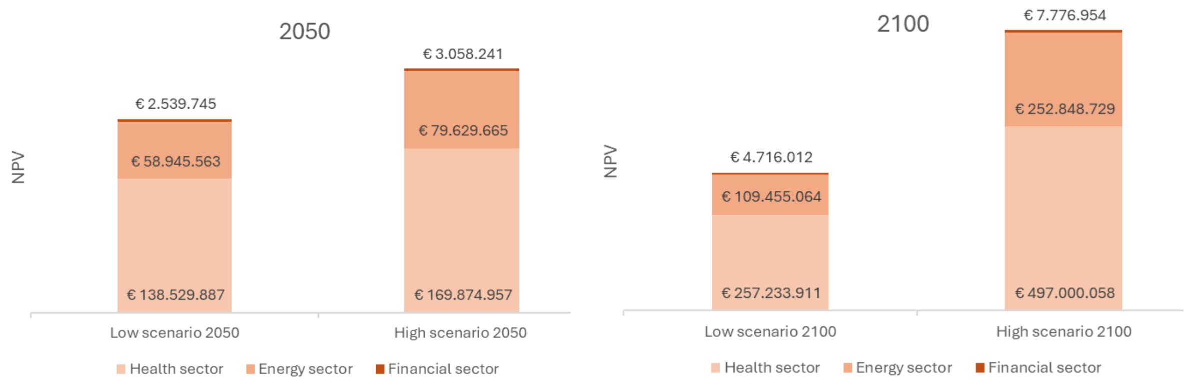



*Figure 8.4: NPV's of the benefits of heat stress in 2050 & 2100 (Own figure)*

In Figure 8.4, the results of the NPV calculations are shown for the benefits of heat stress in Rotterdam. The results show that most of the possible benefits lie in the health and energy sector. Moreover, the costs of the possible benefits will increase significantly if the high climate scenario becomes a reality and global temperatures continue to rise. Nevertheless, there are uncertainties that should be considered for these results, as they consist of estimations and future socioeconomic conditions are still insecure.

### *8.3.3 Mitigation costs SCBA*

The mitigation costs are estimated that for the 15.000 social housing dwellings that were identified as being in most urgent need for heat stress mitigation measures by the Rotterdam housing corporations. To determine the implementation, maintenance and replacement costs of the measures a detailed excel table was created per variant, which is included in Appendix 6. In the excel table the year 2025 represents the first year of implementation and thus includes the implementation costs. The implementation costs were implemented in the table again once a measure reached its end of life. For instance, if a measure has a life span of 20 years, the implementation costs were implemented in the cash flow again in 2045. Moreover, the yearly maintenance costs of the mitigation measures were added to the calculations. These costs were implemented for all the years, except for the years when a measure was implemented, assuming that when a measure was newly implemented it would not need maintenance within that first year. After the yearly costs were determined, the yearly costs were discounted at a rate of 2,25% to determine their present value. Then the yearly discounted costs were summed up to determine the total NPV's of the three variants of the mitigation measures until 2050 and 2100.

Nevertheless, it is important to point out that the timing of the replacement of the measures affects the mid- and long-term results. Since depending on when a measure reaches the end of its lifespan, replacement costs can still fall within the mid-term or long-term analysis period. This can impact on the cost-effectiveness of a variant if multiple costly replacements align in the same term or where benefits decline over time due to discounting. Therefore, it needs to be noted that the lifespan and thus timing of reinvestment can affect the results of each variant. The specific moments of the replacement investments can be found in Appendix 6.

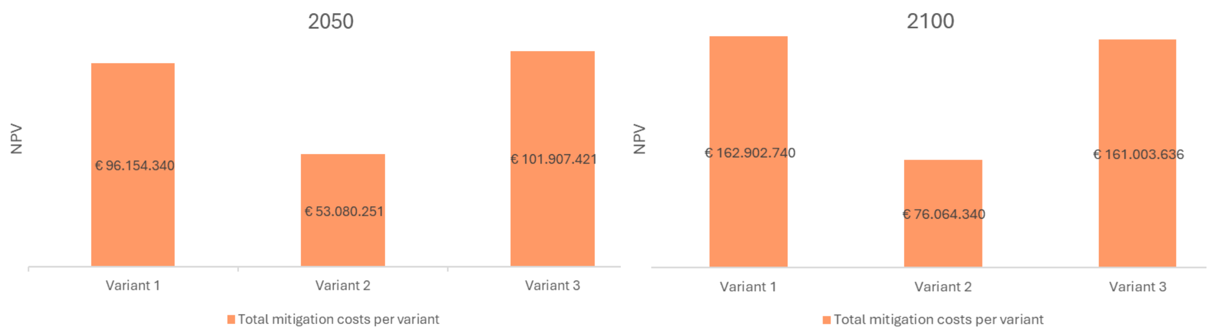



*Figure 8.5: NPV's of the mitigation costs of heat stress in 2050 & 2100 (Own figure)*

Figure 8.5 presents the results of the NPV calculations of the costs of the mitigation measures up to 2050 and 2100. The results indicate that variant 1, the shading variant, incurs higher total costs than variant 2, the ventilation variant. This is due to the shorter lifespan of shading screens and window foils, which requires replacement more frequently than the tilt and turn windows and ventilation rosters. This finding is unfortunate, given that preventing solar radiation from entering a dwelling is the most effective strategy for reducing indoor heat. Remarkably, variant 3, which combines both shading and ventilation measures, results in an investment comparable to variant 1. This suggests that the combined strategy can potentially be performance and cost effective.

## 8.4 SCBA heat stress mitigation Rotterdam

Now that the costs and benefits have been discounted, the resulting NPV's can be compared to each other. In Figure 8.6 the SCBA results of heat stress mitigation in the existing social housing stock in Rotterdam are shown up until 2050. In the figure, the three variants represent the costs, and the two scenarios represent the societal and economic benefits. The figure shows that the costs of the mitigation measures are much lower than the benefits the measures can provide for the health, energy and financial sector. Thus, according to the outcome of the SCBA, the implementation of heat stress mitigation measures is worth the investment for society.

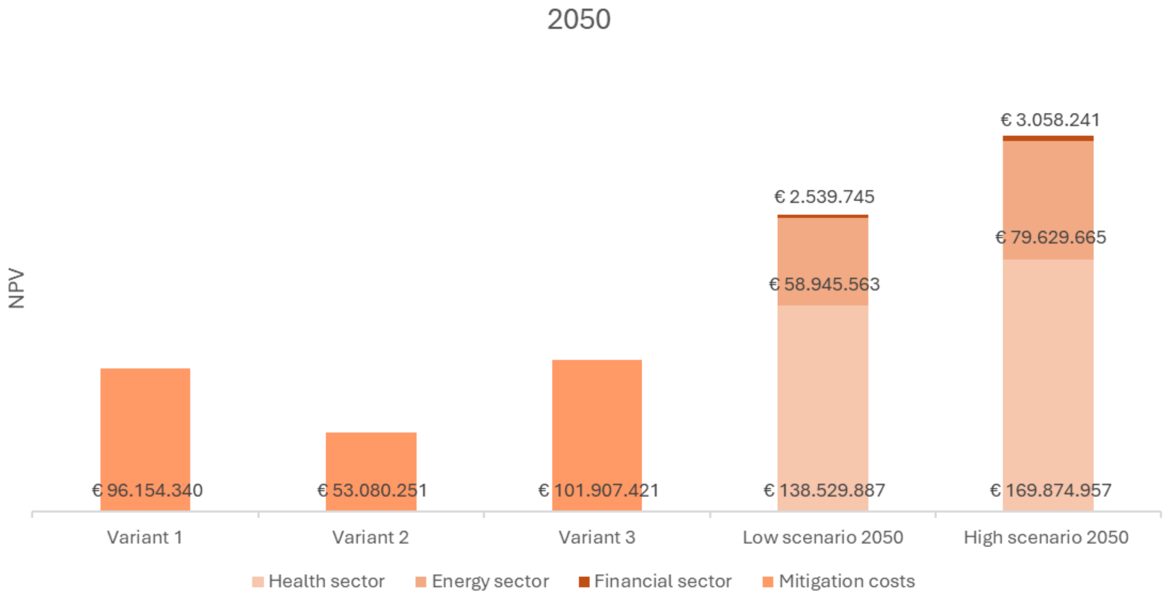



*Figure 8.6: SCBA 2050 (Own figure)*

For the long-term timeframe, until 2100, the results are shown in Figure 8.7. The long-term SCBA shows an even larger difference between the costs and benefits for the high climate scenario, as in the case of this climate scenario there will be a significant temperature increase leading to a substantial amount of heat stress. If the benefits could mitigate this heat stress even partly, this could benefit society considerably.

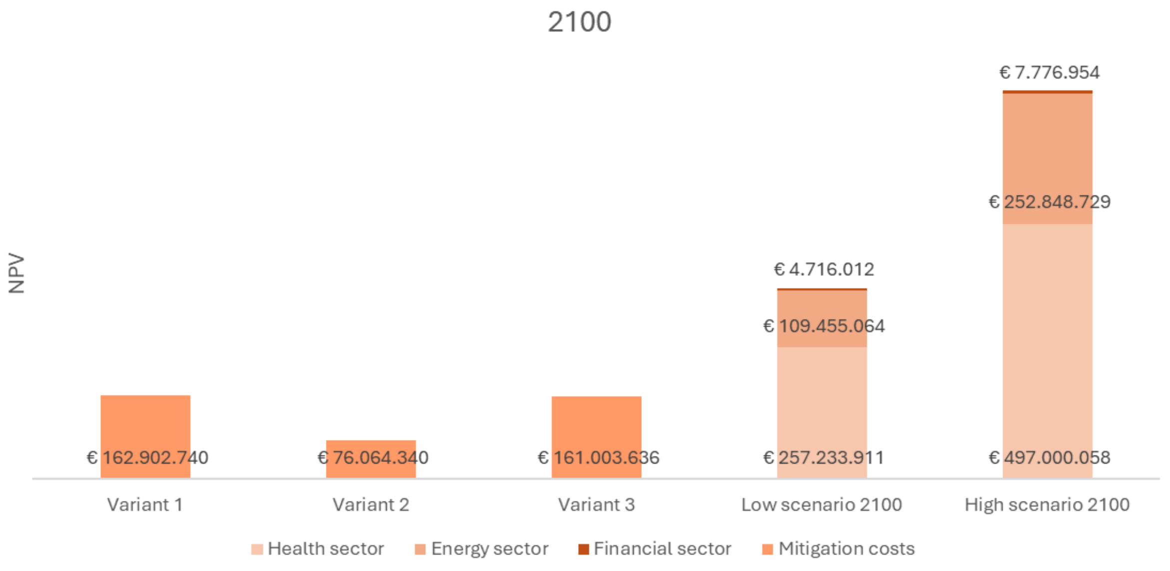



*Figure 8.7: SCBA 2100 (Own figure)*

However, the costs and benefits of heat stress mitigation that were analyzed in the SCBA lie with different stakeholders and therefore does not necessarily result in a positive business case for the investing stakeholder, which in this case are the housing corporations in Rotterdam. These corporations have limited financial means and as the benefits lie with other stakeholders it remains challenging for the corporations to invest in these mitigation measures. This resulting split incentive is further discussed in the following section.

It is also important to recognize that there is a degree of uncertainty in the results (Romijn & Renes, 2013). The climate change uncertainty is reflected in the range of outcomes presented for the different climate scenarios. By having developed results for different scenarios, the analysis aimed to account for these uncertainties related to future climate developments.

Furthermore, even within a single scenario, a degree of uncertainty remains. For instance, there could be uncertainty in knowledge, such as the precise health impacts of heat stress or energy used for cooling and there could be uncertainty related to future policy choices and societal developments (Romijn & Renes, 2013). For this research, averages of existing studies have been used to come up with the most likely future.

## 8.5 SCBA results and split incentive

As mentioned in the previous section, a major challenge of implementing heat stress mitigation measures in the social housing sector lies in the split incentive, where the costs and benefits lie with different stakeholders. As the social housing corporations are responsible for providing safe and livable housing, they are expected to finance and implement heat stress mitigation measures. However, they do not get any financial returns for their investment and have limited financial means.

This raises the question of whether stakeholders who do benefit financially from the mitigation measures could take on more responsibility. The first stakeholders that could take more responsibility are the local and national governments. The municipality of Rotterdam is already involved with the corporations in Rotterdam through consultation and by providing a subsidy for shading. However, this subsidy only covers a very small portion of the costs for the implementation, still leaving the rest of the costs in the hands of the corporations. At a national level, there is no support yet for heat stress mitigation in the existing social housing stock, both financially and in terms of policy regulations. While the national government has introduced new regulations for heat stress in newly developed dwellings through the TO-July requirement, heat in the existing building stock remains unregulated.

Furthermore, the findings of the SCBA show that the societal benefits of heat stress are falling in the health, energy and financial sector. Given the benefits they are expected to gain, these sectors may have financial responsibility in the mitigation. For example, healthcare insurance providers may benefit from fewer heat-related illness claims and energy network providers may benefit from a reduction in the cooling energy demand preventing a strain on the energy network during periods of heat. Engaging these actors in cost-sharing mechanisms could improve the feasibility.

Nevertheless, one of the interviewed experts offered an interesting insight, which suggested that compared to other climate mitigation measures, heat stress mitigation might pose one of the smaller split incentives. This is because tenants directly benefit from the mitigation measures, which include improved living conditions, reduced health risks, and lower energy costs from not needing air conditioning. Since delivering good housing quality is one of the objectives of housing corporations, the benefits for tenants are not necessarily perceived as a split incentive, according to the expert. In contrast to, for example, investments in water buffering, which mainly benefit municipal sewage and infrastructure systems, with limited benefits for individual tenants.

In conclusion, while the split incentive remains a challenge for the implementation of heat stress mitigation measures in the existing social housing stock, the distribution of costs and benefits reveals opportunities for a more balanced responsibility among stakeholders. If both local and national governments take greater responsibility and the cost-sharing arrangements with benefiting sectors are explored, this could help close the feasibility gap.

# 9. Discussion

In this thesis the aim lied in researching the costs and benefits of indoor heat stress mitigation in Rotterdam, where rising temperatures and the UHI effect pose growing risks to vulnerable populations. The findings showed that indoor heat stress presents serious health risks, as well as risks in the energy and financial sectors. Passive mitigation measures, such as shading and natural ventilation showed to be both effective and cost-efficient, but with the limited financial means, housing corporations are often still strained to implement these measures. This is where the findings revealed a split incentive between the societal and economic benefits, and the costs of the mitigation measures, which lie in different sectors. The findings of the research are evaluated and analyzed in this discussion and the interpretation of the results, implications and limitations are presented.

## 9.1 Interpretation of the results

The results of the research show a relationship between indoor heat stress and social vulnerability. The experts interviewed revealed a correlation between socioeconomic status and heat-related impact and risks. When these results were compared to previous findings in the literature, they validated the disproportionate influence of heat-related risks of marginalized populations (Reckien et al., 2017; Ahmed et al., 2023; Betgen et al., 2024). This is particularly visible in social housing, where the older and poorly insulated housing stock is unequipped to keep the dwellings cool and the lower-income tenants often lack the financial means to take mitigation measures themselves. This correlation presented that (indoor) heat stress inequitably affects socially vulnerable populations, including the social housing tenants.

Furthermore, the SCBA results showed that if heat stress is not addressed, the health, energy and financial costs substantially outweigh the investment costs for implementing heat stress mitigation measures. This outcome aligns with expectations and shows the importance of heat mitigation. However, the results also revealed a split incentive, as the societal benefits lie with different stakeholders than the financial investment of the mitigation measures by the housing corporations.

An alternative explanation for the inaction of heat stress mitigation measures of housing corporations includes the presence of competing policy priorities, such as the energy transition. Furthermore, corporations are not legally required to improve the heat resilience of their existing building stock yet, which also leaves room for inaction. Nevertheless, the results of this research show that the challenges mostly lie in the financial feasibility of implementing the measures caused by the mismatch between the costs and benefits. Without structural policy mechanisms to internalize the societal benefits, such as extra subsidies or regulatory mandates, heat resilience in the existing social housing is unlikely to improve at the necessary speed.

## 9.2 Implications

The findings of this thesis support both existing theories and extend from this existing research on heat stress risks, climate vulnerability and heat resilience in social housing. Previous research has identified the risks of heat stress and expressed how heat stress disproportionately affects social housing tenants. Moreover, previous studies have been conducted to determine the effectiveness of several heat stress mitigation measures for the existing building stock. The findings from the expert interviews and document analyses support these theories. Furthermore, this research extends from existing theories by monetizing the risks of heat stress for the health, energy and financial sector. By quantifying the societal benefits of indoor heat stress and comparing them to the costs of the mitigation measures, the research offers additional insights into the long-term value of heat resilience measures.

Additionally, the findings have practical implications for climate adaptation in housing policies. The research shows that without policy interventions, such as extra subsidies or regulatory requirements for indoor heat in the existing building stock, the housing corporations are short of financial means to take heat stress mitigation measures. Thus, even though the SCBA demonstrates the value of the benefits in comparison to the costs, this does not result in a feasible project for the corporations, requiring new policies that support heat resilience as a public good, instead of leaving the entire responsibility in the hands of the already financially restricted housing corporations.

While this thesis focused on indoor heat stress as a growing urban climate risk, this challenge must be understood as part of a broader set of climate-related and socio-economic vulnerabilities facing urban populations. Social housing tenants often also experience related challenges such as energy poverty, poor indoor air quality, and housing affordability challenges. This indicates a need for integrated policy responses that do not treat heat stress in isolation, but as a component of a broader approach to climate adaptation and equity.

## 9.3 Limitations

This thesis aimed to offer a comprehensive analysis of the long-term costs and benefits of heat stress mitigation in the existing social housing stock in Rotterdam. Still, several limitations should be considered for these results.

The first limitation is the qualitative component of the research, which relied on a limited number of expert interviews due to the limited time and availability. Additionally, during the analysis of the interviews and policy documents there might have been a degree of bias, due to personal interpretation. Moreover, for the literature review and document analyses, available literature and documents have been used based on relevance and recency. However, not all available literature has been used, which can limit the breadth of the findings.

For the quantitative part of the research there were limitations in the amount of data available. Moreover, some of the cost estimations are based on complex formulas that involve assumptions. This for instance presented a limitation for the determination of the heat-related health risks, including the monetization of human life and the valuation of years of life lost. While the research used the most recent data available, there is inevitable uncertainty among these findings. For the estimations of the energy demand and labor productivity there were also uncertainties. For example, the literature assumes that people start cooling indoor spaces at 20°C, while interactions with experts suggested that this begins at higher temperatures. Additionally, there may be overlaps between energy use and productivity outcomes, since productivity is expected to increase when a dwelling is cooled.

# 10. Conclusion

## 10.1 Research questions

This thesis was driven by the increasing impact of urban heat stress, which disproportionately affects vulnerable populations living in social housing. As global temperatures continue to rise, the risks of heat stress are becoming more severe, particularly in socioeconomically disadvantaged neighborhoods. Social housing dwellings are often unequipped to deal with extreme heat and the tenants have limited access to measures. Therefore, the societal relevance of this thesis lies in contributing to urban climate adaptation and climate equity. From a scientific perspective, the thesis contributes to bridging a research gap of climate adaptation and heat stress in social housing, where the effects of social vulnerability and inadequate housing conditions were explored. Consequently, the aim of the thesis was to provide a deeper understanding of how climate adaptation in the social housing sector can be made both financially feasible and socially responsible.

Therefore, the objective of this thesis was to evaluate the long-term costs and benefits of implementing heat stress mitigation measures into the existing social housing stock in Rotterdam. The associated research question for the thesis was:

***"What are the long-term costs and benefits of mitigating heat stress in the existing social housing stock?"***

The first sub-question *"What risks and costs could arise if heat stress is not addressed in the existing social housing stock?",* delved into the risks of heat stress and the associated costs of these risks. Moreover, it assessed how at-risk Rotterdam is to the impacts of heat. The findings of sub-question one concluded that the risks of heat stress impact the health, financial, energy and urban infrastructure sectors. These risks that were expected to arise if heat stress is not addressed include health risks, an increased energy demand, loss of productivity and infrastructure risks. The qualitative literature review concluded that the most severe impact of heat stress was identified to occur in the health sector. Furthermore, through a climate risks assessment using the EU Missions risk assessment method, the risk of heat stress in Rotterdam for the current and future scenarios were assessed for the low and high climate scenarios. This risk assessment concluded that Rotterdam currently faces a medium risk to heat stress but will face a medium to high risk to heat stress if climate change keeps on getting worse and the high climate scenario becomes a reality.

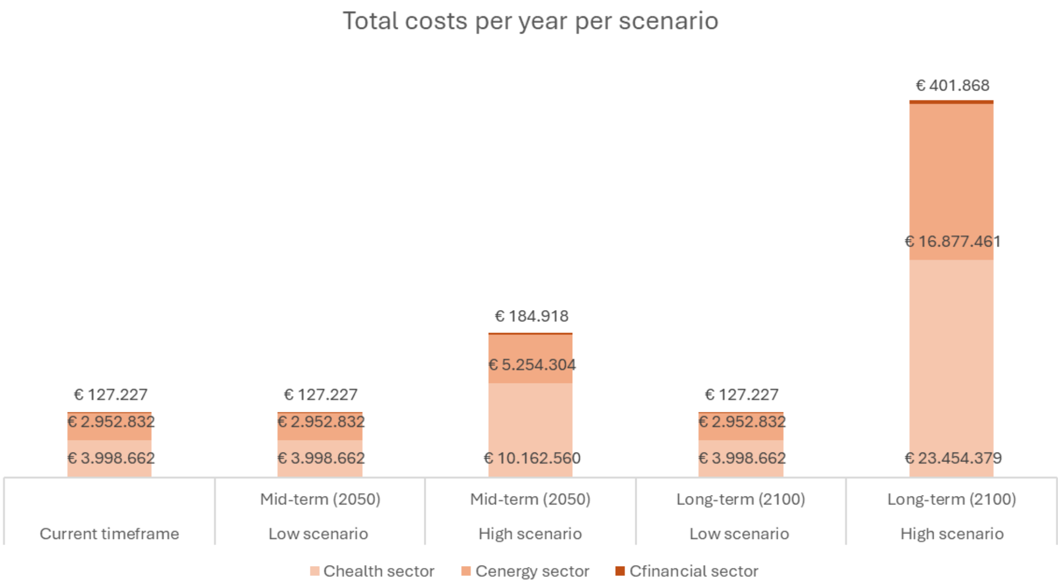



*Figure 10.1: Total costs of the benefits per year per sector (Own work)*

Additionally, the costs of the risks that arise if heat stress is not addressed were estimated for the sectors impacted by indoor heat stress in Rotterdam for the different climate scenarios. Figure 10.1 shows the yearly costs that arose in each of the sectors and for the different scenarios. As shown in the figure, the costs that arise if heat stress is not addressed mainly lie in the health and energy sector.

Sub-question two focused on answering the question: "*What areas are most vulnerable to the risks of heat stress?".* Consequently, the vulnerability of an area was determined by social vulnerability and (bio)physical vulnerability. When these vulnerabilities were combined into one map, the areas in Rotterdam that turned out to be most vulnerable to the risks of heat stress were Delfshaven, Oude Noorden and the neighborhoods Tarwewijk, Afrikaanderwijk, Bloemhof and Hillesluis in the south. Thus, mitigation is most urgently needed in these areas. Furthermore, experts concluded that climate inequity was visible among social housing residents and emphasize that the tenants often rely on housing corporations for mitigation. This dependency makes tenants of social housing extra vulnerable to heat stress.

The third sub-question delved into the possible mitigation measures for heat stress and aimed to answer the following sub-question: *"What measures can be taken to mitigate heat stress in existing properties of housing* corporations *and what are the costs of implementing these measures?".* Through a document analysis the effectiveness, costs of implementation and costs of maintenance were determined for the mitigation measures. The findings concluded that shading, ventilation and installations are the most effective mitigation measures. However, due to the energy usage and the effect on further heating the urban area, housing corporations prefer passive mitigation measures over installations, such as air conditioners. Furthermore, the expert interviews revealed a high awareness of the risks of heat stress among the corporations in Rotterdam and a willingness to act. The corporations in Rotterdam identified that around 15.000 social housing dwellings are considered highly vulnerable to overheating and in need of mitigation, but the limited financial capacity of the corporations restricts them from investing in mitigation measures. To evaluate practical solutions, for this research three mitigation variants were developed for the mitigation of heat stress in these 15.000 identified dwellings. Where one variant focused on shading, one on ventilation and a third one on a combination of both. These variants also formed the basis for the cost scenarios analyzed in the SCBA conducted for the following sub-question.

Lastly, sub-question four assessed the economic and societal costs and benefits of heat stress mitigation through a SCBA, with the sub-question: *"How do the economic and social benefits of implementing heat stress mitigation measures into social housing demonstrate the value of the costs of the mitigation measures?".* As shown in Figure 10.2, the SCBA results show that the costs of the mitigation measures are lower than the potential costs that could arise from unaddressed heat stress under both the low and high climate scenarios.

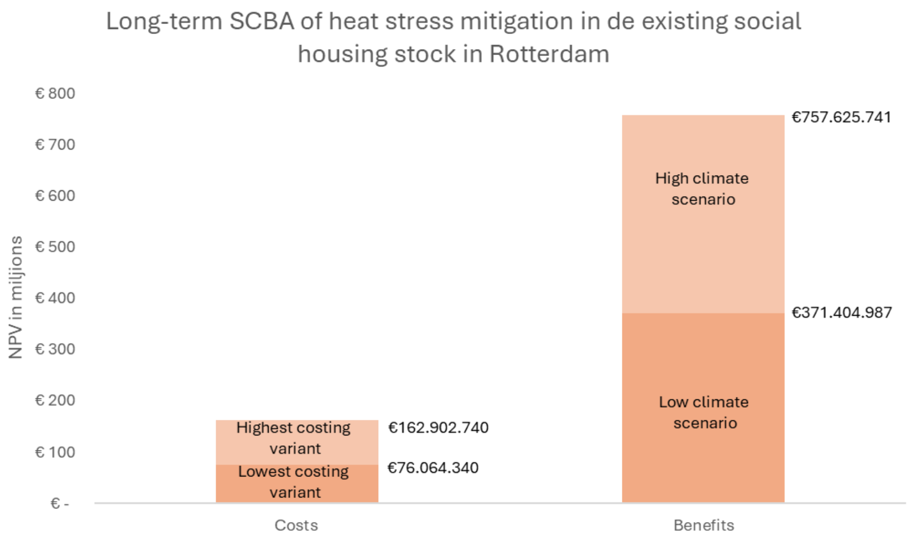



*Figure 10.2: Long-term SCBA (Own work)*

To conclude, the research was driven by the challenges of urban heat stress in Dutch cities, where social housing tenants are disproportionally vulnerable to extreme heat, as they often live in poorer quality dwellings and have limited financial means for mitigation measures. Therefore, the research aimed to answer the following research question: *"What are the long-term costs and benefits of mitigating heat stress in the existing social housing stock?".* The findings of the SCBA of heat stress mitigation in the existing social housing stock in Rotterdam (Figure 10.2) show that the long-term societal and economic benefits significantly outweigh the mitigation costs, particularly for the high climate scenario where the risks of inaction are increasingly high. However, the findings also reveal a split incentive, as the costs of implementation fall on the housing corporations, while the benefits of mitigation lie in other sectors. The thesis therefore concludes that the widespread implementation of heat stress mitigation measures in the existing social housing stock requires more structural policy intervention, such as introducing regulatory requirements for existing buildings or integrating heat mitigation into the *woningwaarderingsstelsel*. At the same time, indoor heat stress represents just one of several interrelated environmental and social challenges disproportionately affecting vulnerable urban populations. Therefore, addressing heat stress should be aligned with broader climate resilience and social equity initiatives for vulnerable populations in social housing.

## 10.2 Recommendations for practical implementation

The findings of this research could hold practical value for the stakeholders involved in heat stress mitigation in the existing building stock, with the focus on social housing. First, the results can increase awareness among the corporations through the identification of the risks in case heat stress is not addressed. Furthermore, insights into the effectiveness and costs of the mitigation measures can help the corporations with making effective investment decisions.

At a municipal level, this research provides a framework for heat stress mitigation of the existing building stock. Vulnerability mapping can allow the Municipality of Rotterdam to identify the neighborhoods that are most at risk and need mitigation and prioritize these areas for interventions. These insights can help local governments to allocate funding more effectively, focus outreach efforts and target support to areas most in need. Additionally, the municipality can use the insights from the SCBA to better understand the cost distribution of heat stress mitigation and inform them while designing equitable subsidy programs. Furthermore, the municipality can use insights to improve collaboration with housing corporations and align local policies with broader municipal climate goals.

At the level of the national government, the outcomes of the thesis emphasize the current policy gap regarding heat in the existing building stock. While a legal requirement has recently been developed for new dwellings, there are no requirements yet for existing dwellings, even though these dwellings are likely to be more vulnerable and form a larger share in the built environment. Developing legal performance standards for overheating in the existing housing stock would contribute to reducing long-term exposure to indoor heat stress. Such standards could be gradually phased in, with flexibility for building age and typology, and accompanied by targeted funding or incentive mechanisms.

Furthermore, integrating heat stress mitigation measures into the *woningwaarderingsstelsel* (housing valuation system) would increase the viability by recognizing these investments. This could enable housing corporations to recover some of their investment through modest rent increases, thereby making mitigation measures more financially viable while safeguarding affordability through tenant protections, as tenants can request a rent allowance (*huurtoeslag*) over their rent.

For an even more comprehensive and strategic approach to heat stress mitigation, it is important to recognize the potential role of additional stakeholders not directly considered in this research. Beyond housing corporations and municipalities, other stakeholders can have a role in enabling and benefiting from heat stress mitigation. For example, health insurance providers could be incentivized to invest in mitigation measures, given the potential to reduce heat-related illnesses and associated medical costs. Similarly, energy network operators have an interest in reducing peak electricity demand during heatwaves. Policies that encourage or require co-investment from these sectors, through for instance direct partnerships or regulatory obligations, could enable additional funding streams and support broader implementation.

More broadly, the success of heat stress mitigation efforts depends on stakeholder interactions that extend beyond individual responsibilities. Effective collaboration requires not only aligning incentives across sectors but also addressing conflicting priorities and capacity disparities. For example, while housing corporations may be positioned to implement mitigation measures, they often face limited budgets. Similarly, municipalities may hold a strategic vision but lack enforcement mechanisms. Building trust, fostering long-term partnerships, and ensuring transparent communication are essential for overcoming these challenges. Moreover, actively including tenants in decision-making can tailor solutions to tenant experiences and build social capital.

In conclusion, the findings of this research highlight both the urgency and the opportunity for targeted, collaborative heat stress mitigation in the existing social housing stock. While technical solutions are increasingly well understood, their successful implementation depends on shared responsibility, strategic alignment across governance levels and the mobilization of diverse stakeholders with varying interests and capacities. Embedding these insights into policy, planning and investment decisions will hold the key to ensure that mitigation efforts are not only effective, but also equitable and resilient over the long term.

## 10.3 Recommendations for future research

For this thesis, the scope was made to focus on the mitigation of indoor heat stress in the existing social housing stock. However, there were a lot more research gaps and questions that arose during the research. A number of these gaps that were discovered during the research could be a topic of interest for future research. These recommendations for future research are discussed in this section.

First, a possibility for future research is to examine the costs and benefits of mitigating outdoor heat stress. For this, a SCBA that focuses on mitigation measures for the outdoor areas could be developed and could give valuable insights into the costs and benefits of outdoor heat stress. This analysis could include benefits to urban infrastructure, reduced outdoor labor productivity and improvements to the population’s health and thermal comfort in outdoor areas. These findings could also be compared to the findings of indoor heat stress to assess if mitigating indoor or outdoor heat stress has higher societal benefits and is more cost-effective. This research could be relevant given the fact that municipal heat policies often focus on outdoor measures, potentially overlooking the gains to be made indoors.

Secondly, future research could be conducted focusing on the costs and benefits of heat stress mitigation on neighborhood level. Due to data limitations, this research was only conducted on a city level. However, zooming in on a neighborhood level in future research could provide more in-depth insights into the vulnerabilities, feasibility and effectiveness of mitigation strategies for each specific neighborhood.

Furthermore, this research focused on a set of benefits across the health, energy and financial sector. However, for future research these benefit categories could be expanded to incorporate additional benefits. For instance, in the health sector the benefits are now based on mortality and hospitalizations related to heat. This could be extended by including mental health effects or sleep disruption. Similarly, the social and community benefits of heat stress could be included in future research. However, these aspects have not been included in this research, as there has been no data yet for these categories.

The last recommendation for future research lies in analyzing the distribution of benefits across stakeholders and exploring how this distribution could inform alternative financial models. As the benefits of the heat stress mitigation measures, such as the reduced healthcare and energy costs, do not end up with the housing corporations, future research could investigate subsidy possibilities or cost-sharing mechanisms. This future research could explore if involving the beneficiary stakeholders in financing, such as healthcare insurers, energy network providers and governments, could enhance implementation feasibility.

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# Appendix 1: Interview protocol (Dutch)

## Introductie

Bedankt voor het deelnemen aan het interview. Mijn naam is Merle Blom en ik ben momenteel aan het afstuderen voor de studie Management in the Built Environment aan de TU Delft en ik loop afstudeerstage bij de Gemeente Rotterdam. Mijn afstudeeronderzoek gaat over het tegengaan van hittestress in woningen van (sociale) woningcorporaties.

Ik zou graag het interview willen opnemen, zodat het interview goed getranscribeerd kan worden en ik zal ondertussen ook aantekeningen maken op papier. Alle getranscribeerde interviews zullen geanonimiseerd worden. Deze opnamen zal ik direct verwijderen na het verwerken van het interview. Daarnaast wil ik u vragen om het informed consentformulier in te vullen en te ondertekenen. In dit formulier staat aangegeven dat de informatie die u verstrekt confidentieel is en binnen het researchteam zal blijven, daarnaast staat hierin aangegeven dat het interview geheel vrijwillig is en dat u kunt terugtrekken op elk moment.

*Document ondertekenen*

Het interview is een semi-gestructureerd interview wat inhoudt dat ik een aantal open vragen zal stellen over een aantal onderwerpen maar dat er veel ruimte openblijft voor onderwerpen die ter sprake komen. Nogmaals bedankt voor uw tijd en heeft u nog vragen?

# Interview woningcorporaties

## Introductie vraag

Wat is uw rol binnen in de corporatie?

Hoe bent u betrokken bij het tegengaan van hittestress in Rotterdam?

## Risico's

In hoeverre ervaart uw corporatie momenteel de gevolgen van hittestress in de woningvoorraad?

Wat zijn de risico's die de bewoners lopen als gevolg van de overmatige hitte in de woning?

Welke klachten of zorgen uiten de bewoners over overmatige hitte in hun woning?

In welke wijken of complexen is de hitteproblematiek in de woningen het grootst?

## Maatregelen

Welke maatregelen worden genomen door de corporatie om woningen hittebestendiger te maken?

Zijn er projecten waar deze maatregelen al zijn toegepast en wat was daarvan het effect?

Wat waren de belangrijkste lessen die jullie uit deze projecten hebben getrokken?

Wat waren de reacties van de bewoners over de effectiviteit van deze maatregelen?

Wordt er in alle renovatieprojecten rekening gehouden met klimaatadaptatie en vooral specifiek hittestress?

Hoe betrekken jullie huurders bij het nemen van maatregelen tegen hitte, zoals bewustwording van natuurlijke nachtventilatie?

## Financiering

Wat voor kosten maken jullie momenteel als gevolg van hitte stress, zonder maatregelen?

De split incentive, waarbij de woningcorporatie investeert in verbeteringen terwijl de voordelen vooral bij de huurders terechtkomen, kan een belemmering vormen voor het toepassen van hittebestendige maatregelen. In hoeverre speelt dit bij jullie een rol bij het nemen van dergelijke maatregelen?

Hoe weegt de woningcorporatie de kosten af tegen de voordelen voor de bewoners?

Wat zijn de grootste financiële beperkingen bij het implementeren van maatregelen tegen hittestress? (Subsidies)

Hoe kijkt de corporatie naar de balans tussen de korte termijn investeringen en de lange termijnvoordelen van de maatregelen?

## Challenges

Wat zijn de grootste uitdagingen bij het implementeren van maatregelen tegen hittestress?

Zijn er beleidsmatige belemmeringen die het moeilijker maken om effectieve hittestressmaatregelen door te voeren? (Beschermd stadszicht, vergunningen)

Hoe gaan jullie om met mogelijke weerstand van huurders of andere belanghebbenden?

Hoe kan de samenwerking tussen jullie, de gemeente en andere sociale organisaties verbeterd worden?

## Reflectie

Heeft de woningcorporatie een lange termijnstrategie om maatregelen tegen hitte te implementeren in de huidige woningvoorraad van de corporatie?

Wat zou u graag anders zien in het beleid of in de regelgeving om hittestress effectiever aan te pakken?

# Appendix 2: Data Management Plan

## Plan Overview

A Data Management Plan created using DMPonline

**Title:** Mitigating Heat Stress in Social Housing

**Creator:** Merle Blom

**Affiliation:** Delft University of Technology

**Template:** TU Delft Data Management Plan template (2025)

**Project abstract:**

Heat events are becoming more common and intense due to climate change, which affects urban populations and puts greater pressure on cities. Housing associations in Rotterdam are facing the issue of heat stress and realize they must take mitigation measures to improve their building stock as the heat stress is impacting the low-income tenants of social housing who are often more vulnerable financially and health-wise. The purpose of this study is to analyze the long-term costs and benefits of putting heat stress mitigation measures in place in social housing, considering the social and economic effects on housing organizations.

**ID:** 166829

**Start date:** 05-11-2024

**End date:** 04-07-2025

**Last modified:** 17-02-2025

## Mitigating Heat Stress in Social Housing

### 0. Adminstrative questions

1. **Provide the name of the data management support staff consulted during the preparation of this plan and the dateof consultation. Please also mention if you consulted any other support staff.**

The data and DMP for this project has been discussed with my supervisor, Audrey Esteban, on the 20th of January 2025.
Janine Strandberg, Data Steward at the Faculty of Architecture, has reviewed this DMP on 28-01-2025.

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

- Yes, leading the collaboration – please provide details of the type of collaboration and the involved parties below

TU Delft is the lead institution for this project, I will also be doing an internship at the municipality of Rotterdam for my thesis.

## I. Data/code description and collection or re-use

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

| **Type of data/code** | **File format(s)** | **How will data/code be collected/generated?** For re-used data/code: what are the sources and terms of use? | **Purpose of processing** | **Storage location** | **Who will have access to the data/code?** |
|---|---|---|---|---|---|
| Names and emails of interview participants | .xlsx | Contact information interview participants, collected through contacts of the municipality of Rotterdam | For administrative purposes (participant communication) | Project Data Storage | The TUD project team and the supervisors from the municipality of Rotterdam |
| Informed consent forms | .docx | Consent form | To gain consent from the interviewees before conducting the interview | Project Data Storage | The TUD project team |
| Audiorecordings of interviews | .mp3 | Recordings of interviews made using Microsoft Teams | To review the interview and make corrections to the transcriptions | Project Data Storage | The TUD project team |
| Anonymous transcriptions of interviews | .docx | Anonymous transcriptions based on adjustments from audio-recordings of Microsoft Teams automatic transcription | To analyze the content of the interviews, allowing for easy reference and searches later without the need to retain audio material | Project Data Storage | The TUD project team and the supervisors from the municipality of Rotterdam |
| Geospatial data (public) | .pdf, .jpg, .png, .tiff | This data is gathered from publicly available sources, such as open data platforms, as well as through municipal documents | To analyze spatial patterns and trends in social housing densities and environmental factors like urban heat | Project Data Storage | The TUD project team and the supervisors from the municipality of Rotterdam |

## II. Storage and backup during the research process

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

- < 250 GB

**5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)** • Project Data Storage (U:) drive at

TU Delft

## III. Data/code documentation

**6. What documentation will accompany data/code? (Select all that apply.)** • Data –

Methodology of data collection

## IV. Legal and ethical requirements, code of conducts

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

**If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.**

- Yes – please provide details in the additional information box below

I am currently in the process of obtaining approval from the Human Research Ethics Committee.

**8. Will you work with personal data? (This is information about an identified or identifiable natural person, either forresearch or project administration purposes.)**

- Yes

For the interviews the name, email address and function will be registered for administrative purposes. This information will not go beyond the research team. Only anonymized data will be used in the final published thesis.

**9. Will you work with any other types of confidential or classified data or code as listed below? (Select all that applyand provide additional details below.)**

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

- Yes, politically-sensitive data (such as research commissioned by public authorities, research in social issues) Yes, I work
- with other types of confidential or classified data/code – please explain below

I will use politically-sensitive data, including research commissioned by public authorities and studies on social issues, to analyze the inequity of heat stress risks in social housing. This data will be gathered through my internship at the municipality of Rotterdam. Additionally, I will work with confidential or classified information, such as municipal research on heat stress and social housing policy documents.

**10. 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 yourF aculty Contract Manager when answering this question.**

The intellectual property rights are framed by a graduation agreement between Delft University of Technology, myself and the municipality of Rotterdam.

**11. Which personal data or data from human participants do you work with? (Select all that apply.)**

- Proof of consent (such as signed consent materials which contain name and signature) Audio
- recordings
- Telephone number, email addresses and/or other addresses as contact details for administrative purposes Names as
- contact details for administrative purposes

I will be conducting interviews for which I will need the names and email addresses of the participants for administrative purposes. The participants will also sign a consent form prior to the interview. The interviews will be audio recorded, this recording will be transcribed after which the recording will be deleted.

**12. Please list the categories of data subjects and their geographical location.**

The participants for the interviews will include professionals directly involved in addressing heat stress in social housing. This will encompass representatives from municipalities, housing associations, and public health organizations such as the GGD.

**13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals ororganisations)?**

- No

**16. What are the legal grounds for personal data processing?**

- Informed consent

**17. Please describe the informed consent procedure you will follow below.**

The participants will be informed about the research goals, procedures, and the processing of their personal data through a digital informed consent form, which will be emailed to them prior to the interview, and their consent will be obtained by signing the form before the interview begins.

**18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?**

The proof of consent will be preserved on the TU Delft Project Data Storage drive.

**19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)**

**If the processing of the personal data results in a high risk to the data subjects, it is required to perform aD ata 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 in your research project.**

**If any category applies, please provide additional information in the box below. Likewise, if you collect other type of potentially sensitive data, or if you have any additional comments, include these in the box below.**

**If one or more options listed below apply, 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.**

- None of the above apply

**23. What will happen with the personal data used in the research after the end of the research project?**

- Anonymised or aggregated data will be shared with others

The anonymized data includes interview transcripts, which will be data will be incorporated in the body of the thesis and included the appendix. They will not be shared in a data repository.

**24. For how long will personal research data (including pseudonymised data) be stored?**

- Personal data will be deleted at the end of the research project

The non anonymized data will be destroyed at the end of the research project.

**25. How will your study participants be asked for their consent for data sharing?**

- In the informed consent form: participants are asked to give their explicit consent for sharing their (pseudonymised) personal data with restricted access with specific recipients for specific purpose(s)

## V. Data sharing and long term preservation

**27. Apart from personal data mentioned in question 23, will any other data be publicly shared?**

**Please provide a list of data/code you are going to share under 'Additional Information'.**

- All other non-personal data/code produced in the project

**29. How will you share research data/code, including those mentioned in question 23?**

- I am a Bachelor's/Master's student at TU Delft and I will share the data/code in the body and/or appendices of my thesis/report in the Education Repository

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

**31. When will the data/code be shared?**

- As soon as corresponding results (papers, theses, reports) are published

## VI. Data management responsibilities and resources

**33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from thisproject?**

My supervisor Audrey Esteban, postdoc, Management in the Built Environment

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

I do not expect to exceed the maximum archive ability of 1TB of data/code per researcher per year.

# Appendix 3: Informed consent form (Dutch)

**Informatie voor deelnemers/Openingsverklaring**

U wordt uitgenodigd om deel te nemen aan een masterscriptie onderzoek met de titel "Het verminderen van hittestress in sociale huisvesting". Dit onderzoek wordt uitgevoerd door Merle Blom van de TU Delft in samenwerking met het afstudeerstagebedrijf, de Gemeente Rotterdam.

Het doel van dit interview is om kennis te vergaren over de kosten en baten van het verminderen van hittestress in sociale huurwoningen en het interview duurt ongeveer 60 minuten. De gegevens worden gebruikt om praktische inzichten te verkrijgen in hittestress in sociale huisvesting vanuit het perspectief van de stakeholders die betrokken zijn bij het verminderen van hittestress van woningen van woningcorporaties. U wordt gevraagd naar de risico's van hittestress in sociale huisvesting, mogelijke mitigerende maatregelen en de kosten van mogelijke mitigerende maatregelen in vergelijking met hun baten.

Zoals bij elke online activiteit is het risico op een inbreuk altijd mogelijk. Uw antwoorden in dit onderzoek blijven naar ons beste vermogen vertrouwelijk. We minimaliseren alle risico's door de gegevens te anonimiseren en de verkregen gegevens veilig op te slaan in de projectgegevensopslag.

Uw deelname aan dit onderzoek is geheel vrijwillig en u kunt zich op elk moment terugtrekken. U bent vrij om vragen weg te laten en gegeven data te verwijderen tijdens de onderzoeksperiode.

Voor vragen of opmerkingen kunt u contact opnemen met de corresponderende onderzoeker Merle Blom en de verantwoordelijke onderzoeker Audrey Esteban.

**Expliciete toestemmingspunten**

| **Vink de juiste vakjes aan** | **Yes** | **No** |
|---|---|---|
| **A: ALGEMENE OVEREENKOMST – ONDERZOEKSDOELEN, DEELNEMERSTAKEN EN VRIJWILLIGE DEELNAME** | | |
| 1. Ik heb de informatie over het onderzoek gedateerd -/-/- gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb vragen over het onderzoek kunnen stellen en mijn vragen zijn naar tevredenheid beantwoord. | ☐ | ☐ |
| 2. Ik geef vrijwillig toestemming om deel te nemen aan dit onderzoek en begrijp dat ik kan weigeren om vragen te beantwoorden en dat ik mij op elk moment uit het onderzoek kan terugtrekken, zonder dat ik daarvoor een reden hoef op te geven. | ☐ | ☐ |
| 3. Ik begrijp dat deelname aan het onderzoek het volgende inhoudt:<br>• De interviews worden opgenomen om de gedeelde informatie vast te leggen.<br>• De opnames worden getranscribeerd als tekst voor analyse. Zodra de transcriptie is voltooid, worden de audio-opnames verwijderd. | ☐ | ☐ |
| 4. Ik begrijp dat het onderzoek op 30 juni eindigt. | ☐ | ☐ |
| **B: MOGELIJKE RISICO'S VAN DEELNAME (INCLUSIEF GEGEVENSBESCHERMING)** | | |
| 5. Ik begrijp dat deelname aan het onderzoek inhoudt dat er specifieke persoonlijk identificeerbare informatie (PII) wordt verzameld voor contactdoeleinden en bijbehorende persoonlijk identificeerbare onderzoeksgegevens (PIRD), waarbij het potentiële risico bestaat dat mijn identiteit wordt onthuld. | ☐ | ☐ |
| 6. Ik begrijp dat de volgende stappen worden ondernomen om de dreiging van een data lek tot een minimum te beperken en mijn identiteit te beschermen in het geval van een dergelijk lek:<br>• Het interview wordt getranscribeerd en de opname wordt verwijderd.<br>• Het getranscribeerde interview wordt geanonimiseerd. | ☐ | ☐ |
| 7. Ik begrijp dat de persoonlijke gegevens die over mij worden verzameld en waarmee ik kan worden geïdentificeerd, zoals uw naam of e-mailadres, niet buiten het onderzoeksteam worden gedeeld. | ☐ | ☐ |
| 8. Ik begrijp dat de (identificeerbare) persoonlijke gegevens die ik verstrek, op 30 juni worden verwijderd. | ☐ | ☐ |
| **C: ONDERZOEKSPUBLICATIE, VERSPREIDING EN TOEPASSING** | | |
| 9. Ik begrijp dat de geanonimiseerde informatie die ik verstrek na afloop van het onderzoek gebruikt zal worden voor het afstudeerverslag. | ☐ | ☐ |
| 10. Ik ga ermee akkoord dat mijn reacties, standpunten of andere input anoniem kunnen worden geciteerd in onderzoeksresultaten. | ☐ | ☐ |

| Vink de juiste vakjes aan | Yes | No |
|---|---|---|
| **D: (LANGE TERMIJN) DATA STORAGE, TOEGANG AND HERGEBRUIK** | | |
| 11. Ik geef toestemming om het geanonimiseerde interviewtranscript dat ik verstrek te archiveren in de Education Repository van de TU Delft. | ☐ | ☐ |
| 12. Ik begrijp dat de toegang tot deze repository alleen is beperkt tot TU Delft-personeel, overeenkomstig de te verlenen toegangsstatus. | ☐ | ☐ |

**Handtekeningen**

____________________________ ___________________________ _________

Naam van de deelnemer [geprint] Handtekening Datum

Als onderzoeker heb ik het informatieblad nauwkeurig voorgelezen aan de potentiële deelnemer en heb ik er, voor zover ik kon, voor gezorgd dat de deelnemer begrijpt waarvoor hij/zij vrijwillig toestemming geeft.

__________________________ ____________________ _________

Onderzoeker naam [geprint] Handtekening Datum

# Appendix 4: Heat stress risk assessment Rotterdam

| | | Near term | | | Near term | | | Medium term | | | Medium term | | | Long term | | | Long term | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Scenario (SSP1-2.6) | | | High Scenario (SSP5-8.5) | | | Low Scenario (SSP1-2.6) | | | High Scenario (SSP5-8.5) | | | Low Scenario (SSP1-2.6) | | | High Scenario (SSP5-8.5) | | |
| Hazard | Location of receptor | Impact rating | Likelihood rating | Risk rating | Impact rating | Likelihood rating | Risk rating | Impact rating | Likelihood rating | Risk rating | Impact rating | Likelihood rating | Risk rating | Impact rating | Likelihood rating | Risk rating | Impact rating | Likelihood rating | Risk rating |
| *List of all relevant climate-related hazards* | *Qualitative description of the location of the receptor* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* | *Determined for each receptor regarding each relevant hazard by combining vulnerability and exposure ratings* | *Use the drop down list to enter the likelihood rating* | *Determined for each receptor in relation to each relevant hazard by combining the ratings of impact and likelihood* |
| Extreme heat | Rotterdam | 3,24 | 2 | **2,62** | 3,24 | 2 | **2,62** | 3,24 | 2 | **2,62** | 3,24 | 3 | **3,12** | 3,24 | 2 | **2,62** | 3,24 | 5 | **4,12** |

**Reference for the excel template**

Smithers, R.J. & Dworak, T. (2023). *Assessing climate change risks and vulnerabilities* (climate risk assessment). A DIY Manual. Version 1, November 2023. EU Mission on Adaptation to Climate Change. European Union, Brussels.

# Appendix 5: Heat stress mitigation measures

| Mitigation measure | Description | Effectiveness measure | Cost of implementation / dwelling | Cost of maintenance / year / dwelling | Lifespan | Notes |
|---|---|---|---|---|---|---|
| **Outdoor shading** | Outdoor movable awnings and blinds | **Very positive effect** (Van der Strate et al., 2022; Stichting RIONED, 2019; Terpstra et al., 2019) | **€2.000 - €5.000** (Porritt et al., 2012; Groene Huisvesters, 2025; Van der Strate et al., 2022) | **€50 - €100** (Expert experience, Groene Huisvesters, 2025) | **15 years** (Groene Huisvesters, 2025) | Vulnerable to storm damage and dependent on tenant usage (Groene Huisvesters, 2025) |
| **Indoor shading (blinds)** | Blinds (preferably with a low absorbtion coefficient and reflective) | **Positive effect** (Van der Strate et al., 2022) | **€2.000 - €5.000** (Van der Strate et al., 2022; Porritt et al., 2012; Groene Huisvesters, 2025) | **0 - €50** (Groene Huisvesters, 2025) | **20 years** (Groene Huisvesters, 2025) | |
| **Indoor shading (curtains)** | Curtains (preferably with a low absorbtion coefficient) | **Neutral - little effect** (Van der Strate et al., 2022) | **€50 - €500** (Van der Strate et al., 2022) | **0 - €50** (Groene Huisvesters, 2025) | **20 years** (Groene Huisvesters, 2025) | |
| **Reflective window foils** | Foil reflects solar radiation | **Positive effect** (Van der Strate et al., 2022) | **€500 - €1000** (Groene Huisvesters, 2025) | **0** (Groene Huisvesters, 2025) | **10 years** (Groene Huisvesters, 2025) | |
| **Solar reflective glazing** | Glazing that reflects solar radiation | **Very positive effect** (De Vries et al., 2021; NKWK, 2023) | **€3500** (Van der Strate et al., 2022) **+- €100** extra per dwelling when already replacing window and windowframe (Glas-gigant, 2025; Homedeal, 2025) | **0** (Expert confirmation) | **40 years** (Glas-gigant, 2025) | |
| **Natural ventilation (tilt and turn window)** | Window openings | **Very positive effect** (Van der Strate et al., 2022) | **€4000** (Homedeal, 2025) | **€45** (Homedeal, 2023) | **50 years** (Kijkopkozijnen.nl, n.d.) | Highly depends on tenant behaviour (van Hooff, 2014) and raises the chances of break ins (Terpstra, 2019) |
| **Natural ventilation (ventilation rosters)** | Ventilation rosters | **Very positive effect** (Van der Strate et al., 2022) | **€1000 - €2500** (Groene Huisvesters, 2025) | **0 - €50** (Groene Huisvesters, 2025) | **50 years** (Groene Huisvesters, 2025) | |
| **Green roof** | Vegetation on roofs to increase evapotranspiration | **Little - positive effect** (Van der Strate et al., 2022; Teun et al., 2019; Stichting RIONED, 2019) | **€80 / m2** (Groene Huisvesters, 2025) **€2.500 - €5.000** (RVO, 2024) | **€100 - €500** (Groene Huisvesters, 2025) | **50 years** (Groene Huisvesters, 2025) | |
| **Green facade** | Vegetation on the facade to increase evatransporation and provide shading | **Neutral - little effect** (Van der Strate et al., 2022; Stichting RIONED, 2019) | **€300 / m2** (RVO, 2024) **€500** (Groene Huisvesters, 2025) | **€100 - €500** (Groene Huisvesters, 2025) | **40 years** (Groene Huisvesters, 2025) | |
| **Cool / reflective roof** | Using high albedo, light colored materials to reduce the heat absorption (e.g. refelctive white tiles) | **Positive effect** (Stichting RIONED, 2019) | **€100 / m2** (Groene Huisvesters, 2025) | **0 - €50** (Groene Huisvesters, 2025) | **50 years** (Groene Huisvesters, 2025) | |
| **Air conditioner** | Draws outdoor air into a room via a cooling element and extracts the warm air out of the room (split unit) | **Positive - very positive effect** (Stichting RIONED, 2019; Willems & Nonner, 2021) | **€1.000 - €5.000** (Gamma, n.d.; Groene Huisvesters, 2025) | **€100 - €500** (Groene Huisvesters, 2025) | **10 - 15 years** (Groene Huisvesters, 2025) | Raises the energy demand and is not good for the environment (Groene Huisvesters, 2025) |
| **Heat pump with ATES** | A collective heat pump with ATES efficiently cools by storing cold water in summer and warm water in winter in underground aquifers | **Very positive effect** (Hogeschool van Amsterdam, 2024; Stichting RIONED, 2019) | **€28.000** (Groene Huisvesters, 2025) | **€100 - €500** (Groene Huisvesters, 2025) | **15 - 20 years** (Groene Huisvesters, 2025) | |

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# Appendix 6: SCBA NPV calculations

## SCBA Benefits

### Low scenario

Discount rate: 2,25%

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **Costs per sector** | | | | | | | | | | | | | |
| Health sector | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Health sector discounted cash flow | € 6.939.547 | € 6.786.843 | € 6.637.499 | € 6.491.442 | € 6.348.598 | € 6.208.898 | € 6.072.272 | € 5.938.652 | € 5.807.973 | € 5.680.169 | € 5.555.177 | € 5.432.936 | € 5.313.385 |
| **Costs per sector** | | | | | | | | | | | | | |
| Energy sector | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 2.952.832 | € 2.887.855 | € 2.824.308 | € 2.762.160 | € 2.701.379 | € 2.641.935 | € 2.583.800 | € 2.526.943 | € 2.471.338 | € 2.416.957 | € 2.363.772 | € 2.311.757 | € 2.260.887 |
| **Costs per sector** | | | | | | | | | | | | | |
| Financial sector | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 127.227 | € 124.427 | € 121.689 | € 119.011 | € 116.392 | € 113.831 | € 111.326 | € 108.877 | € 106.481 | € 104.138 | € 101.846 | € 99.605 | € 97.413 |
| **Total** | | | | | | | | | | | | | |
| Net cash flow | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 |
| Discounted cash flow | € 10.019.605 | € 10.019.605 | € 10.245.046 | € 10.475.560 | € 10.711.260 | € 10.952.263 | € 11.198.689 | € 11.450.660 | € 11.708.300 | € 11.971.736 | € 12.241.101 | € 12.516.525 | € 12.798.147 |

| | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| **Costs per sector** | | | | | | | | | | | | | |
| Health sector | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Health sector discounted cash flow | € 5.196.465 | € 5.082.117 | € 4.970.286 | € 4.860.915 | € 4.753.951 | € 4.649.341 | € 4.547.033 | € 4.446.976 | € 4.349.121 | € 4.253.419 | € 4.159.823 | € 4.068.286 | € 3.978.764 |
| **Costs per sector** | | | | | | | | | | | | | |
| Energy sector | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 2.211.137 | € 2.162.481 | € 2.114.896 | € 2.068.358 | € 2.022.844 | € 1.978.331 | € 1.934.798 | € 1.892.223 | € 1.850.585 | € 1.809.863 | € 1.770.037 | € 1.731.088 | € 1.692.996 |
| **Costs per sector** | | | | | | | | | | | | | |
| Financial sector | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 95.270 | € 93.173 | € 91.123 | € 89.118 | € 87.157 | € 85.239 | € 83.363 | € 81.529 | € 79.735 | € 77.980 | € 76.264 | € 74.586 | € 72.945 |
| **Total** | | | | | | | | | | | | | |
| Net cash flow | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 |
| Discounted cash flow | € 13.086.105 | € 13.380.543 | € 13.681.605 | € 13.989.441 | € 14.304.204 | € 14.626.048 | € 14.955.134 | € 15.291.625 | € 15.635.686 | € 15.987.489 | € 16.347.208 | € 16.715.020 | € 17.091.108 |

| | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| **Costs per sector** | | | | | | | | | | | | |
| Health sector | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Health sector discounted cash flow | € 3.891.212 | € 3.805.586 | € 3.721.845 | € 3.639.946 | € 3.559.849 | € 3.481.515 | € 3.404.905 | € 3.329.980 | € 3.256.704 | € 3.185.041 | € 3.114.954 | € 3.046.410 |
| **Costs per sector** | | | | | | | | | | | | |
| Energy sector | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 1.655.741 | € 1.619.307 | € 1.583.674 | € 1.548.826 | € 1.514.744 | € 1.481.412 | € 1.448.814 | € 1.416.933 | € 1.385.753 | € 1.355.260 | € 1.325.438 | € 1.296.272 |
| **Costs per sector** | | | | | | | | | | | | |
| Financial sector | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 71.340 | € 69.770 | € 68.235 | € 66.733 | € 65.265 | € 63.829 | € 62.424 | € 61.050 | € 59.707 | € 58.393 | € 57.108 | € 55.852 |
| **Total** | | | | | | | | | | | | |
| Net cash flow | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 |
| Discounted cash flow | € 17.475.658 | € 17.868.860 | € 18.270.909 | € 18.682.005 | € 19.102.350 | € 19.532.153 | € 19.971.626 | € 20.420.988 | € 20.880.460 | € 21.350.271 | € 21.830.652 | € 22.321.841 |

| | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| **Costs per sector** | | | | | | | | | | | | |
| Health sector | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Health sector discounted cash flow | € 2.979.374 | € 2.913.814 | € 2.849.695 | € 2.786.988 | € 2.725.661 | € 2.665.683 | € 2.607.025 | € 2.549.658 | € 2.493.553 | € 2.438.682 | € 2.385.019 | € 2.332.537 |
| **Costs per sector** | | | | | | | | | | | | |
| Energy sector | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 1.267.747 | € 1.239.851 | € 1.212.568 | € 1.185.885 | € 1.159.790 | € 1.134.269 | € 1.109.310 | € 1.084.899 | € 1.061.026 | € 1.037.679 | € 1.014.845 | € 992.513 |
| **Costs per sector** | | | | | | | | | | | | |
| Financial sector | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 54.623 | € 53.421 | € 52.245 | € 51.095 | € 49.971 | € 48.871 | € 47.796 | € 46.744 | € 45.716 | € 44.710 | € 43.726 | € 42.764 |
| **Total** | | | | | | | | | | | | |
| Net cash flow | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 |
| Discounted cash flow | € 22.824.083 | € 23.337.625 | € 23.862.721 | € 24.399.632 | € 24.948.624 | € 25.509.968 | € 26.083.942 | € 26.670.831 | € 27.270.925 | € 27.884.521 | € 28.511.922 | € 29.153.441 |

| | NPV 2050= | NPV 2100= |
|---|---|---|
| Health sector | € 138.529.887 | € 257.233.911 |
| Energy sector | € 58.945.563 | € 109.455.064 |
| Financial sector | € 2.539.745 | € 4.716.012 |

Net present value 2050: 341.399.715 | Net present value 2100: 1.927.448.785

### High scenario

Discount rate: 2,25%

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **Costs per sector** | | | | | | | | | | | | | |
| Health sector | € 6.939.547 | € 7.079.054 | € 7.218.562 | € 7.358.070 | € 7.497.578 | € 7.637.085 | € 7.776.593 | € 7.916.101 | € 8.055.609 | € 8.195.116 | € 8.334.624 | € 8.474.132 | € 8.613.639 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Health sector discounted cash flow | € 6.939.547 | € 6.923.281 | € 6.904.370 | € 6.882.940 | € 6.859.109 | € 6.832.994 | € 6.804.708 | € 6.774.357 | € 6.742.048 | € 6.707.880 | € 6.671.951 | € 6.634.355 | € 6.595.184 |
| **Costs per sector** | | | | | | | | | | | | | |
| Energy sector | € 2.952.832 | € 3.044.891 | € 3.136.950 | € 3.229.009 | € 3.321.068 | € 3.413.126 | € 3.505.185 | € 3.597.244 | € 3.689.303 | € 3.781.362 | € 3.873.421 | € 3.965.480 | € 4.057.539 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 2.952.832 | € 2.977.888 | € 3.000.412 | € 3.020.503 | € 3.038.257 | € 3.053.766 | € 3.067.122 | € 3.078.412 | € 3.087.719 | € 3.095.126 | € 3.100.713 | € 3.104.554 | € 3.106.725 |
| **Costs per sector** | | | | | | | | | | | | | |
| Financial sector | € 127.227 | € 129.534 | € 131.842 | € 134.150 | € 136.457 | € 138.765 | € 141.073 | € 143.380 | € 145.688 | € 147.996 | € 150.303 | € 152.611 | € 154.919 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 127.227 | € 126.684 | € 126.103 | € 125.487 | € 124.837 | € 124.155 | € 123.442 | € 122.700 | € 121.932 | € 121.138 | € 120.319 | € 119.478 | € 118.616 |
| **Total** | | | | | | | | | | | | | |
| Net cash flow | € 10.019.605 | € 10.253.480 | € 10.487.354 | € 10.721.228 | € 10.955.102 | € 11.188.977 | € 11.422.851 | € 11.656.725 | € 11.890.600 | € 12.124.474 | € 12.358.348 | € 12.592.222 | € 12.826.097 |
| Discounted cash flow | € 10.019.605 | € 10.027.853 | € 10.030.886 | € 10.028.930 | € 10.022.203 | € 10.010.915 | € 9.995.272 | € 9.975.469 | € 9.951.699 | € 9.924.144 | € 9.892.983 | € 9.858.388 | € 9.820.525 |

| | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| **Costs per sector** | | | | | | | | | | | | | |
| Health sector | € 8.753.147 | € 8.892.655 | € 9.032.163 | € 9.171.670 | € 9.311.178 | € 9.450.686 | € 9.590.194 | € 9.729.701 | € 9.869.209 | € 10.008.717 | € 10.148.224 | € 10.287.732 | € 10.427.240 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Health sector discounted cash flow | € 6.554.523 | € 6.512.459 | € 6.469.072 | € 6.424.441 | € 6.378.642 | € 6.331.748 | € 6.283.829 | € 6.234.953 | € 6.185.185 | € 6.134.588 | € 6.083.224 | € 6.031.149 | € 5.978.420 |
| **Costs per sector** | | | | | | | | | | | | | |
| Energy sector | € 4.149.597 | € 4.241.656 | € 4.333.715 | € 4.425.774 | € 4.517.833 | € 4.609.892 | € 4.701.951 | € 4.794.010 | € 4.886.069 | € 4.978.127 | € 5.070.186 | € 5.162.245 | € 5.254.304 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 3.107.298 | € 3.106.340 | € 3.103.921 | € 3.100.103 | € 3.094.951 | € 3.088.524 | € 3.080.882 | € 3.072.080 | € 3.062.174 | € 3.051.217 | € 3.039.258 | € 3.026.349 | € 3.012.536 |
| **Costs per sector** | | | | | | | | | | | | | |
| Financial sector | € 157.226 | € 159.534 | € 161.842 | € 164.149 | € 166.457 | € 168.765 | € 171.072 | € 173.380 | € 175.688 | € 177.995 | € 180.303 | € 182.611 | € 184.918 |
| **Discounted cash flow** | | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 117.734 | € 116.833 | € 115.915 | € 114.981 | € 114.032 | € 113.069 | € 112.093 | € 111.105 | € 110.106 | € 109.098 | € 108.080 | € 107.055 | € 106.022 |
| **Total** | | | | | | | | | | | | | |
| Net cash flow | € 13.059.971 | € 13.293.845 | € 13.527.720 | € 13.761.594 | € 13.995.468 | € 14.229.342 | € 14.463.217 | € 14.697.091 | € 14.930.965 | € 15.164.840 | € 15.398.714 | € 15.632.588 | € 15.866.462 |
| Discounted cash flow | € 9.779.555 | € 9.735.633 | € 9.688.908 | € 9.639.526 | € 9.587.625 | € 9.533.341 | € 9.476.803 | € 9.418.138 | € 9.357.465 | € 9.294.903 | € 9.230.562 | € 9.164.553 | € 9.096.979 |

| | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |
| **Costs per sector** | | | | | | | | | | | | |
| Health sector | € 10.842.179 | € 11.257.118 | € 11.672.058 | € 12.086.997 | € 12.501.936 | € 12.916.875 | € 13.331.814 | € 13.746.754 | € 14.161.693 | € 14.576.632 | € 14.991.571 | € 15.406.511 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Health sector discounted cash flow | € 6.079.535 | € 6.173.304 | € 6.260.003 | € 6.339.897 | € 6.413.244 | € 6.480.293 | € 6.541.286 | € 6.596.456 | € 6.646.032 | € 6.690.231 | € 6.729.267 | € 6.763.345 |
| **Costs per sector** | | | | | | | | | | | | |
| Energy sector | € 5.486.767 | € 5.719.230 | € 5.951.693 | € 6.184.157 | € 6.416.620 | € 6.649.083 | € 6.881.546 | € 7.114.009 | € 7.346.472 | € 7.578.936 | € 7.811.399 | € 8.043.862 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 3.076.595 | € 3.136.375 | € 3.192.035 | € 3.243.727 | € 3.291.598 | € 3.335.792 | € 3.376.447 | € 3.413.697 | € 3.447.673 | € 3.478.501 | € 3.506.303 | € 3.531.196 |
| **Costs per sector** | | | | | | | | | | | | |
| Financial sector | € 189.257 | € 193.596 | € 197.935 | € 202.274 | € 206.613 | € 210.952 | € 215.291 | € 219.630 | € 223.969 | € 228.308 | € 232.647 | € 236.986 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 106.122 | € 106.167 | € 106.157 | € 106.097 | € 105.989 | € 105.833 | € 105.633 | € 105.391 | € 105.108 | € 104.787 | € 104.428 | € 104.035 |
| **Total** | | | | | | | | | | | | |
| Net cash flow | € 16.518.204 | € 17.169.945 | € 17.821.686 | € 18.473.428 | € 19.125.169 | € 19.776.911 | € 20.428.652 | € 21.080.393 | € 21.732.135 | € 22.383.876 | € 23.035.617 | € 23.687.359 |
| Discounted cash flow | € 9.262.252 | € 9.415.846 | € 9.558.196 | € 9.689.722 | € 9.810.831 | € 9.921.918 | € 10.023.366 | € 10.115.544 | € 10.198.813 | € 10.273.519 | € 10.339.998 | € 10.398.577 |

| | 2063 | 2064 | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| **Costs per sector** | | | | | | | | | | | | |
| Health sector | € 15.821.450 | € 16.236.389 | € 16.651.328 | € 17.066.267 | € 17.481.207 | € 17.896.146 | € 18.311.085 | € 18.726.024 | € 19.140.964 | € 19.555.903 | € 19.970.842 | € 20.385.781 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Health sector discounted cash flow | € 6.792.666 | € 6.817.421 | € 6.837.797 | € 6.853.976 | € 6.866.131 | € 6.874.433 | € 6.879.045 | € 6.880.125 | € 6.877.827 | € 6.872.298 | € 6.863.682 | € 6.852.118 |
| **Costs per sector** | | | | | | | | | | | | |
| Energy sector | € 8.276.325 | € 8.508.788 | € 8.741.251 | € 8.973.714 | € 9.206.178 | € 9.438.641 | € 9.671.104 | € 9.903.567 | € 10.136.030 | € 10.368.493 | € 10.600.956 | € 10.833.420 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Energy sector discounted cash flow | € 3.553.297 | € 3.572.715 | € 3.589.558 | € 3.603.929 | € 3.615.930 | € 3.625.658 | € 3.633.207 | € 3.638.668 | € 3.642.129 | € 3.643.676 | € 3.643.392 | € 3.641.355 |
| **Costs per sector** | | | | | | | | | | | | |
| Financial sector | € 241.325 | € 245.664 | € 250.003 | € 254.342 | € 258.681 | € 263.020 | € 267.359 | € 271.698 | € 276.037 | € 280.376 | € 284.715 | € 289.054 |
| **Discounted cash flow** | | | | | | | | | | | | |
| Financial sector discounted cash flow | € 103.609 | € 103.151 | € 102.663 | € 102.146 | € 101.603 | € 101.034 | € 100.441 | € 99.825 | € 99.187 | € 98.529 | € 97.852 | € 97.158 |
| **Total** | | | | | | | | | | | | |
| Net cash flow | € 24.339.100 | € 24.990.841 | € 25.642.583 | € 26.294.324 | € 26.946.066 | € 27.597.807 | € 28.249.548 | € 28.901.290 | € 29.553.031 | € 30.204.772 | € 30.856.514 | € 31.508.255 |
| Discounted cash flow | € 10.449.572 | € 10.493.286 | € 10.530.018 | € 10.560.051 | € 10.583.664 | € 10.601.125 | € 10.612.692 | € 10.618.617 | € 10.619.143 | € 10.614.503 | € 10.604.926 | € 10.590.631 |

| | NPV 2050= | NPV 2100= |
|---|---|---|
| Health sector | € 169.874.957 | € 497.000.058 |
| Energy sector | € 79.629.665 | € 252.848.729 |
| Financial sector | € 3.058.241 | € 7.776.954 |

Net present value 2050: 252.562.864 | Net present value 2100: 757.625.741

| 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** |
| € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 | € 6.939.547 |
| € 2.281.210 | € 2.231.012 | € 2.181.919 | € 2.133.906 | € 2.086.950 | € 2.041.027 | € 1.996.114 | € 1.952.190 | € 1.909.232 | € 1.867.220 | € 1.826.132 | € 1.785.948 | € 1.746.648 | € 1.708.214 | € 1.670.624 | € 1.633.863 | € 1.597.910 | € 1.562.748 | € 1.528.360 | € 1.494.728 | € 1.461.837 | € 1.429.669 | € 1.398.210 | € 1.367.442 | € 1.337.352 | € 1.307.924 |
| € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 | € 2.952.832 |
| € 970.673 | € 949.313 | € 928.424 | € 907.994 | € 888.014 | € 868.473 | € 849.362 | € 830.672 | € 812.393 | € 794.517 | € 777.033 | € 759.935 | € 743.213 | € 726.858 | € 710.864 | € 695.221 | € 679.923 | € 664.962 | € 650.329 | € 636.019 | € 622.023 | € 608.336 | € 594.949 | € 581.857 | € 569.054 | € 556.532 |
| € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 | € 127.227 |
| € 41.823 | € 40.902 | € 40.002 | € 39.122 | € 38.261 | € 37.419 | € 36.596 | € 35.791 | € 35.003 | € 34.233 | € 33.479 | € 32.743 | € 32.022 | € 31.318 | € 30.628 | € 29.955 | € 29.295 | € 28.651 | € 28.020 | € 27.404 | € 26.801 | € 26.211 | € 25.634 | € 25.070 | € 24.518 | € 23.979 |
| € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 | € 10.019.605 |
| € 29.809.393 | € 30.480.104 | € 31.160.907 | € 31.867.140 | € 32.584.150 | € 33.317.294 | € 34.066.933 | € 34.833.439 | € 35.617.191 | € 36.418.578 | € 37.237.996 | € 38.075.851 | € 38.932.557 | € 39.808.540 | € 40.704.232 | € 41.620.077 | € 42.556.529 | € 43.514.051 | € 44.493.117 | € 45.494.212 | € 46.517.832 | € 47.564.483 | € 48.634.684 | € 49.728.964 | € 50.847.866 | € 51.991.943 |

| 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** |
| € 20.800.720 | € 21.215.660 | € 21.630.599 | € 22.045.538 | € 22.460.477 | € 22.875.417 | € 23.290.356 | € 23.705.295 | € 24.120.234 | € 24.535.173 | € 24.950.113 | € 25.365.052 | € 25.779.991 | € 26.194.930 | € 26.609.870 | € 27.024.809 | € 27.439.748 | € 27.854.687 | € 28.269.626 | € 28.684.566 | € 29.099.505 | € 29.514.444 | € 29.929.383 | € 30.344.323 | € 30.759.262 | € 31.174.201 |
| € 6.837.739 | € 6.820.676 | € 6.801.052 | € 6.778.989 | € 6.754.604 | € 6.728.009 | € 6.699.315 | € 6.668.625 | € 6.636.042 | € 6.601.664 | € 6.565.586 | € 6.527.899 | € 6.488.692 | € 6.448.049 | € 6.406.052 | € 6.362.782 | € 6.318.314 | € 6.272.722 | € 6.226.078 | € 6.178.448 | € 6.129.901 | € 6.080.498 | € 6.030.301 | € 5.979.369 | € 5.927.758 | € 5.875.524 |
| € 11.065.883 | € 11.298.346 | € 11.530.809 | € 11.763.272 | € 11.995.735 | € 12.228.199 | € 12.460.662 | € 12.693.125 | € 12.925.588 | € 13.158.051 | € 13.390.514 | € 13.622.977 | € 13.855.441 | € 14.087.904 | € 14.320.367 | € 14.552.830 | € 14.785.293 | € 15.017.756 | € 15.250.219 | € 15.482.683 | € 15.715.146 | € 15.947.609 | € 16.180.072 | € 16.412.535 | € 16.644.998 | € 16.877.461 |
| € 3.637.644 | € 3.632.334 | € 3.625.495 | € 3.617.198 | € 3.607.512 | € 3.596.500 | € 3.584.226 | € 3.570.750 | € 3.556.133 | € 3.540.429 | € 3.523.695 | € 3.505.982 | € 3.487.343 | € 3.467.827 | € 3.447.481 | € 3.426.351 | € 3.404.482 | € 3.381.916 | € 3.358.695 | € 3.334.858 | € 3.310.444 | € 3.285.490 | € 3.260.030 | € 3.234.101 | € 3.207.734 | € 3.180.961 |
| € 293.393 | € 297.732 | € 302.071 | € 306.410 | € 310.749 | € 315.088 | € 319.427 | € 323.766 | € 328.105 | € 332.444 | € 336.783 | € 341.122 | € 345.461 | € 349.800 | € 354.139 | € 358.478 | € 362.817 | € 367.156 | € 371.495 | € 375.834 | € 380.173 | € 384.512 | € 388.851 | € 393.190 | € 397.529 | € 401.868 |
| € 96.446 | € 95.719 | € 94.977 | € 94.221 | € 93.453 | € 92.672 | € 91.881 | € 91.080 | € 90.269 | € 89.451 | € 88.624 | € 87.791 | € 86.951 | € 86.106 | € 85.255 | € 84.401 | € 83.543 | € 82.682 | € 81.818 | € 80.952 | € 80.085 | € 79.216 | € 78.347 | € 77.478 | € 76.610 | € 75.742 |
| € 32.159.997 | € 32.811.738 | € 33.463.479 | € 34.115.221 | € 34.766.962 | € 35.418.703 | € 36.070.445 | € 36.722.186 | € 37.373.927 | € 38.025.669 | € 38.677.410 | € 39.329.152 | € 39.980.893 | € 40.632.634 | € 41.284.376 | € 41.936.117 | € 42.587.858 | € 43.239.600 | € 43.891.341 | € 44.543.082 | € 45.194.824 | € 45.846.565 | € 46.498.307 | € 47.150.048 | € 47.801.789 | € 48.453.531 |
| € 10.571.830 | € 10.548.728 | € 10.521.523 | € 10.490.408 | € 10.455.568 | € 10.417.182 | € 10.375.422 | € 10.330.456 | € 10.282.444 | € 10.231.544 | € 10.177.905 | € 10.121.672 | € 10.062.986 | € 10.001.981 | € 9.938.789 | € 9.873.534 | € 9.806.339 | € 9.737.320 | € 9.666.590 | € 9.594.259 | € 9.520.429 | € 9.445.204 | € 9.368.678 | € 9.290.948 | € 9.212.102 | € 9.132.227 |

## SCBA Costs

### Variant 1

| | | | |
|---|---|---|---|
| Investment cost of measure | Shading | € 3.500 | € / dwelling / 15 years |
| | Solar reflective foils | € 750 | € / dwelling / 10 years |
| Maintenance cost of measure | Shading | € 50 | € / dwelling / year |
| | Solar reflective foils | € - | € / dwelling / year |
| Dwellings | Total | 15.000 | Number of dwellings |
| | 90% Shading | 13500 | Number of dwellings |
| | 10% Solar reflective foils | 1500 | Number of dwellings |
| Discount rate | | 2,25% | |

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Investment cost** | | | | | | | | | | |
| Shading | € 47.250.000 | | | | | | | | | |
| Solar reflective foils | € 1.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Solar reflective foils | | | | | | | | | | |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 48.375.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Discounted cash flow | € 48.375.000 | € 660.147 | € 645.620 | € 631.413 | € 617.519 | € 603.931 | € 590.641 | € 577.644 | € 564.933 | € 552.502 |

| | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | € 47.250.000 | | | | |
| Solar reflective foils | € 1.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Solar reflective foils | | | | | | | | | | |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 1.800.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 47.250.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Discounted cash flow | € 1.440.918 | € 528.454 | € 516.826 | € 505.453 | € 494.330 | € 33.841.692 | € 472.814 | € 462.410 | € 452.235 | € 442.284 |

| | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | | | | | |
| Solar reflective foils | € 1.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Solar reflective foils | | | | | | | | | | |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 1.800.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Discounted cash flow | € 1.153.470 | € 423.033 | € 413.724 | € 404.620 | € 395.717 | € 387.009 | € 378.493 | € 370.164 | € 362.019 | € 354.052 |

| | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** |
| **Investment cost** | | | | | | | | | | |
| Shading | € 47.250.000 | | | | | | | | | |
| Solar reflective foils | € 1.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Solar reflective foils | | | | | | | | | | |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 48.375.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Discounted cash flow | € 24.815.411 | € 338.642 | € 331.190 | € 323.903 | € 316.775 | € 309.804 | € 302.987 | € 296.320 | € 289.800 | € 283.423 |

| | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | € 47.250.000 | | | | |
| Solar reflective foils | € 1.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Solar reflective foils | | | | | | | | | | |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 1.800.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 47.250.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| Discounted cash flow | € 739.162 | € 271.086 | € 265.121 | € 259.287 | € 253.582 | € 17.360.114 | € 242.544 | € 237.207 | € 231.987 | € 226.883 |

| | | | |
|---|---|---|---|
| **Net present value 2050** | **96.154.340** | **Net present value 2100** | **162.902.740** |

### Variant 2

| | | | |
|---|---|---|---|
| Investment cost of measure | Tilt and turn windows | € 4.000 | € / dwelling / 50 years |
| | Ventilation rosters | € 1.750 | € / dwelling / 50 years |
| Maintenance cost of measure | Tilt and turn windows | € 45 | € / dwelling / year |
| | Ventilation rosters | € 25 | € / dwelling / year |
| Dwellings | Total | 15.000 | Number of dwellings |
| | 50% Tilt and turn windows | 7500 | Number of dwellings |
| | 50% Ventilations rosters | 7500 | Number of dwellings |
| Discount rate | | 2,25% | |

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Investment cost** | | | | | | | | | | |
| Tilt and turn windows | € 30.000.000 | | | | | | | | | |
| Ventilation rosters | € 13.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Tilt and turn windows | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 43.125.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| Discounted cash flow | € 43.125.000 | € 513.447 | € 502.149 | € 491.099 | € 480.293 | € 469.724 | € 459.388 | € 449.279 | € 439.393 | € 429.724 |

| | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** |
| **Investment cost** | | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| Discounted cash flow | € 420.268 | € 411.020 | € 401.975 | € 393.130 | € 384.479 | € 376.019 | € 367.745 | € 359.652 | € 351.738 | € 343.998 |

| | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** |
| **Investment cost** | | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| Discounted cash flow | € 336.429 | € 329.026 | € 321.785 | € 314.705 | € 307.780 | € 301.007 | € 294.383 | € 287.905 | € 281.570 | € 275.374 |

| | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** |
| **Investment cost** | | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| Discounted cash flow | € 269.315 | € 263.388 | € 257.592 | € 251.924 | € 246.381 | € 240.959 | € 235.657 | € 230.471 | € 225.400 | € 220.440 |

| | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** |
| **Investment cost** | | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| Discounted cash flow | € 215.589 | € 210.845 | € 206.205 | € 201.668 | € 197.230 | € 192.890 | € 188.646 | € 184.494 | € 180.435 | € 176.464 |

| | | | |
|---|---|---|---|
| **Net present value 2050** | **53.080.251** | **Net present value 2100** | **76.064.340** |

### Variant 3

| | | | |
|---|---|---|---|
| Investment cost of measure | Shading | € 3.500 | € / dwelling / 15 years |
| | Solar reflective foils | € 750 | € / dwelling / 10 years |
| | Tilt and turn windows with solar reflective glazing | € 4.100 | € / dwelling / 40 years |
| | Ventilation rosters | € 1.750 | € / dwelling / 50 years |
| Maintenance cost of measure | Shading | € 50 | € / dwelling / year |
| | Solar reflective foils | € - | € / dwelling / year |
| | Tilt and turn windows | € 45 | € / dwelling / year |
| | Ventilation rosters | € 25 | € / dwelling / year |
| Dwellings | Total | 15.000 | Number of dwellings |
| | 45% Shading | 6750 | Number of dwellings |
| | 5% Solar reflective foils | 750 | Number of dwellings |
| | 50% Tilt and turn windows with solar reflective glazing | 7500 | Number of dwellings |
| | 50% Ventilations rosters | 7500 | Number of dwellings |
| Discount rate | | 2,25% | |

| | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **Investment cost** | | | | | | | | | | |
| Shading | € 23.625.000 | | | | | | | | | |
| Solar reflective foils | € 562.500 | | | | | | | | | |
| Tilt and turn windows | € 30.750.000 | | | | | | | | | |
| Ventilation rosters | € 13.125.000 | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Solar reflective foils | | | | | | | | | | |
| Tilt and turn windows | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 68.062.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| Discounted cash flow | € 68.062.500 | € 843.521 | € 824.959 | € 806.806 | € 789.052 | € 771.689 | € 754.708 | € 738.101 | € 721.859 | € 705.975 |

| | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | € 23.625.000 | | | | |
| Solar reflective foils | € 562.500 | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Solar reflective foils | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 1.425.000 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 24.150.000 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| Discounted cash flow | € 1.140.727 | € 675.247 | € 660.388 | € 645.856 | € 631.644 | € 17.296.865 | € 604.152 | € 590.857 | € 577.856 | € 565.140 |

| | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | | | | | |
| Solar reflective foils | € 562.500 | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Solar reflective foils | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 1.425.000 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| Discounted cash flow | € 913.163 | € 540.542 | € 528.647 | € 517.015 | € 505.638 | € 494.511 | € 483.630 | € 472.987 | € 462.579 | € 452.400 |

| | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **30** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** | **39** |
| **Investment cost** | | | | | | | | | | |
| Shading | € 23.625.000 | | | | | | | | | |
| Solar reflective foils | € 562.500 | | | | | | | | | |
| Tilt and turn windows | | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Solar reflective foils | | | | | | | | | | |
| Tilt and turn windows | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 24.712.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| Discounted cash flow | € 12.677.020 | € 432.709 | € 423.188 | € 413.875 | € 404.768 | € 395.861 | € 387.150 | € 378.631 | € 370.299 | € 362.151 |

| | 2065 | 2066 | 2067 | 2068 | 2069 | 2070 | 2071 | 2072 | 2073 | 2074 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Period** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** |
| **Investment cost** | | | | | | | | | | |
| Shading | | | | | | € 23.625.000 | | | | |
| Solar reflective foils | € 562.500 | | | | | | | | | |
| Tilt and turn windows | € 30.750.000 | | | | | | | | | |
| Ventilation rosters | | | | | | | | | | |
| **Maintenance costs** | | | | | | | | | | |
| Shading | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Solar reflective foils | | | | | | | | | | |
| Tilt and turn windows | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| Ventilation rosters | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| **Return analysis** | | | | | | | | | | |
| Net cash flow | € 31.837.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 24.150.000 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| Discounted cash flow | € 13.073.934 | € 346.388 | € 338.766 | € 331.311 | € 324.021 | € 8.872.947 | € 309.918 | € 303.098 | € 296.428 | € 289.906 |

| | | | |
|---|---|---|---|
| **Net present value 2050** | **101.907.421** | **Net present value 2100** | **161.003.636** |

| 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** |
| | | | | | | | | | | € 47.250.000 | | | | | | | | | | | | | | | |
| € 1.125.000 | | | | | | | | | | € 1.125.000 | | | | | | | | | | € 1.125.000 | | | | | |
| € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| € 1.800.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 48.375.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 1.800.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 | € 675.000 |
| € 591.707 | € 217.007 | € 212.232 | € 207.562 | € 202.995 | € 198.528 | € 194.159 | € 189.887 | € 185.708 | € 181.622 | € 12.729.812 | € 173.717 | € 169.894 | € 166.156 | € 162.499 | € 158.924 | € 155.426 | € 152.006 | € 148.661 | € 145.390 | € 379.176 | € 139.062 | € 136.002 | € 133.009 | € 130.082 | € 127.220 |

| 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** |
| € 30.000.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| € 13.125.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| € 43.125.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 | € 525.000 |
| € 14.176.312 | € 168.784 | € 165.070 | € 161.437 | € 157.885 | € 154.411 | € 151.013 | € 147.690 | € 144.440 | € 141.261 | € 138.153 | € 135.113 | € 132.140 | € 129.232 | € 126.388 | € 123.607 | € 120.887 | € 118.227 | € 115.626 | € 113.081 | € 110.593 | € 108.159 | € 105.779 | € 103.452 | € 101.175 | € 98.949 |

| 2075 | 2076 | 2077 | 2078 | 2079 | 2080 | 2081 | 2082 | 2083 | 2084 | 2085 | 2086 | 2087 | 2088 | 2089 | 2090 | 2091 | 2092 | 2093 | 2094 | 2095 | 2096 | 2097 | 2098 | 2099 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **50** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **68** | **69** | **70** | **71** | **72** | **73** | **74** | **75** |
| | | | | | | | | | | € 23.625.000 | | | | | | | | | | | | | | | |
| € 562.500 | | | | | | | | | | € 562.500 | | | | | | | | | | € 562.500 | | | | | |
| € 13.125.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 | € 337.500 |
| | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 | € 187.500 |
| € 14.362.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 24.712.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 1.425.000 | € 862.500 | € 862.500 | € 862.500 | € 862.500 | € 862.500 |
| € 4.721.328 | € 277.287 | € 271.186 | € 265.218 | € 259.382 | € 253.674 | € 248.092 | € 242.633 | € 237.294 | € 232.072 | € 6.503.059 | € 221.971 | € 217.087 | € 212.310 | € 207.638 | € 203.069 | € 198.600 | € 194.230 | € 189.956 | € 185.776 | € 300.181 | € 177.690 | € 173.780 | € 169.956 | € 166.216 | € 162.559 |