Designing an agent-based model to help determine what urban heat island mitigation solutions can best be implemented in existing urban areas

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Executive summary

The Urban Heat Island effect increases the air temperature in cities compared to rural areas because cities have a lot more hardened surfaces than rural areas. These hardened surfaces reduce evaporation and increase the absorption of heat. Furthermore, the anthropomorphic heat release from buildings is higher in cities. Combined with the reduced influx of cool fresh air from outside the city because of the smog bubble around a city, this results in higher air temperatures. These higher temperatures have several negative consequences for the liveability of the city and its ecological environment, such as the reducing of biodiversity, and the increase of water consumption, air pollution, electricity demand and health risks (Fabiani, Pisello, Bou-Zeid, Yang, & Cotana, 2019). As the amount of people living in cities increases (United Nations, 2019) and the global air temperatures rise (IPCC, 2013) these negative effects will increase and mitigation action has to be taken.

Different mitigation solutions have been studied extensively. Pisello, Saliari, Vasilakopoulou, Hadad, & Santamouris (2018) conclude that there are several main solutions that can be implemented in cities all over the world. However a limited understanding of the Urban Heat Island effect exists amongst stakeholders in the Netherlands such as municipalities, owner-occupiers, tenants and property owners (Solcerova, Klok, Wilschut, Kleerekoper, & Kluck, 2019). Therefore, this study aims to increase the knowledge of Urban Heat Island mitigation solutions in different climate areas and show different ways in which these stakeholders can take action. By answering the following research question: "*How do technical, household and institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?*"

As the local climate of an area influences the effect of these mitigation solutions (Kim, Gu, & Kim, 2018; Pisello et al., 2018), this study uses the Local Climate Zone classification by Stewart & Oke (2012) to differentiate between different areas. An extensive literature study is performed to find out what technical, household and institutional characteristics influence the adoption of four different Urban Heat Island mitigation solutions (green roofs, green façades, green gardens or cool roofs) by households in existing neighbourhoods in the Netherlands. Also the technical characteristics of four other solutions (planting more trees, creating a grass area, urban park, area with ponds or applying a cool coating to hard ground surfaces) that can be implemented by municipalities are investigated. This information is combined with information from expert interviews to make an agent-based model about the adoption of these solutions in a neighbourhood in the Netherlands. As case study for this graduation research the neighbourhood Bomen en Bloemenbuurt in the Hague is used as it has a variety of dwellings, Urban Heat Island characteristics and Local Climate Zones.

The Theory of Planned Behaviour (Ajzen, 1985) is used as the backbone of the agent-based model to be able to process how households decide to invest in Urban Heat Island mitigation solutions. This theory is combined with the findings of Lam (2006) that show household characteristics improve the Theory of Planned Behaviour and Reid, Sutton, & Hunter (2010), who showed that the meso level of the Theory of Planned Behaviour, regarding households, is the most important level when explaining pro-environmental behaviour. Reid et al. (2010) revise the Theory of Planned Behaviour with their findings and this revised theory is used in this graduation research. Furthermore, the small-world network (Schnettler, 2009) is used to simulate the interactions between households.

The agent-based model of this graduation research is based on the models used in the research of Muelder & Filatova (2018). Households decide to invest in an Urban Heat Island mitigation solution based on the multi-attribute utility of each solution that consists of an economic, environmental, social and comfort factor. Only if their income is above a certain threshold they calculate the utilities. Their household characteristics, such as the amount of vegetation in their neighbourhood, their educational level, whether they own their dwelling and the nearby air temperature, then determine whether they adopt a specific solution or not.

The results show that of the technical characteristics the temperature effect of green roofs, green gardens, green façades and cool roofs does not have a significant positive influence on the adoption of these four solutions. Furthermore, the positive effect of the costs of these four solutions could not be determined, while the energy reduction effect did have a significant positive influence. Regarding the household characteristics, households with a higher educational level do not significantly adopt more Urban Heat Island mitigation solutions. Being an owner-occupier or having a higher income on the other hand do show a significant positive influence. The analysis of institutional characteristics show that performance agreements between municipalities and housing corporations do not have a significant positive influence on the adoption by other households. Being part of an owners' association has a significant negative effect on the adoption of solutions. Introducing or increasing the subsidy for green and cool roofs has a significant positive effect on the adoption while this is not the case for introducing a green façade subsidy or continuing the existing green garden subsidy. Although literature shows that characteristics of the area where an Urban Heat Island mitigation solutions is implemented influence the effect of a solution on the outdoor air temperature. The results of this graduation research did not show any significant differences in the amount of adopted solution while comparing an open neighbourhood with a compact one, a neighbourhood with low rise to one with midrise buildings and a neighbourhood with a lot of vegetation to one with a low amount of vegetation.

The results of the average temperatures show significant differences in the temperatures between the four investigated Local Climate Zones, but the amount of temperature reduction in these areas is roughly the same. Considering the reduced reliability of the temperature outcomes because of the low resolution of the input air temperatures, no conclusion could be drawn about these differences in temperature. Furthermore, changing the existing subsidies does not have a significant influence on the reduction of the average temperature, but it does show that the total fraction of adopted solutions can have a significant increase for a higher green or cool roof subsidy. Lastly, changing the surfaces of squares in an area to ones that can reduce the Urban Heat Island effect reduces the average air temperature in an area, but do not influence the adoption of solutions by households.

This graduation research increased the knowledge about Urban Heat Island mitigation solutions by providing an up-to-date overview of the current literature on the effects of eight of these solutions on the outdoor air temperature in different Local Climate Zones and the literature on the effects of household characteristics. The three different architectures used to create the agent-based model in this graduation research expand the knowledge of the effect of different formalizations of the Theory of Planned Behaviour in agent-based models after Muelder & Filatova (2018) showed that this affects the adoption of PV by households in the Netherlands. This graduation study confirms their findings that the SE model architecture, based on the research by Schwarz & Ernst (2009), lead to a faster adoption of the investigated solutions. However, this graduation study found that the SE architecture had a significant higher fraction of implemented solutions than the MF architecture, based on the research by Muelder & Filatova (2018), while Muelder & Filatova (2018) found the MF architecture resulting in more adopted solutions. The cause of this difference is not clear from the present study.

Two types of future research can be performed following this graduation study. First the different inputs of the agent-based model used in the present study can be confirmed or corrected by new studies. Especially the level of detail of the input air temperature, the specific effects of household characteristics and the household energy use reduction per Local Climate Zone need to be investigated further to improve the reliability and validity of the model. Second, the outcomes of this graduation research can be used in future studies. The agent-based model can, for example, be adapted to represent a different neighbourhood in the Netherlands or another country. Another option is to expand the agent-based model with the effect of information costs for households, as the present research assumes perfect information, or to add the option to adopt a combination of mitigation solutions by households. Finally, it would be interesting to check which of the three model formalizations represents the real-world behaviour best and should thus be used for future studies.

Acknowledgements

Writing this master thesis has been a long journey that started more than one year ago. As I was part of the last shift of students in the Built and Spatial Environment track of the Master Complex Systems Engineering and Management, I wanted to incorporate this in my graduation research. During the elective course Urban Climate and Hydrology in the second year of this master I came across the Urban Heat Island effect and its consequences for urban areas. This topic immediately grabbed my attention and I am grateful that I was able to address this topic in my graduation research. The COVID-19 pandemic did not make the whole graduation process easier, all meetings with supervisors, experts on this topic or important stakeholders had to be done online. The effects cause by this pandemic are one of the main reasons that this graduation study took longer than expected and two extensions of the graduation period were needed to bring this research to a successful end.

I would like to thank all of my supervisors and advisors, Henk Visscher, Thomas Hoppe, Amineh Ghorbani, Arjen Meijer and Tristan de Wildt for believing in me during the past year and helping me whenever I had questions despite the difficult conditions because of the pandemic. Thank you Amineh and Tristan for helping me with creating the agent-based model, providing interesting examples of other models and answering all my model based questions. Thomas, thank you for all your feedback on several versions of my thesis over the past year and for helping me with the formal side of asking permission to extend my graduation period. Thank you Arjen for all of your advice, comments, ideas, tips, improvements and answers to all of my questions that you provided during all our meetings in the past year. I have not counted them, but I am sure that they would add up to multiple days.

Lastly, I want to thank all others who have contributed to this graduation research: The different (assistant) professors that helped me in choosing the topic for this research and forming the exact research questions; The academic counsellors that helped me during the difficult times around extending the graduation period; The experts and representatives of stakeholders which I have contacted and spoken to online about this thesis and helped me with finding all kinds of input data; And lastly all of my friend and family that have supported me during all of my studies at the TU Delft, but especially during the last difficult year while writing this thesis. Without all of your help, advise, distractions but most of all patience this master thesis would not exist.

Bart Groeneveld

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Table of Contents

List of abbreviations

Abbreviation	Full
AB	Agent Based
ABM	Agent Based Model
att	Attitude
CBS	Statistics Netherlands
com	Comfort
DE	Discrete Event
DHIC	The Hague in numbers
DoI	Diffusion of Innovations
EAS	European Adaptation strategy
eco	Economic
env	Environmental
LCZ(s)	Local Climate Zone(s)
MRT	Mean Radiant Temperature
NAS	National Climate adaptation strategy
PBC	Perceived Behavioural Control
PBL	Netherlands Environmental Assessment Agency
PEB	Pro-environmental behaviour
PET	Physiologically Equivalent Temperature
PMV	Predicted Mean Vote
SD	System Dynamics
soc	Social
TPB	Theory of Planned Behaviour
UHI	Urban Heat Island
UTCI	Universal Thermal Climate Index
VVE('s)	Owners' association(s)

List of figures

List of tables

1. Introduction

1.1 Background

When walking or cycling through an urban area you probably have experienced that the air temperature within the city itself is higher than the air temperature in a park or outside of the urban area. Already in 1833 evidence of this effect was provided by L. Howard (as cited in (Oke, 1982). The accumulation of heat in cities has received more and more attention since then (Pisello et al., 2018) and is often referred to as the Urban Heat Island (UHI) effect in scientific literature. Research shows that the UHI effect can increase the air temperature in cities with two or more degrees Celsius during the day and up to 12°C in the early night, compared to rural areas (Garuma, 2018). The UHI effect has a negative influence on the liveability and the ecological environment of cities all around the world (Fabiani et al., 2019). Biodiversity reduces, water consumption increases, air pollution increases, electricity demand increases and health risks increase for all citizens, especially for the young and elderly (Fabiani et al., 2019). Huynen, Martens, Schram, Weijenberg, & Kunst (2001) found that during heat waves in the Netherlands, mortality rates increased with 12%. A study in 2011 found that the UHI effect in Rotterdam could be as big as 8°C and could lead to over 36 extra deaths each year (Kennis voor Klimaat, 2011). An increase in city air temperatures also reduces the work capacity and productivity, according to a study from the International Labour Organization (2019). They state that air temperatures above 24°C already cause a reduction in productivity and at 33°C as much as fifty percent of work capacity is lost.

Urbanisation is the biggest cause of the UHI effect (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017). Therefore, the increasing number of people living in urban areas will increase the negative consequences of the UHI effect. In 1950 only 30% of the global population lived in urban areas, in 2018 this percentage had already increased to 55% and it is expected that in 2050 68% of the total population will live in urban areas (United Nations, 2019). Next to that, the average global air temperature is expected to have increased between 0.3 to 4.8°C by the year 2100 (IPCC, 2013). This will only further increase the maximum air temperature in cities and thus increase the negative effects of the UHI effect.

Several solutions can be implemented to reduce the UHI effect in cities. Kluck et al. (2020) write in their report that these solutions should aim to reduce the city-wide air temperature during the day and night and should create local cool areas with a high wind chill factor. Table 1 presents different mitigation solutions identified in scientific literature (Pisello et al., 2018; M. Santamouris et al., 2017). These are “the main acknowledged and already implemented technologies for energy saving in building and urban heat island (UHI) mitigation” (Pisello et al., 2018. p.2).

Table 1: Mitigation solutions found in literature

Group name	Specific solution
Green infrastructures	Green roofs
	Green façades (vertical greenery)
	Grass
	Trees
	Urban Parks
Water based mitigation	Pools and ponds

	Rivers
	Evaporative towers
	Sprinklers
	Fountains
Reflecting materials	Cool roofs
	Cool pavements
Urban Geometry	Lowering sky-view factor
	Lowering height-to-width ratio
	Orientation of street canyon
Ground cooling techniques	Earth to air heat exchangers

Pisello et al. (2018) conclude that these main solutions show a clear technological readiness to be implemented in cities all over the world. However, they state that a shared and synergistic policy effort is missing. According to Kim, Gu, & Kim (2018) the effectiveness of UHI mitigation solutions depends on the climate classification of the city they are implemented in. For example, increasing the amount of grass coverage is effective in hot climates but could increase the UHI effect in others (Kim et al., 2018).

Gunawardena, Wells, & Kershaw (2017) explain that the urban atmosphere consists of two different layers. The urban canopy layer (UCL), which consists of the atmosphere between the tops of trees and buildings and the surface, and the urban boundary layer (UBL), which is the layer on top of the UCL that includes all the atmosphere influenced by contact with the surface. Figure 1 shows these two levels.

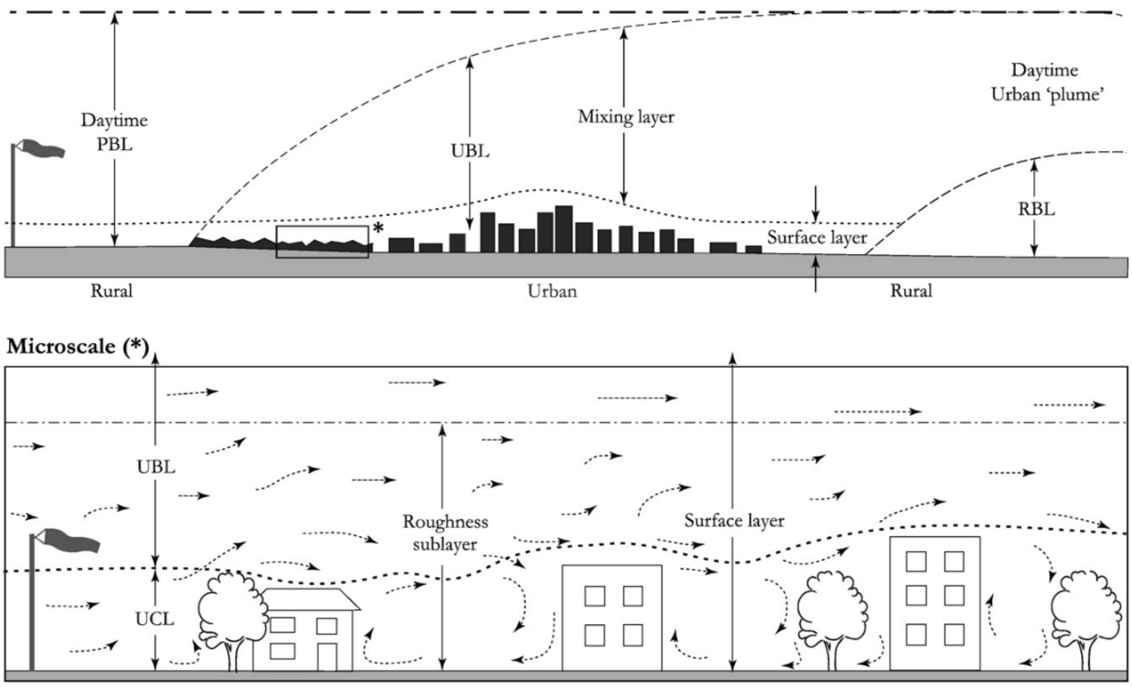


Figure 1: Boundary-layer structures over a city resulting from increased surface roughness. Reprinted from K. Gunawardena, M. Wells and T. Kershaw. (2017). Utilising green and bluespace to mitigate urban heat island intensity. Science of the Total Environment, p. 1042. http://dx.doi.org/10.1016/j.scitotenv.2017.01.158

The UCL is the zone that is vital for protecting human wellbeing, health and comfort in the city (Oke, 1976). It is the layer where people live that is influenced by the materials and characteristics of the local environment (Gunawardena et al., 2017). This microscale layer can have a lot of different characteristics. In most cities each part of the city is different than another and this can even be true for neighbouring streets. Therefore the Local Climate Zone (LCZ) classification was developed by Stewart & Oke (2012). This classification consists of different built types and land cover types that define the local area and can span between hundreds of metres until several kilometres (Stewart & Oke, 2012).

Solcerova, Klok, Wilschut, Kleerekoper, & Kluck (2019) write that the UHI effect is extensively studied all around the world, however only a limited understanding of this effect exists among stakeholders. Cities like Rotterdam and The Hague in the Netherlands focus on increasing the amount of green in their cities by offering subsidies for constructing green roofs (Gemeente Rotterdam, n.d.; Gemeente Den Haag, n.d.), combining densification with more green infrastructure and stimulating individuals to increase the amount of green in their gardens (Gemeente Den Haag, 2018). However other mitigation solutions seem to be left out, while they could also contribute to a cooler city.

As explained, the UHI effect occurs in existing urban areas, but also when planning new neighbourhoods this effect should be taken into account. Otherwise, this problem will keep existing in the future. However, the number of dwellings in the Netherlands only increases with a little less than 1% each year (CBS, 2020). This means that implementing UHI mitigation solutions in existing urban areas will be more effective than only doing this for newly build areas. In newly build neighbourhoods the municipality often takes care of the public space and is sometimes able to oblige developers to implement certain requirements, like UHI mitigation solutions, in their plans when pursuing an active or facilitating land policy. Changing existing urban areas on the other hand can be difficult. Municipalities only own around 2,4% (Republiq, 2019) of the total amount of 1.3 billion square metres of real estate in the Netherlands (Rabobank, 2018) and thus have to work together with other real estate owners such as owner occupiers, housing corporations, private landlords and business owners to implement certain UHI mitigation solutions. Some of these real estate owners are directly affected by the UHI effect and can be more willing to cooperate, while others do not. The process of changing public space in existing urban areas can take a long time, because municipalities in the Netherlands have to involve citizens and other interested parties in the decision-making process. All interested parties can submit their view on the plan and suggest changes that the municipality has to address. There are numerous examples of tenants, or real estate owners that resist plans of municipalities, when they want to demolish a certain area to improve the neighbourhood (NHNieuws, 2019; Haverkate, 2018; Omroep West, 2016; Berkelder, 2019) or when a restructuring is planned (van der Vegt, 2019; Willems, 2020; Talsma, 2019; Visser, 2020).

Municipalities thus need to involve real estate owners early to make sure they will cooperate in making existing urban area more resilient to the UHI effect. Different policies will influence real estate owners differently and have different results. Designing an approach to stimulate these real estate owners to participate in tackling UHI issues may help in introducing effective policies to reduce the UHI effect. To be able to design the most effective approaches, first the ‘way in which real estate owners decide to invest in UHI mitigation solutions’ must be identified. This can then be used to assess the effectiveness of these policies.

1.2 Problem statement

The background introduction has sketched the outlines of the negative consequences of the Urban Heat Island (UHI) effect in cities. In this section a brief summary of the problem, used as the starting point for this graduation study, is presented.

Section 1.1 showed that the UHI effect already exists for many years (Howard, as cited in (Oke, 1982), and research into this topic has increased in the last decade (Pisello et al., 2018). The UHI effect decreases the liveability of cities and increases health risks of citizens (Fabiani et al., 2019). Increasing urbanization (United Nations, 2019) and global warming (IPCC, 2013) will increase the negative consequences of the UHI effect.

Pisello et al. (2018) showed that there are several acknowledged and already implemented technologies that can mitigate the UHI effect. But Kim et al. (2018) conclude that the effectiveness of these technologies differ between climate zones. Solcerova et al. (2019) state that the UHI effect has a limited understanding among stakeholders, such as municipal professionals and business experts. Cities like Rotterdam and The Hague seem to focus mainly on increasing green infrastructure (Gemeente Rotterdam, n.d. & Gemeente Den Haag, n.d.) but do not incorporate other possible solutions. Because most of the real estate in cities is the property of private owners, municipalities will have to work with them to mitigate the UHI effect.

For the present research three main knowledge gaps have been identified:

- What is the effect of different UHI mitigation solutions in different climate areas?
- How do real estate owners decide whether to invest in UHI mitigation solutions?
- What policies can increase the implementation of UHI mitigation solutions by real estate owners?

Problem statement:
“There is a lack of knowledge about the effect of UHI mitigation solutions in different climate areas and about effective policies that can increase the adoption of UHI mitigation solutions by real estate owners”.

1.3 Research objective and scope

The previous section explained the problem statement of this graduation research, which is transformed into a research objective. The objective of the present research consists of two parts. The first part is to create an overview of the effect of UHI mitigation solutions on the air temperature in different urban areas in similar climates as the Netherlands. The second part is to find the most effective policies to stimulate real estate owners to invest in UHI mitigation solutions.

The scope of this graduation research is limited by its fixed time frame. It only takes into account eight selected solutions from the main accepted UHI mitigation solutions as described by Pisello et al. (2018) and M. Santamouris et al. (2017) and their effect on the outdoor air temperature in the Urban Canopy Layer (UCL), as this effect is widely assessed in existing research. These eight solutions are: green roofs, green façades, grass, trees, urban parks, pools and ponds, cool roofs and cool pavements. Solutions to reduce indoor temperatures will thus not be taken into account. Section 2.2 explains the choice for these solutions. Next to the effect of these eight solutions on the outdoor temperature, their costs and their effect on the energy consumption of real estate is taken into account. All other effects of UHI mitigations solutions are not taken into account in the present study, because not much research exists on these, they are not easily stated in numbers or because this graduation research will get too extensive if they are included. Section 2.5 describes these other effects.

The present study focuses on the situation in the Netherlands, but it should be possible to translate the finding of this graduation research to other EU countries that have a similar climate, legislation and urban- and governmental structure. However, as the present study specifically looks at the Netherlands, it only takes into account similar climate classifications as the Netherlands. Therefore, it could be possible that the results cannot be translated directly to EU countries with a very different climate classification. Section 2.3 discusses these climate specifications.

The introduction explained that implementing UHI mitigation solutions in built-up areas is more effective than focussing on newly developments. Therefore, this graduation research focusses on implementing solutions in existing areas. The district 'Bomen- en Bloemenbuurt' in The Hague is used as case study in this graduation study, because it has a variety of dwellings, UHI characteristics and Local Climate Zones (explained in section 2.4). Chapter 3 will go further into this choice. Various information about this district is only known on an aggregated level and not on the level of specific dwellings. This information is therefore distributed evenly within the district.

As shortly mentioned earlier, there are multiple kinds of real estate owners: the municipality, owner occupiers, housing corporations, private landlords and business owners. The present research focusses on the residential sector and thus not takes business owners into account. Furthermore, it uses the Theory of Planned Behaviour (TPB) (Ajzen, 1985) to explain how individuals decide whether to invest in UHI mitigation solutions or not. This theory is extensively used in research into the pro-environmental behaviour (PEB) of individuals, however, does not talk about choices of companies. Therefore, the present study mostly considers individual households: owner occupiers and tenants, and the four UHI mitigation solutions they can implement themselves, green roofs, green façades, green gardens and cool roofs. Housing corporations are incorporated in the model, but differently than households. It is assumed that these households and housing corporations only invest in one solution. Chapter five discusses these choices. The effects of combining multiple solutions are thus not considered.

1.4 Research questions

This section presents the main research question and sub questions of this study. These questions follow from the problem statement and research objective and are answered in the conclusion of this report.

To be able to decide which mitigation solutions will be viable in cities in the Netherlands and improve the understanding of the UHI effect amongst stakeholders, the following main question is researched*: How do technical, household and institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?*

As will be described in chapter 2, the academic literature shows that the specific effect of the main UHI mitigation solutions on the outdoor air temperature in different areas is not clear. Multiple conditions influence the effectiveness of mitigation solutions, but these are different for each city and their exact influence on the effectiveness is not evident. Therefore, a modelling approach is proposed to answer the main research question. This approach can clarify the influence of different UHI mitigation solutions on a specific neighbourhood and how the implementation of these solutions by households will occur based upon their household characteristics.

The main research question is divided in four sub-questions that will be answered trough literature studies, experts interviews and the agent-based model study:

1. *"How do technical characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
2. *"How do household characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
3. *"How do institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
4. *"How do characteristics of residential environments influence the adoption of Urban Heat Island mitigation solutions."*

By making an agent-based model of the functioning of this socio-technical system it is investigated what the effect is of different characteristics and why certain solutions can be effectively applied in one urban area, but not in others. With the use of a model, it is easier to analyse different urban areas and differentiate between different UHI mitigation solutions.

1.5 Thesis structure

Chapter 2 discusses the theoretical background of this graduation research. It explains the Urban Heat Island (UHI) effect, the different mitigation solutions, the climate classifications used in this graduation study and the behaviour theories that are used in the model. Then chapter 3 explains the research methods used to collect the data to answer the research questions and chapter 4 discusses the three parameters influencing UHI mitigation, the technical, household and institutional characteristics. Chapter 5 and 6 explain the conceptualization, formalization and implementation of the model. Thereafter, chapter 7 shows the results of the model and chapter 8 presents the conclusions of the present research, discusses its consequences and relevance, describes its limitations and presents possibilities for future research.

2. Theoretical Background

This chapter introduces the main theories used in this graduation research. First the Urban Heat Island effect and the consequences of several mitigation solutions on this effect are discussed. Then the Köppen-Geiger climate classification is described, the classification of urban areas by Stewart & Oke (2012) is introduced and current UHI mitigation policies in the Netherlands and The Hague are discussed. The second part of this chapter explains the behavioural theories used in the present study, the Theory of Planned behaviour by Ajzen (1985) and Pro-environmental behaviour by Reid et al. (2010).

2.1 The Urban Heat Island effect

Before being able to conduct research into the Urban Heat Island (UHI) effect, first an understanding about this effect must be developed. Mohajerani et al. (2017) provide a clear image to show how the UHI effect occurs and raises air temperatures (figure 2). A higher amount of hardened surfaces increases the absorption of heat and decreases evaporation, resulting in higher surface temperatures. This in turn intensifies the radiant heat and the heat transfer to the air, increasing urban air temperatures. Less green and water also increases the amount of heat that buildings absorb, which enlarges the use of air conditioners and thus increases the anthropogenic heat release and therefore urban air temperatures.

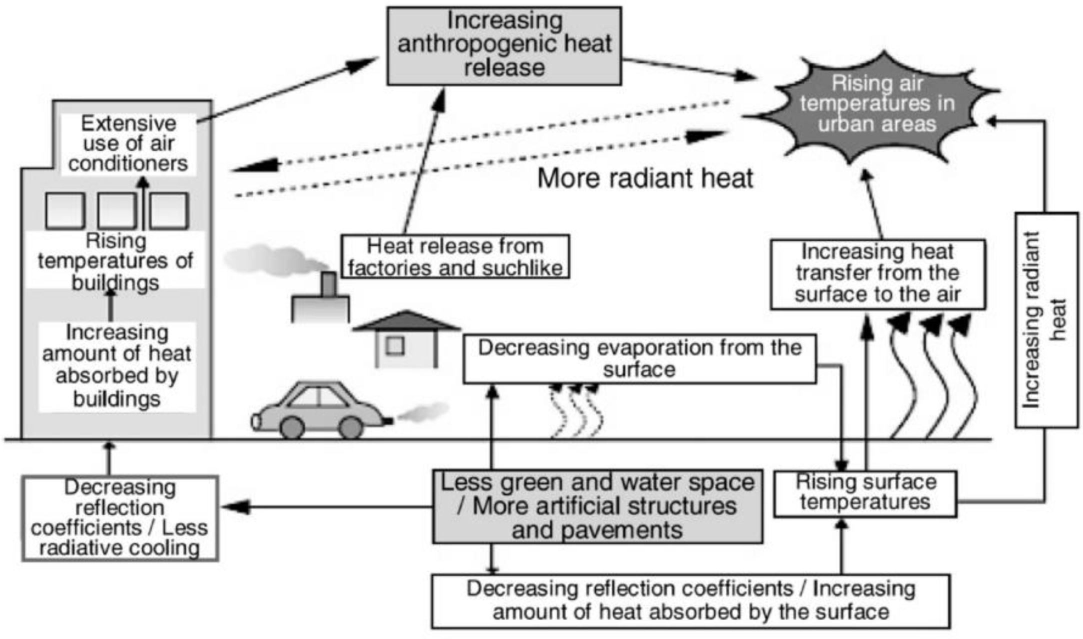


Figure 2: How the Urban Heat Island occurs. Reprinted from Mohajerani, A., Bakaric, J., Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. Journal of Environmental Management, 197, p. 526. http://dx.doi.org/10.1016/j.jenvman.2017.03.095

The intensity of the UHI effect is not only caused by the amount of hardened surface in an area, it also has a self-reinforcing effect (figure 3) (Krusche, Krusche, Althaus & Gabriel, 1982). During the day the hot air inside the city rises and creates a smog bubble, while cool air from outside the city warms up at the edges and cannot get through to the city centre to cool it down. In the night the rising warm air creates an air cushion that stops fresh, clean air from penetrating and cooling the city. That is also the reason why the UHI effect is more intense during the night (Oberndorfer et al., 2007).

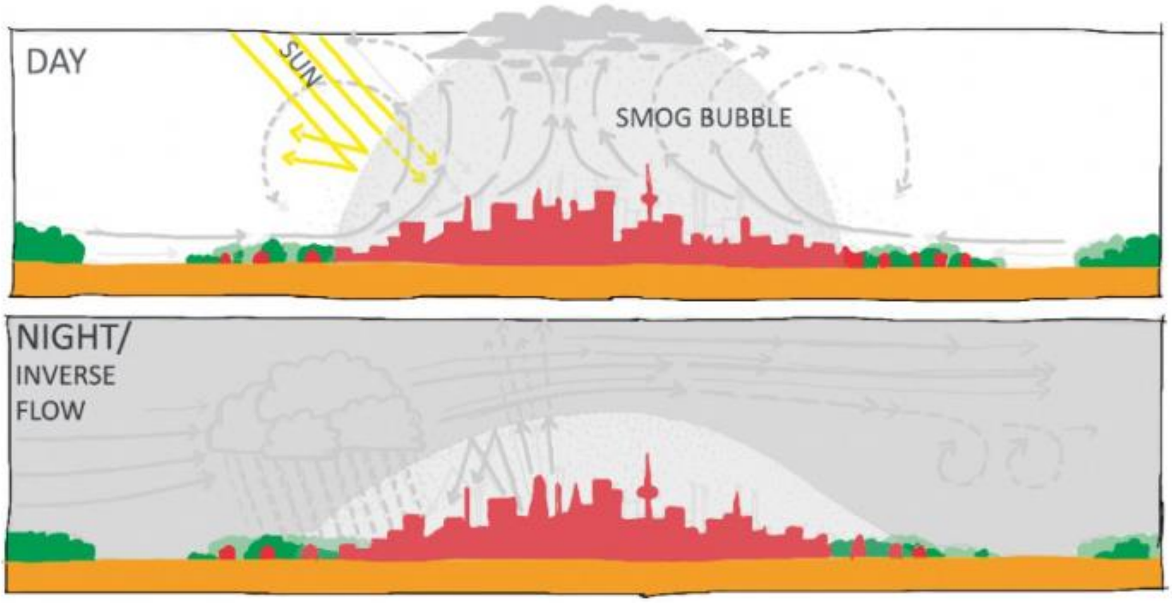


Figure 3: Reprinted from [the creation of smog during day and night] (n.d.). Copyright by Krusche, P., Krusche, M., Althaus, D., and Gabriel, I. (1982). Retrieved from https://nl.urbangreenbluegrids.com/heat/#heading-8

2.2 Mitigating the Urban Heat Island effect

As presented in the introduction, different solutions exist that can mitigate the outdoor UHI effect in cities. Table 2 presents the mitigation solutions identified in scientific literature (Pisello et al., 2018; M. Santamouris et al., 2017).

Table 2: Mitigation solutions discussed by Pisello et al. (2018) and (M. Santamouris et al. (2017)

Group name	**Specific solution**
Green infrastructures	Green roofs
	Green façades (vertical greenery)
	Grass
	Trees
	Urban Parks
Water based mitigation	Pools and ponds
	Rivers
	Evaporative towers
	Sprinklers
	Fountains
Reflecting materials	Cool roofs
	Cool pavements
Urban Geometry	Lowering sky-view factor
	Lowering height-to-width ratio
	Orientation of street canyon
Ground cooling techniques	Earth to air heat exchangers

These solutions all have a different effect and effectiveness. In literature this effect is measured in multiple ways. Some studies investigate the effect of solutions on the albedo, i.e. the reflectivity, of a surface (Yuan, Farnham, & Emura, 2015), while others focus on lower heat gain in KWh/m2 (J. Yang et al., 2018). There are also studies that research the effect on surface temperatures (Wu, Wang, Fan, & Xia, 2018), air temperatures (Völker, Baumeister, Claßen, Hornberg, & Kistemann, 2013) or MRT (Mean Radiant Temperature) (A. Lai, Maing, & Ng, 2017). Other studies have used thermal-physiological indicators like the Physiologically Equivalent Temperature (PET) (Klok, Rood, Kluck, & Kleerekoper, 2019), Predicted Mean Vote (PMV) (Ahmed, 2003), and Universal Thermal Climate Index (UTCI)

(Jendritzky, de Dear, & Havenith, 2012). These thermal-physiological indicators do not show the actual temperature, but are an expression of the amount of heat that people feel at that moment (Klok et al., 2019). Klok et al. (2019) conclude that studies often exclude people's experience and value of thermal conditions as most studies present the impact of mitigation solutions on the surrounding air temperature. Furthermore L. Zhang et al. (2020) found that the air temperature factor affects the outdoor thermal comfort the most. Therefore, the effects of mitigation solutions on urban air temperature are taken into account in this report as the second-best option after thermal-physiological indicators.

In this graduation research, not all UHI mitigation solutions from table 1 will be discussed. It will focus on existing neighbourhoods in the Netherlands and thus on solutions that can be implemented in existing urban areas without demolishing or large-scale restructuring of buildings. Therefore, Urban Geometry solutions will not be taken into account. Also, the creation of rivers will not be included for this reason. Both M. Santamouris et al. (2017) and Pisello et al. (2018) state that knowledge on water based mitigation solutions is relatively limited. M. Santamouris et al. (2017) identified only four studies looking at water sprinkles, three on evaporative towers and two on water fountains. Because of this small number of studies and the available time for the present research, these three water-based solutions will not be taken into account. The same is true for earth to air heat exchangers as a means to reduce outdoor air temperature: there is almost no data available on the impact of such systems on the outside microclimate (M. Santamouris et al., 2017). With regard to Urban Parks, only small sized parks will be taken into account, because large scale parks require large scale urban restructuring. Shashua-Bar & Hoffman (2000) investigated the influence of multiple small parks in Tel-Aviv and found that the cooling effect of small urban parks ranges between 1°C and 4°C and that the cooling effect could be perceived up to 100 metres from the park, following an exponential decay function. Furthermore the present research separates the UHI mitigation solutions in solutions that can be adopted by households and housing corporations: Green roofs, green façades, planting a tree in their garden and cool roofs. And solutions that can only be implemented by the municipality: Planting more trees, creating an urban park, more ponds and cool pavement.

2.3 Climate classification

Kim et al. (2018) showed that the climate classification of a city influences the effectiveness of UHI mitigation solutions. Some solutions have a bigger effect on mitigating the UHI effect in a certain climate than in others. Increasing the amount of grass is for example effective in hot climates but can increase the UHI effect in other climates (Kim et al., 2018). Therefore, the climate classification of the area where the research is done will be taken into account for the literature review and thus for the model. This section explains which climate classifications will be used.

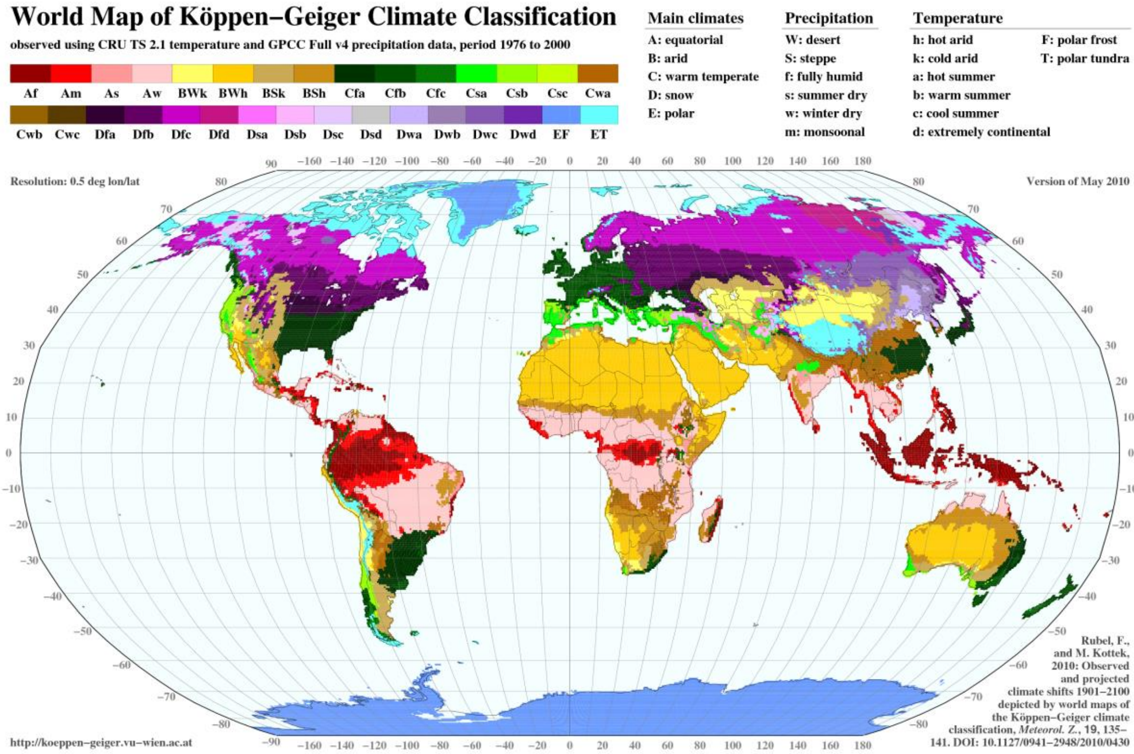


Figure 4: Reprinted from "Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification," by Rubel, F. and Kottek, M. (2010). Retrieved from http://koeppen-geiger.vu-wien.ac.at/shifts.htm

Figure 4 shows the Köppen-Geiger Climate Classification of the world by Rubel & Kottek (2010). For the present research the country of the Netherlands is chosen, which has a Cfb (warm temperature, fully humid, warm summer) classification. Because the local climate of an area influences the result of UHI mitigation solutions (Kim et al., 2018; Pisello et al., 2018) only studies from areas with a similar climate will be considered. These case studies deliver the data to determine the influence of the different UHI mitigation solutions on urban air temperatures. To make sure that the effects used in the model are as accurate as possible, only data from case studies with a climate classification of Cfa, Cfb and Cfc will be used. This covers parts of East Asia, North America and Europe, for which many studies on UHI mitigation solutions are conducted (Aleksandrowicz, Vuckovic, Kiesel, & Mahdavi, 2017).

Rubel & Kottek (2010) not only updated the World Map of Köppen-Geiger Climate Classification shown in figure 4, but also made projected climate classifications for four different IPCC (Intergovernmental Panel on Climate Change) scenarios for 2100. Figure 5 shows the map of scenario A1FI with the most change in Europe. This figure shows that the projected climate classification of the Netherlands will change to Cfa by 2100. Although the precipitation classification is still f (fully humid) and not s (steppe), case studies of locations with precipitation classification s will also be used as data for this graduation research. This choice is made because, even though precipitation has a big influence on some of the UHI mitigations solutions (especially green solutions), the UHI effect in the Netherlands mostly occurs during heat waves when there is almost no precipitation. Therefore, case study locations with a climate classification of Csa or Csb are also included.

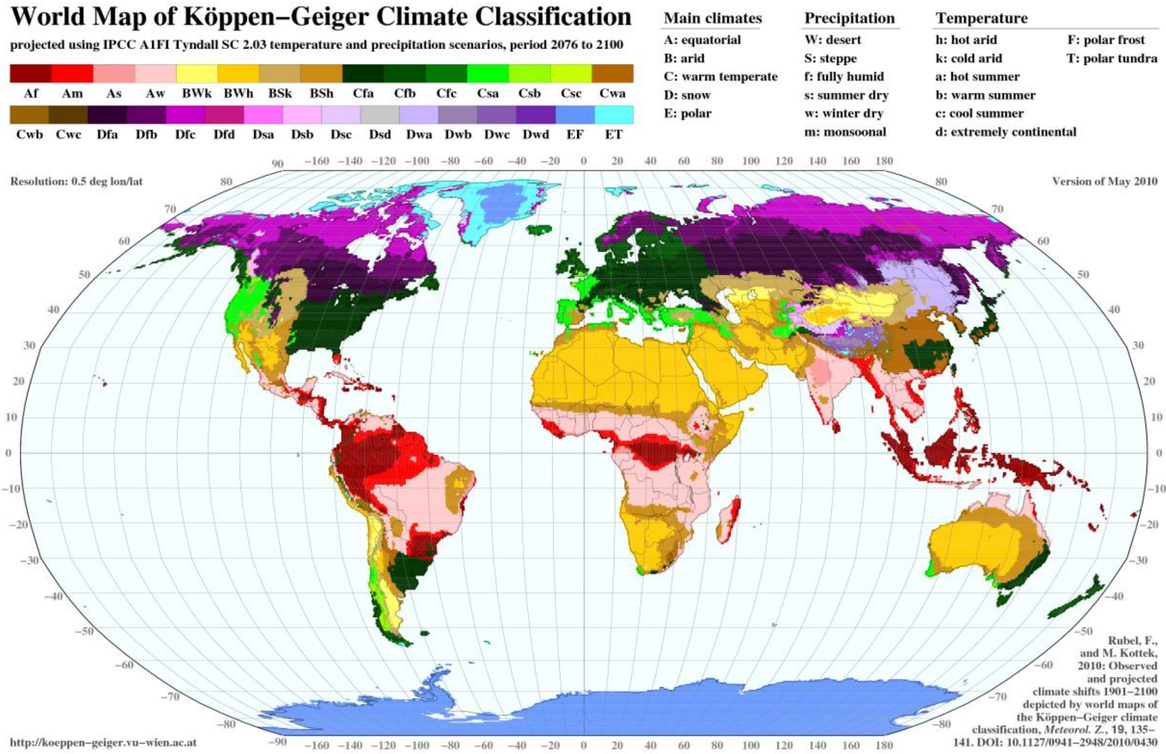


Figure 5: Reprinted from "Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification," by Rubel, F. and Kottek, M. (2010). Retrieved from http://koeppen-geiger.vu-wien.ac.at/shifts.htm

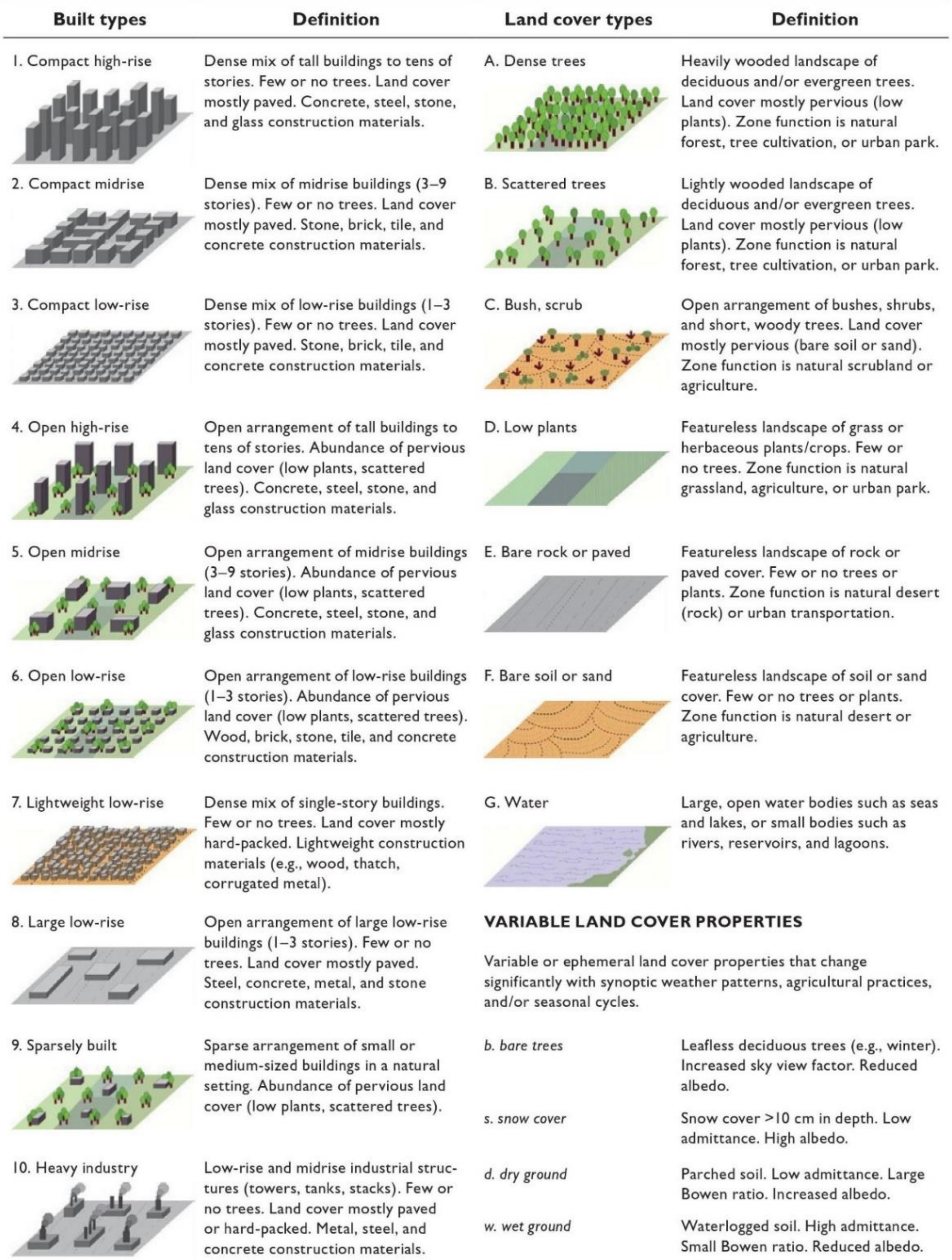
2.4 Classification of urban area

Next to different climate classifications, it is also possible to distinguish different classifications in urban areas. As the UHI effect in an area is influenced by local characteristics (Kim et al., 2018), the classification of these urban areas is important for the effect of UHI mitigation solutions. Because this graduation research is focused on the Netherlands first the standard classification of residential environments in the Netherlands are discussed. Then the Local Climate Zone (LCZ) research framework for research into UHI mitigation solutions by Stewart & Oke (2012) is described.

In the Netherlands a standard classification of the residential environment is used by (local) governments (ABF Research, n.d.). This classification consists of five main types of environments: city centre (centrum stedelijk), outside of city centre (buiten centrum), green urban (groen stedelijk), village centre (centrum dorps) and rural living (landelijk wonen). These five main types can then each be defined in two, three or four (thirteen in total) more specific types. This classification is based upon characteristics such as the distance toward a city centre, employment opportunities, available services, density, accessibility, dwelling types in the area and the historic period that they were build (ABF Research, n.d.). As most of these aspects are not relevant for the UHI effect, the low-level classification will not be used in the present research. Furthermore, because the UHI effect depends on the low-level microclimate, the high-level classification is also not the best fit. Therefore, another classification is used in this graduation study.

Specifically for research in UHI mitigation solutions, Stewart & Oke (2012) developed the Local Climate Zone (LCZ) research framework to improve and objectify the comparison of the present study. This classification system consists of ten building types, seven land cover types and four variable land cover properties that can be used to define the researched urban area. These types can be as large as a few hundred metres until several kilometres depending on the researched area. Figure 6 shows these different LCZs. Next to defining these zones, Stewart & Oke (2012) also presented different surface cover, geometric, radiative, thermal and metabolic properties of the zones and have specified guidelines to determine the zone of an area.

In this graduation research these LCZs and guidelines will be used to translate the effect of UHI mitigation solutions on the local air temperature, which are found in literature, to different urban areas in the Netherlands.



Built types	Definition	Land cover types	Definition
1. Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	**VARIABLE LAND COVER PROPERTIES** Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	*b. bare trees*	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
		s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
10. Heavy industry	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	*d. dry ground*	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 6: Abridged definitions for local climate zones. Reprinted from "Local Climate Zones for Urban Temperature Studies," by I.D. Stewart, and T.R. Oke, 2012, Bulletin of the American Meteorological Society, 93, p. 1885.

2.5 Effects of UHI mitigation solutions

For this graduation research, an overview of the impact of the eight UHI mitigation solutions mentioned in section 2.2 on the outdoor air temperature is made. For this overview only research since 2005 (explained in section 3.3) in similar climates to the Netherlands (section 2.3), is taken into account. The tables in appendix A present an overview of the information per UHI mitigation solution, sorted on the column 'Local Climate Zone'. This section discusses several important remarks from this overview and mention other effects of these UHI mitigation solutions.

An important remark about all studies referenced in appendix A is that they use several different models, inputs and outputs for their research. The cooling effects of UHI mitigation solutions greatly depend on the surrounding environmental conditions, such as current temperature, humidity, urban structure, wind speed, wind direction and wind turbulence (Völker et al., 2013), which differ for each study. Furthermore, some studies measure the air temperature at 1.2 metres above ground level, some at 1.6, or 2 metres and others do not even mention this aspect. The moment of measurements also differs, some studies show the air temperature reduction at an exact time, while others only report the average daily reduction or the average peak daily reduction over several days. This makes comparing these studies difficult and combining their results less reliable. It is also important to keep in mind that these studies are performed in different cities, thus different Local Climate Zones and different climate areas. Although the climate areas are sometimes not that different, they could create different results. Section 2.3 discusses the climate classifications used in this graduation research.

Gunawardena et al. (2017) provide a clear figure that shows how some mitigation solutions work (figure 7). The top part of this figure shows that large green areas at the edges of a city can provide a 'city-country breeze' that cools the outer parts of the city. However, the larger the city the more the cool air gets warmed up at the edges. Also, the smog bubble mentioned in section 2.1 prevents this cooling breeze from penetrating trough to the city centre. The bottom part of figure three shows the city microscale. Creating parks with trees and grass can cool the temperature in that area and create a small scale breeze system (Gunawardena et al., 2017). The same holds true for waterbodies, however Gunawardena et al. (2017) explain that during the night these can increase urban temperatures if the water temperature increases above night time temperatures.

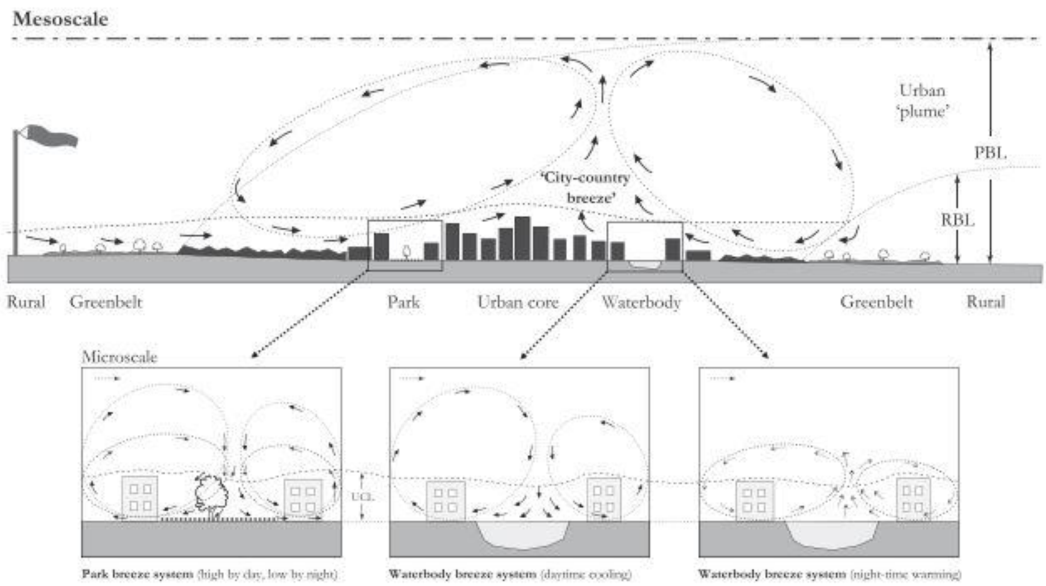


Figure 7: Reprinted from "Utilising green and bluespace to mitigate urban heat island intensity," by Gunawardena, K., Wells, M., and Kershaw, T. (2017). Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969717301754?via%3Dihub

This report will not go into extreme detail on how these UHI mitigation solutions work exactly. Section 4.1 shortly touches this subject, but more information about the exact way in which UHI mitigation solutions reduce the air temperature can be found in the referenced literature in appendix A.

The overview of the effect of UHI mitigation solutions in appendix A supports the findings from other reviews that the effect of these solutions on the air temperature differs a lot (M. Santamouris et al., 2017). The range of the effect of green roofs is 0 – 1.5 degrees, for green façades 0 – 4 degrees, for grass +0.1 – (-)1.2 degrees, for trees +0.2 – (-)2.8 degrees, for urban parks 0 – 4.8 degrees, for pools and ponds 0 – 2.7 degrees, for cool pavement 0.2 – 5.5 degrees and for cool roofs 0 – 3 degrees Celsius (figure 8). Some studies thus do not find any effect of the solution on the outdoor air temperature, while others find a large, or even a negative effect where the temperature rises (Battista, de Lieto Vollaro, & Zinzi, 2019; Égerházi, Kántor, & Gál, 2013).

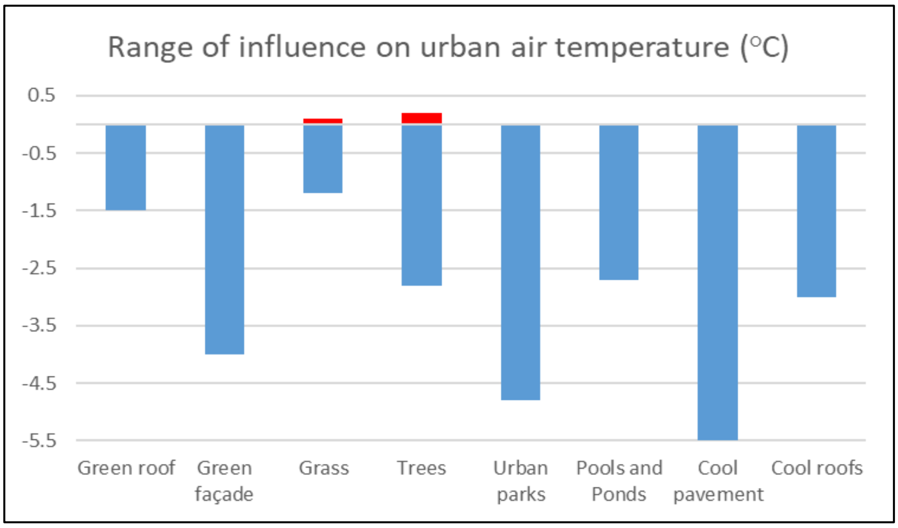


Figure 8: Range of temperature influences of UHI mitigation solutions

2.5.1 Green roofs

The different effects for green roofs can be found within all different LCZs. For LCZ1 (compact high-rise) almost all studies do not find any effect, for LCZ2 (compact midrise) effects between 0 and 1.2 degrees Celsius are found and for LCZ3 (compact low-rise) between 0 and 1.5 degrees. This is consistent with literature that found that green roofs on high rise have a negligible effect on the air temperature at pedestrian level (M. Santamouris et al., 2017; Susca, 2019; S. Tsoka, Tsikaloudaki, & Theodosiou, 2018). Li, Bou-Zeid, & Oppenheimer (2014) and N. Zhang, Chen, Luo, & Wang (2017) show that the temperature reduction per 10% increase in green roofs stays roughly the same. For 10% city wide green roofs Li et al. (2014) find no effect, but after that the reduction in air temperature is around 0.05 – 0.075 degrees Celsius per 10% increase in green roofs. N. Zhang et al. (2017) show an increase of 0.16 degrees per 10% until 25% green roofs, then 0.12 degrees until 50% and 0.1 degrees Celsius until 100% green roofs.

2.5.2 Green façades

De Jesus, Lourenço, Arce, & Macias (2017) show that the effect of a green façade can be found up to 5 metres from the wall in a compact midrise area. On the other hand Perini, Ottelé, Fraaij, Haas, & Raiteri (2011) did not find any difference comparing the effect between 0.1 and 1 metre from a compact low-rise area wall. This could be because the green wall was smaller in the low-rise area, because of the use of different kinds of plants or because the range of the effect is larger than 1 metre. Cameron, Taylor, & Emmett (2014) show that different plants have different effects and plant choice is thus important for green façades.

2.5.3 Grass

In the case of more grass Battista et al. (2019) and Égerházi et al. (2013) find an increase in the air temperature, while all other studies find a decrease ranging from 0.04 to 1.2 degrees Celsius.

2.5.4 Trees

For adding more trees to an area Égerházi et al. (2013) found an increase in air temperature for some areas and a decrease for others. With regard to the increase in air temperature, they explain this is the result of the model ignoring a certain part of existing vegetation, so this increase is not taken into account. Gromke et al. (2015) explain that the cooling effect of a street with a row of trees was noticeable within the first 10 metres of those trees, while Shashua-Bar & Hoffman (2000) find the largest cooling effect of all studies and show that this effect can be found up to 100 metres from the site. They further provide a decay function for this effect showing how fast the cooling effect decreases. However, they measure and calculate these effects in the length of streets without any obstructions. The effect of increasing the number of trees in a neighbourhood does not increase more based on the total percentage change. According to Middel, Chhetri, & Quay (2015) this relation is linear and for each percent of increase in tree cover the air temperature in the area is reduced by 0.14 degrees Celsius.

2.5.5 Urban parks

The range of air temperature reductions found in literature for adding urban parks is broad. Also the distance of the effect outside of the park differs per study. Hamada & Ohta (2010) showed the extend of the effect fluctuates widely above 300 metres, but was never more than 500, while Skoulika, Santamouris, Kolokotsa, & Boemi (2014) found the effect could reach 300 metres at maximum. Furthermore Chang & Li (2014) found that this effect depends on the size of the park. For small parks (< 0.5 ha) the cooling effect was the greatest within 10-20 metres, while the cooling effect for large parks bigger than 1 ha could extend up to 300 metres. The effects could extend even further, but their research is limited on that front (Chang & Li, 2014). By investigating a street alongside a park in Greece Skoulika et al. (2014) found that the cooling effect of an urban park reduces with an average between 0.78 and 1.2 degrees Celsius per 100 metres. The average air temperature reduction in LCZ2 is 3.2 degrees Celsius when including the effect at a specific time or otherwise the maximum reduction. For LCZ3 the average reduction is 2.3 degrees Celsius.

2.5.6 Pools and ponds

Xu, Wei, Huang, Zhu, & Li (2010) found that the effect of a small lake could reach up to 20 metres. Syafii et al. (2016) found almost the same result with a scaled-down experiment, but Tominaga, Sato, & Sadohara (2015) measured an effect over 100 metres downwind of a pool when no obstructions were present. The size of the water body seems to affect the temperature reduction, a scaled-down experiment by Imam Syafii et al. (2017) found larger water bodies having a larger effect.

2.5.7 Cool pavement

The range of the recorded effects of cool pavements is the largest, from 0.2 to 5.5 degrees Celsius. This could be the result of all studies using a different range of albedo increase for their research. Some studies increase the albedo in their simulations up to 0.8 (Georgakis, Zoras, & Santamouris, 2014), while others only increase the albedo of the pavements with 0.12 (M. Santamouris et al., 2012). However, some studies even find small effects with large increases. Mattheos Santamouris et al. (2018) find a cooling effect of 0.5 degrees Celsius at 14:00 while increasing the albedo with 0.6. Kyriakodis & Santamouris (2018) make an important conclusion that ageing can lower the potential of cool surfaces with 50%, so good maintenance is necessary, and replacements should be done in time.

2.5.8 Cool roofs

For the mitigation potential of cool roofs, limitations of green roofs and cool pavements are combined. The height of the building with a cool roof reduces the effect of this solution at street level (Salata et al., 2017). Two studies in LCZ2 show an average effect of 0.55 degrees (Ambrosini, Galli, Mancini, Nardi, & Sfarra, 2014; Maleki & Mahdavi, 2016), while three studies in LCZ3 show an effect of 0.76 degrees Celsius (Evola et al., 2017; Mattheos Santamouris et al., 2018; Taleghani, Sailor, & Ban-Weiss, 2016). The albedo increase and ageing effect are also important, Synnefa, Dandou, Santamouris, Tombrou, & Soulakellis (2008) found that an increase in albedo from 0.18 to 0.63 resulted in a temperature decrease of 1.3 degrees, while an albedo increase to 0.85 increased this effect to 1.6 degrees Celsius. Also the percentage of roofs with a cool coating changes the effect. Li et al. (2014) showed that when ten percent of buildings have a green roof, there was no effect on the air temperature at two metres height. At twenty and thirty percent the reduction effect was the same with 0.1 degree Celsius. At 50% the effect increased to 0.25 degrees, at 70% to 0.4 degrees and at 100% to 0.5 degrees Celsius (Ibid.). From a review of several experimental studies M. Santamouris (2014) found that the average urban air temperature decreases between 0.1 and 0.33 degrees Celsius per 0.1 increase in albedo of the roof.

Next to reducing the air temperature, UHI mitigation solutions also have other positive effects on the urban environment. They can create an extra breeze that increases wind chill (Gunawardena et al., 2017), they reduce energy needs for heating or cooling buildings, provide beneficial ecosystem services, optimize rainwater management and create positive psychological effects because of their recreational space (Žuvela-Aloise, Andre, Schwaiger, Bird, & Gallaun, 2018). They can also increase urban wildlife, improve air and water quality and enhance noise absorption (Hossain, Shams, Amin, Reza, & Chowdhury, 2019). However, some solutions also have negative effects. In some cases extensive maintenance is needed to sustain the positive effects (J. Yang et al., 2018). An important requirement for green solutions is the availability of water: if there is not enough, the effectiveness of these solutions will reduce (Susca, 2019). Green solutions could also reduce the wind speed in their surroundings, which negatively influences the air quality (Susca, 2019).

Although these positive and negative effects can have a big influence on the effect of an UHI mitigation solution, these will not be taken into account in the present study. While the influence of UHI mitigation solutions on outdoor and indoor temperatures is extensively studied, the other effects are not, and reliable conclusions cannot be drawn. As this graduation research also has a limited amount of time it will only consider the effect on outdoor urban temperatures.

2.6 UHI mitigation policies

Section 1.1 already mentioned that cities like Rotterdam and The Hague in the Netherlands focus on increasing the amount of green infrastructure in their cities to tackle climate challenges. The introduction of these policies has had to come a long way. Appendix E describes the process that has led to these kinds of policies and will result in even more UHI mitigating policies in the future.

A city like The Hague does have several policies to reduce the Urban Heat Island (UHI) effect in areas of new development. The municipality has constructed a system that gives points to new developments for building inclusive with nature (Gemeente Den Haag, 2018). A new development plan gets points for certain specific measures and is used by the municipality in their land allocation agreements and tenders (Van de Leemkolk, Jongma, Dekker, & Handgraaf, 2020). However, for existing areas the municipality of The Hague only stimulates the construction of green roofs (Gemeente Den Haag, n.d.) and encourages citizens to increase the amount of green in their gardens (Gemeente Den Haag, 2018).

2.7 Behaviour theories

This section describes the psychological theories, explaining how individuals form a certain behaviour, used in the model. It distinguished three ways to observe behaviour and describes two of these.

To be able to influence the behaviour of people, it is first necessary to know in what way that behaviour is formed. Literature identifies three levels on which behaviour can be observed, the macro-, meso- and micro level (Reid et al., 2010). The macro level analyses ‘top down’ with the most generalization (Schenk, Moll, & Schoot Uiterkamp, 2007), the micro level investigates bottom up from the individual psychology level and the meso level lies in between (Reid et al., 2010). Figure 9 shows these three levels in relation to each other.

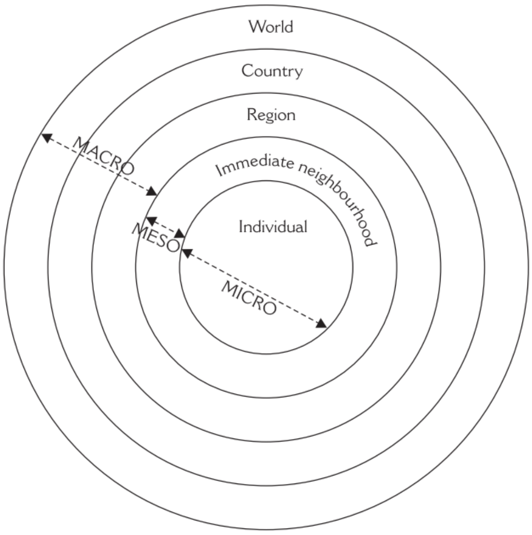


Figure 9: Conceptualization of 'common sense' community types and interactions. Reprinted from "Theorizing the meso level: The household as a crucible of pro-environmental behaviour" by L. Reid, P. Sutton, and C. Hunter, 2010, Progress in Human Geography, 34 (3), p. 316.

The macro view on behaviour investigates from the world, country or region level and explores cultural and/or societal factors to explain individual attributes (Haanpää, 2007). Collins (1981) state that behaviour is not just the effect of micro, individual, actions but caused by abstract and realized social entities. The postmaterial values thesis by Inglehart (1995) is based on this and states that societies' major values began shifting after the second world war as a result of economic and technological advancements in this period. Because of the growing access to goods and ongoing social growth, values within and between societies began to change (Reid et al., 2010). However, macro level studies often fail to recognize the variety of other macro level institutions (Reid et al., 2010) and disregard the heterogeneity of lower level institutions and actors (Schenk et al., 2007). They are suitable for giving a general idea about the path that values take when they change within societies, but only tell one part of the story (Reid et al., 2010).

The meso view is based on the immediate neighbourhood and described by Reid et al. (2010). They have based this view on an extension of the Theory of Planned Behaviour (TPB) by Ajzen (1991), which is a micro level theory. This theory will be explained first.

2.7.1 Theory of Planned Behaviour

Most micro level research on individuals behaviour is based on the TPB and its predecessor, the Theory of Reasoned Action (TRA) (Reid et al., 2010). In two books from 1975 and 1980 Ajzen & Fishbein tried to explain individual's behaviour via the TRA. This theory explains how an individual's intention to perform a certain behaviour results in the execution of that behaviour (Ajzen, 1991). This individual's (behavioural) intention is in turn influenced by two other factors: their attitude towards that behaviour and their perception of what other important individuals do: their subjective norms (Vallerand, Deshaies, Cuerrier, Pelletier, & Mongeau, 1992).

An individual's attitude towards a certain behaviour is in turn influenced by his or her (behavioural) beliefs about the expected consequences of the behaviour and their evaluation (Vallerand et al., 1992). If for example an individual beliefs that by acting in a certain way, a certain outcome will be

reached and he wants that outcome to become true, he will act in that way.
An individual's subjective norms on the other hand are influenced by his or hers (normative) beliefs about the opinion of others (Vallerand et al., 1992). If an individual thinks that it is likely that certain people, that are important to him, approve of a certain behaviour, he will want to comply to these norms and act in that way (Scalco, Ceschi, & Sartori, 2018).
According to Ajzen & Fishbein (as cited in Vallerand et al., 1992) the influence of these two factors on an individual's (behavioural) intention varies "according to the behaviour, the situations, and individual differences of the actor" (p. 98). There is thus no fixed formula that can be followed.

In a later study, Ajzen (1985) extended the TRA into the Theory of Planned Behaviour (TPB) (figure 10) by adding a measure of perceived behavioural control (PBC) as an extra predictor of individual behaviour (Armitage & Conner, 2001). This was necessary because the TRA could not predict an individual's behaviour sufficiently when constraints existed on actions. PBC is the result of an individual's control beliefs and represents the expected difficulty or ease when performing the behaviour (Ajzen, 2002). If physical or perceived barriers and the perception of control over these factors make it more difficult to act in a certain way, an individual is less likely to perform that behaviour (Scalco et al., 2018). PBC can influence both the intention and the behaviour of an individual and its importance also differs across behaviours and situations (Armitage & Conner, 2001).

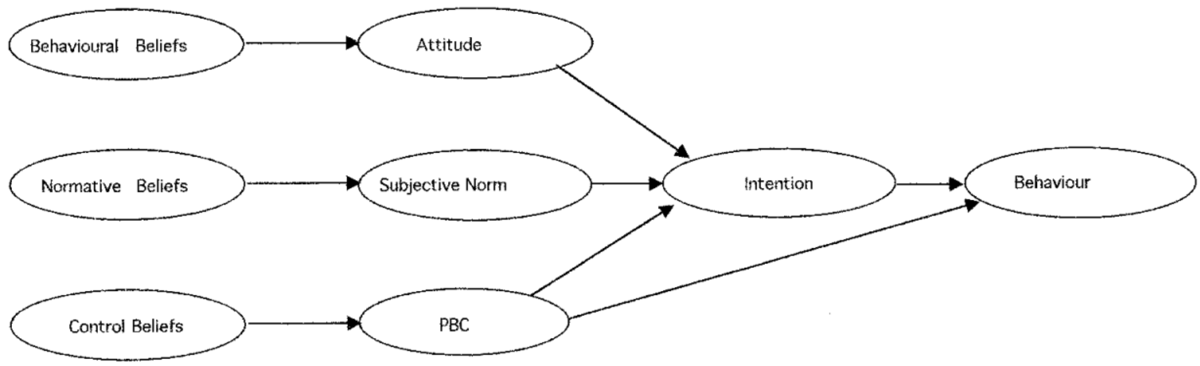


Figure 10: Reprinted from "Efficacy of the Theory of Planned Behaviour: A Meta-Analytic Review" by C. Armitage and M. Conner, 2001, British Journal of Social Psychology, 40, p. 472. Copyright 2001 by The British Psychological Society.

The TPB has been one of the most widely researched models for studying the relationship between attitudes and behaviour (Armitage & Conner, 2001). Scalco et al. (2018) write that multiple reviews and meta-analyses have shown that the TPB is able to efficiently define, demonstrate and predict different sorts of human behaviours. For example organic food consumption (Aertsens, Verbeke, Mondelaers, & van Huylenbroeck, 2009), eating fruit and vegetables (Guillaumie, Godin, & Vézina-Im, 2010), nutrition-related behaviour of the youth (Riebl et al., 2015), smoking behaviour (Topa & Moriano, 2010), the intentions and attitudes of athletes and coaches towards doping (Psouni, Zourbanos, & Theodorakis, 2015) and other health-related behaviours (McEachan, Conner, Taylor, & Lawton, 2011). The TPB also dominates literature about pro-environmental behaviour (Reid et al., 2010), such as socially responsible behaviour (Han & Stoel, 2017) and recycling behaviour (Barr & Gilg, 2005).

Limitations
Although the TPB is widely used for all kinds of human behaviours there are also limitations to this theory. During the last couple of years there has been a discussion about the relevance of the TPB. In 2014 Sniehotta, Presseau, & Araújo-Soares wrote an article with the clear title “Time to retire the theory of planned behaviour”. In this article they mention various criticisms on this theory. They write that the TPB is being criticised because it focusses exclusively on rational reasoning and thus not includes unconscious influences. However, Scalco et al. (2018) deny this statement and mention that peoples beliefs within the TPB can be unproved or even irrational, the theory does not judge the truthfulness or objectivity of individuals beliefs. As Ajzen (2015) writes: “people’s attitudes, subjective norms and perceptions of control follow reasonably and consistently from their beliefs, no matter how the beliefs were formed” (p. 133).

Furthermore Sniehotta et al. (2014) state that the TPB is static in nature and does not take the effects of people’s behaviour on their cognitions and future behaviour into account. Ajzen (2015) subsequently explains that such a statement is incorrect because performing a certain behaviour can result in certain positive of negative unanticipated consequences, reactions, difficulties or factors that will then influence a person’s beliefs and affect his intentions and actions.

Next, Sniehotta et al. (2014) mention that the predictive validity of the TPB is limited. The TPB does not explain the majority of the variability in the observed behaviour, It often occurs that people form a certain intention but do not perform the accompanying behaviour (Sniehotta et al., 2014). Ajzen (2015) however, states that it is confirmed that the TPB is a good predictor of intentions based on the attitudes, subjective norms and perceived behavioural control of individuals. But confirms that the relation between intentions and behaviour is filled with problems. This can be the result of a wide range of causes, such as the occurrence of an important event between the performance of the behaviour and the assessment of intentions of individuals (Ajzen, 2015). It can also be caused by a difference in the accessible beliefs between the real situation of performing a behaviour and “the hypothetical situation in which TPB constructs are typically assessed” (Ajzen, 2015, p. 132). For example, when an individual decides in the morning that he want to exercise in the evening, based on the weather predictions that morning, those predictions can change during the day and if in the afternoon rain is predicted, the individual can choose to not go out and exercise. Ajzen (2015) further explains that imperfect validity cannot be solved easily, the TPB uses a small amount of items to assess the intention of an individual and these will never be able to capture the underlying design for a hundred percent. Therefore he mentions that it often occurs that more variables are added to the model to improve the prediction of intentions if these make sense and are well justified. Armitage & Conner (2001) confirm the predictive validity of the TPB from a review of 185 independent studies. They concluded that 27% of the variance in behaviour and 39% of the variance in intention is explained by the TPB.

The biggest criticism Sniehotta et al. (2014) have, is that the TPB is not a theory of behaviour change. It does not explain how perceptions change, making it difficult to test interventions. Ajzen (2015) agrees that the TPB is not a theory of behaviour change. It explains and predicts the intentions and the behaviour of individuals and can be used as a framework to form “effective behaviour change interventions” (Ajzen, 2015, p. 133). It is able to do this by making a distinction between stimulating individuals that do not want to perform a certain behaviour versus helping people that already have intentions to perform a certain behaviour. Each of these two options require different kinds of interventions and only when various preconditions, different for each of these two, are met, it is possible to change people's intentions and behaviour (Ajzen, 2015).

Despite these limitations Scalco et al. (2018) still clarify the TPB as a good theory according to the six criteria for a 'good' theory defined by (Cramer, 2013). Scalco et al. (2018) explain that the TPB meets all six of these criteria:

1. Comprehensiveness, a good theory has to be able to "describe, explain, predict, and control phenomena and behaviors" (Cramer, 2013, p. 9). As stated in this section, research has shown that the TPB is able to explain individuals behaviour (Armitage & Conner, 2001) and other reviews and meta-analyses support the comprehensiveness of the TPB (Scalco et al., 2018).
2. Applied value, the theory should be able to effectively provide solutions to problems at hand (Cramer, 2013). The TPB has been used extensively for all kinds of behaviours, from health-related (McEachan et al., 2011), to dominating pro-environmental studies (Reid et al., 2010). It's practical application is thus supported (Scalco et al., 2018).
3. Precision and testability, the theory must be clearly described and testable trough measurements (Cramer, 2013). The numerous reviews and meta-analyses of the TPB show that this theory is testable and understood by many different researchers (Scalco et al., 2018).
4. Parsimony, a good theory should not be too complicated and thus easy to test (Cramer, 2013). Armitage & Conner (2001) show that the TPB can explain 39% of individuals behaviour while only focusing on three components of behaviour, attitude, subjective norms and PBC. The theory is thus parsimonious.
5. Empirical validity, a good theory should be able to give clarifications of contradicting evidence (Cramer, 2013). The discussion of the TPB mentioned in this section between Sniehotta et al. (2014) and Ajzen (2015) shows that this theory meets this criteria.
6. Heuristic value, a good theory should be able to show new aspects of other fields (Cramer, 2013). The TPB is already applied in many forms of human behaviour and Scalco et al. (2018) believe that the TPB could also be able to connect psychological research with computer science and this way create new perspectives in this field.

2.7.2 Pro-environmental behaviour

As mentioned in section 2.7, the explanation of the meso level by Reid et al. (2010) is based upon the TPB. As Ajzen (2015) wrote, adding new variables to the TPB is encouraged if they improve the prediction, make sense and can be well justified. Reid et al. (2010) state that when attempting to explain pro-environmental behaviour (PEB), the micro level that the TPB focuses on is often too simplistic (Lam, 1999). They state that "individualistic approaches have only limited purchase when attempting to explain or predict (…) pro-environment behaviour" (Lam, 1999 p.315). These approaches cannot properly explain PEB of larger groups such as households, which behave differently than individuals (Reid et al., 2010). Therefore Reid et al. (2010) introduce the meso level approach into explaining PEB by extending the TPB. Figure 11 shows the conceptual framework for this approach.

Reid et al. (2010) revise the TPB by argueing that the meso level could bring together the macro and micro worlds by contextualizing micro level activity and observing macro level change within. Within the meso level interactions between the macro and micro world can thus be observed (Haanpää, 2007). Reid et al. (2010) define the meso level as a local area "identifiable by heterogeneity, collective interest and shared social identity" (p. 317). Local neighbourhoods or households are examples of this meso level. They state that with regard to PEB households are the most useful level to consider (Reid et al., 2010). Take for example the travel behaviour of a household, sometimes individuals within a household travel together and sometimes they do not. Their individual choices do not summarize to the total traveling behaviour of the household. Therefore these individuals should be considered together and the level of households can best be used as the unit of analysis (Grønhøj, 2006).

Lam (2006) showed that an unexpanded TPB could only explain 18% of the variance in the intention to invest in pro-environmental technology such as water-efficient technologies. An expended TPB model with perceived moral obligation and perceived water rights could already explain 24% of the variance (Lam, 1999), but expending the standard TPB with vulnerability, the subjective effectiveness of alternative solutions and income could explain 36% of the variance to invest in pro-environmental technology (Lam, 2006). Including characteristics from households thus improves the TPB.

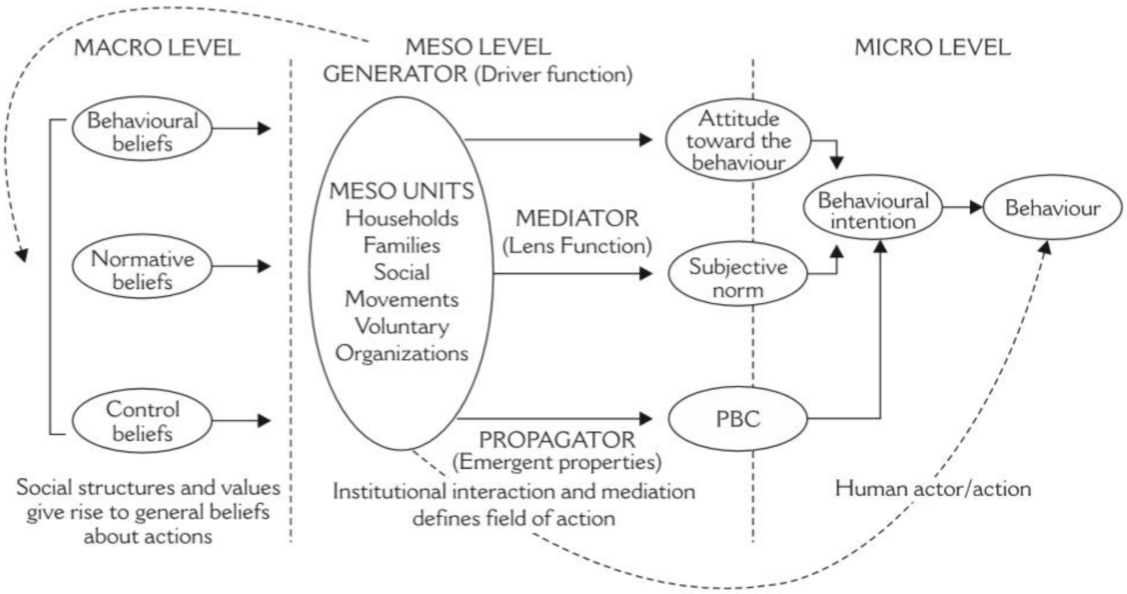


Figure 11: A conceptual framework demonstrating the importance of the meso level on pro-environmental behaviour. Reprinted from "Theorizing the meso level: the household as a crucible of pro-environmental behaviour," by L. Reid, P. Sutton, and C, Hunter, 2010, Progress in Human Geography, 34(3), p. 322.

3 Research methods

The main research question is divided into four separate sub-questions that each represent a part of the total research. When these are answered separately, combining them will form the answer to the main research question. This section explains what research methods are needed to answer each sub-question. First it briefly describes which research methods will be used to answer which sub-questions, thereafter these research methods are explained further.

3.1 Sub-questions and research method

This section introduces the research methods used to answer the sub-questions. For the four sub-questions these methods are the same, although the depth in which the methods are used can differ. These four sub-questions were:

1. *"How do technical characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
2. *"How do household characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
3. *"How do institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
4. *"How do characteristics of residential environments influence the adoption of Urban Heat Island mitigation solutions."*

To answer these four questions three different research methods are used. First these questions are all considered in the context of a small case study. The area 'Bomen- en Bloemenbuurt' in The Hague is used as case study, because of its diversity in dwellings and Urban Heat Island (UHI) characteristics. Section 3.2 explains this choice and the characteristics of this district. Second, desk research is performed. Information about the technical, household and institutional characteristics is gathered from sources such as scientific literature and government reports. Third, a small expert interview is done with scientists and experts working at local governments or companies. The information found in the desk research is checked with the experts and if they have new information this is be added. Fourth the information found through the desk research and expert interviews is combined in an agent-based model representing a real-world case in the Netherlands to be able to check the influence of the different characteristics on the adoption of UHI mitigation solutions. As stated earlier the district 'Bomen- en Bloemenbuurt' in The Hague is used as the case study because this district has a variety of dwellings, UHI characteristics and Local Climate Zones. To decide which results of research into UHI mitigation solutions are used, the Local Climate Zones of different neighbourhoods within this district are determined with the framework of Stewart & Oke (2012).

3.2 Case study

This section describes the characteristics of the chosen area for the case study and why this area was chosen. This area is the district Bomen- en Bloemenbuurt in The Hague. Figure 12 shows the location of The Hague (Den Haag) in the Netherlands and figure 13 shows this district within the city in red.

Figure 12: The city of The Hague (Den Haag) in the Netherlands. Retrieved from https://studentverhuizers.nl/wp-content/uploads/2015/09/verhuisbedrijf-den-haag.jpg

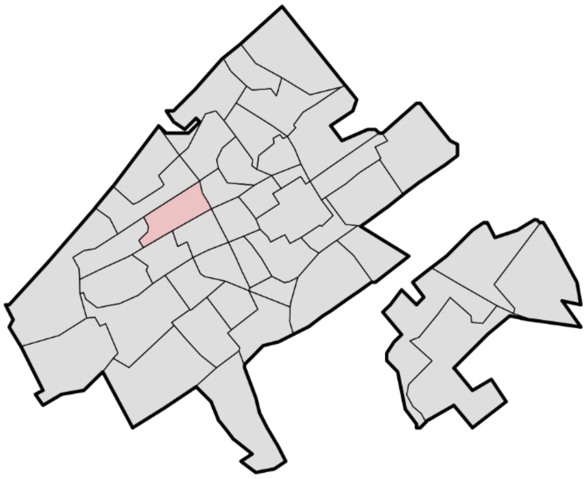


Figure 13: The district Bomen- en Bloemenbuurt within The Hague. Reprinted from https://nl.wikipedia.org/wiki/Bomen-_en_Bloemenbuurt#/media/Bestand:Map_-_NL_-_'s-Gravenhage_-_Wijk_12_Bomen-_en_Bloemenbuurt.svg

This district has about 10,000 inhabitants, with a higher percentage (20%) of elderly (above 65 years) than the average in Den Haag (14,3%) or in the Netherlands (18,5%) (CBS StatLine, 2017). As stated in section 1.1, the UHI effect increases the health risk of especially elderly people (Fabiani et al., 2019). The district has 69% owner occupied dwellings, 6% rental dwellings owned by housing corporations and 25% rental dwellings owned by other landlords. 14% of all dwellings are single-family dwellings and 86% are multi-family dwellings (Wonen en Woningmarkt, 2020). Owners living in multi-family dwellings are united in an owners' association (VVE) that performs maintenance and decides upon new investments (A. Kennis, personal communication, 18-01-2021). The district is also a dense urban area with more than 5000 dwellings per square kilometre (CBS StatLine, 2019). As the density of an area increases the UHI effect (Mohajerani et al., 2017) this occurs in this area.

The 6% housing corporation dwellings are owned by three different corporations: Staedion, Vestia and Omnia Wonen (R. Zuurmond, personal communication, 20-10-2020; I. Boon, personal communication, 5-1-2021). The percentage of houses owned by housing corporations in this district is low compared to the average in Den Haag (31%) or the Netherlands (29%) (CBS StatLine, 2019). Although the difference is smaller, the total percentage of rental dwellings is also low with 32% (CBS StatLine, 2019) against an average of 42% in the whole country (CBS StatLine, 2020).

The Bomen- en Bloemenbuurt consists of three smaller neighbourhoods. Multiple dwelling types can be found in each neighbourhood, such as apartments in high- and low-rise buildings, porch dwellings ('portiekwoningen'), and single-family dwellings (Wonenindenhaag.nl, n.d.). The year round average UHI effect in the Bomen- en Bloemenbuurt is between 0.8 and 2 degrees Celsius (RIVM, 2017). The area lies between a canal to the North-East and a green area with sports fields to the South-West. It also contains some sports fields itself, a green area with the 'Haagse Beek' (a small stream) and some small green areas (see figure 14) (Wonenindenhaag.nl, n.d.). This diverse environment makes the district an interesting UHI area.

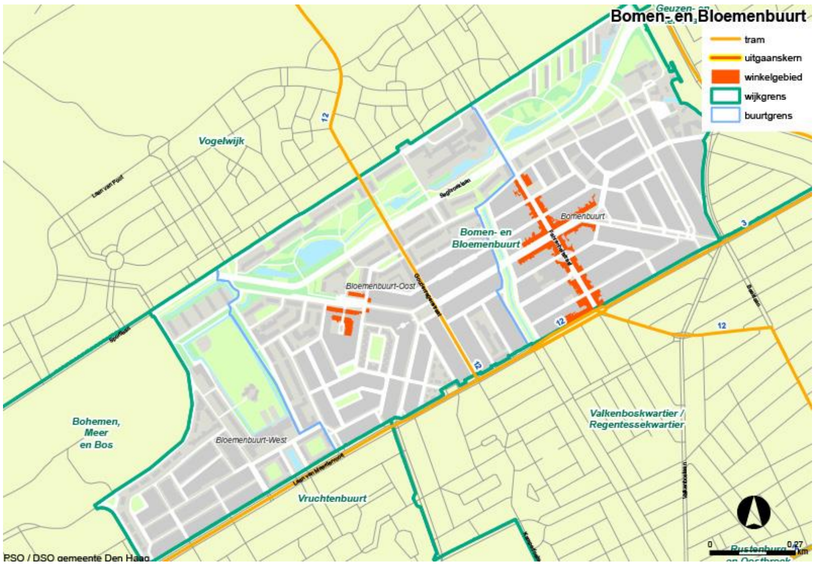


Figure 14: The district Bomen- en Bloemenbuurt and its three neighbourhoods: Bomenbuurt, Bloemenbuurt-Oost and Bloemenbuurt-West. Reprinted from https://wonenindenhaag.nl/w/wp-content/uploads/2017/03/Wijkinformatie_Bomen-en-Bloemenbuurt.jpg

The three main steps and important guidelines by Stewart & Oke (2012) are used to determine the Local Climate Zones (LCZ) of these areas to be able to choose which mitigation results of UHI solutions from literature are used:
First local-scale data about the area must be collected. What does the area look like, what is the building geometry, land cover, is it a wet or dry area, etc. Second, the thermal source of the area must be defined. This is the area upwind of the current imagined location that influences the air temperature that is measured if a measurement took place at that moment. Because of the wind, the area upwind of a measurement spot influences the temperature at that place. In the Netherlands the main wind direction is South-West (KNMI, 2021). Therefore, this direction is considered in the present study. Another impact of the wind is that a LCZ area has an elliptical shape oriented towards the wind direction. Thirdly, the LCZ is determined by deciding which classes best fit the characteristics of the area. If needed, classes can be combined in a parent class and a lower class to better represent the area. It is important to note that a LCZ should have a minimum diametre of 400 metres, otherwise different LCZs will influence each other too much and they cannot be properly separated. (Stewart & Oke, 2012).

Four different LCZs are found within the Bomen- en Bloemenbuurt (Figure 15). One covers the whole North-West part of the area (with blue tint). It has midrise buildings within a green, park like area with water and trees. This is thus determined as parent class LCZ 5, open midrise, combined with lower class LCZ A, dense trees. Another consists of all the buildings, small squares and the small river in the South-East (with black tint). This has mostly low-rise buildings with a row of midrise in the North-West. There are quite a lot of trees in the gardens and streets and there are some small green squares with grass. Therefore, this area is classified as parent class LCZ 3, compact low-rise, with lower class LCZ B, scattered trees. A third area are the sport fields and their close surroundings in the South-West (with red tint). This area has a combination of some low-rise and some midrise buildings, a lot of open grass sports fields and some trees. A large sports park with trees, grass and tennis fields is located at the West side, next to this area, and was taken into consideration for determining the LCZ of this area. Because of the sports field in the area and the sport park next to it, the parent class is determined to be LCZ 9, sparsely built, and the lower-class D, low plants. The last area is the lower South-West side of the district (with green tint) and consists mostly of low-rise buildings with a lot of trees and some grass squares. This is quite similar to the black tint area with LCZ 3_B but the green tint area is located next to a very green area with a sport park and trees. Therefore, this area is seen as more open with even more green, which means a parent class LCZ 6, open low-rise, with lower class LCZ A, dense trees.

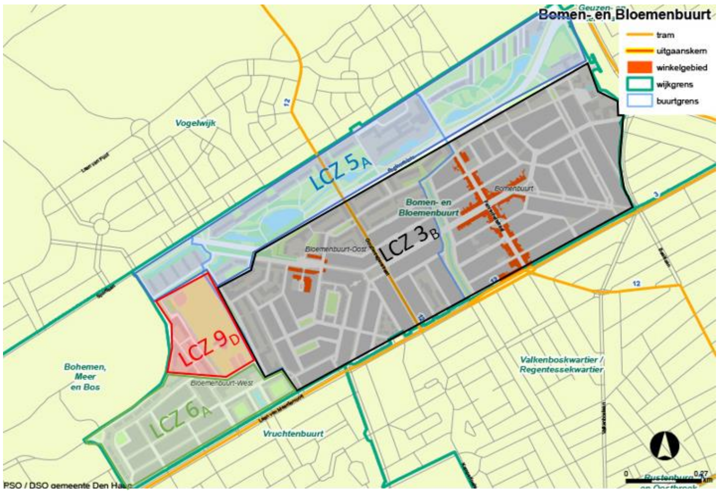


Figure 15: The LCZs within the district Bomen- en Bloemenbuurt adapted from https://wonenindenhaag.nl/w/wp-content/uploads/2017/03/Wijkinformatie_Bomen-en-Bloemenbuurt.jpg

3.3 Desk research

The desk research primarily takes place to gain an understanding about the different parts of this graduation research and collect the data for the model. It is important that the collected data is complete, reliable and unbiased. Therefore, it is collected from existing literature from all over the world. A desk research studying the current worldwide literature on the UHI effect is performed to collect the model data. Different papers are found by searching for papers on UHI mitigation solutions on Google Scholar, in the TU Delft Library and through snowballing by looking at papers mentioned in literature reviews (D. Lai, Liu, Gan, Liu, & Chen, 2019; M. Santamouris et al., 2017; S. Tsoka et al., 2018). During this graduation study it is important that studies since 2005 are taken into account, because since 2005 studies about mitigation solutions for the UHI effect became more widespread (Pisello et al., 2018) and the most recent techniques are used in these studies. Kim et al. (2018) and Pisello et al. (2018) show that the effect of mitigation solutions varies with the local climate. Therefore, only data of studies in similar climate conditions as cities in the Netherlands is taken into account (as discussed in 2.4). The identification of the Local Climate Zones by Stewart & Oke (2012) also helps safeguarding this. Besides data from literature, official data from institutions such as Statistics Netherlands (CBS) and internet websites are used to gather information for the agent-based model.

3.4 Expert interview

Next to acquiring data via a literature study, a number of experts and important stakeholders are interviewed using a semi-structured questionnaire addressing their experience with and knowledge about UHI mitigation solutions. The form of a semi-structured interview is used to make sure that the interviewees get the same kind of questions, which ensures that their answers can be compared to each other. Such an interview technique also leaves some room for adjustments per interview, which in this case is preferred because different experts can mention different conditions and have different opinions. However, it should be clearly monitored whether this does not make the interviews too much dissimilar.

The experts are found by making use of the snowball method (Baarda, van der Hulst & de Goede, 2012) and contacting specifically targeted stakeholders. By contacting individual experts and asking them whether they know someone knowledgeable in this area a list of experts will be composed. It should be noted that it is important to find new experts that look at this topic from another background and field of work than known experts, to come to a well-balanced expert list to improve representability (Baarda et al., 2012). The combination of using a literature review and interviewing experts can contribute to making the result more reliable because the interviews can also act as a check whether all relevant aspects were researched in the literature review.

3.5 Agent based modelling

To check the effect of the different characteristics on the adoption of UHI mitigation solutions in several residential environments, an agent-based model is made of the case study. Section 1.1 showed that the UHI mitigation solutions have different effects in different residential environments and section 2.7.2 showed that household properties influence PEB and thus the choice to invest in UHI mitigation solutions. It is clear that the system is heterogeneous on multiple levels and the model should be able to cope with all these differences. This section explains the choice for using agent-based modelling.

Borshchev & Filippov (2004) explain that there are two different kinds of high-level models, analytical and simulation models. Analytical models are static, and their outcome can result from computations in a spreadsheet, where the outcome depends on the parameter input and is fixed for a certain input. Simulation models on the other hand can show how a system changes over time, based on its internal rules and current state. These models can have different outcomes with the same input and should be used when the dynamic of the system over time is important. In the present research it is important how the implementation of UHI mitigation solutions changes over time and in what ways this can be influenced. A simulation model is thus the best choice.

The group of simulation models consists of three different modelling approaches, System Dynamics (SD), Discrete Event (DE) and Agent Based (AB) (Borshchev & Filippov, 2004). The properties of the system that needs to be modelled influences the choice for a certain approach. Borshchev & Filippov (2004) show that SD models are used for continuous systems with a high level of abstraction, DE models for discrete time systems that jump from event to event with a middle abstraction level and AB models are used for discrete systems with abstraction levels from high all the way to low levels.

Based on the paper by Borshchev & Filippov (2004), De Wildt (2014) created a table with the main system properties of each modelling technique (table 3).

Table 3: Modelling technique choice. Reprinted from "Supporting the adoption of smart grid appliances in city districts," by T. De Wildt, 2014, (Master's thesis, Delft University of Technology).

Modelling technique	Typical system properties represented	Type of systems typically represented
Discrete-event simulation	- Heterogeneous entities - Passive entities	- System with operational processes
System dynamics	- Strong influence of information feedback on the behaviour of the system - Strong influence of system delays	- Urban, social and ecological types of systems in which an aggregated view of these systems can properly reflect its behaviour
Agent-based modelling	- Heterogeneous entities - Active agents who can interact with their environment and make decisions to pursue their personal goals	- Evolutionary systems in which the choices of agents play a key role in the emergent system behaviour

Rahmandad & Sterman (2008) show that AB and SD models are most often used in the dynamics of diffusion. This means that when modelling a certain adoption, for example the adoption of a new technology, AB and SD models are most used in literature. This graduation research investigates the adoption of UHI mitigation solutions and will thus use one of these models.

Rahmandad & Sterman (2008) further explain that SD models can create heterogeneity by using different levels for different types of population, but cannot produce differences within a level. AB models on the other hand are better able to capture heterogeneity within the network of interactions as well as across individuals themselves. They are good at simulating heterogeneous agents with different characteristics (Willensky & Rand, 2015). However, this advantage of AB models comes at a cost as AB models often need more computational power and can take longer to create (Rahmandad & Sterman, 2008). AB modelling should thus only be chosen if the system is characterized by a large amount of heterogeneity between individuals. For the present research heterogeneity exists in several aspects of the system. As section 2.2 showed, the UHI mitigation solutions have different effects, not only between the different solutions but also when applied in different LCZs. Furthermore section 2.7 explained that through the TPB, each household makes a different trade-off when deciding to invest in an UHI mitigation solution and their different characteristics also influence their PEB. Heterogeneity is thus a very important part of the present study and an AB model can represent this best.

As shortly mentioned, Borshchev & Filippov (2004) showed that SD models are used for a high level of abstraction, while AB models can be used for low as well as high abstraction levels. Muelder & Filatova (2018) mention that AB models have become an important tool for studying the impact of behavioural changes in energy consumption, because these models are created bottom-up. They can thus connect micro-level behaviour with macro-level results. This graduation research also investigates behavioural change, not in energy consumption, but in adopting UHI mitigation solutions. An AB model can thus also be useful for the present research.

An important part of the present study is a clear presentation of the results to help increase the understanding of the UHI effect and possible mitigation solutions. AB models are good at showing both an aggregated, as well as an individual level of detail in the model (Willensky & Rand, 2015), which will help communicate the results. Next to that it is important for research into UHI mitigation solutions that the results can easily be understood by different people, in this case amongst others regular citizens, experts and the municipality. AB modelling facilitates this (Willensky & Rand, 2015).

AB models have already been applied successful in different fields, such as technology diffusion (Muelder & Filatova, 2018), market dynamics, environmental psychology, consumer behaviour and organizational psychology (Scalco et al., 2018). Although the research in this report is new it can build upon a lot of different examples, which will help to improve it.

One important remark for all models is that they always show a simplification of the real world because of the use of assumptions and boundaries. The modeller choses what to involve in the model and what to leave out based upon his own world view. Next to that, a model is a representation of how the maker(s) of the model sees the real world and can therefore be biased towards the maker's view. (K. Van Dam, Nikolic, & Lukszo, 2013). It is thus important to properly validate the model.

The agent-based (AB) model is developed by following the approach presented in Van Dam et al. (2013). They show ten steps to create an AB model: problem formulation and actor identification (1), system identification and decomposition (2), concept formalisation (3), model formalisation (4), software implementation (5), model verification (6), experimentation (7), data analysis (8), model validation (9), and model use (10). Chapters five, six and seven discuss these different steps, although they are not presented in the same order and some receive more attention than others because they are more important for creating the agent-based (AB) model.

Section 3.5.1 explains the theoretical background of the agent-based model (ABM), how the theories presented in chapter 2 are used in the model. Then section 3.5.2 shortly explains the possible network structures that can be used in the model.

3.5.1 Theoretical background for ABM

This section presents in what way the theories discussed in chapter 2 are used in the AB model. Using the same order, it briefly mentions the Urban Heat Island (UHI) effect, its mitigation solutions, and the classification of urban areas. The use of the Theory of Planned Behaviour (TPB) is explained in more detail.

The UHI effect is the starting point of this graduation research and for the AB model. However, it will not be modelled in great detail. The air temperature for the city of The Hague from the Master's Thesis by Ntarladima (2016) is used as starting point of a warm summer day. The results found in literature of the effect of the eight different UHI mitigation solutions on the air temperature will influence the local air temperature when a solution is implemented somewhere in the model. The classification of the urban area in LCZs is used to vary the effects of different mitigation solutions in distinct areas of the Bomen- en Bloemenbuurt.

The main part of the model consists of the implementation of the TPB. As explained in chapter two, this theory is used to describe individual's behaviour. In the present research it is used to determine whether a household in the Bomen- en Bloemenbuurt adopts an UHI mitigation solution and which solution that is. Therefore, the three factors influencing an individual's behaviour: attitude, subjective norm and perceived behavioural control (PBC) will be translated to parameters within the AB model. Chapter 5 explains how this translation is made.

Chapter two showed how the TPB is applied in a lot of studies about human behaviour. Furthermore it has also been used for different kinds of AB models, such as the diffusion of water-saving innovations (Schwarz & Ernst, 2009), the adoption of solar panels by households (Muelder & Filatova, 2018; Rai & Robinson, 2015), models about human migration (D. Kniveton, Smith, & Wood, 2011), dietary choice (Richetin et al., 2010) and describing theoretical markets (T. Zhang & Zhang, 2007). Studies about the adoption of UHI mitigations solutions, such as the present research, have not been found. Therefore, these papers can be turned to as examples for this graduation research.

As the current study looks at the adoption of UHI mitigation solutions, which can be considered as some kind of innovative technology, the diffusion of innovations (DoI) theory could also have been used. This choice has not been made because of several reasons: First the TPB is often applied in research about pro-environmental behaviour (PEB) and in combination with AB models. This graduation research can use those papers as examples and can add to the existing literature by investigating UHI mitigation solutions, which has not been done before in this way. Second, the DoI theory consists of five characteristics that affect the diffusion of a technology: relative advantage, compatibility, complexity, trial ability and observability (Glanz, Rimer, & Viswanath, 2002), while the TPB mainly takes an individual's beliefs into account. Furthermore the DoI theory divides individuals in 5 adopter categories (Glanz et al., 2002), while for the adoption of UHI mitigation solutions in the present research the characteristics of individual households are the most important. This is also shown by using the theory of PEB. The DoI theory does not include these individual characteristics in this way and is thus less suitable to use for this graduation study.

Applying the TPB as the main reasoning engine for agents in an AB model does have some downsides. Scalco et al. (2018) describe several possible problems and suggest potential solutions or quick fixes for these problems. The first potential problem they mention is that the collected data should fit with the model based on the TPB. Statistical analysis should be used to check whether the TPB can predict and explain the inspected behaviour. When this is not the case the model and its factors and measures should be reviewed. In the present study, the data for the model will be collected from other papers on PEB, such as investing in solar panels (Muelder & Filatova, 2018). These papers have already investigated the connection between the data and the inspected behaviour. It is thus assumed that the data used in this graduation research fits the model.

The second potential problem Scalco et al. (2018) describe is that AB models consist of causal relationships that describe interactions and behaviour over time, while the TPB was developed as a static predictive model (Ajzen, as cited in Scalco et al., 2018). For this graduation study certain input variables for the TPB will change over time, therefore changing the calculations within the predictive model each time step and thus creating change over time with the help of a static model.

The third problem considers when intention becomes behaviour. In the theoretical framework of the TPB the general formula proposes that "the probability to express a certain behaviour is proportional to intention" (Scalco et al., 2018, p. 24). But to be able to run the model, a specific formula is needed for this relation. Research indicates that options with a higher intention have a higher chance to be executed (Schlüter et al., as cited in Scalco et al., 2018). This option has successfully been applied by D. R. Kniveton, Smith, & Black (2012) where agents choose the alternative with the highest intention value. Another option is to set a threshold value for the behavioural intention (Sogani, Muduganti, Hexmoor, & Davis, 2005), in that case the intention has to be above this value. Different choices of the relation between intention and behaviour will provide different results with the same input data (Muelder & Filatova, 2018). Muelder & Filatova (2018) tested three different TPB-based agent-based model (ABM) architectures of an individual's discussion-making process (figure 16a (MF), b (SE) and c (RR)). The MF architecture was based on their own research into the adoption of solar panels by households in a municipality in the Netherlands. Architecture SE was adapted from the study by Schwarz & Ernst (2009) about different investment choices for sustainable water use and the diffusion of technologies that save water. The RR architecture was adapted from Rai & Robinson (2015) that studied the adoption of PV installations by households in Taxes.

In the MF ABM architecture agents first check whether their income is above a certain threshold. If that is the case, they calculate their status quo utility and the utility of taking an action. If the second one is higher than the first, they perform this action. (Muelder & Filatova, 2018).
In the SE ABM architecture there is no threshold check. Agents immediately calculate their total utility and if this is higher than their current utility, they undertake action. (Muelder & Filatova, 2018).
In the RR ABM architecture agents compare their income to a payback assessment. If that is passed, they calculate the potential utility when they would take action. This potential utility is compared to a threshold value and if it is higher, the agent takes action. It is also important to notice that in this ABM architecture 'payback' is both involved in the PBC, the payback assessment, and in the utility calculations. (Muelder & Filatova, 2018).

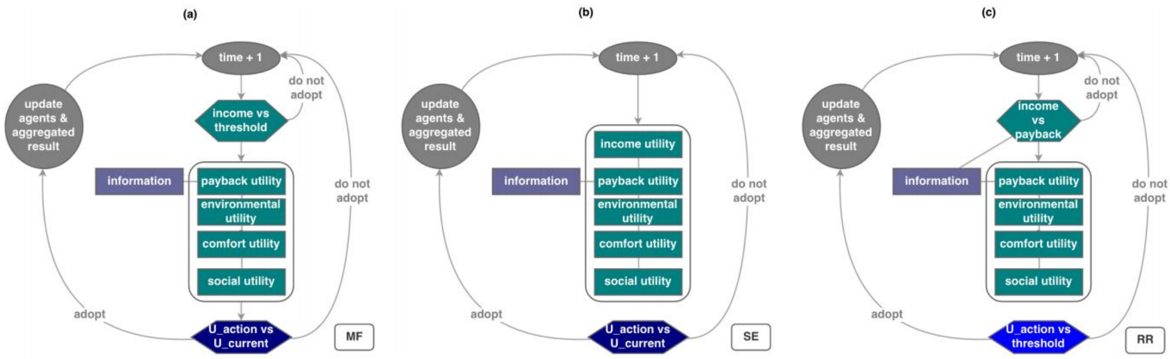


Figure 16: TPB-based architectures of an individual decision-making process. Reprinted from "One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models," by H. Muelder and T. Filatova, 2018, Journal of Artificial Societies and Social Simulation, 21(4), p. 5.

Muelder & Filatova (2018) do not draw conclusions on which architecture could best be used. They only show that slight differences in model architecture, based on the same theory (the TPB), can have big differences in their quantitative and qualitative results. Because it cannot be argued which ABM architecture is the best, the present research uses all three of them to check whether an ABM considering the implementation of UHI mitigation solutions also has different results because of different architectures. However, to answer the questions of this graduation study architecture MF is used for the experiments and sensitivity analyses. Appendix C explains this choice.

The fourth potential problem Scalco et al. (2018) mention is the fact that complex dynamic systems built within ABMs have closed loops and feedback mechanisms in them. Individual level behaviour determines the aggregated outcome of the whole system, which in turn influences the behaviour on the individual level (Scalco et al., 2018). In this case Scalco et al. (2018) state that the TPB is limited, because it cannot specify the exact influence of actual behaviour on the antecedents of intention. They advise that specific assumptions need to be made about this by researchers and give some examples of research where the outcome of a behaviour is a source of information for another's decision. For example penalties or subsidies for the performance of farmers and the opinion of other farmers, influence the behavioural and normative beliefs of that farmer (Verwaart & Valeeva, 2011). Or a feedback loop exists between the number of users of a certain technology and the subjective norms of individuals (Sogani et al., 2005). In the present study, such a feedback mechanism is created through the effect that the implementation of Urban Heat Island (UHI) mitigation solutions have on the nearby air temperature, which influences the decision of households to invest in UHI mitigation solutions. And by letting the number of current users of a certain UHI mitigation solution that a household has contact with, influence the adoption of UHI mitigation solutions by that household. The model itself will thus not be able to specify how the individual choice to invest in an UHI mitigation solution exactly influences the outcome.

The fifth and last problem considers that the TPB can only partially explain the behaviour of agents (Scalco et al., 2018). According to Scalco et al. (2018) impulsive actions and habits can also be used to explain behaviour. If an action is performed a lot of times, such a habit can directly influence behaviour in a way that intentions become irrelevant (Ajzen, 2001). Churchill, Jessop, & Sparks (2008) show that adding impulsiveness, performing an action with poor examination of the consequences, to a TPB model increases the prediction of the model. In the present research the possible action is investing in UHI mitigation solutions that require a considerable investment. A decision to invest a considerable amount of money will not be taken lightly and impulsive. Such decisions are not taken regularly, in this graduation study only once a year an individual calculates whether it is positive to invest in UHI mitigation solutions. Such a yearly consideration can become a habit if it seems to be negative every year, however because it involves investing a considerable amount of money and can also cause real savings it is not treated as a habit.

3.5.2 Networks within ABM

One of the properties influencing an individual's intention in the TPB are subjective norms, which are the beliefs of an individual about the opinion of others (Vallerand et al., 1992). Within ABMs using the TPB, this property is often influenced by the social network of an individual (Muelder & Filatova, 2018; Rai & Robinson, 2015; Schwarz & Ernst, 2009). Rahmandad & Sterman (2008) describe five different network structures: ring lattice networks, where there is only contact between neighbours next to each other on a ring, scale-free networks, where individuals that have more neighbours have a higher chance of having even more neighbours than others, small-world networks, where individuals form multiple close range connections and some longer range, random networks, where individuals form a connection with several random other individuals and fully connected networks, where everyone is connected.

Watts & Strogatz (1998) showed that networks between people often consist of local connections with a small amount of long range relations, thus a small-world network. Schnettler (2009) investigated 50 years of small-world research and concludes that diffusion processes take place within a small-world. In this graduation research, the diffusion of UHI mitigation solutions will thus be considered within a small-world network. This type of network is also used by Schwarz & Ernst (2009) for investigating the diffusion of water-saving innovations and Muelder & Filatova (2018) and Rai & Robinson (2015) for investigating the adoption of solar panels. These articles will be used as examples.

4. Parameters influencing UHI mitigation

This chapter provides answers for the first three sub-questions of this study about the technical-, household- and institutional characteristics influencing the adoption of UHI mitigation solutions in existing neighbourhoods in the Netherlands. The answers to these questions are used to make the ABM that answers the fourth sub-question: "*What Urban Heat Island mitigation solutions are viable in which residential environments?*". First the technical characteristics, second the household characteristics and then the institutional characteristics are described.

4.1 Technical characteristics

Section 2.2 and 2.3 introduced possible UHI mitigation solutions and their effect on the outdoor air temperature. This section shows what technical characteristics of these solutions and the building or area they are implemented in have to be considered when adopting them. As explained in section 1.3 only the eight solutions in table 4 are considered.

Table 4: UHI mitigation solutions considered in this graduation research

Group name	**Specific solution**
Green infrastructures	Green roofs
	Green façades (vertical greenery)
	Grass
	Trees
	Urban Parks
Water based mitigation	Pools and ponds
Reflecting materials	Cool roofs
	Cool pavements

At first there are several general influences impacting the effect of UHI mitigation solutions. As explained in section 2.3 climate characteristics influence the effect of these solutions. Therefore, only research from similar climates to the climate of the Netherlands is considered. Section 2.4 discussed the influence of the local urban area on the effect of these solutions, which resulted in also taking the LCZs of existing research into account. Especially the amount of sun, shadow and the strength and direction of the wind have an influence on the mitigation potential of these solutions. These aspects are tried to capture in the present research by taking into account the climate classification and LCZs of the areas. The rest of this section discusses the technical characteristics per solution.

4.1.1 Green roofs

An important technical characteristic that impacts the possible adoption of green roofs is the strength of the roof. Different types of green roofs exist, from intensive green roofs with trees and plants that require a lot of maintenance, just like a garden, to extensive green roofs with only small vegetation which does not require much care (Oberndorfer et al., 2007). Although intensive green roofs have a bigger effect on the air temperature (Lalosevic, Komatina, Milos, & Rudonja, 2018), the present study will only take extensive green roofs into account as they require less maintenance, roof load capacity and irrigation and thus cost less and can be applied on almost any roof (Oberndorfer et al., 2007). These extensive roofs can be installed as a complete part of the roof, as a modular system which can be placed in parts on top of an existing roof, or as a precultivated blanket which is rolled out on a roof (Oberndorfer et al., 2007). For this graduation research this level of detail is too much and will not be considered further. According to sedumdakaanleggen.nl (n.d.) most roofs in the Netherlands, even small sheds, are able to withstand the extra weight of an extensive green roof of up to 110 kilograms per square metre when soaked with rain. The maximum load capacity of roofs will thus not be included in the present research as it is expected that all roofs are able to bear a green roof. However, in reality the strength of a roof should always be inspected before constructing a green roof. Next to the roof strength, the roof angle is also important. Extensive green roofs can be installed on slopes up to 45 degrees, however in such a case measures are needed to reduce shear force and erosion (Sloped Roofs, n.d.). For the case of the Bomen- en Bloemenbuurt almost all roofs are flat, 121 of 7862 dwellings have a sloped roof, so this will not be taken into account. The height of the building influences the mitigation potential at street level (Salata et al., 2017), therefore these are incorporated by using the LCZs of (Stewart & Oke, 2012).

Next to reducing outdoor air temperature, extensive green roofs also provide insulation and thus reduce cooling demand during summer and heating demand during the winter (Besir & Cuce, 2018). Susca (2019) reports that green roofs can reduce the cooling demand in areas with a Cfa Köppen-Geiger Climate Classification with 67% and with 59% in a Csa climate classification. However, it is not clear whether these numbers are given for intensive or extensive green roofs. This is important as intensive green roofs are better at reducing cooling demand than extensive roofs (Silva, Gomes, & Silva, 2016). Besir & Cuce (2018) report that buildings with extensive green roofs need between 2.2 and 16.7% less energy for cooling during summertime and 10 to 30% less energy for heating in the winter. This is close to Silva et al. (2016) that state that buildings with extensive green roofs need 20% less energy compared to black roofs. According to Besir & Cuce (2018) this reduction will lead to saving around 215 dollars per year in energy costs, which is around 12% of the yearly energy costs in the Netherlands (CBS, 2021).

4.1.2 Vertical greenery

With regard to vertical greenery, two types exist, a green façade where the plants grow from the bottom to the top, or a living wall with pots or pockets on the wall where the plants are located (Bustami, Belusko, Ward, & Beecham, 2018). Although these two types can have different effects (Wong et al., 2010), they will be seen as one in the present study because there are not much studies in the right climate zones available for this solution. In appendix A only seven papers are presented for this solution. The walls where vertical greenery can be applied must be strong enough to resist the installation of a façade or living wall. As fully saturated green walls weigh around 65 kilos per square metre (Biotecture.uk.com, n.d.) it is assumed that these can be applied to almost every wall. Façade orientation is an important aspect for vertical greenery (Pérez, Coma, Martorell, & Cabeza, 2014), walls with more solar radiation are warmer and will thus result in a higher temperature reduction when a green façade is installed than walls that are mostly in the shadow. For the present research this is not taken into account as it considers the whole neighbourhood, and the specific orientation of walls is too much detail. It is assumed that the green façade will be implemented on the wall with the most reduction potential and all implementations have the same effects within the same LCZ. Wong et al. (2010) conclude that the type of plant also influences the mitigation potential of a green wall. This graduation research will look at an overview of existing literature and not take specific plants into account. With regard to the reduction of energy use Besir & Cuce (2018) report that the cooling demand is reduced by 8 to 26,5 percent in summer and around 2% in the winter in Canada. Bustami et al. (2018) present an average reduction of 26% during summer, while Pérez et al. (2014) report a reduction of 10 to 31 percent of cooling energy.

4.1.3 Grass

As mentioned in section 2.5, an important part of the efficiency of green solutions is the availability of water (Susca, 2019). If a grass area is completely dried out, its lowering effect on the air temperature during extreme heat will diminish because it cannot reduce the temperature through evaporation. Extreme heat events in the Netherlands often occur at the same time as a shortage of rain and one of the consequences of climate change is more and longer periods of extreme drought and heat (KNMI, 2012). When implementing more grass as a solution to extreme heat, these areas should thus also be properly irrigated during periods of extreme heat and drought so they can provide their intended cooling effect. This will however not be taken further into account in this graduation study, as it is presumed that this will be done when this solution is chosen to implement.

4.1.4 Trees

An important downside regarding trees is that they reduce the surrounding airflow (Pérez et al., 2014; S. Tsoka et al., 2018) and can therefore increase the amount of harmful particulate matter in a street. Furthermore, trees do also need water. The groundwater level in the area must thus be sufficient when using trees to reduce the air temperature, or the trees should be irrigated during dry periods. Jiao, Zhou, Zheng, Wang, & Qian (2017) conclude that a number of small tree patches can better impact the air temperature than one single larger patch with the same tree cover. They further show that transpiration rates and the amount of shade provided, can vary a lot between different kinds of trees. These effects should be considered besides the local climate and tree water consumption when deciding upon the right tree for an area (Jiao et al., 2017). In hva.nl (n.d.) a list of possible trees for UHI mitigation is given. The height of the tree is also important: Battista et al. (2019) find no effect on the air temperature for six metre trees, but 10 metre trees do reduce the local air temperature. The present research will not look into the detail of specific trees but uses the average effects found in literature.

4.1.5 Urban parks

For urban parks irrigation during dry periods is important (Chang & Li, 2014), but the layout of the park also impacts its effect on the air temperature. Parks should have less than 50% paved surfaces, otherwise they increase the air temperature (Chang, Li, & Chang, 2007). A minimum of 30% shaded area by trees or shrubs is also recommended (Chang & Li, 2014). Chang & Li (2014) show that the cooling effect of a park affects a larger area if the park is bigger, but this also depends on the area around the park (Lin, Yu, Chang, Wu, & Zhang, 2015). Vidrih & Medved (2013) calculated the optimal length of a park to be 130 metres when the leaf area index is three, which means there are around 45 trees that are 50 years old per hectare. Parks with fewer or younger trees have a smaller impact on the air temperature (Vidrih & Medved, 2013), it is thus important to know that a newly cultivated park has a smaller effect on the air temperature. This will not be included in the present research and only 'fully grown' parks will be considered, because that effect will exist for the longest amount of time. As the Bomen- en Bloemenbuurt is an existing built-up area, parks will only be considered for existing squares or open areas.

4.1.6 Pools and ponds

As already mentioned in section 2.5, the size of a water area affects its influence on the air temperature, but considering the limited possibilities in an already existing area, only smaller ponds will be included in the present study. Du et al. (2016) conclude that for a water body with a fixed area, such as pools and ponds, the geometry of this water area should be kept relatively simple like a square or round shape in order to create good water cooling effects . According to Imam Syafii et al. (2017), creating the pond in the dominant wind direction has the biggest effect, however for this graduation research this will not be taken into account, as this will create too much detail.

4.1.7 Reflecting materials

By using cool roofs or pavement, the solar reflection / albedo and the absorptivity coefficients are modified (S. Tsoka et al., 2018). As mentioned in section 2.5 it is important to take in mind that the ageing process can reduce the albedo of surfaces and thus the cooling potential. Lontorfos, Efthymiou, & Santamouris (2018) conclude that after a year the albedo of concrete pavement reduced from 0.47 to 0.40 and of bitumen pavement reduces from 0.26 to 0.15. Concrete pavement thus seems to retain its albedo better. The climate classification of a city where reflecting materials are used influences the optimum albedo of the reflective surface, in warm climates this seems to be 0.5, while for colder climates the albedo should not be higher than 0.4 (Pisello et al., 2018). The present research is aimed at the influence on the air temperature, but it is important to note that reflective materials can reflect sunlight directly on pedestrians increasing the Physiologically Equivalent Temperature (PET) of pedestrians and reducing their thermal comfort (Taleghani et al., 2016), this is thus not taken into account in the present study. Furthermore the height of the building with a cool roof also influences its mitigation potential at street level, as is true for green roofs (Salata et al., 2017).

Paintings and coatings are the most effective cool roof solution and are mostly developed for flat roofs (Pisello, 2017). As stated in section 4.1.1 about green roofs, almost all roofs in the case study neighbourhood are flat, so the specific effects of tilted roofs are not considered. Cool roofs are also able to reduce the cooling energy needs of the building they are applied on, but on the other hand can increase the heating costs in the winter (William et al., 2016). Pisello (2017) reports an annual reduction of cooling energy with 26%, while William et al. (2016) shows a reduction of 92% for cooling costs, but an increase of heating costs by almost 50%. According to M. Santamouris (2014) the increase in heating demand is 5 to 10 percent, while the cooling demand reduction is between 10 and 40 percent.

4.2 Household characteristics

Section 2.7.2 explained that the meso level, which consists of the households within the system, plays an important part in the creation of behaviour and intentions of individuals. For the present study several characteristics of households that influence pro-environmental behaviour (PEB) are considered in the model. This section introduces the household characteristics that influence PEB and are thus able to influence the adoption of UHI mitigation solutions in existing neighbourhoods in the Netherlands.

4.2.1 Literature overview

Studies about the effect of household characteristics on specifically the adoption of UHI mitigation solutions have not been found. However, literature about the relationship between these characteristics and other PEB exists. These are mostly about investments in water or energy saving technologies or pro-environmental habits such as recycling, saving water and energy, and buying environmentally friendly products. Table 5 gives an overview of the literature sources and whether the effect was positive (+), negative (-) or no effect could be found. Adopting UHI mitigation solutions is mostly an investment behaviour, but some of the solution also require a change of habits. Green roofs and façades or increasing the amount of green in one's garden also require maintenance. Therefore, studies about both these types of behaviour will be considered.

Table 5: Literature on household characteristics influencing pro-environmental behaviour

Literature source	**Kind of PEB**	**Characteristics and effect (+/-)**	**No effects**
(Martínez-Espiñeira, García-Valiñas, & Nauges, 2014)	Investments to save water and electricity	Children under 15 (+) Educational level (+) Household size (+) Income (+) Age (-)	Gender
(Martínez-Espiñeira & García-Valiñas, 2013)	Investments to save water	Children (+) Educational level (+) Household size (+) Income (+) Full-time workers (+) Age (-)	Gender
(Lam, 2006)	Investments to save water	Apartments >5 stories (+) Educational level (+) Income (+) Detached house (-)	Dwelling type Educational level Income Age Gender
(Millock & Nauges, 2010)	Investments to save water	Home ownership (+) Household size (+) Household with lawn or garden (+) Income (+) Age of building (-)	Educational level Gender
(Berk, Schulman, McKeever, & Freeman, 1993)	Investments and habits to save water	Children (+) Educational level (+) High status jobs (+) Home ownership (+) Income (+)	
(Gilg & Barr, 2006)	Investments and habits to save water	Age (+) Educational level (+) Female (+) Home ownership (+) Income (+) Household size (-)	
(Rajapaksa, Islam, & Managi, 2018)	Investments and habits to save electricity and recycle waste	Educational level (+) Male (+)	Age Marital status Household size
(Waitt et al., 2012)	Investments and habits to save water and electricity, reduce fossil fuel emission and recycle waste	Detached dwellings (+) Female (+) Income (-)	
(Whitburn, 2014)	Investments and habits to save electricity, recycle waste and reduce fossil fuel emissions	Neighbourhood vegetation (+) Number of children (+) Home ownership (-)	
(Patel, Modi, & Paul, 2017)	Small investments and habits to reduce	Educational level (+) Male (+) Married (+)	

	electricity and fossil fuel emissions	Mid-age (+)	
(X. Chen et al., 2011)	Habits to recycle waste	Educational level (+) Employed (+) Female (+) Leadership position (+) Living in larger city (+) Single (+) Age (-)	Income
(Mainieri, Barnett, Valdero, Unipan, & Oskamp, 1997)	Habits to recycle waste	Female (+) Home ownership (+)	Age Income Educational level
(Hamburg, Haque, & Everitt, 1997)	Habits to recycle waste	Single-family dwellings (+)	Educational level
(Ambrosius & Gilderbloom, 2015)	Habits to save water, electricity, reduce fossil fuel emission and recycle waste	Single-family dwellings (+)	
(Alcock, White, Pahl, Duarte-Davidson, & Fleming, 2020)	Habits to recycle waste, buy eco-friendly products and reduce fossil fuel emissions	Neighbourhood vegetation (+)	
(OECD, 2011)	Unclear	Educational level (+)	
(Kollmuss & Agyeman, 2002)	Unclear	Female (+) Years of education (+)	

The information in table 5 shows that there is no consensus on which characteristics have impact and for some cases, if an impact is found, whether that is a positive or negative impact (e.g. Lam, 2006; McFarlane & Boxall, 2003; Whitburn, 2014). For example, Lam (2006) presents two studies that show different results for the influence of dwelling type, educational level and income: In one study these do not have a significant effect, while in the other study they have a positive effect.

4.2.2 Disputed characteristics

The disputed characteristics in literature are educational level, age, gender, income, household size and the type of dwelling.

Nine studies show that the **educational level** of a household has a positive effect on its PEB, but four studies show that there is no significant relation between educational level and PEB. Martínez-Espiñeira & García-Valiñas (2013) write that people with less education will probably have more difficulty learning about new technologies and have found that educational campaigns have a positive effect on investment decisions regarding PEB. As most studies have found a positive effect of educational level, this will be taken into account in this graduation research.

Three studies found that **young people** show more PEB, while three other studies found no effect of age and one study even found that older people show more PEB. Martínez-Espiñeira et al. (2014) explain that younger households more often have children than older households and thus use more water and energy. Therefore, investing in technology that reduces water and energy consumption could be more attractive for them. On the other hand Martínez-Espiñeira et al. (2014) write that older households show more PEB when it comes to pro-environmental habits because young households are possibly more used to new, efficient appliances and have therefore not yet had the need to develop these habits. As the effect of age has found to be positive, negative and non-existent this will not be taken into account in this graduation study.

Regarding **gender**, four studies showed no effect of gender, while two studies found that men show more PEB and five studies showed females had more PEB. Waitt et al. (2012) explain that further research into gender is needed, as housework in this day and age is still mostly done by women, but the exact relation is unclear. As most papers about investment PEB indicate gender has no effect on this behaviour, this characteristic will not be taken into account for the present study.

Income is another disputed characteristic, three studies showed no effect of income, six studies showed a positive effect, while one study showed that lower income households had more PEB. Millock & Nauges (2010) explain that households with more income can better afford costly pro-environmental investments, but low income households may value the savings from these investments more, or may even install these pro-environmental technologies themselves because of the lower opportunity costs of their time and through that reduce their costs. Martínez-Espiñeira et al. (2014) state that because income plays a significant role, subsidies that reduce investment costs could be effective. As most studies about PEB regarding investments found a positive effect this will be taken into account in this graduation research.

One study found that **household size** had no effect on PEB, while another showed it had a negative effect and three others showed a positive effect on PEB. As larger households use more water and energy this could stimulate them to invest in efficient technologies. This effect will probably be less strong for UHI mitigation solutions, because not all of these solutions are able to reduce the energy use of households. Because of this and the results being unclear, this effect will not be considered in this graduation study.

One study showed the **type of dwelling** having no effect on PEB, but five studies did find an effect. Two studies showed households in single-family dwellings having more PEB than others and one study showed the same effect for households with a lawn and/or garden. On the other hand, two different studies both found a contrasting effect for households living in detached dwellings, one showed the effect to be positive, while the other found a negative effect. Lam (2006) explains that detached-houses often do not share water tanks and could thus have more confidence that they will manage when having to cope with water-supply restrictions. However, in the Netherlands water tanks are not used. The effect for single-family dwellings that Hamburg et al. (1997) found is caused by recycling behaviour. As the behaviours above have no relation to adopting UHI mitigation solutions this characteristic will not be taken into account.

According to four studies **home ownership** has a positive effect on PEB and one study shows a negative effect. Investing in pro-environmental appliances often helps decrease future costs and can have a positive effect on the value of the dwelling. Therefore home owners are expected to invest more in these appliances (Martínez-Espiñeira et al., 2014). Another possible explanation is that renters sometimes do not have the option to make changes to their dwellings and do not have the incentive of value (Berk et al., 1993). This effect will be taken into account in the present research.

4.2.3 Undisputed characteristics

Some characteristics do have only one effect in multiple studies. Four studies found that **having children** makes households have more PEB. Research by Reid et al. (2010) found that children are often better educated about environmental behaviour and inspire parents with that knowledge. Martínez-Espiñeira & García-Valiñas (2013) suggest that this could be explained by households with children using more water and energy, so having efficient appliances will have a bigger positive effect. This is the same effect as with larger households and because it is expected that this effect will be less strong for UHI mitigation solutions, this effect will not be considered in the present research. Although children could thus inspire their parents, more research about this effect is needed to confirm the statement by Reid et al. (2010).

Two studies show the **amount of vegetation in the neighbourhood** having a significant positive effect on the pro-environmental behaviour (PEB) of households (Alcock et al., 2020; Whitburn, 2014). In this graduation research the neighbourhood is divided into different LCZs that take the amount of vegetation into account. This effect will thus be considered in the present study. As this significant effect was only found in two studies, its effect is less reliable than some of the other household characteristics. It could be that households that show more PEB like to live in neighbourhoods with more vegetation and this causes the effect. This should be investigated by future research.

Several studies discussed in section 4.2 show that those that have **experience** with the negative effects or other consequences of environmental change are more likely to change their behaviour. X. Chen et al. (2011) write that citizens may be more willing to make economic sacrifices when they experience these consequences and Rajecki (as cited in Kollmuss & Agyeman, 2002) defined that direct experiences lead to a stronger correlation between attitude and behaviour. Furthermore, Millock & Nauges (2010) concluded that in countries with water scarcity more water-efficient household equipment is adopted. Research by Rajapaksa et al. (2018) showed that scarcity of resources significantly increases the PEB of citizens. This is in line with other existing research on the experience of climate change that report that facing the negative consequences of these changes significantly affects behavioural intentions (Spence, Poortinga, Butler, & Pidgeon, 2011). Regarding the UHI effect the outdoor air temperature is increased with leads to several negative effects: Biodiversity reduces, while water consumption, air pollution, electricity demand and health risks increase (Fabiani et al., 2019). Therefore, the nearby air temperature of households is considered as one of the household characteristics that influences the adoption of UHI mitigation solutions.

It is important to keep in mind that the effects of these characteristics vary a lot between the different studies and populations used in that research. It is therefore difficult to use them as generic tools to explain PEB (Whitburn, 2014). The information in table 5 endorses the claim by Lam (2006) that “the relative importance of demographic variables depends on the type of environmental behaviour” (p.2819). It could thus be the case that the characteristics considered in the present study do not apply to investments in UHI mitigation solutions. However, as both consider investments and other information is not available these will be included.

The studies referenced in table 5 did check whether the researched characteristics had direct or indirect effects or were moderated or mediated by other characteristics. However, as this graduation research combines results from different studies, these effects could resurface. Future research into the relation between household characteristics and investments in UHI mitigation solutions is needed to confirm the choice to consider educational level, income, home ownership and the amount of vegetation in the neighbourhood in this graduation study.

4.3 Institutional characteristics

Section 2.6 showed that municipalities, water boards and provinces often lack knowledge about the legal possibilities of climate adaptive building. Therefore the Dutch government provided examples of specific legal possibilities (Van de Leemkolk et al., 2020). These possibilities are aimed at new developments or redevelopment of an existing area. These do not oblige existing homeowners to immediately change something about their house. As the Urban Heat Island (UHI) effect is a currently existing problem, it is not a good idea to wait for future area redevelopments to adopt UHI mitigation solutions. This section introduces institutional characteristics influencing the adoption of UHI mitigation solutions in existing neighbourhoods in the Netherlands and ways for municipalities to stimulate homeowners to adopt these solutions.

In their research into possible causes that stop municipalities from using all available legal instruments to stimulate climate adaptive buildings, Handgraaf & Dekker (2019) mention several bottlenecks as a reason for this. These bottlenecks fall into five categories: policy-, legal-, technical-, organizational- and financial bottlenecks (Handgraaf & Dekker, 2019). Although not all these categories contain institutional characteristics, they are all discussed in this section, because they help to show why municipalities do not use all available legal instruments at the moment. If a category incorporates institutional characteristics this is clearly stated at that paragraph.

The **policy bottlenecks** mostly consist of: The lack of knowledge, which is especially true for municipalities; Normal routines within governmental bodies not taking into account climate adaption, limited expertise and capacity; And a lack of urgency by local politics but also by home owners (Handgraaf & Dekker, 2019). If homeowners do not even know about the negative effects of the UHI effect on their own lives and their possibilities to reduce this effect in their neighbourhood, they are not able to do something about it. This bottleneck is even more severe if the municipality also does not have sufficient knowledge about the UHI effect. A municipality can try to inform its citizens about the UHI effect and UHI mitigation solutions to try to convince them to adopt some solutions, but if the municipality does not know enough about the UHI effect, they cannot do that properly.

Legal bottlenecks are institutional characteristics that reduce the adoption of UHI mitigation solutions. These bottlenecks are the difficulty in enforcing some climate adaptive requirements, such as the maximum amount of hardened surfaces or because some constructing work does not need permits, and housing corporations that are only allowed to invest in their own property and not in public space (Handgraaf & Dekker, 2019). For some construction work on their own property, homeowners do not need any permits from the municipality (overheid.nl, 2020). In those cases, the municipality cannot demand the adoption of UHI mitigation solutions for the construction and the homeowner can choose if he wants to adopt any. Even if the municipality is able to make certain demands it is sometimes difficult to check whether these demands are properly met (Handgraaf & Dekker, 2019). As Handgraaf & Dekker (2019) mention, disagreement can arise about whether the rules were rightly followed. Furthermore, current legislation constrains housing corporations in their investments. Since 2015 corporations are not allowed to invest in the public space around their property (Van der Velde, 2019), because that is the responsibility of the municipality. Another institutional characteristic is presented in section 3.2. This showed that there are several owners' associations (VVE's) in the Bomen- en Bloemenbuurt. Decision-making regulations of these associations often state that in order to decide to invest in sustainability, a qualified majority of often two-thirds or more of the total votes is needed (Van Riet, 2016). This is of course more difficult than only needing a majority of votes and slows down these investments.

Technical bottlenecks are a lack of attention for increasing roof load capacity practice guidelines, so roofs are able to bear heavier green roofs, and a lack of technical requirements for buildings to be more heat resistant (Handgraaf & Dekker, 2019). Building regulations do not yet incorporate a requirement for the possibility of installing heavy green roofs. Therefore, some newly built buildings are limited in the UHI mitigation solutions they could adopt. This is also the case for existing buildings. If a property owner wants to install a green roof, he will always have to check whether the construction is strong enough. If the construction can only handle a low weight green roof, the owner should decide whether such a thinner green roof can create the desired effect (Bouwman, 2020). This current roof load capacity practice guidelines are thus an institutional characteristic that reduces the possibilities to implement UHI mitigation solutions on roofs of newly built buildings.

Organizational bottlenecks are the result of a gap between the world of climate adaptation on one side and the 'normal' tasks of municipalities on the other side. Climate adaption is not yet part of the daily business of civil servants and thus needs specific attention. Because of this, people with specific knowledge about climate adoption are needed and are often overloaded with work (Handgraaf & Dekker, 2019). This is reinforced by the lack of regulations in land-use plans, program requirements and tenders (Handgraaf & Dekker, 2019). Because the civil servants with knowledge about climate adoption do already have a lot of work for new construction plans, they are not able to also focus on existing dwellings. Even if a municipality wants to focus on that, or is contacted by its citizens with questions about the adoption of UHI mitigation solutions, current employees will need to work even harder or the municipality needs to attract new or external experts to achieve this. (Handgraaf & Dekker, 2019). These organizational bottlenecks are not direct institutional characteristics, but the normal way of working in a municipality, which does not stimulate the adoption of UHI mitigation solutions, is an informal institution that can only be changed over time.

Demanding specific requirements for climate adaptive building can lead to much higher costs, which is part of the **financial bottleneck**. The other part lies with the housing corporations that cannot make a positive business case for implementing climate adaptive measures, research from the Dutch government showed that housing corporations do not have the funds to invest in sustainability issues (Penders, 2020). Increasing the number of climate adaptive requirements will lead to extra costs for developers during redevelopment and could thus lead to even more expensive houses or slow down the redevelopment of current dwellings. Municipalities should weigh these different interests and make choices. This could mean fewer requirements or creating subsidies for implementing UHI mitigation solutions. This last option is even more important for housing corporations or owner occupiers that want to implement such solutions in their own dwelling. While developers can pay for these solutions by increasing the price of the dwelling, corporations and owner occupiers are almost never able to re-earn their investment. Some UHI mitigation solutions have a small effect on the energy consumption of a household but most do not. Especially housing corporations that offer cheap housing will not be able to pay for these solutions. That is also true for owner occupiers with a low income. Even private rental landlords often cannot make a positive business case for these solutions, because they do not pay the energy bill and have limited possibilities to increase the rental price to recoup their investment. Financial bottlenecks are not an institutional characteristic in itself, but the ways in which the municipality can reduce these bottlenecks it. As mentioned a municipality could reduce the climate adaptive requirements of new dwellings, these requirements are part of the institutional characteristics. A municipality could also introduce a new subsidy through a municipal regulation, which is also an institutional characteristic.

Another institutional characteristic that needs to be taken into account in the Netherlands is the ‘aesthetics committee’ (*Welstandscommissie*). Exterior changes to houses, such as most UHI mitigation solutions need to have approval of this commission, otherwise these cannot be implemented (Gemeente Amsterdam, n.d.). Possible changes need to fit with the character of the building and environment and should not disturb the cohesion of the buildings appearance (Gemeente Amsterdam, n.d.). The aesthetics note of the municipality of The Hague mentions that green roofs need to follow the regular rules for roofing structures, but does not include any other UHI mitigation solutions (Gemeente Den Haag, 2017). This characteristic does thus not influence the adoption of UHI mitigation solutions at the moment, but could create barriers in the future if it changes.

A lot of obstacles thus exist that could slow down the adoption of UHI mitigation solutions in existing or newly built dwellings. These will mostly be included within the model. Possible UHI mitigation solutions must adhere to current regulations and be technically possible to implement. Also, the costs of these solutions is considered. Chapter 5 and 6 address how the model takes several technical, household and institutional characteristics into account.

5. Model Conceptual Framework

Chapter five explains the preparations before making the model. It conceptualizes the socio-technical system of the adoption of UHI mitigation solutions by heterogeneous households, housing corporations and the municipality. First the problem formulation is presented in 5.1, then 5.2 presents the main narrative of the model. Thereafter section 5.3 presents the system decomposition and 5.4 discusses the criteria that are used to evaluate the results of the model. In section 5.5 the hypotheses, to be validated with the model, are described and the final part of chapter five elaborates on the formalisation into the agent-based model (ABM) software.

5.1 Problem formulation

5.1.1 Problem

As explained in chapter one, the Urban Heat Island (UHI) effect has negative influences on the liveability and the ecological environment in cities. Because of the increasing urbanisation and global temperatures, these negative effects will increase in the future. Although multiple acknowledged mitigation solutions exist that show a clear technological readiness, these are not widely applied. There is limited knowledge of the UHI effect and its solutions amongst stakeholders (Solcerova et al., 2019), such as municipalities, individual citizens, owners' associations (VVE's) and consultants, and not much action is taken. Section 2.6 explained the history of climate adaption policies to tackle the effect of climate change, such as an increase of extreme heat, and showed that there has not been much action by municipalities to tackle this issue in existing neighbourhoods. The inconsistent results of research into UHI mitigation solutions and their different effects in different regional climate zones and neighbourhood LCZs (Kim, Gu, & Kim, 2018) is also not helpful.

At the moment some municipalities in the Netherlands have introduced subsidies to encourage citizens to implement green UHI mitigation measures around their own homes. However, it is thus unclear if this solution is the most effective.

The problem that is addressed through the agent-based model is the limited understanding of the effect and adoption of UHI mitigation solutions by practitioners such as municipalities, citizens and consultants. By investigating the influence of the meso- and micro level on the pro-environmental behaviour of households, their adoption of UHI mitigation solutions, through the Theory of Planned Behaviour (TPB), the limiting factors influencing the adoption rate can be found and policies can be developed to stimulate these.

5.1.2 Timeline

Each decision-making round in this model takes up one whole year, so when a household or housing corporation decides to invest in an UHI mitigation solution that solution is installed in that year and influence the decisions of other households in the next year. The model runs for 40 years, until the year 2060, so 40 decision rounds take place. This timeline is chosen because it includes the changing climate in the Netherlands, which is also taken into account in the data of the effect of UHI mitigation solutions on the air temperature and incorporate the normal cycle of renovating public space.

However, this long timeline also means that the uncertainty of the model increases a lot over the runtime, as the range of possible events increases over time.

5.1.3 Emergent pattern

The emergent pattern influencing the outcome of this system is the influence of the different aspects of the Theory of Planned Behaviour (TPB) and the household characteristics on the decision of households to invest in UHI mitigation solutions and thus on the outdoor air temperature. As explained in section 2.7 the attitudes, subjective norms and Perceive Behavioural Control (PBC) influence an individual's intention and behaviour. These three aspects are based on the characteristics of the individual, but also on characteristics of other households and on the outdoor air temperature.

5.1.4 Whose problem are we addressing?

There are different actors involved in the adoption of UHI mitigation solutions, the municipality, owner occupiers, tenants, housing corporations, private landlords and business owners. The main problem owner of the negative consequences of the UHI effect is the municipality, because they are responsible for the living environment of their citizens and have to protect them against certain threats. In this case increasingly high temperatures during the summer that have a number of negative effects (reduced liveability, biodiversity and productivity and increased water consumption, air pollution, electricity demand and health risks). As explained in chapter one, the municipality, but also its citizens, do not have enough understanding of the UHI effect within their city and do not have enough information to make a good decision about their strategy on this subject and what mitigation solutions can best be used in which areas. Therefore, the model developed in the present research makes the UHI effect and the results of implementing mitigation solutions in the area more clear, next to giving the municipality information about the reaction of citizens to policies that stimulate the implementation of UHI mitigation solutions.

5.1.5 Agents

The agents in an agent-based model are sometimes also called the actors that play a role in the system. The actors that are taken into account in the present research are incorporated in different ways in the model. The **municipality** is located outside of the model boundaries. It does not make decisions based on the processes inside the model but can influence these by changing inputs. The municipality can for example decide to give a subsidy for a specific mitigation solution, which lowers the costs of that solution, or decide to apply a certain mitigation solution itself and influence the air temperature in the area with that solution.

Owner occupiers and tenants are presented as agents in the model and are also called the 'households'. Households that do not rent a dwelling from a housing corporation, also called 'non-social households', use the TPB and their household characteristics to decide whether they invest in an UHI mitigation solution and apply this solution on or around their house if their choice is positive. Literature shows that tenants are less likely to invest in pro-environmental solutions, this will thus be taken into account in the model. Section 3.2 showed that households living in apartments are part of an owners' association that decides upon new investments. For investments in sustainability two thirds or a larger percentage of households in the association need to support the investment, otherwise the investment does not take place (Van Riet, 2016). Households living in apartments will thus need to check whether this requirement is fulfilled.

Housing corporations are involved in a different way. Housing corporations in the Bomen- en Bloemenbuurt are not yet taking extreme heat into account in all their actions (S. Ros, personal communication, 10-02-2021). Section 4.3 showed that they are not allowed to invest in the public space around their property anymore and do not have the funds to invest in sustainability issues at the moment. Therefore, housing corporations are not incorporated as an actual agent in the model. Municipalities can make performance agreements with housing corporations about investments in their property itself, such as installing green roofs, green façades, green gardens or cool roofs as mitigation solutions. This is included in the model in almost the same way as the influence of the municipality itself. If these agreements are made, the model can take the implementation of one of these solutions on social housing properties into account. Some households in the area are designated as social housing, owned by housing corporations. These households have a chance of once in 25 years to invest in the solution that is chose beforehand. This follows the standard renovation cycle of doing major maintenance once every 25 years.

Private landlords that rent a dwelling to tenants are more difficult to take into account. As specified in section 4.3 they do not directly experience the effects of investing in UHI mitigation solutions, because they do not live in the dwelling and they cannot just increase the rent they ask to the tenants. Their choice to invest in these solutions is thus the result of a different process. For this model the effect of privately rented dwellings is integrated in the decisions of tenants, because they are less likely to make pro-environmental investments, as explained in section 4.2.

In this graduation research it is assumed that households only invest in one type of UHI mitigation solution. This choice is made as green and cool roofs cannot be combined with each other and the costs of implementing a green façade are relatively high so it is not expected that a second solution is implemented after one of these three. As the costs of implementing a green gardens is relatively low combining this solution with another could be possible in the real world. However, when combining two different solutions in such close proximity the effect on the outdoor air temperature cannot just be summed together as the solutions can influence each other's effectiveness. This is also true for implementing two solutions by households living next to one another. To reduce the overestimation of the impact on the outdoor air temperature because of these effects the impact of green roofs and cool roofs is determined based on the percentage of each of these two solutions implemented in the Local Climate Zone (LCZ) and the decision is made that households are only able to implement one solution during the model run.

5.2 Model narrative

This section explains the narrative of the model in 'normal' language. It explains how the model should work from its setup, through the difference phases that happen during each model round (1 year). The structure and narrative of the model are based on the research by Muelder & Filatova (2018) that tested three different agent-based model architectures. As explained in section 3.5.1 the present study applies all three model architectures but focuses on the architecture based on the model by Muelder & Filatova (2018). The actions presented in this section are also shown in figures 17, 18 and 19.

5.2.1 Setup phase

The model area is set up based on the map of the Bomen- en Bloemenbuurt in The Hague. During the setup each household is assigned its different properties. The properties of patches are distributed depending on the characteristics of the Bomen- en Bloemenbuurt. A 'patch' is the smallest level of detail in the agent-based model and has the form of a square, therefore it is sometimes also called a 'square'. In this graduation research a patch has a size of 9x9 metres. This choice is further explained in section 6.2.3.2.

5.2.2 Decision-making phase

Only households that do not live in a socially rented dwelling are able to make a decision. As explained the present study looks at three different TPB-based architecture of the decision-making process, however it focusses mostly on the architecture based on the model by Muelder & Filatova (2018), the MF architecture. Therefore, there are three different options for the decision-making phase depending on the choice of the modeller to run one of the three architectures. It is not possible to use two or three of them within one experiment. This section only addresses the decision-making phase of the MF architecture, the differences in the architecture based on the model by Schwarz & Ernst (2009), the SE architecture, and the architecture based on the model by Rai & Robinson (2015), the RR architecture, are presented in appendix D.

First a non-social household determines its probability to invest in a solution based on its income and the average income of all households in the model. If this probability is above a certain threshold that changes every time, the household continues with the utility estimation of each available UHI mitigation solution. It estimates its economic-, environmental-, comfort- and social utility and determines the multi-attribute utility of each solution. After determining the different multi-attribute utilities, a household checks the effects of its household characteristics. Its educational level, whether the households owns the house, the amount of vegetation in the neighbourhood and the current nearby air temperature all influence whether the household will invest in a solution. If the outcome of this check is positive, a household that lives in a single-family dwelling and is thus not part of an owners' association (VVE) determines which solution has the highest multi-attribute utility, as it can only implement one solution in the model. The household invests in this solution if its utility is higher than the utility of not taking any action. However, if the household characteristics check is positive while the household lives in an apartment and is thus part of a VVE, it notes for each solution whether the multi-attribute utility is higher than the utility of not taking action. Only if a household is the main household in a VVE, also called a 'VVE head', it then continues. The VVE head checks the preferences of the households that are part of the VVE. If a qualified majority of 75% or more of the VVE wants to adopt one specific solution, the VVE head invests in this solution. If there is more than one solution with 75% approval, the head of the VVE checks which solution has the highest overall multi-attribute utility and implement it.

5.2.3 Implementation phase

If a household that lives in a single-family dwelling and is thus not part of a VVE or a household that is the head of a VVE has chosen to implement an UHI mitigation solution, it changes the nearby air temperature based on the properties of that UHI mitigation solution and changes all other global parameters.

5.2.4 Model flow chart

Figure 17 gives a general overview of the model, while figures 18 and 19 zoom into the estimation of the multi-attribute utility and the household characteristics check respectively.

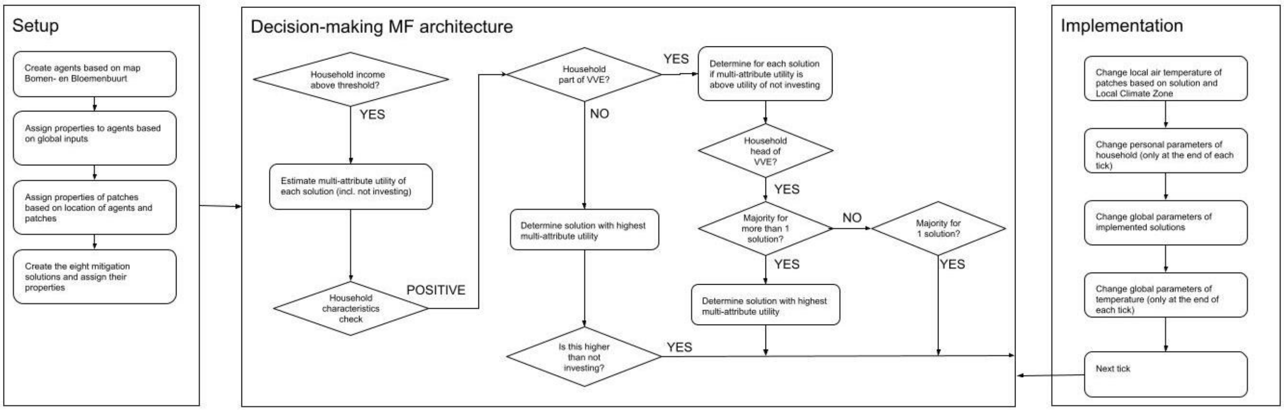


Figure 17: General model flow chart

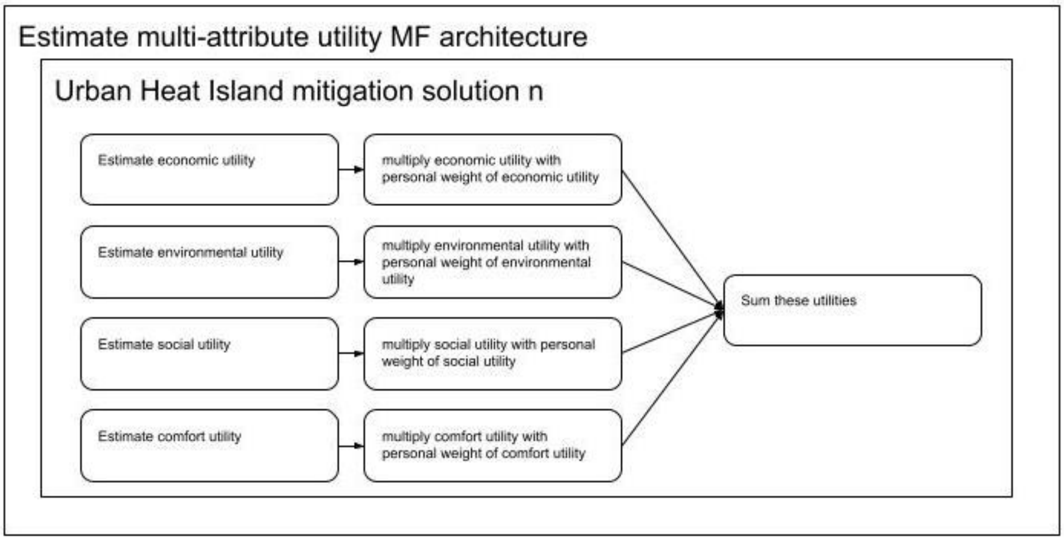


Figure 18: Details of the estimation of multi-attribute utility

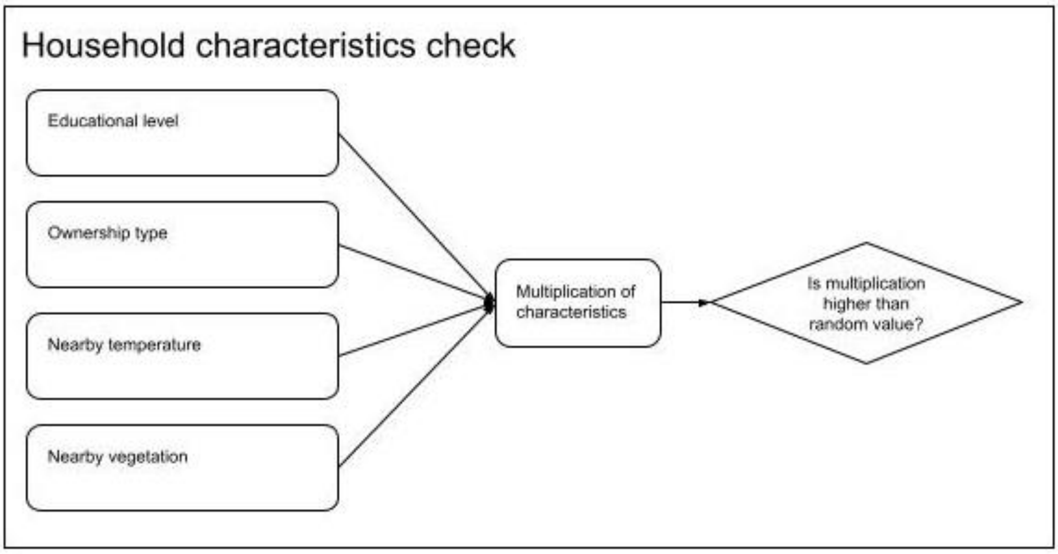


Figure 19: Details of the household characteristics check

5.3 System decomposition

Section 5.2 described from a high-level perspective how the model should work and showed the different processes within the model. This section explains and presents the equations to determine the income threshold, multi-attribute utility, household characteristic check, influence of owners' associations (VVE's) and implementation of an Urban Heat Island (UHI) mitigation solution.

5.3.1 Model setup

During the model setup the Bomen en Bloemenbuurt, the different squares in the area and the households are created. The squares get their properties based on their geographical location in the neighbourhood and the properties of the households are distributed randomly amongst all households in the area. These properties are all presented in section 6.2

5.3.1 The multi-attribute utility

The Theory of Planned Behaviour (TPB) is used in this graduation study to model how agents decide to invest in UHI mitigation solutions. As explained in section 2.7.1 the TPB explains how attitude, subjective norms and perceived behavioural control influence people's intention and behaviour. By influencing these aspects, individual's behaviour can be changed. For the present research the study by Muelder & Filatova (2018), which is briefly mentioned in section 3.5.1, is used as an example. Muelder & Filatova (2018) investigated whether household agents in the municipality of Dalfsen in the Netherlands would invest in solar panels. Figure 20 presents the operationalization of the TPB they used for the agent-based model in their research.

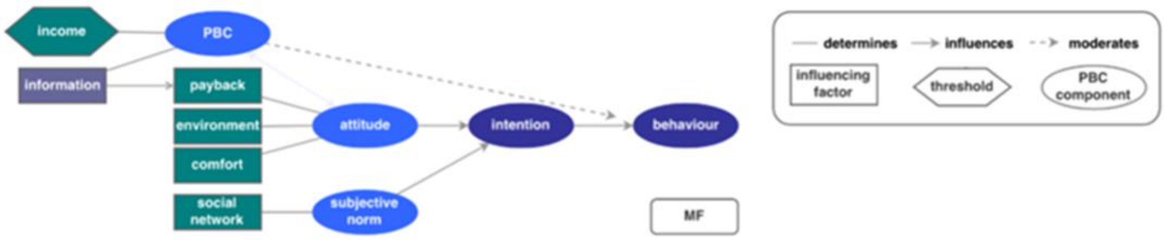


Figure 20: MF operationalization of the Theory of Planned Behaviour. Adapted from "One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models," by H. Muelder and T. Filatova, 2018, Journal of Artificial Societies and Social Simulation, 21(4), p. 19.

Figure 20 shows that Muelder & Filatova (2018) identified four factors influencing the decision to invest in solar panels: An economic factor (payback), an environmental factor (environment), a social factor (social network) and a comfort factor (comfort). These four factors determine the multi-attribute utility of investing in a technology, in the study of Muleder & Filatova (2018) solar panels, and were based on participatory workshop discussions with households in the Netherlands. In this graduation research these factors influence the choice to invest in an UHI mitigation solution and are transformed from the study by Muelder & Filatova (2018). The next sections present these four factors. Table 7, equation 6 shows the evaluation of the multi-attribute utility from these factors. The influencing factor 'information' in figure 20 presents the influence of information on the decision to invest in a solar panel and the difference between seeing information as monetary costs or as a non-monetary uncertainty in the study by Muelder & Filatova (2018). In this graduation research this factor is not included as the timeframe for the present research is limited and not enough data could be found about the influence of this factor. Future research could make this data available and expand the model of this graduation research with the factor information.

5.3.1.1 The economic utility factor

The economic factor are the costs associated with adopting a certain solution. In Muelder & Filatova (2018) this factor consists of the payback period of solar panels. However, for the adoption of UHI mitigation solutions the payback period is not the best parameter. The payback period for these solutions is at best multiple years if all benefits are included. Feng & Hewage (2018) calculate that the individual benefits of a green roof will outweigh the costs after 13 years. However, these individual benefits include not only a reduction of energy use, but also an increase in lifespan of the roof itself, extra acoustic insulation, aesthetic benefits and a LEED (Leadership in Energy and Environmental Design) certification bonus. In this graduation research the public benefits of Urban Heat Island (UHI) mitigation solutions, such as reduced storm water runoff, improved air quality and increased biodiversity are not taken into account. This graduation study only takes the mitigation of the UHI effect and the reduction of the energy use into account in two of the other factors than the economic factor, which are explained later in this section. All other aspects are outside of the scope of the present research, as mentioned in section 1.3. Therefore, the present study uses the actual costs of the solutions for the economic factor. This factor is calculated in a function with the mathematical constant *e* so the utility around the average price of a solutions changes the most and the utility does not change that much when the costs are very low or very high. Subtracting this number from one is needed to make sure the utility is the lowest for a solution with a high price and highest for aa solution with a low price (Table 6, equation 1). This equation is chosen so the economic utility of a solution with the highest costs will be close to zero, but not be zero and also the other way around with a cheap solution. This way, although the costs are the highest, it is still possible that households invest in that solution. In appendix B the input economic utilities of the four UHI mitigation solutions considered by households in the present study (green roofs, green façades, green gardens and cool roofs) are reported.

5.3.1.2 The environmental utility factor

In Muelder & Filatova (2018) the environmental factor includes the CO_2 emissions saving of adopting solar panels. However, for UHI mitigation solutions the amount of CO_2 emissions saved is more difficult to determine, because there are multiple solutions involved, these solutions have different effects and there is little data available for this. Therefore, the choice is made to use the percentage decrease of the energy use of a household when this household adopts a certain solution. These effects are available in literature for the UHI mitigation solutions used in this graduation research. A reduction in energy use also means a reduction in CO_2 emissions if the electricity of the household is not 100% generated with green sources. The environmental factor based on the energy reduction follows an S-shaped function as is the case in the model of Muelder & Filatova (2018). This way the environmental factor does not differ much between two options that are both far away from the average energy reduction, but the difference is larger between two options close to the average reduction (Table 6, equation 2). The input environmental utilities of the four UHI mitigation solutions considered by households in the present study are reported in appendix B.

5.3.1.3 The social utility factor

The social factor is determined by the fraction of neighbours that already have installed solar panels within the households own social group in the research of Muelder & Filatova (2018). This social group are the friends of the household within the same income group. For the present study the same method is used, but the specific solution that the neighbours have adopted is taken into account (Table 6, equation 3). This factor thus depends on the amount of friends of the household that have adopted the UHI mitigation solution for which the social utility is calculated.

5.3.1.4 The comfort utility factor

The comfort factor in Muelder & Filatova (2018) is a stochastic variable between -1 and 1 that represents the spoiled view from seeing solar panels on someone's roof or esteem from owning solar panels. For the present study adopting one of the possible solutions will not create a spoiled view. Changes on flat roofs are not seen by other households and increasing the amount of green in a garden or on the façade of a house will mostly have a positive effect on the view (wur.nl, 2021). A green façade or green roof could possibly increase the esteem of the owner, but this is not that likely for increasing the amount of green in your garden or having a cool roof. Therefore, the comfort factor is chosen to be the possible temperature reduction of the different UHI mitigation solutions, because this reduction creates more comfort for households. This factor will follow an S-shaped function, which means that the comfort factor between two solutions close to the average air temperature reduction of all solutions has a greater difference than the comfort factor of two solutions that are both far away from the average reduction (Table 6, equation 4). The radius of the air temperature reducing effect is also taking into account as this influence the total effect. The comfort utilities for the four different Local Climate Zones (LCZ3, LCZ5, LCZ6 and LCZ9) of the four UHI mitigation solutions considered by households are presented in appendix B.

Table 6: Representations of factors influencing decisions of household to invest in UHI mitigation solutions. Adapted from Muelder & Filatova (2018).

Factor	Representation	Equation	
Economic	Costs	$u_{eco} = 1 - \frac{e^{(C_{UHIt} - \overline{C_{UHIt}})}}{1 + e^{(C_{UHIt} - \overline{C_{UHIt}})}}$	(1)
Environmental	Energy use reduction	$u_{env} = \frac{e^{(r_{ener} - \overline{r_{ener}})}}{1 + e^{(r_{ener} - \overline{r_{ener}})}}$	(2)
Social	Social network	$u_{soc} = \frac{n_{UHIt}}{n_{tot}}$	(3)
Comfort	Air temperature reduction	$u_{cof} = \frac{e^{(r_{air} - \overline{r_{air}})}}{1 + e^{(r_{air} - \overline{r_{air}})}}$	(4)

u - utility, eco - economic, env - environmental, soc - social, cof - comfort, C_{UHIt}- costs of a solution, $\overline{C_{UHIt}}$ - average costs of all solutions,, r_{ener} - energy reduction of a solution, $\overline{r_{ener}}$ - average energy reduction of all solutions, n_{UHIt} - neighbours with specific solution, n_{tot} - total neighbours household, r_{air} - air temperature reduction of a solution in a LCZ, $\overline{r_{air}}$ - average air temperature reduction of all solutions in a LCZ

5.3.2 The income threshold

As figure 20 showed, the economic-, environmental- and comfort factor are part of the attitude of an individual within the Theory of Planned Behaviour (TPB) and the social factor is the subjective norm that represents the influence of other individuals. The third component of the TPB is the Perceived Behavioural Control (PBC), Muelder & Filatova (2018) operationalize this value with a probabilistic affordability barrier. All household have the opportunity to cross this barrier, but if a household has a higher income, it has a higher chance to cross it (Table 7, equation 5). In appendix B a graph of the income threshold is presented for the different incomes in this graduation study.

Table 7: adapted from (Muelder & Filatova, 2018)

ABM	PBC Barrier	Utility resolution mechanism	Functional form
MF	$th_{inc} = \frac{e^{(x-\bar{x})}}{1+e^{(x-\bar{x})}}$ $th_{inc} > r$ (5)	Myopically choose the maximum	$U_{RR,MF} = w_{eco} * u_{eco} + w_{env} * u_{env} + w_{soc} * u_{soc} + w_{cof} * u_{cof}$ (6)

th_{inc} - income threshold, $\bar{x}$ - average income, x - household income, r - random number 0-1, U - multi-attribute utility, w - preference/weight of each individual agent for a specific factor, Definitions and equations for u_{eco}, u_{env}, u_{soc}, u_{cof} are listed in Table 6

5.3.3 The household characteristics check

As explained in section 2.7.2 characteristics of households influence the pro-environmental behaviour (PEB) of these households. Section 4.2 showed which characteristics influence this behaviour and are taken into account in the present study. The educational level of households, whether they own their dwelling or not, the amount of neighbourhood vegetation and the size of the nearby heat stress are combined by multiplying their influences. These influences are presented in section 6.2.1.9 and in appendix B. This way a household with the highest values for these characteristics will still have a 100% chance of investing, but the chance of households with other characteristics is lower. Household income is also mentioned in section 4.2 but is already taken into account within the Perceived Behavioural Control factor of the TPB and is therefore not added again here.

5.3.4 Owners' association influence

Section 4.3 discusses that in owners' associations two third or more households need to be for a sustainable investment, otherwise it will not be implemented. In the model for this graduation study all households living in an apartment dwelling are part of an owners' association (VVE). These thus need to check whether this requirement is fulfilled. For the present study the assumption is made that 75% or more households in a VVE need to support the investment in a specific UHI mitigation solution. This is higher than the two thirds mentioned by Van Riet (2016) as for some VVE's the requirement is higher. This choice could result in an underestimation of the amount of adopted UHI mitigation solutions by VVE's, as for some of them the requirement is lower. However, in the standard model setup the amount of households per VVE is four, so there is no difference between two thirds and 75% of households. This requirement is checked by one of the households in the VVE that is the head of the VVE. This household also created the VVE with closely located random other households that live in apartments during the model setup. This 'VVE head' household checks the preferences of the households in the VVE after they decided whether they have a preference for one or more UHI mitigation solutions or they do not want to invest in a solution. If the 75% requirement is reached this household also makes sure that the other households change their properties to make clear they have implemented a solution.

5.3.5 Implementing a solution

When a household, the head of a VVE or a household living in a dwelling owned by a housing corporation has decided to invest in a specific UHI mitigation solution this solution is implemented by changing the properties of the household, several global parameters tracking the implementation of solutions and the nearby air temperature in the case of a green façade or green garden or when the municipality decided at the start of the model run to change one of the squares in the area. If this is the case the characteristics of that mitigation solution indicate the temperature influence and the radius of this influence. For green and cool roofs the impact on the air temperature in a Local Climate Zone (LCZ) is determined at the end of each model run with the implemented percentage of each of these solutions per LCZ.

5.3.6 Overview of household decision process

Figure 21 shows the individual decision-making process of a household in the MF architecture adapted from Muelder & Filatova (2018). Households first check whether their income probability is above a random threshold value (Table 7, equation 5). Then households calculate the overall utility of the four influencing factors with the weights of these factors (Table 7, equation 6). After determining the highest multi-attribute utility households check whether this is higher than the current utility of not taking action. When they decide to adopt a solution they update different properties and when they do not decide to adopt a solution they go through the whole process again in the next timestep.

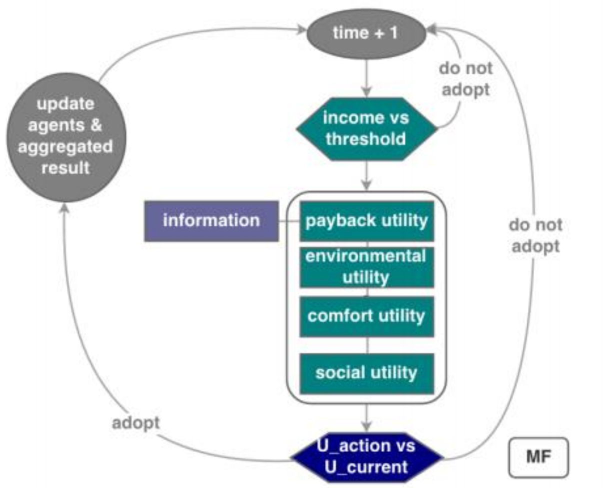


Figure 21: TPB-based architecture of an individual decision-making process. Adapted from "One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models," by H. Muelder and T. Filatova, 2018, Journal of Artificial Societies and Social Simulation, 21(4), p. 5.

5.4 Evaluative criteria

In this section the evaluative criteria of this graduation study are presented. These criteria show the effects of different input parameters and help with determining the results of the sensitivity analysis and experiments. Because these criteria show the performance of the model they are also known as key performance indicators (KPIs). Table 8 presents these KPIs. The first three KPIs are presented on Local Climate Zone (LCZ) level and aggregated to the whole Bomen- en Bloemenbuurt. The others are not presented on LCZ level. The fraction of households that have implemented a solution, the total costs and total subsidies will be presented per solution and in total. This will result in a total of 55 indicators.

Table 8: Description of the key performance indicators

Key performance indicator	Unit	Description
Average air temperature	°C	Current average air temperature (of the LCZ)
Maximum air temperature	°C	Current maximum air temperature (of the LCZ)
Fraction implemented	%	Percentage of dwellings that have implemented a (specific) solution (per LCZ)
Total costs	€	Total costs of all implemented (specific) solutions
Total subsidies	€	Total subsidies given to households or VVE's that have implemented a solution
Fraction implemented per educational level	%	Percentage of households that have implemented a solution per educational
Fraction implemented per income level	%	Percentage of households that have implemented a solution per income level
Fraction implemented per ownership type	%	Percentage of households that have implemented a solution per ownership type
Fraction implemented per dwelling type	%	Percentage of households that have implemented a solution per dwelling type
Fraction implemented by non-social households	%	Percentage of non-social households that have implemented a solution

The KPI 'fraction implemented' is not the percentage of the total amount of households in the area that have implemented an UHI mitigation solution. This percentage is of the total amount of households that are able to implement an UHI mitigation solution. Only 25% of households that live in social rented apartments are thus included in this number as they live in the same building that is only able to invest in one green roof, green façade, green garden or cool roof (as explained in section 5.1.5). Also, households that form a VVE together are counted as one dwelling as they live in the same building.
For the other five KPIs about the 'fraction implemented …' for a specific type of household, households living in social rented apartments are not included as their decision does not depend on this type and households that form an owners' association (VVE) are seen as separate households as they all decide to invest in the solution that is adopted by the VVE.

5.5 Hypotheses

For this graduation research several hypotheses are constructed after a thorough study of the available literature on the subject of UHI mitigation and pro-environmental behaviour. These hypotheses are formulated considering the model should answer the four sub-questions of the present study:

1. *"How do technical characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
2. *"How do household characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
3. *"How do institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
4. *"How do characteristics of residential environments influence the adoption of Urban Heat Island mitigation solutions."*

These hypotheses are separated per research question. They investigate per sub-question whether the effects found in literature can also be seen in the model or that they are mitigated by other effects. The first set thus investigates the technical characteristics, the second the household characteristics

and the third the institutional characteristics. The hypotheses combined with the answers to the sub-questions answer the main research question:
"How do technical, household and institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"

Hypotheses sub-question one:
H1.1 Urban Heat Island mitigation solutions with lower costs have a higher adoption rate.
H1.2 Urban Heat Island mitigation solutions with a larger temperature reduction effect have a higher adoption rate.
H1.3 Urban Heat Island mitigation solutions with a larger energy reduction effect have a higher adoption rate.

Hypotheses sub-question two:
H2.1: Households with a higher education level adopt more UHI mitigation solutions.
H2.2 Households with a higher income adopt more UHI mitigation solutions.
H2.3 Households that own a dwelling adopt more UHI mitigation solutions.

Hypotheses sub-question three:
H3.1: Households that are part of a VVE adopt less UHI mitigation solutions.
H3.2: Increasing the amount of available subsidy increases the overall implementation of the subsidised solution.
H3.3: Performance agreements with housing corporations also increase the adoption of solutions by other households.

Hypotheses sub-question four:
H4.1 Neighbourhoods with a compact LCZ have more adopted UHI mitigation solutions compared to open LCZs.
H4.2 Neighbourhoods with a low rise LCZ adopt more green- and cool roofs than midrise LCZs.
H4.3: Neighbourhoods with more vegetation have more adopted UHI mitigation solutions.
H4.4: Neighbourhoods with a higher average temperature have more adopted UHI mitigation solutions.

5.6 Concept formalization

In the concept formalization the decomposed elements are transformed to be able to fit the Netlogo software that will be used to make the ABM for this graduation research. Table 9, 10 and 11 show the states of agents and objects and the actions of agents. These states are formalized in different basic concepts for the modelling language to understand them. Van Dam et al. (2013) present a non-exhaustive list of these concepts:

- "Numbers (of various formats, e.g. integer (N) or floating point (R))
- Strings (a string of characters, essentially text)
- Booleans (representing truth values in logic, which can have a value of TRUE or FALSE)
- Objects (elements containing both data and functions)
- Classes (types of objects)
- Lists and tables (of various types, containing any of the above)." (K. Van Dam et al., 2013), p.83)

The households living in social dwellings are seen as the 'basic' households. The households living in single-family dwellings have the same states and actions as the households living in social dwellings, but with the extra ones mentioned in the column of those households. The households living in apartments in turn have the same states and actions as households living in social dwellings combined with households living in single-family dwellings and the ones mentioned in the column of those households. A patch is the smallest level of detail in the agent-based model (see also section 6.2.3.2).

Table 9: States and actions of households

Households living in social dwellings	Households living in single-family dwellings	Households living in apartments
States	**States**	**States**
Location, xcor & ycor *(float)* Local Climate Zone *(integer)* Income *(float)* Income class *(integer)* Education level *(integer)* Dwelling type (string) Ownership type (string) Roof type (string) Roof surface *(float)* Façade surface *(float)* Implemented solution? *(boolean per solution)* Costs of implementing a solution *(float)* Subsidy for implementing a solution *(float)* Friends (list of agents) Amount of friends *(integer)* Chance at random friend *(float)* Implement solution this tick? *(boolean per solution)* Owns solution? *(boolean)*	Average neighbourhood vegetation *(float)* Chance at starting with a green roof *(float)* Chance at starting with a green garden *(float)* Weights for TPB factors *(float)* Income probability *(float)* Income threshold *(float)* Social factor for each solution *(float)* Economic factor for each solution *(float)* Economic utility for each solution *(float)* Environmental utility for each solution *(float)* Comfort utility for each solution *(float)* Social utility for each solution *(float)* Multi attribute utility for each solution *(float)* Influence of household characteristics *(float)* Nearby average temperature *(float)*	VVE neighbours *(list of agents)* Amount of VVE neighbours *(integer)* Head VVE? *(boolean)*
Actions	**Actions**	**Actions**
Connect to friends Calculate implementation costs per solution Calculate subsidy Implement specific solution Update personal and global parameters	Determine attribute utility of each solution Determine multi-attribute utility of each solution	Determine if VVE head? Connect to households in VVE Check whether majority of VVE supports a solution Sum the multi attribute utility of all households in the VVE for each solution

Table 10: States and actions of the municipality

Municipality
States
Subsidy for green roofs *(float)* Subsidy for green gardens *(float)*
Actions
Make performance agreement with housing corporations Change the surface of squares, lawns and parks Determine subsidy height

Table 11: States and actions of the mitigation solutions and patches

UHI mitigation solution (object)	Patch (object)
States	**States**
Temperature reduction *(float)* Temperature reduction radius *(integer)* Temperature decline *(float)* Energy reduction per LCZ *(float)* Environmental factor for each solution *(float)* Comfort factor for each solution per LCZ *(float)*	Surface characteristics *(string)* Within area? *(boolean)* Local Climate Zone *(integer)* Square? *(boolean)* Original air temperature *(float)* Current air temperature *(float)* Temperature difference to original *(float)* Distance to solution *(integer)* Temperature influence of specific solution *(float)*

6. Model implementation

In this chapter the data that is used in the model is described. First the different data sources are briefly discussed in 6.1, secondly section 6.2 elaborates on the data preparation before it could be used in the model. Thirdly in 6.3 the validation of the different input parameters is presented, and fourth section 6.4 summarizes how the verification of the model is executed during the model build.

6.1 Data sources

The data used for the model in this graduation research comes from a wide variety of sources. The most important sources are the different governmental bodies in the Netherlands that provide general information about all kinds of subjects and scientific literature. These bodies are Statistics Netherlands (CBS), The Hague in numbers (DHIC) and Netherlands Environmental Assessment Agency (PBL). The data from these sources is mostly used to set the initial fixed values of the model. The input from scientific literature mainly covers the properties and effects of the different UHI mitigation solutions and the starting air temperature in the area. If these sources could not provide the right information, data from other internet sources is used.

Most of the model setup was based on data from DHIC, this municipal organization collect all kinds of information about the city of The Hague and share this data so it can be used in different phases of policy and project processes (DHIC, 2021). The data about income and education distribution, different dwelling types, dwelling ownership types and the amount of existing green roofs in the area are from this source. CBS data is used for the composition of owners' associations (VVE's) in The Hague and data from the PBL showed the average roof and façade surface area of different dwelling types in a Dutch city. The exact location and amount of dwellings in the Bomen en Bloemenbuurt is retrieved from the BAG (the basic registration of addresses and buildings) (BAG, 2020). The initial number of green gardens and neighbourhood vegetation came from the company Cobra Groeninzicht (D. Voets, personal communication, 06-03-2021 & 12-03-2021). Almost all properties of Urban Heat Island (UHI) mitigation solutions such as the temperature reduction per Local Climate Zone (LCZ), radius of temperature effect, the temperature decline and energy reduction came from scientific literature. Only for the amount of energy reduction other internet sources were needed as well. The starting air temperature in the area also came from scientific literature. Lastly the costs of the UHI mitigation solutions came from a variety of internet sources to make sure the chosen values were a representative average of multiple inputs. For all household related inputs data of the whole city of The Hague is used to be able to generalize the results of this graduation study to other cities and neighbourhoods that are similar to The Hague. For other input data regarding the environment of the area, such as the input temperature and surface of squares, it was chosen to use the data of the Bomen en Bloemenbuurt as this district is used as case study in the present research.

6.2 Data collection and preparation

In this section the sources for all input data, how this data was prepared for the model and the sensitivity analyses for some of this data is presented. First the household data is discussed, then the properties of the different UHI mitigation solutions and lastly the remaining environmental values are presented. This section presents the important parts of the data preparation, for some input data a more extensive preparation is needed and extra information about that preparation is presented in appendix B. For each discussed input is clearly stated if more information can be found in this appendix. This is also true for the sensitivity analyses. As some analyses show a lot of effects and others only a few, this section presents the important changes and appendix B shows more information if needed.

Briggs et al. (2012) explain that four main uncertainty types can be identified in agent-based models (ABM). These are stochastic uncertainties, parameter uncertainties, heterogeneity and structural uncertainties. Three of these uncertainties are investigated through the sensitivity analyses in this graduations research. The stochastic uncertainty is reduced by running multiple repetitions of the same input variables. The model had 100 repetitions for the standard model input, 50 repetitions for the different experiments and 30 for the sensitivity analyses. The amount of repetitions is reduced for the sensitivity analyses as the time for this graduation research is limited and the model of this research can do between 150 and 200 runs in one hour. The amount of 30 repetitions makes sure that the sensitivity analyses will not take more than three complete work days to run. The model choice that households can be part of multiple owners' associations is an example of a structural uncertainty. This choice and its effects on the model outcome is explained in section 6.2.1.7 and appendix B. The choice to focus on the model architecture based on the research by Muelder & Filatova (2018) is also made to reduce the structural uncertainty and this choice and its effects are discussed in appendix C. The other sensitivity analyses belong to the parameter uncertainty of the model used for this graduation research. Table B.1 in appendix B presents the input variables that are investigated through sensitivity analyses and their different inputs. These analyses are performed with the OAT (one-at-a-time) approach (ten Broeke, van Voorn, & Ligtenberg, 2016). This method changes one input value at a time and investigates its effects on the model outcomes to see whether there is a significant difference in the model outputs when this input value is changed. This method is chosen as it can show whether changing the input value with a fixed percentage has a significant effect on the model outcomes and the uncertainty of this value is thus important to the model outcome. To be able to decide whether the outcomes of the sensitivity analyses have a significant difference the 2.5th and 97.5th percentile outcome of the 30 repetitions are investigated. If these do not overlap between two different input values it is concluded that the outcomes have a significant difference, as 95% of the outcomes lie between these percentiles and do not overlap in such a case. The outcomes of the sensitivity analyses are presented in a separate Excel file.

6.2.1 Households

Most of the household data is from the DHIC (2021) and can be retrieved per year. However, not all data is available up to the most recent year of 2020. Therefore, some data is from 2019 or 2018. The amount of households in the Bomen en Bloemenbuurt and their geographical location in the area is retrieved from the BAG (2020), the basic registration of addresses and buildings. This source is used to distribute the households in the Local Climate Zones (LCZs) identified in the Bomen en Bloemenbuurt in section 3.2. Table 12 presents the amount of households per LCZ. This adds up to 7862 households for the whole area. However, DHIC (2021) indicates that there are only 7592 households in the Bomen en Bloemenbuurt, which is a difference of 3.43 percent. For this graduation research the data from the BAG (2020) is used as the geographical distribution of households is needed. Future research could investigate why these two data sources are different.

Table 12: Amount of households per LCZ (based on BAG, 2020 data)

LCZ	Households	Percentage of total amount
LCZ3	5962	75.83%
LCZ5	959	12.20%
LCZ6	760	9.67%
LCZ9	181	2.30%

6.2.1.1 Income

The income data of the municipality of The Hague is presented in quintiles. The boundaries of these quintiles are chosen based on the income of all households in the Netherlands, each quintile contains twenty percent of all households. Table 13 presents the boundaries per quintile for the year 2018 (DHIC, 2021).

Table 13: Quintile boundaries in 2018 (DHIC, 2021)

Year	1st quintile	2nd quintile	3rd quintile	4th quintile	5th quintile
2018	< € 21 100	€ 21100 - € 30 300	€ 30 300 - € 42 800	€ 42 800 - € 59 800	> € 59 800

The DHIC (2021) presents the cumulative percentage of households per quintile for the year 2018, These have been recalculated into percentages of all households in table 14.

Table 14: Percentage of households per quantile in the year 2018 (DHIC, 2021)

	1st quintile	2nd quintile	3rd quintile	4th quintile	5th quintile
Cumulative percentage The Hague	27.2%	48.4%	67.2%	82.7%	100%
Percentage of households The Hague	27.2%	21.2%	18.8%	15.5%	17.3%

Within the model, households get their income assigned following a uniform distribution based on the percentages in table 14 and boundaries presented in table 13. This means that households in the first four quantiles all get a random income assigned within that quantile and the average value of the incomes within a quantile lies at the middle of that quantile. For the households with an income in the 5th and highest quantile this is not possible, because this quantile does not have a maximum value. Therefore, those households all get assigned the boundary value of the fifth quantile. Appendix B discusses the difference between the income distribution used in the model and the distribution in the whole of the Netherlands and the Bomen en Bloemenbuurt specifically. It also presents the graph of the income threshold that is calculated based on the income of households.

6.2.1.2 Education

The model uses data for three education levels from the DHIC (2021): Low educational level that includes elementary school, VMBO (pre-vocational education) and the first three years of HAVO (senior general secondary education) and VWO (pre university education); Intermediate educational level, which includes having finished HAVO, VWO or level 2, 3 or 4 MBO (secondary Vocational Education and Training) and high educational level, consisting of university education (HBO and WO). This data is presented in table 15 for the year 2019 (DHIC, 2021). In literature about the effect of educational level on pro-environmental behaviour from other countries, other educational distributions are used. These are addressed in section 6.2.1.9. The education data of the DHIC (2021) shows the level of all individuals living in that area between fifteen and 74 years old, while this graduation study considers whole households. Unfortunately specific information about the educational level of households in these areas could not be found. As it is possible that individuals with a different education level belong to the same household, the outcome of the present study could underestimates the effect of the educational level. In the real world a household with one or two intermediate of highly educated parents can have one, two or three children with a low or intermediate educational level that are still in school or university. This household would rank as high or intermediately educated in the real world, but in this graduation research the existence of lower educated children result in more households with a lower education. Having more lower educated households in the present research could also happen the other way around with intermediate or high educated children and low educated parents. These aspects should be taken into account while looking at the results of this graduation study.

Compared to the whole of the Netherlands the city of The Hague has more inhabitants with a lower educational level as well as more citizens with a high educational level. This could result in an overestimation of the amount of Urban Heat Island (UHI) mitigations solutions implemented compared the the whole country if the positive influence of being high educated is significantly large. Specifically in the Bomen en Bloemenbuurt, which is used as case study in this graduation research, the difference is even larger and there are much more households with a high education. This means that the outcomes of the present research will probably underestimate the amount of adopted UHI mitigation solutions if the positive influence of having a higher education has a significant influence when comparing them to the real world Bomen en Bloemenbuurt. However, to be able to generalize the results of this graduation study to other cities, similar to The Hague the data of the whole city of The Hague is used.

Table 15: Distribution of educational level in The Hague and the Netherlands (DHIC, 2021)

Educational level	**The Hague in 2019**	**The Netherlands in 2019**	**Bomen en Bloemenbuurt in 2019**
Low	31%	28%	18%
Intermediate	35%	41%	33%
High	34%	30%	49%

6.2.1.3 Dwelling type

Within The Hague there are two main types of dwellings: single-family houses that are detached, semi-detached or terraced dwellings and are occupied by one single family, and apartment houses, which are often located on a single story and part of a larger building that contains multiple apartments. The data for the year 2020 (DHIC, 2021) also shows a ‘rest’ category (table 16), to be able to use the data for this model the ‘rest’ percentage is divided between the two other categories, through dividing those percentages by 98.2 and multiplying them with 100. This way the existing proportions between the two categories were preserved. Table 16 shows the percentages from the DHIC (for the year 2020), the percentages used in the model and in the Bomen en Bloemenbuurt that is used as a case study.

Table 16: Distribution of dwelling types in The Hague (DHIC, 2021)

Type of dwelling	**The Hague in 2020**	**Model input**	**Bomen en Bloemenbuurt in 2020**
Single-family	21.9%	22.3%	13.9%
Apartment	76.3%	77.7%	85.3%
Rest	1.8%	0%	0.8%

As input for this graduation research the distribution of dwellings types in the whole of The Hague is used to be able to use the outcomes of this graduation study for other cities in the Netherlands with similar Local Climate Zones (LCZs) or other areas in the Hague. However, the amount of single family dwellings in the Bomen en Bloemenbuurt is higher than in The Hague, therefore when specifically zooming in at this neighbourhood the influence of owners' associations (VVE's) can be underestimated as there are less apartments in the model used for the present study. Furthermore, the total surface area of roofs and thus costs of implementing green and cool roofs is probably underestimated for this specific neighbourhood as apartments have a lower average roof surface per households than single-family dwellings (section 6.2.1.4). Despite these differences the data for the whole of The Hague is chosen to be able to generalize the outcomes of the present study to other areas or cities that are similar to the Bomen en Bloemenbuurt and The Hague.

6.2.1.4 Dwelling properties regarding roof and façade surface

Apart from single-family dwellings and apartments, the model uses another dwelling distribution to determine the costs for a household of installing a green roof, green façade or cool roof. These costs are calculated based on research by the PBL into the average amount of roof surface available for solar panels per household (Vreugdenhil, 2014). The present study takes obstacles such as chimneys and dormer windows into account, but also has a safety margin of 20 centimetres around the eaves. As this is a study into the amount of roof surface fit for solar panels it also takes the surface of sloped roofs into account, which is larger than the flat roof surface if that building had a flat roof. Green roofs can only be implemented on flat roofs or roofs with a small slope, otherwise the costs will increase as extra materials are needed to prevent the green layer from sliding of the roof. As explained in section 3.2 the modelled neighbourhood has almost only flat roofs and it is thus assumed all roofs in the model have flat roofs. However, by using the surface data from the PBL, the amount of roof surface could be overestimated, because of the difference between the surface of a sloped and flat roof. On the other hand Vreugdenhil (2014) takes a safety margin of 20 centimetres around the eaves into account in the average roof surface and Planbureau voor de Leefomgeving & DNV GL (2014) state that the amount of obstacles is probably overestimated as parts of the roof with a higher slope than the most common one are also seen as obstacles. These two characteristics of the research of Vreugdenhil (2014) have an opposite effect and it is therefore assumed that the overall deviation is acceptable. Vreugdenhil (2014) takes thirteen different dwelling types into account and has calculated the percentage of properties that belong to each type for the city of Utrecht and their average roof surface per household. These percentages are presented in appendix B. For these outcomes Vreugdenhil (2014) has used input data from 2006, 2011 and 2013. The DHIC does not have the same data for thirteen types of dwellings for The Hague but does present a distribution of the total amount of dwellings in nine different types for the year 2020 (DHIC, 2021), which are also presented in appendix B.

To be able to use the average roof surface per household by Vreugdenhil (2014) for the DHIC data of The Hague, this data is transformed into the dwelling types used by Vreugdenhil (2014). Appendix B explains how this transformation is performed. As the input percentages for the model are the percentages with regard to the overall dwelling type, single-family dwelling or apartment, presented in the previous section, the input percentages in the model sum to 200 (table 17).

Table 17: Dwelling type and model input, adapted from Vreugdenhil (2014) and DHIC (2021).

Dwelling type	**Model input**	**Average roof surface per household (m^2)**
Vrijstaand (detached)	3.59%	79.6
TweeOnderEenKap (semidetached)	7.62%	64
Rijtjeshuis (terraced dwelling)	88.78%	43.5
FlatTot4 (flat until 4 floors)	11.84%	26.5
Flat4 (flat higher than four floors)	41.57%	20.1
EtageWoning (storey dwelling)	39.51%	35.9
Appartement (apartment)	7.08%	43.7
Total	200%	

Internet sources are used to come to the average façade surface per dwelling type (duurzaamheidsvergelijker.nl, 2021; homedeal.nl, n.d.a; info-en-advies.nl, 2021; Klijn, 2021; Viveen, 2021). Different sources about the façade surface excluding windows are combined to come to the surfaces in table 18. These are then divided by four in case of a detached dwelling, by three for semi-detached dwellings and by two for all other dwellings to achieve the surface of one side of a dwelling, which is used in the model.

Table 18: Total façade surface and model input per dwelling type

Dwelling type	**Total façade surface (m^2)**	**Model input (m^2)**
Vrijstaand (detached)	150	37.5
TweeOnderEenKap (semidetached)	100	33.3
Rijtjeshuis (terraced dwelling)	55	27.5
FlatTot4 (flat until 4 floors)	25	12.5
Flat4 (flat higher than four floors)	25	12.5
EtageWoning (storey dwelling)	25	12.5
Appartement (apartment)	25	12.5

6.2.1.5 Dwelling ownership

There are three different types of dwelling ownership in the model: owner occupied dwellings, private rent dwellings and low rent residential. The last category is part of the social housing stock in the Netherlands and these dwellings are owned by housing corporations. Table 19 shows the data presented by DHIC (2021) for the year 2020. The rest category is divided among the other three categories while preserving existing proportions. It also shows the specific values for the Bomen en Bloemenbuurt. In this district are much more owner occupied and less low rent residential dwellings than in the whole of the Hague. This will affect the reliability of the outcomes when these are applied to this district. Because the amount of owner occupied dwellings is lower in the model input, the total fraction of adopted solutions is underestimated compared to this district, as owner occupiers have a larger chance to perform pro-environmental behaviour (section 4.2). However, at the same time the amount of adopted solutions is overestimated because of the low amount of low residential dwellings in the Bomen en Bloemenbuurt compared to the model input, as in the standard model performance agreements with housing corporations make sure that these corporations also implement Urban Heat Island (UHI) mitigation solutions.

Table 19: Dwelling ownership in the Hague in 2020 (DHIC, 2021) and model input

Dwelling ownership	The Hague in 2020	Model input	Bomen en Bloemenbuurt in 2020
Owner occupied	44.1%	44.54%	68.5%
Private rented	23.5%	23.74%	25.5%
Low rent residential	31.4%	31.72%	5.8%
Rest	0.9%	0%	0.1%

6.2.1.6 Existing green roofs

Data from DHIC shows that there was 127,760.2 square metres of green roofs in The Hague in 2019 (DHIC, 2021). According to a subsidy regulation of the municipality of The Hague from 2016, 0.3% of the total amount of available flat roofs were green roof in 2015 (overheid.nl, 2016). This was 38000 square metres at the time and overheid.nl (2016) states that there was still 11,300,997 square metres available, which is 99.7 percent according to the subsidy regulation. This means there is a total amount of 11335002 square metres of flat roofs available for green roofs in The Hague. Thus in 2019 1.13% of these were already green. This percentage is used in the model as data for 2020 is not available in DHIC (2021).

6.2.1.7 Number of VVE's

All households living in the dwelling type apartment instead of single-family are part of an owners' association (VVE) that makes decisions about maintenance to and investments in the property (A. Kennis, personal communication, 08-01-2021). Table 20 shows the size of the VVE's in The Hague for 2015 (CBS, 2015).

Table 20: Number of VVE's and their size in The Hague (CBS, 2015)

Number of VVE's	Number of apartment rights per VVE in 2015										
Total	0[2]	1 t/m 2	3 t/m 5	6 t/m10	11 t/m 20	21 t/m 50	51 t/m 100	101 t/m 200	201 t/m 500	501 t/m 1000	>1000
22920	80	7870	10595	2475	615	740	335	140	45	5	0
99.91%	0.35%	34.34%	46.23%	10.80%	2.68%	3.23%	1.46%	0.61%	0.20%	0.02%	0.00%

Table 20 shows that 91.36% of VVE's in The Hague have between 1 and 10 apartments in them, with most between 3 and 5. Although a smaller percentage of VVE's has between 6 and 10 apartment rights than between 1 and 2, the total amount of apartment rights within the category of 6 to 10 apartments is bigger if the median of 8 and 1.5 are considered (2475 * 8 = 19800; 7870 * 1.5 = 11805). This is supported by the interview with A. Kennis that mentioned that most VVE's in The Hague consist of three, or 6 apartments (A. Kennis, personal communication, 08-01-2021). Therefore, as input for the model, a standard amount of 4 apartments per VVE is chosen. However, because of the way the model creates VVE's, not all of them will consist of exactly 4 households. Appendix B explains the effects of this limitation for the model outcomes.

The effects of this choice are investigated with a sensitivity analysis, two model options, one where VVE's consist of four households and households that are not head of a VVE can have a connection with multiple VVE heads, and one where VVE's consist of four households and non VVE head households can only have a connection with one VVE head. There are significant differences between the results of the total adopted fraction of solutions, between the adopted fraction of specific solutions, between the costs and the adopted fraction of different household groups. Appendix B discusses these differences.

The effects of a difference of the input for the number of households per VVE is investigated with a sensitivity analysis that includes two, four, six and eight households per VVE. These different inputs have several significant effects on the average and maximum temperature, the total adopted fraction and other KPIs. These are presented in appendix B.

6.2.1.8 Household friends

If friends of a household have adopted a certain UHI mitigation solution, the chance this household also adopts that solution increases. These friends are created based on a small-world network that is used by Muelder & Filatova (2018). The links with friends are based on the proximity of those friends to the household and the specific income class of the household, as research shows that homophily plays a large role in the forming of community structures (Rai & Robinson, 2015). Households can only form a friend connection to another household in the same income class. The income classes are based on the CBS distribution into low, middle and high income. The first and second quintile are part of the low-income class, the third and fourth quintile are middle income, and the fifth quintile is part of the high-income class (Van den Brakel & Ament, 2010).

In Muelder & Filatova (2018) the geographical proximity is 10 kilometres. However, Rai & Robinson (2015) found that a proximity of 610 metre had the "strongest locational clustering of solar adopters" (Rai & Robinson, 2015, p. 170). For this graduation research the model by Muelder & Filatova (2018) is used as example, so their input is used in this model. As the Bomen- en Bloemenbuurt is about 750 metres wide and 2.1 kilometres long, this means all households in the area can form a friend connection with each other, if they belong to the same income class.

Part of the small-world network is the possibility of having a random friend outside of the maximum proximity and, for this model, the specific income class. In Muelder & Filatova (2018) the chance of having a random friend is available in the model, but it's value is set to zero. Rai & Robinson (2015) use a chance of ten percent. That value will be used in this model as it is expected that households do sometimes form a friendly connection outside of their own income class.

The amount of connections with friends in the model is adopted from Muelder & Filatova (2018) and thus set to 3. However according to Dunbar (1992) humans can have up to 150 friendly connections of which 15 are close friend and 5 are intimate. The sensitivity analysis thus investigates the influence of having 5, 10 or 15 friendly connections. Increasing the amount of friends creates a significant difference between the total adopted fractions of LCZ3 and LCZ9. Furthermore, the fraction of green gardens implemented reduces significantly with 0.0144 (=1.44% of households) for five friends and 0.0115 (=1.15% of households) for 10 friends. In the standard model with 3 friend the difference between the adopted fraction of non-social tenants living in apartments is not significant from non-social owner occupiers living in single-family dwellings. However, for five, ten of fifteen friends this difference is significant despite the fact that the changes within the groups itself are not significant. Furthermore the significance between the adopted fraction of non-social households that are part of a VVE compared to non-social households living in single-family dwellings disappears for 3 household friends compared to the standard model run with 100 repetitions that has the same input variables. As this sensitivity analysis only has 30 repetitions for different inputs this result is less reliable and it is assumed that the significance still exists.

6.2.1.9 Influence of household characteristics on TPB

The effect of the **neighbourhood vegetation** on the decision of households to invest in UHI mitigation solutions is derived from different literature sources. Section 4.2 described the different effects found in literature and showed that both Alcock et al. (2020) and Whitburn (2014) found a positive effect of the amount of neighbourhood vegetation. Alcock et al. (2020) find that individuals living in high green space areas (more than 75% green) show six percent more pro-environmental behaviour (PEB) than individuals living in low green space areas (less than 50% green). Whitburn (2014) used seven different vegetation levels between 32% and 56% vegetation for her research and found a difference of 0.014 and 0.043.

For this graduation study it is thus chosen to have a difference of 5% between the highest and lowest vegetation level of Whitburn (2014) on the overall value of the influence of the household characteristics. A vegetation level above 56% will thus get a value of 1 and a vegetation level below 36.8%, which is one fifth of the difference between 32 and 56 added to 32%, gets a value of 0.95. Table 21 shows the five different steps that are used as input for the model.

Table 21: Neighbourhood vegetation level and influence on PEB

Neighbourhood vegetation percentage	**Influence on PEB (model input)**
36.8%	0.95
41.6%	0.96
46.4%	0.97
51.2%	0.98
56.0%	0.99
>56%	1

The influence of the neighbourhood vegetation on the model is investigated in the sensitivity analysis where the range of the influence on the PEB is increased with ten and twenty percent. This had a very small effect on the outcomes, the total fraction adoption reduced with 0.0106 (=1.06% of households) and 0.0197 (=1.97% of households) respectively, but this change was not significant. The effect in LCZ5, which has a higher neighbourhood vegetation percentage is slightly more with 0.0133 (=1.33% of households) and 0.0240 (=2.40% of households), but these differences were also not significant. With the increase of the range the significant difference between the total adopted fraction of non-social households that are part of a VVE compared to non-social households living in single-family dwellings disappears. For an increase of the range with twenty percent this is also true for the difference in the adopted fraction of all non-social households compared to all households.

Section 4.2 also explained that nine studies found a positive effect for **educational level**, while four studies did not find a significant effect. Of these nine studies only five showed what educational levels they used and what the difference was between them. Table 22 shows these outcomes.

Table 22: Educational level and influence on PEB of literature sources

Study	Educational level	Influence on PEB
(Lam, 2006)	high / vocational school	0.121
(Martínez-Espiñeira & García-Valiñas, 2013)	secondary education or lower	0.2106
(Martínez-Espiñeira et al., 2014)	secondary education or lower	0.1543
(Patel et al., 2017)	graduate and less v.s. postgraduate and doctorate	0.1148
(Rajapaksa et al., 2018)	at least high school	0.104

Four of these studies have the same educational level, secondary education / high school. Only Patel et al. (2017) has a higher educational level and will thus not be included further. These educational levels correspond with the low and intermediate educational levels of the CBS that are used in the present study (DHIC, 2021). The average influence on the PEB of the four other studies is 0.1475, so as input for this graduation research households with a low and intermediate educational level will have an influence of 0.85 and high educational level households of 1 (Table 23).

Table 23: Educational level and influence on PEB in model

Educational level	Influence on PEB (model input)
Low	0.85
Intermediate	0.85
High	1

The influence of these values is investigated further with a sensitivity analysis where the range of this value is changed by ten and twenty percent. This has a smaller effect than the influence of the neighbourhood vegetation. The total fraction of adopted solutions reduces with 0.0106 (=1.06% of households) for a decrease of twenty percent and increases with 0.0073 (=0.73% of households) with an increase of twenty percent. However, these changes are not significant as is also true for almost all other KPI changes. Increasing the difference between the educational levels does create a significant difference between the total adopted fraction implemented in LCZ3 and LCZ9. Furthermore, the difference between the adopted fraction of non-social tenants living in apartments has become significant compared to non-social owner occupiers living in single-family dwellings. This difference is also significant in the model run where the inputs are not changed compared to the standard model run with 100 repetitions, while this difference is not significant in that standard model. As more repetitions increase the reliability of the outcomes the results of the standard model run are more reliable.

In four studies **home ownership** had a positive effect, while one showed a negative effect. Only two studies presented the exact effect of this characteristic. Millock & Nauges (2010) found an effect of 0.093, Berk et al. (1993) an effect of 0.19. The average between the two is 0.1415, so as input for the model households that rent there dwelling in the private sector have an influence of 0.86 and owner occupiers of 1. The influence of these values is investigated further with a sensitivity analysis where this value is changed by ten and twenty percent. These changes do not have much significant effects. Reducing the effect of home ownership with twenty percent creates a significant difference between the total adopted fraction in LCZ3 and LCZ9. The significant differences between the amount of adopted solutions by non-social owner occupiers of single-family dwellings compared to non-social tenants living in apartments increases when the influence of 0.86 decreases with twenty percent and decreases the other way around. Because of this effect, the difference is not significant anymore when the home ownership effect is reduced with twenty percent. The significant difference between non-social VVE households and non-social single-family households disappears with a twenty percent increase of the 0.86 ownership effect.

Another household characteristic that influences whether or not a household will adopt an UHI mitigation solution is the **nearby air temperature** of that household. Section 4.2 explained that individuals or households, which experience negative effects of something they can influence with their behaviour, will have a bigger chance to act. As the outdoor thermal comfort is mostly effected by the air temperature (L. Zhang et al., 2020), this value is incorporated in this model. Heng & Chow (2019) determined in their research in Singapore that a temperature of 26.2 degrees Celsius was a neutral temperature where no one experienced heat or cold stress. Above this neutral value, until a value of 31.6 degrees Celsius, was considered as slight heat stress. Matzarakis & Mayer (1996) found very different values in their research in Athens, Greece. They found that thermal stress was neutral between 18 and 23 degrees Celsius, people experienced slight stress until 29 degrees, moderate stress until 35 degrees, strong until 41 degrees Celsius and extreme above that. As the climate classification of Athens is more in line with the climate in the Netherlands, the findings of Matzarakis & Mayer (1996) are more important for the present research than the values of Heng & Chow (2019) from Singapore. As thermal stress is neutral until 23 degrees Celsius (Matzarakis & Mayer, 1996), the effect until this temperature should be low and increase from this value. Until 29 degrees Celsius there is slight heat stress and moderate above that (Matzarakis & Mayer, 1996). Therefore, it is assumed that the influence of the nearby air temperature will follow a S curve, just as the income, energy reduction and air temperature of mitigation solutions. However, the middle of the S curve, the average value, will be a fixed value that is considered as a tipping point around which the influence of the nearby air temperature on the chance of investing in an UHI mitigation solution rapidly increases. It is assumed that this fixed value is 26 degrees Celsius as this is the middle between the temperatures of 23 and 29 degrees Celsius found by Matzarakis & Mayer (1996). The influence of this fixed value is investigated further with a sensitivity analysis where this value is increased with ten (=28.6 degrees Celsius) and twenty (=31.2 degrees Celsius) percent as Heng & Chow (2019) found that there is only slight heat stress until 31.6 degrees Celsius in the city of Singapore and they show that these values can increase as people adjust to warmer temperatures. If these hot temperatures will become more likely in the future, people will thus get more used to them and experience less stress at the same temperature. Appendix B presents the S curve corresponding to these three different input values and discusses the effects of the sensitivity analyses. These are significant for the average and maximum temperature, the fraction of solutions adopted and thus also the total costs and subsidy.

The effect of the nearby air temperature in the model is also influenced by the **radius** around the household that is considered to calculate this temperature. It is difficult to determine what this radius should be. As households mostly live in and around their own dwelling it could be argue that only the air temperature in a small radius around their own house should be taken into account. On the other hand, they will probably go to nearby shops in their own neighbourhood, visit nearby friends, take their children to a nearby school or have other reasons why they experience a broader range of nearby air temperatures. For the present research a smaller radius of 99 metres around the dwelling of the household is chosen. The smallest level of detail in the model is a square of 9 metres in the real world (see section 6.2.3.2), so this way the radius is exactly 11 patches. This choice is made as households spend the largest amount of their time in and around their own house, even more in the current Covid pandemic and probably also afterwards. People work from home and spend even more time than before in and around their own house. If the radius is bigger, this will probably increase the average nearby temperature of households and thus increase their chances of adopting UHI mitigation solutions, as the average temperature in the model is above the fixed value of 26 degrees Celsius. There are thus more places where the temperature is above 26 degrees Celsius than below that value. However, for households in LCZ5 and LCZ9 this effect could be the opposite, as they are located close to a cool area, the park and the sports fields respectively. This could cause their average air temperature to decrease if the radius increases, up to a certain maximum of course. The influence of the radius is investigated further with a sensitivity analysis where the radius is increased to 207, 504 and 999 metres. This increase does not have a significant effect on the outcomes of the model. The mean total fraction adopted seems a little bit higher but there is no difference between the three different inputs and these differences are not significant. The difference between the total adopted fraction of non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments is significant for a radius of 504 metres, but not for other radiuses. At the same time the difference between the adopted fraction of non-social households that are part of a VVE and non-social households living in single-family dwellings is not significant with the standard model inputs, while this difference is significant in the standard model with 100 repetitions. Furthermore it is significant for a radius of 207 and 504 metres, but not for 999 metres.

6.2.1.10 Household weights

The household weights for the economic-, environmental-, social- and comfort factors used in the present study can be one of eleven different combinations (Table 24). These eleven options are adopted from the research by Muelder & Filatova (2018) that determined these weights based on a small survey of residents in the city of Dalfsen in the Netherlands. However, these weights were not tested on their representability and do not change over time. Within the time frame and scope of this graduation research it is not possible to collect a representative set of weights for a municipality like The Hague, or more specific the Bomen- en Bloemenbuurt that is used as a case study in this graduation study. It is also not possible to investigate in what way these weights would change over time as can be expected for a system that includes the behaviour of households over several years. Further research is needed to improve these weights and investigate whether and how they would change over time to improve the validity of the model.

Table 24: Eleven different household combinations for the economic-, environmental-, social- and comfort factor (Muelder & Filatova, 2018)

Weight option	Economic factor	Environmental factor	Social factor	Comfort factor
1	0.286	0.286	0.071	0.356
2	0.294	0.294	0.235	0.176
3	0.143	0.286	0.214	0.357
4	0.308	0.308	0.231	0.154
5	0.231	0.385	0.077	0.308
6	0.267	0.334	0.134	0.267
7	0.214	0.357	0.143	0.286
8	0.357	0.286	0.071	0.286
9	0.233	0.334	0.445	0
10	0.250	0.417	0.167	0.167
11	0.223	0.334	0.445	0

As these eleven weight options have a large influence on the behaviour of the households and thus the effects of the model, this input data is one of the weakest parts of the model. The overall validity would increase enormously if there was a better source for this data. However, the scope and time frame of the present study did not allow more research into these values.

6.2.1.11 Renovation years

The standard renovation time for social dwellings is set to 25 years. It is expected that after 25 years large maintenance is needed to social dwellings and during large renovations the implementation of an Urban Heat Island (UHI) mitigation solution is included (S. Ros, personal communication, 10-02-2021). In reality this value will vary up and down as sometimes renovations can be postponed but are sometimes done earlier than expected. This input value will not be part of the sensitivity analysis as the effect of changing this value is very clear, if the renovation time is extended it takes longer before the same number of social dwellings have an UHI mitigation solution.

6.2.2 UHI mitigation solutions

The characteristics of UHI mitigation solutions mostly come from the literature sources in appendix A that are consulted in the present research. However, for the costs of the solutions, internet sources are also examined.

6.2.2.1 Air temperature reduction

The influence of the UHI mitigation solutions on the outdoor air temperature is determined based on the literature research done for this study. Appendix A shows the investigated studies, which were already shortly discussed in section 2.5. For the model input only the effect of the solutions in the local climate zones (LCZs) that are present in the case study are considered. Appendix B discusses the how the results of the literature research were translated into the air temperature effects used in the model. Table 25 presents these input values per UHI mitigation solution. For green roof and cool roofs the effect depends on the percentage of this solutions adopted in the LCZ. Therefore multiple inputs are presented for these solutions. Appendix B explains for what percentage of adoption these effects increase.

Table 25: Overview of the effect of UHI mitigation solutions on the air temperature

UHI mitigation solution	**Reduction LCZ3 (°C)**	**Reduction LCZ5 (°C)**	**Reduction LCZ6 (°C)**	**Reduction LCZ9 (°C)**
Green roof	0; 0.05; 0.1; 0.25; 0.4; 0.6	0; 0.04; 0.08; 0.19; 0.30; 0.45	0; 0.05; 0.1; 0.25; 0.4; 0.6	0; 0.05; 0.1; 0.25; 0.4; 0.6
Green façade	0.25	0.55	0.25	0.25
Grass	1.2	1.1	1.2	1.2
Tree	0.8	0.6	0.8	0.8
Urban park	2.63	3.48	2.63	2.63
Pools and ponds	1	0.56	1	1
Cool pavement	1.1	1.55	1.1	1.1
Cool roof	0; 0.1; 0.1; 0.25; 0.4; 0.5	0; 0.015; 0.015; 0.04; 0.06; 0.07	0; 0.1; 0.1; 0.25; 0.4; 0.5	0; 0.1; 0.1; 0.25; 0.4; 0.5

As the influence of different UHI mitigation solutions on the air temperature is an important part of the model, it is investigated what the effect is of a change in one of these values on the outcome of the model. This is done with a sensitivity analysis that reduces and increases the reduction of each of the four solutions that households can adopt separately with 20 percent and 50 percent in each LCZ to see what the effect is on the overall outcomes. When increasing the effect of a solution, the radius of that effect should also be increased to make sure the effects are not underestimated. The next section will clarify this connection. The sensitivity analysis shows several differences in the average temperature and adopted fraction of solutions for changing the effect of green roofs and green gardens. These results are presented in appendix B.

6.2.2.2 Radius of reduction

Each UHI mitigation solution has a different radius in the model. Within this radius the effect of the solution reduces with a fixed value per patch until the effect is zero or the edge of the radius is reached. It is possible that the effect of a solution does not reach the end of the radius, because these inputs are both based on a combination of different literature sources. Not all literature that presents the effect of a solution also investigated the exact range of this solution, but these are taken into account in this graduation research as the amount of literature sources would otherwise reduce a lot. Because of this, it could also occur that the air temperature reduction effect of a solution has not yet reached zero at the end of the radius. This could lead to an underestimation of the effect of this solution on the overall air temperature. This is taken into account while determining the exact radiuses of the solutions but will also play a role in the sensitivity analysis where the air temperature reduction effects of the solutions are increased. In that case the radius of the solutions is also increased with the same percentage as the increase of the temperature effect. As will be explained in section 6.2.3.2, each patch in the model covers 9 metres in the real world. Table 26 presents the radiuses in patches and metres for each solution. Appendix B explains how these inputs were determined.

Table 26: Overview of the radius of UHI mitigation solutions

UHI mitigation solution	Radius (patches)	Radius (metres)
Green roof	Per LCZ	Whole LCZ
Green façade	1	9
Grass	7	63
Tree	11	99
Urban park	33	297
Pools and ponds	7	63
Cool pavement	9	81
Cool roof	Per LCZ	Whole LCZ

6.2.2.3 Temperature decline

It was not possible to find information in literature about the exact temperature decline for all investigated Urban Heat Island (UHI) mitigation solutions. If these sources were not available, the same temperature decline found for another solution is adopted. Table 27 shows the temperature decline of all solutions per patch in the model and per ten metres. Appendix B explains how these declines were determined from literature and which declines were based on another solution.

Table 27: Overview of the temperature decline of UHI mitigation solutions

UHI mitigation solution	**Decline (°C/patch)**	**Decline (°C/10 metres)**
Green roof	N/A	N/A
Green façade	0	0
Grass	0.162	0.18
Tree	0.194	0.22
Urban park	0.162	0.18
Pools and ponds	0.150	0.17
Cool pavement	0.162	0.18
Cool roof	N/A	N/A

As the temperature decline is a very important factor in this study, next to the temperature reduction, further research is needed to improve or confirm the input data for this model. The effects of the chosen values are investigated with a sensitivity analysis that increases and decreases the decline for each solution with ten and twenty percent. However, if the temperature decline is reduced, while the radius is not increased, the total effect of this increase is underestimated as these inputs are strongly linked with each other. The radiuses should thus be increased accordingly. Green gardens are the only solution that household can adopt that has a temperature decline. The sensitivity analysis thus only investigates this solution. A decrease or increase of the temperature decline of green gardens with twenty percent has a small significant effect on the mean outdoor air temperature of the total area. A decrease of the decline results in a decrease of the outdoor air temperature with 0.04 degrees Celsius and an increase of the decline in an increase of the temperature with 0.03 degrees Celsius. There are no other significant effects of this analysis.

6.2.2.4 Energy reduction

The energy reduction of the UHI mitigation solutions that households can implement are based on the literature collected in the literature study. Table 28 presents the percentage of energy reduction that implementing a solution will have. Appendix B explains how these values are determined.

Table 28: Energy reduction of the four solutions considered by households

Solution	**Percentage energy reduction / year**
Green roof	20%
Green façade	15%
Green garden	0%
Cool roof	9%

It must be noted that in reality the decrease in energy use will not be the same for each household. This percentage depends on the type of dwelling, the size of the dwelling and household characteristics, such as the size of the household. In this graduation research however, this percentage is kept the same for each household, as other data is not available and taking this into account greatly increases the complexity. This is also true for a different effect between LCZs. It could be the case that the energy reduction of an UHI mitigation solutions differs between LCZ. This is not taken into account as the data from literature is limited and it would again increase the complexity of the model. Future research is needed to determine whether the effects used in the present research can be confirmed and to discover whether the effect differs between LCZs.

The effect of a change in one of the chosen values on the output of the model is investigated with a small sensitivity analysis. For this analysis the values will be increased and lowered with ten and twenty percent. A change in the energy reduction of **green roofs** does not have a significant effect on the mean or maximum outdoor air temperature, but it does influence the total fraction of adopted solutions. It also significantly reduces the total costs and subsidies while there is no effect on the outdoor air temperature. Changing the effect of **cool roofs** and **green façades** only had very few effects. Appendix B discusses the effects of changing the energy reduction of these three solutions in more detail.

6.2.2.5 Costs per solution

The data for the costs of the different UHI mitigation solution is retrieved from a variety of internet sources. Different information is combined to come to a reliable cost indication. During the model runs, only households, and partly social dwellings, can make decisions to invest in a certain UHI mitigation solution. Therefore, only costs for the four solutions that households are able to invest in are used in the model. The costs for the municipality to change the surface area of a certain square is thus not investigated. This choice is made as the changes to the surfaces of squares are made before the model runs and used as input for the model. Furthermore, information about these costs is not widely available and can fluctuate enormously based on the exact choices about what kind of surface changes are done. While creating a new pond- or urban park area, different choices could lead to a big range of costs. Even for changing a currently paved square to grass or cool pavement, different choices about the square metres of grass, the decorations around the grass or the kind of cool pavement could have a big effect on the costs. Because these costs cannot be estimated reliably within the timeframe of the present study, they are excluded for all surface square options. A municipality should be able to determine the costs of changing a square itself and then decide whether they think the investment is justified.

Table 29 presents the average costs in euros per square metre retrieved from internet sources. In appendix B the specific amount of all these sources and how they are combined to the values in table 29 are presented.

Table 29: Energy reduction of the four solutions considered by households

Solution	**Costs (€/m²)**
Green garden	60
Cool roof	90
Green roof	130
Green façade	535

Within the sensitivity analysis is investigated what the effect is of an increase in the costs of each solution on the KPIs. This is done by increasing and decreasing the costs of the four solutions that can be implemented by households with ten and twenty percent. Changing the costs of **green roofs** has a significant effect on the average air temperature, total fraction of implemented solutions, total costs and subsidies. Also changing the costs of **green façades** has a significant influence on the average temperature, fraction of implemented solutions and total costs and subsidies. However, a change in the costs of **green gardens** and **cool roofs** has almost no significant influences. Appendix B discusses the specific effects of the sensitivity analyses.

6.2.3 Environment

The environment is considered here as the 'background' of the model and is thus the specific information that the patches own in the model. This includes information about the amount of neighbourhood vegetation per LCZ and the starting air temperature of the model. While most household input data used information for the whole city of The Hague to be able to generalize the results of this graduation study to other cities similar to the Hague, the data of environmental characteristics is specific for the neighbourhood of the Bomen en Bloemenbuurt. This choice is made because this graduation research investigates the different Local Climate Zones (LCZs) in this neighbourhood and the environmental characteristics in the next sections are properties of these LCZs or could be the result of the characteristic of the LCZ (the current air temperature).

6.2.3.1 Neighbourhood vegetation

The amount of neighbourhood vegetation that influence the decisions of households is derived from data of the company Cobra Groeninzicht for the year 2019 (D. Voets, personal communication, 06-03-2021 & 12-03-2021). They have done research into the total amount of hardened surfaces and the number of gardens with green and hardened surfaces in the Netherlands. Table 30 and 31 present this data for the different LCZs in the Bomen- en Bloemenbuurt.

Table 30: Amount of green surface per LCZ in 2020 (D. Voets, personal communication, 06-03-2021)

Area	Total surface (m^2)	Green surface (m^2)	Green percentage
LCZ3	819576.31	144123.63	17.59%
LCZ5	350795.81	169398.06	48.29%
LCZ6	166208.43	22714.13	13.67%
LCZ9	87944.14	44056.38	50.10%

Table 31: Amount of hardened surfaces in gardens per LCZ in 2020 (D. Voets, personal communication, 12-03-2021)

Area	Garden surface (m^2)	Hardened surface (m^2)	Percentage hardened	Percentage green (model input)
LCZ3	142474	67844	47.62%	52.38%
LCZ5	29853	11929	39.96%	60.04%
LCZ6	41114	22560	54.87%	45.13%
LCZ9	6093	3733	61.27%	38.73%
Total	219534	106066	48.31%	51.69%

It should be noted that the amount of green surfaces per LCZ takes the whole LCZ into account and thus also the green gardens and parks in the area. Because these two are also added separately at a later stage, the amount of green surface in a LCZ would be overestimated in the model.

The overestimation because of the initial number of green gardens is probably very little as each household determines whether it has an initial green garden based on the percentage of green gardens from table 31 and then changes the properties of the patch it is located on. However, because there are a lot of households that live in apartments or other types of dwellings on the same property, they share such a patch, and the patch will end up with the properties that it receives from the last household.

The overestimation because of the number of parks in a LCZ can on the other hand be relatively big. Especially if a large amount of the LCZ consists of a green park, as is the case in LCZ5 with the big park and LCZ9 with the big grass area. These areas are taken into account in the overall estimation of the amount of green in that area, but also added to the model as a specific green area at a later stage, so the effect of changing the surface of these areas can be investigated. Table 32 shows the size of these effects with the average vegetation per neighbourhood as input and after the setup of the model. The after-setup percentages are the average green percentages of fifty different model setups.

Table 32: Original amount of green surfaces per LCZ as input and after setup

Area	Green percentage (model input)	Average green percentage (after setup)	Difference green percentage after setup to Cobra Groeninzicht data
LCZ3	17.59%	24.05%	6.46%
LCZ5	48.29%	67.45%	19.16%
LCZ6	13.67%	18.52%	4.85%
LCZ9	50.10%	83.33%	33.23%

This overestimation influences the decision of households to invest in UHI mitigation solutions positively and can cause more households to invest in a solution. To counter this overestimation the green percentage input per LCZ is lowered to make sure the green percentage after setup is around the original green input percentage. The model input percentage were first lowered with the percentage point difference between the average green percentage after setup and these model inputs. However, this was not yet enough so this procedure was repeated once more. Then these values were changed one last time to reduce the difference with the input. Appendix B shows the intermediate outcomes of these changes. The final inputs into the model and averages after model setup are presented in table 33.

Table 33: Amount of green surfaces per LCZ as input and after setup after the third change

Area	Green percentage third change (model input)	Average green percentage (after setup)	Difference green percentage after setup to Cobra Groeninzicht data
LCZ3	9.02%	17.73%	0.14%
LCZ5	11.12%	48.40%	0.11%
LCZ6	7.66%	13.71%	0.04%
LCZ9	0%	69.53%	19.43%

After all these changes the neighbourhood vegetation in LCZ3, LCZ5 and LCZ6 is almost equal to the Cobra Groeninzicht data, the difference is less than 0.15 percentage point. Only in LCZ9 the amount of vegetation is still overestimated, as the input percentage cannot be lowered further. Because of this, the number of households that invests in UHI mitigation solutions is still slightly overestimated. However, the number of households in LCZ9 is only 181 of the total of 7862 (2.3%), so the effect will be relatively small.

6.2.3.2 Dimensions of patches

In the model used in this graduation research the patches have a dimension of 9x9 metres, so a surface area of 81 square metres. This choice is made as the model calculates households' decisions to invest in UHI mitigation solutions and this results in the best distribution between squares with a house and squares without. The average terraced dwelling in the Netherlands is 132 square metres with a total garden surface of 87 square metres (RTLnieuws.nl, 2019). As the model also takes the creation of a green garden into account, the average garden surface is an important factor. Next to terraced dwellings there is also a small amount of bigger detached and semi-detached dwellings in The Hague. And furthermore, a large number of smaller flats (see section 6.2.1). Therefore, the choice was made to have squares of 81 square metres instead of 100. The average size of a garden and dwelling in the model is thus 81 square metres each, which is one square. The number of squares with a dwelling in the model is checked to see whether this choice is formalized in a right way. There are a total of 7862 households in the model with 22.3% single-family dwellings. This means that there should be 1753 squares with just one dwelling on them. Furthermore, 77.7 percent of these households live in apartments, which is a total of 6109. These households are all part of VVE's with 4 households per VVE, which means that there should be 1527 (6109 / 4) patches with a VVE dwelling on them that has 4 households. Summing these results comes to a total of 3280 squares with dwellings. The model outcome shows there is a total of 3108 squares in the model that have a household on them. This is only a small difference, so it is concluded that the model does this correctly. Furthermore, the choice of having squares of 9x9 metres creates enough space between the dwellings in the model that represent the streets and also creates a relatively good spread of households among the patches in the model. Parts of the Bomen- en Bloemenbuurt with houses that have more distance between are reflected correctly in the model. This is for example the case for the flats in the North side of the area. Those have some distance between them and thus if the radius of an UHI mitigation solution taken at one flat is not large enough, it will not influence the temperature at the other flat. This is also the case for the effects of UHI mitigation solutions with a small radius over streets.

6.2.3.3 Input air temperature

The starting air temperature that is used as input in the model is adopted from the research of Ntarladima (2016). In her master's thesis she investigated a new way to dynamically examine and present Atmospheric UHI. She combined data from 140 sensors in The Hague with data from the KNMI to make a visualization of the UHI intensity of a period of hot summer days in 2015 in the city of The Hague with a 100x100 metre grid. In the present study the air temperature at twelve o clock of the hottest day of that period is used as the starting temperature in the model. The time of twelve o clock is chosen as this is the middle of the day and most literature about the effects of UHI mitigation solutions presented their results at or around this time. This is also the latest available time of the data during the heating-up phase from the research of Ntarladima (2016). For the present study the data presented by Ntarladima (2016) for the fourth of July 2015 is used. From her research can be concluded that this day was the hottest of the visualized period for the city of The Hague. This day was also very hot in the rest of the Netherlands, only the second of July was slightly warmer (KNMI, 2015), but in the data of Ntarladima (2016) the fourth of July seemed hotter for The Hague. Figure 22 shows the output data of her research in the map of the area around the city of The Hague, in large parts of the city the air temperature is above 30 degrees Celsius.

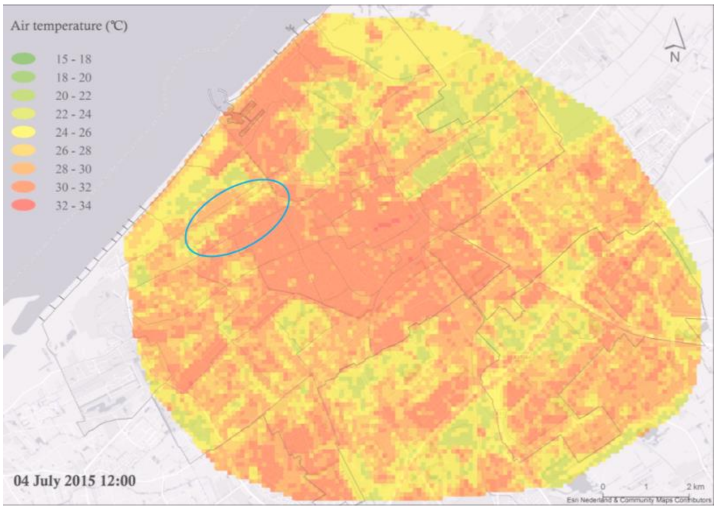


Figure 22: Modelled air temperature in The Hague for July 4, 2015 at 12:00. Adapted from Ntarladima (2016)

Figure 22 shows there is a great variety of temperatures between 24 and 32 degrees Celsius in this area. At the start of this graduation research Ntarladima was contacted to retrieve the exact output data of her research, unfortunately the exact data was no longer available. Therefore, it had to be retrieved from figure 23. Appendix B shows a zoomed in image of the Bomen en Bloemenbuurt from figure 23. Because this image uses nine temperature classes based on the minimum and maximum temperature output of the model, these classes each consist of two degrees Celsius. This means that a relatively large amount of detail from her results is lost while preparing this data to be used in this graduation study. All different temperatures within one of the classes are now seen as the same temperature, while there could be a difference of at maximum two degrees between them. To minimize the temperature change, the temperatures are put into the model as the middle of a temperature class. For example, all squares within the class 30 to 32 degrees Celsius are set to 31 degrees Celsius in the model used in the present study. Because of this, the difference with the actual value is at maximum one degree Celsius but is most likely lower for the majority of squares. This limitation in input data causes the model made for the present research to be less representative of the real world, as the 'real' temperatures could have a difference of one degree Celsius. Therefore, the specific temperature output values are less reliable when comparing them with other research or certain target values for the temperature in an area. Figure 23 shows the Bomen en Bloemenbuurt in the model and the distribution of the temperature inputs. The legend is shown to the left of the area. The white circles are the households and the blue circles are schools or hospitals. The lowest input air temperature is 23 degrees Celsius and the highest is 31 degrees Celsius.

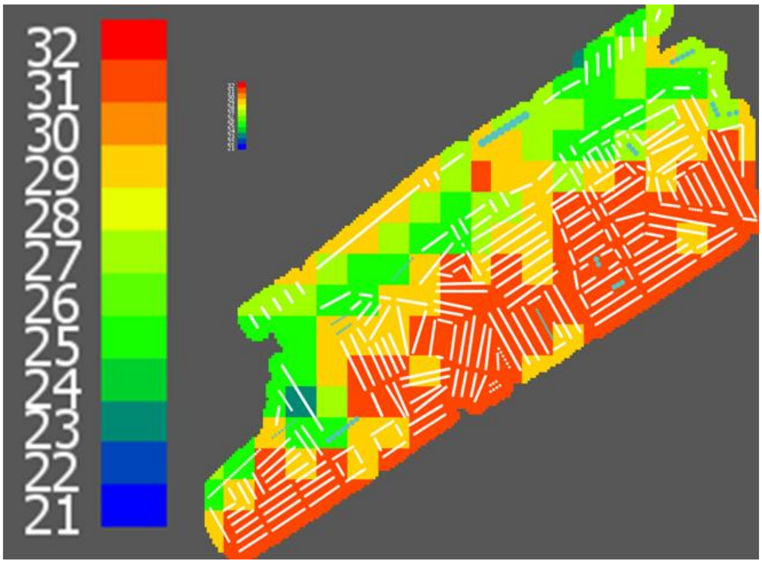


Figure 23: Overview of the input air temperature in the agent-based model

As explained in the previous section (6.2.3.2) the lowest resolution of the squares in the model used for the present study is 9x9 metres. This is much smaller than the air temperatures from the research of Ntarladima (2016) that are calculated for a 100x100 metre grid. Appendix B explains how this difference affect the outcomes of this graduation research.

The effect of an overall change of the input air temperature on the outcomes of the model is investigated with a sensitivity analysis that changes all input air temperature with ten and twenty percent. As a result of changing the input air temperature the total average temperature and maximum temperature also change with roughly the same percentage. The total fraction of implemented solutions only decreases significantly if the input air temperature decreases. Appendix B discusses more results of the sensitivity analysis.

6.2.3.4 Solutions at schools and hospitals

The eleven schools and two hospitals in the area do not have an UHI mitigation solution implemented. An internet search and Google Maps showed that there are no UHI mitigation solutions implemented on these buildings. Their behaviour is also not directly taken into account in the standard setup of the model, as it focuses on the decisions by households. Therefore it is investigated what the effects are of the implementation of one of the UHI mitigation solutions on these large buildings. As these buildings are bigger than the average dwelling, they have a bigger influence on the air temperature in the area. These effects are investigated through a small sensitivity analysis where the model is run with five different inputs that represent all schools and hospitals having implemented no solution, a green roof, green façade, green garden or cool roof. These adoptions only influence the nearby air temperature and the amount of vegetation in the area corresponding to the properties of the adopted solution. It shows that if school and hospitals implement green façades, green gardens or cool roofs the difference between the total implemented fractions of LCZ3 and LCZ6 with LCZ9 becomes significant. Furthermore, it there is a significant difference between the total fraction adopted by non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments, except for the standard model where no solutions are adopted by schools and hospitals.

6.2.3.5 Surface of squares

There are fourteen different squares in the Bomen en Bloemenbuurt, ranging from 1200 square metres for the smallest to around 130,000 square metres for the park area in the North-West of the district. The surface of these squares is used as an input in the model to be able to investigate the effects if these are changed by the municipality. The properties of the square surfaces are determined through an aerial view and pictures of these squares in Google Maps. In the agent based model these squares are presented by the names of the Greek letters they represent. Table 34 shows the surfaces of the squares and figure 24 shows a zoomed image of the Bomen en Boemenbuurt with the Greek letters on the place of the 'square'. Square μ is the complete green sports area it is located in and square ξ incorporates the complete park area in the North-West.

Table 34: Price per square metre and maximum subsidy per square metre for each mitigation solution

Square	α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	ν	μ	ξ
Surface	Paved	Park	Paved	Grass	Grass	Grass	Grass	Grass	Grass	Pond	Grass	Grass	Grass	Park

Figure 24: Zoomed image of the Bomen en Bloemenbuurt with Greek letters at the places of the squares. Adapted from https://wonenindenhaag.nl/w/wp-content/uploads/2017/03/Wijkinformatie_Bomen-en-Bloemenbuurt.jpg

6.3 Parameter set up & validation

As the previous sections explained all 'fixed' input data used for the model, this section discusses the parameters that are experimented with to be able to check the hypotheses from section 5.5. These parameters are the amount of subsidy for one of the solutions, the surface of the different squares in the model and the performance agreements the municipality can make with housing corporations.

6.3.1 Model architectures

The agent-based model (ABM) of this graduation study includes three different formalizations of the Theory of Planned Behaviour (TPB) based on the research by Muelder & Filatova (2018). In appendix C the differences between these ABM architectures are discussed. This appendix also explains why model architecture MF, based on the research by Muelder & Filatova (2018), is chosen as the focus of this graduation research.

6.3.2 Subsidies

In the starting setup of the model there are already two different subsidies incorporated. The municipality of The Hague subsidises green roofs with 25 euros per square metre, with a maximum amount of 50% of the total costs (Gemeente Den Haag, n.d.). Inhabitants of The Hague are also able to request a free tree from the municipality in 2021 and 2022 (nos.nl, 2021). Therefore, the costs of implementing a green garden in the first two model years are reduced with the average costs for planting a tree, which is explained in section 6.2.2.5. After these two years the subsidy reduces to zero euros.

For the experiments to be able to answer the hypotheses, the effect of different subsidies is investigated. As the present subsidy for green roofs has a maximum amount of 50% of the total costs of the green roof, it is assumed that other new subsidies also have this constraint. Table 35 presents the costs of the UHI solutions that households can implement and the maximum value the subsidy could be.

Table 35: Price per square metre and maximum subsidy per square metre for each mitigation solution

UHI mitigation solution	Price per square metre	Maximum subsidy per square metre
Green roof	€130	€65
Green façade	€535	€267.50
Green garden	€60	€30
Cool roof	€90	€45

As the current two-year subsidy for green gardens is already publicly presented, the subsidy for this solution will only change after the first two years. The current subsidy for green roofs is 19.23% of the price in the model and will also keep existing in all experiments. For the experiments, the investigated subsidies begins with 20 percent of the total price as this is close to the existing subsidy for green roofs. Then the maximum of 50 percent of the price will be investigated and a value in between these two, 35 percent, is investigated (table 36).

Table 36: Three different subsidy amount of the mitigation solutions

UHI mitigation solution	20%	35%	50%
Green roof	€26	€45.5	€65
Green façade	€107	€187.25	€267.50
Green garden	€12	€21	€30
Cool roof	€18	€31.5	€45

6.3.3 Surface of squares

There is a total of 14 squares in the model area that range from urban parks to fully paved squares and one pond area. The size and surface of these areas is decided with Google Maps and the type of surface is based on the most common surface type of that square.

To reduce the air temperature in an area the municipality can decide to change the surface of one or more of these squares. Through this choice it can be investigated whether changing the surface of squares will have more impact on the air temperature in the model than the UHI mitigation solutions that households can implement. With this information the municipality can decide whether it will be more effective to have a subsidy for certain solutions, to invest in changing some of the squares themselves or to have a combination of the two. This will be investigated by changing all squares with grass, except for the large sports field in LCZ9, to squares with an urban park. At the same time, the squares that are currently paved are changed to squares with cool pavements. This choice is made because it is often possible to change squares with grass to an urban park but changing a paved square to an urban park is a bigger challenge. As it is expected that the municipality would want to keep the sports fields located in LCZ9, this field was not changed.

6.3.4 Agreements with social housing corporations

Chapter 5 explained that households living in socially rented dwellings owned by housing corporations cannot decide themselves whether they want to implement one of the possible UHI mitigation solutions. The housing corporation is able to decide to invest in these solutions, based on their own policies and priorities. In the standard model, housing corporations renovate their dwellings once in 25 years and at that moment also invest in one of the UHI mitigation solutions. In the standard model they will always choose to implement a green roof. This choice was made based on the interview with S. Ros, which explained that housing corporations were slowly starting with this (S. Ros, personal communication, 10-02-2021).

As 31.72 percent of dwellings in The Hague is a socially rented dwelling, it could be interesting for the municipality to see what the effect is of the adoption of other solutions by housing corporations. If for example the adoption of a green façade, or more green gardens have a bigger effect on the air temperature in the area the municipality could try to capture this within the performance agreements with housing corporations. To investigate whether this is the case, the model will be run with the standard choice of housing corporations investing in green roofs, green façades, green gardens and cool roofs.

6.4 Verification

During the model creation the behaviour of the model, its agents and patches was continuously tracked to make sure these were as intended according to the conceptualization and formalization. The inputs, outputs and intermediate states of the agents and patches were recorded and compared to the presentation of this behaviour in the flowcharts. At the end, a single agent testing was performed for the different agents in the model. Also, single patches were investigated to check whether the model behaved according to its intentions. This section presents the most important single agent and patch tests.

Households

Check income threshold

- In architectures MF & RR non-social household will only determine the utility of UHI mitigation solutions if their income is above the threshold. **Confirmed**
- In architecture SE non-social households will always determine the utility. **Confirmed**

Check household characteristics

- The education distribution and related educational chance are correct distributed. **Confirmed**
- The ownership distribution and related ownership chance are correct distributed. **Confirmed**
- The vegetation per LCZ is correctly calculated and results in the right vegetation chance. **Confirmed**
- Household calculate their nearby air temperature correctly. **Confirmed**

Check right amount of VVE

- Households living in non-socially rented apartments are part of a VVE. **Confirmed**
- A household that is the head of a VVE only creates a link to three other households living in non-socially rented apartments. **Confirmed**

Check VVE choices

- If 75% of a VVE is in favour of one solution that solution is implemented. **Confirmed**
- If the head of a VVE decided to adopt a solution, this is also communicated with the other VVE apartments. **Confirmed**

Check highest multi-attribute utility

- Households only adopt the solution with the highest multi-attribute utility. **Confirmed**
- In VVE's the multi-attribute utility is summed together if more than 75% of the households is in favour of a solution. **Confirmed**

Check if social dwellings have right adoptions

- Only 25% of socially rented apartments adopt a certain solution if the input indicates a solution. **Confirmed**

Check right amount of deciding households

- A correct number of households can adopt a solution, single-family dwellings, heads of VVE's and 25% of socially rented apartments. **Confirmed**

Patches

Check temperature reduction after household implementation

- Patches have the correct starting temperature. **Confirmed**
- After implementation of a solution by a household nearby patches change their temperature based on the radius of the solution. **Confirmed**
- If a household closer to the patch adopts a solution the patch changes its temperature based on the solution that is closer. **Confirmed**
- When a new threshold of the green or cool roof implemented fraction is reached the effect of these solutions on the air temperature is updated. **Confirmed**

Check temperature reduction of square change

- When the surface of a square is changed, its own temperatures change. **Confirmed**
- When the surface of a square is changed to a surface with more temperature reduction, the patches within radius of the square change temperatures accordingly. **Confirmed**
- When the surface of a square is changed to a surface with less temperature reduction, the patches within the radius of the square change temperatures accordingly and thus have a higher temperature. **False**
    - o This aspect does not have consequences for the experiments of this graduation study, but does limit the potential future use of the model.

Check vegetation change

- When households decide to implement a green garden, the vegetation fraction in the area changes. **Confirmed**
- When the surface of a square changes to a grass or urban park surface, the vegetation fraction in the area changes. **Confirmed**

7. Results

This chapter presents the results of the model to help answer the different hypotheses shown in section 5.5. First section 7.1 shows the results of the standard model architecture based on the MF model made by Muelder and Filatova (2018). Appendix C explains why this architecture is chosen. For these results the model is run for 40 years and this is repeated one hundred time to reduce the stochastic uncertainty (Briggs et al., 2012) and make the results more reliable, as a lot of random values are used during the setup and model run. Then section 7.2 shows the results of the three experiments presented in section 6.3. For these experiments the model is run for 40 years, but these are repeated fifty times to improve the reliability of the results, as doing more repetitions would take too much time. Experiment one thus had 600 repetitions in total, experiment two 250 and experiment three 100. Finally section 7.3 discusses how these results answer the hypotheses presented in section 5.5. All results regarding the average and maximum temperature in this chapter are based on the air temperature on a hot summer day as was the input values for the model (section 6.2.3.3).

7.1 Results of standard model

In this section the results of the 100 repetitions of the standard MF model architecture are presented per KPI. For all KPIs a boxplot figure is presented with the outcome after the model ran for 40 years. These boxplots present the median value of the hundred repetitions with a green line in the middle. The edges of the blue box is the range that includes 50 percent of all outcomes. The whiskers up to the black horizontal lines extend up to the 2.5 and 97.5 percentile, so 95% of all outcomes lies within the edges. Outcomes that lie outside of this area are presented as dots. If there is no overlap between the 95% outcome values of two different KPIs it can be concluded that these outcomes do differ from each other. On the other hand if there is overlap between these values this conclusion cannot be drawn. When the development of the KPI during the 40 years the model runs shows an interesting curve, this graph is also presented. The graphs show the mean value of the KPI with a range around it of two times the standard deviation of the KPI value, which is the 95% confidence interval. A figure of the outcome of one of the standard MF model architecture runs is presented in appendix F.

7.1.1 Temperature KPIs

This section discusses the results of the temperature KPIs: The average and maximum temperature on a hot summer day. Section 6.2.3.3 explained that the input air temperature has a margin of error of one degree Celsius. Therefore, the exact outcomes of the average and maximum temperature can differ with one degree Celsius and in some cases even more as the amount of adopted Urban Heat Island (UHI) mitigation solutions also depends on the existing outdoor air temperature. However, significant differences between these outcomes are more reliable than the height of the temperature and can in some instances be used further conclusions.

7.1.1.1 Average temperature

Figure 25 shows the average end air temperatures for the whole area and per LCZ on the left and the development of the average value over the whole model run on the right. The blue value is the total area, orange is LCZ3, green LCZ5, red LCZ6 and purple LCZ9. The graph shows that the average temperature of all areas except LCZ9 has two points, after the initial decline, where it drops relatively fast and the standard deviation is bigger. This is caused by the fraction of adopted green or cool roofs, which reaches a new threshold point around that point in time and thus reduces the air temperature in that area. These moments are around the same time for LCZ3, LCZ5 and LCZ6 so the adoption of green or cool roofs have the same speed in those areas. This effect is not clearly seen in LCZ9, this area has a larger standard deviation over the whole run. This could be because more green gardens adopted in LCZ9 in some runs, which gradually reduce the temperature instead of only when a new threshold in reached. Section 7.2.2.4 shows the fraction of green gardens adopted.

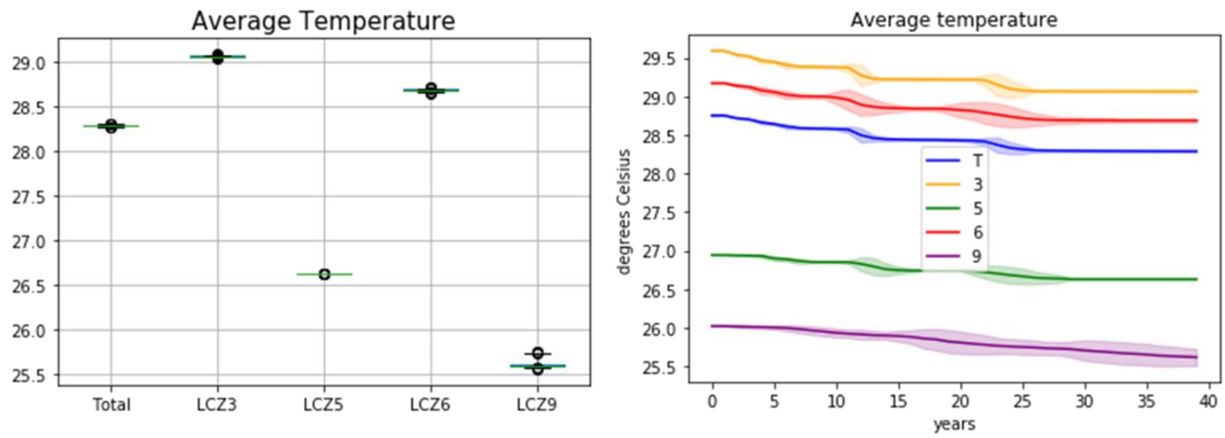


Figure 25: Average temperature outputs and during model run

Table 37 shows the starting average temperatures, the mean end values and the difference between the two for the total area and LCZs. The air temperature difference between LCZ3 and LCZ6 is less than one degree Celsius so this output is not reliable. The difference between LCZ5 and LCZ9 is exactly one degree, however the boxplot in figure 25 shows that the average end value in LCZ9 can also be a bit higher at 25.7 degrees Celsius. Therefore this difference is also not reliable. The difference between the averages of LCZ3 and LCZ6 compared to LCZ5 and LCZ9 is bigger than one degree Celsius so this difference is reliable. This could be caused by the fact that LCZ5 and LCZ9 both have a large green area, an urban park and sports fields respectively. No households are located in these green areas, so the temperature in these areas cannot be reduced through green gardens or façades. However, the effect of green or cool roofs does affect these areas as these solutions affect the whole LCZ. As LCZ5 is a mid-rise area multiple possible solutions have a smaller effect on the air temperature in that area, which can also explain the lower temperature difference.

Table 37: Average temperature at the start and end of all runs

Area	**Start average temperature**	**Mean end average temperature**	**Temperature difference**
Total area	28.75	28.29	0.46
LCZ3	29.59	29.07	0.52
LCZ5	26.94	26.63	0.31
LCZ6	29.17	28.69	0.48
LCZ9	26.02	25.62	0.40

7.1.1.2 Maximum temperature

The maximum air temperature in the LCZs are very similar, the largest difference between the means is 0.1 degree Celsius. The graph also clearly shows the 2 large temperature reductions caused by the threshold fraction of green or cool roofs after the initial decline for LCZ3, LCZ6 and LCZ5 (figure 26).

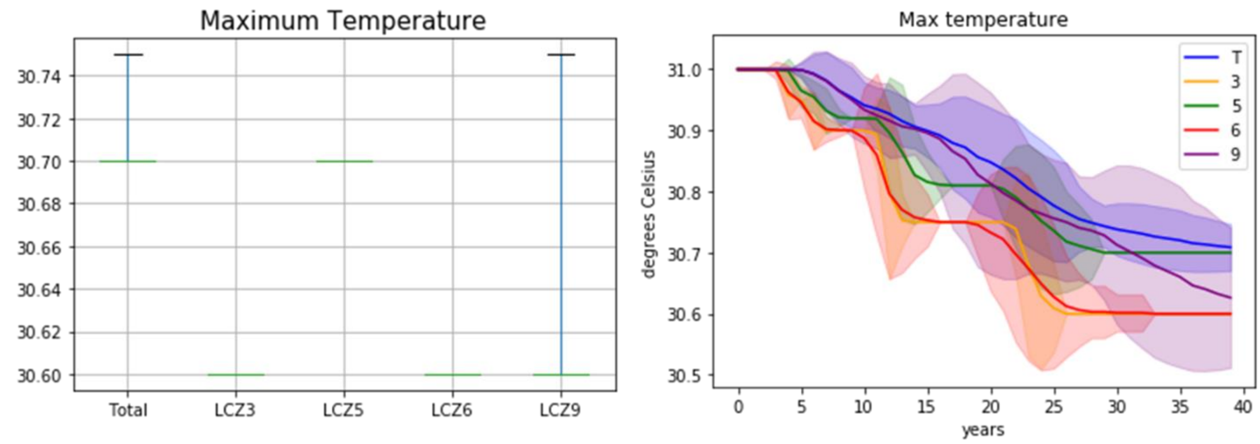


Figure 26: Maximum temperature outputs and during model run

In table 38 the temperature differences with the starting max temperature of the area are shown. All areas have a maximum of 31 degrees Celsius. As the difference between the maximum air temperatures is only 0.1 degree Celsius this output is also not reliable.

Table 38: Maximum temperature at the start and end of all runs

Area	Start max temperature	Mean end max temperature	Temperature difference
Total area	31	30.71	0.29
LCZ3	31	30.60	0.40
LCZ5	31	30.70	0.30
LCZ6	31	30.60	0.40
LCZ9	31	30.63	0.37

7.1.2 Fraction adopted KPIs

This section presents the fraction of household that invests in an UHI mitigation solution compared to the total households that are able to decide if they want to adopt an UHI mitigation solutions. These outcomes are presented in total, per solutions and per LCZ.

7.1.2.1 Total fraction implemented

The total fraction of solutions implemented is close between LCZ3, LCZ5 and LCZ6 (figure 27 & table 39). Only in LCZ9 the range of this fraction is much bigger as 95% of its end values lie between 0.71 and 0.93. However, this upper limit is above the lower limits of the other LCZs so it cannot be concluded that there is a difference between these LCZs. The larger range of values of LCZ9 can be explained by its relatively small amount of households, compared to the other areas. In total there are 7862 households in the area, LCZ3 has 5962 households, LCZ5 has 959, LCZ6 has 760 and LCZ9 only has 181 households. Combined with the random values the model uses to distribute the household characteristics, this can cause larger differences between model runs in LCZ9 compared to the other areas.

The graph of the implemented fraction through the years shows that the adoption rate decreases over the years (figure 27). During the first 5 to 10 years the fraction of households that has adopted a solution quickly rises but then it slows down. This is logical as households with a large multi-attribute utility for a solution quickly adopt that solution in the beginning. Household that still doubt about their decision are then influenced by the household that have adopted an UHI mitigation solution through the social factor of the Theory of Planned Behaviour. However, as more solutions are implemented, the nearby air temperature of household declines, which has a reducing effect on the adoption of solutions by other households. The graph shows that the effect of the social factor, combined with the income threshold that is changed each year, is bigger than the reducing effect of the lower nearby temperature.

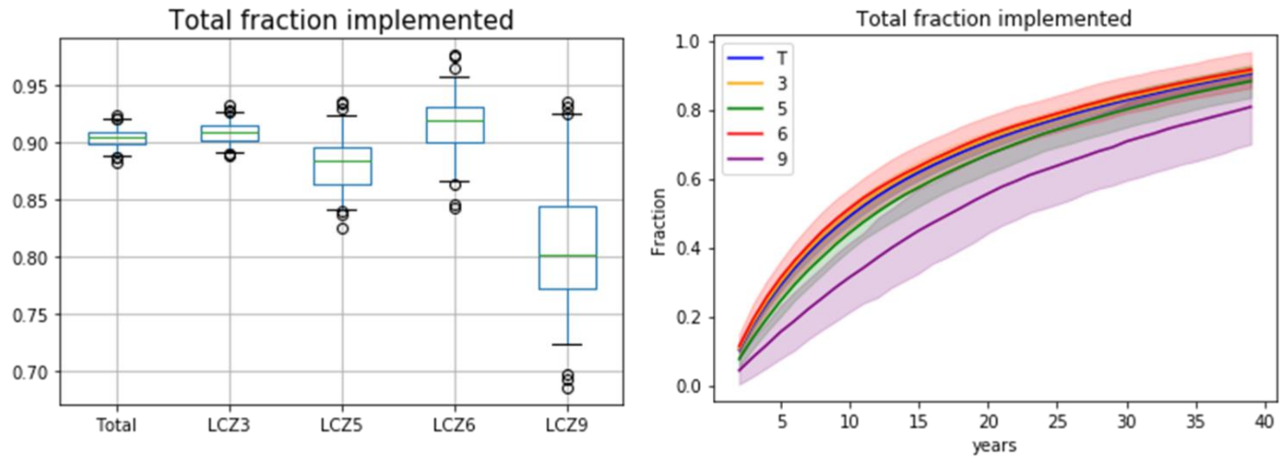


Figure 27: Total fraction implemented outputs and during model run

Table 39: Mean total implemented fraction at the end of all runs

Area	Mean total implemented fraction
Total area	0.9039
LCZ3	0.9089
LCZ5	0.8818
LCZ6	0.9155
LCZ9	0.8075

7.1.2.2 Fraction green roof implemented

The fraction green roof implemented does not show a big difference with the total fraction implemented (figure 28). This means that green roofs are mostly implemented in the standard model run. This is stimulated by the choice that housing corporations only invest in green roofs once in 25 years. The fraction green roof implemented is around 0.05 lower than the total fraction, so this means other solutions are implemented. Again, no difference can be seen between the LCZs as the range of the outcomes is too close to each other.

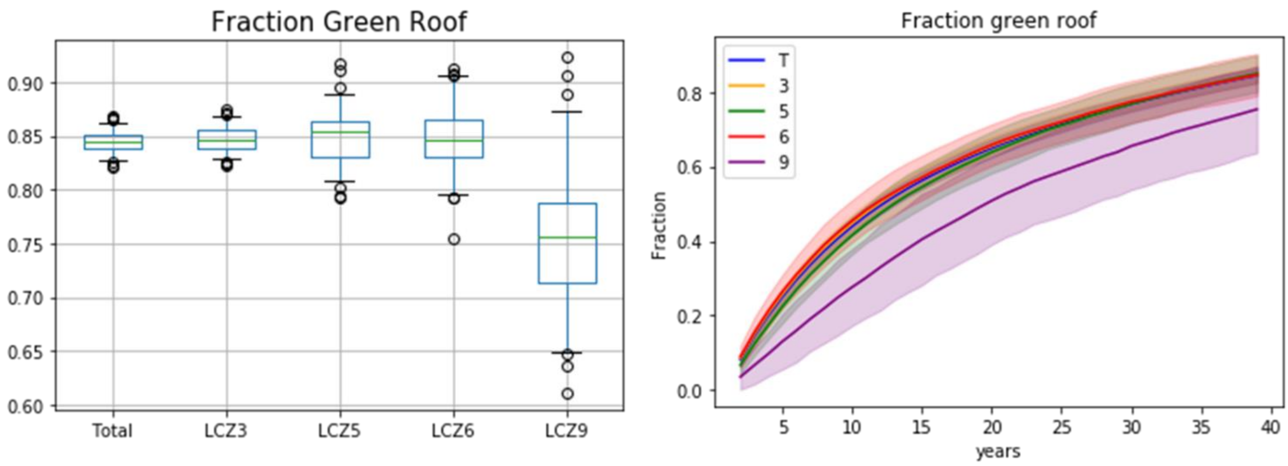


Figure 28: Fraction green roofs implemented outputs and during model run

7.1.2.3 Fraction green facade implemented

The number of green façades implemented in the standard model run is zero in all LCZs (figure 29), the utility of this solution seems to be too low for households to invest in it.

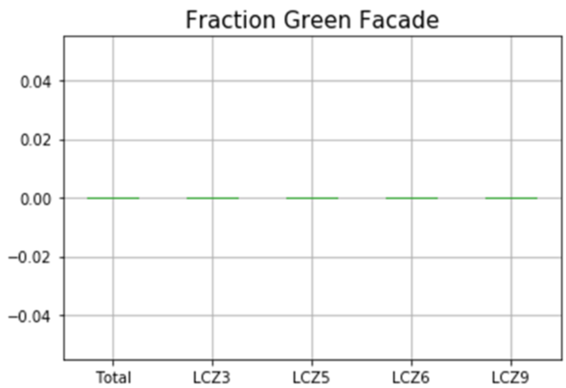


Figure 29: Fraction green façades implemented outputs

7.1.2.4 Fraction green gardens implemented

Next to green roofs there are green gardens adopted as solutions in that standard model run. Around six percent of all household invest in this solution. The graph on the right side of figure 30 shows that green gardens are mostly adopted in the first 10 to 15 years of the model run. After that the fraction green gardens does not increase much anymore. The boxplots in figure 30 show that the fraction of green gardens adopted in LCZ5 is lower than in LCZ3 and LCZ6. This could be because the effect of green gardens on the air temperature in LCZ5 is lower than in the other areas, however the effect of green roofs in this area is also lower. The average temperature in LCZ5 is also lower than in LCZ3 and LCZ6, which could cause a lower amount of adopted solutions. On the other hand the average temperature in LCZ9 is also lower but the fraction of adopted green gardens is not lower.

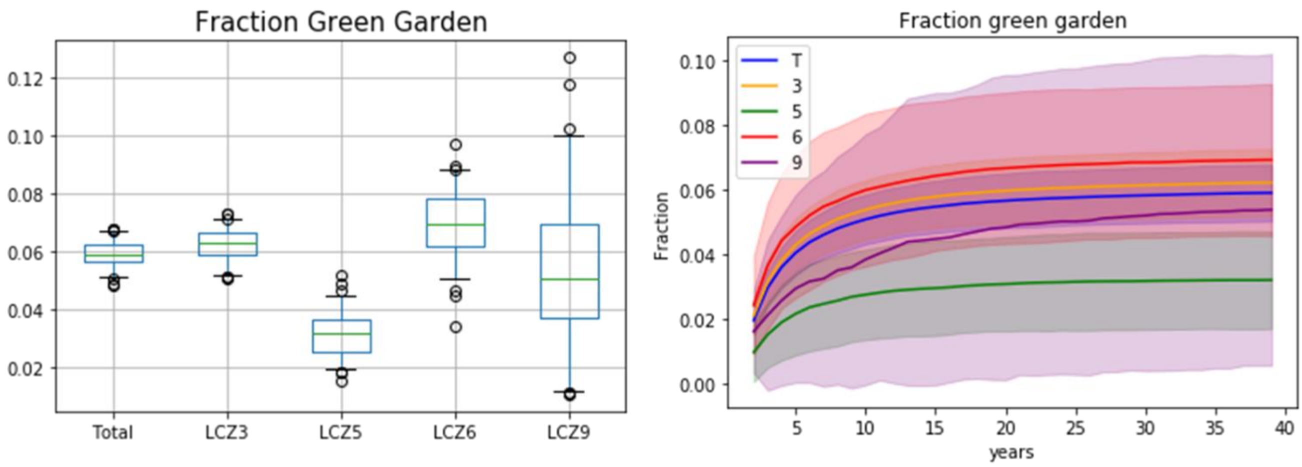


Figure 30: Fraction green gardens implemented outputs during model run

Figure 31 shows that the difference in green garden adoptions between LCZ3 and LCZ6 with LCZ5 becomes clear after the first 5 to 10 years. In the beginning the different values overlap, but after a little more than 5 years this stops for LCZ3 and lCZ5 and the overlap keeps reducing for LCZ6 and LCZ5.

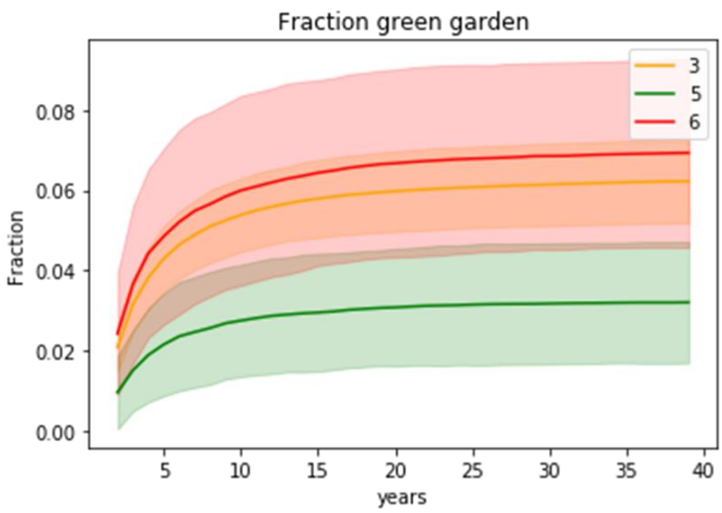


Figure 31: Fraction green gardens implemented in LCZ3, LCZ5 and LCZ6 during model run

The curves in figure 30 and 31 for the adopted fraction of green gardens show a different development than the fraction adopted green roofs in figure 28. This could mean that the growth in adopted fraction after the first 15 years almost only comes from housing corporations and owner occupiers invest in mitigation solutions earlier. Section 7.2.4.5 investigates this further.

7.1.2.5 Fraction cool roofs implemented

Figure 32 shows that there are no cool roofs implemented in the standard model, green roofs and green gardens are thus the only two adopted solutions.

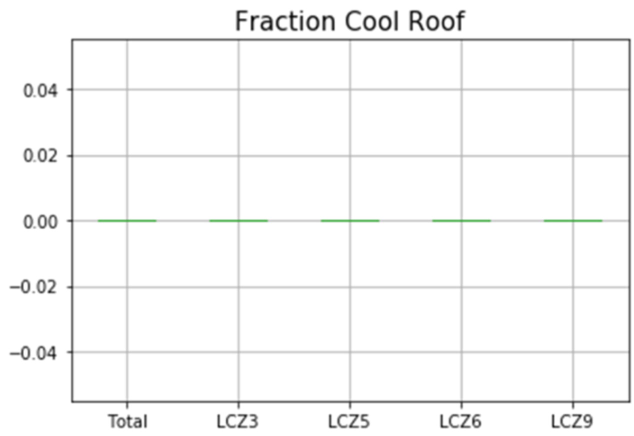


Figure 32: Fraction cool roofs implemented outputs

7.1.3 Monetary KPIs

The total costs of adoptions are consulted to see whether there is a difference between the LCZs and to track the effect of certain policies in other experiments.

7.1.3.1 Costs of solutions

In figure 33 the total costs of green gardens is show separately from the total costs of green roofs as there is a very large difference between the two. The mean total costs of green roofs adds up to 33.56 million euros, while the mean costs of green gardens is only around 6400 euros.

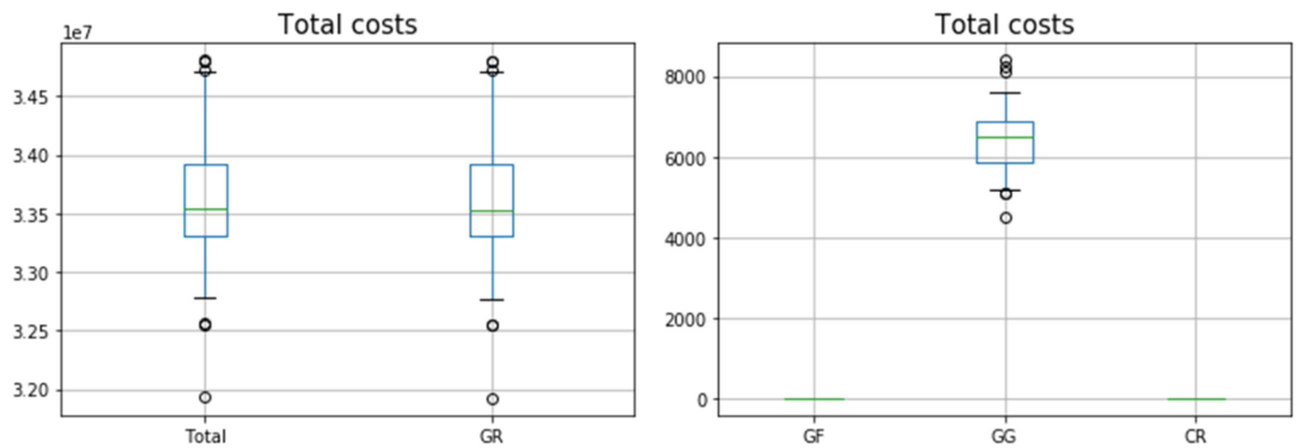


Figure 33: Total costs output and per solution

7.1.3.2 Subsidies

In the standard model two types of subsidies exist. One for green roofs of 19% of the total costs per square meter. This subsidy is available during the whole model run. The other one is available for green gardens and covers 100% of the costs of this solution. However, it can only be used during the first two years of the model run. The results in figure 34 show that the total subsidy for green roofs adds up to 1.84 million euros over the years, while the total subsidy for green gardens has a mean of 6500. The previous section showed the mean total costs of green gardens is only 6400 euros. This thus shows that more green gardens are implemented during the first two years of the model run when the subsidy is available than after the subsidy has ended.

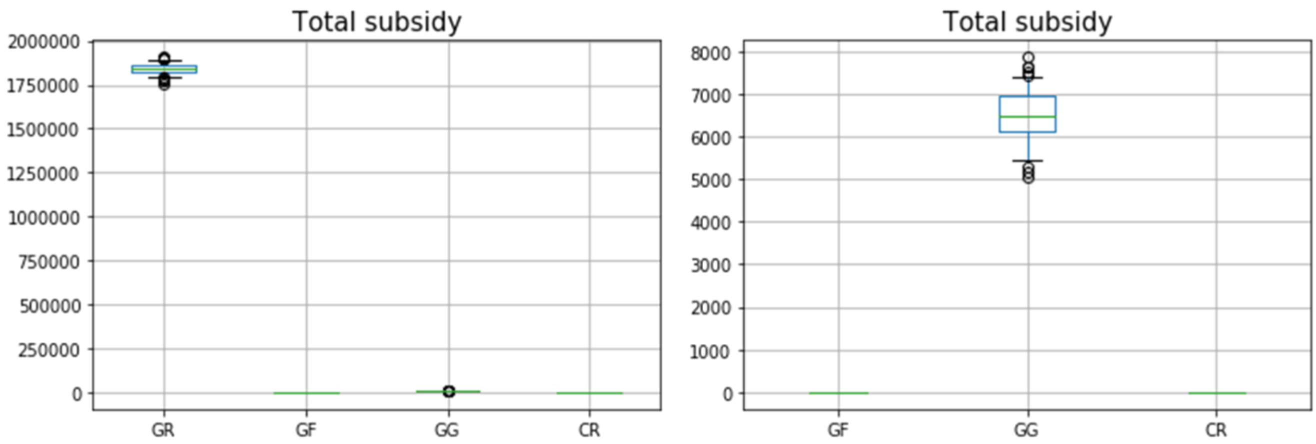


Figure 34: Overall total subsidy per solution

7.1.4 Household characteristics

This sections shows whether household characteristics create a significant difference in the adoption of UHI mitigation solutions. First the level of education is investigated, then the income level, dwelling ownership, dwelling type and lastly the fraction of non-social dwelling households.

7.1.4.1 Education

Figure 35 does not show a difference between the fraction of adopted solutions of households with different educational levels. Although literature does suggest that this effect exists, it is mitigated by other effects in the standard model run.

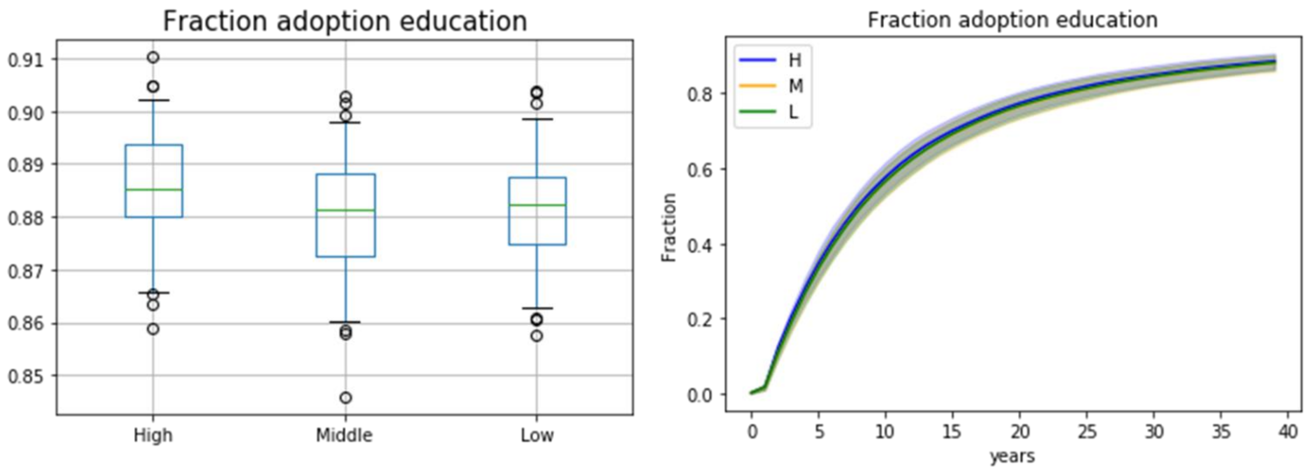


Figure 35: Fraction adoption per educational level

7.1.4.2 Income

The income level of a household affects the chance of a household to invest in a mitigation solution as it is part of the threshold that needs to be overcome to calculate the multi attribute utility of the solutions. The households in the first and second quantile are part of the low income group, the third and fourth quantile is the middle income group and the fifth quantile is the high income group (DHIC, 2021. Figure 36 shows that the fraction adoption in the low income groups is lower than the ranges of the other two income groups. The graph in figure 36 shows that this difference is bigger during the model run and reduces with time.

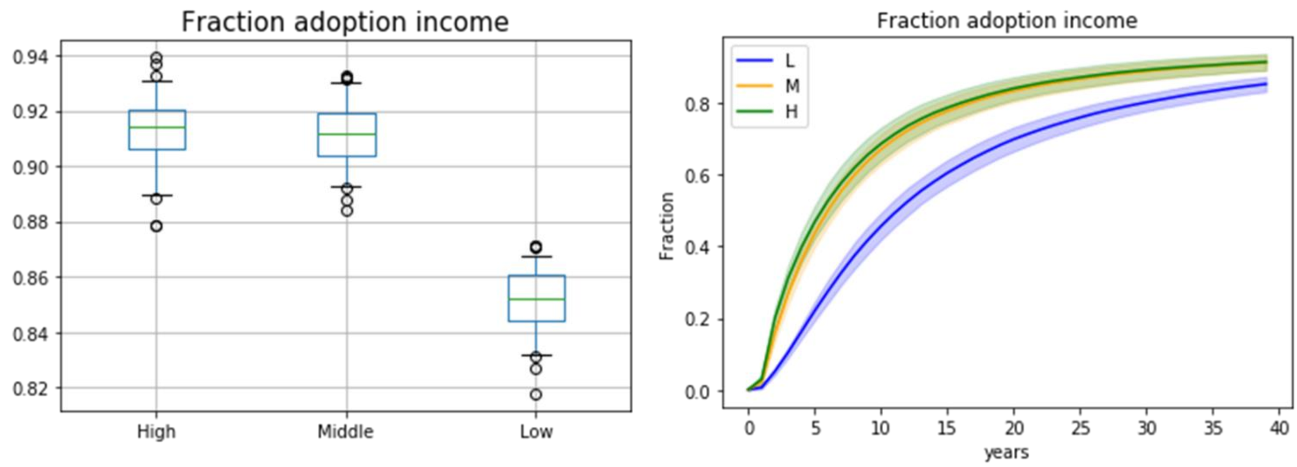


Figure 36: Fraction adoption per income level

7.1.4.3 Owner and tenant

The graph in figure 37 shows that the fraction adoption by tenants is lower during the model than the adoption by owner occupiers, however at the end of the model run this difference diminishes and there is an overlap between the 95 percent confidence intervals of the fractions.

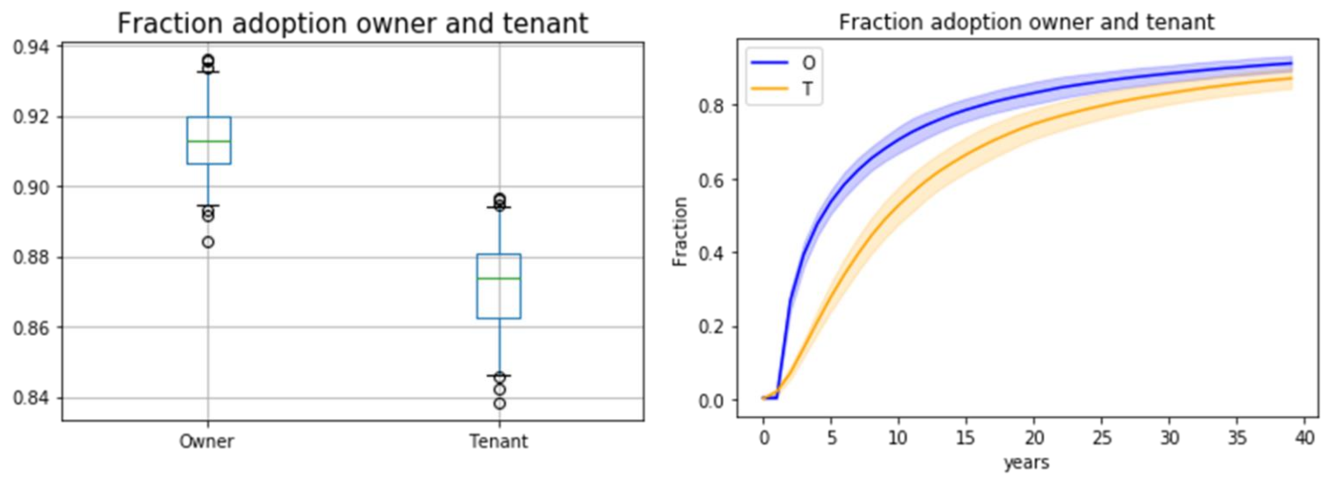


Figure 37: Fraction adoption owner occupier and non-social tenant

7.1.4.4 VVE and single-family

The difference between the fraction adopted by households that are part of a VVE and households that live in a single-family dwelling is almost the same as the previous section, but these values do not overlap in the end (figure 38). Although the difference reduces during the model run there is still a small significant difference in the end.

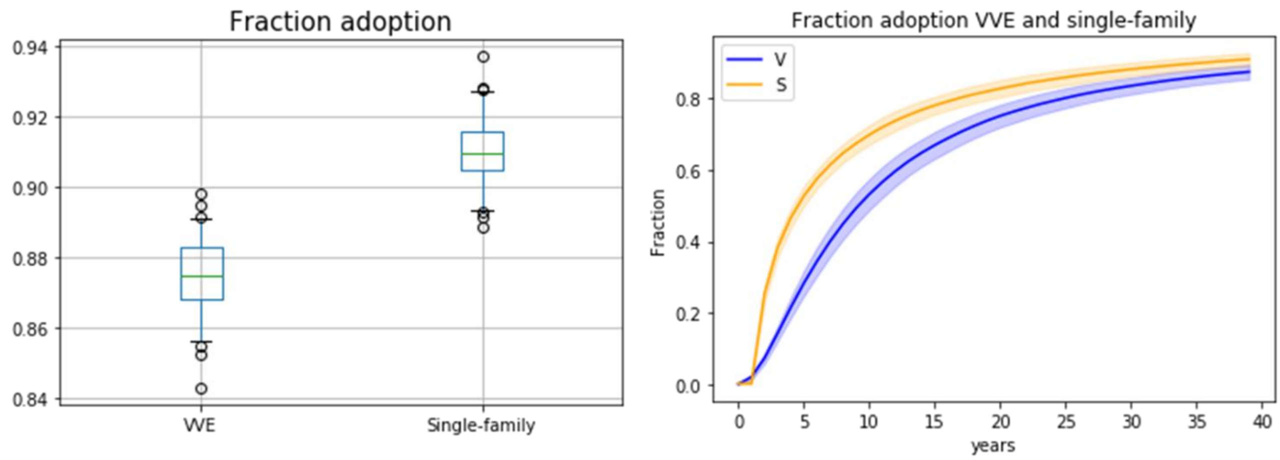


Figure 38: Fraction adoption VVE and single-family

7.1.4.5 Non-social adoptions

Figure 39 shows that the fraction adoptions households that do not live in a social dwelling is lower than the total fraction adoption. The graph clearly shows that non-social households invest in solutions earlier, but also stop earlier compared to the total adoption graph. This is the effect of housing corporations investing in UHI mitigation solutions only once per 25 years per household and continuing with that during the whole model run. While the characteristics of some non-social households will make sure that their multi-attribute utility of investing in a solution is always below the utility of not investing.

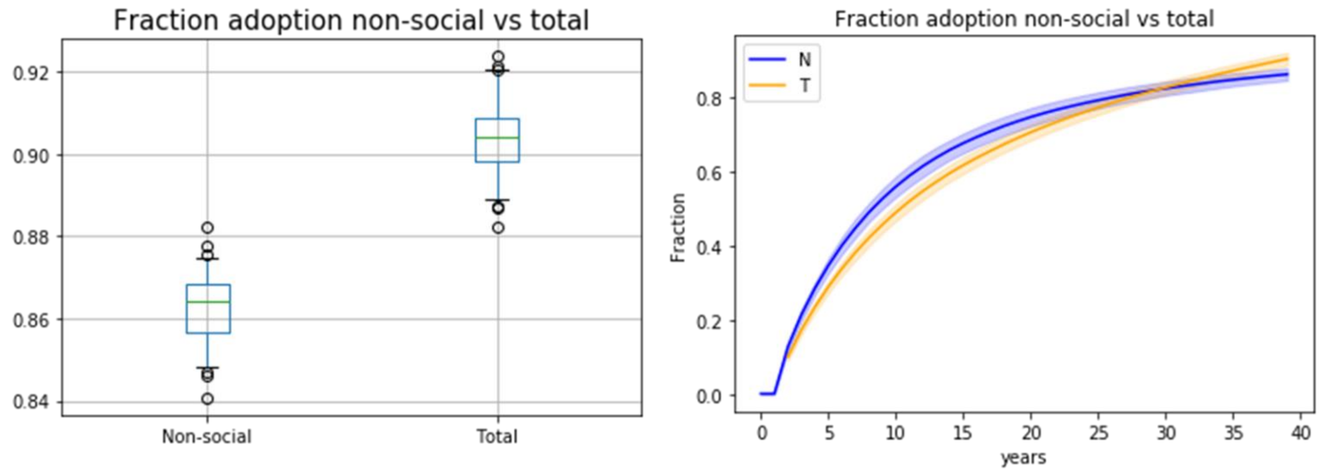


Figure 39: Fraction adoption VVE vs single-family

7.2 Results of three experiments

This section shows per experiment the most important results. When the results do not differ from the outcomes of the standard model presented in the previous section, these are not shown in this section. First the outcomes of changing the amount of subsidy per solution are presented, second the effect of changing the surfaces of different squares in the Bomen- and Bloemenbuurt and thirdly the outcomes of having different agreements with housing corporations are shown.

7.2.1 Changing the amount of subsidy

As explained in section 6.3.2 the amount of subsidy is changed per solution to 20, 35 and 50 percent of the total price of the solution. The next sections present the outcomes of this experiment. The effects on the temperature KPIs on a hot summer day are presented in appendix D as these are not needed to answer the different hypotheses, but they can be important for decision makers.

7.2.1.1 Fraction adopted KPIs

While the average temperature at the end of the model run increases when the subsidy for **green roofs** increases the total adopted fraction increases because of an increase in the total fraction of green roofs implemented (figure 40). However, the total implemented fraction of green gardens reduces to 0.0154 (=1.54% of households) and 0.00627 (=0.62% of households) for 35 percent and 50 percent subsidy respectively compared to 20 percent subsidy. As green gardens have a bigger impact on the average temperature in an area this causes the increase in the average temperature.

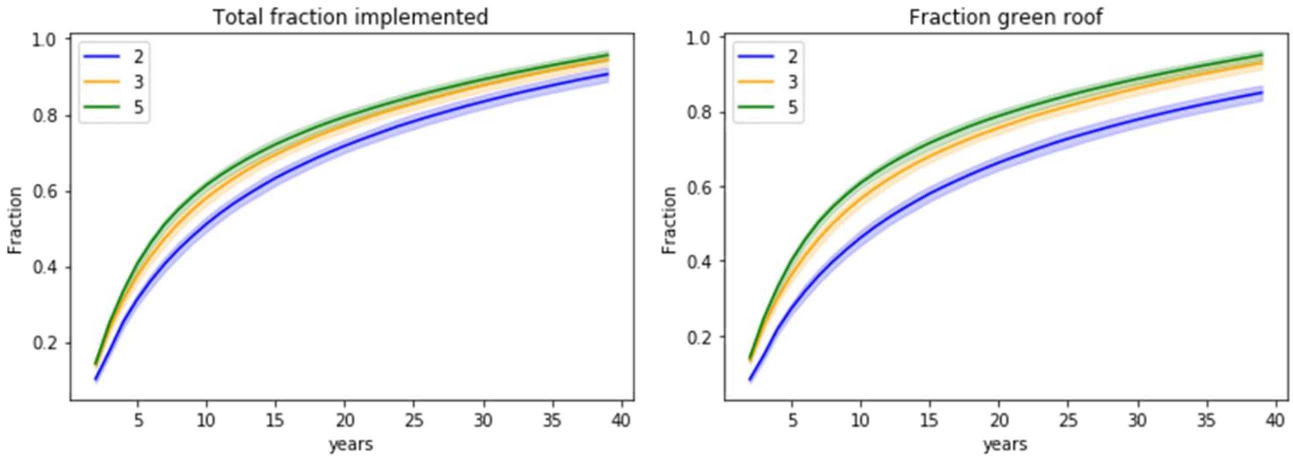


Figure 40: Total fraction and fraction green roofs implemented during model run for green roof subsidy

When there is a subsidy for **green façades** the total fraction and fraction green roof implemented reduce. This effect is even stronger when the subsidy amount for green façades increases (figure 41).

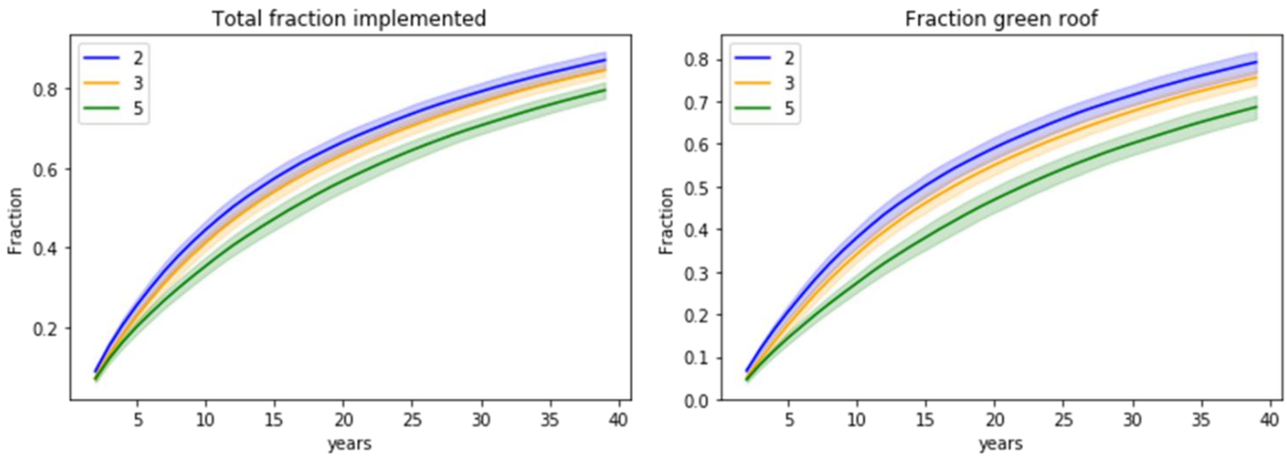
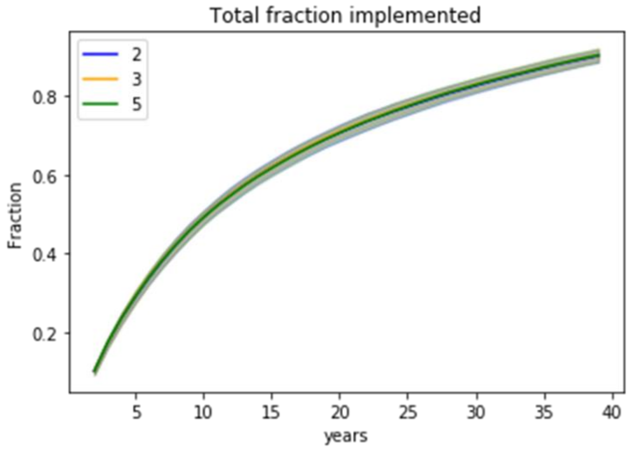


Figure 411: Total fraction and fraction green roofs implemented during model run for green façade subsidy

The fraction of implemented green façades increases when the subsidy increases but is not always above zero. Therefore there is no significant difference between these outcomes.
When the subsidy for green façades increases to 50 percent, the fraction of adopted green gardens increases significantly to 0.1074 (=10.74% of households). Furthermore, the fraction of adopted green gardens is higher when there is a subsidy for green façades, compared to having a subsidy for green

roofs. This explains the difference in the average temperature between these two experiments as green gardens have a larger influence on the nearby air temperature.

The total adopted fraction and fraction of green roofs adopted do not change with an increase of the subsidy of **green gardens** (figure 42). These values are the same as in the standard model. A 35 percent subsidy for green gardens does create a significant difference in fraction implemented between LCZ3 an LCZ9.



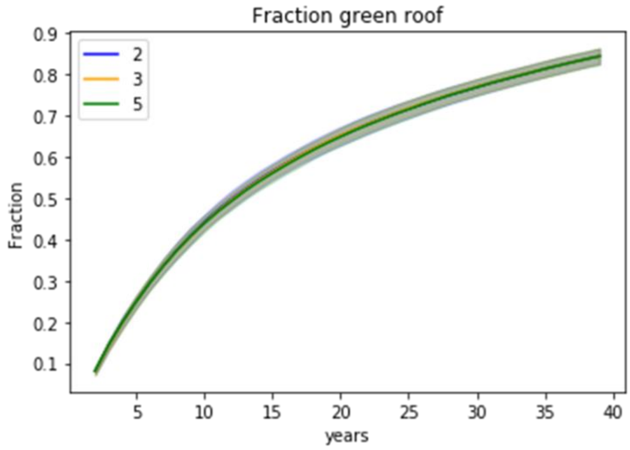


Figure 42: Total fraction and fraction green roofs implemented during model run for green garden subsidy

There is no significant difference in the total fraction of implemented solutions between a subsidy of 20 or 35 percent for **cool roofs** (figure 43). A 50 percent subsidy does increase the total adopted fraction significantly with 0.0417 (=4.17 percent of households) to 0.9456 (=94.56 percent of households) compared to the standard model inputs.

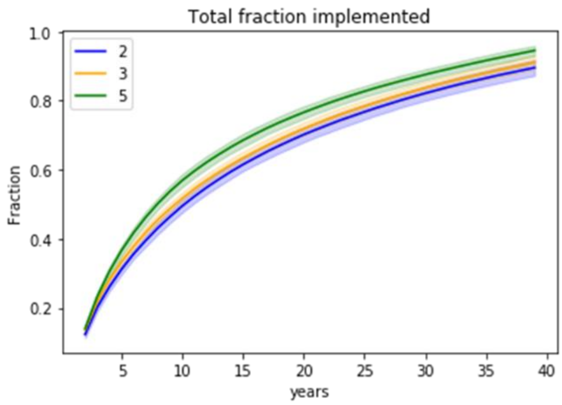


Figure 432: Total fraction implemented during model run for cool roof subsidy

Figure 44 shows that the fraction of green roofs reduces when the subsidy for cool roofs increases and the fraction of cool roofs increases with an increase in the percentage of subsidy. For a subsidy percentage of 20 and 35 the fraction cool roofs implemented stabilizes after the first couple of years, but for a subsidy percentage of 50 this takes more time. The fraction of green roofs implemented does not stabilize because housing corporations that own social dwellings keep investing in green roofs over the years. This shows that the adoption of UHI mitigation solutions primarily takes place in the first couple of years. The outcomes of this experiment also show that the fraction of green gardens reduce when the subsidy for cool roofs increase. Only for a subsidy of 50 percent these values are significant compared to the standard model. In that case the fraction reduces with 0.0281 (=2.81% of households) from 0.0590 (=5.90% of households) to 0.0309 (=3.09% of households).

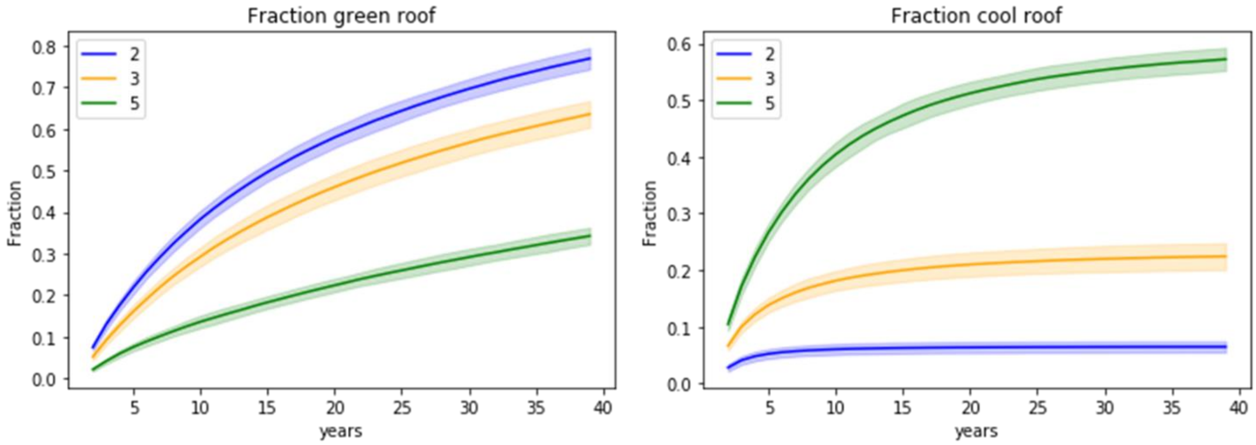


Figure 44: Fraction green roof and cool roof implemented during model run for cool roof subsidy

7.2.1.2 Monetary KPIs

As the amount of subsidy for a green roof increases, the total costs of all solutions decreases with 12.6 percent and 31 percent for 35 percent and 50 percent subsidy respectively compared to 20% subsidy, despite more green roofs being implemented. At the same time the total amount of subsidy for green roofs increases with 100 and almost 200 percent for a subsidy increase of 20 to 35 percent and 20 to 50 percent respectively (table 41).

In the first few years the total costs remain the same despite the different subsidy amount for **green roofs** as solutions are implemented earlier if the amount of subsidy is higher. However, after five to fifteen years the total costs begin to diverge (figure 45).

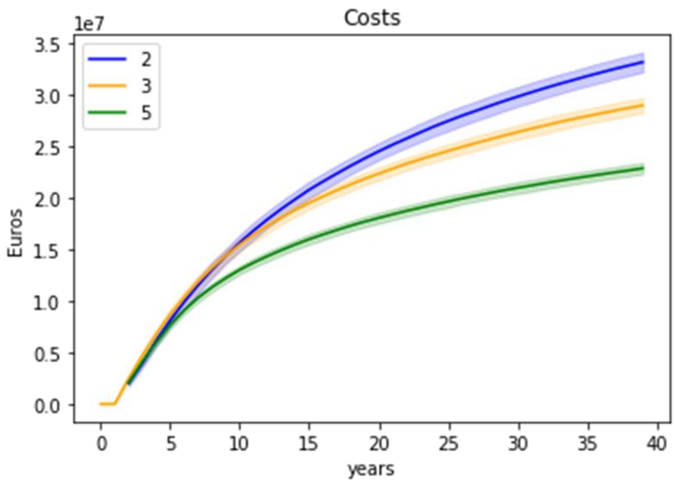


Figure 45: Total costs in euros for green roof subsidy

The difference between the total costs is smaller in the experiment with the subsidy for **green façades** (figure 46). Only the outcomes of a subsidy of 50 percent has a significant difference with the 20% subsidy runs. At the same time the subsidy for green roofs reduces with the reduction of the implementation of green roofs. While the subsidy for green façades increases, the total subsidy spend is still significantly lower than in the standard model (table 41).

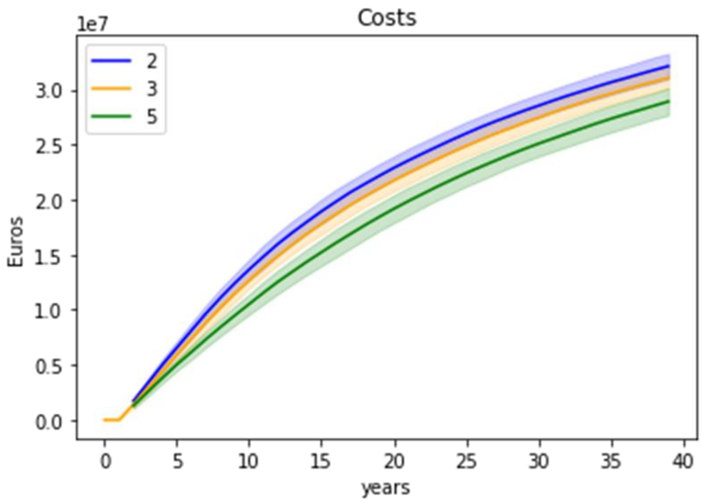


Figure 46: Total costs in euros for green façade subsidy

Having a subsidy for **green gardens** does not influence the costs or subsidy compared to the standard model.

Increasing the subsidy for **cool roofs** decreases the total costs, but only for a subsidy of 50 percent this value is significant compared to a subsidy of 20 percent. The total costs are also closer to each other than in the case of a subsidy for green roofs (figure 47).

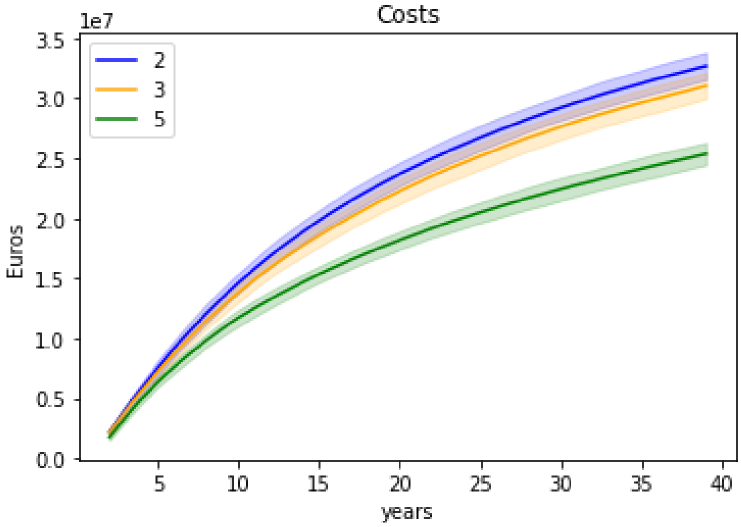


Figure 47: Total costs in euros for cool roof subsidy

Table 40 shows the total costs of the standard model and the different experiments. Italic costs have a significant difference with the standard model. Introducing a subsidy of 20 percent for each of the solutions does not create a significant difference, only when the subsidy is increased to 35 or 50 percent the total costs change significantly. This is not the case for the subsidy of green gardens, introducing a subsidy for this solution does not result in a significant change of the total costs. This is probably the result of the small amount of adopted green gardens combined with the fact that the costs of this solution are the lowest. Therefore its impact on the total costs is very limited.

Table 40: Total costs in euros after model run

Subsidy	20%	35%	50%
Standard model	33567798		
Green roof	33189254	*28998515*	*22883682*
Green façade	32110012	*31055500*	*28902613*
Green garden	33486050	33516642	33568498
Cool roof	32659948	*31029885*	*25360356*

The total amount of subsidy distributed amongst households and housing corporations is shown in table 41. In italic are the total subsidies that have a significant difference with the standard model. For a 20 percent subsidy of a solution, only a subsidy for green façades has a significant effect on the total subsidy. The other experiments only show a significant effect for a 35 or 50 percent subsidy, except for a green garden subsidy.

Table 41: Total subsidy in euros after model run

Subsidy	20%	35%	50%
Standard model	1849364		
Green roof	1957195	*3822409*	*5805606*
Green façade	*1658928*	*1536221*	*1313246*
Green garden	1841724	1839407	1838240
Cool roof	1743754	*2177159*	*3668410*

7.2.1.3 Household characteristics

The difference between households with low income and households with middle or high income remains significant for all three subsidy options for **green roofs**. The increase in the fraction adopted for low incomes is however higher than the increase for middle and high income households so the difference in adoption fraction reduces, although this difference is not significant. The increase for low income households is 0.0574 (=5.74% of households) and 0.0811 (=8.11% of households) respectively for an increase of the subsidy to 35 and 50 percent compared to the standard model, while the increase for middle and high income households is around 0.045 (=4.5% of households) and 0.061 (=6.1% of households) respectively.
Introducing a subsidy for **green façades** does not influence the significance of the difference between households with a low income and households with a middle or high income. However, the decrease of the adopted fraction is larger for low income households than for middle and high income ones.
The significance of the difference between low income households and middle and high income households does not change by increasing the subsidy for **green gardens**.
Also for a subsidy for **cool roofs** the significance still exists, but there is no significant increase in adopted fraction between a 20 and 35 percent subsidy as was shown earlier. Furthermore the increase of adopted fraction is higher for low income households at 0.0572 (=5.72% of households) for a subsidy of 50 percent compared to around 0.047 (=4.7% of households) for high and middle income households, but not significant. This increase is however lower than the increase of a 50 percent green roof subsidy of 50%

In this experiment the difference between the fraction of adopted solutions of non-social owner occupiers living in single-family dwellings compared to non-social tenants living in apartments is significant for 20 percent and 35 percent subsidy for **green roofs**. However, this significant difference disappears for 50 percent subsidy. This is the result of the subsidy increase having a larger effect on

non-social tenants living in apartments than on owner occupier living in single-family dwellings. The fraction adoption of the first group increases with 0.0539 (=5.39% of households) and 0.0786 (=7.86% of households) for 35 percent and 50 percent subsidy of green roofs respectively compared to the standard model. While the total fraction adopted for owner occupiers living in single-family dwellings only increases with 0.0498 (=4.98% of households) and 0.0522 (=5.22% of households).
The same is true for the difference between non-social households that are part of a VVE and non-social households living in single-family dwellings, the significant difference between the adopted fraction of these two groups also disappears for a subsidy increase of 50 percent. On the other hand the difference between the adopted fraction of all non-social households and the total adopted fraction of all households remains for all three subsidy amounts. The subsidy amounts are thus not enough to close this gap.

For the experiments with a subsidy for **green façades** the difference between the fraction of adopted solutions of non-social owner occupiers living in single-family dwellings compared to non-social tenants living in apartments is not significant. The difference between non-social households that are part of a VVE and non-social households living in single-family dwellings is only significant for a subsidy of 50 percent, while the difference between the adopted fraction of all non-social households and the total adopted fraction of all households remains significant for all three subsidy amounts.

While increasing the amount of subsidy of **green gardens** the significant difference between non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments disappears if the subsidy is 50 percent of the price of a green garden after the first two years compared to having a 20 or 35 percent subsidy. The other significant differences of the standard model remain.

In the case of a **cool roof** subsidy there is a significant difference between the fraction of adopted solutions of non-social owner occupiers living in single-family dwellings compared to non-social tenants living in apartments. This significant difference does not exist in the standard model. The other significant differences that exist in the standard model keep existing in this experiment.

7.2.2 Changing square surfaces

For this experiment several squares in the Bomen en Bloemenbuurt that are incorporated in the model were changed to a surface type that had the largest reduction effect on the nearby air temperature. Paved squares were changed to squares with a cool pavement coating and squares with grass were changed to small urban parks. The big park area in LCZ5 and the sports field in LCZ9 were not changed. The next sections present the relevant results of this experiment.

7.2.2.1 Temperature KPIs

The average temperature on a hot summer day in the whole area reduces significantly with 0.1 degree Celsius. Figure 48 shows the average temperature during the modelled years. No difference can be seen in the development of the average temperature during the years. There is also no effect on the maximum temperature on a hot summer day in the areas.

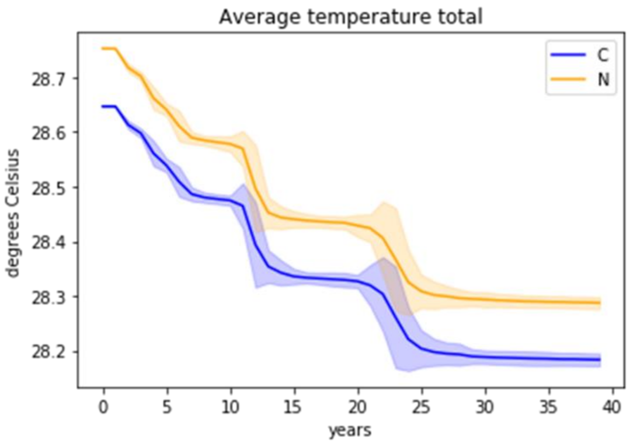


Figure 48: Average temperature for changed squares and no changed squares

For all other KPIs no significant difference exists between changing the squares in the area and the standard model where these squares are not change. Compared to the standard model with 100 repetitions the difference between non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments is significant for this experiment that has 30 repetitions. However, there is no difference between the model run with no changed squares and the standard model run except for the amount of repetitions. Increasing the amount of repetitions increases the reliability of the outcomes, so it is assumed that the outcomes of the 100 repetitions are more reliable and there is thus no significant difference between these two household groups at the end of the model run. Section 7.1.4.3 showed that there is a significant difference during the run, but not at the end.

The temperature reducing effect of changing the surfaces of the squares in the area does thus only effect the average air temperature in the area but has no effect on the amount or type of solutions implemented.

7.2.3 Agreements with housing corporations

In this experiment the solution that housing corporation will implement on their property is changed. The five possible option are no solution, implementing green roofs, green façades, green gardens or cool roofs. This section presents the important outcomes of this experiment, compared to the standard model with the implementation of green roofs.

7.2.3.1 Temperature KPIs

There are significant differences in the average temperature and the maximum temperature on a hot summer day in the total area between the different options in this experiment. The average temperature is the lowest in the standard model with green roofs and the option with the implementation of green gardens. The difference of the average temperature in the total area between these two options is not significant, however the difference in LCZ3 and LCZ5 is. For green gardens the average temperature in LCZ3 is significantly lower, but for LCZ5 the temperature is higher than with the implementation of green roofs (Table 42). The maximum temperature is significantly higher for all other options compared to the standard model with the implementation of green roofs. Figure 49 shows that the average temperature after the first ten years is lower with the option of green façades or green gardens installed but after that the option with green roofs has the lowest average total temperature.

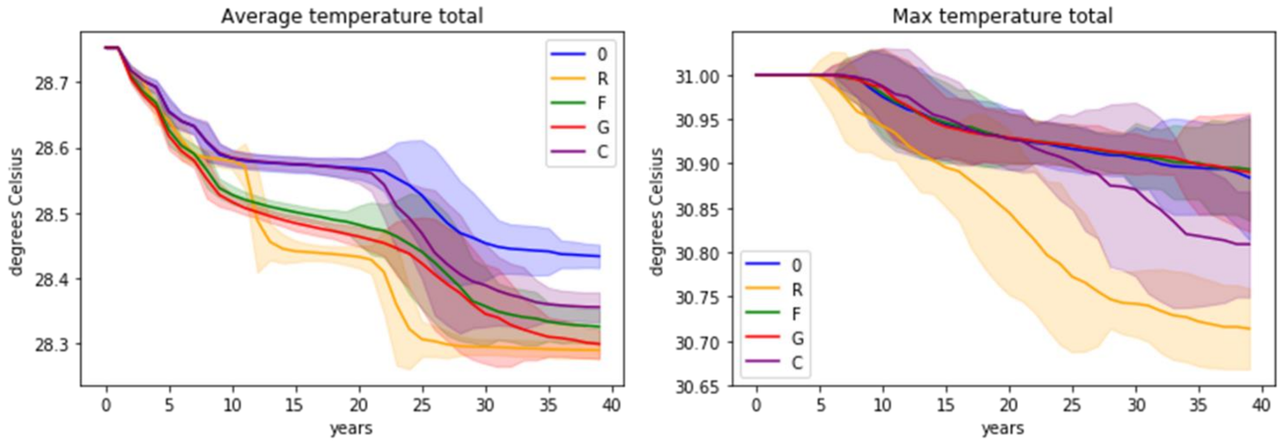


Figure 49: Average and maximum temperature for no solution (0), green roofs (R), green façades (F), green garden (G) and cool roofs (C)

Table 42 presents the differences between the four different LCZs and the total area. In italic are the total subsidies that have a significant difference with the standard model that implements green roofs.

Table 42: Average temperature in total area in degrees Celsius after model run

Average temperature	**No change (°C)**	**Green roof (°C)**	**Green façades (°C)**	**Green gardens (°C)**	**Cool roofs (°C)**
Total area	*28.43*	28.29	*28.33*	28.30	*28.36*
LCZ3	*29.21*	29.07	29.08	*29.03*	*29.11*
LCZ5	*26.74*	26.63	*26.66*	*26.72*	*26.73*
LCZ6	*28.85*	28.69	*28.76*	28.70	28.75
LCZ9	25.91	25.75	25.84	25.81	25.77

7.2.3.2 Fraction adopted KPIs

The total amount of adopted solutions has a significant difference for the option where no solutions are implemented by housing corporations and for the adoption of green gardens (figure 50). When housing corporations do not implement a solution the total fraction adoption reduces with 0.3109 to 0.5941 (=59.41% of households) from 0.9050. As the input for the fraction of social households in the model is 0.3172 the adoption of a solution by these households does not significantly influence the adoption of solutions by non-social households. In that case the reduction of the total implemented fraction should have been higher. This means the total effect of the friends of households is very small. The sensitivity analysis in section 6.2.1.8 where the total amount of friends was changed also came to this conclusion.

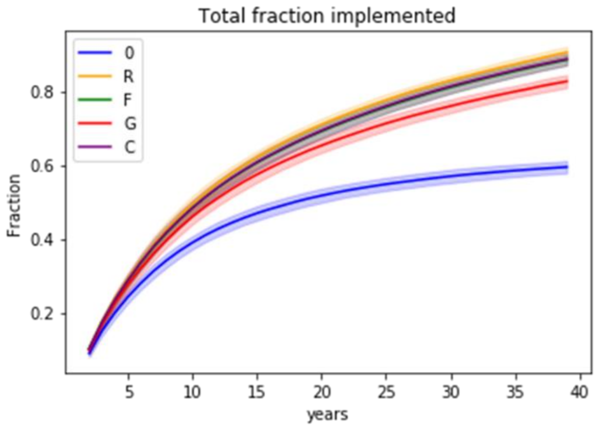


Figure 50: Total fraction implemented for no solution (0), green roofs (R), green façades (F), green garden (G) and cool roofs (C)

In the standard model there is no difference between the total adopted fractions in the LCZs, however when social housing corporations do no adopt a solution or adopt green façades there is a significant difference between the total fraction implemented in LCZ3 and LCZ9. This is not the result of an increase of the adoption of one single solution. For the total adopted fraction of green roofs there is no significant difference between the LCZs in the five different options. For the total fraction of green gardens adopted there is a significant difference between the amount adopted in LCZ5 with LCZ3, LCZ6 and the total area for no solutions and for the adoption of green roofs by housing corporations. The adoption of green façades only creates a significant difference between the adopted fraction of LCZ5 and the adopted amount in the total area and LCZ3.

7.2.3.3 Monetary KPIs

The total costs increase change significantly between the different options (figure 51). As green façades are the most expensive solution, the total costs increase the most when social housing corporations implement this solution at their dwellings. Cool roofs are slightly less expensive than green roofs therefore those costs are a bit lower. The costs of green gardens is very low thus implementing these at social dwellings costs on average 56.000 euros. Because of this the total costs are almost the same as in the option where no solutions are implemented by social housing corporations. There are no significant differences between the subsidies for the five different options.

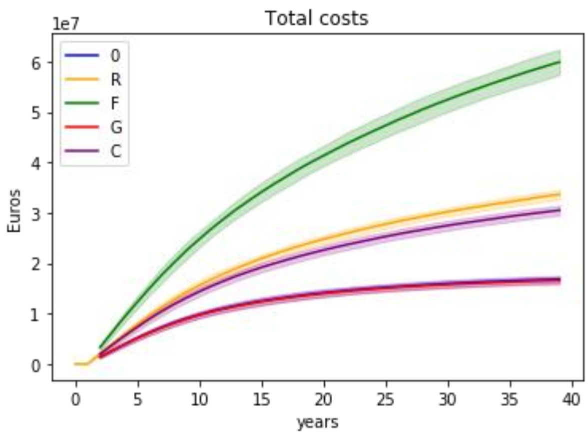


Figure 51: Total costs for no solution (0), green roofs (R), green façades (F), green garden (G) and cool roofs (C)

7.2.3.4 Household characteristics
There are no significant differences in the fraction adoption between households with different educational levels. As is true for the standard model low income households adopt significantly less solutions than middle and high income households. Only when cool roofs are implemented at social dwellings there is a significant difference between the adopted fraction of non-social owner occupiers living in single-family dwellings compared to non-social tenants living in apartments. The owner occupiers have a higher adopted fraction than the tenants. Non-social households that are part of a VVE have a significant lower adopted fraction than non-social households living in single-family dwellings in the standard model where housing corporations implement green roofs and for the run where they implement cool roofs. For the option where they implement no solution, green façades or green gardens, this difference is not significant anymore. The difference between the adopted fraction by non-social households and the total fraction adopted is not significant anymore for the option of green gardens. In all other instances this difference is significant.

7.3 Hypothesis testing
With the results presented in section 7.1 and 7.2, this section tests the hypotheses formed in section 5.5. The hypotheses are presented per research question. In this section the 'standard model results' are the 100 repetitions of the model with the standard inputs presented in appendix G. If other results are referred the experiment or sensitivity analysis that lead to these results is mentioned.

7.3.1 Hypotheses sub-question one
Sub-question one formed in section 1.4 is *"How do technical characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
In section 5.5 three hypotheses were formed for this sub-question, which are discussed consecutively.

H1.1 Urban Heat Island mitigation solutions with lower costs have a higher adoption rate.
Undetermined

The standard model results show that there are some green gardens adopted by households but almost all households adopt a green roof. Although there is a subsidy for this solution, cool roofs and green gardens still have lower costs than green roofs, but these are much less or not adopted at all. The outdoor air temperature and energy reduction effects of adopting a green roof are thus more important than the higher costs. On the other hand the experiment with different subsidies for the solutions showed that the adopted fraction of green roofs and cool roofs increase significantly as the subsidy for those solutions increase. However, this is not true for a subsidy for green façades and green gardens. The sensitivity analysis of the costs of the different solutions demonstrated that lowering the costs of green roofs increases its relative adoption fraction and the other way around for a cost increase. This was also seen for a twenty percent reduction of cool roof costs, but an increase of decrease of the costs of green façades and green gardens did not show significant results. This hypothesis can therefore not be falsified or confirmed with the present study.

H1.2 Urban Heat Island mitigation solutions with a larger temperature reduction effect have a higher adoption rate. **Falsified**

At the start of the model investing in a green garden has the biggest reduction effect on the outdoor air temperature as there are not yet enough green or cool roofs to impact the outdoor air temperature in the whole area. The standard model results show that several green gardens are implemented in the beginning of the model when the green garden subsidy exists and even when this subsidy does not exist anymore some green gardens are implemented. However, there are also households investing in green roofs while these do not have any effect on the outdoor air temperature at the start of the model. Only when the amount of green roofs reaches a certain threshold its effect on the outdoor air temperature increases. Thus, although investing in a green façade or green garden has a bigger effect on the outdoor air temperature at the start of the model than investing in a green roof, there are far more households that invest in a green roof. The other properties of green roofs have thus a bigger influence on the adopted fraction of green roofs. With the increase in the amount of green roofs in the areas the effect of this solution on the outdoor air temperature also increases and installing a green roof only gets more advantages. The sensitivity analysis showed that a change in the effect of green roofs does not influence the adopted fraction of green roofs. This is also true for a change in the effect of green façades and cool roofs for their respective adopted fractions. However, a change in the air temperature reducing effect of green gardens does have a significant influence on the adopted fraction of green gardens. Despite this positive relation for green gardens this hypothesis is falsified. The large adoption of green roofs at the start of the model run, while its effect on the outdoor air temperature is still zero shows that other characteristics of the UHI mitigation solutions have larger effects. Adopting a green garden has a larger influence on the nearby air temperature than the other solutions and thus a percentage change of this effect results in a larger absolute change of the temperature effect than for the other solutions. It could be that a larger change of the temperature reduction effect does influence the fraction adoption of that solution, but the present study did not investigate this.

H1.3 Urban Heat Island mitigation solutions with a larger energy reduction effect have a higher adoption rate. **Confirmed**

In the standard model setup green roofs have the largest reducing effect on the energy use of households, followed by cool roofs and green façades. The results of the standard model show that green roofs has the highest adoption fraction and cool roofs and green façades are not adopted at all. The sensitivity analysis investigating the effect of the energy reduction showed that a twenty percent change of the energy reduction effect of green roofs influences the amount of green roofs adopted significantly. It also reduced the fraction of adopted green gardens when the effect was increased by twenty percent and increased this fraction when the effect was reduced. A change in the energy reduction effect of green façades and cool roofs did not have significant effects. Therefore, this hypothesis can be confirmed.

7.3.2 Hypotheses sub-question two

Sub-question two is: *"How do household characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
For this sub-questions also three hypotheses were formed.

H2.1: Households with a higher education level adopt more UHI mitigation solutions. **Falsified**

The results of the standard model did not show a significant difference in the fraction of adopted solutions between the three different educational levels. The sensitivity analysis revealed that the total adopted fraction reduces a little with an increase of the educational effect and increases when this effect is larger, but these were not significant. It also did not displayed any significant differences between the educational levels when the effect was increased. Therefore this hypotheses is falsified.

H2.2 Households with a higher income adopt more UHI mitigation solutions. **Confirmed**

A significant difference exists between the adopted fraction of low income households and households with a middle or high income in the standard model results. Even in the experiment with a ten or twenty percent subsidy for each of the four possible solutions that households can implement this significant difference remained. However, the adopted fraction of low income households increased more than the fraction of middle and high income households although this was not significant. The sensitivity analyses showed the same significant effect as the standard model results. This hypothesis can thus be confirmed.

H2.3 Households that own a dwelling adopt more UHI mitigation solutions. **Undetermined**

The results of the standard model show that non-social owner occupiers living in single-family dwellings adopt UHI mitigation solutions much quicker than non-social tenants that live in apartments and the difference is significant for the first couple of years. However after some time the fraction adopted by these tenants increases to the same level as the fraction of these owner occupiers and the difference is not significant anymore. The experiments present contradicting results. Having a 20 or 35 percent subsidy for green roofs show a significant difference, but this disappears with a 50 percent subsidy. When there is a subsidy for green façades there is no significant difference, while a subsidy for cool roofs does result in a significant difference. If a 20 or 35 percent subsidy exists for green gardens, the difference is significant, but it disappears for a subsidy of 50 percent. For the experiment with different solutions adopted by housing corporations the difference in the adopted fraction between non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments is only significant for the implementation of cool roofs. The results of the sensitivity analyses also show different results. An increase in the amount of households per VVE creates a significant difference where those tenants have a higher adopted fraction than the owner occupiers. Increasing the amount of friends per household also creates a significant difference as is true for a change in the effect of neighbourhood vegetation. Changing the costs of the solutions also creates a significant effect, as is true for increasing the input temperature with ten percent. The experiments thus show different results and the sensitivity analysis even shows an effect that is the other way around for one input. Therefore this hypotheses cannot be confirmed nor falsified.

7.3.3 Hypotheses sub-question three

Sub-question three is: *"How do institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
Again three hypotheses were formed for this question, which are discussed in this section.

H3.1: Households that are part of a VVE adopt less UHI mitigation solutions. **Confirmed**

The standard model outcomes show that non-social households that are part of a VVE adopt solutions slower than non-social households living in single-family dwellings. Over the years this difference reduces but is still significant at the end of the model run. This significance disappears for a 50 percent subsidy for green roofs or green façades but remains in the other subsidy experiments. When housing corporations implemented green and cool roofs this significance remains, but when they do not adopt a solution, adopt green façades or green gardens this disappears as well. In the sensitivity analyses households that are part of a VVE adopt more solutions when the amount of households per VVE increase to eight. However, in all other instances they adopt less solutions and in one case this difference is not significant. This is when the costs of green façades decrease with ten or twenty percent. The hypotheses can thus be confirmed as the significant difference only disappears in a small amount of cases.

H3.2: Increasing the amount of available subsidy increases the overall implementation of the subsidised solution. **Confirmed** and **Falsified**

The experiment that investigates the effect of implementing and increasing the subsidy per solutions shows that the hypothesis can be confirmed for green and cool roofs, but not for green façades and green gardens. Those adopted fractions did not increase significantly with a 20, 45 or 50 percent subsidy of the total costs. These did however show other interesting results for the average temperature and total fraction implemented. These will be discussed in the next chapter. Therefore this hypothesis is confirmed for increasing the subsidy of green and cool roofs, but falsified for green façades and green gardens.

H3.3: Performance agreements with housing corporations also increase the adoption of solutions by other households. **Falsified**

The standard model results show a significant difference between the total adopted fraction by non-social households and the overall total adopted fraction. There is thus a difference between non-social and social households. It further presented that non-social households implement UHI mitigation solutions earlier but that social household caught up after several years. The experiment with different solutions implemented by housing corporations showed that the total fraction implemented reduced with almost the same percentage points as there are social households in the model. Therefore it is concluded that the adoption of solutions by non-social household is not increased by the agreement with housing corporations. Although these two groups do influence each other through friendships and the nearby temperature that they both affect with implementing solutions this is not big enough to show a significant effect.

7.3.4 Hypotheses sub-question four

Sub-questions four is *"How do characteristics of residential environments influence the adoption of Urban Heat Island mitigation solutions."*
For this sub-question four hypotheses were formed.

H4.1 Neighbourhoods with a compact LCZ have more adopted UHI mitigation solutions compared to open LCZs. **Falsified**

In the present study LCZ3 is a compact neighbourhood, while LCZ5, LCZ6 and LCZ9 are open. Therefore this hypotheses suggests there is a difference in the total fraction adopted solutions between LCZ3 and the other LCZs. As most households are located in LCZ3 (75.83%) it could prove difficult to find a significant difference between these areas. With less households in other areas the confidence intervals of these areas are larger and finding a significant difference is more difficult. To check this hypothesis only the total adopted fraction is investigated, the differences between the different solutions is not taken into account. The standard model results do not show a significant difference between these areas. A green garden subsidy of 35 percent does create a significant difference between LCZ3 and LCZ9. This is also true for the experiment where housing corporations adopt no solution or green façades. That experiment also creates a significant difference between LCZ3 and LCZ5 for the adoption of green façades. Several sensitivity analyses show a significant difference between the total adopted fraction of LCZ3 and LCZ9, but some also show that this difference exists at the same time between LCZ6 and LCZ9. Because of all these effects this hypothesis is falsified as the fact that a LCZ is compact or not does not seem to influence the amount of adopted solutions in that area.

H4.2 Neighbourhoods with a low rise LCZ adopt more green- and cool roofs than midrise LCZs. **Falsified**

As green and cool roofs have a bigger effect on the outdoor air temperature when they are implemented on low roofs, it is expected that these solutions are more implemented in areas with low rise. In the present study LCZ5 is a midrise area and LCZ3, LCZ6 and LCZ9 are low rise areas. It is thus investigated whether there is a significant difference between the amount of green and cool roofs adopted in LCZ5 compared to the other LCZs. The standard model results do not show a significant difference. Also the different experiments and sensitivity analyses do not present this. It can thus not be concluded that such a difference exists and the hypothesis is falsified.

H4.3: Neighbourhoods with more vegetation have more adopted UHI mitigation solutions. **Falsified**

Section 6.2.3.1 showed that LCZ9 has the highest amount of vegetation with almost 70%, followed by LCZ5 with around 48%. LCZ3 and LCZ6 follow from a distance with 17.7 and 13.7 percent vegetation respectively. It was expected that these differences would have an impact on the fraction of solutions implemented in these neighbourhoods however the results of the standard model, experiments and sensitivity analyses do not immediately show this. Increasing the subsidy for green gardens with 35 percent shows a significant difference between LCZ3 and LCZ9. If housing corporations implement green façades the same result is achieved. However, if they implement green gardens there is a significant difference between LCZ5 compared to LCZ3 and LCZ6 and if they implement green façades the only significant difference is between LCZ5 and LCZ3. All other experiments do not show significant differences. Furthermore several sensitivity analyses show a significant difference between LCZ3 and LCZ9, but apart from temperature effects only when schools and hospitals implement a solution and when the costs of cool roofs increase with ten percent there is also a significant difference between LCZ6 and LCZ9. A significant difference between LCZ5 and LCZ3 or LCZ6 is only seen if the nearby air temperature tipping point or the input air temperature changes. Therefore the hypothesis is falsified, because of the lack of proof with regard to LCZ6 and LCZ5.

H4.4: Neighbourhoods with a higher average temperature have more adopted UHI mitigation solutions. **Falsified** and **Confirmed**

The average temperature in LCZ3 and LCZ6 are higher, 29.6 and 29.2 degrees Celsius respectively, than LCZ5 and LCZ9 with 26.9 and 26 degrees Celsius, respectively. The fraction of solutions implemented in LCZ3 and LCZ6 should thus be higher than the other two LCZs. However, only LCZ9 shows a lower implemented fraction than the other LCZs, that are all around the same values. Some experiments show that there is a significant difference between LCZ3 with the highest average temperature and LCZ9 with the lowest average temperature. In one experiment this difference is also significant between LCZ6 and LCZ9, and several other experiments shows a significant effect between LCZ5 with LCZ3 and LCZ6, or LCZ5 and LCZ3, or LCZ5 and LCZ6. However, the sensitivity analysis regarding the influence of the nearby air temperature tipping point and the input air temperature show a clear difference between LCZs with a higher temperature and LCZs with a lower temperature. Increasing the tipping point of the nearby air temperature with ten or twenty percent creates a significant difference between the total adopted fraction of LCZ3 and LCZ6 with LCZ5 and LCZ9, while decreasing the input air temperature with the same percentage creates an equal result. Therefore, this hypothesis is falsified for the standard model, if all input variables proof to be correct there is no significant difference between these neighbourhoods. However, if there is a small change regarding the nearby air temperature tipping point or the input air temperature the differences are significant.

8 Conclusions and discussion

8.1 Conclusion

The negative effects of the Urban Heat Island (UHI) effect in cities increase as global temperatures increase (IPCC, 2013) and the amount of people living in cities keeps rising (United Nations, 2019). Several solutions exist that can reduce the heat in cities and thus the UHI effect. However, this graduation research showed that there is a lack of knowledge about the effect of UHI mitigation solutions by municipalities and households and municipalities do not know how they can effectively use and stimulate the adoption of these solutions to reduce the UHI effect in their cities. Therefore, this graduation study arrived at the following main research question:

How do technical, household and institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?

To answer this main question, it was divided into four different parts. A literature study, expert interviews and ABM model were used to answer these sub-questions:

1. *"How do technical characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
2. *"How do household characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
3. *"How do institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
4. *"How do characteristics of residential environments influence the adoption of Urban Heat Island mitigation solutions."*

8.1.1 Technical characteristics

Section 4.1 explains for the eight UHI mitigation solutions investigated in this graduation study the technical characteristics influencing their adoption. Several of these effects, such as their air temperature reduction, effect on energy use and their costs based on the characteristics of the dwelling, were tested in the agent-based model to check whether these characteristics had a significant effect on the outcome of the model for the Bomen en Bloemenbuurt neighbourhood in The Hague.

The conclusion for hypothesis one of sub-question one (1.1) that UHI mitigation solutions with lower costs have a higher adoption rate could not be formed. Some green gardens, that have the lowest costs, were implemented in the model but green roofs were implemented the most even though these are more expensive than cool roofs. The results from the experiments and sensitivity analyses give contradictory results, so this hypothesis could not be confirmed nor falsified.

Hypothesis 1.2 that solutions with a larger temperature reduction effect have a higher adoption rate is falsified. The model showed that almost only green roofs were adopted in the Bomen en Bloemenbuurt, although this solution did not have any effect on the outdoor air temperature at the start of the model run. Each time when the amount of green roofs in an area reaches a threshold percentage the effect on the air temperature increases. Implementing green gardens had a larger effect on the outdoor air temperature but this solution was only implemented by very few households.

UHI mitigation solutions with a larger energy reduction effect were expected to be implemented more through hypothesis 1.3. The model results could confirm this hypothesis as green roofs have the highest effect on the energy use of households and changing this effect also influenced the amount of adoptions significantly.

The conclusions to the hypotheses show that only the energy reduction of UHI mitigation solutions have a significant influence on the adoption of these solutions. The influence of the costs could not be determined and no significant influence of the temperature reduction effect could be found. Together with the overview of the technical characteristics in section 4.1 and the overview of literature regarding the effects of different UHI mitigation solutions on the outdoor air temperature in appendix A, the present study shows what and how technical characteristics influence the adoption of UHI mitigation solutions. The technical characteristics can be useful for parties interested in adopting an UHI mitigation solution. It shows what characteristics should be considered for different solutions and thus helps in reducing the lack of knowledge of interested parties.

8.1.2 Household characteristics

The household characteristics influencing the adoption of UHI mitigation solutions are discussed in section 4.2. That section presents an overview of the household characteristics that influence pro-environmental behaviour and therefore the adoption of UHI mitigation solutions according to literature. It was concluded that several characteristics had disputed effects and only a few show a clear effect. The characteristics educational level, income, home ownership and the amount of vegetation in the neighbourhood were tested in the agent-based model to see if they have a significant effect on the outcome for the Bomen en Bloemenbuurt.

Section 7.2.3 showed that hypothesis 2.1 about households with higher educational level implementing more solutions was falsified as there was no significant differences regarding this characteristic.

Hypothesis 2.2 stating that households with higher income would adopt more UHI mitigation solutions was confirmed. The model results, experiments and sensitivity analysis showed that high and middle income level households almost always had a significantly higher fraction of solutions adopted than low income households.

The conclusion for hypothesis 2.3 that owner occupiers would adopt more UHI mitigation solutions could not be determined. As all results showed different effects and in some instances owner occupiers had even a lower fraction adopted.

The overview of the effects of housing characteristics on pro-environmental investments in section 4.2, together with the conclusions to the hypotheses that showed that the income level of households has a significant effect on the adoption of UHI mitigation solutions, the effect of owning a dwelling could not be determined and there is no significant effect of the educational level of households, explain which household characteristics influence the adoption of UHI mitigation solutions by households. This information can help parties, such as municipalities, to decide how far they should go in convincing households to invest in UHI mitigation solutions. A neighbourhood with a high average income level and a lot of vegetation does not need the same amount of persuasion as areas with a low income level and less vegetation. On the other hand, it is also concluded that the nearby air temperature influences the decision of households and a high amount of vegetation in the area often leads to a lower nearby air temperature than areas with a lot of hard surfaces.

8.1.3 Institutional characteristics

In section 4.3 the institutional characteristics are discussed. It explains that there are several bottlenecks that reduce the adoption of UHI mitigation solutions, such as the decision making process in owners' associations (VVE's). Several of these were tested in the agent-based model to check the significance of their effect.

Hypothesis 3.1 stating that non-social households, which are part of an owners' association (VVE) adopt less UHI mitigation solutions than non-social owner occupiers living in single-family dwellings is confirmed. Only in a very small amount of specific cases the difference between these two groups was not significant.

Through increasing the amount of available subsidy for a specific solution could increase the implementation of that solution was part of hypothesis 3.2. The results of the model confirmed this hypothesis for green and cool roofs and falsified it for green façades and green gardens. The characteristics of the system considering the implementation of UHI mitigation solutions in the Bomen en Bloemenbuurt caused an increase of the subsidy for green and cool roofs to change the implementations significantly, but this was not the case for green façades and green gardens. Therefore the conclusion to this hypothesis is both ways.

The third hypothesis of sub-question three considered the performance agreements with housing corporations and suggested that these could also increase the adoption of solutions by other households. This hypothesis is falsified as the experiment with housing corporations implementing different solutions showed that when these did not implement solutions the reduction of the total adopted fraction is almost the same as the amount of social dwellings in the area.

The hypotheses regarding sub-question three showed that non-social households that are part of a VVE adopt less UHI mitigation solutions than non-social households living in single-family dwellings, that increasing the amount of subsidy would increase the implementation of green and cool roofs but did not have an effect for green façades and green gardens, and that agreements with housing corporations do not influence the fraction of adopted solutions by non-social households. Combined with section 4.3 about institutional characteristics the present study shows how these characteristics influence the adoption of UHI mitigation solutions by households. The presented information about the institutional characteristics can be used by governmental bodies to improve their policies to increase the adoption of UHI mitigation solutions. It shows several bottlenecks that can be improved to increase the adoption of these solutions by households.

8.1.4 Characteristics of residential environments

Sub-questions four is investigated by considering the Local Climate Zones (LCZs) within the Bomen en Bloemenbuurt. Section 3.2 explains that there are four different LCZs within this area, LCZ3, LCZ5, LCZ6 and LCZ9. The differences between these LCZs are presented in section 2.4.

Hypothesis 4.1 investigated whether neighbourhoods with a compact LCZ had more UHI solutions implemented than open LCZs. This hypothesis is falsified as the significant differences found between the four LCZs in this graduation research, were not the result of the difference between open and compact.

Whether neighbourhoods with low rise buildings would adopt more green- and cool roofs (hypothesis 4.2) is also falsified. No significant differences related to building height were found in the present study. This could be the result of the present study only investigating the difference between low rise

and midrise neighbourhoods. Investigating the difference with high rise neighbourhoods could be the topic for a future study.
For hypothesis 4.3 it was examined if more vegetation in a neighbourhood would result in more adopted UHI mitigation solutions. This hypothesis is also falsified. Although some results considering LCZ3 and LCZ9 seemed to support this hypothesis these were not backed by significant differences regarding LCZ6 and LCZ5.
Regarding hypothesis 4.4 about the difference of the amount of adopted solutions in neighbourhoods with a higher average temperature the results of this study show two different conclusions. If all standard model inputs turn out to be correct there is no significant difference between areas with a different average temperature. However, different input temperatures or a different nearby air temperature tipping point can change this and create significant differences between these areas. Therefore this hypothesis is both falsified and confirmed.

The present study shows that the amount of vegetation, having an open or compact neighbourhood or having low or midrise buildings does not significantly influence the amount of adopted UHI mitigation solutions. The current air temperature however does influence the fraction of adopted solutions in some systems. This was not clear for the standard model inputs in the present study but was shown by several analyses.

The answers of the four sub-questions combined answer the main question of this graduation research: "*How do technical, household and institutional characteristics influence the adoption of Urban Heat Island mitigation solutions in existing neighbourhoods in the Netherlands?"*
The temperature reduction effect does not have a positive influence on the adoption, the positive effect of the costs of solutions is undetermined, while the energy reduction effect does influence the adoption positively. A higher educational level of households does not have a positive influence on the adoption, the positive effect of a household being an owner-occupier is undetermined and having a higher income does influence the adoption positively. Performance agreements with housing corporations do not have a positive influence on the adoption of solutions by other households, increasing the amount of subsidy has positive influence for green and cool roofs but not for green façades and green gardens, while being part of a VVE does influence the adoption negatively. Furthermore whether a neighbourhood is open or compact, has low or midrise buildings or has more vegetation does not have an influence on the adoption of UHI mitigation solutions. A higher outdoor air temperature in areas can have a positive influence in specific cases.

The results of the different experiments on the outdoor average and maximum temperature were not investigated through the different hypotheses but are relevant to policy makers so they can make decision that will have the biggest air temperature reduction effect. The results of the agent-based model of this graduation research show that the amount of temperature reduction in the four investigated Local Climate Zones is roughly the same, however considering the reduced reliability of the temperature outcomes because of the low resolution of the input air temperatures, no conclusion can be drawn about exact temperature reduction. Changing existing subsidies does not influence the reduction of the average temperature significantly, but do show a significant increase in the total implemented fraction of solutions for a higher green or cool roof subsidy. Finally the average temperature in an area can be significantly reduced by changing the surfaces of squares in that area to ones that reduce the Urban Heat Island effect, but do not show a significant influence on the fraction of adopted solutions by households.

8.2 Discussion

This section discusses the uncertainties as a result of the input data and limitations as a result of the research method and model operationalization. It present the effects of these uncertainties and limitations on the conclusion of this graduation study.

8.2.1 Uncertainties

The uncertainties caused by the input data are related to the data quality. In some cases it was not possible to use the exact data that was intended to be used as model input and in other instances the aggregation of the input data used for the model differed between inputs.

8.2.1.1 Different aggregated data

Considering the latter case it was deliberately chosen to use data of the whole city of The Hague for household related inputs to be able to generalize the results of the present study to other cities and neighbourhoods that are similar to The Hague in a better way, because the data for the whole of The Hague would be more mediate than the data for the specific district of the Bomen en Bloemenbuurt. For other input data regarding the environment of the area, such as the input temperature and surface of squares, it was chosen to use the data of the Bomen en Bloemenbuurt as this district is used as case study in the present research. This choice has as a result that the outcomes of the present study are less reliable when only considering the Bomen en Bloemenbuurt, because the input data for the whole city of The Hague differs for several variables from the characteristics of this district. These difference are presented in section 6.2 during the presentation of this data. The next paragraph shortly mentions the most important differences between the input data of city of The Hague and the Bomen en Bloemenbuurt and their effects. These are relevant for decision makers that want to interpret the outcomes of the model made in this graduation research and apply them to the Bomen en Bloemenbuurt.

As the amount of owner occupier in the Bomen en Bloemenbuurt is much higher than in the whole of The Hague the amount of adopted Urban Heat Island (UHI) mitigation solutions could be underestimated. However, the hypothesis about the effect of dwelling ownership is undetermined so this effect is unclear. At the same time there are far less dwellings owned by housing corporations in the Bomen en Boemenbuurt. This means that when the municipality is able to make performance agreements with these housing corporations about the implementation of a UHI mitigation solution the amount of adoptions will be overestimated in the model compared to the Bomen en Boemenbuurt. The amount of flats in the Bomen en Bloemenbuurt is lower, while the amount of porch dwellings is higher than for the whole of The Hague. This leads to an overestimation of the costs of UHI mitigation solutions by the model as flats have a smaller roof surface per household than porched dwellings. At the same time the costs of installing a green or cool roof are overestimated for some households which can lead to an underestimation of the amount of adopted solutions. Lastly the Bomen en Bloemenbuurt has a lower amount of multi-family dwellings than The Hague. As households living in multi-family dwellings are part of an owners' association (VVE) and this graduation research confirms that household that are part of a VVE adopt less UHI mitigation solutions, the amount of adopted solutions is underestimated for this district.

8.2.1.2 Use of intended data

In some cases it was not possible to use the exact data that was intended to be used as model input. Section 6.2 sometimes shortly mentions this for different input data, this section explains the effects of these uncertainties that have a scientific relevance.

8.2.1.2.1 UHI mitigation solutions

The effects of the UHI mitigation solutions addressed in this graduation study differ between the Local Climate Zones (LCZs) in the model. However, an area does never exactly follow the characteristics of the specific LCZ, they are almost always combinations of multiple zones. Therefore, the four areas in the model were first presented with a sub-LCZ. For the effect of the UHI mitigation solutions this sub-zone was not considered anymore, and effects found for one LCZ had to be applied to similar LCZs if there was not enough data for the specific LCZ. Because of this there were no differences between the effects of Urban Heat Island (UHI) mitigation solutions in LCZ3, LCZ6 and LCZ9. Therefore, differences between the results of the model, such as the amount of implementations or average temperature in a LCZ, are reduced and can be found less easily.

The different literature sources used as input for the effects of the UHI mitigation solutions in the model each measured these effects differently. Appendix A shows the moment of measurement, the measurement height and the method of measurements of these sources. Because of all these differences, it was more difficult to determine the exact effect of the UHI mitigation solutions in different LCZs and these effects are less reliable. This also reduces the reliability of the outcomes of this graduation study. This effect is slightly reduced by combing the effects found in multiple literature sources, but it would be best if new research would all follow the same measurement methods so their results can be compared better.

Most literature sources did not mention the climate classification of the location the research was done at or the LCZ of that location. These were determined during this graduation research based on the available information about the locations in the literature sources. Determining the Köppen-Geiger Climate Classification could easily be done most of the time as the location of the research was often mentioned by the authors. Sometimes it was not possible to determine the LCZ and these were reported as N/A. Because this information had to be determined afterwards, the chance of making a mistake is larger than when the original researchers themselves, that are probably familiar with the location they are investigating, determined the LCZ. This affects the reliability of the comparison between the effect of UHI mitigation solutions in different LCZs and thus the outcome of this graduation research. It would be better if the LCZ of an area is mentioned in future research into the effects of UHI mitigation solutions to improve the ability to combine or compare results.

The Urban Heat Island (UHI) mitigation solutions incorporated into the model of the present study can be implemented in a lot of different ways. As section 4.1 mentions green roofs can be extensive or intensive and extensive green roofs can also have differences in the thickness of the soil, or the type of greenery used. These type of differences also exist for the implementation of a cool roof caused by the type of reflective material used, for green façades for the type of plants used and whether a green garden only exists of one small tree, a big tree or whether a households also changes tiles for grass. In the present research these differences are not considered and the average type of these solutions is considered. However, if households all implement solutions with small or big differences the uncertainty in the present study increases and the results become less reliable.

The temperature reduction effect of green and cool roofs were only available for certain percentages of households having these solutions installed. Therefore this effect was incorporated with threshold percentages where the influence of all green or cool roofs in a Local Climate Zone (LCZ) would instantly increase to a new amount as the temperature effects between these threshold percentages were not available. However, in reality the temperature influence would increase gradually as the total percentage of households that implemented the solutions increases. Because of this difference the effect of green and cool roofs on the air temperature during and at the end of the model run are underestimated. This in turn increases the uncertainty of the outcomes as the actual temperature effect between two LCZs could be further apart and in other cases closer together.

It is assumed that **green roofs** could be applied directly on all existing roofs in the area and these roofs did not need any improvements. In reality a percentage of roofs always needs more improvements and the costs would thus be higher for these households. This results in an underestimation of the costs of green roofs in the model and thus could lead to an overestimation of the amount of green roofs adopted. Furthermore the total costs of all implementations is also underestimated when green roofs are implemented the most. For **cool roofs** the costs may be overestimated as it is assumed that household not just apply a cheap reflective coating on their roof, but the whole roof is adjusted. This thus causes an underestimation of the amount of cool roofs adopted and an underestimation of the total costs if cool roofs are implemented the most. The costs of **green façades** are partly underestimated as the increased maintenance of this solution over the years is not directly taken into account. For **green gardens** the costs are also underestimated as it is expected that households will implement this solutions themselves and not need an external party to do the work. This will thus lead to an overestimation of the amount of green gardens in the model.
These effects are important for policy makers that want to introduce new policies based on the outcomes of the total costs or subsidies of this research. These should take a look at section 6.2.2.5 that reports that a change in the costs of green roofs and façades have significant influences on the outcome of the present study.

8.2.1.2.2 Input air temperature
As explained in section 6.2.3.3, the air temperature used as input into the model had a level of detail of 100x100 metre, while the model in this graduation study has a detail level of 9x9 metres. Furthermore, the input air temperature had to be determined from a figure of the area of the city of The Hague that had 9 classes of air temperature that each included two degrees Celsius, while the model of this graduation research uses effects of UHI mitigation solutions up to two decimal places. The range of the input air temperature could be reduced to 1 degree, but most effects of UHI mitigation solution in this model lie in a range between 1 and 1.2 degrees Celsius. As the outcomes of the model are presented by LCZs that are larger than just 100x100 metres the results are somewhat reliable and could be used to come to several conclusions about these LCZs. However, an overview of a model run that shows where in the LCZ the temperature is still high or already low is less reliable when these effects are less than 1 degree Celsius in an area less than 100x100 metres.

As the input temperatures are provided for 100x100 metre squares the temperature at the boundaries of these squares abruptly change from one to the other. In reality the temperature would gradually change between the two areas. This creates an underestimation of the outdoor air temperature if a small amount of these squares with a lower temperature are close to a larger amount of these squares with a higher temperature. This in turn reduce the amount of adopted solutions by households as the nearby air temperature influences their decision making process. At the same time this effect is the other way around when a small amount of squares with a high temperature is located close to a large amount of squares with a lower temperature. As section 6.2.3.3 shows that there are more areas with a higher air temperature in the investigated district the sum of these effects will cause an underestimation of the average temperature and thus of the total amount of adopted solutions. The effect of this aspect of the input data on households is limited as they consider the nearby air temperature within a certain range of their dwelling and thus also take the higher or lower temperature of a neighbouring square into account. However, it does affect the influence of green façades and green gardens on the outdoor air temperature as they have a fixed influence on their nearby area. This results in an underestimation of the average temperature in the agent-based model of the present study and thus an underestimation of the amount of Urban Heat Island mitigation solutions implemented.

8.2.1.2.3 Households

As input for the model of this graduation study household characteristics were used that influence the pro-environmental behaviour according to literature. The exact definition of a household can however differ between these studies and more importantly households change over time (Reid et al., 2010), as is also possible for the effect of their characteristics. As this model runs over a period of 40 years, characteristics as the distribution of the level of education of households and the type of ownership could change in the area and effect the results.

The present study uses data from the BAG (2020) for the geographical location of households in the Bomen en Bloemenbuurt. This adds up to a total of 7862 households in the whole district. However, data from DHIC (2021) indicates that there are 7592 households in the area in the year 2020. This is a difference of 270 households (3.4%). A lower amount of households in the area would mean that the effect of green façades and green gardens on the average temperature is overestimated in the model of the present study as these have a specific effect per adopted solution. In the standard model setup green façades are not implemented, but green gardens are and thus the outcome average temperature could be slightly underestimated.

With regard to the effect of household characteristics on pro-environmental behaviour Lam (2006) mentions that “the relative importance of demographic variables depends on the type of environmental behavior that is concerned” (p. 2819). As research on the connection between these variables and investments in Urban Heat Island (UHI) mitigation solutions could not be found, an overview of other environmental investments was presented, and the results adopted for the present study. Future research into the connection of demographic variables and investments in UHI mitigation solutions should thus validate whether this choice was correct or Lam (2006) is correct and the effects are different from other types environmental behaviour. If the effects turn out to be different the results of this graduation study could prove to be false and it should be adjusted with the right effects.

Another model input that causes uncertainty are the weights used by the households to determine their multi-attribute utility. These are adopted form the research of Muelder & Filatova (2018), however they have based these weights on a small survey amongst residents in Dalfsen, the Netherlands and already indicate themselves that these weights were not tested on their representability. Furthermore, these weights were set to a fixed value, while it could be expected that during the 40 years the model runs these weights would change up and down as the priorities of households change. It is thus not clear whether these weights are the right choice for a city like The Hague, as Dalfsen is only a small municipality compared to The Hague. Because of this, the exact height of the outcomes of this model are less reliable. The behaviour of the model and the direction of the effects caused by different inputs are reliable, but the exact numbers are less reliable. Future research into the exact weights of households in The Hague is thus needed to increase the reliability of the results. The possibility that these weights change over time should also be part of such research.

Section 6.2.1.2 explained that the input data for the educational level of households was only available for all individuals between fifteen and 74 years old. This leads to an underestimation of the effect of education on the outcomes of the agent-based model as it underestimates the average educational level of households.

In appendix B, section B.6.2.1.1 shows that the income distribution used in the agent-based model differs from the 'normal' income distribution. Because of the limited input data the incomes within a certain quantile is distributed with a uniform distribution and all households in the highest income quantile receive the low boundary of this quantile as income. These effects result in an overestimation of the amount of low income households in the model and thus an underestimation of the results as there is a significant difference in the amount of adopted solutions by low income households and middle and high income households.

8.2.2 Limitations

This sections presents the limitations of this graduation research as result of the research method and model operationalization. Making a model always comes with several limitations, as it is a simplified representation of a real-world system.

8.2.1.1 Research method limitations

The small-world network is used in this present study to create the friends of households that influence the social factor of the TPB. However, it is also possible to use other ways of creating the friends network (Rahmandad & Sterman, 2008). Future research could investigate what the effect is of different ways of creating this network. As the model runs for 40 years there is a big chance that in reality the friend connections of households change. In a realistic network new friendships can form or current ones can fade over time (Rahmandad & Sterman, 2008). The effect of a more realistic network could also be researched in future work. Another network limitation is that in this graduation research the social network only includes other household friends. Rai, Reeves, & Margolis (2016) show that local installers can also influence households and their role is often supplementary of the role of friends.

The three different model architectures of this graduation research were based on the research by Muelder & Filatova (2018). The RR and SE architecture in their research were both adapted from two earlier studies, by Rai & Robinson (2015) for the RR architecture and by Schwarz & Ernst (2009) for the SE architecture. This means the these two architectures are adapted for a second time to be able to use them for this graduation study. For each adaptation, the model moves further away from its original form, the uncertainties of its results increase and its reliability is more limited. Because of this and other effect it was chosen to focus on the MF architecture, which is only adapted once from model Muelder & Filatova (2018) created, in this graduation research as the impact of multiple adaptions is lower for this architecture. However, it is still present and limits the reliability of the outcomes of this graduation study.

In section 2.7.1 the ongoing debate about the use of the Theory of Planned Behaviour (TPB) between Sniehotta et al. (2014) and Ajzen (2015) is presented. Ajzen (2015) reflects various criticisms by Sniehotta et al. (2014), but these criticisms do have some ground and can thus also be applied to this graduation study.

Section 3.5.1 presents five problems described by Scalco et al. (2018) when applying the TPB in an agent-based model (ABM). That section also explains how these were mitigated as best as possible for the present graduation research, but it was not able to mitigate all of them completely. Therefore, the ABM of the present research does still have some limitations regarding the explanation of agents behaviour and the exact relation between intention and behaviour.

This graduation research only investigates the effect of UHI mitigation solutions on the outdoor air temperature and does not take the indoor air temperature in account. The nearby outdoor air temperature does of course influence this indoor temperature, but there are a lot more effects that do the same. It also does not include other effects of the UHI mitigation solutions, positive or negative, as mentioned in section 2.5. This choice was made to make the model less complex and made it possible to do this graduation study within the set time period. Furthermore, the research about some of these effects is still limited. However, these other effects could be very interesting and future research could investigate these.

The research by Muelder & Filatova (2018) also included the costs of searching for information about the effect of PV panels through an amount of time or a monetary cost. For this graduation research it is assumed that there is perfect information and households exactly know the effects and prices of UHI mitigation solutions and are able to correctly assess the influence of their friends and in some cases the households that are part of their VVE. In reality there is no perfect information and searching for information costs time and/or money. Future research could add this aspect to the model and see what its effect is.

8.2.1.2 Model operationalization limitations

In the model verification in section 6.4 on statement is not confirmed. This is the following: When the surface of a square is changed to a surface with less temperature reduction, the patches within the radius of the square change temperatures accordingly and thus have a higher temperature. The agent-based model of this graduation research cannot deal with this change in the right way as it only considers changes that reduce the outdoor air temperature. Because of this the square itself does increase its temperature in the right way, but the radius of the effect of this change on the nearby area is not correct. This limits the use of the model to only incorporate surface of square changes that reduce the nearby air temperature. The different experiments in this graduation study adhere to this limitation and it does thus not influence the results of the present study. However, it does influence the potential future use of the model.

As explained in section 6.2.1.7 the households in the standard model that live in a multi-family dwelling and are thus part of an owners' association (VVE) can form a connection with multiple VVE heads and can thus be part of multiple VVEs. This operationalization of the model cause this effect and it could not be adjusted anymore once it was discovered. This limitation of the model operationalization results in an underestimation of the fraction of adopted solution and reduces the reliability of the outcomes.

The operationalization of the effect of green and cool roofs on the air temperature cause an underestimation of these effects, because they stop abruptly at the end of a Local Climate Zone (LCZ). This underestimation in turn causes an overestimation of the amount of adopted solutions as the a higher outdoor air temperature has a significant effect on the adoption of Urban Heat Island (UHI) mitigation solutions in specific scenarios. Furthermore, the effects of green and cool roofs are considered separate from each other, while it could be possible that the combination of the effects of these solutions is higher than the effect of the solution based on adoption percentage of that specific solution.

The temperature reduction effects of a change of the surface of squares do not take obstructions by dwellings or other buildings into account. They all have a fixed radius of their effect. This could lead to an overestimation of their effect on the outdoor air temperature and thus an underestimation of the air temperature itself. This will lead to an overestimation of the amount of adopted solutions as the a higher outdoor air temperature has a significant effect on the adoption of Urban Heat Island (UHI) mitigation solutions

In the agent-based model 75% or more households in an owners' association (VVE) need to support the adoption of a specific solution before all households in that VVE adopt a solution. As section 5.3.4 explains in some VVEs a two third majority is already enough. Because of this, the model underestimates the amount of solutions adopted by households that are part of a VVE compared to the real world. As the present study concludes that being part of a VVE has a significant negative influence on the adoption of UHI mitigation solutions, this limitation could be the cause of this effect and it is possible that this effect was not found when this threshold value was set to a lower percentage. Future research should investigate whether this is true and confirm or deny the results found in the present study.

Section 5.1.5 explains that when municipalities make performance agreements with housing corporations to implement a specific Urban Heat Island (UHI) mitigation solution at their properties, this solution will be implemented with a chance of once in 25 years during regular larger maintenance. However, it could be that in reality some housing corporations are more passive and take more time to implement these solutions or that they already have a certain policy on this and do not want to change this because of a performance agreement with the municipality. The present research considers one kind of behaviour for all housing corporations but in reality these could differ between different corporations. This limits the reliability of the outcomes of the present study. Future research could investigate what the effect is of such differences to check the outcomes of this graduation research.

Using air temperature as the way to measure the effect of mitigation solutions is not the best method, as mentioned in section 2.2. Although the air temperature has the largest influence on the outdoor thermal comfort (Zhang et al., 2020), values that better indicate how people experience heat could improve the model. Even more because some UHI mitigation solutions seem to have a larger effect on for example the Physiologically Equivalent Temperature than on air temperature (Chatterjee et al., 2019).

To reduce the complexity of the model, the orientation of streets, building façades and gardens is not taken into account. As the orientation of building façades and gardens influence the amount of direct sunlight on the dwelling, these could influence the effect of a green façade or garden on the air temperature reduction. Furthermore, some research suggest that wind is an important factor in the UHI effect and wind can reduce the air temperature, but more specifically the outdoor thermal comfort trough values like the Physiologically Equivalent Temperature or Universal Thermal Climate Index. As the present research focuses on the air temperature the effect of wind is smaller, but still has an influence.

In the beginning of the model creation the boundaries of the model were set to 5 squares, so 45 metres around the buildings, to make sure the model would not include areas outside of the Bomen- en Bloemenbuurt. However, the radius of the nearby air temperature that influences the decisions of household was later set to 11 squares, or 99 metres. Because of this choice, the households living at the edge of the area base the influence of the nearby air temperature on less patches than household living more than 99 metres from the edge of the area. Therefore, households living at the edge will over- or underestimate the influence of the nearby air temperature. Figure 23 in section 6.2.3.3 shows that the air temperature at the edges of the Bomen- en Bloemenbuurt are mostly the same as the neighbouring squares of 100x100 metres. As the influence radius for households is 99 metres this will include the air temperature of two different squares so this limitation is less as it could have been. Furthermore, most households, around 74%, base the comfort factor of the multi-attribute utility on a complete radius.

Another limitation is caused by the choice to look at the effect of UHI mitigation solutions individually. Multiple literature sources show that a combination of different solutions can have a bigger influence on the air temperature than only implementing one solution (M. Santamouris et al., 2017; S. Tsoka et al., 2018). Households are also able to only adopt one UHI mitigation solution during the model run, however in reality it is possible that some households want to implement a green roof as well as a green garden, or a green roof and a green façade. Because of this limitation, the total implementations and the effect on the air temperature can be underestimated. In this graduation research the effect of different solutions is also summed together. For example, if one household implements a green façade, but the neighbouring household implements a green garden, the effects these two have on the air temperature are summed. In reality this would not be the case as the effect of one solution can influence the magnitude of the effect of another solution.

8.3 Scientific relevance

Through answering the sub-question formed in section 1.4 this graduation research improved the current scientific knowledge in multiple ways. It provides a detailed overview with the characteristics of recent research into the effects of UHI mitigations solutions, it shows an overview of the effects of household characteristics on pro-environmental behaviour found in literature and it explores the differences between three possible agent-based model (ABM) architectures of the Theory of Planned Behaviour (TPB).

Although overviews of the effects of UHI mitigation solutions on the air temperature already existed (M. Santamouris et al., 2017; S. Tsoka et al., 2018), these did not all show the climate classification of the studies they collected or the method of measurement. Furthermore, not one of them stated the Local Climate Zone (LCZ) of the location of the studies or more details about the moment of measurement or measurement height. In the present research the overview of studies into the effects of UHI mitigation solutions shows the effect within five different climate classifications that represent the possible future climates in Europe and indicates the LCZ where the present study took place. Additionally, it shows other characteristics of these studies such as the location of the research, the method of measurement, the moment of measurement and the measurement height. Such a detailed overview did not exist before this study and can be used by other researchers to investigate the effect of UHI mitigations solutions in different climate classifications or LCZs. It also shows the differences between all research into the effects of UHI mitigation solutions that make it more difficult to compare their results. Therefore, it shows the importance of creating a standardised approach for research into the effects of these solutions.

Although Lam (2006) already showed that including household characteristics improves the TPB and Reid et al. (2010) explain the meso level with household characteristics is an important level to consider, research into the effects of household characteristics on pro-environmental behaviour has not yet provided a clear overview of these effects. New studies show a small overview of existing findings, but this study is the first to present an overview of the different effects found in literature and for what kind of PEB these effects were found. This overview clearly shows that the effect of some characteristics are found by multiple studies, while the effect of others differ between all the studies and thus confirms the statement in Lam (2006) that the type of PEB influences the importance of different demographic variables.

Muelder & Filatova (2018) showed that the TPB could be formalized into an agent-based model in three different ways and that these three models show different behaviour for the adoption of PV by households in the Netherlands. This graduation research confirms that this is also true for the adoption of multiple UHI mitigation solutions and that the different behaviours in this graduation study were the same as in the study by Muelder & Filatova (2018).

8.4 Societal relevance

The conclusions of this graduation research fulfil the problem stated in the beginning. They increase the knowledge about the effects of Urban Heat Island (UHI) mitigation solutions and indicate how certain policies can stimulate the adoption of these solutions. The conclusions can be split into recommendations for households and for the municipality.

8.4.1 Recommendations for households

- According to the literature review, the adoption of a green garden has the biggest effect on the nearby outdoor air temperature in the Local Climate Zones (LCZs) considered in this graduation study and is also the cheapest possibility. However, it does not influence the energy use indoor air temperature of a dwelling.
- Tenants adopt less UHI mitigation solutions as they often need permission from the landlord. For them adopting a green garden could prove to be the best solution as it has the biggest effect on the air temperature and is relatively easy to implement and even change back to its original form if this is required by the landlord.
- If the fraction of households implementing a green roof increases, the effect of this solution on the whole air temperature in the area also increases. When a majority of households thus decides to implement this solution, it will have a larger influence on the outdoor air temperature.

8.4.2 Recommendations for the municipality

- According to the literature review, the creation of urban parks has the biggest local effect on the outdoor air temperature in all Local Climate Zones (LCZs) investigated in this graduation study and should thus be applied where possible.
- Changing the surfaces of squares in an area reduces the local air temperature, but does not significantly influence the adopted fraction of solution by households, except when the square area covers a large portion of the total area.
- There is no significant differences between the adopted fraction of Urban Heat Island (UHI) mitigation solutions of the investigated LCZs. The policy of the municipality does thus not have to be different between these LCZs. However, the height of the income of households in an area does have a significantly positive influence on the adopted fraction and the positive effect of the amount of owner-occupiers is undetermined. These neighbourhood characteristics could thus be taken into account when determining the policy for an area.
- The results of the subsidy experiments show that the average temperature reduction is the same for different types of subsidies, while the total amount of adopted solutions does significantly differ between different subsidy types and also the total amount of subsidy payed by the municipality has significant differences. Depending on the policy of the municipality it can choose to minimize the total amount of subsidy by introducing a green façade subsidy, minimize the total costs for households and housing corporations while having the same temperature reduction through introducing a 35 percent green façade subsidy, or it can choose to maximize the fraction of adopted solutions by introducing a cool roof subsidy of 50 percent of the prize of a cool roof or increase the current subsidy for green roofs.
- Lastly, municipalities and consultants could use the agent-based model made in this graduation study to investigate how much households in other neighbourhoods or cities adopt green roofs, green façades, green gardens and cool roofs and what for effect that has on the temperature and the total costs and subsidies. To be able to do this they need to change the input parameters of the model that are specific for a certain area, such as the amount of households, household characteristics, the effects of these solutions in certain Local Climate Zones (LCZs), the input air temperature and geographic features like the specific location of dwellings and squares with the coordinates of these features. The agent-based model can then be run with different policy options for that area to investigate the effects of these policies.

8.4.3 Further use

The model made for this graduation research is relevant for society as shows the standard scenario for the adoption of Urban Heat Island (UHI) mitigation solutions by households, but is also able to calculate the effect of different policies on the adoption of solutions in Local Climate Zones (LCZs). Therefore, it can be used by municipalities or other parties to show the effects of their ideas about certain policies. However, the limitations of the model should be taken into account when it is used for this purpose as it is a simplification of the real world. At the moment its conclusions are only reliable at LCZ level, but if the input air temperature is improved the model will be able to show more detail.
It could also be used to calculate the effect in other areas by changing multiple input values and using the coordinates of households and squares of these areas. Therefore, it can contribute to an efficient discussion about the adoption of UHI mitigation solutions in neighbourhoods in the Netherlands.

8.5 Future research

Multiple times within this graduation study the topic of future research is mentioned. As multiple inputs of the model have strong limitations, future research can reduce these and improve the reliability of this graduation study. This section briefly mentions the possibilities for future research that can improve the agent-based model used for the current research and then discusses what future research can be performed with the conclusions of this graduation research.

8.5.1 Research into model inputs

Almost all input parameters discussed in section 6.2 could be improved through future research. However, there are some inputs that could not be based on reliable data and should be the topic of future research to check whether this graduation research uses the right inputs and improve the reliability of its conclusions. The sensitivity analyses showed which of the input parameters had a significant effect on the outcomes of the agent-based model. These parameters should be improve by future research and are mentioned in this section.

Regarding the effect of Urban Heat Island (UHI) mitigations solutions the reliability of the following inputs could be improved:

- The air temperature reduction per Local Climate Zone for each solution.
- The radius of the air temperature reduction effect.
- The decline of the air temperature reduction effect within the radius.
- The energy reduction effect of the UHI mitigation solutions.

Inputs considering the properties of households that need to be researched further are:

- The weights that households use to determine their multi-attribute utility and whether these change over time.
- The amount of household friends and the way this network of friends is formed and can change over time.
- The role of local installers compared to friends.
- The effect of household characteristics on adopting UHI mitigation solutions.

However, the most important input parameter that needs further research is the level of detail of the starting air temperature data, as this data is only available for 100x100 metre squares and could have an error of one degree Celsius at maximum. Furthermore it is a snapshot of one hot summer day in The Hague and using averaged data of multiple hot days would improve the reliability this graduation study.

8.5.2 Possible research with current outcomes

Next to future research to improve the inputs of the model and thus improving the reliability of this graduation research, the present study also creates opportunities for further research with its outcomes. This sections mentions these opportunities.

The model for this graduation study uses the area of the Bomen- en Bloemenbuurt in The Hague as a case study but other neighbourhoods could also be used. The input document with the coordinates of the households, squares and input air temperature of this neighbourhood could be changed to inputs of another area in The Hague or even another city. This way the architecture of this model could be used as a basis of research into the effect of Urban Heat Island (UHI) mitigation solutions in other areas in the Netherlands. However, as most inputs in the present model are specific for the area of The Hague this should be done carefully, and more inputs could be changed to increase the reliability of the results if the model is adapted to another city within the Netherlands.

Another interesting possibility for future research is extending the present model with the effect of information costs. As the agent-based model of this graduation research assumes perfect information, information costs could be implemented in the model as monetary or time costs to investigate their effect. Muelder & Filatova (2018) show how this could be done in their research.

This graduation research investigates the effect of UHI mitigation solutions on the air temperature separately, while M. Santamouris et al. (2017) and S. Tsoka et al. (2018) show that the effect of combining certain solutions influences their effect. Expending the model of this graduation study with these effects to increase its reliability could be the topic of future research.

The outcomes of the three different agent-based model formalizations of the Theory of Planned Behaviour in this graduation study showed similar behaviours for the adoption of UHI mitigation solutions as Muelder & Filatova (2018) found for the adoption of solar panels by households in the Netherlands. However, their research, as well as the present study, do not investigate which of the three options is the best indicator of the real-world behaviour. Future research could take the findings from both studies and examine which agent-based model formalization can best represent the behaviour of households seen in the real world and should thus be used in future studies.

References

Papers and reports

Aan de slag met de Omgevingswet. (n.d.). *Wisselwerking tussen omgevingsvisies gemeente, provincie, Rijk*. pp. 1–5. Retrieved from https://aandeslagmetdeomgevingswet.nl/regelgeving/instrumenten/omgevingsvisie/wisselwerking-tussen/

ABF Research. (n.d.). *ABF Woonmilieutypologie*. 5. Retrieved from http://new.abfresearch.nl/css/abf/pdfs/woonmilieutypologie.pdf

Aertsens, J., Verbeke, W., Mondelaers, K., & van Huylenbroeck, G. (2009). Personal determinants of organic food consumption: A review. *British Food Journal*, *111*(10), 1140–1167. https://doi.org/10.1108/00070700910992961

Ahmed, K. S. (2003). Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments. *Energy and Buildings*, *35*(1), 103–110. https://doi.org/10.1016/S0378-7788(02)00085-3

Ajzen, I., Fishbein, M. (1970). The prediction of behaviour from attitudinal and normative variables. Journal of Experimental Social Psychology, 6, 466–487.

Ajzen, I. (1985) From Intentions to Actions: A Theory of Planned Behavior. In: Kuhl J., Beckmann J. (eds), Action Control (pp. 11-39). SSSP Springer Series in Social Psychology. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-69746-3_2

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decisoin Processes*, *50*(2), 179–211. https://doi.org/0749-5978/9

Ajzen, I. (2001). Nature and Operation of Attitudes. *Annual Review of Psychology*, *52*(1), 27–58.

Ajzen, I. (2002). Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *Journal of Applied Social Psychology*, *32*(4), 665–683. https://doi.org/10.1111/j.1559-1816.2002.tb00236.x

Ajzen, I. (2015). The theory of planned behaviour is alive and well, and not ready to retire: a commentary on Sniehotta, Presseau, and Araújo-Soares. *Health Psychology Review*, *9*(2), 131–137. https://doi.org/10.1080/17437199.2014.883474

Akkerman, J., & Brans, M. (2019). *Een juridische verkenning naar klimaatadaptatie in steden*. (15), 1–23. Retrieved from https://www.houthoff.com/insights/News/Toenemende-hittestress-wateroverlast-en-droogte-in-de-fysieke-leefomgeving

Alcock, I., White, M. P., Pahl, S., Duarte-Davidson, R., & Fleming, L. E. (2020). Associations between pro-environmental behaviour and neighbourhood nature, nature visit frequency and nature appreciation: Evidence from a nationally representative survey in England. *Environment International*, *136*(April 2019), 105441. https://doi.org/10.1016/j.envint.2019.105441

Aleksandrowicz, O., Vuckovic, M., Kiesel, K., & Mahdavi, A. (2017). Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository. *Urban Climate*, *21*(February), 1–26. https://doi.org/10.1016/j.uclim.2017.04.002

Ambrosini, D., Galli, G., Mancini, B., Nardi, I., & Sfarra, S. (2014). Evaluating mitigation effects of urban heat islands in a historical small center with the ENVI-Met® climate model. *Sustainability (Switzerland)*, *6*(10), 7013–7029. https://doi.org/10.3390/su6107013

Ambrosius, J. D., & Gilderbloom, J. I. (2015). Who's greener? Comparing urban and suburban residents' environmental behaviour and concern. *Local Environment*, *20*(7), 836–849. https://doi.org/10.1080/13549839.2014.926870

Andrade, H., & Vieira, R. (2012). A climatic study of an urban green space: the Gulbenkian Park in Lisbon (Portugal). *Finisterra*, *42*(84), 27–46. https://doi.org/10.18055/finis1420

Armitage, C. J., & Conner, M. (2001). Efficacy of the Theory of Planned Behaviour: A meta-analytic review. *British Journal of Social Psychology*, *40*(4), 471–499. https://doi.org/10.1348/014466601164939

Baarda, B., Van der Hulst, M., De Goede, M. (2012). Basisboek interviewen. Handleiding voor het voorbereiden en afnemen van interviews. Groningen/Houten, Netherlands: Noordhoff.

Barr, S., & Gilg, A. W. (2005). Conceptualising and analysing household attitudes and actions to a growing environmental problem. Development and application of a framework to guide local waste policy. *Applied Geography*, *25*(3), 226–247. https://doi.org/10.1016/j.apgeog.2005.03.007

Battista, G., de Lieto Vollaro, R., & Zinzi, M. (2019). Assessment of urban overheating mitigation strategies in a square in Rome, Italy. *Solar Energy*, *180*(January), 608–621. https://doi.org/10.1016/j.solener.2019.01.074

Battista, G., & Pastore, E. M. (2017). Using Cool Pavements to Mitigate Urban Temperatures in a Case Study of Rome (Italy). *Energy Procedia*, *113*, 98–103. https://doi.org/10.1016/j.egypro.2017.04.027

Berk, R. A., Schulman, D., McKeever, M., & Freeman, H. E. (1993). Measuring the impact of water conservation campaigns in California. *Climatic Change*, *24*(3), 233–248. https://doi.org/10.1007/BF01091831

Besir, A. B., & Cuce, E. (2018). Green roofs and facades: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *82*(October 2017), 915–939. https://doi.org/10.1016/j.rser.2017.09.106

Borshchev, A., & Filippov, A. (2004). From System Dynamics and Discrete Even to Practical Agent Based Modelingg: Reasons, Techniques, Tools. *The 22nd International Conference of the System Dynamics Society*. Retrieved from http://www2.econ.iastate.edu/tesfatsi/systemdyndiscreteeventabmcompared.borshchevfilippov04.pdf

Briggs, A. H., Weinstein, M. C., Fenwick, E. A. L., Karnon, J., Sculpher, M. J., & Paltiel, A. D. (2012). Model Parameter Estimation and Uncertainty: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force-6. *Value in Health*, *15*(6), 835–842. https://doi.org/10.1016/j.jval.2012.04.014

Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. *Building and Environment*, *146*(August), 226–237. https://doi.org/10.1016/j.buildenv.2018.09.045

Cameron, R. W. F., Taylor, J. E., & Emmett, M. R. (2014). What's "cool" in the world of green façades? How plant choice influences the cooling properties of green walls. *Building and Environment*, *73*, 198–207. https://doi.org/10.1016/j.buildenv.2013.12.005

Carnielo, E., & Zinzi, M. (2013). Optical and thermal characterisation of cool asphalts to mitigate urban temperatures and building cooling demand. *Building and Environment*, *60*, 56–65. https://doi.org/10.1016/j.buildenv.2012.11.004

Chang, C. R., & Li, M. H. (2014). Effects of urban parks on the local urban thermal environment. *Urban Forestry and Urban Greening*, *13*(4), 672–681. https://doi.org/10.1016/j.ufug.2014.08.001

Chang, C. R., Li, M. H., & Chang, S. D. (2007). A preliminary study on the local cool-island intensity of Taipei city parks. *Landscape and Urban Planning*, *80*(4), 386–395. https://doi.org/10.1016/j.landurbplan.2006.09.005

Chatterjee, S., Khan, A., Dinda, A., Mithun, S., Khatun, R., Akbari, H., … Wang, Y. (2019). Simulating micro-scale thermal interactions in different building environments for mitigating urban heat islands. *Science of The Total Environment*, *663*, 610–631. https://doi.org/10.1016/j.scitotenv.2019.01.299

Chen, D., Wang, X., Thatcher, M., Barnett, G., Kachenko, A., & Prince, R. (2014). Urban vegetation for reducing heat related mortality. *Environmental Pollution*, *192*, 275–284. https://doi.org/10.1016/j.envpol.2014.05.002

Chen, H., Ooka, R., Huang, H., & Tsuchiya, T. (2009). Study on mitigation measures for outdoor thermal environment on present urban blocks in Tokyo using coupled simulation. *Building and Environment*, *44*(11), 2290–2299. https://doi.org/10.1016/j.buildenv.2009.03.012

Chen, X., Peterson, M. N., Hull, V., Lu, C., Lee, G. D., Hong, D., & Liu, J. (2011). Effects of attitudinal and sociodemographic factors on pro-environmental behaviour in urban China. *Environmental*

Conservation, *38*(1), 45–52. https://doi.org/10.1017/S037689291000086X
Churchill, S., Jessop, D., & Sparks, P. (2008). Impulsive and/or planned behaviour: Can impulsivity contribute to the predictive utility of the theory of planned behaviour? *British Journal of Social Psychology*, *47*(4), 631–646. https://doi.org/10.1348/014466608X284434
Collins, R. (1981). On the Microfoundations of Macrosociology. *American Journal of Sociology*, *86*(5), 984–1014.
Cramer, K. M. (2013). Six Criteria of a Viable Theory: Putting Reversal Theory to the Test. *Journal of Motivation, Emotion, and Personality: Reversal Theory Studies*, *1*(1), 9–16. https://doi.org/10.12689/jmep.2013.102
de Jesus, M. P., Lourenço, J. M., Arce, R. M., & Macias, M. (2017). Green façades and in situ measurements of outdoor building thermal behaviour. *Building and Environment*, *119*, 11–19. https://doi.org/10.1016/j.buildenv.2017.03.041
De Wildt, T. (2014). *Supporting the adoption of smart grid appliances in city districts*. Delft University of Technology.
Du, H., Song, X., Jiang, H., Kan, Z., Wang, Z., & Cai, Y. (2016). Research on the cooling island effects of water body: A case study of Shanghai, China. *Ecological Indicators*, *67*, 31–38. https://doi.org/10.1016/j.ecolind.2016.02.040
Dunbar, R. I. M. (1992). Neocortex size as a constraint on group size in primates. *Journal of Human Evolution*, *22*(6), 469–493. https://doi.org/10.1016/0047-2484(92)90081-J
Égerházi, L. A., Kántor, N., & Gál, T. (2013). Evaluation and modelling the micro-bioclimatological conditions of a popular playground in Szeged, Hungary. *International Review of Applied Sciences and Engineering*, *4*(1), 57–61. https://doi.org/10.1556/irase.4.2013.1.8
Evola, G., Gagliano, A., Fichera, A., Marletta, L., Martinico, F., Nocera, F., & Pagano, A. (2017). UHI effects and strategies to improve outdoor thermal comfort in dense and old neighbourhoods. *Energy Procedia*, *134*, 692–701. https://doi.org/10.1016/j.egypro.2017.09.589
Fabiani, C., Pisello, A. L., Bou-Zeid, E., Yang, J., & Cotana, F. (2019). Adaptive measures for mitigating urban heat islands: The potential of thermochromic materials to control roofing energy balance. *Applied Energy*, *247*(April), 155–170. https://doi.org/10.1016/j.apenergy.2019.04.020
Fallmann, J., Forkel, R., & Emeis, S. (2016). Secondary effects of urban heat island mitigation measures on air quality. *Atmospheric Environment*, *125*, 199–211. https://doi.org/10.1016/j.atmosenv.2015.10.094
Feng, H., & Hewage, K. N. (2018). Economic Benefits and Costs of Green Roofs. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 307–318). https://doi.org/10.1016/B978-0-12-812150-4.00028-8
Garuma, G. F. (2018). Review of urban surface parameterizations for numerical climate models. *Urban Climate*, *24*, 830–851. https://doi.org/10.1016/j.uclim.2017.10.006
Gemeente Den Haag. (2017). *Welstandsnota Den Haag*. Retrieved from https://denhaag.raadsinformatie.nl/document/5642074/1/RIS297760_bijlage_1_Welstandsnota_Den_Haag_2017
Gemeente Den Haag. (2018). *Puntensysteem voor natuur- en groeninclusief bouwen*. Retrieved from https://denhaag.raadsinformatie.nl/document/7416644/1/RIS301953_bijlage_het_rapport
Georgakis, C., Zoras, S., & Santamouris, M. (2014). Studying the effect of "cool" coatings in street urban canyons and its potential as a heat island mitigation technique. *Sustainable Cities and Society*, *13*, 20–31. https://doi.org/10.1016/j.scs.2014.04.002
Gilg, A., & Barr, S. (2006). Behavioural attitudes towards water saving? Evidence from a study of environmental actions. *Ecological Economics*, *57*(3), 400–414. https://doi.org/10.1016/j.ecolecon.2005.04.010
Glanz, K., Rimer, B. k., & Viswanath, K. (2002). *Health behavior and health education* (4th ed.). San Francisco: Jossey-Bass.
Gromke, C., Blocken, B., Janssen, W., Merema, B., van Hooff, T., & Timmermans, H. (2015). CFD analysis of transpirational cooling by vegetation: Case study for specific meteorological conditions during a heat wave in Arnhem, Netherlands. *Building and Environment*, *83*, 11–26.

https://doi.org/10.1016/j.buildenv.2014.04.022
Grønhøj, A. (2006). Communication about consumption: a family process perspective on 'green' consumer practices. *Journal of Consumer Behaviour*, *5*(6), 491–503. https://doi.org/10.1002/cb.198
Guillaumie, L., Godin, G., & Vézina-Im, L. A. (2010). Psychosocial determinants of fruit and vegetable intake in adult population: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *7*, 1–12. https://doi.org/10.1186/1479-5868-7-12
Gulyás, Á., Unger, J., & Matzarakis, A. (2006). Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements. *Building and Environment*, *41*(12), 1713–1722. https://doi.org/10.1016/j.buildenv.2005.07.001
Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment*, *584–585*, 1040–1055. https://doi.org/10.1016/j.scitotenv.2017.01.158
Haanpää, L. (2007). Structures and mechanisms in sustainable consumption research. *International Journal of Environment and Sustainable Development*, *6*(1), 53–66. https://doi.org/10.1504/IJESD.2007.012736
Hamada, S., & Ohta, T. (2010). Seasonal variations in the cooling effect of urban green areas on surrounding urban areas. *Urban Forestry and Urban Greening*, *9*(1), 15–24. https://doi.org/10.1016/j.ufug.2009.10.002
Hamburg, K. T., Haque, C. E., & Everitt, J. C. (1997). Municipal waste recycling in Brandon, Manitoba: Determinants of participatory behaviour. *Canadian Geographer*, *41*(2), 149–165. https://doi.org/10.1111/j.1541-0064.1997.tb01155.x
Han, T. I., & Stoel, L. (2017). Explaining Socially Responsible Consumer Behavior: A Meta-Analytic Review of Theory of Planned Behavior. *Journal of International Consumer Marketing*, *29*(2), 91–103. https://doi.org/10.1080/08961530.2016.1251870
Handgraaf, S., & Dekker, G. (2019). *Advies aanpak knelpunten klimaatadaptief bouwen*.
He, Y., Yu, H., Ozaki, A., Dong, N., & Zheng, S. (2017). An investigation on the thermal and energy performance of living wall system in Shanghai area. *Energy and Buildings*, *140*, 324–335. https://doi.org/10.1016/j.enbuild.2016.12.083
Heng, S. L., & Chow, W. T. L. (2019). How 'hot' is too hot? Evaluating acceptable outdoor thermal comfort ranges in an equatorial urban park. *International Journal of Biometeorology*, 801–816. https://doi.org/10.1007/s00484-019-01694-1
Hossain, M. A., Shams, S., Amin, M., Reza, M. S., & Chowdhury, T. U. (2019). Perception and Barriers to Implementation of Intensive and Extensive Green Roofs in Dhaka, Bangladesh. *Buildings*, *9*(4), 79. https://doi.org/10.3390/buildings9040079
Huang, J., Ooka, R., Okada, A., Omori, T., & Huang, H. (2009). *THE EFFECTS OF URBAN HEAT ISLAND MITIGATION STRATEGIES ON THE OUTDOOR THERMAL ENVIRONMENT IN CENTRAL TOKYO – A NUMERICAL SIMULATION*.
Huang, L., Li, J., Zhao, D., & Zhu, J. (2008). A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China. *Building and Environment*, *43*(1), 7–17. https://doi.org/10.1016/j.buildenv.2006.11.025
Huynen, M. M. T. E., Martens, P., Schram, D., Weijenberg, M. P., & Kunst, A. E. (2001). *The Impact of Heat Waves and Cold Spells on Mortality Rates in the Dutch Population*. *109*(5), 463–470.
Imam Syafii, N., Ichinose, M., Kumakura, E., Jusuf, S. K., Chigusa, K., & Wong, N. H. (2017). Thermal environment assessment around bodies of water in urban canyons: A scale model study. *Sustainable Cities and Society*, *34*(April), 79–89. https://doi.org/10.1016/j.scs.2017.06.012
Imran, H. M., Kala, J., Ng, A. W. M., & Muthukumaran, S. (2019). Effectiveness of vegetated patches as Green Infrastructure in mitigating Urban Heat Island effects during a heatwave event in the city of Melbourne. *Weather and Climate Extremes*, *25*(November 2018). https://doi.org/10.1016/j.wace.2019.100217
Inglehart, R. (1995). Public Support for Environmental Protection: Objective Problems and Subjective Values in 43 Societies. *PS: Political Science and Politics*, *28*(1), 57. https://doi.org/10.2307/420583

International Labour Organization. (2019). Working on a warmer planet. The impact of heat stress on labour productivity and decent work. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_711919.pdf

IPCC. (2013). Climate change 2013: the physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M.(Eds.), Contribution of working group I to the Fifth Assessment Report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacobs, C., Klok, L., Bruse, M., Cortesão, J., Lenzholzer, S., & Kluck, J. (2020). Are urban water bodies really cooling? *Urban Climate*, *32*(January), 100607. https://doi.org/10.1016/j.uclim.2020.100607

Jansson, C., Jansson, P. E., & Gustafsson, D. (2007). Near surface climate in an urban vegetated park and its surroundings. *Theoretical and Applied Climatology*, *89*(3–4), 185–193. https://doi.org/10.1007/s00704-006-0259-z

Jendritzky, G., de Dear, R., & Havenith, G. (2012). UTCI-Why another thermal index? *International Journal of Biometeorology*, *56*(3), 421–428. https://doi.org/10.1007/s00484-011-0513-7

Jiao, M., Zhou, W., Zheng, Z., Wang, J., & Qian, Y. (2017). Patch size of trees affects its cooling effectiveness: A perspective from shading and transpiration processes. *Agricultural and Forest Meteorology*, *247*(May), 293–299. https://doi.org/10.1016/j.agrformet.2017.08.013

Kim, H., Gu, D., & Kim, H. Y. (2018). Effects of Urban Heat Island mitigation in various climate zones in the United States. *Sustainable Cities and Society*, *41*(June), 841–852. https://doi.org/10.1016/j.scs.2018.06.021

Klok, E.J., C.J.M. Jacobs, J. Kluck, J. Cortesão, S. Lenzholzer. (2018). The cooling effect of small blue urban spaces is negligible. Poster presented at ICLEI - Resilient Cities 2018 Conference 26-28 April 2018, Bonn, Germany. Retrieved from https://www.hva.nl/binaries/content/assets/subsites/kc-techniek/publicaties-klimaatbestendige-stad/klok_2018_the_cooling_effect_of_small_blue_urban_spaces.pdf?1527091499810

Klok, L., Jacobs, C., Kluck, J., Cortesão, J., & Lenzholzer, S. (2018). *The cooling effect of small blue urban spaces is negligible*. Retrieved from https://www.hva.nl/binaries/content/assets/subsites/kc-techniek/publicaties-klimaatbestendige-stad/klok_2018_the_cooling_effect_of_small_blue_urban_spaces.pdf?1527091499810

Klok, L., Rood, N., Kluck, J., & Kleerekoper, L. (2019). Assessment of thermally comfortable urban spaces in Amsterdam during hot summer days. *International Journal of Biometeorology*, *63*(2), 129–141. https://doi.org/10.1007/s00484-018-1644-x

Kluck, J., Klok, L., Solcerová, A., Kleerekoper, L., Wilschut, L., Jacobs, C., & Loeve, R. (2020). *De hittebestendige stad : een koele kijk op de inrichting van de buitenruimte*. Retrieved from https://www.hva.nl/binaries/content/assets/subsites/kc-techniek/publicaties-klimaatbestendige-stad/hva_2020_hittebestendige_stad_online.pdf

Kluck, J., Loeve, R., Bakker, W., KLeerekoper, L., Rouvoet, M., Wentink, R., … Boogaard, F. (2017). *Het klimaat past ook in uw straatje: De waarde van klimaatbestendig inrichten - Achtergronden*. Retrieved from https://www.pwve.nl/wp-content/uploads/2017/01/hva_klimaatbestendige_stad_2017-01-achtergronden.pdf

Kniveton, D. R., Smith, C. D., & Black, R. (2012). Emerging migration flows in a changing climate in dryland Africa. *Nature Climate Change*, *2*(6), 444–447. https://doi.org/10.1038/nclimate1447

Kniveton, D., Smith, C., & Wood, S. (2011). Agent-based model simulations of future changes in migration flows for Burkina Faso. *Global Environmental Change*, *21*(SUPPL. 1), S34–S40. https://doi.org/10.1016/j.gloenvcha.2011.09.006

Kollmuss, A., & Agyeman, J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260. https://doi.org/10.1080/13504620220145401

Kolokotsa, D. D., Giannariakis, G., Gobakis, K., Giannarakis, G., Synnefa, A., & Santamouris, M. (2018). Cool roofs and cool pavements application in Acharnes, Greece. *Sustainable Cities and Society*, *37*(November 2017), 466–474. https://doi.org/10.1016/j.scs.2017.11.035

Krusche, P., Krusche, M., Althaus, D., Gabriel, I. (1982). Ökologisches Bauen. Wiesbaden & Berlin: Bauverlag GmbH. ISBN-10: 3528016752, ISBN-13: 978–3528016753.
Krusche, P., Krusche, M., Althaus, D., Gabriel, I. (1982). [The creation of smog during day and night] [Drawing]. Retrieved from https://nl.urbangreenbluegrids.com/heat/#heading-8
Kyriakodis, G. E., & Santamouris, M. (2018). Using reflective pavements to mitigate urban heat island in warm climates - Results from a large scale urban mitigation project. *Urban Climate*, *24*, 326–339. https://doi.org/10.1016/j.uclim.2017.02.002
Lai, A., Maing, M., & Ng, E. (2017). Observational studies of mean radiant temperature across different outdoor spaces under shaded conditions in densely built environment. *Building and Environment*, *114*, 397–409. https://doi.org/10.1016/j.buildenv.2016.12.034
Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of the Total Environment*, *661*, 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062
Lalosevic, M., Komatina, M., Milos, M., & Rudonja, N. (2018). Green roofs and cool materials as retrofitting strategies for urban heat island mitigation: Case study in Belgrade, Serbia. *Thermal Science*, *22*(6 Part A), 2309–2324. https://doi.org/10.2298/TSCI171120086L
Lam, S. P. (1999). Predicting intentions to conserve water from the theory of planned behavior, perceived moral obligation, and perceived water right. *Journal of Applied Social Psychology*, *29*(5), 1058–1071. https://doi.org/10.1111/j.1559-1816.1999.tb00140.x
Lam, S. P. (2006). Predicting intention to save water: Theory of planned behavior, response efficacy, vulnerability, and perceived efficiency of alternative solutions. *Journal of Applied Social Psychology*, *36*(11), 2803–2824. https://doi.org/10.1111/j.0021-9029.2006.00129.x
Lee, H., Mayer, H., & Chen, L. (2016). Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany. *Landscape and Urban Planning*, *148*, 37–50. https://doi.org/10.1016/j.landurbplan.2015.12.004
Li, D., Bou-Zeid, E., & Oppenheimer, M. (2014). The effectiveness of cool and green roofs as urban heat island mitigation strategies. *Environmental Research Letters*, *9*(5), 055002. https://doi.org/10.1088/1748-9326/9/5/055002
Lin, W., Yu, T., Chang, X., Wu, W., & Zhang, Y. (2015). Calculating cooling extents of green parks using remote sensing: Method and test. *Landscape and Urban Planning*, *134*, 66–75. https://doi.org/10.1016/j.landurbplan.2014.10.012
Lobaccaro, G., & Acero, J. A. (2015). Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons. *Urban Climate*, *14*, 251–267. https://doi.org/10.1016/j.uclim.2015.10.002
Lontorfos, V., Efthymiou, C., & Santamouris, M. (2018). On the time varying mitigation performance of reflective geoengineering technologies in cities. *Renewable Energy*, *115*, 926–930. https://doi.org/10.1016/j.renene.2017.09.033
Macintyre, H. L., & Heaviside, C. (2019). Potential benefits of cool roofs in reducing heat-related mortality during heatwaves in a European city. *Environment International*, *127*(February), 430–441. https://doi.org/10.1016/j.envint.2019.02.065
Mainieri, T., Barnett, E. G., Valdero, T. R., Unipan, J. B., & Oskamp, S. (1997). Green buying: The influence of environmental concern on consumer behavior. *Journal of Social Psychology*, *137*(2), 189–204. https://doi.org/10.1080/00224549709595430
Makropoulou, M. (2017). Microclimate improvement of Inner-city urban areas in a Mediterranean coastal city. *Sustainability (Switzerland)*, *9*(6). https://doi.org/10.3390/su9060882
Maleki, A., & Mahdavi, A. (2016). Evaluation of Urban Heat Islands mitigation strategies using 3dimentional urban micro-climate model envi-met. *Asian Journal of Civil Engineering*, *17*(3), 357–371.
Martínez-Espiñeira, R., & García-Valiñas, M. Á. (2013). Adopting versus adapting: Adoption of water-saving technology versus water conservation habits in Spain. *International Journal of Water Resources Development*, *29*(3), 400–414. https://doi.org/10.1080/07900627.2012.721695
Martínez-Espiñeira, R., García-Valiñas, M. A., & Nauges, C. (2014). Households' pro-environmental

habits and investments in water and energy consumption: Determinants and relationships. *Journal of Environmental Management*, *133*, 174–183. https://doi.org/10.1016/j.jenvman.2013.12.002

Matzarakis, A., & Mayer, H. (1996). Another Kind of Environmental Stress: Thermal Stress. *WHO Newsletter*, *18*(JANUARY 1996), 7–10. Retrieved from https://www.researchgate.net/publication/233759000_Another_kind_of_environmental_stress_Thermal_stress

McEachan, R. R. C., Conner, M., Taylor, N. J., & Lawton, R. J. (2011). Prospective prediction of health-related behaviours with the theory of planned behaviour: A meta-analysis. *Health Psychology Review*, *5*(2), 97–144. https://doi.org/10.1080/17437199.2010.521684

McFarlane, B. L., & Boxall, P. C. (2003). The role of social psychological and social structural variables in environmental activism: An example of the forest sector. *Journal of Environmental Psychology*, *23*(1), 79–87. https://doi.org/10.1016/S0272-4944(02)00080-4

Middel, A., Chhetri, N., & Quay, R. (2015). Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods. *Urban Forestry and Urban Greening*, *14*(1), 178–186. https://doi.org/10.1016/j.ufug.2014.09.010

Millock, K., & Nauges, C. (2010). Household Adoption of Water-Efficient Equipment: The Role of Socio-Economic Factors, Environmental Attitudes and Policy. *Environmental and Resource Economics*, *46*(4), 539–565. https://doi.org/10.1007/s10640-010-9360-y

Ministerie van Infrastructuur en Milieu and Ministerie van Economische Zaken. (2015). Deltaprogramma 2016. Retrieved from https://www.deltaprogramma.nl/documenten/publicaties/2015/09/15/deltaprogramma-2016-pdf

Mitchell, V. G., Cleugh, H. A., Grimmond, C. S. B., & Xu, J. (2008). Linking urban water balance and energy balance models to analyse urban design options. *Hydrological Processes*, *22*(16), 2891–2900. https://doi.org/10.1002/hyp.6868

Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management*, *197*, 522–538. https://doi.org/10.1016/j.jenvman.2017.03.095

Moradpour, M., Afshin, H., & Farhanieh, B. (2018). A numerical study of reactive pollutant dispersion in street canyons with green roofs. *Building Simulation*, *11*(1), 125–138. https://doi.org/10.1007/s12273-017-0373-0

Morakinyo, T. E., Dahanayake, K. W. D. K. C., Ng, E., & Chow, C. L. (2017). Temperature and cooling demand reduction by green-roof types in different climates and urban densities: A co-simulation parametric study. *Energy and Buildings*, *145*, 226–237. https://doi.org/10.1016/j.enbuild.2017.03.066

Muelder, H., & Filatova, T. (2018). One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models. *Journal OfArtificial Societies and Social Simulation*, *21*(4). https://doi.org/10.18564/jasss.3855

Noro, M., & Lazzarin, R. (2015). Urban heat island in Padua, Italy: Simulation analysis and mitigation strategies. *Urban Climate*, *14*, 187–196. https://doi.org/10.1016/j.uclim.2015.04.004

Ntarladima, A.-M. (2016). *Modelling the Atmospheric Urban Heat Island and its Contributing Spatial Characteristics The case of The Hague, the Netherlands* (Delft University of Technology). Retrieved from http://repository.tudelft.nl/.

O'Malley, C., Piroozfar, P., Farr, E. R. P., & Pomponi, F. (2015). Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis. *Sustainable Cities and Society*, *19*, 222–235. https://doi.org/10.1016/j.scs.2015.05.009

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., … Rowe, B. (2007). Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*, *57*(10), 823–833. https://doi.org/10.1641/B571005

Oke, T. R. (1976). The distinction between canopy and boundary-layer urban heat Islands. *Atmosphere*, *14*(4), 268–277. https://doi.org/10.1080/00046973.1976.9648422

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1–24. https://doi.org/10.1002/qj.49710845502

Oliveira, S., Andrade, H., & Vaz, T. (2011). The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Building and Environment*, *46*(11), 2186–2194. https://doi.org/10.1016/j.buildenv.2011.04.034

Park, M., Hagishima, A., Tanimoto, J., & Narita, K. ichi. (2012). Effect of urban vegetation on outdoor thermal environment: Field measurement at a scale model site. *Building and Environment*, *56*, 38–46. https://doi.org/10.1016/j.buildenv.2012.02.015

Patel, J., Modi, A., & Paul, J. (2017). Pro-environmental behavior and socio-demographic factors in an emerging market. *Asian Journal of Business Ethics*, *6*(2), 189–214. https://doi.org/10.1007/s13520-016-0071-5

Pérez, G., Coma, J., Martorell, I., & Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and Sustainable Energy Reviews*, *39*, 139–165. https://doi.org/10.1016/j.rser.2014.07.055

Perini, K., Ottelé, M., Fraaij, A. L. A., Haas, E. M., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287–2294. https://doi.org/10.1016/j.buildenv.2011.05.009

Piselli, C., Castaldo, V. L., Pigliautile, I., Pisello, A. L., & Cotana, F. (2018). Outdoor comfort conditions in urban areas: On citizens' perspective about microclimate mitigation of urban transit areas. *Sustainable Cities and Society*, *39*(December 2017), 16–36. https://doi.org/10.1016/j.scs.2018.02.004

Pisello, A. L. (2017). State of the art on the development of cool coatings for buildings and cities. *Solar Energy*, *144*, 660–680. https://doi.org/10.1016/j.solener.2017.01.068

Pisello, A. L., Saliari, M., Vasilakopoulou, K., Hadad, S., & Santamouris, M. (2018). Facing the urban overheating: Recent developments. Mitigation potential and sensitivity of the main technologies. *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(4). https://doi.org/10.1002/wene.294

Planbureau voor de Leefomgeving & DNV GL. (2014). *Het potentieel van zonnestroom in de gebouwde omgeving van Nederland*. Retrieved from http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2014-dnv-gl-het-potentieel-van-zonnestroom-in-de-gebouwde-omgeving-van-nederland_01400.pdf

Potchter, O., Cohen, P., & Bitan, A. (2006). Climatic behavior of various urban parks during hot and humid summer in the mediterranean city of Tel Aviv, Israel. *International Journal of Climatology*, *26*(12), 1695–1711. https://doi.org/10.1002/joc.1330

Psouni, S., Zourbanos, N., & Theodorakis, Y. (2015). Attitudes and Intentions of Greek Athletes and Coaches Regarding Doping. *Health*, *07*(09), 1224–1233. https://doi.org/10.4236/health.2015.79137

Rahmandad, H., & Sterman, J. (2008). Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models. *Management Science*, *54*(5), 998–1014. https://doi.org/10.1287/mnsc.1070.0787

Rai, V., Reeves, D. C., & Margolis, R. (2016). Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renewable Energy*, *89*(April), 498–505. https://doi.org/10.1016/j.renene.2015.11.080

Rai, V., & Robinson, S. A. (2015). Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors. *Environmental Modelling and Software*, *70*, 163–177. https://doi.org/10.1016/j.envsoft.2015.04.014

Rajapaksa, D., Islam, M., & Managi, S. (2018). Pro-environmental behavior: The role of public perception in infrastructure and the social factors for sustainable development. *Sustainability (Switzerland)*, *10*(4). https://doi.org/10.3390/su10040937

Razzaghmanesh, M., & Razzaghmanesh, M. (2017). Thermal performance investigation of a living wall in a dry climate of Australia. *Building and Environment*, *112*, 45–62. https://doi.org/10.1016/j.buildenv.2016.11.023

Reid, L., Sutton, P., & Hunter, C. (2010). Theorizing the meso level: the household as a crucible of pro-

environmental behaviour. *Progress in Human Geography*, *34*(3), 309–327. https://doi.org/10.1177/0309132509346994
Richetin, J., Sengupta, A., Perugini, M., Adjali, I., Hurling, R., Greetham, D., & Spence, M. (2010). A micro-level simulation for the prediction of intention and behavior. *Cognitive Systems Research*, *11*(2), 181–193. https://doi.org/10.1016/j.cogsys.2009.08.001
Riebl, S. K., Estabrooks, P. A., Dunsmore, J. C., Savla, J., Frisard, M. I., Dietrich, A. M., … Davy, B. M. (2015). A systematic literature review and meta-analysis: The Theory of Planned Behavior's application to understand and predict nutrition-related behaviors in youth. *Eating Behaviors*, *18*, 160–178. https://doi.org/10.1016/j.eatbeh.2015.05.016
Rubel, F., & Kottek, M. (2010). Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. *Meteorologische Zeitschrift*, *19*(2), 135–141. https://doi.org/10.1127/0941-2948/2010/0430
Salata, F., Golasi, I., Petitti, D., de Lieto Vollaro, E., Coppi, M., & de Lieto Vollaro, A. (2017). Relating microclimate, human thermal comfort and health during heat waves: An analysis of heat island mitigation strategies through a case study in an urban outdoor environment. *Sustainable Cities and Society*, *30*, 79–96. https://doi.org/10.1016/j.scs.2017.01.006
Salata, F., Golasi, I., Vollaro, A. D. L., & Vollaro, R. D. L. (2015). How high albedo and traditional buildings' materials and vegetation affect the quality of urban microclimate. A case study. *Energy and Buildings*, *99*, 32–49. https://doi.org/10.1016/j.enbuild.2015.04.010
Santamouris, M. (2014). Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, *103*, 682–703. https://doi.org/10.1016/j.solener.2012.07.003
Santamouris, M., Ding, L., Fiorito, F., Oldfield, P., Osmond, P., Paolini, R., … Synnefa, A. (2017). Passive and active cooling for the outdoor built environment – Analysis and assessment of the cooling potential of mitigation technologies using performance data from 220 large scale projects. *Solar Energy*, *154*, 14–33. https://doi.org/10.1016/j.solener.2016.12.006
Santamouris, M., Gaitani, N., Spanou, A., Saliari, M., Giannopoulou, K., Vasilakopoulou, K., & Kardomateas, T. (2012). Using cool paving materials to improve microclimate of urban areas - Design realization and results of the flisvos project. *Building and Environment*, *53*, 128–136. https://doi.org/10.1016/j.buildenv.2012.01.022
Santamouris, Mattheos, Haddad, S., Saliari, M., Vasilakopoulou, K., Synnefa, A., Paolini, R., … Fiorito, F. (2018). On the energy impact of urban heat island in Sydney: Climate and energy potential of mitigation technologies. *Energy and Buildings*, *166*, 154–164. https://doi.org/10.1016/j.enbuild.2018.02.007
Scalco, A., Ceschi, A., & Sartori, R. (2018). Application of psychological theories in agent-based modeling: The case of the theory of planned behavior. *Nonlinear Dynamics, Psychology, and Life Sciences*, *22*(1), 15–33.
Schenk, N. J., Moll, H. C., & Schoot Uiterkamp, A. J. M. (2007). Meso-level analysis, the missing link in energy strategies. *Energy Policy*, *35*(3), 1505–1516. https://doi.org/10.1016/j.enpol.2006.04.013
Schnettler, S. (2009). A structured overview of 50 years of small-world research. *Social Networks*, *31*(3), 165–178. https://doi.org/10.1016/j.socnet.2008.12.004
Schwarz, N., & Ernst, A. (2009). Agent-based modeling of the diffusion of environmental innovations — An empirical approach. *Technological Forecasting and Social Change*, *76*(4), 497–511. https://doi.org/10.1016/j.techfore.2008.03.024
Shashua-Bar, L., & Hoffman, M. E. (2000). Vegetation as a climatic component in the design of an urban street. *Energy and Buildings*, *31*(3), 221–235. https://doi.org/10.1016/S0378-7788(99)00018-3
Silva, C. M., Gomes, M. G., & Silva, M. (2016). Green roofs energy performance in Mediterranean climate. *Energy and Buildings*, *116*, 318–325. https://doi.org/10.1016/j.enbuild.2016.01.012
Skelhorn, C., Lindley, S., & Levermore, G. (2014). The impact of vegetation types on air and surface temperatures in a temperate city: A fine scale assessment in Manchester, UK. *Landscape and Urban Planning*, *121*, 129–140. https://doi.org/10.1016/j.landurbplan.2013.09.012

Skoulika, F., Santamouris, M., Kolokotsa, D., & Boemi, N. (2014). On the thermal characteristics and the mitigation potential of a medium size urban park in Athens, Greece. *Landscape and Urban Planning*, *123*, 73–86. https://doi.org/10.1016/j.landurbplan.2013.11.002

Sniehotta, F. F., Presseau, J., & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. *Health Psychology Review*, *8*(1), 1–7. https://doi.org/10.1080/17437199.2013.869710

Sogani, S., Muduganti, R., Hexmoor, H., & Davis, F. (2005). Introducing agent based implementation of the theory of reasoned action: a case study in user acceptance of computer technology. *International Conference on Integration of Knowledge Intensive Multi-Agent Systems, 2005.*, *2005*, 507–511. https://doi.org/10.1109/KIMAS.2005.1427134

Solcerova, A., Klok, L., Wilschut, L., Kleerekoper, L., & Kluck, J. (2019). *Heat Resilient Cities – adaptation to extreme temperatures in the Netherlands*. *21*, 7049.

Spence, A., Poortinga, W., Butler, C., & Pidgeon, N. F. (2011). Perceptions of climate change and willingness to save energy related to flood experience. *Nature Climate Change*, *1*(1), 46–49. https://doi.org/10.1038/nclimate1059

Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Stone, B., Vargo, J., Liu, P., Habeeb, D., DeLucia, A., Trail, M., … Russell, A. (2014). Avoided Heat-Related Mortality through Climate Adaptation Strategies in Three US Cities. *PLoS ONE*, *9*(6), e100852. https://doi.org/10.1371/journal.pone.0100852

Susca, T. (2019). Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate. *Building and Environment*, *162*(March), 106273. https://doi.org/10.1016/j.buildenv.2019.106273

Syafii, N. I., Ichinose, M., Wong, N. H., Kumakura, E., Jusuf, S. K., & Chigusa, K. (2016). Experimental Study on the Influence of Urban Water Body on Thermal Environment at Outdoor Scale Model. *Procedia Engineering*, *169*, 191–198. https://doi.org/10.1016/j.proeng.2016.10.023

Synnefa, A., Dandou, A., Santamouris, M., Tombrou, M., & Soulakellis, N. (2008). On the use of cool materials as a heat island mitigation strategy. *Journal of Applied Meteorology and Climatology*, *47*(11), 2846–2856. https://doi.org/10.1175/2008JAMC1830.1

Taleghani, M., Sailor, D., & Ban-Weiss, G. A. (2016). Micrometeorological simulations to predict the impacts of heat mitigation strategies on pedestrian thermal comfort in a Los Angeles neighborhood. *Environmental Research Letters*, *11*(2). https://doi.org/10.1088/1748-9326/11/2/024003

Taleghani, M., Sailor, D. J., Tenpierik, M., & van den Dobbelsteen, A. (2014). Thermal assessment of heat mitigation strategies: The case of Portland State University, Oregon, USA. *Building and Environment*, *73*, 138–150. https://doi.org/10.1016/j.buildenv.2013.12.006

ten Broeke, G., van Voorn, G., & Ligtenberg, A. (2016). Which Sensitivity Analysis Method Should I Use for My Agent-Based Model? *Journal of Artificial Societies and Social Simulation*, *19*(1), 1–35. https://doi.org/10.18564/jasss.2857

Tominaga, Y., Sato, Y., & Sadohara, S. (2015). CFD simulations of the effect of evaporative cooling from water bodies in a micro-scale urban environment: Validation and application studies. *Sustainable Cities and Society*, *19*, 259–270. https://doi.org/10.1016/j.scs.2015.03.011

Topa, G., & Moriano, L. (2010). Theory of planned behavior and smoking: meta-analysis and SEM model. *Substance Abuse and Rehabilitation*, *1*, 23–33. https://doi.org/10.2147/sar.s15168

Tsoka, S., Tsikaloudaki, A., & Theodosiou, T. (2018). Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. *Sustainable Cities and Society*, *43*(July), 55–76. https://doi.org/10.1016/j.scs.2018.08.009

Tsoka, Stella, Tsikaloudaki, K., & Theodosiou, T. (2017). Urban space's morphology and microclimatic analysis: A study for a typical urban district in the Mediterranean city of Thessaloniki, Greece. *Energy and Buildings*, *156*, 96–108. https://doi.org/10.1016/j.enbuild.2017.09.066

United Nations. (2019). *World Urbanization Prospects*. Retrieved from https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

Vallerand, R. J., Deshaies, P., Cuerrier, J. P., Pelletier, L. G., & Mongeau, C. (1992). Ajzen and Fishbein's Theory of Reasoned Action as Applied to Moral Behavior: A Confirmatory Analysis. *Journal of Personality and Social Psychology*, *62*(1), 98–109. https://doi.org/10.1037/0022-3514.62.1.98

Van Dam, K., Nikolic, I., & Lukszo, Z. (2013). *Agent-Based Modelling of Socio-Technical Systems* (K. H. Dam, I. Nikolic, & Z. Lukszo, Eds.). https://doi.org/10.1007/978-94-007-4933-7

Van de Leemkolk, W., Jongma, C., Dekker, G., & Handgraaf, S. (2020). *Handreiking decentrale regelgeving klimaatadaptief bouwen en inrichten*. Retrieved from https://www.rijksoverheid.nl/documenten/brochures/2020/04/30/handreiking-regelgeving-klimaat-adaptief-bouwen-en-inrichten

Verwaart, T., & Valeeva, N. I. (2011). An Agent-based Model of Food Safety Practices Adoption. In S. Osinga, G. J. Hofstede, & T. Verwaart (Eds.), *Emergent Results of Artificial Economics* (pp. 103–114). https://doi.org/10.1007/978-3-642-21108-9_9

Vidrih, B., & Medved, S. (2013). Multiparametric model of urban park cooling island. *Urban Forestry & Urban Greening*, *12*(2), 220–229. https://doi.org/10.1016/j.ufug.2013.01.002

Völker, S., Baumeister, H., Claßen, T., Hornberg, C., & Kistemann, T. (2013). Evidence for the temperature-mitigating capacity of urban blue space – a health geographic perspective. *Erdkunde*, *67*(04), 355–371. https://doi.org/10.3112/erdkunde.2013.04.05

Vreugdenhil, C. (2014). *Een studie naar de potentie van PV in Nederland*.

Waitt, G., Caputi, P., Gibson, C., Farbotko, C., Head, L., Gill, N., & Stanes, E. (2012). Sustainable household capability: Which households are doing the work of environmental sustainability? *Australian Geographer*, *43*(1), 51–74. https://doi.org/10.1080/00049182.2012.649519

Wang, Y., Bakker, F., de Groot, R., Wörtche, H., & Leemans, R. (2015). Effects of urban green infrastructure (UGI) on local outdoor microclimate during the growing season. *Environmental Monitoring and Assessment*, *187*(12), 1–14. https://doi.org/10.1007/s10661-015-4943-2

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature*, *393*(June), 440–442. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/9623998

Whitburn, J. (2014). Urban vegetation, wellbeing and pro-environmental behaviour: A socio-ecological experiment in Wellington City, New Zealand. *Thesis*, 205. Retrieved from https://researcharchive.vuw.ac.nz/xmlui/handle/10063/3774

William, R., Goodwell, A., Richardson, M., Le, P. V. V., Kumar, P., & Stillwell, A. S. (2016). An environmental cost-benefit analysis of alternative green roofing strategies. *Ecological Engineering*, *95*, 1–9. https://doi.org/10.1016/j.ecoleng.2016.06.091

Wong, N. H., Kwang Tan, A. Y., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., … Wong, N. C. (2010). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment*, *45*(3), 663–672. https://doi.org/10.1016/j.buildenv.2009.08.005

Wu, D., Wang, Y., Fan, C., & Xia, B. (2018). Thermal environment effects and interactions of reservoirs and forests as urban blue-green infrastructures. *Ecological Indicators*, *91*(February), 657–663. https://doi.org/10.1016/j.ecolind.2018.04.054

Xi, T., Li, Q., Mochida, A., & Meng, Q. (2012). Study on the outdoor thermal environment and thermal comfort around campus clusters in subtropical urban areas. *Building and Environment*, *52*(July 2007), 162–170. https://doi.org/10.1016/j.buildenv.2011.11.006

Xu, J., Wei, Q., Huang, X., Zhu, X., & Li, G. (2010). Evaluation of human thermal comfort near urban waterbody during summer. *Building and Environment*, *45*(4), 1072–1080. https://doi.org/10.1016/j.buildenv.2009.10.025

Yang, F., Lau, S. S. Y., & Qian, F. (2011). Thermal comfort effects of urban design strategies in high-rise urban environments in a sub-tropical climate. *Architectural Science Review*, *54*(4), 285–304. https://doi.org/10.1080/00038628.2011.613646

Yang, J., Mohan Kumar, D. llamathy, Pyrgou, A., Chong, A., Santamouris, M., Kolokotsa, D., & Lee, S. E. (2018). Green and cool roofs' urban heat island mitigation potential in tropical climate. *Solar Energy*, *173*(February), 597–609. https://doi.org/10.1016/j.solener.2018.08.006

Yuan, J., Farnham, C., & Emura, K. (2015). Development of a retro-reflective material as building coating and evaluation on albedo of urban canyons and building heat loads. *Energy and Buildings*,

103, 107–117. https://doi.org/10.1016/j.enbuild.2015.06.055
Zhang, L., Wei, D., Hou, Y., Du, J., Liu, Z., Zhang, G., & Shi, L. (2020). Outdoor Thermal Comfort of Urban Park—A Case Study. *Sustainability*, *12*(5), 1961. https://doi.org/10.3390/su12051961
Zhang, N., Chen, Y., Luo, L., & Wang, Y. (2017). Effectiveness of different urban heat island mitigation methods and their regional impacts. *Journal of Hydrometeorology*, *18*(11), 2991–3012. https://doi.org/10.1175/JHM-D-17-0049.1
Zhang, T., & Zhang, D. (2007). Agent-based simulation of consumer purchase decision-making and the decoy effect. *Journal of Business Research*, *60*(8), 912–922. https://doi.org/10.1016/j.jbusres.2007.02.006
Zölch, T., Maderspacher, J., Wamsler, C., & Pauleit, S. (2016). Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale. *Urban Forestry and Urban Greening*, *20*, 305–316. https://doi.org/10.1016/j.ufug.2016.09.011
Žuvela-Aloise, M., Andre, K., Schwaiger, H., Bird, D. N., & Gallaun, H. (2018). Modelling reduction of urban heat load in Vienna by modifying surface properties of roofs. *Theoretical and Applied Climatology*, *131*(3–4), 1005–1018. https://doi.org/10.1007/s00704-016-2024-2

Internet sources

BAG. (2020). Basisregistratie Adressen en Gebouwen. Retrieved from https://bagviewer.kadaster.nl/lvbag/bag-viewer/#?geometry.x=77854.467016907&geometry.y=454685.38834427&zoomlevel=7&objectId=0518100000216957&detailsObjectId=
Berkelder, N. (2019). Bewoners Wielewaal vragen opnieuw aandacht voor hun eigen woningplan. Retrieved from https://www.ad.nl/rotterdam/bewoners-wielewaal-vragen-opnieuw-aandacht-voor-hun-eigen-woningplan~adfd44ea/
Biotecture.uk.com. (n.d.). Biotecture Living Green Wall Specification. Retrieved from https://www.biotecture.uk.com/design-and-specify/specifications-and-compliance/specifications-and-drawings/
Bouwman, H. (2020). Nationaal Daken Plan legt focus op onbenut dak. Retrieved from https://stadszaken.nl/artikel/3215/nationaal-daken-plan-legt-focus-op-onbenut-dak
CBS StatLine. (2017). Regionale kerncijfers Nederland. Retrieved from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/70072ned/table?ts=1584895389728
CBS StatLine. (2018). Inkomen van huishoudens. Retrieved from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83932NED/table?%20ts=1565008102724
CBS StatLine. (2019). Kerncijfers wijken en buurten 2019. Retrieved from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84583NED/table?ts=1584895623250
CBS StatLine. (2020). Voorraad woningen; eigendom, type verhuurder, bewoning, regio. Retrieved from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82900NED/table?fromstatweb
CBS. (2015). Kenmerken van verenigingen van eigenaren. Retrieved from https://www.cbs.nl/-/media/_excel/2016/20/tabellenrapportvves.xlsx
CBS. (2020). Bijna 71 duizend nieuwbouwwoningen in 2019. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2020/05/bijna-71-duizend-nieuwbouwwoningen-in-2019
CBS. (2021). 2. Daling gemiddelde energierekening door lagere prijzen en verbruik. Retrieved from https://www.cbs.nl/nl-nl/longread/rapportages/2021/lagere-energierekening-effecten-van-lagere-prijzen-en-energiebesparing/2-daling-gemiddelde-energierekening-door-lagere-prijzen-en-verbruik
Claessens, E., Steenstra, M. (2018). *Hoe borg je ruimtelijke adaptatie in je bestemmingsplan?* Retrieved from https://www.stadszaken.nl/klimaat/openbare-ruimte/1863/hoe-borg-je-ruimtelijke-adaptatie-in-je-bestemmingsplan
De Coster, J. (2021). Verticaal tuinieren: Maak zelf een groene wand voor de leefkamer. Retrieved from https://www.tuinadvies.nl/artikels/verticaal_tuinieren

De Verticale Tuinman. (2020). Outdoor Greenwall. Retrieved from https://www.deverticaletuinman.nl/wp-content/uploads/2020/09/OUTDOOR-GREENWALL-2020-.pdf
DHIC. (2021). Databank. Retrieved from https://denhaag.incijfers.nl/Jive?sel_guid=233d9374-cb29-44eb-bc6a-c42762ffa2f2
Duurzaamheidsvergelijker.nl. (2021). Spouwmuurisolatie kosten berekenen. Retrieved from https://duurzaamheidsvergelijker.nl/spouwmuurisolatie/spouwmuurisolatie-kosten-berekenen
Eigenhuis.nl. (2020). Prijzenindicator. Retrieved from https://www.eigenhuis.nl/wonen/onderhoud/prijzenindicator/plat-dak#/
Gemeente Amsterdam. (n.d.). Welstandscriteria duurzame stad. Retrieved from https://www.crk.amsterdam.nl/welstandsnota/criteria-duurzame-stad
Gemeente Den Haag. (2018). Afdoening motie 'onderzoek aanpak hittestress'. Retrieved from https://denhaag.raadsinformatie.nl/document/6168747/1/RIS297523%20Afdoening%20motie%20%27Onderzoek%20aanpak%20hittestress%27
Gemeente Den Haag. (2020). Structuurvisie CID Den Haag. Retrieved from https://repository.officiele-overheidspublicaties.nl/externebijlagen/exb-2020-22387/1/bijlage/exb-2020-22387.pdf
Gemeente Den Haag. (n.d.). Subsidie groene daken 2020 aanvragen. Retrieved from https://www.denhaag.nl/nl/subsidies/subsidie-groene-daken-2020-aanvragen.htm#
Gemeente Rotterdam. (n.d.). Subsidie klimaatadaptatie vanaf € 1.500. Retrieved from https://www.rotterdam.nl/loket/subsidie-klimaatadaptatie-vanaf-1500/
Gevelbekleding-info.nl. (n.d.). Groengevel/Plantengevel. Retrieved from https://www.gevelbekleding-info.nl/groengevel/
Gevelwand.nl. (n.d.). Groene gevels. https://gevelenwand.nl/gevelbekleding/groene-gevels/#:~:text=Alles%20bij%20elkaar%20gezien%20doe,400%20euro%20per%20vierkante%20meter
Groendak.nl. (2011). Prijs sedumdak + epdm + isolatie. Retrieved from https://www.groendak.nl/prijs-sedumdak-epdm-isolatie/
Habitos.be. (n.d.). Prijs groengevel. Retrieved from https://www.habitos.be/nl/tuin/prijs-groengevel-8265
Haverkate, H. (2018). Erfgoedorganisaties tegen sloopplannen in Hengelose wijk De Nijverheid. Retrieved from https://www.tubantia.nl/hengelo/erfgoedorganisaties-tegen-sloopplannen-in-hengelose-wijk-de-nijverheid~adf8813f/
Hiemstra, J. A., Spijker, J. H., & de Vries, S. (2019, Jan). De meerwaarde van groen in de stedelijke omgeving: Groen: meer dan mooi en gezond. Wageningen Environmental Research. https://edepot.wur.nl/412084
Hiemstra, J. A., Spijker, J. H., & de Vries, S. (2019, Jan). Groen en Wonen: De meerwaarde van groen in de stedelijke omgeving. Wageningen Environmental Research. https://edepot.wur.nl/412102
Homedeal.nl. (n.d.a). Gevelspecialist prijzen. Retrieved from https://www.homedeal.nl/gevelreiniging/gevelspecialist-prijzen/
Homedeal.nl. (n.d.b). Kosten groendak. Retrieved from https://www.homedeal.nl/dakbedekking/kosten-groendak/
Homedeal.nl. (n.d.c). Kosten dakbedekking plat dak. Retrieved from https://www.homedeal.nl/dakbedekking/kosten-dakbedekking-plat-dak/
Houhetwarm.nl. (n.d.). Kosten groendak. Retrieved from https://houhetwarm.nl/groendak/groen-dak/kosten-groendak/
Houhetwarm.nl. (n.d.b). Kosten verticale tuin. Retrieved from https://houhetwarm.nl/verticaletuin/verticale-tuinen/kosten-verticale-tuin/
Hva.nl. (n.d.). Bomen. Retrieved from: https://www.hva.nl/kc-techniek/gedeelde-content/contentgroep/klimaatbestendige-stad/resultaten/bomen.html
Info-en-advies.nl. (2021). Spouwmuurisolatie kosten. Retrieved from http://www.info-en-advies.nl/spouwmuurisolatie/spouwmuurisolatie-kosten

Jacobs, R. (2011). DuraGreen: prefab verticaal groen. Retrieved from https://www.vakbladdehovenier.nl/upload/artikelen/dg311duragreen.pdf
JNWR. (2013). Verticaal groen. Retrieved from https://www.standaard.be/cnt/dmf20130211_059
Kennis voor Klimaat. (2011). Hittestress in Rotterdam. Retrieved from https://library.wur.nl/WebQuery/wurpubs/408053
Klijn, B. (2021). Gevelreiniging kosten. https://www.metsel-gigant.nl/gevel-reinigen-kosten/
Klijn, B. (2021b). Groendak plaatsen https://www.dakdekker-concurrent.nl/dakbedekking/groendak/
KNMI. (2012). Extreem weer en klimaatveradering. Retrieved from https://www.knmi.nl/kennis-en-datacentrum/achtergrond/extreem-weer-en-klimaatverandering
KNMI. (2015). Juli, 2015. Retrieved from https://www.knmi.nl/nederland-nu/klimatologie/maand-en-seizoensoverzichten/2015/juli#:~:text=Met%20een%20gemiddelde%20temperatuur%20van,juli%20een%20vrij%20warme%20maand.
KNMI. (2021). Windrozen van de Nederlandse hoofdstations. Retrieved from https://www.knmi.nl/nederland-nu/klimatologie/grafieken/maand/windrozen
Kosten-stratenmaker.nl. (n.d.). Kosten boom plaatsen. Retrieved from https://www.kosten-stratenmaker.nl/boom-plaatsen/
Middelie, G. (2009). Groene gevels. Retrieved from https://edepot.wur.nl/50567
NHNieuws. (2019). 'Sloop van Alkmaarse Bloemwijk moet tegengehouden worden'. Retrieved from https://www.nhnieuws.nl/nieuws/244983/sloop-bloemwijk-alkmaar-moet-tegengehouden-worden
Nos.nl. (2021). Bewoners Den Haag krijgen gratis boom in strijd tegen verstening. Retrieved from https://nos.nl/artikel/2369908-bewoners-den-haag-krijgen-gratis-boom-in-strijd-tegen-verstening.html
Offerteadviseur.nl. (n.d.). Kosten dakbedekking plat dak. Retrieved from https://www.offerteadviseur.nl/categorie/bouw/dakdekker/kosten-dakbedekking-plat-dak/
Offertebutlet.nl. (n.d.). Kosten nieuw dak. Retrieved from https://www.offertebutler.nl/dakdekker/
Omroep West. (2016). Huizen Oude Kooi in Leiden voorlopig nog niet gesloopt. Retrieved from https://www.omroepwest.nl/nieuws/3228701/Huizen-Oude-Kooi-in-Leiden-voorlopig-nog-niet-gesloopt
Overheid.nl. (2016). Subsidieregeling groene daken Den Haag 2016-2018. Retrieved from http://decentrale.regelgeving.overheid.nl/cvdr/XHTMLoutput/Actueel/'s-Gravenhage/CVDR620287.html
Overheid.nl. (2020). Besluit omgevingsrecht. Retrieved from https://wetten.overheid.nl/BWBR0027464/2020-01-01/#BijlageII
Penders, E. (2020). Onderzoek: 'Woningcorporaties hebben onvoldoende geld voor al hun opgaven'. Retrieved from https://www.aedes.nl/artikelen/financi-n/financi-n-n/onderzoek-woningcorporaties-hebben-onvoldoende-geld-voor-al-hun-opgaven.html
Rabobank. (2018). De stand van Nederland. Retrieved from https://www.rabobank.nl/bedrijven/cijfers-en-trends/vastgoed/vastgoedbericht-2018/economische-stand-nederland/#:~:text=In%20Nederland%20staan%20zo%27n,maatschappelijk%20vastgoed%2C%20en%20agrarisch%20vastgoed.
Regionale klimaat Adaptatie Strategie Haaglanden. (2014). Met oog op de toekomst. Retrieved from https://klimaatadaptatienederland.nl/@158594/regionale-klimaat/
Republiq. (2019). Cijfers gemeentelijk vastgoed 2019. Retrieved from https://www.republiq.nl/images/uploads/20190918_-_Cijfers_gemeentelijk_vastgoed_2019_final_1.pdf
RIVM. (2017). Stedelijk hitte-eiland effect (UHI) in Nederland, Atlas Natuurlijk Kapitaal. Retrieved from https://www.atlasnatuurlijkkapitaal.nl/kaarten
RTLnieuws. (2019). Uitbouw-effect: woningen steeds groter, tuinen steeds kleiner. Retrieved from https://www.rtlnieuws.nl/economie/artikel/4750031/woningmarkt-tuin-kleiner-huizen-groter-perceeloppervlakte-bouwen

Sedumdakaanleggen.nl. (n.d.). Gewicht sedumdak. Retrieved from https://www.sedumdakaanleggen.nl/sedumdak-doe-het-zelf/gewicht-sedumdak/
Sedumdakbedekking.nl. (n.d.). Sedumdak prijs. Retrieved from https://www.sedumdakbedekking.nl/sedumdak-prijs
Sloped Roofs. (n.d.). Retrieved from http://www.greenrooftechnology.com/sloped_green_roofs
Talsma, L. (2019). Zonder draagvlak, geen renovatie. Retrieved from http://www.duizendwoningenperdag.nl/duurzaamheid-2/zonder-draagvlak-geen-renovatie/
Van den Brakel, M., Ament, P. (2010). Inkomensverschillen tussen en binnen gemeenten. Retrieved from https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwibjLnJ1ubvAhU9hv0HHTcGDWgQFjACegQIAxAD&url=https%3A%2F%2Fwww.cbs.nl%2F-%2Fmedia%2Fimported%2Fdocuments%2F2010%2F35%2F2010-k3-v4-p07-art.pdf%3Fla%3Dnl-nl&usg=AOvVaw3FRcG5mUer6H-J2UaPBqS8
Van der Vegt, E. (2019). Over het Lange Water gaat pur te lijf met flinke stapel flyers. Retrieved from https://www.gelderlander.nl/arnhem/over-het-lange-water-gaat-pur-te-lijf-met-flinke-stapel-flyers~a76fec38/
Van der Velde, J. (2019). De rol van woningcorporaties in de Omgevingswet. Retrieved from https://www.omgevingsweb.nl/nieuws/de-rol-van-woningcorporaties-in-de-omgevingswet/
Van Riet, E. (2016). Duurzaamheid en besluitvorming binnen de VvE. Retrieved from https://www.rijssenbeek.nl/duurzaamheid-en-besluitvorming-binnen-vve/
Visser, Y. (2020). “We keken naar de stenen, terwijl we naar de mensen hadden moeten kijken”. Retrieved from https://www.duurzaamgebouwd.nl/artikel/20200224-we-keken-naar-de-stenen-terwijl-we-naar-de-mensen-hadden-moeten-kijken
Viveen, P. (2021). Spouwmuurisolatie kosten. Retrieved from https://www.verbouwkosten.com/spouwmuurisolatie/kosten/
Viveen, P. (2021b). Groen dak 2021. Retrieved from https://www.verbouwkosten.com/dakbedekking/groen-dak/
Viveen, P. (2021c). Dakbedekking prijzen | De kosten van een plat dak op een rij. Retrieved from https://www.verbouwkosten.com/dakbedekking/prijzen/
Werksport.nl. (n.d.). Wat zijn de gemiddelde kosten voor het plaatsen van een groendak?. Retrieved from https://www.werkspot.nl/daken/prijzen-kosten/groendak
Werkspot.nl. (n.d.b). Wil jij een boom planten? Dit zijn de gemiddelde kosten. Retrieved from https://www.werkspot.nl/tuinieren-buiten/prijzen-kosten/boom-planten
Werkspot.nl. (n.d.c). Een plat dak vervangen? Dit zijn de gemiddelde kosten. Retrieved from https://www.werkspot.nl/daken/prijzen-kosten/plat-dak-vervangen
Willems, G. (2020). Gemeente: Jerusalem na renovatie liefst gasloos. Retrieved from https://www.gelderlander.nl/nijmegen/gemeente-jerusalem-na-renovatie-liefst-gasloos~a74d4fa24/
Wonen en woningmarkt. (2020). Retrieved from https://denhaag.incijfers.nl/dashboard/wijkprofielen/wonen-en-woningmarkt/
Wonenindenhaag.nl. (n.d.). Bomen- en Bloemenbuurt. Retrieved from https://wonenindenhaag.nl/wijken/bomen-en-bloemenbuurt/
Wur.nl. (2021). Groen in de stad. Retrieved from https://www.wur.nl/nl/Dossiers/dossier/Groen-in-de-stad.htm?f10039056=0

Appendix

Appendix A Overview of UHI mitigation literature

This appendix presents all tables with the effects of the Urban Heat Island (UHI) mitigation solutions found in literature.

Table A.1 Effect of green roofs in literature

Author(s)	Air temperature reduction (°C)	Moment of measurement	Measurement height (m)	Method of measurement	Location (city, country)	Climate classification (Köppen-Geiger)	Local Climate Zone (Stewart & Oke, 2012)
(H. Chen, Ooka, Huang, & Tsuchiya, 2009)	0.1	at 15:00	1.5	Computational Fluid Dynamics (CFD) simulations	Tokyo, Japan	Cfa	1
(J. Huang, Ooka, Okada, Omori, & Huang, 2009)	0	at 15:00	1.5	Computational Fluid Dynamics (CFD) simulations	Tokyo, Japan	Cfa	1
(Morakinyo, Dahanayake, Ng, & Chow, 2017)	0	at 15:00	1.5	ENVI-met and EnergyPlus	Tokyo	Cfa	1
(Morakinyo et al., 2017)	0	at 15:00	1.5	ENVI-met and EnergyPlus	Paris	Cfb	1
(Ambrosini et al., 2014)	1.2	at 14:00	1.2	ENVI-met	Teramo, Italy	Cfa	2
(Gromke et al., 2015)	0	at 15:00	2	Computational Fluid Dynamics (CFD) simulations	Arnhem, Netherlands	Cfb	2
(Maleki & Mahdavi, 2016)	0.5	at 12:00	N/A / 1.75	ENVI-met	Vienna, Austra	Cfb	2
(Zölch, Maderspacher, Wamsler, & Pauleit, 2016)	0	at 15:00	1.4	ENVI-met	Munich, Germany	Cfb	2
(Morakinyo et al., 2017)	0	at 15:00	1.5	ENVI-met and EnergyPlus	Tokyo	Cfa	2
(Morakinyo et al., 2017)	0 - 0.06	at 15:00	1.5	ENVI-met and EnergyPlus	Paris	Cfb	2
(Moradpour, Afshin, & Farhanieh, 2018)	0.3	N/A	1.5	Computational Fluid Dynamics (CFD) simulations	N/A	N/A	2

(Lobaccaro & Acero, 2015)	0.43	Average peak 24h values	2	ENVI-met	Bilbao, Spain	Cfb	2
(D. Chen et al., 2014)	0.5	Average daily max temperature	N/A	urban climate model (UCM-TAPM)	Melbourne, Australia	Cfb	2_1
(Morakinyo et al., 2017)	0 - 0.1	at 15:00	1.5	ENVI-met and EnergyPlus	Tokyo	Cfa	3
(Morakinyo et al., 2017)	0 - 0.05	at 15:00	1.5	ENVI-met and EnergyPlus	Paris	Cfb	3
(Lobaccaro & Acero, 2015)	0.13	Average peak 24h values	2	ENVI-met	Bilbao, Spain	Cfb	3
(Li et al., 2014)	0; 0.05; 0.1; 0.25; 0.4; 0.6	at 13:30	2	Weather Research and Forecasting (WRF) + Princeton Urban Canopy Model (PUCM)	Baltimore, US	Cfa	3_5, city wide
(Taleghani et al., 2016)	0.2	at 14:00	1		Los Angeles, US	Csb	3_B
(Mattheos Santamouris et al., 2018)	0.5	at 14:00	2	ENVI-met	Sydney, Australia	Cfa	3_B
(Evola et al., 2017)	1.5	at 13:00	1.5	ENVI-met	Avola, Italy	Csa	3_D
(Lobaccaro & Acero, 2015)	0.34	Average peak 24h values	2	ENVI-met	Bilbao, Spain	Cfb	4
(Lalosevic et al., 2018)	0.37	at 13:00	1.5	ENVI-met	Belgrade, Serbia	Cfa	4
(Mitchell, Cleugh, Grimmond, & Xu, 2008)	0.4	Peak afternoon temperature	N/A	LUMPS	Canbera, Australia	Cfb	N/A
(Skelhorn, Lindley, & Levermore, 2014)	0.17	N/A	4	ENVI-met	Manchester, UK	Cfb	N/A
(N. Zhang et al., 2017)	0.4; 0.7; 1.0; 1.3	at 15:00	2	Weather Research and Forecasting (WRF)Model	Yangtze River delta, China	Cfa	N/A

Table A.2 Effect of green façades in literature

Author(s)	Air temperature reduction (°C)	Moment of measurement	Measurement height (m)	Method of measurement	Location (city, country)	Climate classification (Köppen-Geiger)	Local Climate Zone (Stewart & Oke, 2012)
(Gromke et al., 2015)	0.3	at 15:00	2	Computational Fluid Dynamics (CFD) simulations	Arnhem, Netherlands	Cfb	2
(Zölch et al., 2016)	0.2	at 15:00	1.4	ENVI-met	Munich, Germany	Cfb	2
(de Jesus et al., 2017)	1.3; 3.3; 1.5; 1.1	13:00 - 14:00	1.5	Measurement	Madrid, Spain	Csa	2
(Razzaghmanesh & Razzaghmanesh, 2017)	0.08; 0.05	Average whole day	+/- 2	Measurement	Adelaide, Australia	Csa	2_B
(Perini et al., 2011)	0	12:00 - 15:00	1.5	Measurement	Benthuizen and Delft and Rotterdam, Netherlands	Cfb	3
(Cameron et al., 2014)	3	at 16:00	0.4	experiment	Reading, UK	Cfb	4_B
(He, Yu, Ozaki, Dong, & Zheng, 2017)	4	Average whole day	N/A	Model	Shanghai, China	Cfa	N/A

Table A.3 Effect of grass in literature

Author(s)	Air temperature reduction (°C)	Moment of measurement	Measurement height (m)	Method of measurement	Location (city, country)	Climate classification (Köppen-Geiger)	Local Climate Zone (Stewart & Oke, 2012)
(L. Huang, Li, Zhao, & Zhu, 2008)	0.1	at 12:00	1.5	Measurement	Nanjing, China	Cfa	1
(F. Yang, Lau, & Qian, 2011)	0.7	at 13:00	N/A	ENVI-met	Shanghai, China	Cfa	1_B
(Battista et al., 2019)	+0.03	at 12:00	1.8	ENVI-met	Rome	Csa	2
(Lobaccaro & Acero, 2015)	0.48	Average whole day	2	ENVI-met	Bilbao, Spain	Cfb	2
(L. Huang et al., 2008)	1	at 12:00	1.5	Measurement	Nanjing, China	Cfa	2
(Égerházi et al., 2013)	+0.1	at 11:00	1.5	ENVI-met	Szeged, Hungary	Cfb	2_B

(Lobaccaro & Acero, 2015)	0.04	Average whole day	2	ENVI-met	Bilbao, Spain	Cfb	4
(Potchter, Cohen, & Bitan, 2006)	0.6	Average whole day	2	Measurement	Tel Aviv, Israel	Csa	4
(Lee, Mayer, & Chen, 2016)	1.1	10:00-16:00	1.5	ENVI-met	Freiburg, Germany	Cfb	5_{B}
(Klok et al., 2019)	1.2	Afternoon average	1.1	Measurement	Amsterdam, Netherlands	Cfb	6_{A}
(L. Huang et al., 2008)	0.5	at 12:00	1.5	Measurement	Nanjing, China	Cfa	A
(L. Huang et al., 2008)	0.25	at 12:00	1.5	Measurement	Nanjing, China	Cfa	B
(Skelhorn et al., 2014)	0.25	at 18:00	4	ENVI-met	Manchester, UK	Cfb	N/A

Table A.4 Effect of trees in literature

Author(s)	**Air temperature reduction (°C)**	**Moment of measurement**	**Measurement height (m)**	**Method of measurement**	**Location (city, country)**	**Climate classification (Köppen-Geiger)**	**Local Climate Zone (Stewart & Oke, 2012)**
(L. Huang et al., 2008)	0	at 15:00	1.5	Computational Fluid Dynamics (CFD) simulations	Tokyo, Japan	Cfa	1
(F. Yang et al., 2011)	0.7	at 13:00	N/A	ENVI-met	Shanghai, China	Cfa	1_{B}
(Battista et al., 2019)	0.37; 0.26	at 12:00	1.8	ENVI-met	Rome	Csa	2
(Gromke et al., 2015)	1.6	at 15:00	2	Computational Fluid Dynamics (CFD) simulations	Arnhem, Netherlands	Cfb	2
(Klok et al., 2019)	0.9; 0.5	Afternoon average	1.1	Measurement	Amsterdam, Netherlands	Cfb	2
(Maleki & Mahdavi, 2016)	0.6	at 12:00	N/A / 1.75	ENVI-met	Vienna, Austra	Cfb	2
(Park, Hagishima,	0.3	11:00 - 13:00 average	0.1	Scale experiment	Saitama, Japan	Cfa	2

Tanimoto, & Narita, 2012)							
(Shashua-Bar & Hoffman, 2000).	2.8	at 15:00	1.8	Measurement	Tel-Aviv, Israel	Csa	2
(Zölch et al., 2016)	0.5	at 15:00	1.4	ENVI-met	Munich, Germany	Cfb	2
(Gulyás, Unger, & Matzarakis, 2006)	1.7	12:00 - 15:00	1.1	RayMan model	Szeged, Hungary	Cfb	2_A
(Égerházi et al., 2013)	0.2 / +0.2	at 11:00	1.5	ENVI-met	Szeged, Hungary	Cfb	2_B
(Stella Tsoka, Tsikaloudaki, & Theodosiou, 2017)	0.14	at 12:00	1.5	ENVI-met	Thessaloniki, Greece	Cfa	2_B
(Taleghani et al., 2016)	0.15	at 14:00	1		Los Angeles, US	Csb	3_B
(Lee et al., 2016)	0.6	10:00-16:00	1.5	ENVI-met	Freiburg, Germany	Cfb	5_B
(Wang, Bakker, de Groot, Wörtche, & Leemans, 2015)	max daily = 2.2 average = 1	Whole day	1.5	Measurement	Assen, Netherlands	Cfb	6_A
(Skelhorn et al., 2014)	0	9:00 - 21:00	4	ENVI-met	Manchester, UK	Cfb	N/A

Table A.5 Effect of urban parks in literature

Author(s)	**Air temperature reduction (°C)**	**Moment of measurement**	**Measurement height (m)**	**Method of measurement**	**Location (city, country)**	**Climate classification (Köppen-Geiger)**	**Local Climate Zone (Stewart & Oke, 2012)**
(Oliveira, Andrade, & Vaz, 2011)	4.8	Average whole day	1.5	Measurement	Lisbon, Portugal	Csa	2
(Andrade & Vieira, 2012)	4.1	Average daily maximum	N/A	Measurement	Lisbon, Portugal	Csa	2
(Jansson, Jansson, &	0.5-0.8; maximum 2	Average whole day	0.19 - 2.47	Measurement	Stockholm, Sweden	Cfb	2

Gustafsson, 2007)							
(Potchter et al., 2006)	2; 3.5	at 12:00; Maximum whole day	2	Measurement	Tel Aviv, Israel	Csa	2_B
(Noro & Lazzarin, 2015)	3	at 15:00	1.8	ENVI-met	Padua, Italy	Cfa	2_B
(Hamada & Ohta, 2010)	1.9	at 16:00	2 - 3.3	Measurement	Nagoya, Japan	Cfa	3
(Skoulika et al., 2014)	3.3	Average whole day	1.7	Measurement	Athens, Greece	Cfa	3_B
(Potchter et al., 2006)	1; 2.3	at 12:00; Maximum whole day	2	Measurement	Tel Aviv, Israel	Csa	3_B
(Evola et al., 2017)	3	at 13:00	1.5	ENVI-met	Avola, Italy	Csa	3_D
(Vidrih & Medved, 2013)	maximum 4.8; average 3	at 15:00	1.2	CFD	Ljubljana, Slovenia	Cfb	A
(Chang & Li, 2014)	0.3	at 12:00	2	Measurement	Taipei, China	Cfa	N/A
(Fallmann, Forkel, & Emeis, 2016)	1	Average whole day	2	WRF-Chem model	Stuttgart, Germany	Cfb	N/A
(Imran, Kala, Ng, & Muthukumaran, 2019)	0	Hottest part of the day	2	Weather Research and Forecasting (WRF)	Melbourne, Australia	Cfb	Region wide
(Imran et al., 2019)	0.6 (20%); 1.6; 2.2; 3.7 (50%)	Night	2	Weather Research and Forecasting (WRF)	Melbourne, Australia	Cfb	Region wide

Table A.6 Effect of pools and ponds in literature

Author(s)	**Air temperature reduction (°C)**	**Moment of measurement**	**Measurement height (m)**	**Method of measurement**	**Location (city, country)**	**Climate classification (Köppen-Geiger)**	**Local Climate Zone (Stewart & Oke, 2012)**
(Xu et al., 2010)	2-2.7	10:00 - 16:00	1.5	Measurement	Shanghai, China	Cfa	1
(Battista et al., 2019)	0.77	at 12:00	1.8	ENVI-met	Rome	Csa	2

(Imam Syafii et al., 2017)	big pond = 0.7 small pond = 0.5	Average whole day	0,3 (scaled-down average human height)	Comprehensive Outdoor Scale Model (COSMO)	Saitama Prefecture, Japan	Cfa	2
(Syafii et al., 2016)	0.5	at 12:00	0,3 (scaled-down average human height)	Measurement	Saitama Prefecture, Japan	Cfa	2
(Égerházi et al., 2013)	0	at 11:00	1.5	ENVI-met	Szeged, Hungary	Cfb	2_B
(Klok et al., 2019)	0.5	Afternoon average	1.1	Measurement	Amsterdam, Netherlands	Cfb	2_B
(Klok et al., 2019)	0.7	Afternoon average	1.1	Measurement	Amsterdam, Netherlands	Cfb	2_B
(O'Malley, Piroozfar, Farr, & Pomponi, 2015)	0.2	at 12:00	2	ENVI-met	London, UK	Cfb	2_B
(Taleghani, Sailor, Tenpierik, & van den Dobbelsteen, 2014)	1.1	at 18:00	2	ENVI-met	Portland, US	Csb	2_B
(Tominaga et al., 2015)	2	at 15:00	1.5	Computational fluid dynamics (CFD) simulation	Hadano, Japan	Cfa	3_B
(Xi, Li, Mochida, & Meng, 2012)	2	at 12:00	1.5	Measurement	Guangzhou, China	Cfa	5
(L. Huang et al., 2008)	0	at 12:00	1.5	Measurement	Nanjing, China	Cfa	B
(Jacobs et al., 2020)	0.4 - 0.5	at 15:00	1.5	ENVI-met	Netherlands	Cfb	N/A
(Klok, Jacobs, Kluck, Cortesão, & Lenzholzer, 2018)	0.4	at 15:00	1.5	ENVI-met	Amsterdam, Netherlands	Cfb	N/A

Table A.7 Effect of cool pavement in literature

Author(s)	**Air temperature reduction (°C)**	**Moment of measurement**	**Measurement height (m)**	**Method of measurement**	**Location (city, country)**	**Climate classification (Köppen-Geiger)**	**Local Climate Zone (Stewart & Oke, 2012)**
(J. Huang et al., 2009)	0.5	at 15:00	1.5	Computational Fluid Dynamics (CFD) simulations	Tokyo, Japan	Cfa	1

(F. Yang et al., 2011)	0.3	at 14:00	N/A	ENVI-met	Shanghai, China	Cfa	1_B
(Battista et al., 2019)	0.41	at 12:00	1.8	ENVI-met	Rome	Csa	2
(Salata, Golasi, Vollaro, & Vollaro, 2015)	0.2	at 14:00	N/A	ENVI-met	Rome, Italy	Csa	2
(Georgakis et al., 2014)	1	at 12:00	2	Computational Fluid Dynamics (CFD) simulations	Athens, Greece	Cfa	2
(Lontorfos et al., 2018)	1.7	Average peak 12:00 - 15:00	2	ENVI-met	Athens, Greece	Cfa	2
(Lalosevic et al., 2018)	1.39	at 13:00	1.5	ENVI-met	Belgrade, Serbia	Cfa	2_B
(Taleghani et al., 2014)	1.3	at 18:00	2	ENVI-met	Portland, US	Csb	2_B
(M. Santamouris et al., 2012)	1.9	at 14:00	1.8	Computational Fluid Dynamics (CFD) simulations	Athens, Greece	Cfa	2_B
(Noro & Lazzarin, 2015)	4	at 15:00	1.8	ENVI-met	Padua, Italy	Cfa	2_B
(Stella Tsoka et al., 2017)	0.4	at 12:00	1.5	ENVI-met	Thessaloniki, Greece	Cfa	2_B
(Battista & Pastore, 2017)	1; 3	at 14:00	1.75	ENVI-met	Rome, Italy	Csa	2_B
(Carnielo & Zinzi, 2013)	5.5	at 15:00	3	ENVI-met	Rome, Italy	Csa	2_B
(Piselli, Castaldo, Pigliautile, Pisello, & Cotana, 2018)	0.4	at 14:00	1	ENVI-met	Perugia, Italy	Cfa	2_B
(Kyriakodis & Santamouris, 2018)	1.5	Average peak 12:00 - 17:00	1.5	Computational Fluid Dynamics (CFD) simulations	Athens, Greece	Csa	3
(Makropoulou, 2017)	1.7	Max decrease 10:00 - 18:00	1.8	ENVI-met	Volos, Greece	Csa	3
(Kolokotsa et al., 2018)	0.3	at 14:00	1.8	ENVI-met	Acharnes, Greece	Csa	3_2
(Lalosevic et al., 2018)	0.90	at 13:00	1.5	ENVI-met	Belgrade, Serbia	Cfa	3_A
(Taleghani et al., 2016)	0.8	at 14:00	1	ENVI-met	Los Angeles, US	Csb	3_B

(Mattheos Santamouris et al., 2018)	0.5	at 14:00	2	ENVI-met	Sydney, Australia	Cfa	3_B
(Evola et al., 2017)	2	at 13:00	1.5	ENVI-met	Avola, Italy	Csa	3_D
(Lalosevic et al., 2018)	1.33	at 13:00	1.5	ENVI-met	Belgrade, Serbia	Cfa	4
(Lalosevic et al., 2018)	1.60	at 13:00	1.5	ENVI-met	Belgrade, Serbia	Cfa	5
(Salata et al., 2017)	1.5	at 15:00	1.1	ENVI-met	Rome, Italy	Csa	5_B

Table A.8 Effect of cool roofs in literature

Author(s)	**Air temperature reduction (°C)**	**Moment of measurement**	**Measurement height (m)**	**Method of measurement**	**Location (city, country)**	**Climate classification (Köppen-Geiger)**	**Local Climate Zone (Stewart & Oke, 2012)**
(Ambrosini et al., 2014)	0.5	at 14:00	1.2	ENVI-met	Teramo, Italy	Cfa	2
(Maleki & Mahdavi, 2016)	0.6	at 12:00	N/A / 1.75	ENVI-met	Vienna, Austra	Cfb	2
(Mattheos Santamouris et al., 2018)	0.6	at 14:00	2	ENVI-met	Sydney, Australia	Cfa	3_B
(Taleghani et al., 2016)	0.2	at 14:00	1	ENVI-met	Los Angeles, US	Csb	3_B
(Evola et al., 2017)	1.5	at 13:00	1.5	ENVI-met	Avola, Italy	Csa	3_D
(Li et al., 2014)	0; 0.1; 0.1; 0.25; 0.4; 0.5	at 13:30	2	Weather Research and Forecasting (WRF) + Princeton Urban Canopy Model (PUCM)	Baltimore, US	Cfa	3_5, city wide
(Salata et al., 2017)	0.1	at 15:00	1.1	ENVI-met	Rome, Italy	Csa	5_B
(Fallmann et al., 2016)	1.3	Average whole day	2	WRF-Chem model	Stuttgart, Germany	Cfb	N/A
(N. Zhang et al., 2017)	0.4; 0.8	at 15:00	2	Weather Research and Forecasting (WRF)Model	Yangtze River delta, China	Cfa	N/A

(Macintyre & Heaviside, 2019)	max 3 (average 0.5)	Average whole day	2	WRF regional weather model	West Midlands, UK	Cfb	N/A, region wide
(Synnefa et al., 2008)	1.3; 1.6	12:00 - 13:00	2	Pennsylvania State University–NCAR Mesoscale Model	Athens, Greece	Cfa	whole city
(Stone et al., 2014)	0.18	Average	2	Weather Research Forecasting (WRF) mesoscale meteorological model	Atlanta	Cfa	whole city
(Stone et al., 2014)	0.2	Average	2	Weather Research Forecasting (WRF) mesoscale meteorological model	Phoenix	Cfa	whole city

Appendix B Extra information data preparation and sensitivity analysis

This appendix is an addition to section 6.2 Data collection and preparation. It presents extra information for some input data if the preparation of that data will take up too much space in the main text of this thesis. It also presents more details of several sensitivity analyses performed for the input data. The heading of each section has the same numbers as that section has in the main text to make it easier to find the right part of this appendix that belongs to the discussed input data in the main text. Table B.1 presents all input variables for which a sensitivity analysis was performed. It also shows the type of uncertainty and whether that variable has a scientific relevance, which means that its analysis is interesting for investigating the behaviour of the model, or a policy relevance, which means that its analysis is interesting for policy- and decision makers because they can influence this variable or can use the outcome to change their decisions based on the area of interest. The information in table B.1 shows that a lot of variables have both a scientific and a policy relevance. They can thus be used for both purposes.

Table B.1: Input variables with sensitivity analysis and type of variable

Input variable	Type of uncertainty	Type of variable
Multiple VVE heads (true & false)	Structural	Scientific
Amount of households per VVE (2, 4, 6, 8)	Parameter	Scientific & Policy
Amount of household friends (3, 5, 10, 15)	Parameter	Scientific
Neighbourhood vegetation (+0%, +10%, +20%)	Parameter	Scientific & Policy
Educational level influence (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Home ownership (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Nearby air temperature (+0%, +10%, +20%)	Parameter	Scientific & Policy
Radius nearby air temperature (+0%, +55%, +100%, +200%)	Parameter	Scientific & Policy
Air temperature reduction per household solution (+0%, +55%, +100%, +200%)	Parameter	Scientific & Policy
Air temperature decline green garden (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Energy reduction green roofs, green façade, cool roofs (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Costs per household solution (/m2) (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Input air temperature (-20%, - 10%, +0%, +10%, +20%)	Parameter	Scientific & Policy
Solution of schools & hospitals (no implementations, green roof, green façade, green garden, cool roof)	Parameter	Scientific & Policy

B.6.2.1 Households

This section presents extra information for four household input characteristics, the income, dwelling properties, amount of VVE's and influence of the nearby air temperature on the chance of the household characteristics . For two of these it also discusses the sensitivity analyses in more detail.

B.6.2.1.1 Income

The total income distribution for the Netherlands can be seen in figure B.1, this figure shows that the household income is not evenly distributed within these quintiles, but the distribution is right skewed and that there are households with a much lower income than €21 100 and also much higher incomes than €59 800. However, this kind of data is not available for smaller geographical areas and is thus not taken into account in the model.

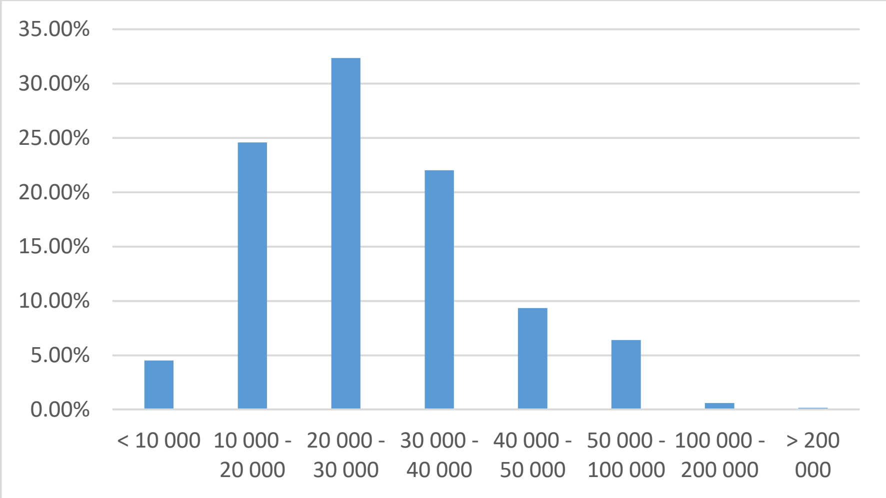


Figure B.1: Income distribution in the Netherlands in 2018 (CBS Statline, 2018)

Within the model, households get their income assigned following a uniform distribution. This means that households in the first four quantiles all get a random income assigned within that quantile and the average value of the incomes within a quantile lies at the middle of that quantile. For the households with an income in the 5th and highest quantile this is not possible, because this quantile does not have a maximum value. Therefore, those households all get assigned the boundary value of the fifth quantile. Figure B.2 shows what the total income distribution in the model looks like.

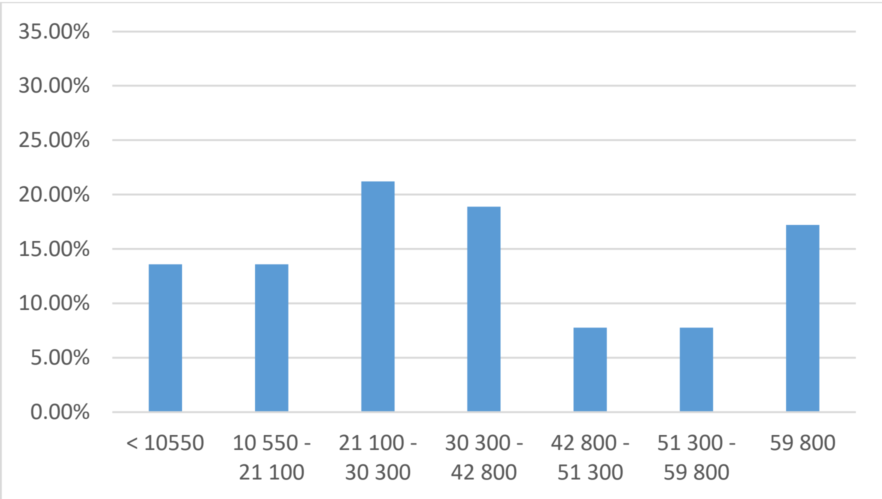


Figure B.2: Input percentage of household income distribution (year 2018)

Because of the limits of the input data this distribution does not match the distribution of household income in the whole of the Netherlands, figure B.1. It is important to notice that the x-axis of these two figures is not the same.

The distribution in figure B.2 is not right skewed, the third and fourth categories are the highest but the difference with the other categories are not as big as in figure B.1 and the last category of a household income over 59 800 euros is almost the same height. The difference between these two distributions is partly explained because the input for the model is the household income data from The Hague and figure B.1 shows household income data for the whole of the Netherlands. However, it does not explain all differences. The limits of the household income data of The Hague explain the others. This input only shows the percentage of households in one of the five quintiles but does not show the distribution within those quintiles. The model therefore uses a uniform distribution within the quintiles (except for quintile five), but figure B.1 shows that this does not completely overlaps with reality. Within the whole of the Netherlands the number of households with an income below 10 thousand euros is much lower than between 10 and 20 thousand euros. Also, the distribution above 50 thousand euros slowly reduces towards 200 thousand euros, instead of all households in the highest category having the same income as is the case in the model.

Because of these limits the number of households with an income below 10 550 euro is higher in the model than in the real world, and the distribution of high-income households stops at 59 800 euros, while it should continue. An overestimation of the number of households with a low income reduces the number of households that are able to invest in UHI mitigation solutions, as the PBC barrier is an income barrier. Because the income distribution does not continue after 59 800 euros, there is a higher chance that households with a high income do not pass the PBC barrier and thus fewer households will invest in UHI mitigation solutions. The limits of the household income data used in the model will thus probably reduce the amount of UHI mitigation solutions implemented compared to the whole of the Netherlands.

Figure B.3 shows the differences between the income input data of the whole of The Hague used in the present research and the data for the Bomen en Bloemenbuurt that is used as a case study. It is clear that there are more households in the Bomen en Bloemenbuurt with a high income than in the whole city of The Hague. To be able to generalize the results of this graduation study to other cities similar to The Hague, the data of the whole of The Hague is used in the present study. However, for the properties of the area, the neighbourhood Bomen en Bloemenbuurt and its four different Local Climate Zones (LCZs) are used. This could result in an underestimation of the amount of Urban Heat Island (UHI) mitigation solutions implemented by households in the present research, when it is compared to the real world outcomes of Bomen en Bloemenbuurt.

Figure B.3: Percentage of household income distribution for The Hague (blue) and in the Bomen en Bloemenbuurt (orange) for the year 2018

With the income of households the income threshold is calculated. This threshold represents a chance of a household to calculate the multi-attribute utility of investing in an Urban Heat Island (UHI) mitigation solution, or not taking any action. The chance decreases as household have a lower income but does not reduce to zero (figure B.4). Households will thus always have a chance to calculate their multi-attribute utility and determine whether they want to invest in a UHI mitigation solution.

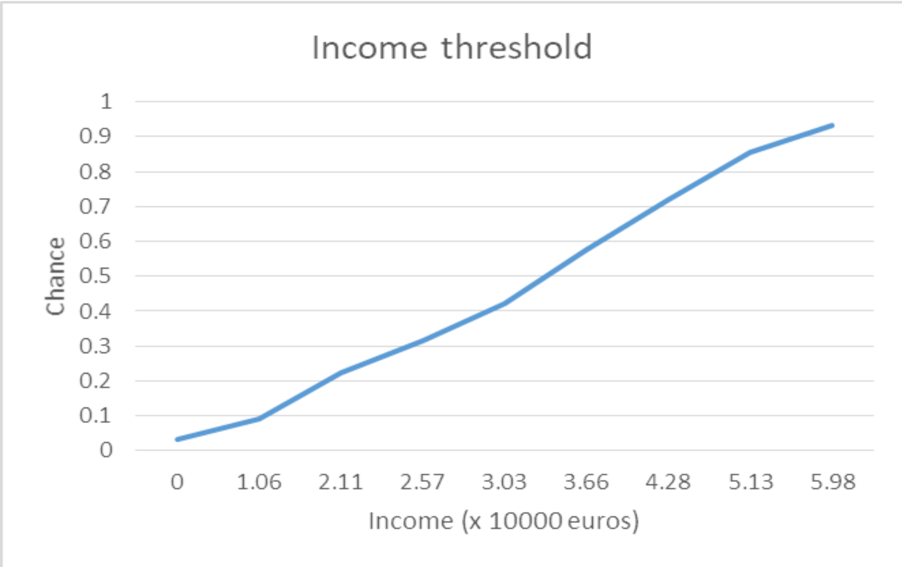


Figure B.4: Income threshold corresponding to household income

B.6.2.1.4 Dwelling properties regarding roof and façade surface

Vreugdenhil (2014) takes thirteen different dwelling types into account and has calculated the percentage of properties that belong to each type for the city of Utrecht and their average roof surface per household (table B.2). For these outcomes Vreugdenhil (2014) has used input data from 2006, 2011 and 2013.

Table B.2: percentage of total dwellings and roof surface per dwelling type for the city of Utrecht (Vreugdenhil, 2014)

Dwelling type	**Percentage of properties**	**Average roof surface per household (m^2)**
Onbekend (unknown)	8.68%	44.5
Vrijstaand (detached)	3.61%	79.6
TweeOnderEenKap (semidetached)	4.33%	64
Rijtjeshuis (terraced dwelling)	65.69%	43.5
FlatTot4 (flat until 4 floors)	4.07%	26.5
Flat4 (flat higher than four floors)	0.77%	20.1
EtageWoning (storey dwelling)	4.82%	35.9
Appartement (apartment)	0.96%	43.7
Herenhuis (townhouse)	3.15%	57.8
BejaardenWoning (senior housing)	0.95%	48.2
Boerderij (farmhouse)	0.46%	129.9
StudentenWoning (student housing)	0.51%	40.5
Divers (other types)	2.00%	42.5

The DHIC does not have the same data for thirteen types of dwellings for The Hague but does present a distribution of the total amount of dwellings in nine different types for the year 2020, table B.3 (DHIC, 2021).

Table B.3: Distribution of dwelling types in The Hague in 2020 (DHIC, 2021)

Type of dwelling (multiple classes)	**The Hague in 2020**	**Bomen en Bloemenbuurt in 2020**
Benedenwoning (ground floor apartment)	5.4%	4.9%
Bovenwoning (upstairs apartment)	10.9%	9.4%
Maisonette (maisonette)	2.7%	0.2%
Flat (flats)	40.7%	31%
Portiekwoning (porch dwelling)	16.6%	39.8%
Eengezinshoekwoning (single-family corner dwelling)	3.9%	1.5%
Eengezinstussenwoning (single-family terraced dwelling)	15.5%	12.0%
Vrijstaande woning (detached dwelling)	0.8%	0.3%
Twee-onder-een-kap woning (semidetached dwelling)	1.7%	0.7%

In this graduation study the percentages for the whole city of The Hague are used to be able to generalize the conclusions of the present study to other cities that are similar to The Hague. However, these inputs do differ from the percentages in the Bomen en Bloemenbuurt that is used as case study in this graduation research. Table B.3 shows that there are especially more porch dwellings and less flats in this neighbourhood compared to the whole of The Hague. As porch dwellings are part of the story dwellings of Vreugdenhil (2014), they have a larger average roof surface per household than flats have. Therefore, the total costs of implementing green or cool roofs can be underestimated compared to the real values for the Bomen en Bloemenbuurt specifically, but they can be generalized to other cities more reliably.

To be able to use the average roof surface per household by Vreugdenhil (2014) for the DHIC data of The Hague, this data is transformed into the dwelling types used by Vreugdenhil (2014). Detached and semidetached dwellings are the same in both data sources. Terraced dwellings from Vreugdenhil (2014) consist of single-family corner dwellings and single-family terraced dwellings of the DHIC data. Storey dwellings consist of porch dwellings, upstairs apartments and maisonettes. And apartments from Vreugdenhil (2014) are ground floor apartments in the DHIC data (DHIC, 2021). The difference between storey dwellings and apartments is not very clear: online research showed that a story dwelling can only be reached by stairs or elevator and thus the current distribution is chosen. The average roof surface per household in storey dwellings is lower than in apartments, thus if the definitions turn out to be different than used in this research and the number of apartments should be larger, the overall roof surface will increase and the overall costs for green and cool roofs in the model will also increase. It is thus possible that this research underestimates the costs of these two solutions for some dwellings.

The percentage of flats from the DHIC data (DHIC, 2021) has to be split into flats until four floors and flats higher than four floors. This is done by observations in the Bomen- en Bloemenbuurt. In this neighbourhood there are a total of 35 flats, nine flats are up to four stories high and 26 are higher than four stories. The number of households in these nine flats is 395 of a total of 1787 households that live in flats in the Bomen- en Bloemenbuurt. Thus, 22.1 percent of flats is up to four stories and 77.9 percent higher than four stories.

The other dwelling types from the PBL data (Vreugdenhil, 2014), unknown, townhouse, senior housing, farmhouse, student housing and other types are not used in this research. The percentages of these dwelling types are relatively low, apart from the unknown category, so they have little influence on the results. Furthermore, it is not clear which DHIC dwelling type the diverse and unknown category belong to and farmhouses are not present in the Bomen- en Bloemenbuurt.

When summing the percentages of the DHIC data (DHIC, 2021), the total is 98.2 instead of 100 percent. To make sure the total percentage adds up to 100 the separate percentages were divided by 98.2 and multiplied by 100 to preserve the existing proportions (table B.4). The cause of this difference is not mentioned in DHIC (2021) and could be the result of the rounding of percentages.

Table B.4: Combined and input percentages of dwelling types, adapted from Vreugdenhil (2014) and DHIC (2021)

Dwelling type	**Combined DHIC & PBL (%)**	**Proportional (%)**
Vrijstaand (detached)	0.8	0.8
TweeOnderEenKap (semidetached)	1.7	1.7
Rijtjeshuis (terraced dwelling)	19.4	19.8
FlatTot4 (flat until 4 floors)	9	9.2
Flat4 (flat higher than four floors)	31.7	32.3
EtageWoning (storey dwelling)	30.2	30.7
Appartement (apartment)	5.4	5.5
Total	98.2	100

As the input percentages for the model are the percentages with regard to the overall dwelling type, single-family dwelling or apartment, the input percentages in the model are stated in table B.5 and sum to 200.

Table B.5: Dwelling type and model input, adapted from Vreugdenhil (2014) and DHIC (2021).

Dwelling type	**Model input**
Vrijstaand (detached)	3.59%
TweeOnderEenKap (semidetached)	7.62%
Rijtjeshuis (terraced dwelling)	88.78%
FlatTot4 (flat until 4 floors)	11.84%
Flat4 (flat higher than four floors)	41.57%
EtageWoning (storey dwelling)	39.51%
Appartement (apartment)	7.08%
Total	200%

B.6.2.1.7 Amount of VVE’s

Because of the way the model creates VVE’s, not all VVE’s will consist of exactly 4 households when this is the input into the model. When a household gets the task to create a VVE in the setup procedure, the household will become the head of the VVE and will connect to the closest three households that are not head of a VVE. This way, all households that are head of a VVE have 3 other households linked to them. However, it is possible within the model that a household, which is not the head of a VVE, has a connection with two different VVE heads and is because of that technically part of two different VVE’s. This choice was made because when testing a model where this could not happen, VVE heads made connections to other households all the way across the model when there were no available households left close to the VVE head. This could result in VVE’s where one household was located all the way to the south of the Bomen- en Bloemenbuurt and another household of the same VVE at the north side of the neighbourhood, which would result in a VVE wherein households have different neighbourhood effects. That is not desirable as VVE’s should be part of the same property. Because of this choice, around 34.4% of apartments that are not social dwellings are the head of a VVE and 65.6% is not a VVE head. Each VVE head has a connection to three other households, and each household that is not the head of a VVE has on average 1.52 to 1.58 connections to VVE heads. This means a bit more than every second household that lives in a non-social apartment and is not a VVE head has a connection to two different VVE heads. Because of this, there are more VVE's in the model and the average size of a VVE is smaller than the input suggests. Another effect is that some households now influence the decision of two different VVE's.

When households cannot be part of multiple VVE's 25% of apartments that are not social dwellings is head of a VVE and 75% is not a VVE head. Each household that is not a VVE head now has only 1 connection to a VVE head. This means that in this model there are less VVE's and the average VVE size is thus 4 households. However, it is possible that there are VVE's with households that are on other sides of the area.

Sensitivity analysis

The effects of this choice are investigated with a sensitivity analysis, two model options, one where VVE's consist of four households and non VVE head households can have a connection with multiple VVE heads, and one where VVE's consist of four households and non VVE head households can only have a connection with one VVE head. Having only one VVE head per non VVE household creates a significant difference in the total implemented fraction of LCZ3 compared to LCZ9. Furthermore, the fraction of adopted green roofs in the total area has a significant difference with 0.0373 (=3.73% of all households), however this does not result in a significant difference in the outdoor air temperature. While the fraction of adopted green roofs of households with a connection with only one VVE head is higher, the costs are 7% lower and also the subsidy is around 7.5% lower. This could be because in the model with multiple connections to VVE head households, the installation costs of some non VVE head households is used multiple times as they are part of multiple VVE's in the model. This thus leads to an overestimation of the total costs, but an underestimation of the total fraction adopted. The last difference is that the significant difference between non-social households that are part of a VVE and non-social households living in single-family dwellings disappears when VVE households cannot be part of multiple VVE's. This is because the fraction adoption increases slightly, however non-significant, for non-social VVE households when they cannot be part of multiple VVE's, but this fraction does change for single-family households. Therefore the difference between the two fraction reduces and is not significant anymore.

The effects of a difference of the input for the number of households per VVE is investigated with a sensitivity analysis that includes two, four, six and eight households per VVE. As explained in this section, not all VVE's will have exactly the input amount of households. In the standard model it is possible that a household that is part of a VVE creates a connection with more than 1 VVE head household. Therefore the average amount of households per VVE is lower than the input number. The total mean average temperature increases significantly when VVE's only consist of 2 households. The average temperature in the total area than increases with almost 0.3 degrees Celsius. Also the maximum temperature in the total area increases significantly with 0.2 degrees Celsius. Because 75 percent or more households in a VVE need to support investing in a UHI mitigation solution and they should also agree on the kind of solution, both households must decide the exact same in this model run. This seems to be difficult as the fraction adopted in the total area is almost 0.4337 (=43.37% of all households) lower than in the standard model. It is reduced to around 46.72 percent of all households.

Increasing the amount of households in a VVE to 6 only increases the average temperature in LCZ3 significantly with 0.03 degrees Celsius. Increasing it to 8 increases the average temperature in the total area with 0.03 degrees and in LCZ3 with 0.05 degrees Celsius. The maximum temperature does not change. While the average temperature in the total area increases with 6 and 8 households per VVE, the fraction adoption in this area also increases significantly. There is thus a difference in the kind of solution adopted to explain the temperature difference. The fraction green roofs adopted in the total area increases significantly for 6 and 8 households per VVE with 4 percentage points in both cases. At the same time the amount of green gardens implemented reduces. However, this reduction is only significant for the runs with 8 households per VVE with 1.5 percentage points. For 2 households per VVE both the fraction of green roofs and green gardens implemented in the total area and in LCZ3 reduce significantly. Because of this reduction the total costs also reduce significantly with 57 percent. For 6 and 8 households the costs increase with 22.8 and 39 percent respectively, as the fraction of green roofs implemented also increases. At the same time the costs of green gardens reduce significantly in these runs, however this reduction is only small with 3000 to 4000 euros in total as the amount of green gardens adopted is low.
While the adopted fraction and total costs for green roofs increase for 8 households per VVE, the total subsidy for green roofs decreases significantly compared to the standard setup. It is not clear what causes this difference, it could be connected to the way the total subsidy is calculated. Future research is needed to discover this cause. In the standard model the fraction of solutions adopted by non-social tenants living in apartments is lower than for non-social owner occupiers living in single-family dwellings. The same is true for the fraction adopted by non-social households that are part of a VVE compared to non-social households living in single-family dwellings. However, for six and eight household per VVE this changes and non-social tenants living in apartments have a higher fraction of solutions adopted than non-social owner occupiers living in single-family dwellings. Which is also true for non-social VVE households and non-social single-family households. At the same time the significant difference of the fraction adoption of all non-social households with the total fraction adopted disappears. This could be caused by the fact that it is easier for VVE's with more households to decide to invest in UHI (Urban Heat Island) mitigation solutions than for VVE's with less households. If there are more households in a VVE, the minimum percentage that needs to agree with the investment stays the same but in absolute terms more households can be against the investment while the minimum percentage is still reached. The difference between low income households and middle and high income households is not significant anymore for two households per VVE. This is probably caused by the low fraction of adoptions overall that reduce the differences.

B.6.2.1.9 Influence of household characteristics on TPB

Figure B.5 shows the S curve corresponding to the tipping point of the **nearby air temperature** used in the standard model, 26 degrees Celsius, in blue. It shows that the chance that a households invests in an Urban Heat Island (UHI) mitigation solution, after it has determined which solution has the highest multi-attribute utility, starts increasing at 22 to 23 degrees Celsius and changes quickly until 29 to 30 degrees Celsius. If the nearby air temperature of a household is around those values or even higher this chance is very close to one. The yellow and orange lines show the different input values used in the sensitivity analysis.

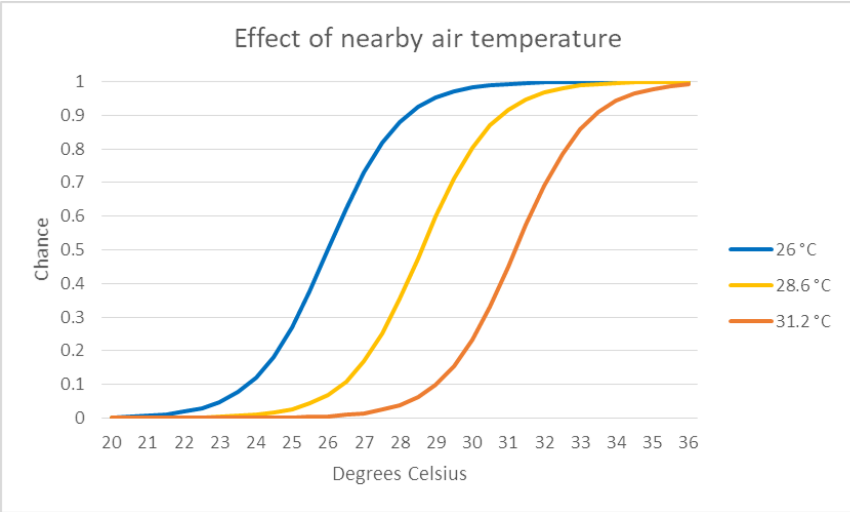


Figure B.5: Effect of nearby air temperature on the chance to invest in an UHI mitigation solution

Sensitivity analysis

Figure B.5 shows the S curve corresponding to the three different input values for the tipping point of the **nearby air temperature** used for the sensitivity analysis. When the tipping point of the nearby air temperature effect increases, the average and max temperature also increase. However, in LCZ3 and LCZ6 this increase is smaller. The total average temperature increases with 0.05 and 0.20 degrees Celsius, while the average temperature in LCZ3 and LCZ6 does not significantly increase for a ten percent change, and increases with 0.19 and 0.17 degrees Celsius for a twenty percent increase of the nearby air temperature tipping point. The same is true for the decrease of the total fraction of solutions adopted. The fraction adopted in the total area decreases with 0.0975 (=9.75% of all households) and 0.2946 (=29.46% of all households) for an increase of ten and twenty percent respectively, while the fraction adopted in LCZ3 decreases with 0.0723 (=7.23% of all households) and 0.2611 (=26.11% of all households) and in LCZ6 only decreases with 0.0553 (=5.53% of all households) and 0.2327 (=23.27% of all households). This is a big difference with LCZ5 and LCZ9 where the decrease is 0.2342 (=23.42% of all households) and 0.4124 (=41.24% of all households) for a ten percent increase and 0.5102 (=51.02% of all households) and 0.5076 (=50.76% of all households) for a twenty percent increase. The increase of the nearby air temperature also creates a significant difference in the total implemented fraction of LCZ3 and LCZ6 compared to LCZ5 and LCZ9. As a result of the decrease of implemented solutions the total costs and subsidy also decrease significantly. The difference between the LCZs is caused by the difference in average temperature between these areas. The average starting temperature in LCZ3 and LCZ6 is more than 29 degrees Celsius, while the average starting temperature in LCZ5 and LCZ9 is less than 27 degrees Celsius. Therefore an increase in the nearby air temperature tipping point to 28.6 and 31.2 degrees Celsius has less effect on the fraction adoption in these areas. The difference between the total adopted fraction of non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments is significant for all three different nearby air temperatures. Although, for an input of 26 degrees this difference is very small and in the standard model with 100 repetitions no significant difference was found. Increasing the value with ten and twenty percent increases the difference between these two households groups.

B.6.2.2 UHI mitigation solutions

In this section extra information is presented for five characteristics of UHI mitigation solutions, the air temperature reduction, radius of that reduction, decline of the air temperature reduction, energy reduction and costs per solution. For three of these characteristics more detailed results of the sensitivity analysis is presented. The characteristics of UHI mitigation solutions mostly come from the literature sources in appendix A that are consulted in this research. However, for the costs of the solutions, internet sources are also examined.

B.6.2.2.1 Air temperature reduction

The influence of the UHI mitigation solutions on the outdoor air temperature is determined based on the literature research done for this study. Appendix A shows the investigated studies, which were already shortly discussed in section 2.5. For the model input only the effect of the solutions in the local climate zones (LCZs) that are present in the case study are considered.

Within the model there are four different LCZs: $LCZ3_B$, $LCZ5_A$, $LCZ6_A$ and $LCZ9_D$. However, in the effects found in the literature that is presented in appendix A not all these LCZs are represented. Therefore, the secondary LCZ presented in subscript are not considered when determining the air temperature reduction of an UHI mitigation solution. If there is no available data for a specific LCZ, the data for the most similar LCZ was taken into account to determine the air temperature reduction of that solution. In this study this similarity is mostly based on the height of the buildings in that area, as this height seems to play a large role for the effects of green and cool roofs (M. Santamouris et al., 2017; Susca, 2019; S. Tsoka et al., 2018) and in the occurrence of the UHI effect in general, because the height of the buildings influences the size of the micro scale (section 2.5) where the effect of the air temperature reduction is considered. It could be the case that for some UHI mitigation solutions, the height of the buildings is less important than other properties of the LCZ and the most similar LCZ should be another than is chosen for this model. Future research could investigate what properties of a LCZ have the most influence on the effect of certain mitigation solutions in that LCZ and which LCZs are thus the most similar for different solutions. In this research the most similar LCZ to LCZ5 is LCZ2 as both have midrise building, for LCZ6 this is LCZ3 as both are low-rise and for LCZ9 this is also LCZ3 as LCZ9 has some small or medium rise buildings. For each mitigation solution will be mentioned whether data from other LCZs is used.

The air temperature reduction effect for **green roofs** ranges between zero and 1.2 degrees in LCZ2 and zero and 1.5 degrees Celsius in LCZ3. For LCZ2 the average effect is 0.3322 degrees Celsius (2.99 / 9) and for LCZ3 this is 0.44 degrees Celsius (3.08 / 7). The effect in LCZ2 is thus 75.5% of the effect in LCZ3. Li et al. (2014) calculate the effect of green roofs based on the percentage of green roofs in the area. Their study looks at the effect of green roofs city wide, which could be classified as a $LCZ3_5$ as the area has mostly compact low-rise buildings with some open midrise in it. The highest value they find for 100% green roofs is 0.6 degrees Celsius and one step below that is 0.4 degrees Celsius for 70% green roofs. This is somewhat close to the average effect of 0.44 degrees Celsius for LCZ3. Therefore, the results from their study will be used as input for the model (table B.6). As the average effect in LCZ2 was 75.5% of the effect in LCZ3 the input for LCZ5 will be calculated as the rounded values of 75.5% of the effects Li et al. (2014) found.

Table B.6: Influence of green roofs on the air temperature in the LCZs in the model

Percentage green roofs in the area	**LCZ5 (°C)**	**LCZ3, LCZ6, LCZ9 (°C) (Li et al., 2014)**
10%	0	0
20%	0.04	0.05
30%	0.08	0.1
50%	0.19	0.25
70%	0.30	0.4
100%	0.45	0.6

The model calculates the fraction of green roofs per LCZ and if this value meets one of the percentages in table B.6 the effect of green roofs in that area increases and households will take the new effect into account in their decisions. This way the effect of green roofs in an area suddenly increases once a new threshold percentage is reached, while in reality the effect will probably increase evenly between the percentages. However, as it is not clear how this increase exactly happens, this is not implemented in the model. As a result of this choice, the effect of green roofs could be underestimated in the model, as the effect only increases once a new step is reached. Another effect of the current choice is that the effect of the number of green roofs in a LCZ stop at the border of the LCZ, while in reality they would probably extend for a few more metres. This could also result in an underestimation of the total reduction effect as this effect will stop immediately at the edge of a LCZ and not continue for a few metres.

The amount of data from literature about **green façades** is limited, but some effects were found. For LCZ2 the effect ranges between 0.05 and 3.3 degrees Celsius, while Perini et al. (2011) cannot find an effect in LCZ3. They however only compare the effect of a green façade on the air temperature 10 centimetres from the façade with the air temperature one metre from the façade, while de Jesus et al. (2017) even find an effect up to 5 metres from the green façade. Comparing the effect on the distances of 0.1 and 1 metre is thus not a very good method to check whether there is an effect. The average effect in LCZ2 is 0.55 (1.65 / 3), this is the input for LCZ5 in the model. It is assumed that the effect of a green façade in LCZ3, LCZ6 and LCZ9 is smaller than the effect in LCZ2, as the façades in these areas cannot be as big as a façade on a midrise building and there is more green and more space in LCZ6 and LCZ9 as they are respectively open low-rise and sparsely build. Therefore, the effect of green façades in these three LCZs is calculated based on the effects found by Gromke et al. (2015) and Zölch, Maderspacher, Wamsler, & Pauleit (2016) in Arnhem, the Netherlands and Munich, Germany respectively. This average is 0.25 degrees Celsius.

For the effect of changing a surface area to **grass** two studies in LCZ2 find a small increase of the air temperature in that area (Battista et al., 2019; Égerházi et al., 2013), while two other studies do find an average air temperature reduction for the whole day of 0.48 degrees Celsius (Lobaccaro & Acero, 2015) or a reduction of one degree Celsius at 12:00 (L. Huang, Li, Zhao, & Zhu, 2008). Lee, Mayer, & Chen (2016) find a reduction of 1.1 degrees between 10:00 and 16:00 for $LCZ5_B$, while Klok et al. (2019) find a reduction of 1.2 degrees Celsius as afternoon average in $LCZ6_A$. These are thus used in the model with LCZ3 and LCZ9 having the same reduction as LCZ6.

There are ten studies about the effect of **trees** in LCZ2 with in total 12 temperature reduction effects and an average effect of 0.82 degrees Celsius (9.87 / 12), while there is only one study each for LCZ3, LCZ5 and LCZ6. The effect in LCZ3 is 0.15 degrees Celsius (Taleghani et al., 2016), however this effect

was measured directly in the sun. The effect in LCZ5 is 0.6 degrees (Lee et al., 2016) and the effect in LCZ6 has a daily average of one degree Celsius (Wang, Bakker, de Groot, Wörtche, & Leemans, 2015). As it is plausible that the effect in an open midrise area (LCZ5) is less big than in a compact midrise area (LCZ2) the effect of 0.6 degrees Celsius reduction is used in the model for LCZ5. The effect of one degree reduction for LCZ6 found by Wang et al. (2015) was in a garden with multiple trees, thus it is expected that less trees have a smaller effect on the air temperature. As the average effect in LCZ2 was 0.82, the model input for LCZ3, LCZ6 and LCZ9 will be a bit lower at 0.8 degrees Celsius.
The effect of trees is used in the model as the effect of adopting the solution of a green garden. The municipality of The Hague has the policy to provide a tree to every citizen that wants one (nos.nl, 2021). Therefore, it is assumed that all households that decide to invest in a greener garden will put a tree in their garden while also reducing the amount of hardened surface. Not all households will follow this assumption in reality, as some do not want a tree in their garden or do not have the space for it. To make the model not more complex than it already is, it is thus assumed that the overall effect of making a garden more green is the same as planting a tree in the garden.

The literature about **urban parks** consists of five studies in LCZ2, four studies in LCZ3 and 5 other studies that are region or city wide. The average temperature reduction in LCZ2 is 3.48 degrees Celsius (17.4 / 5) and in LCZ3 is 2.625 (10.5 / 4). The value for LCZ3 is rounded to two decimal places, 2.62, and is also the input for LCZ6 and LCZ9 as is explained in the beginning of this chapter. The average reduction of LCZ2 is used as input for LCZ5.

Regarding the effect of **pools and ponds,** the literature shows a wide variety. The effects from all sources range between zero- and 2.7-degrees Celsius reduction and the specific literature for LCZ2 shows effects between zero and 1.1 degrees Celsius. Both sources for LCZ3 (Tominaga et al., 2015) and LCZ5 (Xi, Li, Mochida, & Meng, 2012) report a reduction of two degrees Celsius. At the same time Klok, Jacobs, Kluck, Cortesão, & Lenzholzer (2018) write that the air temperature cooling effect in 29 different scientific papers about rivers, ponds and lakes is less than 1.5 degrees Celsius and Jacobs et al. (2020) state that 14 out of 20 analysed papers showed an effect of one degree Celsius or less with a median of 0.5 degrees Celsius. As input for the model, the rounded average reduction found for LCZ2: 0.56 (4.47 / 8) is used as the reduction for LCZ5, while the air temperature reduction in LCZ3, LCZ6 and LCZ9 is set to 1 degree Celsius. The choice to reduce the effect to one degree instead of two degrees Celsius is made because of the results the analyses by Klok et al. (2018) and Jacobs et al. (2020).

A lot of studies investigated the effect of adopting **cool pavements** in LCZ2, the average reduction of these papers is 1.725 (20.7 / 12) degrees Celsius. The effect in LCZ3 is based on seven papers coming to an average reduction of 1.1 (7.7 / 7) degrees Celsius, while the effect for LCZ5 is only based on two papers showing an effect of 1.5 degrees Celsius (Salata et al., 2017) and 1.6 degrees Celsius (Lalosevic, Komatina, Milos, & Rudonja, 2018). These two are roughly the same as the average effect found in LCZ2 and thus are expected to be reliable. The model input for LCZ5 is thus 1.55 degrees Celsius. The model input value for LCZ6 and LCZ9 is the same as LCZ3 at 1.1 degrees Celsius.

The last UHI mitigation solution is the adoption of **cool roofs** by households. Four studies in LCZ3 show an average effect of 0.7 (2.8 / 4) degrees Celsius, while the effect in LCZ5 is only 0.1 degrees Celsius. This difference could be explained by the fact that LCZ5 consists of midrise buildings and the effect of green roofs, and also cool roofs, on higher buildings have less effect on the air temperature at ground level than lower buildings, as mentioned in section 4.1. The average of two studies in LCZ2 show a larger effect of 0.55 (1.1 / 2) degrees Celsius reduction (Ambrosini et al., 2014; Maleki & Mahdavi, 2016). However LCZ2 has compact midrise in comparison to the open midrise of LCZ5, therefore there is a larger surface area available for cool roofs in LCZ2 and the effect could be larger. Li et al. (2014) present the cooling effect of cool roofs in LCZ3 based on the percentage of cool roofs in such an area. Their research is also used for the input for the effect of green roofs. Table B.7 shows the effects they calculated for different percentages. Although it was just discussed that a more open LCZ could have a reducing effect on the influence of cool roofs on the air temperature at pedestrian level, the same values presented for LCZ3 will be used for LCZ6 and LCZ9 as other data is not available. The value found for LCZ5 is 14.3% of the value of LCZ3 and thus 14.3% of the effects found by Li et al. (2014) will be used as input for LCZ5 in the model (table B.7).

Table B.7: Influence of cool roofs on the air temperature in the LCZs of the model

Percentage green roofs in the area	**LCZ5 (°C)**	**LCZ3, LCZ6, LCZ9 (°C) (Li et al., 2014)**
10	0	0
20	0.015	0.1
30	0.015	0.1
50	0.04	0.25
70	0.06	0.4
100	0.07	0.5

The same reasoning why the effect of green roofs could be underestimated in the model, is true for the effect of cool roofs. As the increase of the temperature reduction effect does not follow a linear path between the different percentages in table B.7, but only increases when a new percentage from this table is reached and the effects stops at the border of the LCZ.

Another characteristic of the model that can result in an underestimation of the effect of green and cool roofs is the fact that only the percentage of green roofs is considered for the effect of green roofs in a LCZ and the same is true for cool roofs. It could be possible that the adoption of green roofs and cool roofs could also strengthen each other's effect. The current configuration of the model sees green and cool roofs as two separate solutions. If 30% of all roofs in LCZ3 is green and 30% of all roofs is cool, the total effect will be 0.1 degrees for green and 0.1 degrees for the cool roofs, thus 0.2 degrees Celsius reduction in total. However, if all these roofs were green this would result in 0.25 degrees Celsius reduction, and the same is true for cool roofs. Further research could investigate if these two solutions could influence each other in such a way.

Households can decide to adopt four different UHI mitigation solutions, green roofs, green façades, green gardens and cool roofs. The effects of these solutions are thus used by the households to determine their comfort utility. As the amount of green roofs and cool roofs implemented influences the effect that these two solutions have on the outdoor air temperature, this comfort utility changes during the model run. Figure B.6 presents the comfort utility in the different LCZs at the end of the standard model run where no cool roofs are implemented and more than 80 percent of households implemented a green roof.

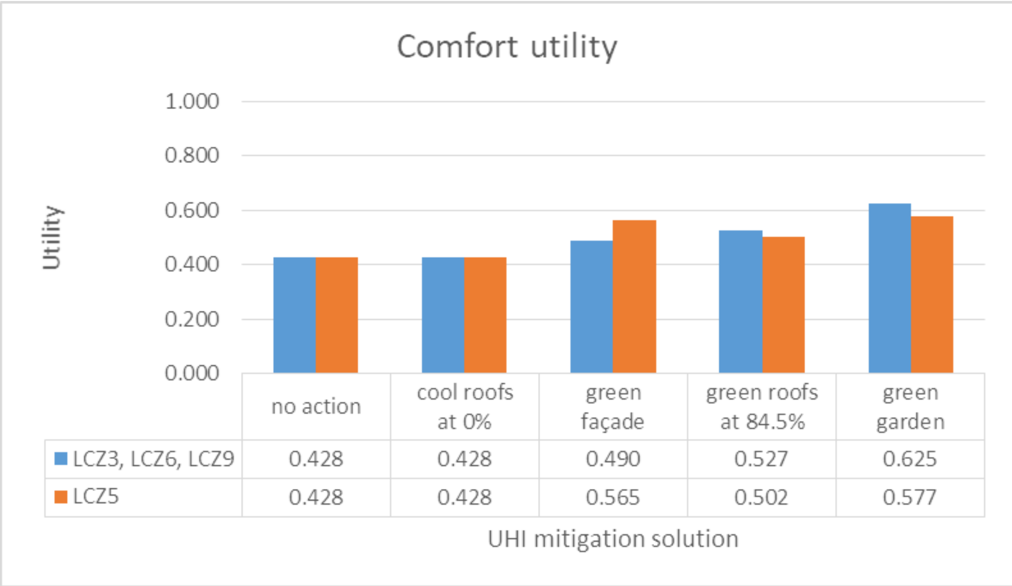


Figure B.6: Comfort utility of UHI mitigation solutions adopted by households

Sensitivity analysis

The sensitivity analysis shows that a decrease in the air temperature mitigation effect of **green roofs** results in an increase in the total average temperature and the other way around. This is also true for the maximum temperature. However, there is no significant influence on the total amount of adopted solutions. As almost all adopted solutions are green roofs and this solutions affects the whole area, the decrease of the average temperature is roughly the same for a ten percent increase of the mitigation effect as the increase of the average temperature for a ten percent decrease of the mitigation effect. Around 0.076 degrees Celsius. The same is true for a twenty percent change in the mitigation effect. This is around 0.18 degrees Celsius. A twenty percent increase of the mitigation effect creates a significant difference between the total adopted fraction of LCZ3 and LCZ9. This is also present in the analysis with no change to the mitigation effect, but the standard model run with 100 repetitions did not show this. As the results of an analysis with more repetitions is more reliable it is assumed that this difference does not exist in the standard model.

A difference in the effect of **green façades** does not result in significant change.

Changing the mitigation effect of **green gardens** on the other hand has a significant effect on the mean outdoor air temperature despite the low amount of green gardens adopted in the area. However, it does not affect the maximum temperatures as green gardens only affect a small area around them. This suggest that green gardens have a larger effect on the mean total outdoor air temperature than green roofs. An increase of the mitigating effect of green gardens with ten percent results in a decrease of the mean total air temperature of 0.09 degrees Celsius. A twenty percent increase has a decreasing effect of 0.28 degrees Celsius. Furthermore, an increase of ten or twenty percent creates a significant difference between the total adopted fraction of LCZ3 and LCZ9. A twenty percent change in the mitigating effect of green gardens also has a significant effect on the fraction of green roofs adopted in LCZ3. As most households are located in that area a decrease or increase has the most effect in this area. Furthermore the fraction of adopted green gardens changes significantly in the sensitivity analysis. A ten percent reduction in the effect on the air temperature results in a reduction of around 0.0168 (=1.68% of households), while a ten percent increase results in an increase of 0.0198 (=1.98% of households) and even more in some LCZs. A twenty percent decrease causes a decrease of around 0.0297 (=2.97% of households) in the fraction of green gardens adopted and an increase of

twenty percent results in an increase of 0.0498 (=4.98% of households). As the mean total fraction adoption of green gardens without a change is relatively low with 0.0582, or 5.82 percent of all households these changes are relatively big if the percentage change are considered.
A difference in the effect of **cool roofs** only results in a significant difference between the total adopted fraction in LCZ9 and LCZ3. It does not create any other significant effects between the different areas or subsidy percentages.

B.6.2.2.2 Radius of reduction

The radius of the effect of **green roofs** and **cool roofs** does not have a specific input value, as the air temperature effect of these solutions depend on the percentage of these roofs in the LCZ. These effects will thus occur in the whole LCZ when this percentage increases.

Razzaghmanesh & Razzaghmanesh (2017) show that the effect of **green façades** can be measure at one metre from the façade itself and de Jesus et al. (2017) even measured an effect five metres away from the green façade. Because the façade of a dwelling is adjacent to its garden and therefore in this model adjacent to the next patch, the radius of a green façade will be 2 patches in total, the patch of the dwelling and parts of its adjacent patches.

The radius of a **grass** area could not be specified from literature directly. Therefore, it is deduced from the temperature decline for such an area. This decline is 0.162 degrees Celsius per patch and addressed in section 6.2.2.3. The maximum effect of grass is a reduction of 1.2 degrees Celsius, dividing this with 0.162 gives a rounded radius of 7 patches. This will thus be used as model input.

For **trees** the radius is based on the research by Shashua-Bar & Hoffman (2000), they write that the effect of a small green side can be perceived up to around 100 metres from the site. Divided by nine, this results in a rounded radius of eleven patches.

The radius of **urban parks** depends on the size of the park according to Chang & Li (2014), they write that the cooling effect of larger parks reaches further than that of smaller parks. The cooling effect of parks over 1 hectare can reach up to 300 metres far (Chang & Li, 2014), which is supported by Skoulika et al. (2014). The radius for urban parks will thus be set to 33 patches.

For **pools and ponds** three different radiuses are presented in literature. Xu et al. (2010) measure an effect at 20 metres away from the water body in LCZ1, but the effect does seem to extend even further. Syafii et al. (2016) find an effect until 4.5 metres in a scaled down experiment in LCZ2 that represents 22.5 metres when scaled up. The largest radius is presented by Tominaga et al. (2015). In LCZ3 they found a perceptible effect over 100 metres downwind of a pond. However, this value was found downwind without obstructions from buildings (Tominaga et al., 2015). Because these values are far away from each other the temperature decline, discussed in section 6.2.2.3, is also consulted. This decline is 0.15 per patch and results in a radius of 60 metres, around 6.67 patches. This radius lies between the values found in literature and also takes effect of Xu et al. (2010) into account, that the radius is more than 20 metres. Therefore, the radius of 7 patches, or 63 metres is used as input for the model.

The last radius is for the effect of areas with **cool pavements**. This radius could not be directly deduced from literature and is thus determined based on the temperature decline of this solution, which is 0.162 degrees Celsius. The biggest effect from literature is seen in LCZ5 with a temperature decrease of 1.55 degrees Celsius, which results in a radius of 86 metre rounded. The lower effect of one degree Celsius shows a rounded radius of 56 metres. Therefore, the radius is chosen to be nine patches, which is 86 divided by nine rounded downwards.

As some radiuses could not be found in existing literature and other literature on these radiuses seems scarce, further research is needed to improve and/or confirm the radiuses used in this research. A change in the radiuses itself does not immediately affect the results of the model, except when the radius is reduced. However, in that case the temperature reduction of the solution should be reduced, or the temperature decline increased as these values all interact with one another. The radiuses will not be further investigated separately but are included in the sensitivity analyses of the temperature reduction and temperature decline.

B.6.2.2.3 Temperature decline

Shashua-Bar & Hoffman (2000) show that the cooling effect of small green sites with **trees** can be perceived up to 100 metres from this site and present information about the decay function of the cooling effect over this radius. They show that the decay of this effect is not completely linear. It has a smaller decay at the end of the radius (Shashua-Bar & Hoffman, 2000). However, to keep the complexity of the model down, it is assumed that this decay follows a linear function of 2.15 degrees Celsius in 100 metres. This means that the cooling effect will reduce with 0.194 per patch (2.15 / 100 * 9) in the model.

As discussed in the previous section, the effect of an **urban park** can reach up to 300 metres away from the park. Skoulika et al. (2014) investigated the decay function of an urban park along two different road traverses. When they used the average temperature of the park, the temperature gradient of the first traverse ranged between 0.45 and 1.1 K per 100 metres, while the gradient of the second travers ranged between 1.0 and 1.8 K per 100 metres. These gradients were measured on two different roads alongside the park and do thus not take obstructions from buildings into account. To keep the complexity of the model of this research down it will also not consider obstructions from buildings. However, this could lead to an overestimation of the cooling effect of urban parks as these obstructions do have an effect. Therefore, the highest gradient of 1.8 K per 100 metres is used as input in the model, to make sure that the overestimation is on the low side. The reduction per patch is thus 0.162 (1.8 / 100 * 9) degrees Celsius.

For the temperature decline of **grass** areas, no specific effect could be found in literature. However, Skoulika et al. (2014) write that their findings for the second traverse of the temperature decline of an urban park is probably influenced by the proximity to an open field. Therefore, the maximum decay of this traverse is adopted as the temperature decline for grass areas. This value is 0.162 degrees Celsius per patch, which is also used for urban parks.

Tominaga et al. (2015) concluded that a **pond** could reduce the air temperature up to 100 metres away from the centre of the pond. Their analysis shows that the difference between the edge of the pond and the 100-metre point is around 1 degree Celsius, and this edge is 40 metres from the centre of the pond. The decline in their research is thus 0.0167 degrees Celsius per metre, which is 0.15 (1 / 60 * 9) degrees Celsius per patch in the model of this research. Xu et al. (2010) show that the radius of pools and ponds can be larger than 20 metres, but the exact range is not presented. Therefore, it is not possible to deduce a temperature decline from their research. The decline of 0.15 degrees Celsius per patch is thus used in this model. This value is slightly lower than the effect found for urban parks, which could be because air from pools and ponds has a higher humidity than air from urban parks and thus warms slower. However, future research will need to confirm this.

As a cooling radius could not be found in literature for areas with **cool pavements**, this can also not be used to determine the temperature decline. Therefore, the temperature decline for urban parks is also used as input for the decline of the effect of cool pavements. This choice can result in an overestimation of the effect of areas with cool pavements as cool air from urban parks will most likely have a higher humidity, because of all the vegetation, and will thus warm slower than air from an area with cool pavements that has a lower humidity. However, because of a lack of data from literature this choice is made.

An overview of all input parameters for the different UHI mitigation solutions discussed in section 6.2.2 is presented in table B.8. The radius of the temperature reduction effect and the temperature decline within this radius were determined in this section for the whole system and not per LCZ, because there is not enough available data from literature to be able to change these for each LCZ. Further research is needed to investigate whether these parameters are different for each LCZ or if the current choice to use one value is correct.

Table B.8: Overview of UHI mitigation solution input parameters

UHI mitigation solution	**Reduction LCZ3 (°C)**	**Reduction LCZ5 (°C)**	**Reduction LCZ6 (°C)**	**Reduction LCZ9 (°C)**	**Radius (patches)**	**Decline (°C/patch)**
Green roof	0; 0.05; 0.1; 0.25; 0.4; 0.6	0; 0.04; 0.08; 0.19; 0.30; 0.45	0; 0.05; 0.1; 0.25; 0.4; 0.6	0; 0.05; 0.1; 0.25; 0.4; 0.6	Per LCZ	N/A
Green façade	0.25	0.55	0.25	0.25	1	0
Grass	1.2	1.1	1.2	1.2	7	0.162
Tree	0.8	0.6	0.8	0.8	11	0.194
Urban park	2.63	3.48	2.63	2.63	33	0.162
Pools and ponds	1	0.56	1	1	7	0.150
Cool pavement	1.1	1.55	1.1	1.1	9	0.162
Cool roof	0; 0.1; 0.1; 0.25; 0.4; 0.5	0; 0.015; 0.015; 0.04; 0.06; 0.07	0; 0.1; 0.1; 0.25; 0.4; 0.5	0; 0.1; 0.1; 0.25; 0.4; 0.5	Per LCZ	N/A

B.6.2.2.4 Energy reduction

Permpituck & Namprakai (2012) show that the energy consumption in a building in Thailand can be reduced by 37 percent per year with a **green roof** of 20 centimetres thick and 31 percent per year for a green roof of 10 centimetres. On the other hand, Besir & Cuce (2018) conclude that the heating demand of a building can be reduced by 10 to 30 percent and that buildings with green roofs consume between 2.2 and 16.7 percent less energy during summer compared to buildings with normal roofs. They further state that a green system can create an energy saving of 215 dollars per year depending on the regional and climate conditions. Based on the average energy bill of 1513 euro in the Netherlands in 2021 (CBS, 2021), this would mean a reduction of 12 percent. As this study considers the Netherlands and not Thailand, the amount of energy reduction in the summer will probably be lower. However, there will also be a reducing effect on the heating demand during the winter that is not seen in places like Thailand. Therefore, a total energy reduction of 20% is chosen for the effect of having a green roof.

The energy reduction of **green façades** are mainly presented during the ‘cooling season’, where outdoor temperatures are high and households use air conditioning to reduce the temperature inside their houses. Besir & Cuce (2018) write that a green façade can reduce the energy consumption of air conditioners by 20 percent and Stec, van Paassen, & Maziarz (2005) show a reduction of up to 19%. Kontoleon & Eumorfopoulou (2010) report a reduction of 18.17% in cooling energy demand if the green wall is located on an east-oriented wall, 20.08% reduction on a west-oriented wall and just 7.60 percent for a south-oriented wall in Greece. Coma et al. (2017) a reduction of 58.9 percent for a green wall and 33.8 percent for a green façade in the month of July in Spain. They also showed that the energy reduction in winter is 4.2 percent and 1.9 percent for a green wall and green façade respectively. Perini, Bazzocchi, Croci, Magliocco, & Cattaneo (2017) come to a reduction of 26.5% in energy savings during a cooling period. Next to reducing the energy needed for cooling, a green façade could also reduce heating demand as it increases insulation, just like a green roof. However, it is assumed that green façades are not as good as green roofs at the overall energy reduction as green façades are limited to one side of a building and as warm air rises upwards, green roofs should be better at keeping a dwelling warm in the winter. Therefore, it is assumed that the overall energy reduction of a green façade is 15 percent.

The implementation of a **green garden** by a household and thus planting a tree in their garden, will probably not influence the energy use of the household. It could have a small effect if the tree is located on the south side of the house and causes a shadow on a wall of the house, however this is not included in the model as the size of this effect is not clear and no data could be found for this effect. Therefore, the energy reduction of implementing a green garden is set to zero.

For **cool roofs** Kolokotsa et al. (2018) report an annual cooling energy reduction of 17 percent, while the overall reduction for cooling and heating is 8.9 percent. However, as cool roofs have better reflection and become less warm, they will also be cooler during the winter. In a cold winter this will result in an increased heating demand as the building will absorb less heat from the sun. Therefore, the energy reduction in the model is set to nine percent. Table B.9 shows the effect of all solutions considered by households in the model.

Table B.9: Energy reduction of the four solutions considered by households

Solution	Percentage energy reduction / year
Green roof	20%
Green façade	15%
Green garden	0%
Cool roof	9%

In the model itself the energy reduction is used as an energy reduction fraction between one and zero, so these percentages are divided by 100. To calculate the environmental factor for each solution within the S shaped function, the energy reduction fraction is multiplied by ten. This choice is made to increase the differences between the environmental factors of the solutions. Otherwise, there is only a very small difference of 0.05 between an energy reduction of zero and an energy reduction of 20 percent and now this is 0.46. Figure B.7 shows the environmental utility corresponding to the UHI mitigation solutions that households can implement.

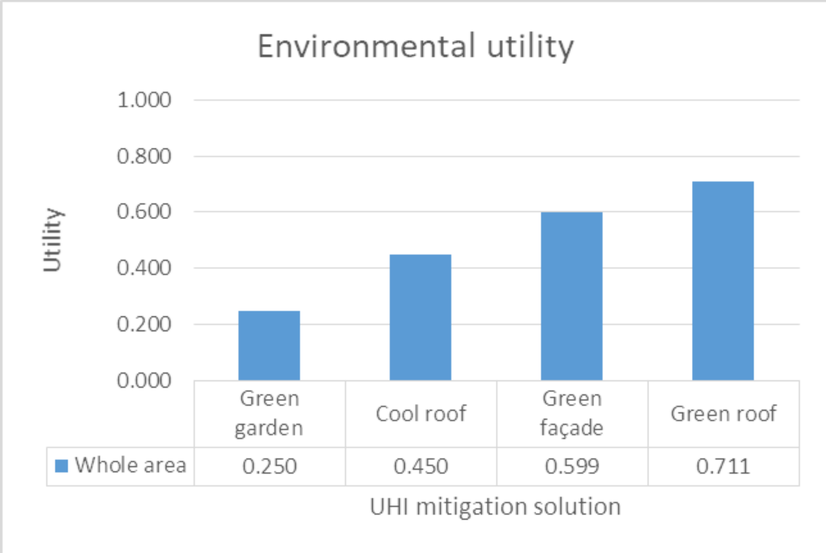


Figure B.7: Environmental utility of UHI mitigation solutions adopted by households

Sensitivity analysis

A change in the energy reduction of **green roofs** does not have an effect on the mean outdoor air temperature or the maximum air temperature. However, there is a significant effect on the total fraction of adopted solutions for a decrease or increase of twenty percent. This fraction is reduced from 0.90 to 0.82 and increased to 0.93. The reduction of the total fraction adopted is caused by the reduction of the amount of adopted green roofs with 0.1158 (=11.58% of households). It is slightly mitigated by the amount of green gardens that increases with 0.0271 (=2.71% of households) and the fact that in some runs there is a very small amount of green façades adopted, which is not significant. It is interesting that the mean outdoor air temperature or maximum air temperature are not reduced, while the total fraction adopted and the fraction green roof are reduced. This should have increased the air temperatures but has been mitigated by the increase in the amount of green gardens adopted. Green gardens thus have a bigger effect on the outdoor air temperatures than green roofs. As green gardens are cheaper to implement than green roofs, a reduction of twenty percent in the energy reduction of green roofs also has a significant effect on the total costs for UHI (Urban Heat Island) mitigation solutions and total subsidy for green roofs. The costs for green gardens increase with 83 percent, but the overall costs reduce with 12.4 percent, which is more than 4 million euros. Furthermore the total subsidy for green roofs reduces with more than twenty percent, or 370000 euros, while the air temperature does not change.

Changing the energy reducing effect of **cool roofs** does not have a significant effect on most outcomes. It only creates a significant difference between the adopted fraction of LCZ3 and LCZ9 with a ten percent increase. However, it does also show this significant difference with the same model input as the standard model that has 100 repetitions and did not show this effect.

Reducing the energy reducing effect of **green façades** with twenty percent does in some instances result in a small amount of green façades adopted, but this effect is not significant. Changing the reduction with ten percent or decreasing it with twenty does create a significant difference between the total adopted fractions of LCZ3 and LCZ9.

B.6.2.2.5 Costs per solution

The costs of installing a **green roof** are based on seven different sources. First, a new root-resistant layer needs to be installed, these costs range between 50 and 65 euros with an average of 58.75 per square metre (werkspot.nl, 2021; Klijn, 2021b; Viveen, 2021b; homedeal.nl, n.d.b). Then the green roof sedum layer is installed, which costs can very a lot based on the exact choices about the properties of the green roof. In this research an extensive green roof is considered, so the costs of installing a sedum roof layer are examined. Even within this category the costs could range between 40 and 120 euros (Viveen, 2021b). For this model, the averages of these ranges are considered. These ranged between 65 and 80 euros with an average of 71.53 euros (werkspot.nl, n.d.; groendak.nl, 2011; Viveen, 2021b; homedeal.nl, n.d.b; sedumdakbedekking.nl, n.d.; houhetwarm.nl, n.d.). Combining these two, the rounded average is 130 euros per square metre for installing a green roof. These choices assume that the root-resistant layer and green roof layer can be installed on top of the current roof and that the current roof does not need to be removed or improved. In reality this could be the wrong choice as a lot of roofs in The Hague are poorly maintained (A. Kennis, personal communication, 08-01-2021) and thus need extra work before a green roof can be installed. However, the installation of a new root-resistant layer and the green roof layer itself also improve the existing roof, as these layers protect the roof and reduce the generation of wear. Because of this, the current costs choice was made. It could thus be possible that the costs of green roofs in the model are underestimated, which could result in an overestimation of the number of green roofs that is adopted in the model. This is further investigated with the sensitivity analysis at the end of this section.

There are several different options for installing a **green façade** with a wide costs range. Middelie (2009) presents six different green façade systems that range between 350 and 1200 euros per square metre. For this research nine different sources are used, when one of these presents a price range the mean value of this range was considered. The value from these sources ranges between 400 and 750 euros per square metre with an average of 534.24 euros (gevelbekleding-info.nl, n.d.; De Coster, 2021; houhetwarm.nl, n.d.b; De Verticale Tuinman, 2020; Jacobs, 2011; gevelwand.nl, n.d.; Middelie, 2009; JNWR, 2013; habitos.be, n.d.). As input for the model a price of 535 euros per square metre is thus considered.

As explained in section 6.2.2.4, the effects of the choice for a **green garden** are based on the temperature reduction effects of a tree. The costs of changing into a green garden are thus also based on this. Werkspot.nl (n.d.b) and kosten-stratenmaker.nl (n.d.) both present the costs of several different tree species. The total range of these costs is between 15 and 165 euros. The average costs of all these species combined without counting the same species double is 59.21 euros. The input in the model is therefore set to 60 euros. It is expected that the household is able to make its garden more green by itself and does not need a gardener for this. In reality the age or health issues of members in the household will cause some households to hire a gardener to make their garden more green. Because of this, it is possible that the costs of a green garden are underestimated in the model and as a result the model overestimates the number of green gardens adopted by households. However, this effect is relatively small as most households are able to do the work themselves.

Installing a **cool roof** can be as easy as adding a cool layer on top of your existing roof. However, most roofs in the Hague are poorly maintained (A. Kennis, personal communication, 08-01-2021) and if a household or VVE decides to invest in a cool roof, the current roof should be redone. Therefore, the costs of a cool roof in this model are based on the initial costs of a green roof, the installation of a new roof layer, in combination with removing the existing roof layer. This ranges between 85 and 105 euros per square metre, with an average cost of 90.35 euros (offertebutlet.nl, n.d.; homedeal.nl, n.d.c; Viveen, 2021c; werkspot.nl, n.d.c; eigenhuis.nl, 2020; offerteadvisuer.nl n.d.). Therefore, the costs for installing a cool roof in the model is set to 90 euros per square metre. The choice that households and VVE's invest in a completely new roof, when deciding to go for the cool roof solution, leads to an overestimation of the costs of this solution and thus an underestimation of the number of households choosing this solution, as in reality not all roofs will need a completely new layer when installing a cool roof. However, based on the available information most roofs do need this and the choice is made to include it in this way. Further research could investigate what the exact percentage of roofs is where this is required to make the model more representative of the real world. Because of the limited time and scope of this research this is not included here, but the effect of a change in the costs is investigated in a sensitivity analysis.

The costs of the UHI mitigation solutions considered in this research do not include the maintenance costs of these solutions. Having a green garden requires a bit more maintenance than having a garden full of stone tiles, but it is expected that households do this maintenance themselves, which will reduce the monetary costs but does cost more time. However, this is not included in the model. The maintenance costs of a cool roof during the modelled period is considered the same as a normal roof, as it is expected that the cool coating has a similar design life as a regular roof (William et al., 2016). Besir & Cuce (2018) write that the maintenance costs for an extensive green roof are notably low and it could even be argued that a green roof will cost less over its lifetime, as it increases the lifespan of the underlying roof (Oberndorfer et al., 2007). Therefore, there are also no maintenance costs for green roofs in the model. According to Perini & Rosasco (2013), the maintenance costs of green façades are notably high and even higher for living wall systems. The yearly maintenance is on average 12.56 euros per square metres, with living walls having the biggest share of this with 27.02 euros per square metre (Perini & Rosasco, 2013). JNWR (2013) presents maintenance costs in the same range, between 10 to 25 euros per square metre each year. As these are considered notably high costs, the maintenance costs of green and cool roofs are thus much lower per year. The choice to not include these costs in this research could result in an underestimation of the total costs of green façades and thus an overestimation of the number of green façades implemented by households in the model.

The costs of the UHI mitigation solutions are used to determine the economic utility of a household. The costs per square metre are combined with the surface area of the roof or the façade of the household. Figure B.8 presents the economic utility for the four different solutions households can implement for a household that has an average roof and façade area.

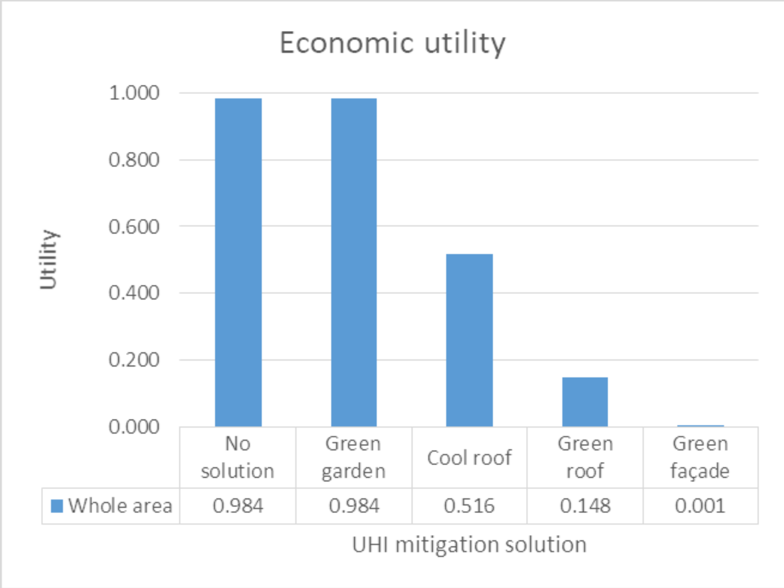


Figure B.8: Economic utility of UHI mitigation solutions adopted by households

Sensitivity analysis

The effect of increasing and decreasing the costs of **green roofs** with ten and twenty percent is interesting as multiple effects occur. The average temperature in the whole area has a significant increase in for all changes, except an increase of the costs of ten percent. The effect is not significant in LCZ9, but this can be linked to the low amount of households in that area. Secondly for the maximum temperature there is only a significant increase of 0.1 degree Celsius for a cost increase of twenty percent. Thirdly the total fraction implemented decreases with 0.0558 (=5.58% of households) and 0.1182 (=11.82% of households) with an increase of ten and twenty percent respectively, but only increases with 0.0299 (=2.99% of households) to 0.0456 (=4.56% of households) with a costs decrease of ten and twenty percent. This effect in significant in the total area, while the significance of the values changes per LCZ (Local Climate Zone). Changing the costs of green roofs with ten percent also creates a significant difference between the total adopted fraction of LCZ3 and LCZ9. The fraction of green roofs adopted is of course affected the most by changing the costs of this solution with an increase of 0.0917 (=9.17% of households) when decreasing the costs with twenty percent and a decrease of 0.2111 (=21.11% of households) when the costs increase with twenty percent.
Furthermore, when the costs of a green roof increase with ten or twenty percent in some runs green façades are adopted but this is not significant. With the increase of the costs of green roofs by twenty percent, cool roofs are adopted in all runs. The fraction green gardens implemented also increases significantly with an increase of the costs of green roofs and the same is true for a decrease. As the costs of a green roof decrease the total costs of all implementations also decreases with 18.4 percent for a costs decrease of twenty percent and 7.9 for a costs decrease of ten percent. The increase of the costs of green roofs do not create a significant increase in the total costs as households choose other, often cheaper, solutions. Because of this the total subsidy for green roofs decreases while the costs of green roofs increase. On the other hand, a reduction of the costs of green roofs causes an increase in the amount of subsidy for green roofs with 12.4 percent and 18.9 percent for a costs decrease of ten and twenty percent respectively.

A decrease or increase of the costs of green roofs creates a significant difference between the total fraction adopted by non-social owner occupiers living in single-family dwellings and non-social tenants living in apartment, which does not exist in the standard model. What causes this difference is not clear and can be investigated in further research. At the same time a decrease of the costs of green roofs with twenty percent reduces the difference to a non-significant amount in the total fraction adopted between non-social households and the overall adopted fraction.

For a change of the costs of **green façades** the mean average temperature of the total area increases when the costs increase with twenty percent. This is interesting as there are no green façades implemented in the standard model. There is no significant influence of the maximum temperature or the total fraction of adopted solutions. However, the total fraction of green roofs has a significant increase if the costs of green façades increase with twenty percent. This is also the case the other way around for a decrease of the costs by twenty percent. In some runs there are a couple of green façades implemented when the costs are decreased by twenty percent, but this is not significant. The amount of adopted green gardens is significantly influenced by an increase of the costs of green façades by ten or twenty percent. In that case the adopted fraction reduces with 0.0148 to 4.39% of households and 0.0330 to 2.57% of households respectively. On the other hand, when the costs of green façades decrease with twenty percent, the amount of adopted green gardens increases with 0.0180 to 0.0766 (=7.66% of households).
These changes do not significantly influence to total costs of all adoptions, only the costs of green gardens reduce significantly when the costs of green façades increase. Because of the lower amount of adopted green gardens when the costs of green façades increases with twenty percent, the total subsidy for green gardens also decreases significantly. The total subsidy for green roofs does reduce significantly with almost ten percent when the costs of green façades reduce with twenty percent. An increase of the costs of green façades with ten and twenty percent creates a significant difference between the total adopted fraction of non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments. On the other hand a decrease of the costs of green façades mitigates the significant difference between the total adopted fraction of non-social VVE households and households living in single-family dwellings. The cause of these differences should be investigated in future research.

Changing the costs of **green gardens** with ten and twenty percent does not have any significant results. It seems to increase the overall adoption of all solutions and thus green roofs and green gardens but these are not significant. However, it does create a significant difference in the total adopted fraction between LCZ3 and LCZ9 if the costs are increased with ten percent. The total costs and subsidy of green gardens are influenced, but as the amount of implemented green gardens is very low these changes are not significant. In this analysis the difference between the total adopted fraction of non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments was significant for all options while this is not the case in the standard model run.

Changing the costs of **cool roofs** by ten and twenty percent has almost no significant effects. When the costs are lowered by twenty percent all runs see a small fraction of cool roofs installed in the area. This is around 6.34% of all households. Except for a twenty percent increase in the costs of green roofs there is a significant difference between the total adopted fraction of LCZ3 and LCZ9. For an increase of the costs of cool roofs with ten percent there is even a significant difference between LCZ6 and LCZ9. The reduction of the total subsidy for green roofs when the costs of cool roofs is reduced by twenty percent is significant with more than 320000 euros, which is a bit more than seventeen percent. Furthermore this analysis also shows a significant difference between the total adopted fraction of non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments.

B.6.2.3 Environment

For two environmental characteristics, neighbourhood vegetation and the input air temperature, extra information is presented in this section. It also discusses the sensitivity analyses of the input air temperature in more detail. The environment is considered here as the 'background' of the model and is thus the specific information that the patches own in the model. This includes information about the amount of neighbourhood vegetation per LCZ and the input air temperature of the model.

B.6.2.3.1 Neighbourhood vegetation

Table B.10 shows the chosen input and the output after the first and second change of the green percentage model input.

Table B.10: Amount of green surfaces per LCZ as input and after setup used in the model for the first and second change

Area	Green percentage first change (model input)	Average green percentage (after setup)	Green percentage second change (model input)	Average green percentage (after setup)
LCZ3	11.13%	19.26%	9.45%	18.02%
LCZ5	29.13%	57.71%	19.71%	52.88%
LCZ6	8.82%	14.60%	7.89%	13.90%
LCZ9	16.87%	74.17%	0.01%	69.41%

After the second time, the average green percentages after setup of LCZ3 and LCZ6 only have a difference of 0.43 and 0.23 percentage point with the input data from Cobra Groeninzicht respectively (D. Voets, personal communication, 06-03-2021 & 12-03-2021). LCZ5 has a bit more difference with 4.59 percentage point and LCZ9 has the biggest difference with 19.31 percentage point. The input for LCZ9 is already changed to 0.01 percent, so for the last input this will be set to zero percent. LCZ3 and LCZ6 will be changed one last time with the difference between the input from Cobra Groeninzicht and the outcome after the second change. For LCZ5 the difference is still relatively large compared to LCZ3 and LCZ6 so this value will be lowered a bit more with 8.59 percentage point instead of the difference of 4.59. These last modifications and their results are presented in table B.11.

Table B.11: Amount of green surfaces per LCZ as input and after setup for third change

Area	Green percentage third change (model input)	Average green percentage (after setup)	Difference green percentage after setup to Cobra Groeninzicht data
LCZ3	9.02%	17.73%	0.14%
LCZ5	11.12%	48.40%	0.11%
LCZ6	7.66%	13.71%	0.04%
LCZ9	0%	69.53%	19.43%

B.6.2.3.3 Input air temperature

In figure B.9 the Bomen en Bloemenbuurt is zoomed into with its boundaries highlighted in blue to determine the input air temperature of the model.

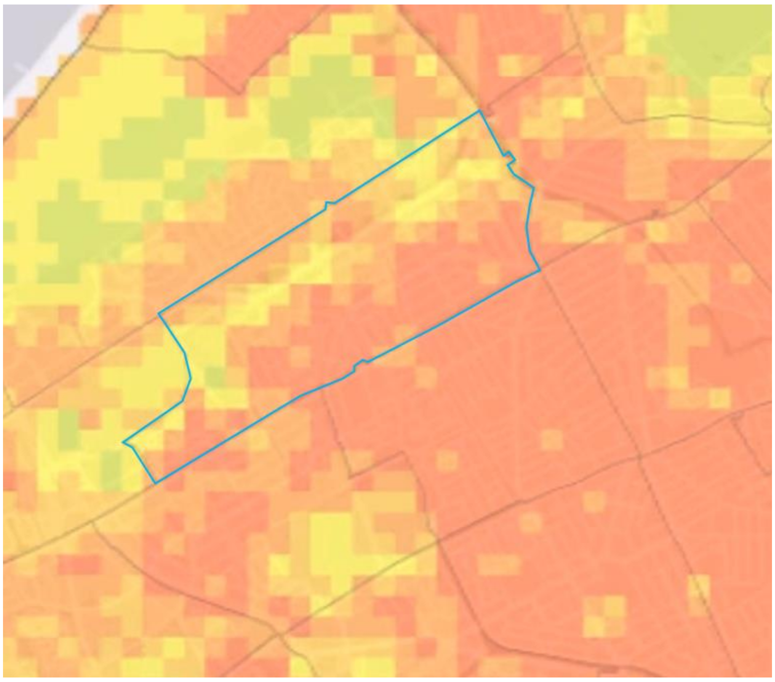


Figure B.9: Zoomed in version of modelled air temperature in The Hague for July 4, 2015 at 12:00. Adapted from Ntarladima (2016)

The air temperatures from the research of Ntarladima (2016) are calculated for a 100x100 metre grid within the city of The Hague. As this research only looks at the Bomen- en Bloemenbuurt area and thus zooms into a small part of the whole city these 100x100 metre squares do not show a very high level of detail for the air temperature. From North to South the area is just around 8 squares, 800 metres, wide. From East to west the area is a bit larger with around 15 squares, so 1500 metres. This is in sharp contrast with the level of detail of the model used in this research. In that model a single square / patch is around 9 metres in length and the temperate differences can thus be calculated with 11 times more detail. The choice for these dimensions is explained in section 6.2.3.1, however it does create some downsides. As the radiuses of the UHI mitigation solutions in the model range between 1 and 33 squares, the air temperate in the model will be calculated on that level of detail. However, the starting air temperature is not based on this level of detail. Because of this, the outcomes of the model will not be as reliable as they could have been if the input data had a higher level of detail. The model output of the KPIs in the different LCZs is more reliable as they present the effect in a bigger area, but the visualization of the Bomen- en Bloemenbuurt of one model run is not the best representation as it shows a high level of detail of the temperature differences, but the temperature input is a much lower level of detail. Another effect of this data constraint is that the is a sharp edge between squares with different temperatures. In some areas a square with a temperature of 27 degrees is next to a square with a temperature of 31 degrees Celsius. In reality there would be a gradual transition of the temperature between these squares. Because of this the temperature in some areas will be underestimated when a small area with a lower temperature is close to a larger area of higher temperatures. In other areas the temperature is overestimated when a small area with a higher temperature is close to a larger area of lower temperatures. Within the model these effects could nullify each other, however there are more areas with a higher temperature then there are areas with a low temperature. Therefore, it is expected that overall, the temperature in the model is slightly underestimated.

At the start of this research several other data sources were investigated to see if there was better data available, unfortunately these could not be found. A more detailed level of input temperature data would greatly improve the reliability of the results of the model and future research should be aimed at creating this data.

The dimensions of a square in the model of this research are thus nine by nine metres, while the air temperature input data is 100 by 100 metres, each of these input data squares thus includes 11.11 model squares in the length and width. As the input can only be assigned to a whole square, this was done per eleven squares. However, because of this the input squares and squares in the model will diverge after a couple of these squares. To mitigate this effect as much as possible the assignment of temperatures to squares starts in the bottom left and the upper right side of the model. The temperatures in those areas thus follow the input temperature from Ntarladima (2016) the best and towards the middle of the model these boundaries will differ more. Because of this effect the temperature input squares in the middle of the model are smaller than all other squares. From West to East the temperature input squares in the middle are only seven squares wide instead of eleven and from North to South the temperature input squares are fourteen squares high to counter this effect. Another possibility is to increase the width and decrease the height of the temperature input squares gradually, but this cannot be done easily within the creation of the model. Therefore, this second-best option is chosen. As the temperature input squares with different dimensions because of this choice range between 25 and 31 degrees Celsius, the overall effect of this choice on the temperature in the model is kept as low as possible.

Sensitivity analysis

The effect of an overall change of the input air temperature on the outcomes of the model is investigated with a sensitivity analysis that changes all input air temperature with ten and twenty percent. As a result of changing the input air temperature the total average temperature and maximum temperature also change with roughly the same percentage. The total fraction of implemented solutions only decreases significantly if the input air temperature decreases. This reduction is overall larger than the percentage decrease of the input air temperature and the decrease is relatively larger for a temperature decrease of twenty percent. It also creates a significant difference of the total adopted fraction of LCZ3 and LCZ6 compared to LCZ5 and lCZ9. In LCZ5 and LCZ9 the decrease of the total fraction adopted is higher than in the other areas. This could be caused by these two areas having a lower average temperature in the standard model and therefore also having a lower temperature when this is decreased with twenty percent. As the results show that the decrease in adopted fraction is relatively larger when the temperature is lower, this could cause this difference between the areas. The total fraction of green roofs adopted is the largest in the model and thus reduces with almost the same percentages as the overall total fraction of solutions adopted. The reduction of the fraction of green gardens implemented is only significant for an input temperature reduction of twenty percent. The percentage reduction of the fraction of green gardens is even larger than that of green roofs. Because of the reduction in adopted fraction, the total costs and subsidies are also reduced. There is a significant difference between the total fraction adopted by non-social owner occupiers living in single-family dwellings and non-social tenants living in apartments. However, this disappears for an increase of the input air temperature of twenty percent. This is probably the result of the adopted fraction increasing so far that it reaches its top value.

Appendix C Three ABM architectures

This appendix presents the difference between the three agent-based model (ABM) architectures based on the Theory of Planned Behaviour (TPB) in the model narrative and the system decomposition. It also discusses the outcomes of the different model architectures and explains why architecture MF, based on the research by Muelder & Filatova (2018), is chosen as the main model architecture in this thesis. At the end two small sensitivity analyses with architecture RR, based on the research by Rai & Robinson (2015), and architecture SE, based on the research by Schwarz & Ernst (2009), are presented.

C.1 Model narrative of the three different ABM architectures

This section explains the narrative of the model in 'normal' language. It explains how the model should work from its setup, through the difference phases that happen during each model round (1 year). The structure and narrative of the model are based on the research by Muelder & Filatova (2018) that tested three different ABM architectures. The actions presented in this section are also shown in figures C.1, C.2 and C.3.

C.1.1 Setup phase

The model area is set up based on the map of the Bomen- en Bloemenbuurt in The Hague. During the setup each household is assigned its different properties. The properties of patches are distributed depending on the characteristics of the Bomen- en Bloemenbuurt. A 'patch' is the smallest level of detail in the ABM and has the form of a square, therefore it is sometimes also called a 'square'. In this research a patch has a size of 9x9 metres. This choice is further explained in section 6.2.3.2.

C.1.2 Decision-making phase

Only households that do not live in a socially rented dwelling are able to make a decision. This research looks at three different TPB-based architecture of the decision-making process. Therefore, there are three different options in this phase depending on the choice of the modeller to run one of the three. It is not possible to use two or three of them within one experiment. The calculation of the multi-attribute utility for each solution differs between the three options. Thereafter the model is almost the same for each of the three architectures. First the three differences are presented, then the shared narrative is shown with a small difference in the end.

Architecture 1 (MF):

A non-social household checks whether its income is above a certain threshold. If that is the case, the household continues with the utility estimation of each available UHI mitigation solution. It estimates its economic-, environmental-, comfort- and social utility and determines the multi-attribute utility of each solution.

Architecture 2 (SE):

A non-social household directly determines the utility of each available UHI mitigation solution by calculating its economic-, environmental-, comfort- and social utility. Then it does an extra weighting in the utility function to determine the multi-attribute utility. It takes into account the importance of its own attitude towards the economic-, environmental- and comfort utility combined and its own attitude towards the PBC (the income threshold) against the importance of existing social norms (the attitude-, PBC- and social importance).

Architecture 3 (RR):
A non-social household checks whether its income is above the economic utility. When that is the case, it continues with determining the economic-, environmental-, comfort- and social utility of each available UHI mitigation solution. Then it determines the multi-attribute utility of each solution.

Shared narrative of architecture 1, 2 and 3:
After determining the different multi-attribute utilities, a non-social household checks the effects of its household characteristics. Its educational level, whether the households owns the house, the amount of vegetation in the neighbourhood and the current nearby air temperature all influence whether the household will invest in a solution. If the outcome of this check is positive, a household that lives in a single-family dwelling and is thus not part of a VVE determines which solution has the highest multi-attribute utility, as it can only implement one solution in the model. In architecture 1 and 2, the household invests in this solution if its utility is higher than the utility of not taking any action. In architecture 3 its utility is compared to a threshold value and if the value of the solution is higher the household invests in that solution. However, if the household characteristics check is positive and the household lives in an apartment and is thus part of a VVE, it notes for each solution whether the multi-attribute utility is higher than the utility of not taking action for architecture 1 and 2. For architecture 3 it checks whether the multi-attribute utility of each solution is higher than a threshold value. Only if a household is the head of a VVE it then continues. The head of a VVE checks the preferences of the households that are part of the VVE. If a qualified majority of 75% or more of the VVE wants to adopt one specific solution the VVE head invests in this solution. If there is more than one solution with 75% approval the head of the VVE checks which solution has the highest overall multi-attribute utility and implement it.

C.1.3 Implementation phase

If a household that lives in a single-family dwelling and is thus not part of a VVE or a household that is the head of a VVE has chosen to implement an UHI mitigation solution, it changes the nearby air temperature based on the properties of that UHI mitigation solution and change other global parameters.

C.1.4 Model flow chart

Figure C.1 gives a general overview of the model, while figures C.2 and C.3 zoom into the estimation of the multi-attribute utility and the household characteristics check respectively.

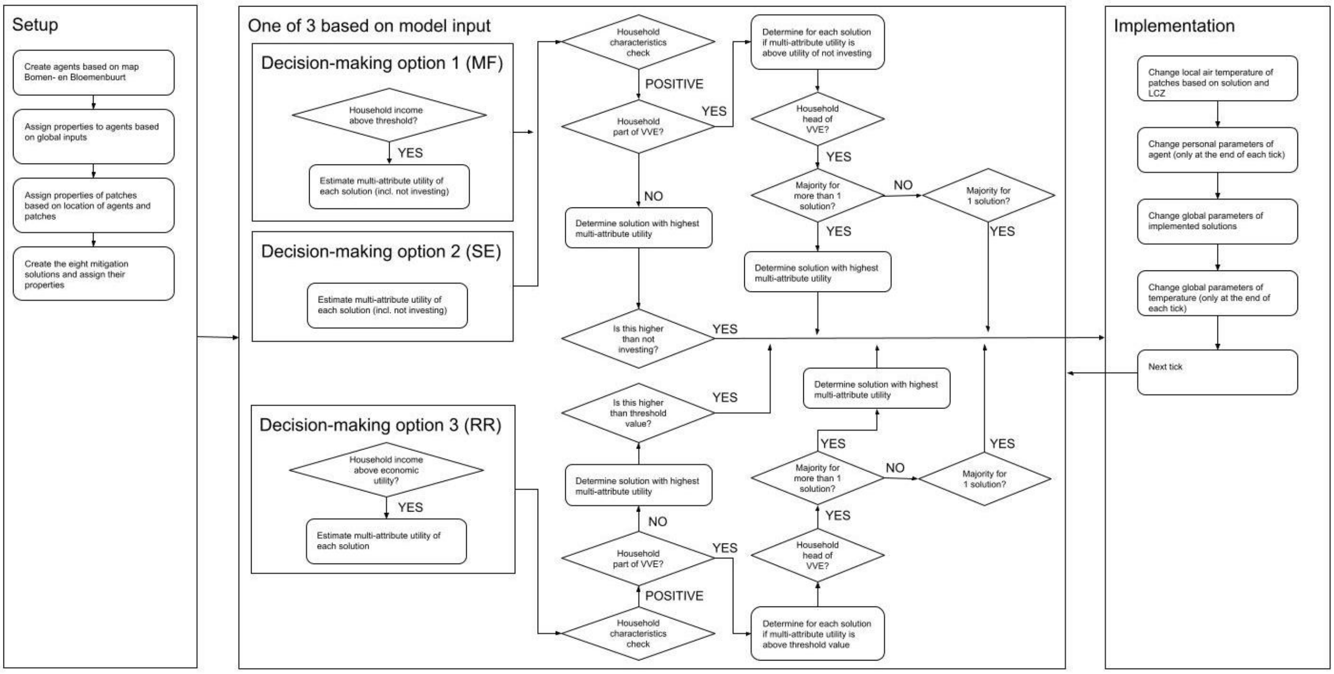


Figure C.1: General model flow chart

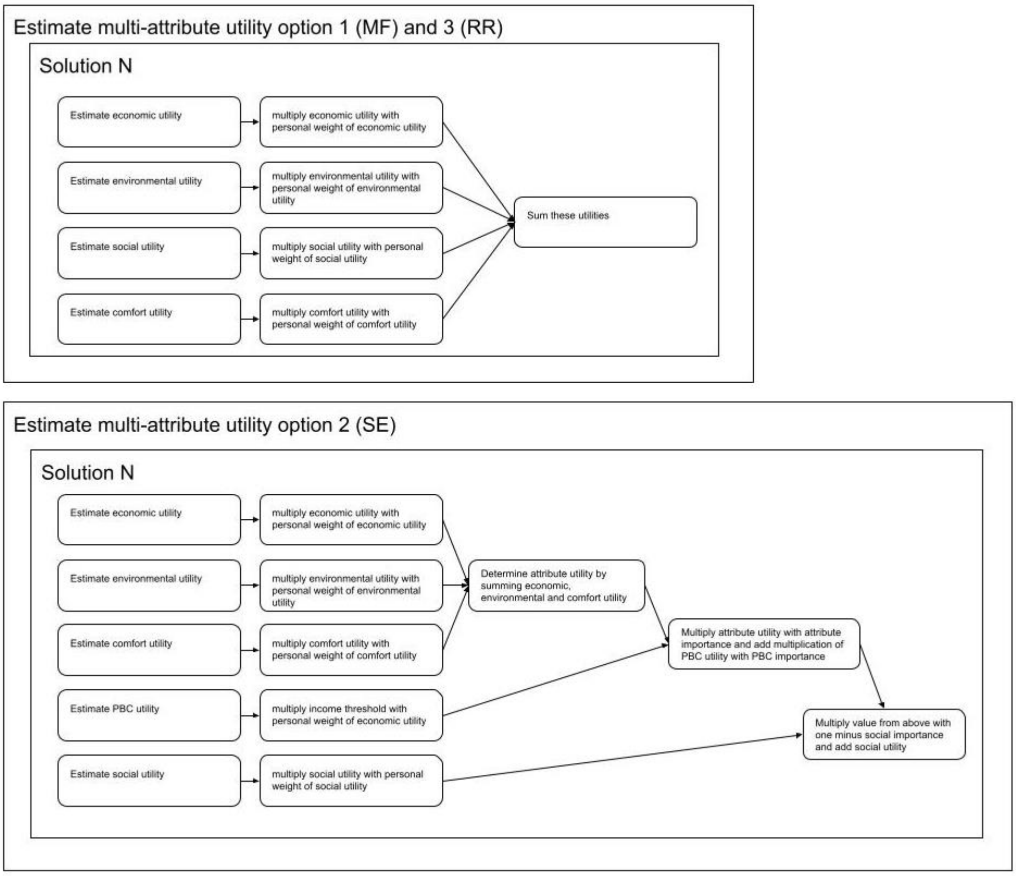


Figure C.2: Details of the estimation of multi-attribute utility

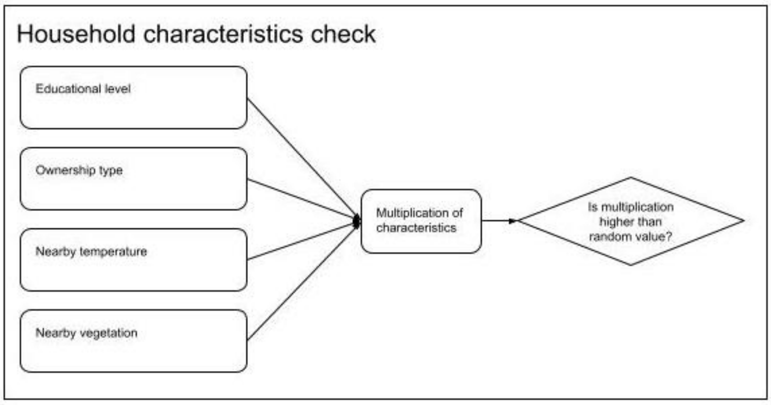


Figure C.3: Details of the household characteristics check

C.2 System decomposition of the three different ABM architectures

Section 5.2 described from a high-level perspective how the model should work and showed the different processes within the model. This section explains these processes in more detail.

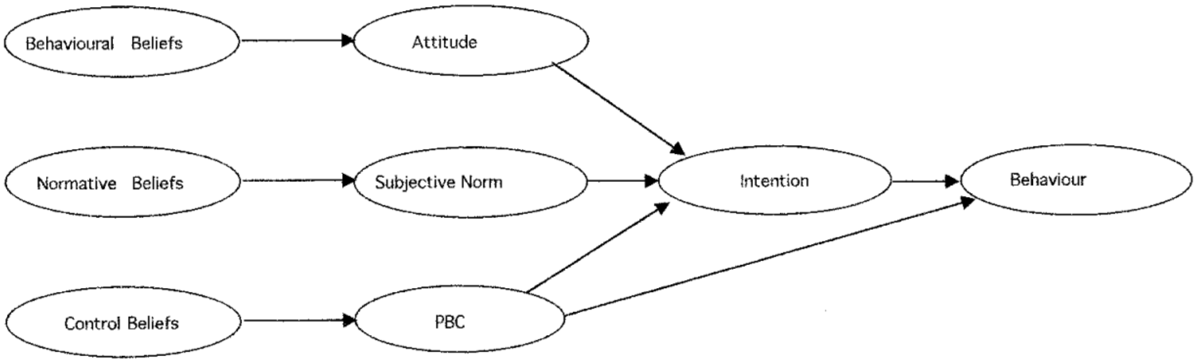


Figure C.4: Reprinted from "Efficacy of the Theory of Planned Behaviour: A Meta-Analytic Review" by C. Armitage and M. Conner, 2001, British Journal of Social Psychology, 40, p. 472. Copyright 2001 by The British Psychological Society.

The Theory of Planned Behaviour (TPB) (figure C.4) is used in this research to model how agents decide to invest in UHI mitigation solutions. As explained in section 2.7.1 the TPB explains how attitude, subjective norms and perceived behavioural control influence people's intention and behaviour. By influencing these aspects, individual's behaviour can be changed. For this research the study by Muelder & Filatova (2018), which is briefly mentioned in section 3.5.1, is used as an example. Muelder & Filatova (2018) investigated whether household agents in the municipality of Dalfsen in the Netherlands would invest in solar panels. Figure 19 presents the three operationalizations (MF, SE and RR) of the TPB they used in their research.

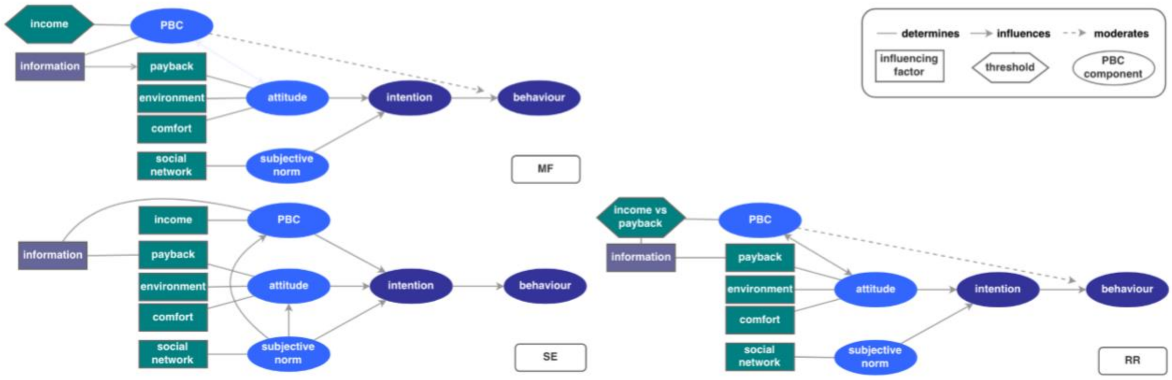


Figure C.5: Alternative operationalizations of the Theory of Planned Behaviour. Reprinted from "One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models," by H. Muelder and T. Filatova, 2018, Journal of Artificial Societies and Social Simulation, 21(4), p. 19.

Figure C.5 shows that Muelder & Filatova (2018) identified four factors influencing the decision to invest in solar panels: An economic factor (payback), an environmental factor (environment), a social factor (social network) and a comfort factor (comfort). These four were based on participatory workshop discussions with households in the Netherlands and will be transformed to be able to use them in this research. Section 5.2.3 explains this transformation as it is the same for all three different agent-based model (ABM) architectures.

Figure C.6 shows the individual decision-making process of a household in each of the three TPB-based architectures from Muelder & Filatova (2018). The differences between the three become clear from this figure. Households in architecture MF and RR first check whether their income is above a random value or the economic utility respectively (Table C.1, equation 5), while households in architecture SE immediately start with determining their multi-attribute utility. In architectures MF and RR households both calculate the overall utility of the four influencing factors with the weights of these factors (Table C.1, equation 6), while households in architecture SE apply extra weighting in the utility function. They compare "the importance of their own attitudes i_{att} and of PBC i_{pbc} against the importance of prevailing social norms i_{soc}" (Muelder & Filatova, 2018, p.5) (Table C.1, equations 8-10). After determining the highest multi-attribute utility households in architecture MF and SE check whether this is higher than the current utility of not taking action. In architecture RR households compare their utility with a threshold value.

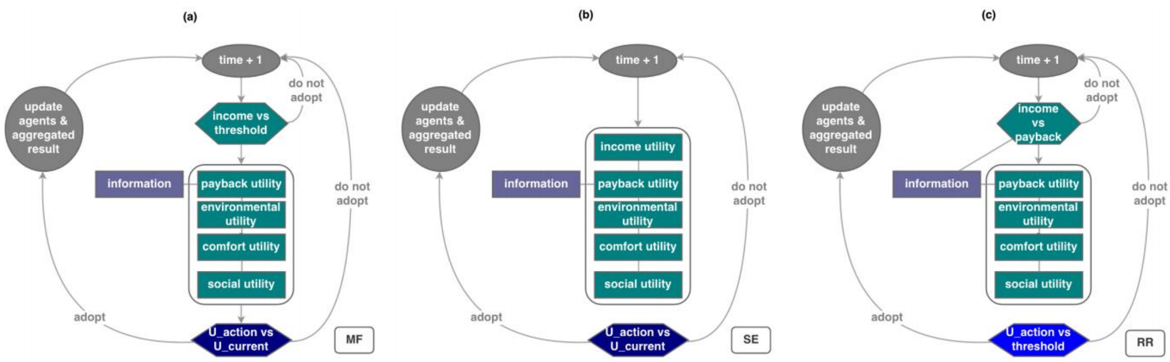


Figure C.6: TPB-based architectures of an individual decision-making process. Reprinted from "One theory-many formalizations: Testing different code implementations of the theory of planned behaviour in energy agent-based models," by H. Muelder and T. Filatova, 2018, Journal of Artificial Societies and Social Simulation, 21(4), p. 5.

Table C.1: adapted from (Muelder & Filatova, 2018)

ABM	PBC Barrier	Utility resolution mechanism	Functional form
MF	$th_{inc} = \frac{e^{(x-\bar{x})}}{1+e^{(x-\bar{x})}}$ $th_{inc} > r$ (5)	Myopically choose the maximum	$U_{RR,MF} = w_{eco} * u_{eco} + w_{env} * u_{env} + w_{soc} * u_{soc} + w_{cof} * u_{cof}$ (6)
RR	$th_{inc} > u_{eco}$ (7)	Compare to an exogenous threshold	
SE	Part of utility	Myopically choose the maximum	$U_{SE} = \left(i_{att} * u_{att} + i_{pbc} * u_{pbc}\right) * (1 - i_{soc}) + w_{soc} * u_{soc}$ (8) $u_{att} = w_{eco} * u_{eco} + w_{env} * u_{env} + w_{cof} * u_{cof}$ (9) $u_{pbc} = w_{eco} * th_{inc}$ (10)

th_{inc} - income threshold, $\bar{x}$ - average income, x - household income, r - random number 0-1, U - multi-attribute utility, w - preference/weight of each individual agent for a specific factor, i - importance, att - attitude, pbc - Perceived Behavioural Control, Definitions and equations for u_{eco}, u_{env}, u_{soc}, u_{cof} are listed in Table 6

C.3 Outcomes different model architectures

The possibility of three model architectures is a structural uncertainty (Briggs et al., 2012) of the agent-based model (ABM). The effects of this uncertainty are investigated through an analysis of the model outcomes of these three different architectures. These results are presented in the next sections. For this experiment the model is run for 40 years for each model run with these three different inputs. To reduce the stochastic uncertainty (Briggs et al., 2012) of the outcomes each different model setup has 50 repetitions to make the result more reliable, as several random values are used in the model. The experiment thus has 150 runs in total. The results of this experiment are presented in this section per overall category. For all KPIs a boxplot figure is presented with the outcome after the model ran for 40 years. These boxplots present the median value of the fifty repetitions with a green line in the middle. The edges of the blue box is the range that includes 50 percent of all outcomes. The whiskers up to the black horizontal lines extend up to the 2.5 and 97.5 percentile, so 95% of all outcomes lies within the edges. Outcomes that lie outside of this area are presented as dots. If there is no overlap between the 95% outcome values of two different KPIs it can be concluded that these outcomes do differ from each other. On the other hand if there is overlap between these values this conclusion cannot be drawn. When the development of the KPI during the 40 years the model runs shows an interesting curve, this graph is also presented. The graphs show the mean value of the KPI with a range around it of two times the standard deviation of the KPI value, which is the 95% confidence interval.

C.3.1 Temperature KPI's

This section discusses the results of the temperature KPI's, the average and maximum temperature.

C.3.1.1 Average temperature

Figure C.7 shows the average end temperatures of the different architectures per Local Climate Zone (LCZ) and for the whole area. The difference of the overall average temperature between the three architectures is only around 0.4 degrees Celsius. This is also true for the results of the LCZs, except for some outliers. The RR architecture has a higher end average temperature, which probably means that the amount of adopted UHI mitigation solutions is lower in this architecture. Other KPIs show whether this assumption is right. Another interesting difference is that the average temperature difference in LCZ3 between the MF and SE architectures is bigger than the difference in LCZ5, LCZ6 and LCZ9. In

LCZ9 the difference is even not significant. This could mean that the SE architecture has slightly more solution adopted and, as LCZ3 is the area with the most households, this results in the biggest difference between the architectures in that area.

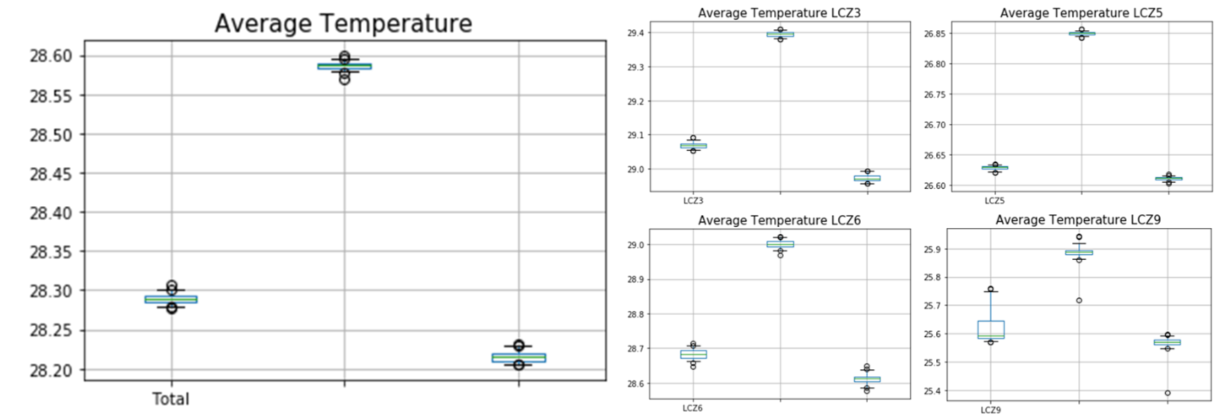


Figure C.7: Overall average temperature outputs and per LCZ for MF, RR and SE respectively

Figure C.8 shows the development of the average temperature of the total area for the three different model architectures. It is clear that the average temperature reduces the quickest in architecture SE, while architecture RR has the highest average temperature at the end of the model run. The fast reduction of the average temperature in the first 5 years for architecture SE suggests that a lot of households adopt an UHI mitigation solution during the first few years.

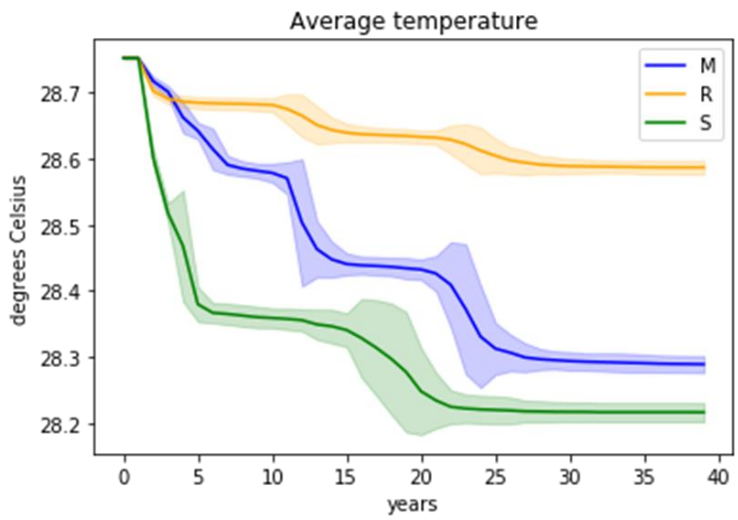


Figure C.8: Average temperature of the total area for architectures MF, RR and SE

C.3.1.2 Maximum temperature

The maximum temperature at the end of the runs show almost no difference between the MF and SE architecture (figure C.9). Although the average temperature of the SE architecture is lower this does not affect the whole area. In architecture RR the maximum temperature is higher in all LCZs.

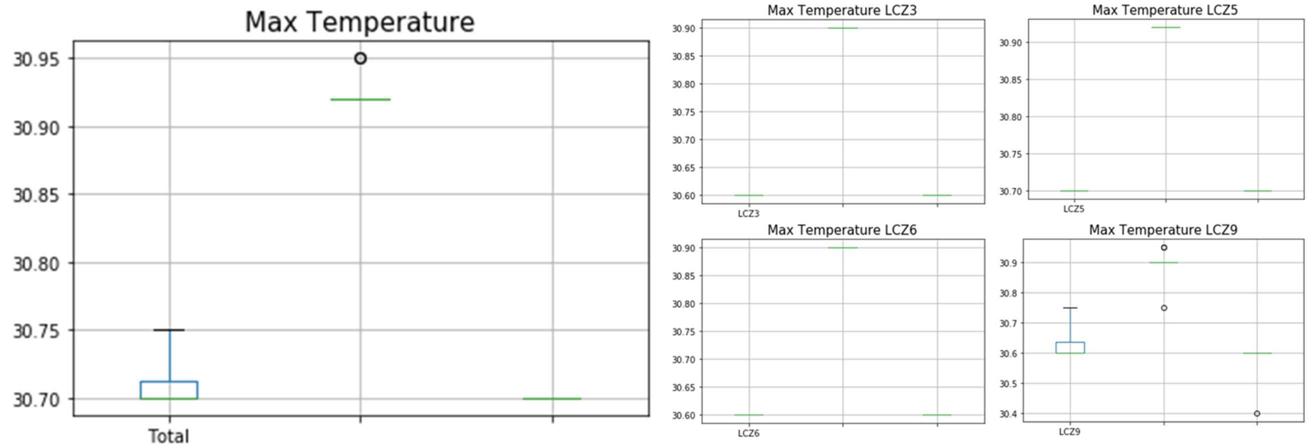


Figure C.9: Overall maximum temperature outputs and per LCZ for MF, RR and SE respectively

The development of the maximum temperature (figure C.10) almost shows the same as the average temperature of the whole area. However, the difference of the maximum temperature between architecture MF and SE is not significant during most of the model run. Only between ten and fifteen years the 95% confidence interval does not overlap.

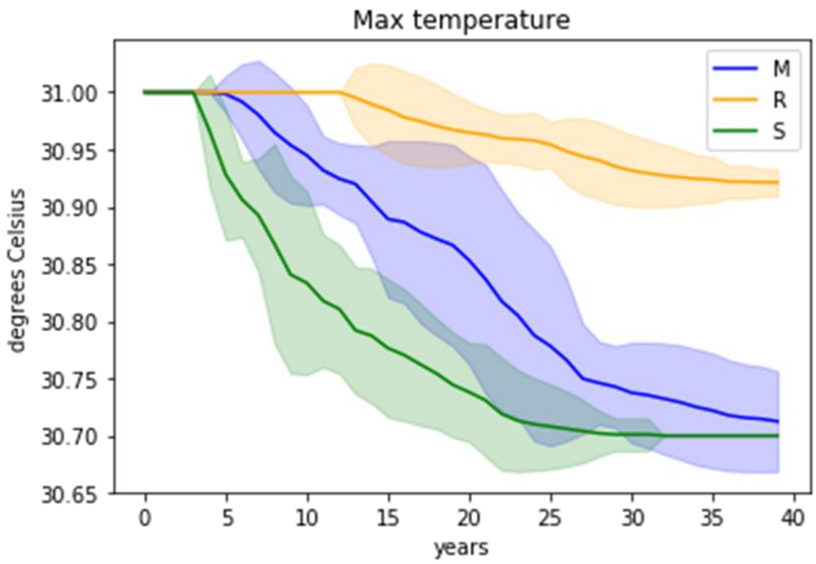


Figure C.10: Maximum temperature of the total area for architectures MF, RR and SE

C.3.2 Fraction adopted KPI's

This chapter presents the fraction of household that invest in a UHI mitigation solution compared to the total households that are able to decide if they want to adopt a UHI mitigation solutions. These outcomes are presented in total, per solutions and per LCZ.

C.3.2.1 Total fraction implemented

Figure C.11 shows that the lower temperatures in architectures MF and SE are caused by the fact that there are more solutions implemented in those architectures than in architecture RR. In some LCZs of architecture SE the fraction is even higher than 1 for some repetitions. This could be caused by using random values to distribute households in the LCZs and these LCZs having the least amount of households in them. Because of that it is possible that in some runs more households that are able to decide on an UHI mitigation solution are present in a LCZ than there should be based on the amount of single-family houses, heads of VVEs and social dwellings in that area. This is probably cause by the social dwellings that have a 25% chance to decide whether they implement a solution this year based on a renovation change of once in 25 years. As the amount of households in LCZ5, LCZ6 and LCZ9 is relatively low with 12.2, 9.7 and 2.3 percent respectively the random values that are used for this 25% chance can cause more adoptions than should be possible. The difference between the MF and SE fractions implemented in the total area, LCZ3 and LCZ5 is significant.

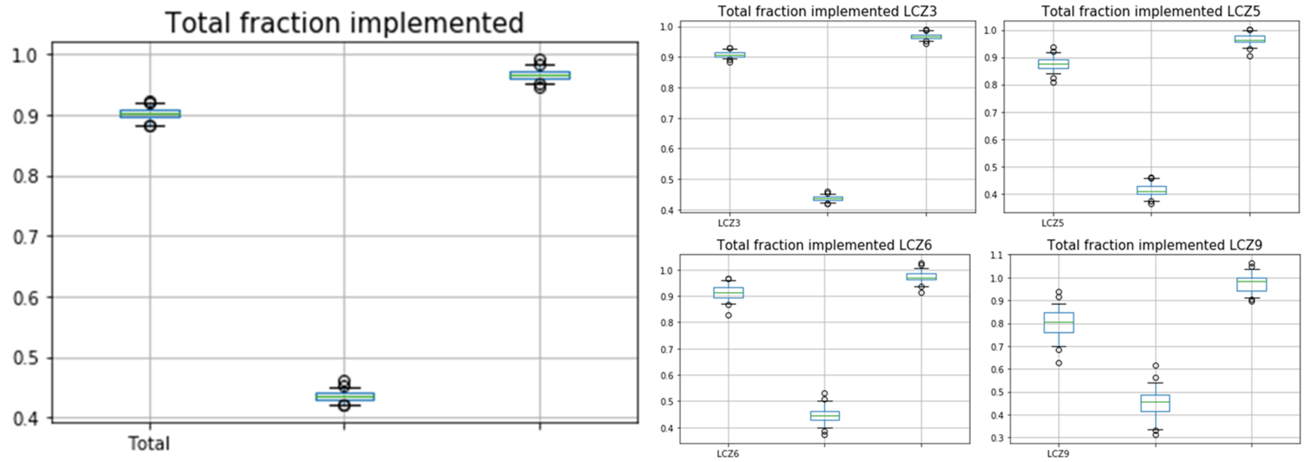


Figure C.11: Overall fraction implemented outputs and per LCZ for MF, RR and SE respectively

Figure C.12 with the development of the total fraction of implemented solutions for the whole area confirms that the quick reduction of the average temperature in architecture SE is the result of more solutions being adopted in the beginning of the model. Already after five years the adopted fraction in architecture SE is above 0.6.

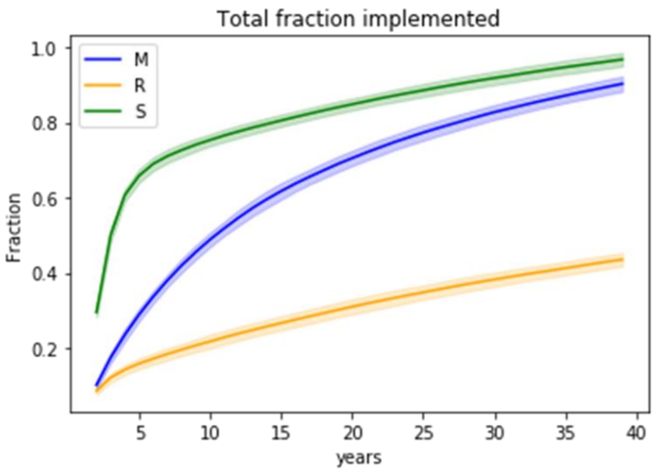


Figure C.12:Total fraction of implemented solutions for the whole are for architectures MF, RR and SE

C.3.2.2 Fraction green roof implemented

The differences in temperature between the different architectures can partly be explained by the fact that there are more green roofs implemented in architecture MF and SE compared to architecture RR (figure C.13). However, there is no significant difference in the fraction of green roofs adopted between architecture MF and SE. There is thus another reason that the average temperature in architecture SE is lower than in MF.

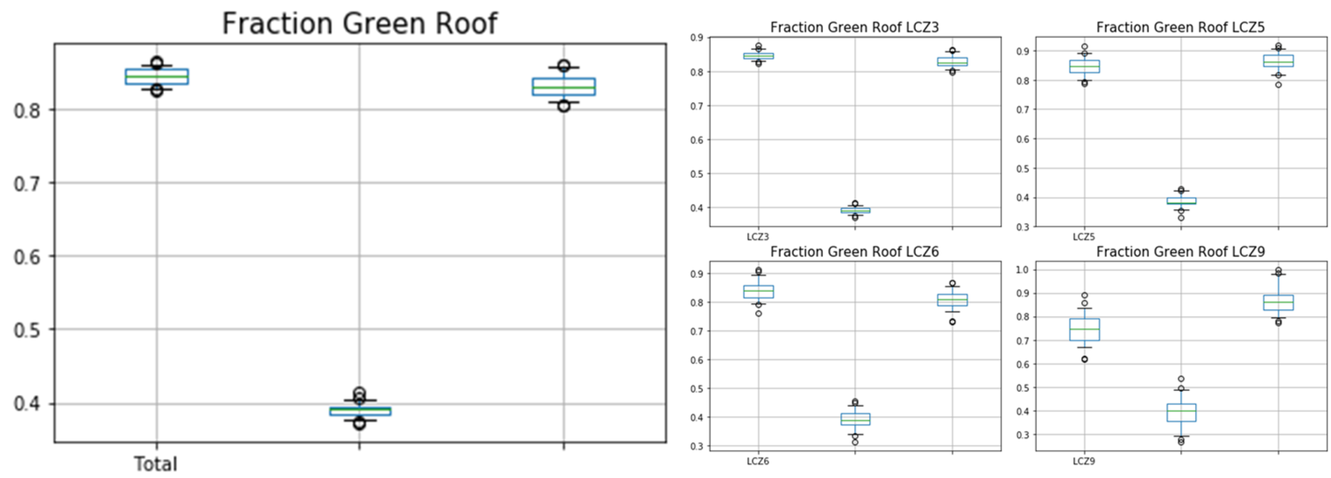


Figure C.13: Overall fraction of green roofs implemented and per LCZ for MF, RR and SE respectively

C.3.2.3 Fraction green facade implemented

The amount of green façades implemented is zero in all architectures (figure C.14), the price of this solution compared to its benefits seems to be too high for households to invest in this solution.

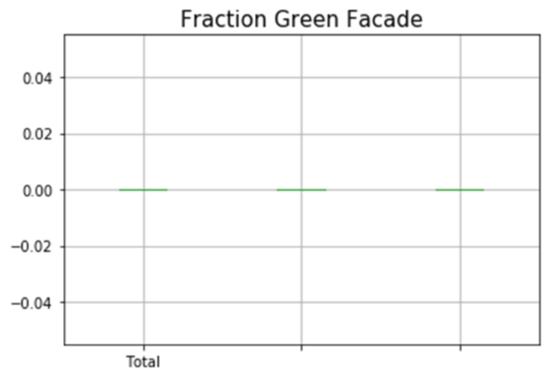


Figure C.14: Overall fraction of green facades implemented

C.3.2.4 Fraction green gardens implemented

In architecture SE more green gardens are implemented than in the other two architectures (figure C.15). This explains the difference in the average temperature between architectures MF and SE as green gardens have a larger temperature reducing effect than green roofs. However, this difference is not significant for LCZ9.

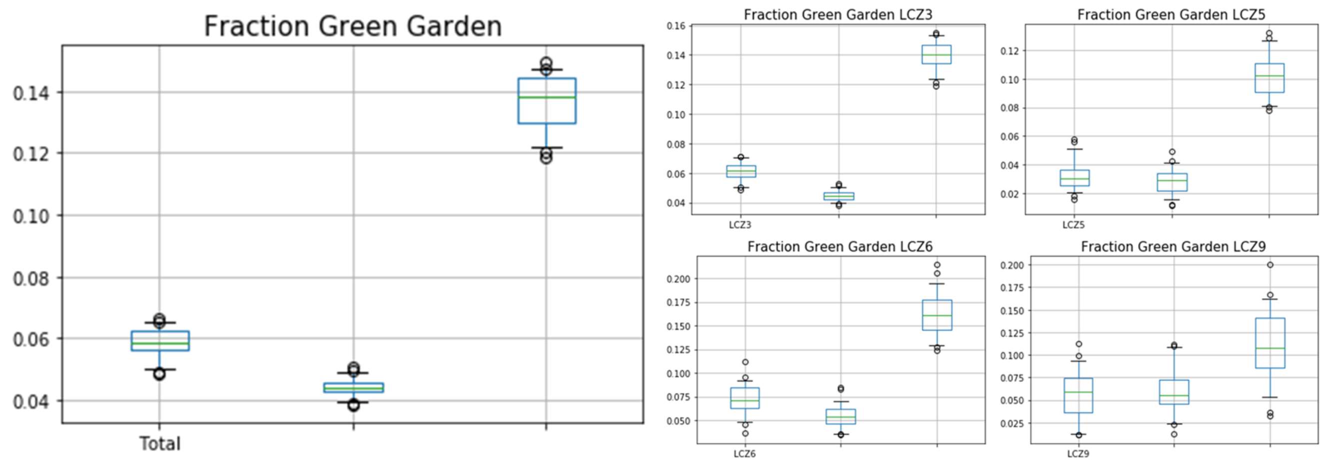


Figure C.15: Overall fraction of green gardens implemented and per LCZ for MF, RR and SE respectively

C.3.2.5 Fraction cool roofs implemented

Figure C.16 shows that cool roofs are only implemented in architecture RR, but only for a very small amount. The mean is lower than 0.002, thus less than 0.2 percent of households decide to implement a cool roof. This could be caused by architecture RR using the economic utility of a solution as the threshold value. As cool roofs cost less than green roofs or façades, this barrier is passed quicker and a household will quicker decide to invest in a cool roof. It is interesting to see that cool roofs are almost only implemented in LCZ5 and LCZ9. This could be the result of these LCZs having a lower average temperature than LCZ3 and LCZ6, but this relation is unclear. Future research could investigate this.

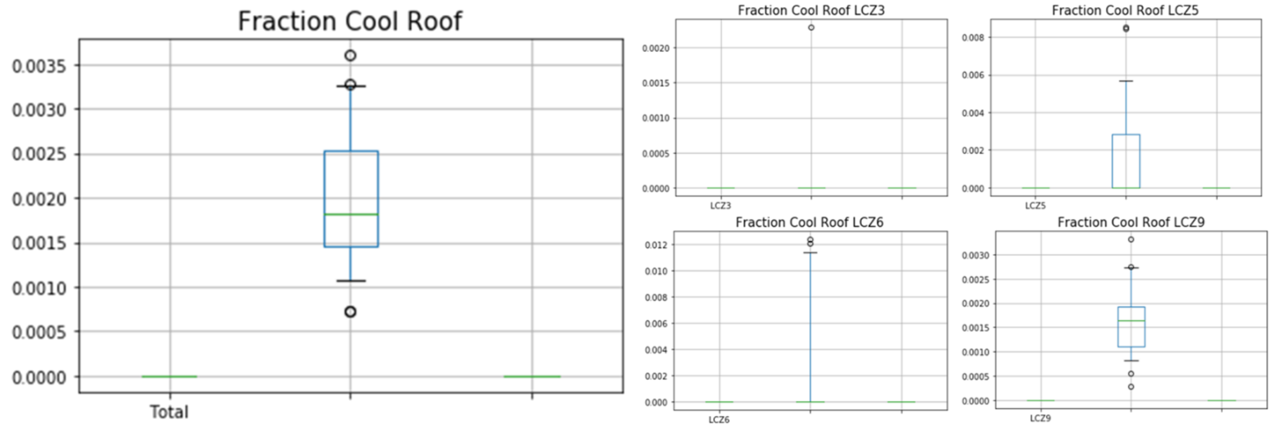


Figure C.16: Overall fraction of cool roofs implemented and per LCZ for MF, RR and SE respectively

C.3.3 Monetary KPI's

The total costs of adoptions are consulted to see whether there is a difference and to track the effect of certain policies in other experiments.

C.3.3.1 Costs of solutions

In figure C.17 the model behaviours presented by previous KPIs is confirmed, the total costs in architectures MF and SE is higher than in architecture RR as there are more solutions implemented in these architectures. An interesting result is the costs of green gardens in architecture MF, this is significantly higher than the costs in architecture SE, but architecture SE has a lot more implemented green gardens than MF. This effect is caused by the subsidy for green gardens that is only available during the first two years of the model run. Apparently the green gardens in architecture SE are more implemented during these first two years than in MF and therefore the total costs of green gardens for households are lower in SE.

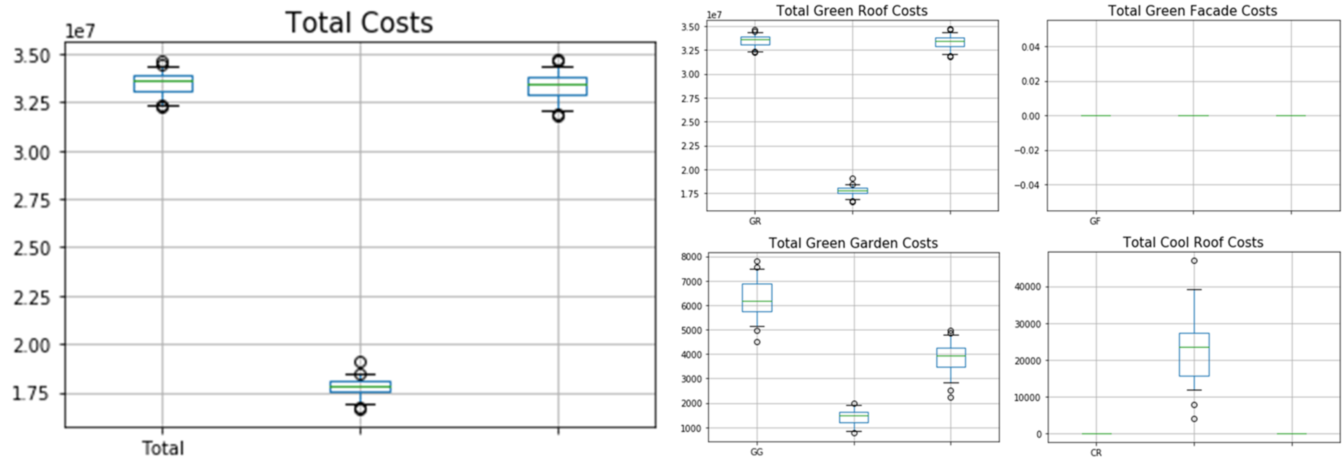


Figure C.17: Overall total costs output and per solution for MF, RR and SE respectively

C.3.3.2 Subsidies

In the standard model are two types of subsidies, one for green roofs that is available during the whole model run, and one for green gardens that is only available during the first two years of the model run. The results in figure C.18 show that green gardens in architecture SE are implemented early in the model run. The amount of adopted green gardens in architecture SE is not only significantly higher than in the other architectures, the total subsidy for green gardens in architecture SE is also significantly higher. Even the amount of subsidy for green gardens in architecture RR is higher than for MF, while the faction of green roofs in RR is lower than in architecture MF. However, this difference is not significant. This could mean that the green gardens in architecture RR are also more implemented during the first two years.

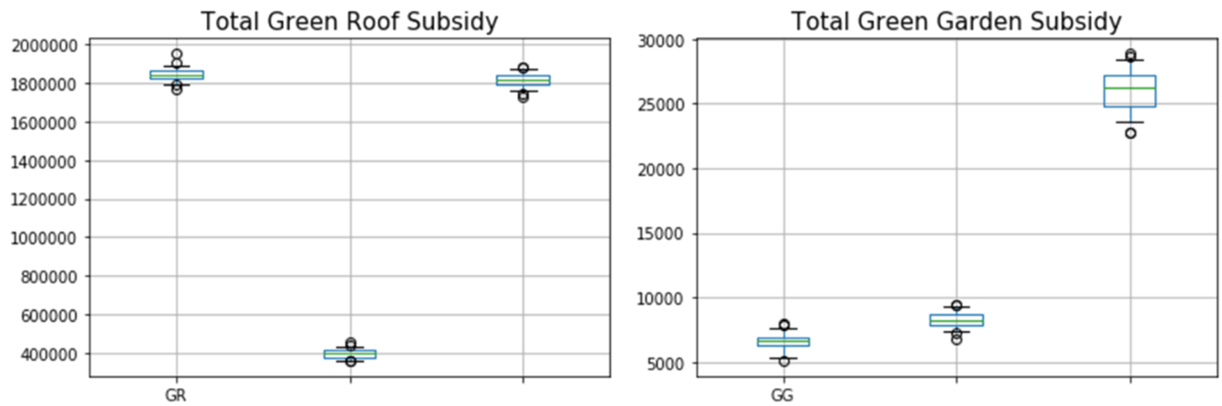


Figure C.18: Overall total green roof and green garden subsidy for MF, RR and SE respectively

C.4 Choice for MF architecture

This thesis study uses the MF model architecture based on the model by Muelder & Filatova (2018) as the main model architecture. The sensitivity analyses and experiments to check the hypothesis formed for this thesis were all performed with the MF model architecture. This choice is made as the comparison between the three architectures shows that the results of the MF model architecture are located between the results of the RR and SE architecture, although they are closer to the SE architecture. The MF architecture thus shows more moderate effects.

Furthermore, architecture MF used in the current study has only been adapted once from its original form created by Muelder & Filatova (2018). Architectures RR and SE are both adapted twice from their original form. They are both adapted from the RR and SE architectures in the research of Muelder & Filatova (2018) that in turn formed these two architectures based on the research of Rai & Robinson (2015) for the RR architecture and the research by Schwarz & Ernst (2009) for the SE architecture. As the sensitivity analyses were not performed for the RR and SE architecture, the next sections present two sensitivity analyses with the architecture specific inputs for the RR and SE models.

C.5 RR external threshold

In the RR architecture the multi-attribute utility is compared to an external threshold. If the utility is higher than this threshold the household adopts this UHI mitigation solution. The value for this threshold is set to 0.5 to make sure households invest in a solution if the utility of that solution is high enough and the adoption is worth the costs. As this value could not be determined from literature it is chosen arbitrarily and is part of the parameter uncertainty (Briggs et al., 2012) of the model. For the present research it was not possible to perform a sensitivity analysis regarding this input. However, as this value acts as a threshold for the multi-attribute utility it is expected that an increase of this value leads to a decrease of the amount of adopted solutions. Future research could investigate the exact relation between this value and the amount of adopted solutions.

C.6 SE household importance

The values of the **attitude** importance, **PBC** importance and **social** importance used in the SE architecture are also adopted from Muelder & Filatova (2018). They explain that the value for the importance of the social norm is related to the agent group in the SE study (Schwarz & Ernst, 2009). For their research they thus set this value equal to the weight of the social factor, which is adopted in this thesis study. The attitude and Perceived Behavioural Control (PBC) importance are exogenous parameters related to the investigated technology in the study by Schwarz & Ernst (2009). Muelder & Filatova (2018) therefore set these parameters to 0.2 in their own study into the adoption of PV panels. As this thesis study is based on the work by Muelder & Filatova (2018) these values were also adopted from their research (table C.2). These three values are part of the parameter uncertainty (Briggs et al., 2012) of the model.

Table C.2: Educational level and influence on PEB in model (Muelder & Filatova, 2018)

Importance factor	Influence on PEB (model input)
attitude	0.2
PBC	0.2
social norm	Same as social factor weight

The social importance value has an opposite effect on the multi-attribute utility in the SE architecture than the weight for the social factor. Table C.1 (section C.2) shows that the overall attitude and PBC values are multiplied by one minus the social importance, while this value is subsequently summed with the overall weight of the social factor. As these two values are linked in the model and both have the same value, it could be interesting to see which of the two has a larger effect on the model output. Because of the scope of the current study this was not investigated further, but this could be performed in a future study.

In the study by Schwarz & Ernst (2009) the attitude and PBC importance were related to the investigated technology. This could mean that these values should be different for the investigated

UHI mitigation solutions in this research. However, because of the limited time and scope of this research this is not investigated further. Future research could study this relation and investigate what the values should be for the technologies used in this research. Based on the equations presented in table C.1 (section C.2) it is expected that a higher attitude and PBC importance for one solution would increase the number of households that implement that solution if the difference is large enough. This is shortly investigated with a sensitivity analysis that increases these two values separately and combined to 0.4 and checking whether this increases the overall adoption of UHI mitigation solutions by households. This analysis does not show any significant differences in the KPIs.

C.7 Conclusions different architectures

Muelder & Filatova (2018) showed in their research that the Theory of Planned Behaviour (TPB) could be formalized in different ways in an agent-based model (ABM) about the adoption of solar panels by Dutch households. The three different options they investigated each showed different results and different behaviour. The results from the model made for this graduation research presented in section C.3 show that these differences can be partly found in an ABM about adopting different Urban Heat Island (UHI) mitigation solutions. Compared to the results of Muelder & Filatova (2018) the present research found that architecture SE, based on the research by Schwarz & Ernst (2009) resulted in the most adoptions and therefore the lowest average temperatures. Furthermore, the adopted fraction of solutions in the SE architecture increases much faster in the first few years than in the other two architectures. Because of this effect the average temperature and maximum temperature in architecture SE both reduce faster in the first few years. The fraction of green roofs adopted in architecture SE is not significantly different from architecture MF, based on the research by Muelder & Filatova (2018), but the average temperature in architecture SE is lower. This is caused by the amount of green gardens being significantly higher in architecture SE than in MF.

The amount of green gardens adopted in the total area do not differ significantly between architecture MF and architecture RR, based on the research by Rai & Robinson (2015). However, the total adopted fraction and average temperature have a significant difference cause by the amount of adopted green roofs being much higher in architecture MF than in architecture RR. Architecture RR shows another significant difference with architecture MF and also SE in the amount of adopted cool roofs in the total area. Operationalizing the TPB in the way of the RR ABM thus leads to a wider variety of adopted solutions than the other two architectures.

The total costs differ significantly between some architectures in the same way as the fraction of adopted solutions. It is higher in architecture MF and SE because there are more solutions implemented in those architectures. However, there is an interesting result in the significant difference between the costs of green gardens in architecture MF and SE. Although there are significantly more green gardens adopted in architecture SE than in MF, the total costs for green gardens in architecture MF are significantly higher. This is the result of the SE architecture adopting these green gardens earlier in the model run when the subsidy still existed for this solution. The significantly higher subsidy for green gardens in the SE architecture, compared to the MF architecture shows this effect.

The analysis of the results of the three different ABM architectures show that there can exists significant difference between ABM models that are based on the same theory, but are operationalized in a slightly different way. This is an important conclusion to take into account by decision makers as well as scientists when presented with the results of a specific model. These results are always influence by the way the researcher that made the model operationalized the theory he or she used for the model. Future studies and decision making could be improved by showing the effect of different ways of operationalizing an agent-based model on the results of the study. However, there is not always enough time or budget for the study to incorporate different operationalisations.

Appendix D Effect of subsidy on temperature KPIs

In this appendix the effects of the experiments that introduce different amounts of subsidies for green roofs, green façades, green gardens and cool roofs on the average and maximum air temperature on a hot summer day are presented. These values are not needed to answer the hypotheses, but can be important for decision makers to see whether introducing a subsidy for a solution has a significant effect on the temperature in the area. It also presents the tables of the mean outcomes of the total adopted fraction of the Urban Heat Island (UHI) mitigation solutions of the subsidy experiments.

D.1 The effect of subsidies on temperature KPIs

As explained in section 6.3.2 the amount of subsidy is changed per solution to 20, 35 and 50 percent of the total price of the solution. Figure D.1 shows that the total average temperature on a hot summer day is higher when the subsidy for **green roofs** is increased to 35 or 50 percent. This difference is seen in all LCZs, except LCZ9. The maximum temperature does not differ significantly. It is interesting to see that the average temperature reduces earlier for a subsidy amount of 35 and 50 percent compared to 20 percent of the green roof price, but the end average temperature is higher for these two subsidy amounts. This is probably cause by a difference in the type of solutions that are adopted, which is shown in the next section.

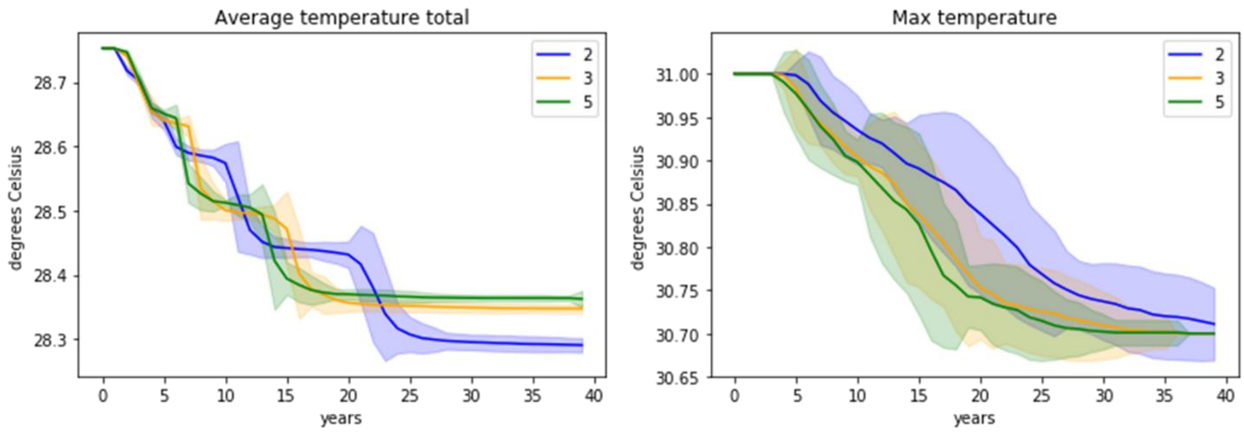


Figure D.1: Average and maximum temperature for 20, 35 and 50 percent subsidy of green roofs

Table D.1: Average temperature in degrees Celsius after model run for green roof subsidy

Area	20% green roof	35% green roof	50% green roof
Total area	28.29	*28.35*	*28.36*
LCZ3	29.07	*29.15*	*29.17*
LCZ5	26.63	*26.64*	*26.64*
LCZ6	28.69	*28.75*	28.75
LCZ9	25.63	25.61	25.62

The italic values in table D.1 have a significant difference with the 20% green roof subsidy run up to 2 decimal places.

The average total temperature when the subsidy for **green façades** is set to 20, 35 or 50 percent is shown in figure D.2. It shows that the temperature reduction is slower compared to having a subsidy for green roofs. However, the total average temperature is in the end lower than in the experiment with green roof subsidies. There is no significant difference between the maximum temperature between the three subsidy options.

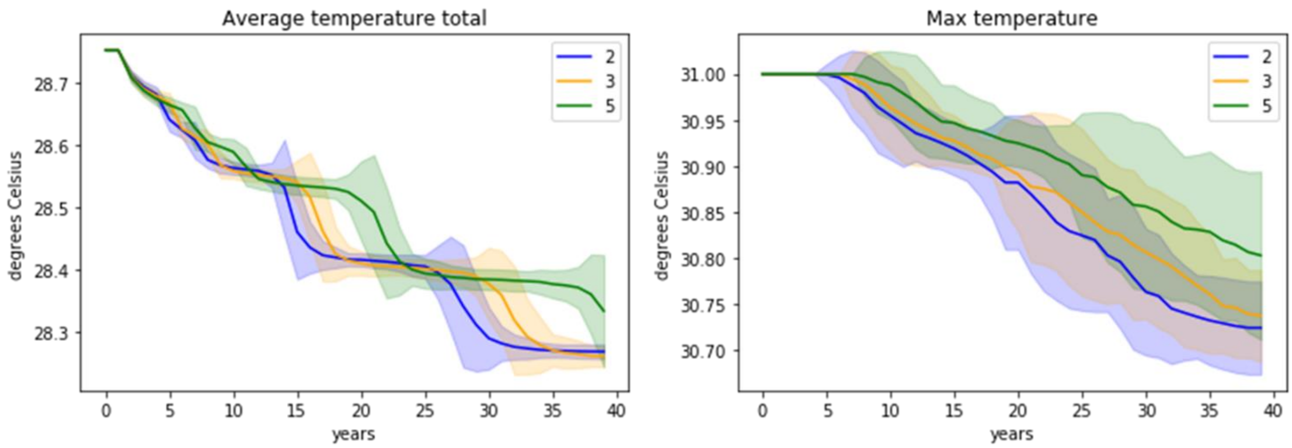


Figure D.2: Average and maximum temperature for 20, 35 and 50 percent subsidy of green façades

Table D.2: Average temperature in degrees Celsius after model run for green façade subsidy

Area	20% green façade	35% green façade	50% green façade
Total area	28.27	28.26	28.33
LCZ3	29.04	29.02	29.10
LCZ5	26.62	26.62	26.69
LCZ6	28.67	28.66	28.75
LCZ9	25.66	25.68	25.73

The differences between average temperatures of different subsidies for green façades are not significant, so there are no values in italic in table D.2.

Figure D.3 shows the average and maximum temperature if the subsidy for **green gardens** is set to 20, 35 or 50 percent. There is no significant difference between the three options. Furthermore, there is also no difference with the standard model.

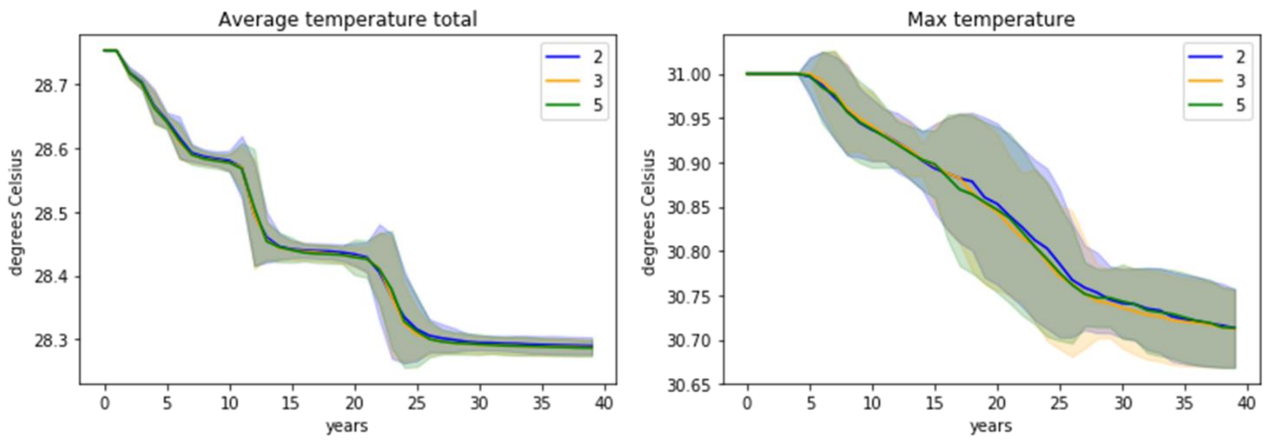


Figure D.3: Average and maximum temperature for 20, 35 and 50 percent subsidy of green gardens

Table D.3: Average temperature in degrees Celsius after model run for green gardens subsidy

Area	20% green roof	35% green roof	50% green roof
Total area	28.29	28.29	28.29
LCZ3	29.07	29.07	29.07
LCZ5	26.63	26.63	26.63
LCZ6	28.68	28.68	28.68
LCZ9	25.63	25.63	25.63

The differences between the subsidies are not significant, so table D.3 does not present values in italic.

When introducing a 20, 35 and 50 percent subsidy for **cool roofs** the average temperature of the total area increases with an increase of this subsidy (figure D.4). With a subsidy of 50 percent the average temperature reduces more in the first 5 years, but thereafter the runs with less subsidy have a lower average temperature. Furthermore, the maximum temperature in the total area is also higher with more subsidy for cool roofs

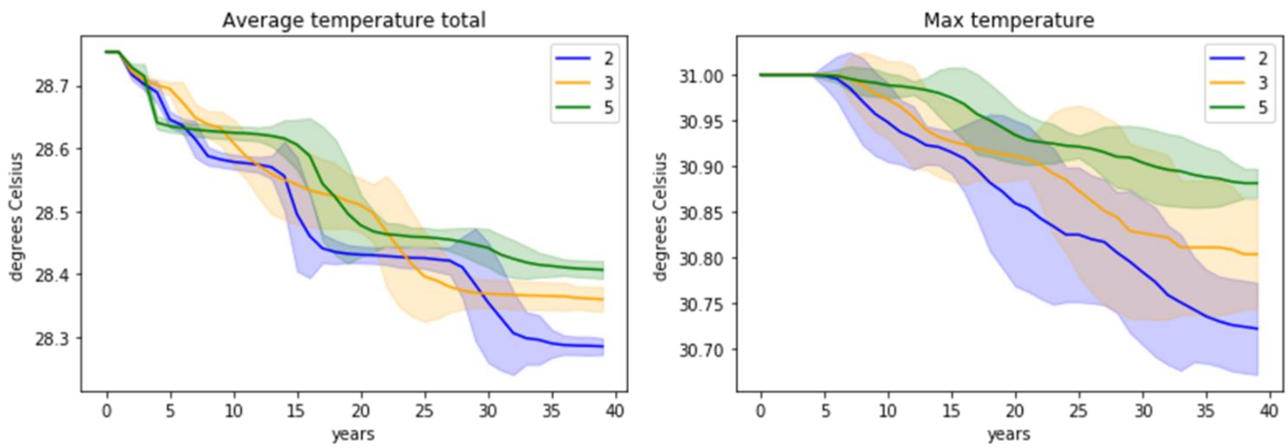


Figure D.4: Average and maximum temperature for 20, 35 and 50 percent subsidy of green gardens

Table D.4: Average temperature in degrees Celsius after model run for cool roofs subsidy

Area	20% green roof	35% green roof	50% green roof
Total area	28.29	*28.36*	*28.41*
LCZ3	28.27	*28.33*	*28.40*
LCZ5	26.63	*26.72*	*26.82*

LCZ6	28.68	28.75	*28.77*
LCZ9	25.66	25.73	25.73

The italic values in table D.4 have a significant difference with the 20% cool roof subsidy run up to 2 decimal places.

Table D.5 shows that introducing a 20% subsidy for one of the possible UHI mitigation solutions does not create any significant difference with the standard model. A 35 percent of 50 percent subsidy does create a significant difference in some cases (the values in italic), however the average temperatures are all higher compared to the standard model.

Table D.5: Total area average temperatures in degrees Celsius after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	28.29		
Green roof	28.29	*28.35*	*28.36*
Green façade	28.27	28.26	*28.33*
Green garden	28.29	28.29	28.29
Cool roof	28.29	*28.36*	*28.41*

D.2 Fraction adopted KPIs

The italic values in the table D.6 have a significant difference between the different subsidy percentages.

Table D.6: Total fraction adopted after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	0.9038		
Green roof	0.9063	*0.9444*	*0.9567*
Green façade	0.8700	*0.8448*	*0.7946*
Green garden	0.9019	0.904	0.904
Cool roof	0.8957	0.9111	*0.9456*

For table D.7 to D.13 the italic values have a significant difference between the different subsidy percentages.

Table D.7: Total fraction green roof adopted after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	0.8448		
Green roof	0.8495	*0.9290*	*0.9505*
Green façade	*0.7922*	*0.7559*	*0.6866*
Green garden	0.8439	0.8440	0.8437
Cool roof	*0.7686*	*0.6351*	*0.3424*

Table D.8: Total fraction green façade adopted after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	0		
Green roof	0	0	0
Green façade	0.0001	0.0001	0.0006
Green garden	0	0	0

Cool roof	0	0	0

Table D.9: Total fraction green garden adopted after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	0.0591		
Green roof	0.0569	*0.0154*	*0.0062*
Green façade	0.0777	*0.0887*	*0.1074*
Green garden	0.0580	0.0600	0.0601
Cool roof	0.0625	0.0518	*0.0309*

Table D.10: Total fraction cool roof adopted after model run

Subsidy	**20%**	**35%**	**50%**
Standard model	0		
Green roof	0	0	0
Green façade	0	0	0
Green garden	0	0	0
Cool roof	*0.0646*	*0.2198*	*0.5722*

Appendix E Process leading to existing policies

This appendix describes the process that has led to the existing policies on reducing the extreme heat and will result in even more UHI mitigating policies in the future.

In 2013 the European Commission established the European Adaptation strategy (EAS) to make Europe resilient to the consequences of climate change (Akkerman & Brans, 2019). This was a non-binding strategy to encourage member states to make a National Climate adaptation strategy (NAS) (Akkerman & Brans, 2019).

Already in 2014 the national government, the Association of Dutch Municipalities (VNG), the provinces (IPO) and the Association of Water Boards (UvW) decided that municipalities had to make their neighbourhoods climate-proof when redesigning the public space, starting in 2020 (Kluck et al., 2017). However, in the Deltaprogram 2016 it was stated that the consequences of heat stress are not well known on all governmental levels in the Netherlands (Ministerie van Infrastructuur en Milieu and Ministerie van Economische Zaken, 2015). Next to that, of the governmental bodies that were aware of heat stress, most hardly took it into account in their decisions (Ministerie van Infrastructuur en Milieu and Ministerie van Economische Zaken, 2015).

Thus, something had to change and as a result of the EAS, the Dutch NAS was ready in 2016. This strategy covers the six most important short term effects of climate change: heat stress, the failure of vital and vulnerable functions due to extreme weather events and more frequent harvest and other damage in the agriculture sector as a result of extreme events (Akkerman & Brans, 2019). This document led to the implementation program NAS 2018-2019, which goal was to make sure that the responsibility of governmental parties for the most urgent climate risks was clear by 2020 (Akkerman & Brans, 2019).

The implementation program NAS resulted, in conjunction with the Deltaprogram 2019, in the Delta Plan on Spatial adaptation, which had clear goals for governmental bodies to have made plans before 2021 for implementing climate adaptive measures in their area (Akkerman & Brans, 2019). By 2020 municipalities thus had to have policies about extreme heat and act on these (Kluck et al., 2020). As a result of this Delta Plan on Spatial adaptation provinces and municipalities in the Netherlands have made multiple climate stress tests, which show the consequences of, for example, draughts, heat and floods in the area (Akkerman & Brans, 2019). The municipality of The Hague made a website that shows these: https://denhaag.klimaatatlas.net/. Kluck et al. (2020) present some policies made by different lower governments in the Netherlands. They show that some policies focus on temperature specifically with a directive that should be followed, while other policies have a more general character as a vision for the future or a general directive. The province of South-Holland for example, formed a vision in 2018 to make sure that public space would not create unnecessary heat, but should provide cooling and made a more specific directive in 2019 that forty percent of all surfaces should be designed to resist heat (Kluck et al., 2020).

However, according to Dutch law provinces and municipalities can only bind themselves to such rules that are set in an *Omgevingsvisie* (environmental vision) (Aan de slag met de Omgevingswet, n.d.). A municipality within the province of South-Holland is thus not obliged to follow the vision and directives of the province precisely. These municipalities do have to involve the vision of the province when making their own plans, although the amount of involvement is up to the municipality (Aan de slag met de Omgevingswet, n.d.).

In 2014 the area of Haaglanden, which The Hague is part of, made a Regional Climate Adaptation Strategy, where the UHI effect, its negative consequences and possible mitigation measures are mentioned (Regionale klimaat Adaptatie Strategie Haaglanden, 2014). However, as is already mentioned in this report, not much real action was taken since then. In the 'structuurvisie CID Den Haag', a vision for the future of a certain area in The Hague, heat stress is mentioned as an important aspect to consider (Gemeente Den Haag, 2020). This shows that the municipality wants to tackle this problem in new developments but does not say anything about other built-up areas. The municipality of The Hague also constructed a system that gives points to new developments for building inclusive with nature (Gemeente Den Haag, 2018). A new development plan gets points for certain specific measures and is used by the municipality in their land allocation agreements and tenders (Van de Leemkolk, Jongma, Dekker, & Handgraaf, 2020).

However, for existing areas the municipality of The Hague only stimulates the construction of green roofs (Gemeente Den Haag, n.d.) and encourages citizens to increase the amount of green in their gardens (Gemeente Den Haag, 2018).

The national government in the Netherlands has noticed the slow adoption of climate adaptation policies by lower governments and ordered research to uncover the cause for this (Handgraaf & Dekker, 2019). This graduation research concluded that the current law system has several opportunities to legally support climate adaptive building. Land-use plans (*bestemmingsplannen)* can be used to set specific requirements, in operating agreements (*exploitatieovereenkomst)* for making an area fit for building, demands can be made and for tenders, procurement law offers opportunities to involve climate adaptation in its procedures (Handgraaf & Dekker, 2019). However the research also showed that lower governments often lack knowledge about the legal possibilities of building climate adaptive (Van de Leemkolk et al., 2020). To help these lower level governments, the national government in the Netherlands constructed a document with these legal possibilities (Van de

Leemkolk et al., 2020). This document shows specific legal possibilities that municipalities can use in land-use plans and environmental plans (*omgevingsplannen)*, such as requiring a new building to create shade on at least a certain percentage of the adjacent public space or the obligation to plant a certain number of trees with a sufficient foliage. Claessens and Steenstra (2018) also give some examples of how climate adaptation requirements can be used in land-use plans. They make a distinction between land-use rules, building rules and usage rules. As a land-use rule they mention the obligation to have projecting eaves for buildings with the land-use ‘dwelling’, as a building rule the obligation to have a maximum building height based on the minimum width of the street, or the option not to count projecting eaves as a part of the legal building area. As a usage rule they mention the duty to complete a green area next to a newly build building.

Appendix F Figure of standard model output

Figure F.1 shows a screenshot of the outcome of one of the standard MF model architecture runs to show how the model presents the results of the air temperature in the area. The white dots are the households in the area. The blue dots are the locations of schools or hospitals.

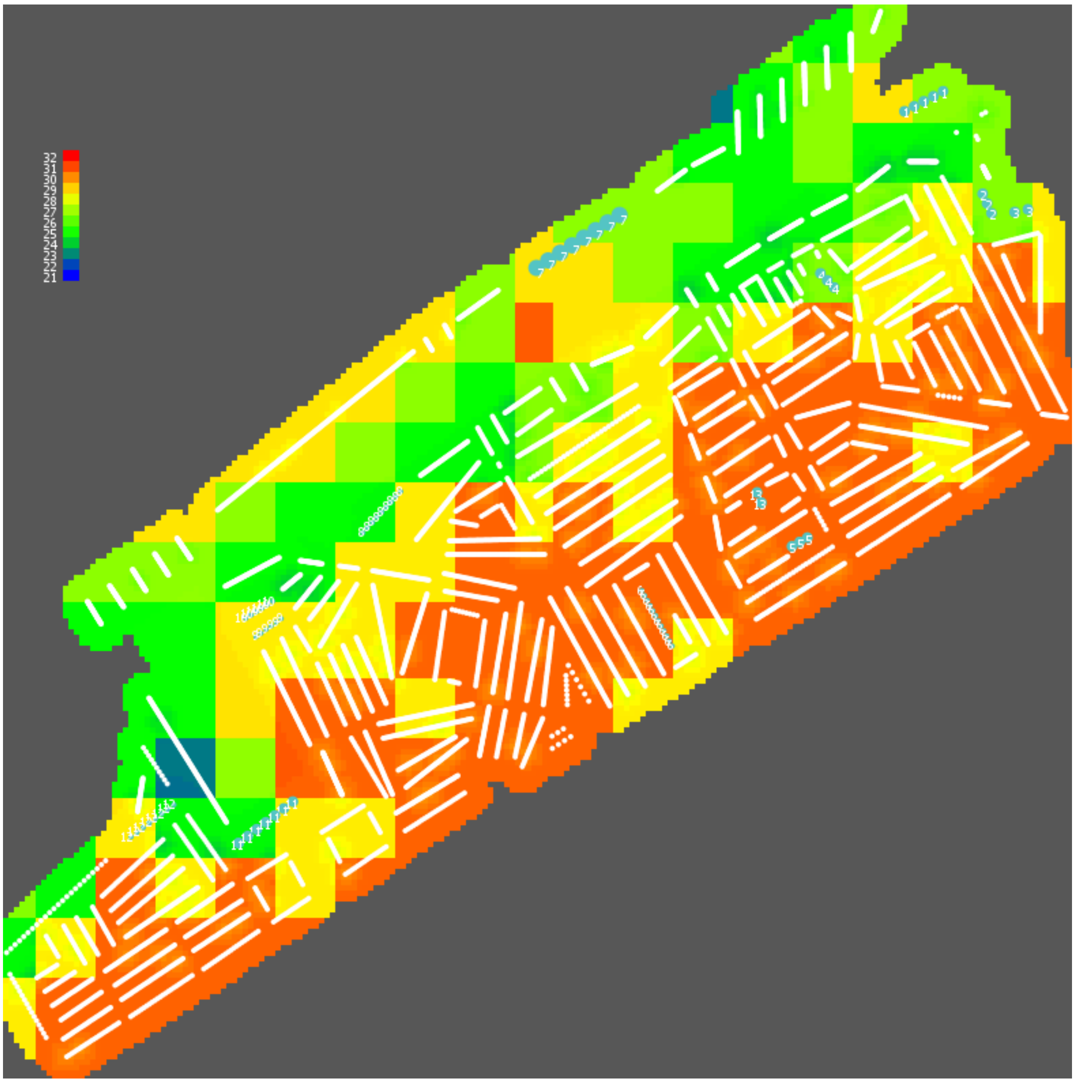


Figure F.1: Screenshot of the outcome of one model run

Appendix G Main assumptions

In this appendix the most important main assumptions of this graduation research are presented in bullet points. These are not all of the assumptions but the ones that are the most important. The presentation order is not deliberately chosen.

- This graduation study only takes the outdoor air temperature effect and the energy reduction effect of Urban Heat Island (UHI) mitigation solutions into account and does not consider all other effects these solutions can have.
- The implementation of UHI mitigation solutions in a currently built up area is investigated, newly built areas are outside of the scope of this graduation research.
- For the temperature effects of Urban Heat Island (UHI) mitigation solutions only literature from climate classifications Cfa, Cfb, Cfc, Csa and Csb are used.
- This graduation research uses a revised version of the Theory of Planned Behaviour by Reid et al. (2010) as example how households decide to invest in UHI mitigation solutions.
- The research by Muelder & Filatova (2018) into different agent-based model (ABM) architectures of the decision by households to invest in solar panels is used as the lead example for the ABM of the present study.
- The graduation study uses the Local Climate Zones (LCZs) as defined by Stewart & Oke (2012).
- The four LCZs present in the case study area of the Bomen en Bloemenbuurt and used in this graduation research are LCZ3, LCZ5, LCZ6 and LCZ9.
- Eight UHI mitigation solutions are considered in the present study: Green roofs, green façades, grass, trees, urban parks, pools and ponds, cool roofs, cool pavements.
    - Four of these UHI mitigation solutions can be implemented by households, housing corporations and schools and hospitals: Green roofs, green façades, green gardens (planting a tree in the garden and changing its surface to grass), cool roofs.
    - The other four UHI mitigation solutions can be implemented before the model is run by the municipality: Creating a grass area, urban park, pond area, cool pavement area. The researcher can choose what squares in the area are changed to what surface.
- Each actor in the model, non-social and social households and schools and hospitals can only implement one UHI mitigation solution during the whole model run.
- Through performance agreements is decided up front that housing corporations implement one of the four solutions at all of their properties.
    - This solutions is then implemented with a chance of once in twenty five years
- The solutions implemented by the schools and hospitals in the area are decided before the model is run by the researcher and implemented directly at the model setup.
- The exact properties of a specific UHI mitigation solution implemented by a household can differ between households for the same solution. Therefore, the characteristics of the UHI mitigation solutions considered in this graduation study, influence on temperature, energy reduction and costs, are based on the averages found in literature and other sources for the solutions. Only for green roofs the results are specifically based on the extensive variant.

- The household characteristics implemented in the model are determined based on literature into different pro-environmental behaviour than investing in UHI mitigation solutions as these studies do net yet exist.
- Households that are part of an owners' association (VVE) only invest in one of the four UHI mitigation solutions if 75% or more of the households in the VVE are in favour of the specific UHI mitigation solution.
- The friends of a household that influences the social factor of its multi-attribute utility for a specific solution are determined based on the small-world network (Schnettler, 2009) and the income group of the household. The amount of friends per households is assumed to be three and its chance to have a random friend connection with a household outside of its network range or income groups is ten percent.
- The effects of green and cool roofs on the air temperature is considered for the whole LCZ and thus changes the temperature in the whole LCZ if a new threshold percentage is reached. These effects do thus also abruptly stop at the end of the LCZ.
- Because of limitations of the income input data households do not have an income above 59800 euros.
- For the input of household characteristics data of the whole city of The Hague is used so the results can better be generalized to other areas.
- For the input of environmental characteristics specific data of the Bomen en Bloemenbuurt is used as this district is used as case study and the geographical features of the model, like the LCZs, are based on this district.
- The input air temperature data is for the year of 2015, but information about the amount of green gardens and vegetation in the Bomen en Bloemenbuurt is from the year 2020. It is assumed that in the years in between this data did not change very much as the lack of implementations of UHI mitigations solutions is one of the reasons for this graduation study. The effect of slightly more green gardens and more vegetation in 2020 on the input air temperatures is thus not taken into account.
- As the input air temperature data only had a 100x100 meter detail level it is assumed that this complete 10000 square meter area has the same air temperature and that the temperature at the boundary of such an area abruptly changed to the input temperature of the other square.
- The household weights influencing the multi-attribute utility of the UHI mitigation solutions for households are adopted from the research by Muelder & Filatova (2018).