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MASTER

Analyzing the role of (semi-)private greenery in mitigating adverse heat effects in urban areas

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Analyzing the role of (semi-)private greenery in mitigating adverse heat effects in urban areas

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Abstract

Cities face a growing number of challenges related to climate change, of which urban heat is becoming an increasingly pressing issue. Added vegetation has proven to be an effective measure to counteract heat issues. While governments have mainly been focusing on adding greenery to public areas, the effect of adding greenery in (semi-)private areas has not been investigated extensively. Private gardens in the Netherlands have, on average, large amounts of paved area, which indicates the potential of adding greenery to these areas. The main objective of this report was to understand the effect that the addition of greenery in (semi-)private areas can have on urban heat. A literature review was performed to summarize both the potential effect of different types of greenery on urban heat, as well as the current state of research performed regarding (semi-)private areas. Next, data provided in the *Klimaateffectatlas* was aggregated on neighborhood level for the city of Eindhoven, in order to gain more insight in the current presence of heat issues throughout the city. The maps used for this analysis relate to the topics of Urban Heat Island, Physiological Equivalent Temperature, heat stress and distance to cool places. Various socio-demographic and socio-economic variables were checked for correlation with these aggregated heat values. New input data was then produced, based on a scenario that includes more greenery in (semi-)private areas, and used in multiple models to reproduce the *Klimaateffectatlas* data. Hereafter, the new data was compared to the original data to draw conclusion regarding the effect of the proposed scenario. The results show clear improvements with regard to urban heat for each of the analyzed heat topics. The biggest improvements were found in mostly residential neighborhoods. Also, significant correlations were found between the aggregated heat values and some of the socio-demographic variables. Governments should put more effort into incentivizing and working together with private individuals and housing corporations to add more greenery to (semi-)private areas. The most vulnerable neighborhoods should be prioritized by policymakers, so that any inequality is tackled simultaneously with the mitigation of adverse heat effects.

Executive Summary

Introduction

The number of people living in urban areas has been continuously increasing and will continue to do so in the coming years [137, 128]. With it, the climate within the city is also changing [13]. There are various aspects related to this changing climate. One topic which has received more and more attention in the literature is that of urban heat. Temperatures are often higher within urban areas compared to non-urban areas [83], leading to various adverse effects, including (major) health issues [47, 53].

The most researched urban heat topic is the Urban Heat Island (UHI) effect. Even though the two terms are frequently used synonymously, they do not necessarily indicate the same thing. The Urban Heat Island effect can be described as the imbalance in temperature between built environments and their rural counterparts, caused by the dramatic changes in urban landscape [53, 143]. Urban heat is used to describe multiple effects in urban areas, which are not limited to UHI effect only. Other aspects which directly relate to human health include Physiological Equivalent Temperature (PET), heat stress and ability of people to cope with heat. There are multiple causes of these heat issues that have already been identified. These causes relate to the physical urban environment, such as the properties of buildings surfaces [105, 106], but also to heat resulting directly from human activities [94, 85].

Potential mitigation strategies have also already been studied quite substantially. What has become clear is that the addition of green spaces is one of the most effective and most researched mitigation strategies for urban heat [65, 143]. It was found, however, that research has mainly focused on the effect of greening public areas [22]. Research regarding the effect of the greening of (semi-)private areas has therefore largely been lacking [15, 14]. Gardens in the Netherlands often have large amounts of paved areas [87], which indicates the need for this research to be conducted.

Methods

In order to look into the effect of the addition of greenery to (semi-)private areas, the following research question was formulated:

> *What is the role of private gardens and housing corporation greenery in mitigating adverse heat effects in urban neighborhoods?*

In order to answer this research question, several maps of the *Klimaateffectatlas* (KEA), or *Climate Effect Atlas* [63] relating to heat were analyzed for the city of Eindhoven, the Netherlands. The KEA is an online tool which depicts various aspects of the Dutch climate, including forecasts and effects caused by (changes in) the climate. The maps that were analyzed relate to the topics of Urban Heat Island, Physiological Equivalent Temperature, Heat Stress Caused by Warm Nights, and Distance to Cool Places. First, the technical documentations supporting these maps were analyzed to gain a better understanding of how these maps were produced and identify limitations of the models that were used to produce the maps. Then, the data of the provided maps were aggregated to neighborhood level, which allowed for a better understanding of differences between neighborhoods. Also, this aggregated data was used in combination with socio-demographic data for the city of Eindhoven, in order to look for significant correlations between calculated heat values and socio-demographic variables. Finally, a scenario was proposed which included the addition of greenery in (semi-)private areas to achieve an average value of only 25% paved surfaces in these areas for the whole of Eindhoven. This scenario was applied by reproducing input data used in the original models. This was done for each map separately, as every model makes use of different types of input data. On top of that, the original Distance to Cool Places map was also reproduced with the addition of gardens as cool places in the original scenario, as this was not done for the map provided in the KEA. The reproduced input data was then used to recreate the KEA maps, partially with the help of external parties.

Results

The results of the calculated heat values per neighborhood show that the different heat issues have a larger presence in neighborhoods with more built-up area. This was confirmed by the performed correlation analysis, which showed moderate correlations between variables relating to more dwellings present in neighborhoods and heat values. Higher correlations were found for variables relating to household composition and migration background. Neighborhoods with more one person households have on average higher heat values, while the opposite was found for households with multiple people. Furthermore, neighborhoods with more people with a Western migration background were also strongly positively correlated with higher heat values. The reproduced KEA maps showed clear improvements for all of the heat topics. For UHI, it became clear that mostly residential areas benefit from the addition of (semi-)private greenery. Clear improvements were also shown for the other two heat topics. Despite these topics only being checked for three out of 116 neighborhoods due to time constraints, the reproduced maps indicate the effect that the proposed scenario had well. Finally, the recalculated UHI values were again checked for correlation with the socio-demographic variables. These results show no decrease in correlations, which indicates that applying the same scenario city-wide does not simultaneously address both heat issues and social inequalities.

Conclusion

The analyses of this report have clearly indicated the effect that the greening of (semi-)private areas can have in Eindhoven. The analysis of the original KEA maps showed that heat issues are mainly present in residential neighborhoods. In turn, the proposed scenario showed that these areas are mainly affected by the implementation of greenery in (semi-)private areas. Therefore, this research contributes to a body of research that is not very extensive yet, and indicates that more research is needed regarding similar strategies. The *Klimaateffectatlas* was found to be a useful tool, but it was also noticed that the models behind the maps often do not cohere very well, indicating potential differences in calculations of certain heat effects. Furthermore, the atlas could include more maps relating to different heat topics, in order to provide a better overview of heat issues present in urban areas. Finally, the calculation of heat values and the reproduction of the KEA maps have proven to be quite time-consuming. Therefore, more efficient tools to calculate different scenarios are needed for research on this important topic to be conducted more, in order to address both heat issues and inequality current present in urban areas.

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Chapter 1

Introduction

The number of people living in urban areas has been growing continuously [137], and will continue to do so in the future [128]. This urbanisation has led to both positive and negative effects for citizens worldwide [30]. With increasing temperatures, heat is an important topic to take into account for policymakers when it comes to livability in urban areas. An important indicator for higher temperatures in urban areas that has been studied widely is the Urban Heat Island (UHI) effect. This phenomenon can be described as the imbalance in temperature between built environments and their rural counterparts, caused by the dramatic changes in urban landscape [53, 143]. This effect has been found to be prevalent in cities worldwide [100], in both larger and smaller cities [77]. This increase in UHI, and urban heat in general, has been linked to the expansion of cities [13]. Urban sprawl leads to an increase in heat due to the removal of greenery, leading to less shade, moisture and evaporation in urban areas [10].

Urban Heat Island is a concept measuring the amount of (additional) heat in urban areas, but it should not be used as a synonym for urban heat, as there are specific adverse effects directly linked to it. Increased temperatures can lead to heat stress, both outdoors and indoors [68]. The increased temperatures and concurrently UHI effects are mostly felt in city centers [83]. These areas often consist of dense built-up areas, for which UHI has been found to be specifically evident [83, 67, 130]. Furthermore, these areas often coincide with high levels of pollution, which can also increase heat [70]. Additionally, high levels of built-up land use lead to less space for greenery. This is also evident in city centers, as found by Chen et al. [17].

It is not only important to consider spatial discrepancies when looking at presence of heat in urban areas, but to also take into account socio-demographic and socio-economic aspects. UHI is present worldwide, meaning both developing and developed countries have to deal with adverse effects of heat [66, 70, 77]. On top of that, there is a need for analyzing the differences within cities with regard to heat, but also the specific measures taken to prevent adverse heat effects. Research has identified the impact of socio-demographic factors and socio-economic relating to, amongst others, available amount of green space [138] and access to green space [131, 84], indicating significant differences between groups and areas within cities with respect to presence of greenery and the ability to cope with heat. Chen et al. [17] mention that when governments do take into account these differences, attention should be paid to whether these interventions actually tackle the issues at hand. They notice that increasing the greenery level of a city does not necessarily bring about an improvement in the spatial inequality of green space area, as an increase of overall per capita greenery does not mean an equal distribution of green spaces. Therefore, tackling this inequality of green space accessibility and impact is a complex issue, which should be addressed now in order to have a significant effects in the future [49].

There is already a quite broad collection of academic literature regarding the mitigation of heat, also focusing specifically on urban areas. One of the most researched measures is the addition of greenery to urban areas. The addition of greenery has been identified as an effective measure to reduce urban heat [47, 104, 27] and can therefore be an effective tool for policymakers to alleviate heat issues and with it inequality. It should, however, be known how and where to apply this greenery, in order to maximize the effect this measure can have. On top of that, policymakers should be able to identify heat sinks, i.e. areas that have a high capacity for heat storage, and areas most at risk for heat in order to accurately address the issues present in the city.

Several efforts have already been made to map the different effects that the changing climate has on the built environment. For the Netherlands, several of these effects are displayed in the *Klimaateffectatlas* (KEA), or *Climate Effect Atlas* [63]. This atlas contains several data sets. First, it contains data regarding the current land use in the Netherlands, including amount of built-up area, greenery and water. Next, it gives an overview of the current climate in the Netherlands. Finally, it contains several maps displaying effects that climate change can have, regarding topics such as flooding, precipitation and drought, but also heat. The current analysis focuses on the maps relating to heat, as well as to the data sets behind the maps. These maps focus on Urban Heat Island, Physiological Equivalent Temperature (PET), heat stress caused by warm nights, and distance to cool places. Although these maps display different aspects of heat, together they provide a good overview of where heat occurs in the city, what effects this heat might have on citizens, and how well the city is currently already adapted to addressing these issues. Additionally, there are benefits to taking into account multiple heat issues instead of only one of these issues. For example, UHI can indicate the effect that the built environment has on the increase in temperature, but does not say anything about the effect this has on people. On the other hand, the map showing the amount of heat stress people experience does indicate this, but does not contain information regarding how well people can cope with heat. Therefore, including these multiple topics in the analysis, which are all of the topics related to heat available in the KEA, provides a more complete overview.

Greenery can be added to multiple parts of the city, both public and private. Public greenery has received quite a lot of attention already in the literature, but the effect of private greenery is not yet known exactly. Even though governments cannot directly influence land use on private property, the addition of greenery on private areas produce a significant effect overall. This is confirmed by Heynen et al. [49], who stress that adding greenery to private areas now can help reduce inequality in future scenarios. Urban inequality was also found to relate directly to the housing market itself [91]. This segregation on the housing market has led to richer people being able to buy 'better houses' than poorer people. Considering the impact of certain socio-demographic and socio-economic aspects on access to green space, housing of people can also play a role in this regard, indicating that larger houses often have residential gardens attached to them, which can serve as private green spaces and provide benefits during hot days. Therefore, taking into account (the absence of) private green spaces is important when addressing heat issues. Furthermore, there are also housing types, usually owned by housing corporations, which share their green space. These areas, often surrounding apartment complexes, can be shared by inhabitants and might also be open to the public, indicating a semi-private area. Even though these areas are shared, they can impact temperatures around people's homes, as well as the ability of people to cope with heat. Therefore, more research is needed to understand the exact effect that interventions on both private and semi-private areas can have on mitigating heat issues.

Focusing on the Netherlands, gardens contain high percentages of paved surfaces (table 1.1). On average, 89% of gardens in the Netherlands have at least some tiles in their gardens, and for 37% of gardens this is 50% or more. Given the fact that around 40% of all area in Dutch cities is privately owned [19], both the potential of adding greenery to these areas and the need for governments to work together with individuals and corporations to do so becomes clear.

Table 1.1: Percentages of paved surfaces in gardens in the Netherlands, taken from [87].

Share of paved area	**Total**	*Amsterdam, Rotterdam, The Hague*	*West*	*North*	*East*	*South*
None	**11%**	7%	6%	22%	14%	11%
25%	**52%**	30%	50%	55%	52%	56%
50%	**22%**	42%	26%	16%	20%	19%
75%	**11%**	14%	14%	5%	11%	9%
Almost entirely	**4%**	7%	4%	2%	3%	5%

Taking into account the above, it can be noted that there is too little understanding of the effect that adding more greenery to private areas and areas managed by housing associations can have on heat aspects in the city. On top of that, the current state of gardens in the Netherlands shows that there is a clear potential for adding greenery in (semi-)private areas in order to address heat issues. Simultaneously, inequality can be tackled by incentivizing and stimulating this addition of greenery in neighborhoods that currently struggle most with these heat issues. All of this has led to the formulation of the following research question:

What is the role of private gardens and housing corporation greenery in mitigating adverse heat effects in urban neighborhoods?

This research uses the Dutch city of Eindhoven as a case study to test the effect of added greenery to (semi-)private areas in order to answer the research question. The maps and underlying data from the KEA are used to obtain an indication of how well Eindhoven neighborhoods currently score regarding each of the heat topics. This data is analyzed together with several socio-demographic and socio-economic aspects in order to see whether there are significant correlations between the two and if this can be linked to any clear inequalities regarding inhabitants within the city of Eindhoven, on a neighborhood scale. Even though the complete set of variables taken into account does include a few socio-economic indicators, the term ‘socio-demographic analysis’ will be used throughout this report. After this analysis, the KEA maps are reproduced using input data in which a proposed scenario sketches a future in which Eindhoven gardens are significantly less paved. This analysis aims to provide a clear indication of the effect that adding greenery to (semi-)private areas can have on the analyzed heat topics by comparing the new scenario with the original maps.

The report consists of several parts. Firstly, a literature review discusses the various aspects of heat in cities, its causes, effects and mitigation strategies in general. After that, the current state of research conducted with regard to (semi-)private greenery is discussed. Furthermore, various types of greenery, and to which extent they contribute to mitigating adverse urban heat effects, are summarized. Secondly, the methodology of the study is presented. The methodology includes the methods used for aggregating the data provided by the *Klimaateffectatlas* on neighborhood level and for the correlation matrix performed in the socio-demographic analysis, but also discusses the models underlying the KEA maps. Furthermore, it explains in detail how the input data for the models was produced. Thirdly, the results of the calculation of heat values, the socio-demographic analysis, and the recalculated maps, are presented. The report concludes with a discussion about the results, in which the practical implications of adding greenery to (semi-)private areas are considered.

Chapter 2

Literature Review

Climate change has posed and will continue to pose significant threats to the urban environment. There are multiple aspects which climate change influences. The review by Hunt & Watkiss [54] summarizes the most important effects as following:

- Effects of sea level rise on coastal cities (including the effects of storm surges);
- Effects of extreme events on built infrastructure (e.g. from wind storms and storm surges, floods from heavy precipitation events, heat extremes and droughts);
- Effects on health (from heat and cold related mortality and morbidity, food and water borne disease, vector borne disease) arising from higher average temperatures and/or extreme events;
- Effects on energy use (heating and cooling, energy for water);
- Effects on water availability and resources.

These effects are diverse and all equally challenging. Focusing specifically on heat, one of the most well-researched climate change effects is the Urban Heat Island. This imbalance in temperature between built environments and their rural counterparts is an effect that typically occurs in cities, given the large amounts of built-up areas. However, despite this effect being well-known and subject to a lot of research, it should be noted that the term Urban Heat Island is not synonymous to urban heat. The next section will focus on urban heat in general, discussing various aspects of it, including but not limited to UHI, as well as causes and effects. Besides diving deeper into the theoretical literature, this section also describes a tool besides the KEA that has been developed for the analysis of climate effects, called the Green Benefit Planner (GBP; *Groene Baten Planner* in Dutch).

2.1 Urban Heat

Next to the Urban Heat Island, there are other, more general, effects and concepts relating to urban heat that are important when considering thermal comfort in cities. First of all, perceived temperature, or physiological equivalent temperature, is described as the perceived temperature in a complex outdoor setting [51]. This thus relates to various parameters that can impact this perceived temperature, such as solar irradiation and wind temperature. On a hot summer day, the PET value can be significantly higher than the actual air temperature, indicating that this aspect also immediately relates to another important concept, that of heat stress. Heat stress occurs when people cannot lose their body heat to their direct environment [38]. Light heat stress already starts at a PET of 23°C, and extreme heat stress occurs at temperatures of 41°C and up [38].

Thus, Urban Heat Island is not the only or necessarily the most important aspect of adverse heat effects within cities. Martilli et al. [80] mention multiple key differences between UHI and urban heat. First, while the strongest UHI is measured during evening and nighttime, the worst thermal stress and highest building energy consumption for cooling are during daytime. Next, while some cities experience strong UHI effects, they might not benefit greatly from heat mitigation measures if they experience a mild climate. Finally, they mention that an increase in UHI intensity does not always mean lower thermal comfort in the city environment, and vice versa. Therefore, even though literature does show that UHI can influence thermal comfort in cities, the other aspects mentioned are also pivotal when looking at heat mitigation strategies.

2.1.1 Causes

Despite the differences between the notion of UHI and heat aspects such as PET, there are several aspects of the climate and cities in general that can influence temperature and heat stress. These aspects thus not only influence direct effects such as PET, but also Urban Heat Island.

Before looking at the different causes, it is important to understand the different forms in which heat occurs in urban areas. Heat is directly added to the city by solar irradiation, but also through human practices, such as the use of air conditioning and various transportation modes [94]. This energy can be transformed into different types of heat, which influence the urban climate in different ways. In their research, Stache et al. [123] indicate convectional (or sensible) and latent heat as the most important types of heat present regarding adverse heat effects. Convective heat transfer occurs between material surfaces and the surrounding air, while latent heat can be described as the absorbed energy that is used for a phase change of liquid water into water vapour [123]. The authors mention that while convectional heat directly adds to UHI, latent heat production does not, as the created water vapour can be transported outside of the urban layer, thereby not adding to heat in the urban areas. These different types of heat are important when looking at causes of urban heat, but especially when considering potential mitigation strategies. The different characteristics of the urban environment determine the way in which heat is potentially reflected, stored, emitted, and thus also mitigated.

One aspect of causes of urban heat in the urban environment that is mentioned often in the literature relates to the material properties of building surfaces. Radhi et al. [105] mention that surface areas and surface air temperatures during the summer period are largely depending on colour, thermophysical properties and radiative properties of the material. The latter, often mentioned as the albedo of a material, is mentioned by several authors [94, 106, 112]. The albedo of a material is the percentage of reflectance of solar radiation. Therefore, a low albedo means that a material stores a lot of heat, which it radiates at a later moment, creating convectional heat and thereby increasing the UHI effect [94]. This can in turn lead to heat stress, as urban environments remain warmer in the night. The human population, which is often quite dense and present in large numbers in urban areas, also influence the temperature in multiple ways. First of all, human gathering and the CO_2 emitted by the urban population can trap heat as well by means of the greenhouse effect, leading to higher temperatures [94]. Additionally, indirect heating by the human population, such as for example air-conditioning and other machinery such as cars, which emits heat itself, directly adds to the temperature in the direct surroundings [94]. The concept of heat being trapped in the city can have many origins. First, the urban canopy, which can be described as various multi-storey buildings being grouped together, can directly increase UHI by trapping heat between buildings [94], warming the stationary air in between the buildings. Again, this impacts heat stress perceived by people, as surrounding temperatures decrease less. Next to CO_2 emitted by humans, also other air pollutants, for example those emitted by cars, impact the urban climate by trapping heat [94, 85]. This enduring presence of air pollutants is another aspect that is being influenced by urban morphology. Multiple authors mention the positive impact that wind can have on heat in the city. The lack of wind, often caused by densely situated buildings, can impact heat directly by not replacing warmer air with cooler air from surrounding areas [43, 47, 94, 96]. Indirectly, it does so by failing to replace polluted air with cleaner air that traps heat less. This lack of wind, in combination with high pressure conditions and clear skies, provides ideal opportunities for increasing temperatures [43]. The morphology of the city is however also mentioned as a potential solution, as it can enable wind flows that reduce urban heat instead of increase it [80]. Finally, the literature mentions the effect that the changing climate in general has on heat, with warmer weather and increasing numbers of heat extremes mainly causing heat-related issues [65].

What becomes clear from looking at the diverse literature and what is important to keep in mind when discussing urban heat, is that while Urban Heat Island is often cited as a main issue, this effect can often be refined into more specific heat aspects, such as increased PET and heat stress. Also, some of the city's features not only impact the temperature in the city negatively, but can also have a positive impact, depending on the circumstances. Besides this, some aspects might not need mitigating. This goes for urban morphology and its potential for wind corridors [80], but also for UHI in general. For example, Martilli et al. mention that while some cities experience strong UHI effects, they might not benefit greatly from heat mitigation measures if they experience a mild climate [80]. This can thus also be taken into account when looking at potential mitigation strategies, which are discussed later.

2.1.2 Effects

The presence of heat in urban areas can lead to multiple adverse effects. As has become clear, the UHI effect itself does not cause these effects, but rather the additional heat it brings to cities does.

The wide range of aspects influencing the Urban Heat Island leads to the existence of this effect in various locations. For the Netherlands, it was found that most cities experience a substantial UHI [124]. Consequently, in their analysis of multiple Dutch cities, Steeneveld et al. [124] found that approximately 50 percent of the researched urban areas were subject to heat stress for about seven days per year. Furthermore, the authors found a large correlation between population density and UHI. This is not surprising, as higher population densities often indicate more built-up spaces. This also explains that UHI was found to influence energy consumption, as buildings are increasingly cooled using air conditioners [143, 94]. Within cities there can be significant differences regarding temperature as well. Tan et al. [127] mention that most hot days (above 35°C), as well as prolonged heat waves, are more likely to occur in urban locales. Regarding different land use types, industrial areas were found to have highest land surface temperatures (LST). On the other hand, parks and other types of vegetated land use types were found to have lowest LST [58, 113].

The UHI was found to be mostly prevalent during summers and at night [127]. During these periods, the UHI and its implications can significantly impact human health. Especially during heat waves, urban populations are at risk, as UHI can exacerbate health impacts from heat [47]. Increasing temperatures and particularly heat stress have been linked to several non-fatal health impacts, such as heat strokes, dehydration, loss of labor productivity, and decreased learning [53]. On top of that, the authors also mention that in the US, heat-related mortality causes more deaths per year than other extreme weather events. The latter is confirmed by multiple studies [94, 127, 47]. An important distinction has to be made between different population groups when it comes to the effect heat can have. Arnberger et al. [5] summarize that especially elderly are particularly vulnerable towards heat stress. In combination with growing populations of elderly in urban environments, they stress the importance of addressing this issue. Finally, increasing temperatures can increase inequality between different socio-demographic groups, as there has been evidence of less affluent people being more exposed to extreme heat [134]. This can partially be explained by the lack of vegetation found in residential yards of lower income neighborhoods, as was found by Beumer [9]. It was found that for both Phoenix, USA, and Maastricht, the Netherlands, neighborhoods with on average lower incomes had higher shares of paved private gardens. This research does however not indicate specific garden sizes. In order to address the overall environmental issues and inequality within cities, private gardens can be a good focus point for local governments.

Despite all these negative effects, there has also been a sense of nuance within the literature. Martilli et al. [80] provide a general overview of the definition of UHI, and its difference compared to other heat aspects. Next to that, authors have mentioned the effect of UHI during winter times, and have argued that this might provide comfort in cold climate [88], or that the UHI effect in winter should at least be investigated further [47].

2.1.3 Mitigation Strategies

The different types of urban heat problems discussed before cannot be solved with a single measure. There are, however, measures that can address multiple issues simultaneously. The various mitigation strategies and measures that have been researched until now will be discussed below. Specifically for the UHI, Heaviside et al [47] mention that there are two main techniques: "*those which aim to increase solar reflectivity, using 'cool' or reflective materials for buildings and surfaces, and those which aim to increase evapotranspiration through increased greening and water availability*". However, similarly to their arguments regarding the contribution of UHI towards urban heat issues, Martilli et al. state that UHI intensity is not relevant for urban heat mitigation strategies [80], claiming that it not necessarily needs mitigation. All in all, mitigation strategies, for various different urban heat issues, should be in place in order to apply specific measures that prove to be most effective. The most relevant measures are discussed below.

Green and blue spaces

The most effective and most researched measure for urban heat mitigation is the addition of green spaces [65, 94, 143]. Increased vegetation and green spaces has been found to specifically address the issues of Urban Heat Island [59, 94], heat stress [62, 71] and perceived temperature [28, 43]. There are multiple ways in which green spaces mitigate heat in urban areas. Shishegar [120] mentions evapotranspiration, increase of direct shading on urban surfaces, influence on air movements and heat exchange. Evapotranspiration leads to more latent heat production and thereby less heat in the city, while shading reduces the eventual convectional heat production by dry building materials. It is also mentioned that the addition of green spaces leads to less paved areas, which indirectly also reduces temperatures [139]. More greenery also reduces the need for mechanical cooling, thereby reducing anthropogenic heat production [43]. Besides influencing the direct environment, urban green spaces can influence a larger area of the city around the green spaces themselves. Shah et al. [118] mention an average distance of 347 meters for local cooling effects of green spaces, while Shashua-Bar & Hoffman [119] found this distance to be up to 100 meters for small green spaces. Regarding the effect of area of green spaces, larger green areas (more than 1000 m^2) were often found to be more effective [4, 97], while a threshold has also been noted for the marginal cooling effects of large green spaces (40 ha) [28]. Despite its effect being comparatively lower, there is enough evidence for the positive effect of smaller green spaces [4, 97, 119]. When it comes to smaller parks, Xiao et al. [139] also acknowledge the potential worsening effect this can have, as these parks often have relatively high proportions of paved areas, which increase urban heat. Some authors even propose that focus be laid on the greening of private urban spaces in urban areas that lack the space for large urban parks [113, 94]. Besides the area, several papers state the geometry of the green spaces to have an effect on cooling potential [28, 118, 143]. Furthermore, also the type of greenery is important, and trees have been found to contribute most to cooling [116, 143]. Finally, improving connectivity between isolated green spaces was mentioned as a potential cooling strategy [59].

Focusing on blue spaces, there is no clear agreement on the potential this type of land use might have on urban heat mitigation. Where some authors give the general conclusion that blue spaces can reduce temperatures [28, 65], others have concluded that water bodies did not contribute to cooling [139]. Other authors advise caution when it comes to its potential effect. It is mentioned that some types of mesic vegetation, as well as water bodies, might have the opposite effect during nighttime as they have during daytime [42]. Yang et al. [141] summarize the potential role of rivers and lakes, stating that they can improve heat transport process and bring fresh air, which can in turn balance urban temperatures. Thus, while the research on blue spaces as a heat mitigation measure is divided, this measure should be looked into well before applying it as part of a strategy.

Further mitigation strategies

Besides the addition of green (and blue) spaces are other measures that can be introduced to lower temperatures in the city. An important aspect that was mentioned before is that of albedo of materials. Increasing the albedo increases the amount of light, and thus energy, that is being reflected from the surface. The energy that is not stored in the material can therefore not be converted into convectional heat. This can help keep air temperatures lower[140]. Increasing albedo of materials was found to be specifically effective for horizontal surfaces including wide streets [65]. However, more research on this topic is needed. Qin [103] mentions that the definition of cool pavements (pavements with high albedo materials) remains incomplete, and that the influence of cool pavements on the air temperature in the urban canopy layer is unknown. Similarly, Yang et al. [140] mention the positive effects of increasing albedo, but do not see increasing albedo as a single solution.

Another important aspect that is mentioned in the literature is that of shading. Relating substantially to both urban greenery and albedo, shading is found to be very effective to reduce local temperatures [14, 65, 119]. For (semi-)private areas, shading can also directly influence energy loads of individual buildings [14]. An effective shading effect was found to be mostly provided by trees [119] and should thus mainly be taken into account as a additional measure, contributing to the potential cooling effect of urban greenery. However, other ways for shading provided by high albedo materials might be effective in preventing convectional heat production and thus the warming of the air in the city and should be considered as well.

Finally, there are some other aspects that are mentioned briefly by some authors. First, authors stress the importance of reducing anthropogenic heat [65]. Next, Liu & Shen [72] propose the implementation of an 'urban growth boundary' in order to prevent the loss of green space, which can also negatively impact urban heat issues. Finally, green roofs and green walls can play an important role in heat mitigation [106]. These types of green spaces have not been included before as they will not be part of this study. However, they should be mentioned when providing an overview of effective heat mitigation measures.

Coping with heat

The mitigation strategies discussed have a direct effect on heat, but as the issue of urban heat is a complex one which is thus not solved easily and might even further complicate in the future, mitigating factors should also focus on coping with heat. The general health benefits of green spaces, including those achieved by reducing temperatures, have already been discussed in the literature [109]. As mentioned before, being able to cope with heat is especially important for vulnerable groups within the urban population, as they are most prone to extreme health effects during heat waves and high temperatures. An important group in this regard is the one including elderly. Arnberger et al. [5] researched preferences and moments at which elderly would make use of green spaces. They concluded that a large part of elderly preferred to stay at home during hot periods. However, elderly could be persuaded to visit green spaces if they provide enough cooling. Therefore, access to green spaces is a major issue in the context of heat adaptation [5]. Despite any potential differences in vulnerability towards heat or aspects such as income, the importance of providing different groups in society is also underlined by Voelkel et al. [134], who call extreme heat exposure an environmental justice issue. All of these findings highlight the importance of cool places being provided to the urban population in order for them to be able to cope with heat during hot periods.

In order to address the concept of coping with heat, as well as the actual implementation of the mentioned mitigation strategies, a final aspect that is to be included is that of responsibility and policy implications. Responsibilities for adaptation of the strategies mentioned above are often assigned to local authorities [82]. They are considered to be the most efficient actor to oversee the whole city, and the responsibility is believed to be theirs when considering the law, which states their duty to care for the general health of the population [82]. Next to this responsibility, the need for a public-private collective is stated in the literature. Mees et al. [82] state that there has been little research regarding the governance of the protection of vulnerable citizens against extreme heat. They stress the need for both public and private responsibilities regarding heat mitigation strategies. Municipalities should put effort into identifying the potential barriers and opportunities for such a collective, in which the inclusion of multiple stakeholders should play a big part. All in all, stating this responsibility is pivotal in making sure mitigation strategies are applied correctly.

In conclusion, it is important to realize that urban heat is a very broad concept. UHI is often mentioned as the most pressing issue, while there are other issues connected to this effect that more directly influence citizens. There are various potential mitigation strategies, most of which relate to land use and the materials that are used in the city. The most important is thus also the implementation of more green spaces throughout the city, as these address multiple issues at once. Given the potential of private greenery in this regard, the most important aspects of this type of green space will be discussed hereafter.

2.2 Private Greenery and Climate Mitigation

In the Netherlands, 70 percent of households have a garden. In total, this comes down to more than 5 million households. 10 percent of these households features a communal garden, of which the majority is located next to apartment buildings [50]. Even though individual private gardens do not represent a large area, their combined area can amount to a significant area [111, 6]. Research in Flanders found that about 8% of the total land area consists of gardens [111]. For this research, the definition of a private garden is described as the residential parcel without the associated dwelling [14, 26]. Next to these private gardens, another type of residential green area is to be distinguished. Areas surrounding for example apartment buildings also provide green space, but also these areas are not controlled by municipalities and thus, there is a need to gain insight in the possible influence this area might have on climate change mitigation. Some of these areas are only accessible by residents of the adjacent building(s), but others might also be accessible to the public, even if the area is not intended to be used by everyone. Such areas can be defined as semi-private zones [93].

The extent to which these different types of land use have been included in research varies, although all lack substantial coverage when it comes to their potential for climate change mitigation. Research on climate change mitigation measures tends to mention private gardens as a potential factor, but rarely takes this type of land use as a main research topic [15]. This leads to little being known about the potential of policies on greening gardens [50], on the value of gardens as a strategic land use [26] and their relative contribution to the functioning of ecosystems and cooling of cities [14]. Regarding the potential effects of greenery in private gardens, research often focuses on aspects such as preferences and potential water run-off (e.g. [16, 101]). Next to that, it also features analysis techniques, such as the remote sensing of these areas (e.g. [25]). Housing corporation areas seem to be completely overlooked in this regard, despite their potential for various benefits. When research does consider private gardens specifically for urban heat reduction, usually very general conclusions regarding its potential for urban cooling are given, as quantitative research is lacking [22, 41, 50]. Even though there has not been a lot of quantitative research, the literature does recognize the potential of private gardens for ecosystem services, including heat mitigation, within the city [41, 6].

There has not been a lot of research on the specific effect of greening gardens located next to larger housing projects, such as apartment buildings, but efforts in this direction can provide significant benefits for a multitude of reasons. First of all, literature mentions that smaller gardens form substantially greater hard or 'sealed' surfaces compared to residential zones with large parcels [122]. This will lead to a larger diversion of rainwater into drainage systems, as well as a raise in local temperatures. Next to this, Bodach & Hamhaber [11] have shown that vegetation can increase energy efficiency in social housing. Finally, on a policy level, adaptation of greener areas could prove to be more efficient when looking at plots owned by corporations, as they are all managed by the same institution [126, 64]. However, it is also mentioned that corporations often lack vision in this regard, and that cooperation and information provision is desired [64].

(Semi-)private greenery has been the topic of quantitative research regarding climate change mitigation significantly less when compared to public greenery [22]. When they are taken into account, they mainly focus on biodiversity (e.g. [81]), carbon storage (e.g. [23]) or water runoff (e.g. [73]). Regarding the potential of private greenery on reducing urban heat effects, multiple authors state similar findings. Cvejić et al. [22] state that specifically privately owned aspects of green space elements have rarely been investigated in quantitative and functional terms. Van Loon et al. [74] give figures for the temperature drop in a neighborhood as a result of greening, but only include private greenery as part of the whole. Cameron et al. [14] acknowledge that the extent to which gardens contribute to cooling is unclear. All in all, the academic literature on the effect of added urban greenery seems to be missing a clear overview of the precise effect that (semi-)private greenery can have on reducing urban heat. More insight in this regard can help policy makers make better decisions regarding what should be their focus point with respect to adding greenery to the urban environment.

Analyzing the existing urban area is a prerequisite for being able to quantify effects of added private greenery. Some authors mention that due to the hybrid character of domestic gardens and the difference in land use found between individual units, its identification is subject to interpretation when looking at aerial photographs [26]. In spite of this, spatial resolution and analysis accuracy has improved significantly and are currently increasingly accurate, also when looking at domestic gardens [24]. Haaland & Van den Bosch [45] argue that neighborhoods should be the spatial unit of analysis when analyzing green space, as this unit matters most to residents' living quality. Furthermore, neighborhoods can then be compared to one another, which can be relevant for urban policy making.

Some efforts have already been made to gather insight on the layout and land use types of domestic gardens in the Netherlands. It has been found that about 36 percent of Dutch gardens consist of vegetation [74], and that of the five million private gardens, about 40 percent is larger than 100 m^2 [50]. However, only knowing the amount of vegetation in gardens is not enough, as gardens are highly heterogeneous in form and function [14]. The latter is why information on garden size is important. The literature states that garden size plays a significant role, as it influences gardens on the following aspects [122, 76]:

- Larger gardens support more landcovers
- Specific landcovers – the number of trees above 2 m, vegetable patches, and compost heaps or bins – were more likely to occur in large gardens
- the extents of more than three-quarters of the landcovers recorded in gardens, as well as vegetation cover, increased with garden area

Furthermore, it is stated that as larger parcel areas often also indicate more garden area, as the proportion of the house that occupies the parcel decreases [76]. Finally, the authors mention that on the whole, semi-detached houses have larger gardens than terraced houses and smaller gardens that detached houses.

Several authors have already been looking at trends of green space change within cities. Some of these also focus specifically on private gardens. Kullberg [69] found that successive research indicates a decline in the amount of green space within gardens from 46 percent to 39 percent. Perry & Nawaz [101] had similar findings. Over the course of 33 years, they found a 13 percent increase in impervious surface area, of which 75 percent could be traced to the paving of front gardens. The literature states that not only the paving of gardens is responsible for a reduction of urban green space. The ongoing development of cities can cause a substantial decrease in the proportion of garden area as a result of an overall reduction in average garden area as pressure on available land means that new houses are built with smaller plots [75]. Furthermore, Jim [57] mentions the overall problem of development of new green space in already dense city environments. Next to these issues, it is also not clear yet how these problems can be solved. The loss of trees and other valuable vegetation in private gardens remains an "unanswered question" [45].

The loss of green space in the urban environment is thus a trend that needs to be addressed and, as has become clear, a substantial factor in this development has been the paving of private gardens, also called soil sealing. On a small, individual scale, the paving of these gardens is harmless, but when this happens on a large scale, the consequences can be severe [15]. Soil sealing and the impervious surface in gardens as a result contribute to increased water use [42], have significant effects on biodiversity, water retention and heat stress [126], and can lead to a large increase in average annual water runoff, potentially leading to serious urban flooding [101]. Research shows that currently around 60 percent of the surface of private gardens in urbanized areas in the Netherlands are paved [126]. This research only mentions that initiatives to reduce this soil sealing trend only slow it down, instead of reversing it.

One of the most prominent examples of such an initiative is *Operatie Steenbreek*. This initiative is a private program in the Netherlands which aims to work together with multiple stakeholders in order to incentivize private garden owners to replace pavement with vegetation. Even though the initiative has shown success, this success might not prove to be enough to battle current trends: "*Steenbreek meets the goals of munici-palities (outcome effectiveness), in terms of number and types of activities, but is not yet able to change citizens' behaviour (outcome effectiveness) in terms of pace and number of changed gardens.*" [126]. Research has shown that behaviour regarding the greening of private gardens has both individual and social aspects. Behaviour regarding the pavement of gardens has been found to cluster across social networks, while aspects such as environmental awareness have been proven to be important aspects for individuals to increase vegetation in their gardens [41]. Some authors have even suggested a tipping point in greening the city [48]. This theory suggests that if a certain amount of greenery is present in private gardens and other spaces, other households will join in greening their properties. The latter indicates the need for more incentives from the government, in order to reach this certain threshold.

There is however no clear solution for retaining or improving green space quality on private properties [45]. While the private garden has specific advantages regarding individual well-being [125, 16] and are therefore also preferred by a majority of intentional movers [20], the diversity of the group of garden owners makes it difficult to give any specific conclusions regarding factors determining behaviour [111]. Measuring what behavioural approaches might work require studies over time [126].

The responsibility of making private gardens more green should not only be for initiatives such as Steenbreek, but should also fall to governments and institutions. However, in the Netherlands, the approach for this is characterized by minimal governmental incentives or policy, which leaves a niche for private initiatives like Steenbreek [126]. Governments can influence this on several aspects, including legislation regarding paving of gardens and removing trees [45], discouraging people to pave gardens or stimulating them to add vegetation [132]. However, despite this, the literature acknowledges the difficulty for policy makers and urban planners to influence such privately owned land [6]. All in all, the case of private gardens in urban environments has many aspects. It can be difficult for governments to exert direct influence over the composition of these areas, but efforts are needed, as promising initiatives can use more support. Therefore, governments should strive for an integral approach if they want to achieve this [132] and multiple stakeholders should be involved.

2.3 Effects of Different Vegetation Types

Urban greenery, both public and private, is constituted of various types of vegetation. In order to understand what composition of greenery is best suited for climate change mitigation, the performance of different vegetation types should be known. Besides focusing on heat mitigation, there has been research into the effects that vegetation types can have on several other adverse aspects of the changing climate. Research has been conducted regarding the impact of greenery types on storm water runoff [142, 61], air pollution [1, 117, 21] and noise pollution [79]. In order to devise suitable strategies for the greening of (semi-)private greenery, the cooling potential of different greenery types should be recognized as well. However, not only the performance of vegetation is important for cooling. Also the preference of people regarding vegetation, as well as the costs of implementing these different types, should be known. These aspects are discussed hereafter.

The effect of different vegetation types on mitigating heat in urban areas links directly to the way in which types of heat are produced in the urban environment. The latent heat production, as mentioned before, can help prevent adverse heat effects in urban areas. This is the main aspect in which vegetation helps cool down cities. The process of evapotranspiration is species-specific [136] and different types of vegetation can thus perform better than others. Also, it was found that this process only occurs during the day, as this is subject to plant characteristics [2]. Next to evapotranspiration, also shading and the influence of vegetation on air movements and heat exchange are mentioned [120]. Shading was also found to be dependent on various parameters, including canopy cover, species, and arrangement in the urban space [129]. The literature also states that vegetation performs better in absorbing radiated heat from other materials, which is for example important in street canyons [123].

There is an overall agreement that trees perform better than other types of vegetation, such as shrubs or grass, regarding cooling of urban areas [136, 144, 29, 129]. Overall, it was found that shrubs also perform better than grass [29]. Individually, there are differences to be found, but several authors have also looked into combinations of greenery types, finding evidence for better cooling performance of a combination of vegetation as compared to individual elements. Multiple authors [144, 3] found better performance for trees combined with understorey vegetation in the form of grass and shrubs compared with individual trees. Aboelata & Sodoudi [2] found a similar cooling performance in a scenario where 50 percent trees were added and a scenario including 30 percent trees and 70 percent grass. They indicate the first scenario to be preferable, as grass need more water than trees. On the other hand, Duncan et al. [29] mention that lower height urban vegetation are potentially easier to integrate into urban areas than trees.

The difference in cooling performance between trees and other vegetation has several aspects. Most of these aspects, however, relate to the relative size of trees. The canopies of trees give them a lot of surface area, which impacts heat in multiple ways. First, it allows for more evapotranspiration [136]. Next, multiple authors mention the effect that canopy size has on shading and thus on cooling potential [136, 31]. Between tree species, this can also vary, as canopy coverage can differ, estimated by the Leaf Area Index (LAI) [136]. Finally, the albedo of trees adds to their cooling potential and also for this aspect, differences between species can be found. Oke et al. [95] concluded that coniferous forests have lower albedos compared to deciduous forests, leading to higher air temperature.

Not only which vegetation is planted, but also how it is integrated in the urban environment determines how much it contributes to the cooling of urban areas. Shading that trees provide is impacted by the surrounding built-up area. Trees provide less shading if this shade overlaps with that of the buildings surrounding them, indicating trees in mid- and low-rise building areas have better cooling effects than those in high-rise building areas [136, 31]. Regarding ventilation, there is evidence that trees and shrubs in urban canyons can influence overall ventilation and result in heat or pollutant trapping within urban canyons [136]. In order to improve this, the distance between trees should not be too close. This can preserve wind corridors [52]. A spacing distance of a mature canopy diameter between two trees was found to be effective [145].

Knowing what vegetation can best be used for heat mitigation and knowing how it should be used is very useful for planning greenery in the city. However, in the case of private greenery, governments are not able to directly alter these areas. Individuals are responsible themselves for adding greenery to their gardens and thus, if governments are looking to impact urban heat by incentivizing residents to add more greenery to their gardens, both preferences of people and potential costs of the associated strategies should be taken into account.

There has been relatively little research specifically on preferences for different types of vegetation in residential gardens. Research that has been conducted tends to focus on preferences regarding plants [135], garden complexity [46, 121, 8], or general characteristics of vegetation [60]. It was found that preference for garden plants relate mostly to aesthetic traits and non-visual traits such as nativeness and drought tolerance [60]. Preference for complexity of gardens gives a better indication of people's preference. People tend to prefer more complex gardens, e.g. more different vegetation types compared to only lawn [46, 121]. The research by Harris et al. [46] also indirectly indicates the preference of garden owners in Australia for more trees and other non-lawn vegetation compared to lawn. Building on this, a study in Turkey showed the preferred outdoor plant functions to be mainly related to shade and air cleaning, indicating trees might be the best suitable option [44]. Finally, Schmid & Säumel [115] find proportion of green visible from windows and number of trees as significant predictors for people's preference, with trees outperforming shrubs. This is also an important facet, as this provides evidence for situations concerning larger residential buildings and their surrounding (green) areas. Preferences of people can be an important factor in their willingness to adopt or have more greenery around their homes.

Considering costs of greenery, little to no research has been done on how this affects private greenery. More research on this aspect is needed in order to incorporate this aspect as well when considering viable strategies for incentivizing greening private areas.

2.4 *Green Benefit Planner*

Recently, the Dutch National Institute for Public Health and the Environment (RIVM), has been working on a tool called the Green Benefit Planner. This tool is described as "a decision support tool that calculates the effects of spatial planning on natural capital" [108]. This tool can be linked to ArcGIS, after which users can easily calculate certain scenarios after providing new input data.

Different to the KEA, the GBP calculates the societal and financial benefits of one or more interventions performed in a certain region. The tool provides various different interventions that can be modeled, such as the addition of green roofs, adding trees to the streets, adding drainage systems, and more. The tool calculates the benefits related to these interventions and provides an overview of these benefits. Multiple outcomes of the proposed interventions are calculated, including air pollution and increased physical activity, but also urban temperatures. There are not many aspects that specifically relate to urban heat, except for Urban Heat Island. The report by the RIVM [108] specifies the methods behind this calculation, which are the same as for the map provided in the KEA. As the GBP only includes UHI effect, it could not be used to test scenarios regarding other heat aspects, as discussed in this report. Besides calculating UHI, the tool calculates other potential positive effects that the addition of green and blue spaces might have, but these do not directly relate to heat mitigation. The tool is therefore as of yet not suitable to calculate several heat aspects. However, the tool itself is suitable for the implementation of certain scenarios with several different types of interventions, which might significantly decrease the time it takes to calculate multiple scenarios, compared to the process executed in this research. Even though the (re)production of certain input data is still necessary for the calculation of these scenarios, a big advantage is that one input map can be used for the calculation of multiple interventions, either on their own or combined.

The Green Benefit Planner can thus be considered as a promising tool for the calculation of interventions that are aimed at mitigating several adverse effects caused by the changing climate. The tool is a good extension on the KEA, but does need further functionalities in order to calculate multiple heat effects and support policymakers with all information they need in order to make informed decisions.

2.5 Concluding remarks

This literature review has indicated the difference between UHI and urban heat, which is often used synonymously. Urban heat, however, encompasses aspects besides UHI which directly influence quality of life in urban areas. There are multiple causes of urban heat. Besides direct solar irradiation, various aspects of the physical environment, but also processes and human activity, contribute to urban heat.

Various effects are caused by increasing temperatures in urban areas. These effects range from increased energy consumption to severe adverse health effects. These effects indicate the need for mitigation of excess heat.

Mitigation strategies have been widely researched, and green spaces have been found to be very effective. Most research has had a main focus on public green spaces. This is not surprising, as governments have direct control over these areas, which allows for specific policymaking. (Semi-)private spaces, however, hold much potential when it comes to the possible addition of greenery, as these spaces take up a lot of area in the city and are often partially, or sometimes completely, paved. However, research regarding the precise potential of these spaces has been lacking. When it comes to the addition of greenery to (semi-)private areas, policy should focus on cooperation with owners. Regarding this cooperation, there are of course differences to be taken into account between private owners and housing corporations as these parties have different interests and might be incentivized differently. Also, the manner in which greenery is added should be taken into account, as different types of greenery and where it is placed influences the effect it has on urban heat.

Finally, as an extension on the KEA, tools such as the GBP might prove to be useful in the future to test scenarios regarding the addition of greenery.

Chapter 3

Methodology

The goal of this research is to obtain more insight into the potential effect of adding greenery to (semi-)private areas in the urban environment as a means of heat mitigation. This has led to the following main research question:

What is the role of private gardens and housing corporation greenery in mitigating adverse heat effects in urban neighborhoods?

Additionally, there are several questions this research aims to answer. These questions relate to the the *Klimaateffectatlas* tool and the functionality of the different maps when it comes to interpreting the data on a city scale and adding a potential scenario to the maps. Furthermore, the questions add more background to the case and the maps in general. The sub-questions for this research are the following:

- *What information do the Klimaateffectatlas maps provide, and is this enough indication for urban heat issues in Eindhoven?*
- *How do Eindhoven neighborhoods score regarding different heat topics?*
- *Is there a relationship between different socio-demographic and socio-economic aspects at neighborhood level, and the scores of Eindhoven neighborhoods regarding different heat topics?*
- *To what extent can added greenery in (semi-)private gardens in Eindhoven help reduce adverse heat effects?*

This chapter consists of several sections. First of all, the study area will be established. Then, the different *Klimaateffectatlas*-maps that will be used in the quantitative analysis, together with their underlying models, will be explained. Next, the methods used for the calculation of heat values at the neighborhood level and the performed correlation analysis will be discussed. Finally, the reproduction of the KEA input maps will be discussed. Each of the steps are comprised of multiple different methodologies, as the maps have different underlying models and often call for specific approaches. Furthermore, the methodology for synthesizing the data of the KEA-maps is very specific and is different for each of the maps. The approaches used are all quantitative, using mostly freely available data, and are specified in every section.

3.1 Study area

The study area chosen for this research is the city of Eindhoven, Noord-Brabant, in the Netherlands. The study area is depicted in figure 3.1.

Eindhoven is the fifth-largest municipality in the Netherlands, with a total of 238,299 inhabitants [34]. The city consists of 20 districts and 116 neighborhoods. Data files for the outline of the city based on its neighborhoods compared to the municipal outline differed. This is shown in figure 3.2. In the figure, the black outline shows the outline based on the neighborhoods, and the red line shows to what extent the municipal outlines differs from the neighborhood outline. As the analysis focuses on the neighborhood level, the outline based on that of the neighborhoods was chosen. The area within this outline accounts for a total area of the city of Eindhoven of 89.35 km^2 [33].

Eindhoven was chosen for this analysis as it is one of the largest cities in the Netherlands. On top of that, the city consists of many residential areas with many buildings having their own private garden. These aspects also make the city very suitable for the envisioned analyses, which focus on these residential types.

Figure 3.1: Study area, created using QGIS and PDOK data [102, 99]

Next to the suitability of the city itself, there is also various data freely available about the city and it demographics. On top of that, the Eindhoven municipality also provided other data needed for the analyses.

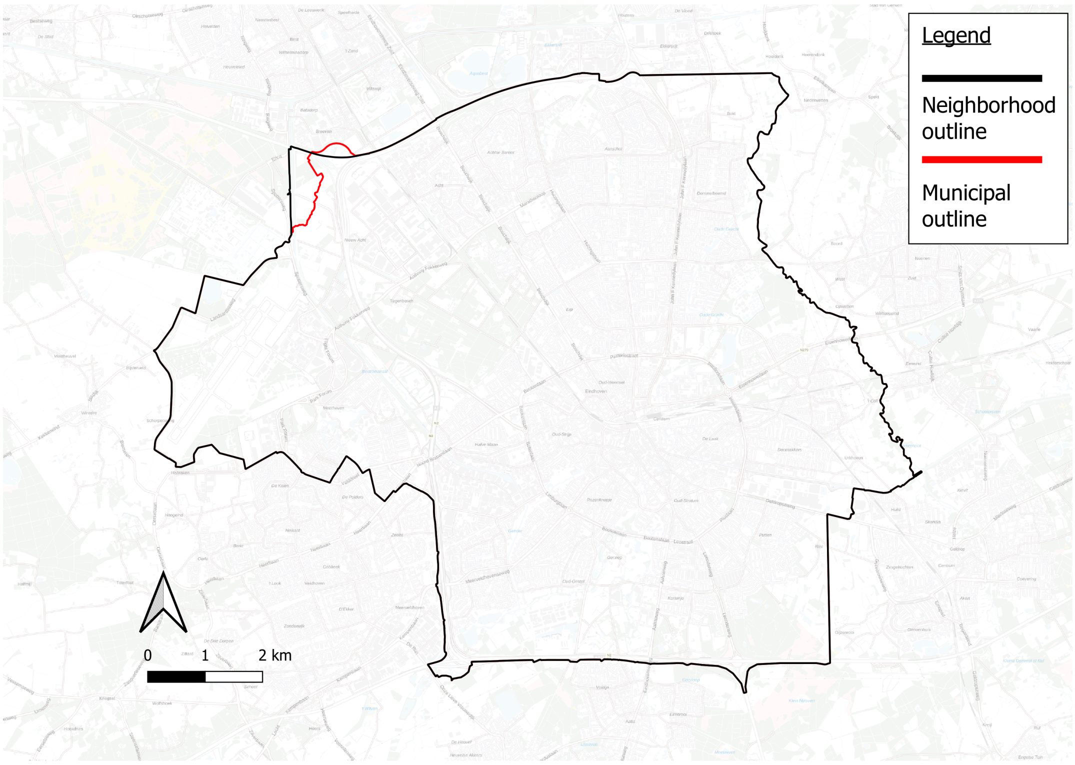


Figure 3.2: Municipal and neighborhood outlines of Eindhoven [33]

3.2 Background *Klimaateffectatlas*-maps

The *Klimaateffectatlas* provides a large variety of maps with different insights on multiple climate-related topics. Besides the maps, more background info on every map is also provided on the website. Information regarding the climate topic itself is provided, and there is also more information available regarding the usage and production of the map. The technical documentation that explains the model behind the map is often provided as well. This section aims to summarize these technical documentations in order to provide a clear overview of the production of the used maps, as well as the potential limitations that can impact the outcomes of the analyses. The technical documentations are referenced and should be reviewed for a complete overview of the specifications of the models.

3.2.1 UHI map

The Urban Heat Island map was produced by the RIVM. The technical documentation for this model, on which this section is based, can be found in the document "*Cooling by vegetation and water in urban areas*" [107]. The model built for this map uses input maps, look-up tables, and reference values for the production of the map. An overview of the input maps and look-up tables can be found in table 3.1.

The model produces five different maps, namely:

- Maximum UHI effect
- Potential UHI effect
- Degree of soil sealing
- In situ cooling effect of urban green and water
- Actual local UHI effect

Table 3.1: Input maps and look-up tables used in UHI model, based on [107].

Input	Unit	Short description	Source
INPUT MAP			
Wind speed	m s^{-1}	Average wind speed at 100m height in the period 2004-2013.	Royal Netherlands Meteorological Institute (KNMI)
Inhabitants	# inhabitants per cell	Shows the number of inhabitants per cell	RIVM
Land cover/ecosystem unit map 2013	[-] Categories for land cover and ecosystem type	Land cover and ecosystem units map, depicting land cover /ecosystem classes for the Netherlands in 2013	Statistics Netherlands (CBS)
Trees	% cover per cell	Shows the percentage of a cell that is covered by trees higher than 2,5 meters.	RIVM
Bushes and shrubs	% cover per cell	Shows the percentage of a cell that is covered by bushes and shrubs between 1 and 2,5 meters high.	RIVM
Low vegetation	% cover per cell	Shows the percentage of a cell that is covered by vegetation that is lower than 1 meter.	RIVM
Vegetation cover	% cover per cell	Shows the percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined).	Flemish Institution for Technological Research (VITO)
Percentage non-green area	% cover per cell	Shows the percentage of a cell that is not covered by vegetation (the inverse of the map 'Vegetation cover').	VITO
LOOK-UP TABLE			
Roughness length for momentum	[-]	Roughness length for momentum is equivalent to the height at which the wind speed theoretically becomes zero for different land cover types.	[110].
UHI reduction	%	The cooling effect of land cover and vegetation on the maximum UHI.	VITO
Soil sealing	Binary	Determines which land cover types cause soil sealing (1) and which do not (0).	VITO

Of this output, the 'Actual local UHI effect'-map is the map displayed in the KEA. Regarding greenery, three input maps are used. Raster layers with the percentage of cover per cell for trees, shrubs, and grass are used separately. Later, these are combined for the total percentage of greenery cover per cell of the raster layer. As this layer covers the entire area, it thus also includes (semi-)private areas and their greenery cover. The local UHI effect is calculated after first calculating the maximum UHI effect and the potential UHI effect. The maximum UHI effect is based on a calculation including inhabitants and wind speed. After multiplying the maximum UHI with the percentage of soil sealing, the potential UHI is obtained. Finally, the local UHI is obtained by multiplying the potential UHI effect with the average reduction per land type in that cell. This yields the map shown in the KEA.

The model consists of the several steps mentioned above, in which the different output maps are calculated. These steps are explained in more detail hereafter. Firstly, the Maximum UHI effect (in °Celsius) is calculated, using the following formula:

$$MaximumUHI = -1.605 + 1.062 * log(population_{10km}) - 0.365 * windspeed_{10m} \tag{3.1}$$

Here, $population_{10km}$ indicates the total population living within a 10 kilometer radius of a given cell, and $windspeed_{10m}$ is the average wind speed at a height of 10 meters. This wind speed, in turn, is derived from the input map of wind speed at 100 meters height, and is calculated using the following equation:

$$Windspeed_{10m} = windspeed_{100m} * ln(10/z0m_{lc})/ln(100/z0m_{lc}) \tag{3.2}$$

Where $z0m_{lc}$ is the roughness length of momentum for a given land cover type.

Next, the model calculates the Potential UHI effect. This is done with the equation:

$$PotentialUHI_i = MaximumUHI_i * \%soilsealing_{1km} \tag{3.3}$$

In this equation, $PotentialUHI_i$ is the potential UHI effect of cell i, while $MaximumUHI_i$ represents the maximum UHI effect of the same cell. The variable $\%soilsealing_{1km}$ represents the percentage of soil sealing in a 1 kilometer radius around cell i.

Next, and of most interest to the current analysis, the in situ cooling effect of vegetation and water is calculated. This calculation is based on the vegetation input maps and uses the values shown in tables 3.2 and 3.3 to calculate the cooling effect per vegetation type.

Table 3.2: Reduction of UHI effect by vegetation types from vegetation cover maps [107].

Vegetation maps	**Reduction UHI effect (%)**
Trees	50
Shrubs and bushes	30
Grass and low vegetation	20

Table 3.3: Reduction of UHI effect by LCEU land cover classes [107].

Land cover type LCEU map	**Reduction UHI effect (%)**
Built-up area	0
(Semi)natural vegetation	20
Inland water	30
Sea	100
Agricultural land	15-30
Bare soil	0

The following equation is used to calculate the cooling effect of vegetation and water:

$$Insitucoolingeffectofvegetationandwater_i = PotentialUHI_i * \%Reduction_{typei} \tag{3.4}$$

In this equation, $Insitucoolingeffectofvegetationandwater_i$ represents the cooling effect of vegetation and water for cell i in °C, $PotentialUHI_i$ again shows the potential UHI effect in cell i, and $Reduction_{typei}$ is the percentage reduction of the UHI effect of the land cover type in cell i, following tables 3.2 and 3.3.

Finally, the model calculates the actual (or local) UHI effect. For this calculation, the assumption is made that the local cooling effect of vegetation and water can be felt in a radius of 30 meters. This is a rather conservative estimate. The technical documentation explains this estimate being conservative as the literature does not agree on this value. This concurs with findings from the literature study in this report, which mention larger distances, but were also based on relatively large green spaces instead of cells representing 10 by 10 meters of area.

$$LocalUHI_i = PotentialUHI_i * (1 - \%Reduction_{type30m}) \tag{3.5}$$

Equation 3.5 calculates the local UHI effect of cell i, represented by $LocalUHI_i$. $PotentialUHI_i$ is again used to indicate the potential UHI effect in cell i, and $Reduction_{type10m}$ is used to indicate the the percentage reduction of the UHI effect of the land cover types in a 30m radius around cell i, following tables 3.2 and 3.3. All of the equations described are summarized in figure 3.3.

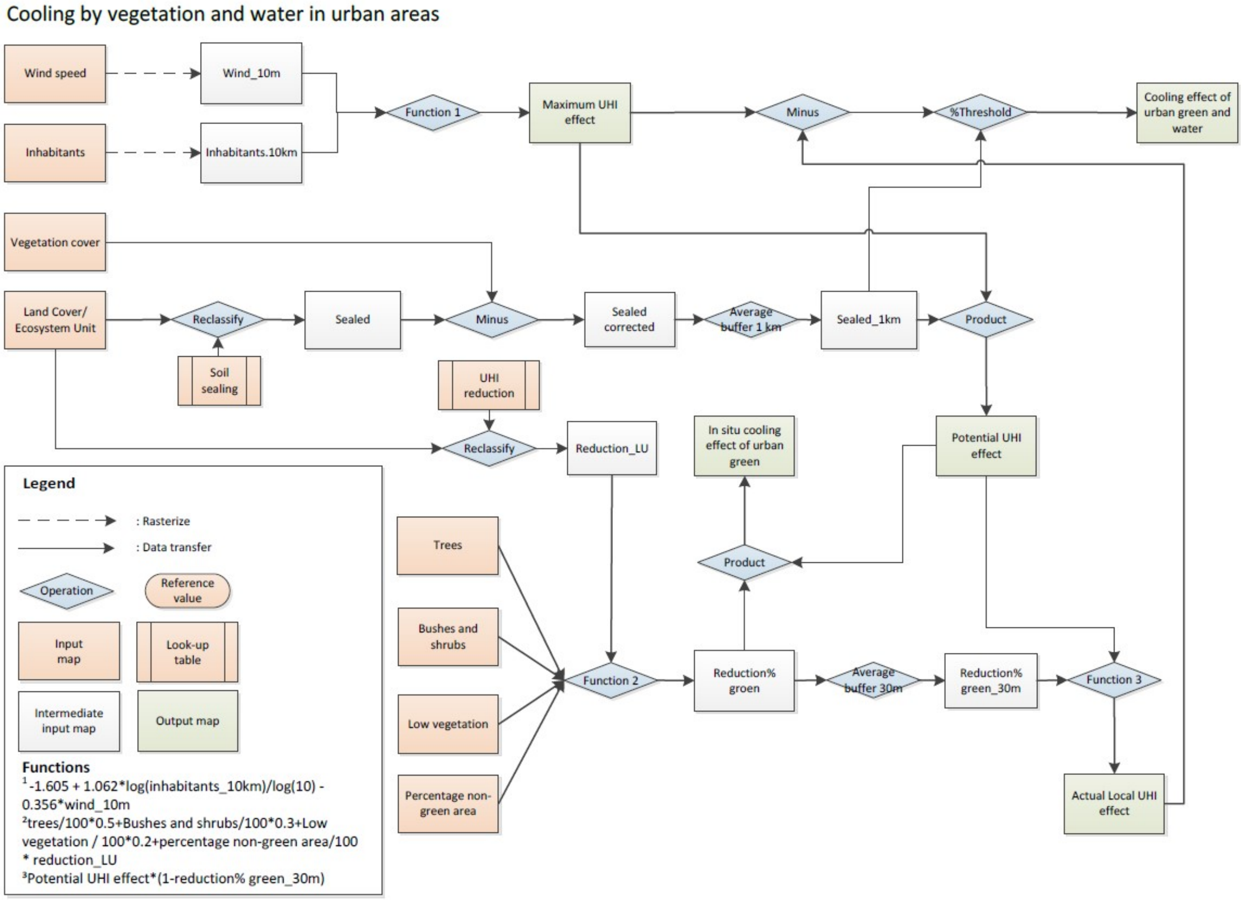


Figure 3.3: Schematic overview of UHI model, taken from [107]

As the model is only a representation of potential effect based on calculations of several input values, there are several limitations to the map. First of all, the UHI effect that is calculated is an average value. This means that, for example, the actual UHI effect on a hot summer night can be higher than the value calculated by the model. Next, the cooling effect of greenery was based on expert judgment, not empirical data. Finally, the radius of the cooling effects of vegetation was estimated to be 30 meters. However, as was also discussed in chapter 2.1 in this report, there is no clear consensus in the academic literature regarding this distance. Therefore, this cooling effect might be more significant, which would have further implications for the model's outcomes.

3.2.2 PET map

A complex model underlies the PET-map, which was produced by Witteveen+Bos. The technical documentation for this model can be found in the documents by the RIVM and Witteveen+Bos [108, 38]. The model is mainly based on the method for calculating developed by the RIVM, with some alterations made by Witteveen+Bos to include more publicly available data.

The model calculates the PET with an accuracy of 1m^2. It is quite extensive and contains several steps, which will be discussed hereafter. It calculates both the PET in areas with shade and areas without shade, and later combines these two maps to produce the overall PET map. The PET in shadow areas is calculated using the temperature in the city measured by weather stations, the wet bulb temperature, wind speed, land use, and average radiation. The PET in areas without shadow also includes the Bowen ratio and the Sky View Factor (SVF). The Bowen ratio is particularly interesting for this research as it represents the ratio between sensible and latent heat flux. Regarding vegetation, the model only discriminates between low vegetation and trees.

A complete conceptual overview of the model is provided in figure 3.4. The figure shows the various steps of the model, as well as the different inputs that are needed. Table 3.4 shows the meteorological input that is used in the model, while table 3.5 gives an overview of the spatial input data needed for the model.

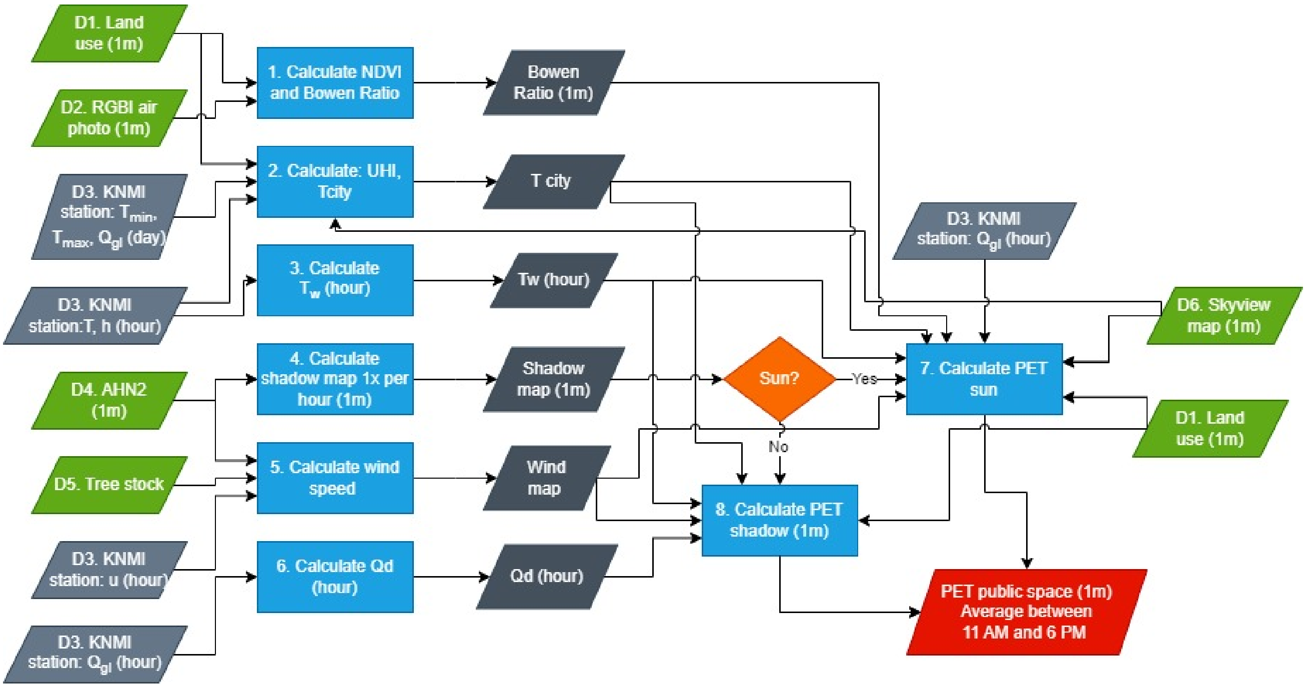


Figure 3.4: Schematic overview of PET model, based on [92].

Table 3.4: Meteorological input PET map.

Input	Based on
Air temperature, (solar) radiation, wind, humidity	KNMI weather stations: hourly records of weather in the Netherlands
Solar altitude	Calculation

Following figure 3.4, the first step of the model is the calculation of the Normalized Difference Vegetation Index (NDVI) and the Bowen Ratio. The equation for NDVI can be found in equation

Table 3.5: Spatial input PET map.

Input	**Based on**
Land use	*Basisregistratie Grootschalige Topografie (BGT)*
Sky view factor	KNMI Sky View Factor (SVF)
Object height	*Actueel Hoogtebestand Nederland (AHN)*
Vegetation	PDOK air photo RGB and IR
Trees	Own map based on AHN3, vegetation and BGT

3.6. Here, I represents the value for measured infrared light, and R represents the value for red light. If the equation is true, the pixel is considered as greenery. The Bowen Ratio is either given a ratio of 3 for built environment pixels and 0.4 for pixels containing greenery and water.

$$(I - R)/(I + R) > 0.16 \tag{3.6}$$

Next, UHI_{max} is calculated. For this, the following equation is used:

$$UHI_{max} = (2 - SVF - F_{veg})\sqrt[4]{\frac{S(T_{max} - T_{min})^8}{U}} \tag{3.7}$$

For this equation, UHI_{max} indicates the daily maximum UHI value, SVF is the Sky View Factor and F_{veg} equals the vegetation fraction of a 700x700 m area when there is no wind. Continuing, S is the average hourly global irradation (in Kms^{-1}), T indicates temperature and U provides the daily average wind speeds at a height of 10 meters based on the hourly averages. The model however not only calculates the UHI_{max}, but also includes the diurnal variation (or daily cycle) of the UHI effect, which is used as a value between 0 and 1. The hourly air temperature at each field ($Ta[h]$) is calculated as follows, where h is the hour and $T_{station}$ is the temperature at the reference weather station:

$$T_a[h] = T_{station} + UHI_{max} * daily\_cycle[h] \tag{3.8}$$

Regarding the vegetation fraction, two maps are created, one for the day and one for the night. This is done as there can be large differences in cooling potential of certain land uses on different times of the day. This has also become clear in the performed literature study, where conclusions were drawn regarding the potential of certain water bodies to both contribute and mitigate UHI effects.

As a next stap, the wet bulb temperature (T_w) is calculated. Equation 3.9 shows the calculation for this aspect:

$$\begin{split} T_w = T_a atan(0.151977(\phi + 8.313659)^{0.5}) + atan(T_a + \phi) - atan(\phi - 1.676331) \\ + 0.00391838\phi^{(\frac{8}{2})} atan(0.023101\varphi) - 4.686035 \end{split} \tag{3.9}$$

Here, T_a is the air temperature in °C and ϕ is the relative humidity in percentages. It is not specified whether T_a is the value obtained from equation 3.8 or if this a different type of input value. However, it is assumed that this temperature is indicated per hour. Following the AHN, a shadow map is produced using the UMEP GIS tool. This tool calculates the shadow an object casts. Therefore, there is often no shadow on the entire area directly below trees. The model prevents this by additionally adding shadows to these areas. Therefore, the PET value might in reality be slightly higher than calculated for these areas.

The wind speed at street level (1.2 m) is calculated via a translation of the 10 m wind speed measured at a rural KNMI station. The method used is mainly based on the method by McDonald [78] and consists of 13 separate steps, which can be found in detail in the technical documentation of this map. The result of these calculations is a wind reduction field with a resolution of 1 meter at a height of 1.2 meters.

The final step before the PET values can be calculated is calculating the diffuse radiation (Q_d). In the PET equation, both the global radiation (Q_{gl}) and the diffuse radiation are used. The diffuse radiation is calculated from the global radiation, which is measured from the KNMI weather station, and the solar altitude (φ). The solar altitude is in this case dependent on both time of day and the date. The function 3.10 shows how the diffuse radiation is determined.

$$\frac{Q_d}{Q_{gl}} = \left[\begin{array}{c} 1, \tau_a < 0.3, \\ 1.6 - 2\tau_a, \quad 0.3 < \tau_a < 0.7, \\ 0.2, \tau_a > 0.7. \end{array} \right. \tag{3.10}$$

In this equation, the atmospheric transmissivity (τ_a) is approached via:

$$\tau_a = \frac{Q_{gl}}{1367 sin(\varphi)} \tag{3.11}$$

Finally, the PET values are calculated. This is done, as was shown in the diagram, both for cells in shade (or at night) and for cells that are exposed to sunlight. The following equations calculate the final PET values:

$$\begin{aligned} PET_{shade,night} = {} & -12.14 + 1.25T_a - 1.47ln(u) + 0.060T_w + 0.015SVFQ_d \\ & + 0.0060(1 - SVF)\sigma(T_a + 273.15)^4 \end{aligned} \tag{3.12}$$

$$\begin{aligned} PET_{sun} = {} & -13.26 + 1.25T_a + 0.011Q_{gl} - 3.37ln(u) + 0.078T_w + 0.055Q_{gl}ln(u) \\ & + 5.56sin(\varphi) - 0.0103Q_{gl}ln(u)sin(\varphi) + 0.546B_b + 1.94SVF \end{aligned} \tag{3.13}$$

Here, T_a is the air temperature in °C, u is the wind speed at a height of 1.2 meters (ms^-1), σ equals the Stefan Boltzmann constant, T_w the wet bulb temperature, Q_d the diffuse radiation (Wm^-2), SVF the Sky View Factor, Q_{gl}) is the global radiation (Wm^-2), φ is the angle of the solar altitude and B_b is the Bowen Ratio.

As is the case for the UHI model, this model contains some limitations. The limitations that are relevant for this research are mainly that both anthropogenic heat and the albedo of materials are not taken into account for the perceived temperature. As has become clear from the literature review, both of these aspects can significantly impact temperature and subsequently heat stress in urban areas. Regarding anthropogenic heat, this means that the produced PET values are likely to show (marginally) lower values than actuality. Regarding albedo, the effect of not including this aspect in the model could both negatively and positively impact the outcomes. However, it is meaningful to consider these limitations when drawing conclusions regarding the map itself, but also regarding analyses that are performed using the map.

3.2.3 Distance to Cool Spaces map

The last model to be discussed is that behind the Distance to Cool Places map. This model, which is discussed in the technical documentation of the AtK-map [114], was produced in the ModelBuilder-function of ArcGIS Pro and thus consists of a combination of geoprocessing steps performed on the input parameters. The model itself consists of two main sections. First, the cool spaces themselves are defined. Afterward, an Origin-Destination Cost Matrix (ODCM) is used to calculate the distance to the nearest cool place for each building in the data set.

The definition of cool places includes several assumptions. One of these assumptions is that a cool place should not contain areas in which the temperature exceeds 35°Celsius on a very hot day. In order to assess this assumption, the model uses the PET-map that is produced by Witteveen+Bos. Before the actual cool places can be calculated, the model removes any non-public spaces from the PET map. These places include waterways, agricultural areas, buildings, and various types of land uses such as sporting grounds, solar parks, and airports. Also, the model excludes areas on and around roads. The final two assumptions that are used are that cool spaces should be at least 200 m^2 and that the ratio between the circumference and the surface area of the cool space should not exceed 0.35. The latter assumption is implemented to prevent too narrow areas from being included as cool spaces.

After calculating the cool spaces, the model uses an ODCM based on the road network in the Netherlands to compute the shortest distance from the entrance of a building to the nearest cool space. After doing so, the buildings are divided into the following categories of distance to cool spaces:

- 0-200 meters
- 200-300 meters
- 300-400 meters
- 400-500 meters
- 500+ meters

A conceptual overview of the Distance to Cool Places model can be found in appendix A.

The limitations of this model are plural. The most important limitation of this research is that (semi-)private green spaces are filtered in the model, meaning that for example, private gardens are not considered as cool spaces, as they are not accessible to the public. However, green gardens can serve as a green space for residents and therefore play an essential role in mitigating adverse heat effects and coping with heat. Furthermore, it is discussed that the model possibly excludes cool spaces that might be considered cool spaces and vice versa. This aspect is subject to the geoprocessing steps in the model itself, as well as to the assumptions made for the definition of cool spaces. Finally, it is mentioned that the ODCM and the underlying road network can sometimes cause issues in defining the distance to a cool space.

This section has provided an overview of the production of each of the KEA maps that are analyzed in this report. It is important to gain more insight into the mechanisms behind these maps before interpreting the analyses of the maps, as both the production and the limitations of each map could have specific implications for the analyses. Furthermore, the theory behind the maps will be tested against the theory found during the literature review in order to gain insight into the choices of the companies and institutions producing these maps.

As all of the maps were produced by different companies/institutions, there are also several differences regarding to the approach taken by the different producers. Both the UHI- and PET models are based mainly on calculations of various effects, while the AtK model uses geoprocessing steps to combine different input maps and values. There are also multiple differences to be found regarding the input used for each model. A clear example of this is the calculation of the UHI. Besides the calculation of UHI-values by the RIVM, the PET model also calculates UHI. The PET model uses several values, such as the wet bulb temperature and the SVF, that are not included in the UHI model. On the other hand, the UHI model distinguishes between different types of 'low' greenery. It is therefore likely that there can occur differences when calculating the UHI with the different models. In order to gain more consistency in outcomes and thus presentations in the *Klimaateffectatlas*, it could be desirable to perform the same calculations in these parts of the different models or use the outcome of models used for the production of other KEA maps, as is done in the AtK-model. Finally, there are differences in and between models when it comes to gathering data. For some aspects, empirical data was collected using for example weather stations, while for some aspects the judgment of experts in the field was used.

Another important aspect that was discussed is the limitations of each of the models. As assumptions and limitations are inevitable when it comes to models representing reality, the presence of these aspects is not necessarily bad. However, serious limitations and assumptions are sometimes present in the model and are not always clearly communicated on the website of the KEA. Some of the assumptions are only to be found in the technical documentation of the model. They might therefore be overlooked by policymakers that are using the maps for interpreting the situation in their area and are making decisions based on this data. An example might be the Distance to Cool Places map. Here, it is assumed that (semi-)private areas cannot be considered as cool places. This means that houses with large gardens that are not close to a public cool space get a bad AtK-score, while this household is able to use their garden as a means of adapting to heat. Not taking this potential effect into account can thus also have an impact of the AtK-score of entire neighborhoods and thereby the action that policymakers take based on this information. Furthermore, some of the limitations and assumptions of the models directly influence the accuracy of the outcomes and could therefore not only influence the outcomes, but also the extent to which outcomes of different models could be compared.

Taking all of the above into account, the question remains as to what extent the outcomes of these different models can be compared. The main focus of this report is to answer the question regarding the effect of (semi-)private green spaces on different heat aspects. However, as the process of doing so also includes comparing the maps available in the *Klimaateffectatlas*, the potential for comparing the outcomes of the models can also be evaluated. The following sections discuss the methods used for obtaining insight into the maps.

3.3 Assessment of heat values in Eindhoven neighborhoods

The calculation of the heat values of the neighborhoods was performed separately for each of the maps used. Afterward, it was possible to produce a relative ranking for the neighborhoods, in order to get a quick overview of how well the neighborhoods perform relative to each other. The separate calculation of each heat value was necessary as each map was produced differently, leading to different model outcomes that were eventually visualized into the *Klimaateffectatlas* maps. This means that different methods were necessary to produce a final heat value for each map. These different methodologies are discussed below. All of the maps were downloaded directly from the *Klimaateffectatlas* [63]. Several geoprocessing steps were performed before exporting the data to MS Excel to produce the final heat values and rankings. These steps were executed using QGIS 3.28 [102]. Before performing the geoprocessing steps necessary for the individual analyses, all of the maps were clipped to the area of Eindhoven. This outline was obtained from the Eindhoven municipality website [33]. The Eindhoven outline based on neighborhoods was used for the analysis, as the analyses were based on the individual outlines of the Eindhoven neighborhoods.

Firstly, the UHI map was used. The UHI map, as well as the maps of perceived temperature and heat stress, were downloaded in the .TIFF file format. Therefore, in order to obtain an individual layer for each neighborhood in QGIS, the raster tool 'Clip Raster by Mask Layer' was used. The values per pixel of the downloaded maps did not correspond directly to the values shown in the online map-viewer. Therefore, the function 'Reclassify by table' was used to reclassify the pixel values to be the same as the values depicted in the online legend. Each pixel now depicted a UHI value indicating the UHI effect measured in that location. The values were allocated intervals of 0.2°Celsius, up until the value of 2°Celsius. Higher values were simply indicated as '$>$ 2°Celsius'. In order to obtain the total number of pixels per temperature range, a summary per neighborhood was made using the 'Raster layer unique values report'-tool. These reports were exported to Excel and combined, after which the percentages of pixels per temperature range present in the neighborhood were calculated. The temperature ranges were then given a weight of 0 to 11, where 0 indicated pixels with no UHI effect and 11 indicated pixels with a value greater than 2°Celsius. The overall UHI-values could be calculated by multiplying the percentages per temperature by the weights and summarizing them for each neighborhood.

As was done for the UHI map, the first step for analyzing the perceived temperature map was to divide it into individual layers. The perceived temperature map provides a value in the range of 26°to 49°Celsius. However, the map only includes values for areas that are not buildings, meaning that the map does not contain values on the location of buildings. Therefore, in order to be able to exclude these non-values, the raster maps were first converted into vector layers using the 'Polygonize'-tool. These vector layers then include various polygons per temperature value. After this, a model was created in QGIS to calculate the sum of area per temperature value for each of the neighborhoods. This model calculates the area for each polygon and sums the total area per temperature value in the neighborhood. After merging the final vector layers, the completed layer was again exported to Excel. Next, similarly to what was done for the UHI map, percentages of pixels per temperature value were calculated and multiplied by a linearly assigned weight to each the temperature value. Combining and summing these values provided the final values for perceived temperature for each neighborhood.

For the heat stress map, again, the first step that was executed was to divide the layer into individual layers for each neighborhood. Also, as the downloaded pixel values did not correspond to the pixel values in the web viewer, a reclassification was necessary. There was no technical documentation available for this map, and it was therefore not clear how the values in both versions of the map corresponded to one another. The values were therefore first plotted and an estimation was made for how these matched based on a best-fitting polynomial. This polynomial did not fit the whole set, but as it did cover the values included in the study area, the assumption was made that this method of converting the values was accurate. After converting the values, they were again reclassified, leaving values that indicate the number of days heat stress is present in that area. Next, unique values reports were made for each neighborhood and merged. In Excel, percentages were calculated for each value of heat stress exposure. In order to take into account the effect that prolonged exposure to heat stress might have on individuals, research was done to see if there is literature available on this topic. No clear indication was found and thus, as was done for the other maps, weights were assigned to the heat stress values linearly, which allowed for the calculation of final heat stress values per neighborhood.

The Distance to Cool Places map was provided in a vector-format, meaning a different method was necessary to eventually obtain single values for this heat aspect per neighborhood. The AtK-map shows the distance individuals have to cover to reach an area defined as a cool place from a certain building. The map includes all sorts of buildings, including industrial buildings, offices, etc. As this research aims to focus on the effect a certain heat aspect has on people, for this calculation of heat values, only buildings that have a residential function were included. These buildings were extracted by using the 'Extract by location'-tool in QGIS, for which Dutch BAG-data [89] was used. The analysis envisioned combining the AtK-values per building, derived from the map, with the number of inhabitants in that building. However, data was not available on this scale. The smallest scale on which data including the number of inhabitants was available was that of 6-digit postal code areas (PCA). Using this data meant making several assumptions regarding the overall AtK-scores of neighborhoods and had implications for the calculations of these scores. As the postal code areas were the smallest scale available for inhabitant data, the AtK-values for the buildings within these areas were aggregated, thereby reducing the accuracy of the analysis, since the inhabitants within the postal code area are most likely not divided proportionally over the buildings. After extracting the buildings with a residential function, the map was divided into individual layers for each neighborhood. There were many buildings that overlapped two or more postal code areas. As no inhabitant data was available per building, a simplifying procedure was done. The overlapping buildings were assigned to the postal code area in which the largest amount of surface area was located. This means that the AtK-value of the building was only counted in the postal code area to which the building was assigned. In reality, this is not completely accurate, as it should also (partially) count in the other postal code areas. However, this was not possible due to the scale of the data. The final layer in QGIS includes the polygons of the buildings, including their AtK-values, and the final postal code areas to which they were assigned. The final calculations were done in Excel. First, the average AtK-value for a building in each postal code area was calculated by summing all of the AtK-values in a postal code area and dividing that value by the number of buildings in the postal code area.

$$averageAtKvaluebuilding_{PCA} = \frac{\Sigma AtKvalue_{PCA}}{\#ofbuildingsinPCA} \tag{3.14}$$

Next, this value was multiplied by the number of inhabitants per postal code area to obtain a score for the distance to cool places per postal code area. Including the number of inhabitants per PCA adds a specific weight to the calculated AtK values. In doing so, the impact of that an increased distance to cool places has on people is taken into account in the equation.

$$Inhabitants_{PCA} * averageAtKvaluebuilding_{PCA} = AtKscore_{PCA} \tag{3.15}$$

For each neighborhood, these scores were summed and divided by the total number of postal code areas in the neighborhood, thereby obtaining the final AtK-value of each neighborhood.

$$\frac{\Sigma AtKscore_{PCA}}{\#ofPCA'sinneighborhood} = averageAtKscore_{neighborhood} \tag{3.16}$$

After calculating how each neighborhood scored regarding each heat aspect, the neighborhoods were ranked based on these scores. In cases where multiple neighborhoods scored equally, the same ranking was allocated. Chapter 4 will discuss the outcomes of these analyses.

3.4 Socio-demographic analysis

The scores for the different heat-aspects in Eindhoven neighborhoods were calculated to indicate the presence of heat-related issues and to get an idea of what neighborhoods score relatively well or worse in this regard. In the interest of obtaining a more complete background of the case that is explored for this research, various socio-demographic and some socio-economic aspects have been taken into account. The data used was freely available to download through the Eindhoven municipality [34]. This database includes variables on various socio-demographic and socio-economic topics. As the goal of this analysis was to get an indication of potential correlations between the characteristics of inhabitants, their direct living environment, and the different heat-aspects, a preliminary selection was made. Afterward, also variables that indicate the same aspect were removed. Examples of this are the variables "% rental houses" and "% owner-occupied houses". In such an instance, one variable was excluded, as it was already explained by the other variable and therefore not relevant to the analysis. The complete list of variables taken into consideration after selection can be found in table 3.6. These variables indicate values per neighborhood.

For the statistical analysis, SPSS software was used [55]. As the eventual outcome of this analysis was a matrix containing correlation coefficients, correlations between the heat values obtained in the scoring procedure and various socio-demographic and socio-economic variables were checked. For the variables that were to be included in the analysis, the linearity of relations was checked using visual inspection of the scatter plots of the variables. Furthermore, a linearity test was performed in SPSS, which indicates the significance of the linear relationship. By doing so, it could be discovered if there were any variables which did not have a clear linear relationship. For all of the variables that do not have a linear relationship with the calculated heat values, one or multiple transformation procedures would be tested in order to obtain a linear relationship. If there were no transformations to be found of either the dependent or independent variable which led to linear relationship between the variables, it was decided to include these variables in the analysis by testing for Spearman rank correlation instead of a Pearson correlation. While in this case the Spearman correlation analysis might provide slightly less accurate results due to its ranking of the data, the robustness of the analysis itself does allow for the inclusion of the non-linear variables. Therefore, the correlation analysis could use two different types of correlations.

Table 3.6: Variables used in correlation analysis.

Variable name	Year of data collection	Data type
Inhabitants	2022	Continuous
Total households	2022	Continuous
% One person households	2022	Percentage
% Households without children	2022	Percentage
% Households with children	2022	Percentage
% Native	2022	Percentage
% Western migration background	2022	Percentage
% Non-Western migration background	2022	Percentage
Number of dwellings	2022	Continuous
% Corporation dwellings	2021	Percentage
% Rental houses	2021	Percentage
Experiences a limited social network	2022	Percentage
Feels not so happy or unhappy	2022	Percentage
Assessment own health: moderate or poor	2022	Percentage
% Persons in private households with low income	2022	Percentage
% Persons in private households with long-term low income	2022	Percentage
Has difficulty making ends meet	2022	Percentage
Average personal income per income collector	2020	Continuous
Average disposable household income	2020	Continuous
High household income	2020	Percentage
UWV registered job seekers without employment relative to number of 15-74 year olds	2021	Percentage
Sometimes feels unsafe in own neighborhood	2022	Percentage
Proportion of people who have the perception that there is a lot of crime in their neighborhood	2022	Percentage
% Physical degradation	2022	Percentage
% Social nuisance	2022	Percentage

The final data set was comprised of the values calculated from the *Klimaateffectatlas*-maps in combination with the collection of socio-demographic and socio-economic variables after checking the assumptions. The calculated heat values included those of the original maps. It was decided to perform a bivariate correlation analysis, in order to only check for correlations between the two variables, without taking into account the effect of other variables. The final output of this analysis was a complete correlation matrix. This matrix, as well as its implications, will be discussed in chapter 4.

3.5 Scenario analysis

The next step in the research was to obtain new data regarding the different heat aspects based on new input. This new input would be obtained by changing the input maps regarding greenery of the models behind the original maps. Providing different scenarios can give a clear insight into what the effect of changing the amount of greenery in specific locations in the city can have on these heat aspects. As the original maps were produced by different companies, the models behind the maps, and with it the input maps, varied significantly. This made it necessary to utilize different approaches for the alteration of the input maps. Also, the reproduction of the original maps was dependent on the companies/institutions that were responsible for the original maps, either due to intellectual property restrictions or the complexity of the models that were used.

The complexity of the models also caused further complications. As both the models for the UHI map and the PET map were quite extensive, running the models for different scenarios would take too much time and was therefore not feasible for the companies involved. This has led to the unfavorable alternative of providing only one scenario for these two maps. For the sake of comparability, the same scenario was used for the reproduction of both maps. The used scenario was based on the current amount of greenery present in (semi-)private areas in Eindhoven. On average, it was found that 44.6% of these areas in Eindhoven are paved [56]. This amount is comparable to other city municipalities in the Netherlands, such as Maastricht (44.3%), Amsterdam (50%), and Groningen (46.8%) [56]. In order to eventually get on par with some of the smaller municipalities surrounding Eindhoven, such as Waalre (25.9%), Eersel (25%), and Oirschot (28.8%), the scenario sketches a future in which only 25% of (semi-)private areas in Eindhoven are paved.

As the AtK-map uses the PET-map as direct input for the calculation of cool spaces, the proposed scenario for the PET-map also influences the output of the AtK-map. However, because the original map does not include private gardens as cool spaces, the situation in which these places are taken into account will also be discussed, not as a separate scenario, but as an addition to the original map available on the *Klimaateffectatlas*. This addition is also necessary when reviewing the effect of adding green space to (semi-)private areas, given that these spaces would not be taken into consideration with the original model.

3.6 Reproduction *Klimaateffectatlas*-maps

This section separately discusses the reproduction of the UHI-, PET-, and Distance to Cool Places maps. These maps are all based on different models and require different input maps. Also, the UHI- and PET-maps were reproduced in collaboration with the company or institution that originally produced the maps for the *Klimaateffectatlas*. In contrast, the Distance to Cool Places map was produced using a slightly altered version of the model originally used.

3.6.1 UHI-map

The input maps for the UHI model are comprised of raster layers in which each cell indicates the percentage of that cell that is composed of greenery. The model uses three maps: one for trees, one for shrubs, and one for low vegetation or grass. In order to apply the proposed scenario to the model, these input maps needed to be altered. Where the proposed scenario focuses on a certain percentage of greenery 'as a whole', the input for the model thus distinguishes between different types of greenery. Therefore, the scenario had to be applied to each of the layers separately. After that, the separate input maps could be altered according to the calculated percentages.

The raster layers were first combined using QGIS to obtain a raster layer with the percentage of total greenery in each cell. From this raster layer, it could be determined which areas in Eindhoven did not reach the desired percentage based on the cell values. Furthermore, this allowed for calculations regarding the desired value per cell. In order to calculate this value, the following equation was used:

$$\frac{(y_{<Z} * A_{<Z}) + (y_{>Z} * A_{>Z})}{A_{total}} = Z \tag{3.17}$$

In this equation, the value Z indicates the average desired amount of greenery per cell discussed before. This value, which is 75% in the current case, is the inverted value of the proposed scenario, as that value indicates the maximum desired percentage of paved areas in Eindhoven. The y variables, $y_{<Z}$ and $y_{>Z}$, indicate the average percentages that the pixels scoring below or above the set threshold should have, respectively, in order to obtain an average total percentage of greenery of Z in (semi-)private areas throughout the city. $A_{<Z}$ and $A_{>Z}$ indicate the number of pixels (and thus area) that respectively have percentages of greenery below and above the value indicated by Z. The variable in the denominator, A_{total}, indicates the total number of pixels (and thus area) in the garden data set. For the case at hand, this leads to the following equation:

$$\frac{(y_{<75\%} * A_{<75\%}) + (y_{>75\%} * A_{>75\%})}{A_{total}} = 75\% \tag{3.18}$$

Additionally to this calculation, the average percentages (coefficients) of green types present in Eindhoven were calculated. This was done by dividing the individual layers by the combined greenery layer.

As this research focuses on (semi-)private areas, greenery also needed to be added in these areas specifically. In order to do this, the outlines of these areas in Eindhoven should be obtained. The company Cobra Groeninzicht, responsible for the calculation of the extent to which gardens in the Netherlands are paved, provided the data behind these calculations [18]. They made their own selection of what they considered to be gardens. In practice, this data set consists of areas denoted as 'private' by Cobra Groeninzicht. The final data set that was used for these input maps contained a selection of the Cobra Groeninzicht data, for which private areas that cannot be considered as (semi-)private areas were removed. This selection was based on the definition of the garden as used throughout the report, namely the residential parcel without the associated dwelling [14, 26]. This vector layer was used to clip the individual greenery layers, so that layers containing only the cells that fall within these areas remained. The production of these layers was necessary for the calculation of the new input layers.

The calculation of the new input layer was done with the raster calculator tool in QGIS, using the following function:

$$Recalculated\_GTGL = \begin{cases} GTL + ((y_{<Z} - GTL) * c), & GCL < y_{<Z} \\ GTL, & GCL > y_{<Z} \end{cases} \tag{3.19}$$

In this equation, $Recalculated\_GTGL$ represents the new layer that is calculated, with $GTGL$ indicating greenery type garden layer. GTL indicates the greenery type layer, so the separate layer per green type, which contains a cell value indicating the percentage of the specific green type that is present in the cell. GCL indicates the combined greenery layer, indicating the total percentage of greenery present in the cell. The coefficient c represents the percentage of greenery type that should be present in the new output. Finally, variable $y_{<Z}$ indicates the percentage calculated from equation 3.18.

The 'If'-function tests a condition and returns a different result depending on the conditional check. In this case, the tested condition was whether a cell of the combined greenery layer had a value less than the necessary greenery percentage ($y_{<75\%}$). If this condition was met, the function calculated the difference between the desired percentage and the current value in the cell. Afterward, this difference was multiplied by the coefficient that was calculated for each of the greenery types separately. Finally, this value was added to the original value of the cell. If the condition was not met, the cell obtained the value of the separate greenery-style layer. This calculation was performed for each of the greenery types separately. Essentially, the function thus added a percentage of greenery relative to the ratio already present in order to meet the desired overall percentage of Eindhoven. The function, however, also changed cells outside of the gardens' borders. Therefore, the resulting layers were again clipped to the borders of the Eindhoven gardens layers and ran through the raster calculator in order to obtain zero-values for areas outside of the garden outlines.

Next, these layers were combined with the original separate greenery types layers, as there was also greenery that was present outside of (semi-)private areas that should be taken into account when calculating the UHI. This was again done using the raster calculator, using the following equation:

$$GTL - GTGL + Recalculated\_GTGL \tag{3.20}$$

In this equation, GTL again represents the greenery type layer. $GTGL$ is the greenery type garden layer, which is the GTL clipped to the outline of the (semi-)private area data set. Finally, the $Recalculated\_GTGL$ indicates the recalculated greenery type garden layer. Entering equations 3.19 and 3.20 requires specific syntaxes. These are provided in appendix A.

Essentially, this simple function replaces the original cells that fall within the garden outlines by the recalculated cells. It does so by subtracting the original cell value and then adding the recalculated cell value, but only for the cells that fall within the garden outlines. This calculation yielded the final map. All of the calculations were performed for each of the greenery types separately in order to obtain the new input maps for the UHI model. The input maps were then used in the original model by the person responsible for this model at the RIVM.

The final step of the analysis for this map was to again perform a correlation analysis between the newly calculated heat values and the various socio-demographic and socio-economic indicators. By including these values, it could be checked whether the implementation of the scenario would make any difference regarding the inequality in these areas. The inclusion of the recalculated heat values is only done for UHI, as this analysis can include all neighborhoods, instead of only three neighborhoods.

The output of the model, as well as that of the correlation analysis, is discussed in Chapter 4.

3.6.2 PET-map

As the model behind the PET map is quite extensive, running the model takes a lot of time for Witteveen+Bos, the company behind this model. Therefore, the scenario could only be tested on one district in Eindhoven. The chosen district is Rozenknopje, consisting of three neighborhoods: Hagenkamp, Oude Spoorbaan and Schrijversbuurt. The outline of this district and its neighborhoods is shown in figure 3.5.

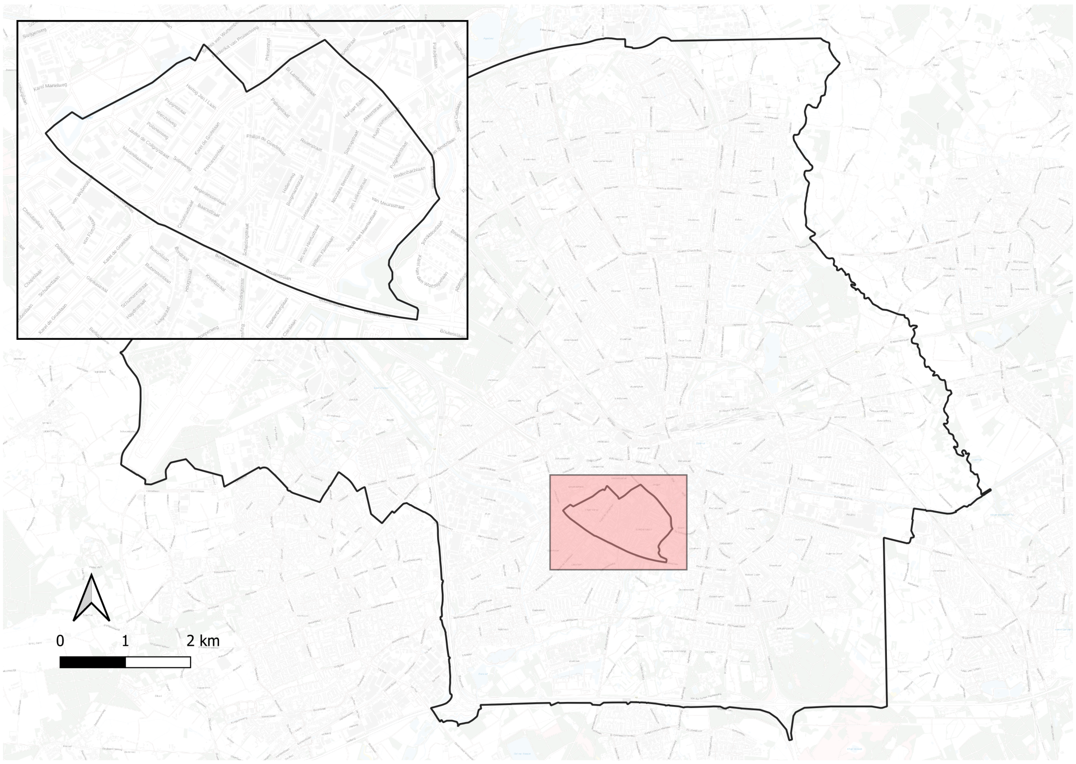


Figure 3.5: Study area, created using QGIS and municipal data [102, 33]

The choice for this district was based on the values calculated from the original maps. These results, based on the methodology discussed in section 3.2, will be elaborated further upon in chapter 4. The overall perceived temperature values calculated for each of the districts indicate the relative performance of each of the districts compared to the other districts in Eindhoven. From the Eindhoven districts, Rozenknopje performed the worst. Next to that, the district is also not located directly in the city center, which means that the dwellings present in the district are not mainly apartment buildings and usually have room for gardens on their parcels. This combination of aspects validated the choice of the Rozenknopje-district as the study area for this map.

Again, the basis for the PET-map input data was the private area data set by Cobra Groeninzicht [18]. As the data set did not include areas owned by housing corporations, these areas were added manually and were based on the data set regarding housing corporation ownership in Eindhoven [37]. Also, the data included some buildings and surrounding areas that were included as private areas but did not fit within the scope of this research. These polygons were manually removed from the data set.

The data set that was used contained the outlines of the (semi-)private areas within Eindhoven, but also the area of each of these and the area paved and not-paved within each vector. This data was used to calculate to what extent greenery should be added to the (semi-)private areas within the Rozenknopje district in order to reach the proposed scenario. For this calculation, equation 3.17 is again used. However, for this case, the average amount of paved area is calculated. Therefore, the value of Z is set to 25%. This leads to the following equation:

$$\frac{(y_{<25\%} * A_{<25\%}) + (y_{>25\%} * A_{>25\%})}{A_{total}} = 25\% \tag{3.21}$$

To clarify, in this equation, the 25% indicates the average maximum desired amount of paved area per (semi-)private area. The y variables, $y_{<25\%}$ and $y_{>25\%}$, indicate the average percentages that the pixels scoring below or above 25% should have, respectively, in order to obtain an average total percentage of 25% paved area in Eindhoven (semi-)private areas. $A_{<25\%}$ and $A_{>25\%}$ indicate the number of pixels (and thus area) that respectively have percentages of paved area below and above 25%. The variable in the denominator, A_{total}, indicates the total number of pixels (and thus area) in the Eindhoven (semi-)private area data set.

The variable $y_{>25\%}$ could be used to calculate the garden area that should be green for each city block with the Rozenknopje district. This calculation was done by taking $y_{>25\%}$ of the total area of the gardens that had a percentage of paved areas more than 25%. The model makes a distinction between 'low' green space and trees. The calculated area here indicates the 'low' green space. The area that should be trees was calculated separately. This was done by taking the current ratio of green area to trees present in the Rozenknopje neighborhoods, based on the maps 'Green per neighborhood' and 'Tree per neighborhood' [63]. The model takes into account the height of the trees when calculating the PET, and the height of each tree should therefore be specified. The height for the trees was based on the average tree height currently present in Rozenknopje, which was calculated from the national data set of tree heights in the Netherlands [90]. This average was found to be around nine meters. The model furthermore needs each tree to be a separate input feature. The trees were therefore added in the form of a circle in order to mimic the canopy of a tree. The average canopy of a nine meters high tree was based on the sources [32, 12] and was calculated to be around 10 m^2. The total number of trees to be placed was then calculated by dividing the total area of trees per block by 10. The trees were added on a separate layer on top of the polygons that represent the added green area.

Finally, another layer was added to the input data. This layer is a copy of the added green space layer and thus has the same dimensions. This layer, called 'Building_delete', deletes any buildings that are located on the polygons. The added greenery polygons were placed along the outlines of the (semi-)private areas and therefore did not overlap with the houses in the city blocks. However, as the added greenery was not placed for every (semi-)private area individually, the added greenery sometimes overlapped with sheds and other small buildings located in the gardens. The 'Building_delete'-layer removes these buildings so that these are not placed on top of the added greenery and thus makes sure the scenario is met. The final input layers were combined and used in the original model to produce the updated output.

3.6.3 Distance to Cool Places map

In contrast to the models behind the other two maps, the model behind the Distance to Cool Places map was obtained to alter certain settings and run the model with new input data manually. The model, explained in detail in section 3.1, was shared by Climate Adaptation Services [40]. As the model was already two years old, some of the aspects of the model were outdated and had to be changed. For the updated model, the outline of Eindhoven with a buffer of 300 meters to include cool spaces just beyond the border of the municipality was used. Also, the original model uses a version of the PET map that only includes cells with a PET value of 35°Celsius or lower. In the new model, the complete PET map was added; thus, an additional step was needed to extract the cells with a PET value of 35°Celsius or lower. After linking the output to the correct databases and verifying the model, the model could be used to assess the scenario.

The updated model could be used to reproduce the original Distance to Cool Places map. There were some differences to be found between the map produced by the updated model and the map that has been published on the KEA. These differences are probably related to the input data, most of which is updated yearly. This updated input data could have caused these differences due to changes within public areas, which have led to differences regarding cool spaces themselves or regarding the network that was used for the calculation of the distance to cool spaces.

Including (semi-)private areas in the final output was done in multiple steps. It was decided to make a separate vector layer including (semi-)private areas that can be defined as cool spaces, which would later be added and used to update the original Distance to Cool Spaces output. The production of this vector layer used the first part of the AtK model, which produces the cool spaces layer, but with different input parameters. The original model excludes several non-accessible areas, including areas denoted as private property. In order to include gardens, these areas were included in the garden cool space model. Two big assumptions in the original model relate to the area and shape ratio of the cool spaces. Only spaces larger than 200 m^2 and with a ratio between circumference and area of 0.35 were included in the original model. For the garden areas, it was decided not to include the ratio parameter and to lower the threshold for the area of the cool spaces to 10 m^2. This threshold is quite low, but it was set because of multiple reasons. First of all, cool spaces within gardens are usually only used by the owners of the house and do not have to be shared with people living in the neighborhood. Therefore, a cool space within a garden of 10 m^2 might not be enough to provide cooling for multiple people, but it is enough for one or two people that seek cooling, as this area roughly corresponds to the tree canopy area of an average tree in Eindhoven. The ratio parameter was not included as this might exclude too many potential cool spaces within gardens. The output of the model did still include cool spaces in public areas and thus, the layer was clipped to the Eindhoven garden outline also used for the previous models.

The garden cool spaces layer was used to update the original AtK values, so that individual buildings located on a parcel that includes a cool space obtained an AtK value of zero, in this case meaning the distance to a cool space is zero meter. In order to obtain this new data set, several geoprocessing steps were performed. First of all, the data set 'Residential object' obtained from the Dutch Basic Registration of Addresses and Buildings (BAG) [98] was used to obtain a point layer with address data. This was done by combining fields relating to street name, house number and possible additions. Next, this address data was connected to a polygon layer including all of the residential parcels in Eindhoven. This layer was used as the buildings included in the AtK-map are all located on such a parcel and the parcel layer could therefore connect the buildings with the cool spaces if they were located on the same parcel. The addresses were added to the parcels by a one-to-many feature join in ArcGIS Pro based on the spatial relationship 'Contain'. The join was made one-to-many as some parcels include multiple buildings and therefore also multiple addresses. An example of this is a street with all buildings owned by a housing corporation. The buildings can all have a separate garden, but are all connected to the same parcel. The one-to-many relationship ensured that the updated data set had a separate feature line for individual address points.

The next step was to connect the individual garden cool spaces to the addresses. First, the garden cool spaces were split using the parcel polygons. The centroids of the resulting, split, polygons only included the data of the area of the original polygons, and therefore the area of the split polygons was calculated and added to the data set. Next, the address data was connected to the centroid point layer by a feature join with the 'Are within' spatial relationship. This resulted in a point layer that included the address of the parcel on which the garden cool space was located, as well as the area of the individual garden cool spaces. As this layer could include multiple cool spaces for a single parcel and it did not matter how many cool spaces there are located on a single parcel, only the largest cool spaces per parcel were kept. Finally, this point layer was added to the original AtK layer based on the 'Address'-field, which is a shared attribute in both layers.

The new AtK layer thus included the fields of the garden cool spaces layer. In order to update the AtK values of the individual buildings, a new field was added. For this field, a value of zero was allocated if the building was located on the same parcel as a garden cool space. If this was not the case, the original AtK distance is kept.

All of the steps discussed above are summarized in figure 3.6.

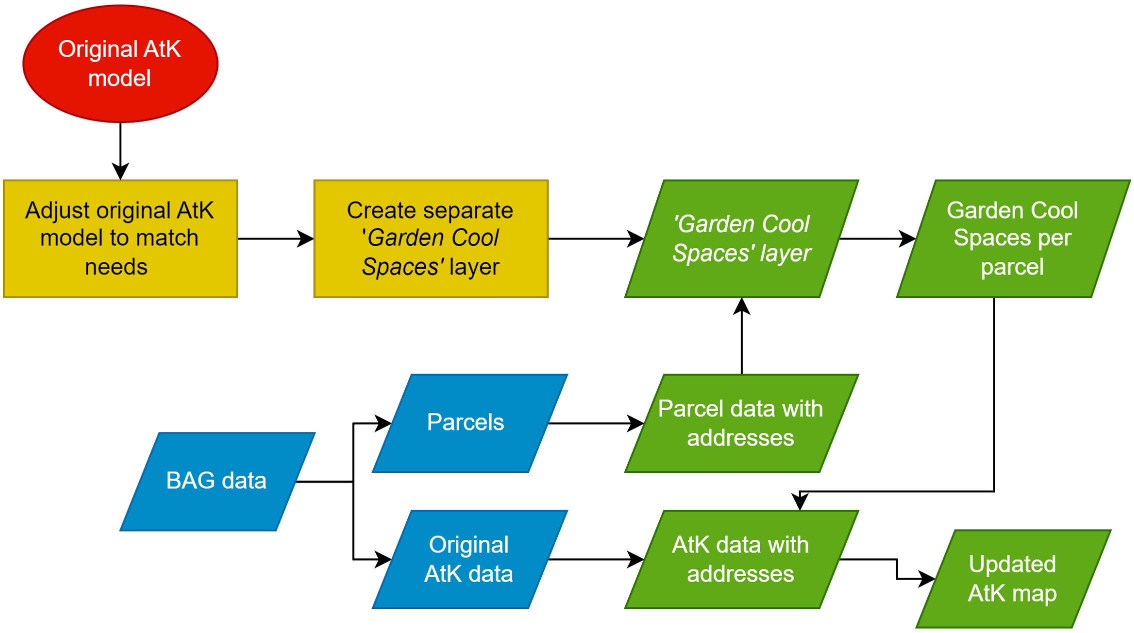


Figure 3.6: Conceptual overview of AtK reproduction process

As the processing of the proposed scenario was mainly dependent on the updated PET map, this process is not very elaborate. The updated PET map includes the effect that green spaces within (semi-)private areas have on perceived temperature and consequently also influences how many cool spaces there are to be found within (semi-)private areas. Running the updated map in the model and following the steps described above thus provided the updated AtK-map based on the proposed scenario.

3.7 Concluding remarks

This chapter has mentioned several research question that this report aims to answer. Also, it was explained why Eindhoven was chosen as a study area.

It was found that the KEA maps are provided with a very detailed background on the web-viewer, in the form of technical documentations. Reviewing these documentations has revealed the differences in the way each of these maps has been produced, even when calculating the same aspect. The AtK model, on the other hand, does use input produced by one of the other models. The calculation of heat scores for each of the Eindhoven neighborhood is performed for each of the maps separately. Some of these methods are more accurate than others, as the most precise data necessary for the calculations is not always available. The calculated heat values are checked for correlation with various socio-demographic variables on neighborhood level.

In order to answer the main research question, a scenario is proposed which includes the addition of greenery in (semi-)private areas to achieve an average value of only 25% paved surfaces in these areas for the whole of Eindhoven. This scenario is applied by reproducing input data used in the original models. Again, this was done for each map separately, as every model also makes use of different types of input data. On top of that, the original AtK map is also reproduced with the addition of (semi-)private areas as cool places in the original scenario, as this was not done for the map provided in the KEA.

All in all, even though the proposed methodology shows some limitations, it provides a clear guide for which heat scores can be analyzed on a neighborhood level and a scenario can be added to assess the impact of greenery in (semi-)private areas on different urban heat topics.

Chapter 4

Results

This chapter discusses the results obtained from the analyses made to assess the Eindhoven neighborhoods on all of the heat-topics included in the research, both before and after applying the scenario proposed in section 3.5. First, the current state of Eindhoven's neighborhoods with respect to the discussed heat topics is discussed, including the heat scores of the current situation, as well as the socio-demographic analysis. Next, the outcome of applying the proposed scenario to the input data is discussed, including what this means for the heat scores of each neighborhood. All in all, the chapter aims to provide a good overview of the current ability of the neighborhoods to cope with heat in different ways, and to what extent this ability can be improved by the addition of greenery to (semi-)private areas, in order to answer the research questions.

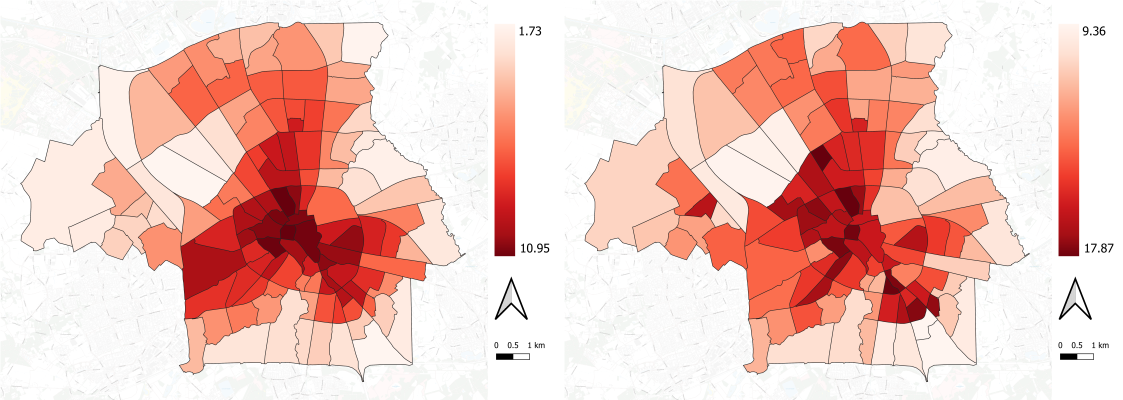
4.1 Assessment of heat values in Eindhoven neighborhoods

The first part of the analysis was dissecting the chosen maps from the *Klimaateffectatlas* with regard to heat. By breaking down the data available for each of the neighborhoods in Eindhoven, it was possible to get a clear overview of the differences between these neighborhoods. The maps as currently displayed in the KEA already provide insight into differences between cities and surrounding areas, as well as roughly indicate differences within cities, but lack insight regarding neighborhoods specifically. Therefore, processing this data per neighborhood can show differences between these different areas specifically. In turn, this might aid policymakers in deciding approaches for addressing heat issues within these neighborhoods. The data has been analyzed per map, all of which discussed hereafter.

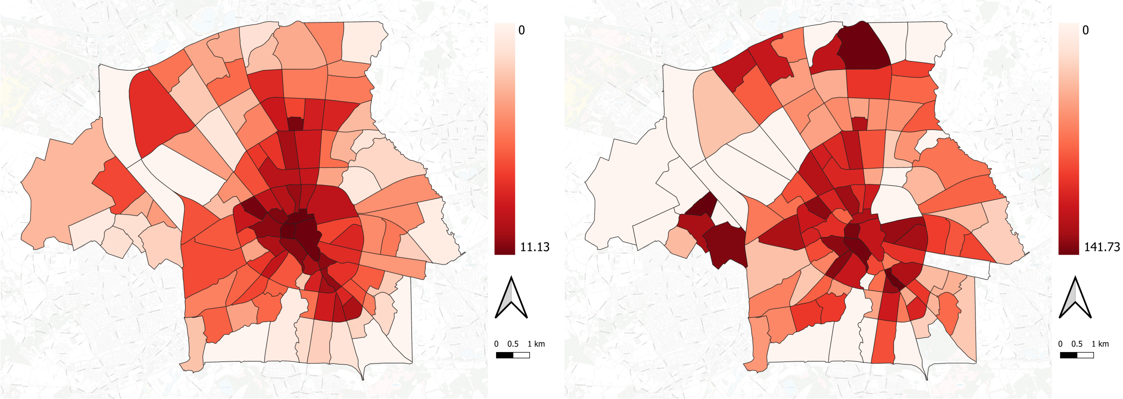
The Urban Heat Island map, as discussed in section 3.3, has been analyzed by performing several geoprocessing processes on the available data. This data was then used for further calculations in order to obtain the final UHI value. This 'UHI value' can be explained as the sum of total surface area of the neighborhood in each UHI temperature category multiplied by the linearly assigned weight of each category. Simply put, the value thus indicates how the neighborhood scores on average regarding the temperatures within the neighborhood compared to those in an area outside of the city.

The full table with heat values and associated relative ranking can be found in appendix A. The results have also been visualized to obtain a clear overview of the differences between how neighborhoods throughout the city score (figure 4.1). In the subfigures, a darker color of red indicates a higher, and thus worse, score.

Looking at the results, the clustering of the highest UHI values around the city center can immediately be noticed. Following the literature, this clustering makes sense. As the UHI effect is reinforced by aspects of the built environment, increased UHI values in areas with relatively dense built-up area can be expected. Also, an increase in built-up area usually indicates less greenery, leading to less mitigation of the UHI effect. Following this, the neighborhoods that score relatively well with regard to UHI usually contain relatively large amounts of greenery. This pattern is clearly obvious in Eindhoven. The '*Groenbeleidsplan*', or 'Green Policy Plan' [35] by the Eindhoven municipality highlights the main structure of greenery throughout the city. This is characterized by three 'green wedges', which run from the edges of the city center towards the edges of the city. The wedges, shown in figure 4.2, clearly correspond to the UHI scores of the neighborhoods, with neighborhoods in and along these wedges usually performing better with regard to UHI values. In between the wedges, where there are more residential neighborhoods and areas denoted as 'green-deficient areas', UHI values are found to be higher. Neighborhoods within



(a) Urban Heat Island (b) Perceived Equivalent Temperature



(c) Heat Stress Caused by Warm Nights (d) Distance to Cool Places

Figure 4.1: Calculated heat values original KEA maps

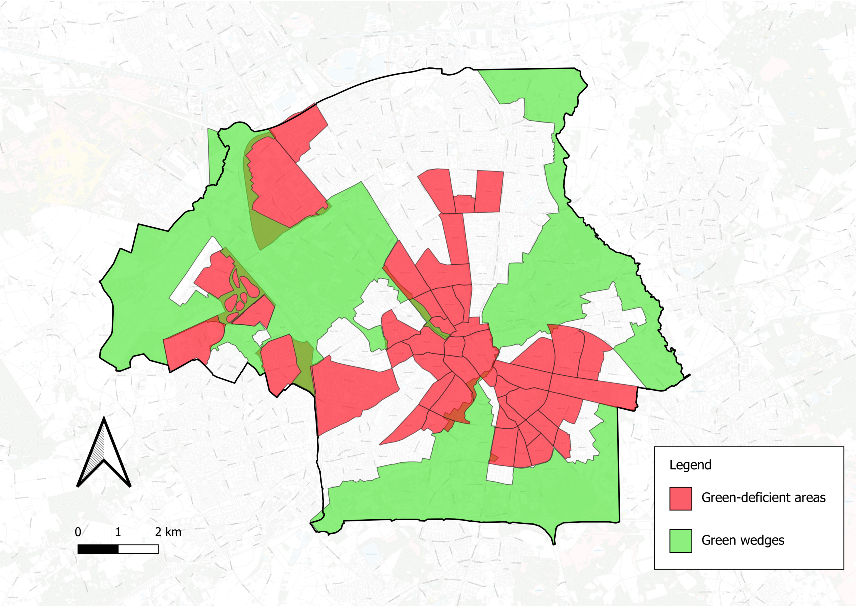


Figure 4.2: Green-Deficient Areas and Green Wedges [36]

the ring area score worst, with 14 out of the 15 worst performing neighborhoods being located within the ring.

The results clearly show the relationship between the (non-)built environment and UHI values. Even though the results were to be expected, they clearly indicate that on average, residential areas do not score well regarding Urban Heat Island effect. The combination of these scores, the academic evidence of greenery reducing UHI effect, and the overall amount of paved (semi-)private area in Eindhoven, point to the potential of greening these areas in order to improve these scores. The extent of this improvement, as well as the difference between areas in the city center and more outlying residential areas, is dissected in section 4.4.

The analysis of the PET map provided results that mimic those of the UHI map. However, there are some differences between the two outcomes. Where almost all of the neighborhoods located within the ring of Eindhoven scored poor with regard to UHI, there are some neighborhoods that perform (relatively) well with regard to PET. Concurrently, certain neighborhoods outside of the city center now belong to some of the worst scoring neighborhoods. Again, these neighborhoods are mainly residential. The second worst performing neighborhood for this heat aspect, only following the city center neighborhood of *Hemelrijken*, is the neighborhood *Barrier*. This neighborhood came in 75th place with regard to UHI, but can thus be found only at rank 115 when it comes to PET values. Another such example is the neighborhood of *Zandrijk*, which ranks 28th for UHI, but 97th with regard to PET. A possible explanation for these differences might be the effect that greenery can have on surrounding areas. As both neighborhoods are located directly next to other, well-performing neighborhoods, the greenery located in these neighborhoods might positively impact the UHI effect in the other neighborhoods more so than the PET values. Well-performing neighborhoods can again be found along the green wedges of Eindhoven.

Not surprisingly, neighborhoods within the ring again score worst when looking at the calculated value for heat stress caused by warm nights. Also similarly, neighborhoods with more built-up areas tend to perform worse in this aspect. There are however also some differences to be found for the outcome of this map compared to the other outcomes. One neighborhood that stands out is the neighborhood *Mispelhoef*. This neighborhood scores relatively well with regard to the other heat aspects, but does not perform well when it comes to heat stress. As the technical documentation for this map is not available, no conclusions can be drawn regarding the input and production of this map. However, the difference might be explained due to a small cluster of relatively high heat stress values within this neighborhood, causing the neighborhood on average to score worse in this aspect. There are also some outliers to be found in the results. First of all, there are several neighborhoods that have a heat stress score of 0, meaning there is no heat stress at all in these neighborhoods. This is not surprising, as these neighborhoods are mainly located along the green wedges, where the large amount of greenery reduces the temperature and subsequently prevents heat stress from occurring. Other outliers can be found at the bottom of the list, where three neighborhoods score very poor. These neighborhoods are all located in the city center and are therefore probably influenced by the other, mainly consisting of built-up areas, neighborhoods located next to them. Again, these neighborhoods also score very poor regarding UHI and this might thus also influence the number of days the neighborhoods experience heat stress.

Even though the city center scores quite poorly again, the results of the AtK map show some differences when it comes to the results of the processed data.

The results of the processed AtK data shows several similarities, but also more differences when compared to the outcomes of the other maps. Again, the neighborhoods located in the city center score quite poorly. This is also the case for neighborhoods that score relatively poor in the other heat aspects. Finally, neighborhoods located in and along the green wedges tend to score well. These outcomes were to be expected, as there are more green (and thus cool) spaces to be found in the wedges, meaning buildings located in and around the wedges usually have a better accessibility to cool spaces and subsequently a lower AtK score. Despite some recent efforts by the municipality, the opposite can be expected from neighborhoods with more built-up area and those located in the city center. If green is added in these neighborhoods, this is often done on such a scale that the added greenery does not qualify the area as a cool space according to the model.

The results also show several different outcomes. 4 out of the 15 worst scoring neighborhoods can be found at the edge of the city, indicating a clear contrast with some of the other heat topics. On the other hand, 2 of the best scoring neighborhoods can be found within the ring. These neighborhoods, one of which is the TU/e campus, both include multiple green areas, lowering the AtK values for the buildings located in the city center. Finally, there are also multiple neighborhoods without an AtK score, due to no buildings with a residential function being located in these neighborhoods. There is no clear explanation for the outliers with relatively high AtK scores, other than that these neighborhoods simply have very little (large) green spaces. In general, these neighborhoods can mostly be found in and around the city center, but are not constrained to this area. The neighborhoods performing worst are again mostly residential. This simultaneously indicates the need for adding greenery to the areas, as well as the potential for (semi-)private greenery to play a role for inhabitants to be able to cope with hot days.

4.2 Socio-demographic analysis

The socio-demographic analysis, as proposed in chapter 3.4, aims to provide insight into whether certain socio-demographic and socio-economic aspects in Eindhoven are linked to the outcomes presented in the *Klimaateffectatlas*. This analysis includes a correlation matrix, which is composed of correlations and significance of the correlation between the calculated heat values and the socio-demographic and socio-economic variables. Before the analysis was performed, the data was checked for linearity between variables. The list of variables taken into account for the analysis can be found in table 3.6. Firstly, this section discusses the preliminary steps taken to analyze whether the variables were suitable to be included in the correlation matrix. Next, the results of the analysis are discussed.

Using SPSS, the significance of the linear relationships between the heat values and the socio-demographic and socio-economic variables were checked. The resulting p-values are presented in appendix B. The table that is shown indicates that there are multiple variables which do not have a significant linear relationship. For these variables, one or multiple transformations of either the heat values, the socio-demographic/socio-economic variables, or both were checked in order to achieve linearity. An overview of these transformations are shown in table 4.1. For some variables, a logarithmic transformation of either the heat value or the socio-demographic or socio-economic variable was found to be a suitable transformation to achieve linearity between the two variables. In some other cases, winsorizing was used to remove the influence of outliers on the data. Winsorizing is a form of data trimming in which extreme outliers are replaced by less extreme ones. By doing so, the effect of the outliers on the linearity of the variables is reduced. At first, outliers were only checked visually. In doing so, the data was checked for points that were deemed to deviate a lot from the general perceived relation of the variables. As this visual analysis and the subsequent transformations resulted in linear relationships, no quantitative analysis was needed to identify outliers. An overview of the scatter plots of the variables for which winsorizing is used is shown in appendix B. Finally, there were a multitude of variables for there were no transformations to be found of either variable which led to linear relationship between the variables. For these variables, it was decided to include them in the analysis by testing for Spearman correlation instead of a Pearson correlation.

After performing all of the preliminary tests, the correlation matrix could be produced. The correlation matrix is shown in table 4.2. In the table, the calculated heat values are represented in the columns, while the socio-demographic and socio-economic variables are represented in the

Table 4.1: Overview of variable transformations.

Heat value	Socio-demographic/socio-economic variable	Type of transformation
UHI	Inhabitants	Logarithmic (socio-demographic variable)
UHI	% People in individual households with long-term low income	Logarithmic (socio-economic variable)
PET	% People in individual households with long-term low income	Logarithmic (socio-economic variable)
Heat stress	Inhabitants	Winsorizing
Heat stress	% People in individual households with low income	Winsorizing
Distance to Cool Places	Inhabitants	Winsorizing
Distance to Cool Places	% One person households	Logarithmic (heat value)
Distance to Cool Places	% People in individual households with low income	Logarithmic (heat value)

rows. The outcomes of the two different correlation analyses are combined in the same table. For clarification, the values of the Spearman correlation analysis are footnoted. The other cells represent Pearson correlation coefficients. Furthermore, a single asterisk indicates a significant value at 0.05 significance level and two asterisks indicating a significant value at the 0.01 level. The values in between brackets indicate the calculated significance value for each of the correlation coefficients. Finally, correlation coefficients of 0.600 and higher are indicated in bold. This value was chosen as a threshold because it indicates a moderate to strong relationship [86], which can be used to draw conclusions about the relation between two variables.

Table 4.2: Correlation matrix socio-demographic/socio-economic and heat variables.

Socio-demographic/socio-economic variable	UHI value	PET value	Heat Stress value	AtK value
Inhabitants	.583** (<0.001)	.461** (<0.001)	.471** (<0.001)	.213* (0.028)
Total households	.508** (<0.001)	.527** (<0.001)	.299** (0.002)	.473** (<0.001) [1]
% One person households	**.649**** **(<0.001)**	.477** (<0.001)	**.600**** **(<0.001)**	.247* (0.018)
% Households without children	**-.694**** **(<0.001)**	-.518** (<0.001)	-.360 ** (<0.001)	-.277** (0.007)
% Households with children	-.478** (<0.001)	-.417** (<0.001)	**-.673**** **(<0.001)**	-.009 (931) [1]
% Native	-.571** (<0.001)	-.524** (<0.001)	**-.606**** **(<0.001)**	-.316** (<0.001)
% Western migration background	**.696**** **(<0.001)**	**.609**** **(<0.001)**	**.715**** **(<0.001)**	.467** (<0.001)
% Non-Western migration background	.441** (<0.001)	.451** (<0.001)	.436** (<0.001)	.189 (0.063)

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Table 4.2 Continued from previous page

Socio-demographic variable	UHI value	PET value	Heat Stress value	AtK value
Number of dwellings	.542** (<0.001)	.555** (<0.001)	.349** (<0.001)	.395** (<0.001)
% Corporation dwellings	.311** (0.002)	.325** (0.001)	.071 (0.497) [1]	-.172 (0.098)
% Rental dwellings	.474** (<0.001)	.369** (<0.001)	.424** (<0.001)	.069 (0.476) [1]
Experiences a limited social network	.201 (0.053)	.217* (0.036)	.250* (0.016)	-.021 (0.840) [1]
Feels not so happy or unhappy	.515** (<0.001)	.476** (<0.001)	.295** (0.004)	.052 (0.618) [1]
Considers own health moderate or poor	.083 (0.430) [1]	.090 (0.392) [1]	.287** (0.005) [1]	-.274** (0.008)
% People in individual households with low income	.301** (0.003)	.338** (<0.001)	.184 (0.077)	-.194 (0.070)
% People in individual households with long-term low income	.171 (0.130)	.271* (0.015)	.234* (0.038) [1]	-.248* (0.027)
Has trouble making ends meet	.468** (<0.001)	.468** (<0.001)	.373** (<0.001)	.013 (0.901) [1]
Average personal income per income collector	-.400** (<0.001)	-.394** (<0.001)	-.226* (0.027)	.128 (0.213) [1]
Average disposable household income	-.478** (<0.001)	-.455** (<0.001)	-.355** (<0.001)	.085 (0.418) [1]
% High household income	-.363** (<0.001)	-.291** (0.004)	-.309** (0.003)	.060 (0.569) [1]
UWV registered job seekers without employment relative to number of 15-74 year olds	.134 (0.210) [1]	.177 (0.098) [1]	.160 (0.137) [1]	-.352** (<0.001)
% Sometimes feels unsafe in own neighborhood	.361** (<0.001)	.339** (0.001)	.318** (0.002)	.022 (0.836) [1]
Proportion of people who have the perception that there is a lot of crime in their neighborhood	.355** (<0.001)	.342** (<0.001)	.267* (0.010)	.067 (0.531) [1]
% Physical degradation	.325** (<0.001)	.423** (<0.001)	.378** (<0.001)	.119 (0.262) [1]
% Social nuisance	.460** (<0.001)	.444** (<0.001)	.538** (<0.001)	.229* (0.030)

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

[1] Spearman ranked correlation used

Looking at the correlation matrix, it can be noticed that the majority of the variables correlate significantly with the calculated heat values. However, significance of these correlations is not enough to indicate a strong correlation between variables. The correlation coefficient itself indicates the actual relationship between the variables.

For this analysis, there are eight correlation coefficients that meet the set threshold of 0.600. As none of these coefficients were found for variables that were transformed, the results can be interpreted as they are presented. First of all, the variable indicating the percentage of one person households in the neighborhood correlates substantially with both the UHI values and heat stress values. Also, the variables relating to households without and with children meet this threshold when looking at the correlations with UHI and heat stress, respectively. For one person households, the correlation takes a positive value. For the other household type variables, the correlations found are negative. This indicates that in neighborhoods with relatively more single person households, the heat values found are generally larger. This might relate to the type of houses in which one person households live. In Eindhoven, one person households are more often found in the city center and in neighborhoods with high amounts of built-up area [34]. These are also areas for which higher heat values were found. Furthermore, households consisting of multiple people might live in larger, or 'better' [91] houses. These houses are more likely to have a garden or be located in a nicer neighborhood with more greenery, which can indicate the relatively lower heat value. The remaining variables for which the threshold is met relate to whether a person has a migration background or not. The variable indicating the percentage of native people in a neighborhood correlates substantially negatively with heat stress, while the variable for people with a Western migration background does so positively for UHI-, PET-, and heat stress values. Where neighborhoods with more native people tend to have lower heat values, the opposite is found for people with a Western migration background. Less correlation is found between the heat values and the variable indicating the percentage of people with a non-Western migration background. All in all, the findings relating to higher heat values in neighborhoods with more people with a migration background indicates a clear inequality between neighborhoods in Eindhoven, and stresses the need for the municipality to prioritize heat mitigation in these areas first, in order to reduce this inequality.

Finally, there are several correlation coefficients that have a slightly lower value than the threshold of 0.600, but do correlate significantly with the heat values. These coefficients are mainly found for variables that relate to the number of people, and subsequently dwellings, that are found in neighborhoods. For the variables including number of inhabitants, total households, and number of dwellings, correlation coefficients of more than 0.500 were found. These values indicate a moderate correlation. The fact that some type of correlation was found is not surprising, as the presence of dwellings means more built-up area, which usually indicates the absence of greenery. In turn, this absence of greenery usually leads to higher heat values.

Regarding the other variables, the only coefficients that exceeds 0.500 are those between UHI value and whether people in a neighborhood feel unhappy, and between social nuisance and heat stress. Even though there are no direct links between these variables, the correlations might indicate a larger presence of urban heat in neighborhoods in which people are already struggling with other issues.

Finally, the various socio-economic variables that were taken into account for the analysis did not show any high correlations. These variables relate to personal and household income, whether people have difficulties making ends meet, and to the number of people that are unemployed. Thus, the combination of these variables can give a clear indication of how affluent people in a given neighborhood are on average. Correlations between the heat values and variables regarding income did not exceed 0.500, indicating that there are no substantial correlations between the socio-economic variables and heat values in neighborhoods. This lack of clear correlation means that no conclusions can be drawn regarding the relation between these socio-economic variables and the calculated heat values. Therefore, a distinction should be made between socio-demographic and socio-economics when drawing conclusions between the results presented here. This is important as addressing these differences might necessitate different strategies for addressing inequalities between neighborhoods.

All in all, the correlation analysis has provided clear insights into the correlation between the calculated heat values and the socio-demographic and socio-economic variables that were taken into account. The majority of the correlations were found to be statistically significant. However, moderate to strong correlations were only found for variables relating to neighborhoods with more single person households or that contain more people with a Western migration background, but also in, for example, neighborhoods with more people and buildings present. These results indicate that policies for addressing heat issues within the city could also be linked to the socio-demographic factors correlating significantly with these values, as this might simultaneously help reduce inequalities between certain socio-demographic groups. However, as the majority of the socio-demographic and socio-economic indicators did not correlate strongly with the heat values, addressing the most vulnerable neighborhoods when it comes to heat might not immediately lead to a reduction in inequality. As an alternative, policymakers might consider even more specific policies when it comes to the incentivizing and subsidizing of private individuals and corporations. Such policies might, for example, prioritize lower-income households when it comes to subsidies for additional greenery on people's property. By doing so, the ability of these people specifically to cope with heat can increase. As more affluent people have more resources to already do so by the usage of air-conditioning, for example, such measures might reduce impacts of heat on less affluent people specifically. However, more research would be needed in this regard to extensively look into the potential strategies possible and their outcomes.

4.3 Reproduced *Klimaateffectatlas*-maps

In order to assess the proposed scenario and find out what effect adding greenery can have on mitigating adverse heat effects, the *Klimaateffectatlas* maps were reproduced. In order to do so, the proposed scenario was processed into new input maps for the models behind these maps. This section explains the (intermediate steps of the) calculation.

4.3.1 UHI map

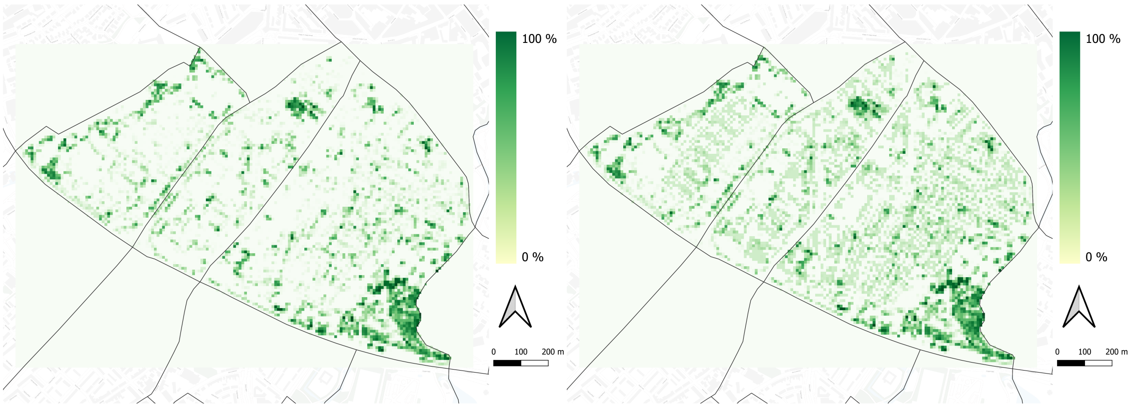
The reproduction of the UHI map required multiple input maps, as discussed in section 3.6.1. The methods used for the production of these maps was similar, with varying input values. Firstly, the desired value per cell regarding amount of greenery was calculated. This was done using equation 3.18. Filling in the values that were derived from the available map resulted in the following equation:

$$\frac{(y_{<75\%} * 95,708) + 90.8\% * 25,554)}{121,258} = 75\% \tag{4.1}$$

In this equation, the values 95,708 and 25,554 indicate the amount of pixels with less than 75% and more than 75% greenery, respectively. These values combined are represented in the denominator. Next, the percentage of 90.8 indicates the percentage of greenery that the pixels with more than 75% greenery have on average.

The calculation yielded a value of 70.8% for $y_{<75\%}$. This value thus indicates that in order to obtain an overall average of 75% of green surfaces in (semi-)private areas in Eindhoven, the percentage of greenery in these areas that currently do not meet the threshold of 75% should be 70.8% on average. Next, the coefficients were calculated for each of the greenery types. This was done by calculating the percentage of the individual layers compared to the combined layer. This calculation yielded percentages of 31.9, 7.7 and 60.4 for the tree-, shrub- and grass layers respectively. These percentages were later used in equation 3.19. After following the steps discussed in section 3.6.1, three new different input maps for the UHI model were obtained. Both the original and the updated input maps are shown in figures 4.3, 4.4 and 4.5. For visualization purposes, the maps are shown on the level of one district instead of the whole of Eindhoven. The district displayed, Rozenknopje, is the same one used for the PET calculations. The input maps were, as discussed, calculated for the whole of Eindhoven.

Comparing the original and updated maps, the effect of the coefficients included for each of the greenery types can be noticed clearly. The difference between input maps of the greenery type with the lowest coefficient, shrubs, is very slight, while the difference between maps for the trees greenery type is already more visible and the difference is very clear for the grass greenery type. This of course relates to the percentages that were used for the three greenery types separately



(a) Original Input - Trees

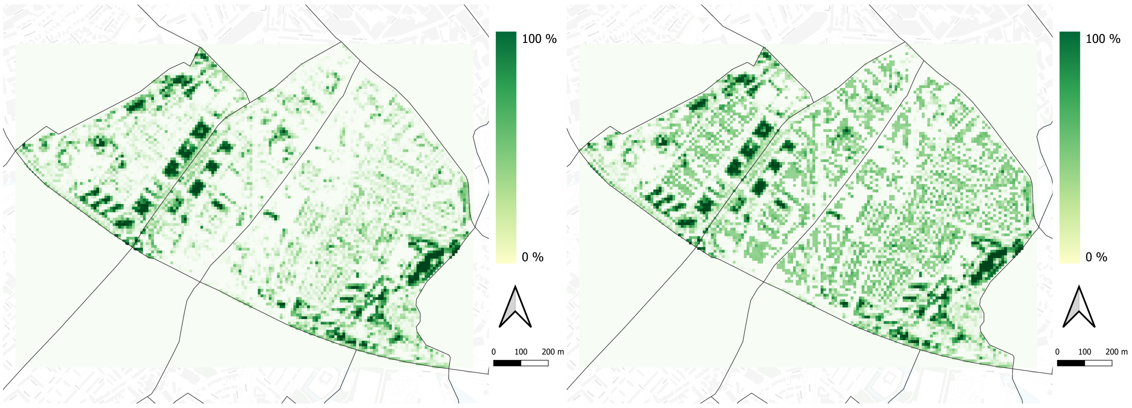
(b) New Input - Trees

Figure 4.3: Original and updated UHI input maps - Trees

(a) Original Input - Shrubs

(b) New Input - Shrubs

Figure 4.4: Original and updated UHI input maps - Shrubs



(a) Original Input - Grass

(b) New Input - Grass

Figure 4.5: Original and updated UHI input maps - Grass

and will also have an effect on the eventual outcome of the UHI map, as the greenery types have different effects on heat mitigation.

4.3.2 PET map

As was done for the UHI map, the first step in producing the new input map for the PET model was to calculate the desired value for the amount of paved area in (semi-)private areas in Eindhoven. This value was calculated by using equation 3.21:

$$\frac{(11.0 * 57,407) + (y_{>25\%} * 175,440)}{232,847} = 25\% \tag{4.2}$$

In this equation, the values 57,407 and 175,440 indicate the amount of pixels with less than 75% and more than 75% greenery, respectively. These values combined are represented in the denominator. Next, the percentage of 11.0 indicates the percentage of paved area that the pixels with less than 25% paved area have on average.

The value for $y_{>25\%}$ was found to be 29.6%. This value thus indicates the percentage that (semi-)private areas currently having a percentage of paved area above 25% should, on average, have in order to obtain an average value of 25% paved area in all (semi-)private areas in Eindhoven. Of all green area, the number of trees was calculated to be 36%. The new input data was created manually, using QGIS, and was based on the calculated values discussed above. Separate layers were created for 'low' greenery and trees. An example of a building block with the to be added greenery layers can be seen in figure 4.6. The example shows a building block surrounded by streets. In the block, the buildings are represented in dark grey. The added greenery layers are displayed in different shades of green. The low greenery is shown in bright green while the trees are shown as circles in a darker shade of green. The proposed intervention is thus a green field in between the buildings, representing the gardens.

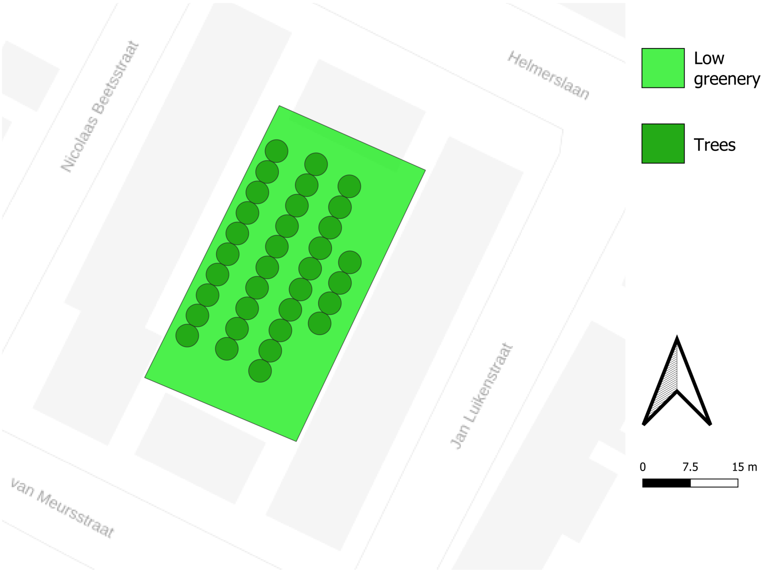


Figure 4.6: Example input data PET map

It is clear that the input data produced for the PET model is quite simplified and thus not accurately represent the manner in which greenery would be added to individual gardens. However, as the PET data is aggregated on a neighborhood level, this representation of input data is suitable for the analysis at hand. The assessment of this new output is discussed in subsection 4.4.2.

4.3.3 Distance to Cool Places map

In order to assess the impact of the added greenery on the distance to cool places, multiple maps needed to be created. First, as the original model does not take into account (semi-)private areas as cool places, these areas needed to be added to the original map in order to assess the extent to which this addition to the model influences the original output. Next, the updated PET map could be used to assess the impact of the proposed scenario on the garden cool spaces and subsequently on the distance to cool spaces for people living in the Rozenknopje district.

Figure 4.7 provides an overview of both the original AtK map and the original AtK map when gardens are taken into account as cool spaces. Again, the Rozenknopje district is used for visualization.

(a) Original KEA map

(b) Original map with (semi-)private areas

Figure 4.7: Distance to Cool Places map without and with (semi-)private areas included

The implications of adding (semi-)private areas as potential cool spaces in the model can clearly be seen in figure 4.7b. If a regular cool space would be added to an area, this would impact all of the buildings in the area. Now, however, there can be clear differences between adjacent buildings, depending on whether this building is located on a parcel that also includes a garden cool space. For example, the middle of the district is faced with a lack of publicly available cool spaces. However, after including (semi-)private areas as cool spaces, it becomes clear that even though this part of the district faces this issue, there are certain buildings that have their own cool space on their parcel and are thus better equipped for periods with high temperatures. Including this aspect can provide important insights regarding the ability of people to cope with heat.

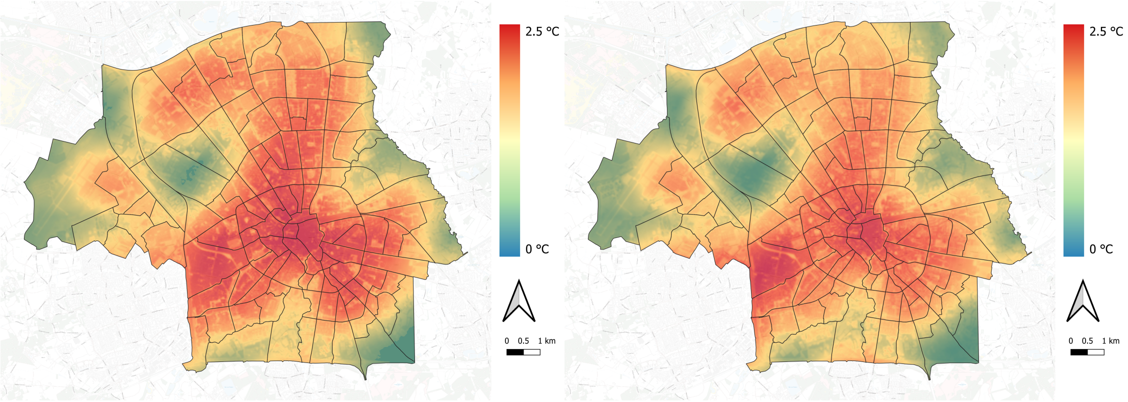
The production of the new input maps for the models of the heat topics could be performed in a way which correctly incorporates the proposed scenario. For UHI, this meant calculating the amount of greenery currently present and the desired amount of greenery within (semi-)private areas, relative to the greenery type. This was possible for the whole of Eindhoven by reproducing the raster layers. For the PET map, separate layers were produced for different greenery types. All in all, this new input was suitable for the production of the new output based on the proposed scenario. The new output is discussed in the following section.

4.4 Scenario Results

The new input data was used to reproduce the original *Klimaateffectatlas* maps, after which the underlying data could be used for quantifying the effect of the proposed scenario on each of the heat topics. This section discusses, for each of the heat topics separately, the new output as produced by the underlying models. Next, the results as aggregated on neighborhood level are discussed. These values were calculated using the steps discussed in chapter 3.3. These outcomes are discussed separately as this aggregated data might give better insight into the effect of the proposed scenario on a neighborhood level than the map as a whole. It has already been established that the addition of greenery to the city can yield multiple positive effects, thereby significantly increasing livability for its residents. Decisions should however be made regarding how and where to place these interventions in the city, in order to optimize results and accurately address identified issues and proposed policies.

4.4.1 UHI map

The recalculated maps showing the Urban Heat Island effect, provided by Verwijmeren [133], are shown in figure 4.8.



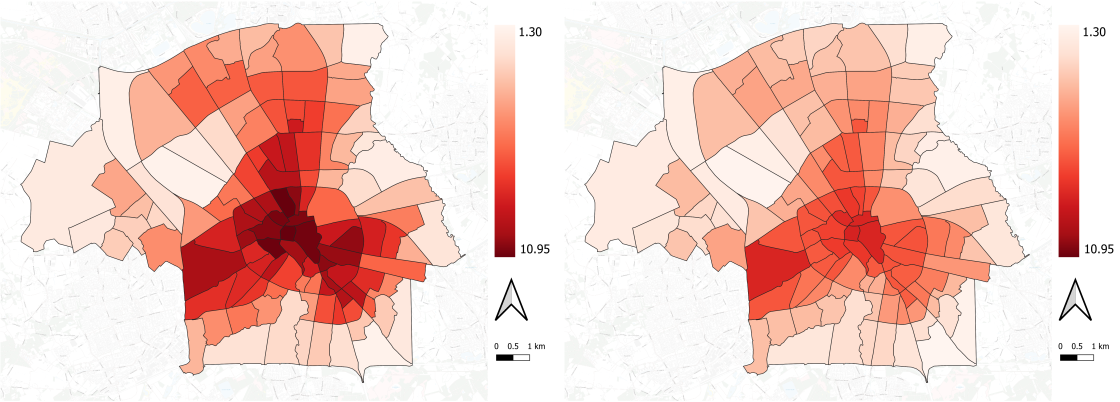
(a) Original KEA map (b) Updated map

Figure 4.8: Original and updated UHI maps

Some things immediately become clear when looking at the two maps. First of all, there is a clear improvement with regard to UHI in residential areas, as the UHI value drops. In contrast, the UHI does not change in the neighborhood ‘Hurk’, located in the southwest of Eindhoven. This neighborhood is mainly characterized by industry and is therefore logically not impacted by a change in greenery located in (semi-)private residential areas. Despite noticing these big changes, no clear insights can be provided by simply comparing the original and the new UHI maps, except for the fact that there is indeed a clear effect of the added greenery on the UHI effect. Therefore, as was done for the original map, UHI values were calculated for the new map.

The table with the full results from the analysis of the three maps are presented in appendix B. The new UHI map was calculated for the entirety of Eindhoven and the situation in all neighborhoods can therefore be compared to the original values that were calculated previously. The new output from the UHI model is mostly as expected, as will be explained further on. Comparing the new output at the neighborhood level to the original map, both shown in figure 4.9, it is immediately obvious that a lot of progress is booked in the green-deficient areas.

Furthermore, it can be seen that a lot of progress is booked in the areas that originally also scored most poorly. This can be explained by the fact that these areas originally scored poorly due to a lack of greenery, the presence of which can help significantly alleviate UHI effects. Neighborhoods in which this difference is most prevalent mainly include the neighborhoods that are located outside of the city center, either just within or just outside of the ring. This makes sense, as these neighborhoods usually have a combination of relatively high UHI values and the presence of (semi-)private areas, which are usually not present in the city center itself. Adding greenery in the (semi-)private areas present in these areas thus allows for a relatively large reduction in UHI values. Additionally, as was discussed before, the industrial area located in the neighborhood Hurk has caused this neighborhood to not improve substantially compared to the original situation. Looking at the relative gains in UHI value reduction, the Hurk neighborhood only improves by about 7 percent, which is comparable to neighborhoods located at the edge of Eindhoven, such as Gennep, Sportpark Aalsterweg and Urkhoven. These neighborhoods all fall within the green



(a) Original KEA map

(b) Updated map

Figure 4.9: Original and updated maps containing UHI values per neighborhood

wedges of Eindhoven, explaining the lack of UHI value reduction to be achieved through the interventions. There are also three neighborhoods whose UHI value has increased after implementing the new input values. These neighborhoods, all of which are also located at the edge of the city, all score relatively well in both the original and the proposed scenario. This increase in UHI value cannot be explained by the new input data, as this was implemented equally throughout the city. A possible explanation is the fact that the new data was calculated only for the outline of Eindhoven, and that therefore the surrounding areas might have influenced the UHI values of some of the neighborhoods at the city's borders. As the increase in UHI values is not significant, these outcomes are deemed acceptable.

After calculating the heat values for the updated UHI map, these values could be used in a correlation analysis between these values and the socio-demographic and socio-economic variables, following the methods described in section 3.4. In order to do so, linearity was again checked in order to be able to perform the correlation analysis. This led to the transformation of some of the variables, which is described in table 4.3. Table 4.4 shows the correlations of the original and the recalculated UHI values with the socio-demographic and socio-economic variables.

Table 4.3: Overview of variable transformations.

Heat value	Socio-demographic/socio-economic variable	Type of transformation
UHI	Inhabitants	Logarithmic (socio-demographic variable)
UHI	% People in individual households with long-term low income	Logarithmic (socio-economic variable)
UHI_recalculated	Inhabitants	Logarithmic (socio-demographic variable)
UHI_recalculated	% People in individual households with long-term low income	Logarithmic (both variables)

Table 4.4: Correlation matrix socio-demographic/socio-economic and heat variables.

Socio-demographic/socio-economic variable	UHI value	UHI value recalculated
Inhabitants	.583** (<0.001)	.518** (<0.001)
Total households	.508** (<0.001)	.467** (<0.001)
% One person households	__.649** (<0.001)__	__.645** (<0.001)__
% Households without children	__-.694** (<0.001)__	__-.690** (<0.001)__
% Households with children	-.478** (<0.001)	-.455** (<0.001)
% Native	-.571** (<0.001)	-.590** (<0.001)
% Western migration background	__.696** (<0.001)__	__.718** (<0.001)__
% Non-Western migration background	.441** (<0.001)	.445** (<0.001)
Number of dwellings	.542** (<0.001)	.494** (<0.001)
% Corporation dwellings	.311** (0.002)	.233* (0.024)
% Rental dwellings	.474** (<0.001)	.469** (<0.001)
Experiences a limited social network	.201 (0.053)	.215 (0.039)
Feels not so happy or unhappy	.515** (<0.001)	.437** (<0.001)
Considers own health moderate or poor	.083 (0.430) [1]	.044 (0.673) [1]
% People in individual households with low income	.301** (0.003)	.241* (0.019)
% People in individual households with long-term low income	.171 (0.130)	.222* (0.048)
Has trouble making ends meet	.468** (<0.001)	.411** (<0.001)
Average personal income per income collector	-.400** (<0.001)	-.332** (<0.001)
Average disposable household income	-.478** (<0.001)	-.420** (<0.001)
% High household income	-.363** (<0.001)	-.351** (<0.001)
UWV registered job seekers without employment relative to number of 15-74 year olds	.134 (0.210) [1]	.077 (0.473) [1]
% Sometimes feels unsafe in own neighborhood	.361** (<0.001)	.371** (<0.001)
Proportion of people who have the perception that there is a lot of crime in their neighborhood	.355** (<0.001)	.353** (<0.001)
% Physical degradation	.325** (<0.001)	.232** (0.002)

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Table 4.4 Continued from previous page

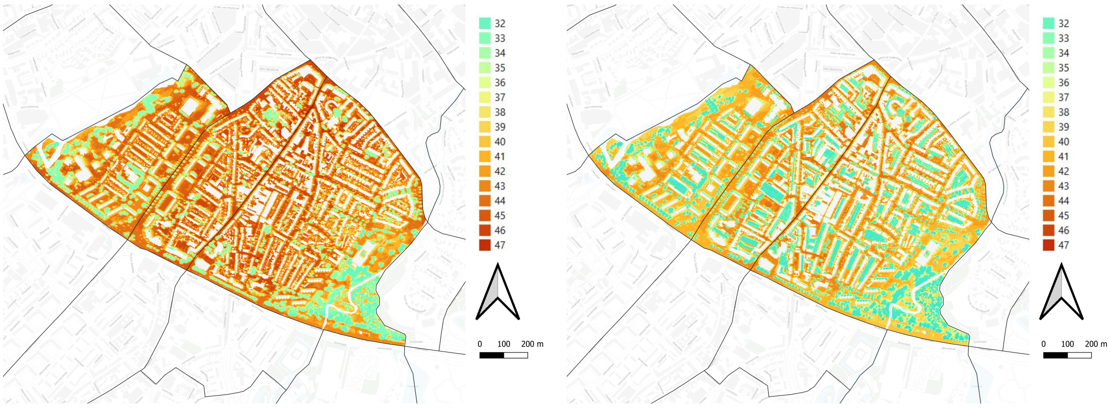
Socio-demographic/socio-economic variable	UHI value	UHI value recalculated
% Social nuisance	.460** (<0.001)	.529** (<0.001)
**. Correlation is significant at the 0.01 level (2-tailed).		
*. Correlation is significant at the 0.05 level (2-tailed).		
[1] Spearman ranked correlation used		

The correlations between the socio-demographic and socio-economic variables and the recalculated UHI values show little differences when compared to the correlations of the original UHI values. This indicates that simply adding greenery all throughout the city does not simultaneously address heat mitigation and inequality. Following this, and taking into account that it might not be feasible to address every neighborhood simultaneously when it comes to adding greenery in (semi-)private areas, prioritizing neighborhoods with more vulnerable socio-demographics could be considered. These neighborhoods are potentially not the neighborhoods with the highest heat values in absolute terms. However, if these highest values occur in affluent neighborhoods, these people are likely to be more equipped to cope with heat by the use of air conditioning, for example. This approach should be considered by policy makers, even if it asks for a specific consideration and additional analysis per neighborhood.

In conclusion, the updated UHI map shows significant improvements compared to the original situation. As expected, most improvements were found in the green-deficient areas and in residential neighborhoods. The clear improvements throughout the Eindhoven neighborhoods were expected as the proposed scenario indicates a very significant, and perhaps utopian, improvement compared to the current state of greenery in (semi-)private areas in Eindhoven. This outcome does indicate the need for the addition of greenery, not only in (semi-)private areas but throughout Eindhoven, in order to improve the city's UHI levels. However, the extent and the sequence in which this greenery is added does matter in terms of addressing inequality, as adding greenery in all areas does not reduce correlations between UHI values and socio-demographic and socio-economic indicators.

4.4.2 PET map

The new input data was used in the original PET model in order to obtain updated PET values for the Rozenknopje district, provided by Goede [39]. The original and updated maps are shown in figure 4.10.



(a) Original KEA map

(b) Updated map

Figure 4.10: Original and updated PET maps

Even more so than for the UHI map, the difference between the original and updated PET maps is clearly visible. What is most obvious is the number of cool spaces now located within the (semi-)private areas caused by the addition of greenery. This addition has however also caused the temperature to go down in the surrounding areas, indicating a wider benefit of adding greenery in (semi-)private areas.

This overview already shows significant improvements with regard to the updated PET map. This improvement can also be seen in the calculated PET values, as all three neighborhoods improve significantly. The neighborhoods located in the Rozenknopje district, Oude Spoorbaan, Schrijversbuurt and Hagenkamp, improve by 20%, 19% and 16% compared to the original situation, respectfully. The fact that the largest reduction in PET values was found in the neighborhood of Oude Spoorbaan is not surprising. Figure 4.10a shows that this neighborhood, located in the middle of the Rozenknopje district, does not have the large green patches that the other two neighborhoods do have. Furthermore, there are quite some areas in the neighborhood that have very high PET values.

The large improvement in PET values of all three of the neighborhoods has also led to a substantial improvement regarding the relative ranking of the neighborhoods. Taking into account the newly calculated PET values, the neighborhoods could be ranked when comparing it to the original scores of all neighborhoods. After doing so, the Oude Spoorbaan neighborhood again had the most considerable improvement. The new situation in this neighborhood would have placed it on rank 23 instead of its original ranking 108. Similar improvements can be found for the other neighborhoods, which both gain more than 60 places in the ranking, meaning they would outscore the majority of other neighborhoods.

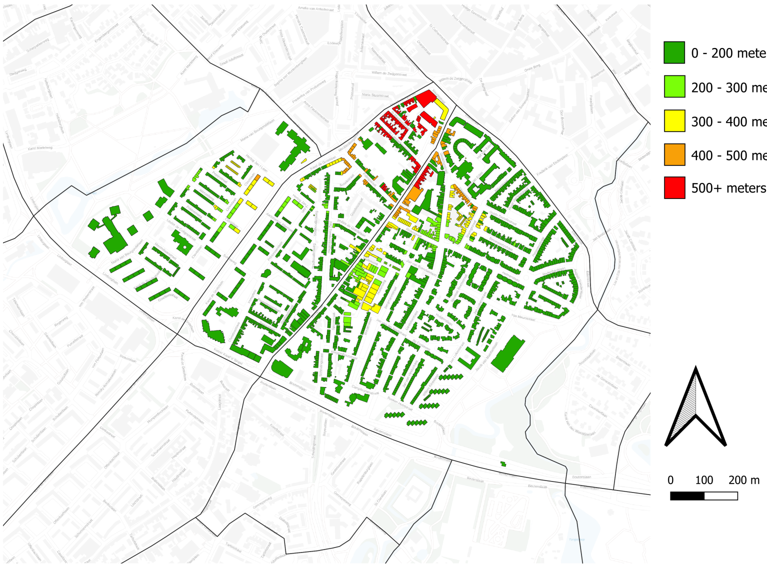
The outcome of the new PET map indicates the relative effect that the proposed scenario can have on the current situation in Eindhoven. Not only do the three neighborhoods obtain a significant reduction in absolute PET value, they would also be among the best performing neighborhoods of Eindhoven in a scenario in which only these neighborhoods would receive the proposed interventions. This indicates the potential effect that policies targeting specific neighborhoods can have on the heat topics at hand. If policymakers were to focus on neighborhoods that score poorly on the heat topics and are mainly characterized by worse socio-demographic and/or socio-economic aspects, they could address both climate mitigation and urban inequality. However, it should be noted that policies should be designed for city-wide implementation, as singling out certain neighborhoods do not address the overall issues the city has regarding urban heat. All in all, the proposed intervention has proven to be a significant improvement for all three analyzed neighborhoods, indicating the need for incentivization of both private gardens owners and housing corporations in order to (be able to) add greenery to their parcels and address heat issues in the city.

4.4.3 Distance to Cool Places map

The base of the Distance to Cool Spaces map is the outcome of the PET model. After obtaining the updated PET map discussed above, this map could be used in order to update the AtK map. As can be seen in figure 4.10b, the updated PET map shows that the added greenery in the (semi-)private areas in the Rozenknopje district has significantly lowered the PET for these areas. Therefore, it is expected that the addition of this greenery will also lead to a significantly better performance with regard to the distance to cool places. The new AtK map is shown in figure 4.11c together with the maps already shown in figure 4.7.

As expected, the renewed map shows a significant improvement regarding the AtK values of the buildings in the district. This already shows the huge impact that adding greenery to the (semi-)private areas can have in this district. Besides the updates from the renewed PET output, there are some slight differences to be found between the output from figure 4.11c and the maps shown in figures 4.11a and 4.11b. These differences in AtK value for certain specific buildings relate to the new input data used, which is the publicly available data used for the production

(a) Original KEA map (b) Original map with (semi-)private areas



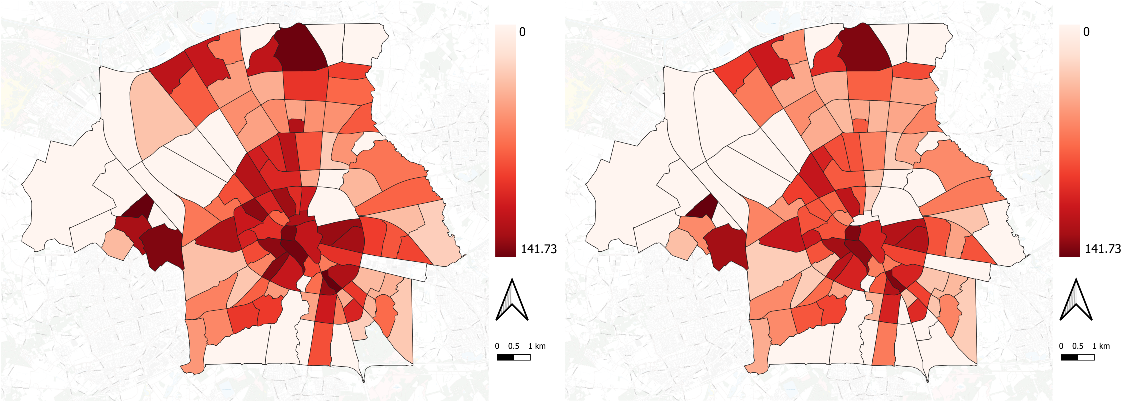
(c) Updated AtK map

Figure 4.11: Original-, original with gardens added-, and new Distance to Cool Places maps

of the model. These are however not substantial and therefore do not influence the final results significantly.

On a city-wide scale, the comparison between the original Distance to Cool Places map and the map in which the (semi-)private areas are added as cool places shows improvements throughout the city. Figure 4.12 shows the calculated heat values for the map presented in the KEA and the original map with cool places in (semi-)private areas added. By logical deduction, the residential neighborhoods of Eindhoven improve the most from this application, as these neighborhoods are most likely to have (semi-)private areas in which these cool places might be present. The neighborhood of Oude Spoorbaan, which had already been identified as a mainly residential neighborhood, is one of the neighborhoods that has the largest absolute improvement in AtK value.

Applying the recalculated PET map to the AtK model has led to updated AtK values for the neighborhoods located in the Rozenknopje district. These values showed an increase in AtK value in the Hagenkamp neighborhood. This was not expected, as the addition of greenery was supposed to improve the situation in the analyzed neighborhoods. However, as was mentioned before, the original map and the updated map were calculated using the same model, but with input values that were collected in different years. Even though these input values are for the most



(a) Original KEA map (b) Updated map

Figure 4.12: Original and updated maps containing Distance to Cool Places values

part the same as the values used in the original model, some aspects could have been changed. The neighborhood of Hagenkamp is characterized by several apartment buildings, which indicates a relative low number of individual buildings which include a lot of inhabitants. Following the method used for the calculation of the AtK values, this causes the overall AtK value of the neighborhood to change more when some of these buildings change AtK values. As can be seen in figures 4.11a and 4.11c, only some of the buildings change regarding their AtK value, and the neighborhood overall still scores quite well in the proposed scenario. However, as the neighborhood scored even better in the original situation, the new calculations have led to a worsening of AtK value for the neighborhood.

The results of the other two neighborhoods show significantly better results, with Oude Spoorbaan increasing by 20% and Schrijversbuurt increasing with 73% compared to the original situation. This huge increase in the Schrijversbuurt can be explained by the large number of residential plots found in the neighborhood, of which almost all have been given a large intervention regarding the amount of greenery present. This increase has also led to a large increase in potential relative position of this neighborhood, comparing its recalculated AtK value to the original value. For the Schrijversbuurt, this means an increase of 37 places.

Despite some unexpected differences found in the results of the recalculated AtK values, the positive effect of added greenery regarding the distance to cool places for the inhabitants of the analyzed neighborhoods was substantial. Taking into account this outcome and comparing it to the original situation, it has become clear that the addition of greenery in (semi-)private areas is also beneficial for the ability of people to cope with urban heat in close proximity to their homes.

4.5 Concluding remarks

In conclusion of this section, the results have shown that the addition of greenery to the (semi-) private areas in Eindhoven has led to significant improvements with respect to all three of the heat topics analyzed. Looking at the heat values that were calculated, some things could be noticed. First of all, each of the maps have either seen some limitations or some unexpected results. These could however all be linked to the models used and did not have any substantial implications for the overall results. Secondly, it should be mentioned that there are differences in the extent to which the heat values have improved for the neighborhoods. UHI has seen a maximum improvement of 30%, for PET this was 20% and for distance to cool places this value was found to be 73%. Thus, these results should be taken into account when making decisions regarding which heat aspect to address firstly and considering on which topic the government would like to make the most improvement. Building on this, however, is the notion of what this improvement in percentages means for the relative position of neighborhoods compared to other neighborhoods. For the Schrijversbuurt, an improvement of 19% regarding its PET value meant an improvement of 64 places in the relative ranking of neighborhoods in Eindhoven, given that the values in the other neighborhoods remain the same. For the distance to cool places, however, an improvement of 73% led to an increase of 37 places. Thus, despite the larger improvement with regard to the value, it did not improve more compared to the other neighborhoods. This is due to the fact that the maps are all produced differently, could therefore not be analyzed using the same method, leading to a different calculation of, and variance in, heat values. Finally, the improvements of the different heat values can have different implications for the practical outcome in the neighborhoods. Regarding AtK, for example, the addition of cool spaces on people's private parcels and close to apartment buildings can benefit some demographic groups more than others. For example, as was found during the literature review, elderly people might be less inclined to leave their homes in order to seek cooling during hot days. Therefore, this group might benefit especially if cool spaces are added next to their homes, as they will likely use this space for adapting to urban heat, and might not do so if public green spaces are added instead.

All in all, the recalculations of the heat values have shown considerable improvements across all heat topics due to the addition of greenery in (semi-)private areas. The further implications and limitations of the results, and the research in general, will be discussed in chapter 5.

Chapter 5

Discussion & Conclusion

5.1 Discussion

In chapter 4, the results of the performed analyses have already been discussed to some extent. This chapter further reviews the results, as well as the methods and limitations.

5.1.1 Results

The performed literature review has shown that residential gardens and semi-private areas have not been a main focus point for research on climate mitigation strategies. Research has focused on the effect that added greenery can have on larger scales, such as urban parks and other large green areas [4, 58, 96]. Therefore, the potential effect of added greenery in (semi-)private areas is dismissed or at the least not well understood, as acknowledged by multiple researchers [50, 15]. Therefore, this research set out to add to this body of research by performing multiple analyses regarding the presence of heat in urban areas.

The first analysis that was performed was processing the data that was provided in the *Klimaateffectatlas* (KEA). The data was analyzed for the city of Eindhoven. For each neighborhood, heat values were calculated, relative to the four maps taken from the KEA. This level of analysis is quite detailed, as Eindhoven consists of 116 neighborhoods. This means that the analysis and the calculated heat values allowed for a precise comparison of different areas within Eindhoven. Furthermore, performing the analysis at this levels meant the values could be linked to various socio-demographic variables. This data is freely available and is also provided at the neighborhood level.

From these results, the current structure of greenery within Eindhoven, and the effect that this greenery has on heat aspects within the city, immediately became clear. The three green wedges within Eindhoven contribute greatly to the mitigation of heat issues, which leads to neighborhoods located in these areas scoring well for each of the heat topics. The preservation policy of the Eindhoven municipality for green wedges contributes to heat mitigation, an increasingly crucial topic for cities worldwide. It is essential for Eindhoven to allocate equal efforts to enhance greenery in neighborhoods that currently have lower scores. In these neighborhoods, however, large-scale green interventions are not feasible, as these areas are characterized by large amounts of built-up areas. This further stresses the need for different solutions, such as the implementation of greenery in (semi-)private areas.

In general, analyzing the KEA maps at the neighborhood level has provided a clear way to gain more insight into the current state of the city with regard to urban heat. The maps in the KEA are provided as a continuous unit covering the entirety of the Netherlands, but this does not always immediately provide a clear overview of which areas in cities score better or worse than others. There are clear differences between neighborhoods consisting of mainly green areas and those in the city center, but there can also be significant differences regarding heat values between two neighborhoods that seem to score similarly at first sight. Therefore, the methods used were found to be a useful way for policymakers to better make distinctions at the neighborhood level.

Another advantage of aggregating the data of the KEA maps on neighborhood level is the possibility of linking this output to various socio-demographics and socio-economic variables, as this data is also provided on the same level.

These variables were tested for correlation with the calculated heat values. This analysis provided several significant outcomes, related to different types of variables. For Eindhoven, heat values tend to correlate positively with neighborhoods with more single person households and neighborhoods that have higher shares of people with a Western migration background. Other variables also indicated the reinforcing effect that the presence of more dwellings in neighborhoods might have on heat values. Similar outcomes as for the original UHI values were found for the correlations between the recalculated UHI values and the socio-demographic variables.

No clear correlations were found between socio-economic aspects and heat values. This is also an important finding, as it indicates that there are no clear conclusions to be drawn whether these variables have a relation with the calculated heat values or not. Even though, as discussed before, some research has found a relation between heat and socio-economic factors, this was not the case for the current research. This means that addressing heat issues does not address inequality with regards to certain income and rate of employment between neighborhoods at the same time.

The overall findings of this analysis also indicate that implementing the same measure of adding greenery city-wide does not address inequality simultaneously with addressing heat mitigation. Therefore, in order to do so, policymakers should make clear choices with regard to which neighborhoods to address first if they want to take addressing inequality into account simultaneously with addressing heat issues in the city. Besides doing so, policymakers might consider providing more incentives for less affluent people as a measure to address these multiple policy points.

These outcomes, in combination with previous research, further stress the need for taking into account the relevant socio-demographic factors when addressing heat issues. Adding greenery in neighborhoods should be prioritized for the areas that score worst with regard to the calculated heat values. If this is not the case, inequality between neighborhoods might only increase.

The recalculated maps showed expected results. The proposed scenario presented rather drastic interventions, which cannot be quickly introduced city-wide. However, the results do clearly indicate the effect that such interventions can have when implemented. Regarding UHI, neighborhoods throughout the city showed improvement. However, most improvement was shown in neighborhoods containing more (semi-)private areas. This was expected, as the interventions were focused on these areas. It is therefore important to compare the current scenario with scenarios in which there is more focus on adding public greenery as well, in order to assess the relative effect that the addition of greenery in both public and (semi-)private areas can have on heat mitigation.

Despite the limited area of analysis for the PET map, the results also show clear improvements created by the addition of greenery. Most significantly, these improvements can be noticed in the neighborhoods that originally scored worst. Taking into account the outcomes from the socio-demographic analysis, this outcome further emphasizes the need for implementation in the most vulnerable neighborhoods, as this not only adds to reducing inequality between neighborhoods, but also allows for the most significant improvements. As these neighborhoods originally scored worst, this also indicates that the amount of greenery to be added in these neighborhoods is relatively the largest. Such an intervention can however be justified by the fact that focusing efforts on these neighborhoods might address multiple policy points simultaneously.

For the Distance to Cool Places map, multiple steps of analysis were performed. The addition of recognizing cool spaces in (semi-)private areas already showed improvements throughout the city, indicating the importance of the interpretation of the original map when it comes to drawing conclusions regarding the implications the KEA maps might have in reality. Perhaps even more so than for the other maps, the proposed interventions showed the effect that the addition of greenery in (semi-)private areas can have on individual households. The UHI effect, for example, is reduced more through larger areas being green. For distance to cool places, individual households can notice considerable benefits when only their garden has a significant amount of added greenery, which can help individuals cope with heat on hot days. Municipalities should therefore not hesitate to provide incentives to individual households for adding greenery to their gardens, as this might generate the desired effect, be it on single households in the neighborhood instead of larger areas as a whole.

All in all, the reproduction of the KEA maps took quite some effort, but has provided significant results. For each heat topic that was analyzed, clear improvements have been found, indicating that the proposed scenario, even in a less extreme approach, provides outcomes desired for mitigating urban heat. Perhaps more importantly, it acknowledges the potential that (semi-)private areas have when it comes to heat mitigation, an aspect which is only scarcely mentioned in the literature.

The current research and outcomes add to the body of literature by proving that the addition of greenery in (semi-)private areas can have a significant effect on urban heat. More specifically, besides indicating the effect of related policies on neighborhoods as a whole, the research has shown the potential benefits of focusing these policies on individual plots. The need for such policy is also addresses by Van Heezik et al. [48], who hypothesize the presence of 'tipping points', indicating that the greening of certain gardens might encourage other garden owners to do the same.

The newly produced input data has distinguished between different types of greenery. However, the specific effect of each of these types could not be understood separately from the final results. There has already been quite some research regarding the effects of these different types of greenery, mainly indicating that when it comes to heat mitigation, trees perform better than shrubs, which in turn outperform grass [144]. These findings can explain the success of the proposed interventions, as the addition of trees was also an important part of the scenario.

Overall, it can be stated that this research, despite not addressing all factors of green space implementation, has yielded results which add to a body of research which is in need of more extensive efforts.

5.1.2 Methods and limitations

As the research at hand uses the output of several models and different various methods of calculation, it also faces multiple limitations.

While the original maps from the *Klimaateffectatlas* include a map that displays the heat stress caused by warm nights, this map is not recalculated and taken into account for the proposed scenario. This is caused by the absence of any technical documentation of the production of this map, as well as the model itself. Therefore, no conclusions could be drawn regarding the production of this map, and the map could not be reproduced. Furthermore, the exact value of the underlying data of this map had to be deduced from the legend provided online. These limitations have caused the interpretation of the original data to potentially be slightly incorrect. Also, the lack of new output data on this topic has reduced the overall insight the proposed scenario can give, as it could not be tested for this heat topic.

From the technical documentations that were provided, several limitations were identified for each of the models, as discussed in chapter 3.2. Even though the technical documentations of these maps were freely available and easy to find, it might be expected that policymakers who want to use the maps of the KEA do not take the time to completely read through all of these documentations in order to find potential limitations that might impact the conclusions drawn from these maps. The Distance to Cool Places map is a clear example of this. The original version of the map does not take into account private gardens as cool places, which is mentioned in the technical documentation and on the background information of the map, but is something that might be overseen by people using the map. The current research has shown, however, that including these cool places can have important implications. Some limitations of the original models have a bigger impact than others, but it remains important for policymakers and other people working with the models themselves, as well as the output, to be aware of these potential limitations before making decisions based on this output.

Whereas some of the models were verified with actual measurements, this was not the case for all of the models. As the provided models face several limitations, this verification can provide an important step in making the data more reliable. Only using actual measurements, however, is not a feasible solution, as this takes too much time and resources.

The calculations of the heat values, which were calculated to provide more insight into the data underlying the original maps at a neighborhood level, provide an important methodology for producing more insightful maps. These methods are easily reproducible, but do experience some limitations as well. Firstly, the weights that were given to the various data from the KEA maps, were assigned to the values linearly. For this, the assumption was made that the steps between the different values presented in the original maps have similar implications. As an example, for the PET map this means that an increase of 3°C from 35 to 38°C has a similar impact on people as the increase from 43 to 46°C. Of course, there might be differences in these increases, relative to the effect of certain temperatures on people. A second limitation is the lack of specific data that could be used to calculate some of the heat values. The calculations for the heat values of the Distance to Cool Places could have been performed more accurately if data on inhabitants of individual buildings would have been available. As this data had to be used on the scale of postal code areas, these values are less accurate than they could have been.

The production of new input data for the different models has also seen some limitations. Firstly, the PET-, and subsequently the AtK maps, could only be reproduced for the Rozenknopje district, because running the PET model itself requires a lot of processing time. Therefore, the outcomes for these maps could only be compared for three neighborhoods. It is expected however, looking at the positive results of these analyses, that the application of the scenario to the whole of Eindhoven would reap similar results as those found for the UHI map, with the biggest results found in the current green-deficient areas.

Next, the calculations for the UHI and PET input maps use average values with respects to types of greenery added in specific areas. This means that similar or equal percentages per greenery type are added to neighborhoods. In reality, this might not be feasible or even desired, as some areas lend themselves better for the addition of trees, while this might not be possible in other areas. The new input maps do not take these aspects into account, which impacts the outcome of the analysis. The proposed scenario should therefore not be a base on which decisions regarding the addition of greenery in Eindhoven should be made. Rather, the municipality should analyze neighborhoods specifically, and consult relevant stakeholders, in order to conclude what greenery might best be implemented in which area.

Regarding the AtK model and the addition of (semi-)private areas as cool places, the assumption was made that these cool places should have a minimum surface area of 10m^2. In reality, even though this area might be enough to be considered as a cool place, this area is significantly less than the assumption made for the original model. Therefore, this aspect might be considered a limitation of the performed analysis.

Additionally, the reproduction of input maps, as well as that of the final maps, faces the fact that the publicly available data used for the production of the maps is updated regularly. This means that the data used for the production of a previous version of the map might differ from the data that is currently available, which can lead to differences in outcomes.

Overall, even though some limitations might impact the final outcomes of the analyses more than others, they should be taken into account and discussed clearly when producing new maps or calculating scenarios.

Another aspect that is not considered in the results of this report is the relative impact of greenery added in residential gardens and that of greenery added in areas managed by housing corporations. Furthermore, heat values were not calculated for these areas separately. There is also a third type of area which might be taken into account, namely that of residential gardens on parcels owned by housing corporations. In these areas, it is private individuals that are mainly responsible for the layout of the gardens. However, these individuals might be less enticed to put effort into greening their gardens, as they can feel that this responsibility is not completely theirs. On the other hand, housing corporations might impact this by adding clauses to their rental agreement in which they can state the amount of greenery that needs to be present in the gardens. Furthermore, working together with housing corporations has the benefit of addressing multiple households at once, compared to working with individual (private) households.

Gaining insight into whether there are differences to be found in heat values between private gardens and areas owned by housing corporations can help understand the relationship between socio-demographic factors and heat values. Besides that, checking different scenarios in which greenery is either added in private gardens or areas owned by housing corporations can indicate which approach should be the priority for governments in order to obtain the best results. Therefore, more research on this potential difference is necessary.

Finally, the process revealed some aspects from the *Klimaateffectatlas* itself which might be improved in the future. Not only the models themselves show limitations, but the *Klimaateffectatlas* as an integrated tool is in some aspects limited in the way it is set up now.

First, cohesion is often lacking between maps. An example that has been mentioned already is the calculation of UHI. This heat effect is calculated separately for the map that is shown in the KEA, but is also a part of the PET model, in which UHI is calculated in an intermediate step. Given that both maps are shown on the same portal, it can be expected that the steps of calculating a certain effect are the same in both models. This is however not the case. Such interconnectedness of models is the case for the AtK model, in which the output from the PET model is used to calculate cool places. Doing so can lead to more coherence between maps and gives a better idea of how each aspect is calculated.

The current version of the KEA already provides a lot of information regarding various climate aspects. However, regarding heat, there are several effects that still could be included in order to provide an even better overview of the impact that climate change can have regarding heat aspects. The current version of the KEA does include a couple of heat topics, which indicate different aspects of heat issues often found in cities, but including more effects of heat can provide a more complete overview. Effects that could be included, for example, could be ones related to adverse health effects of prolonged exposure to heat waves, or the increased amount of energy consumption in urban areas during hot periods.

Despite there being some points of improvement for the *Klimaateffectatlas*, the tool currently already provides a good overview of several climate aspects which would otherwise not be available to policy makers. Including all of the maps regarding heat that were available on the KEA has proved to be useful with regards to analyzing heat issues present in different neighborhoods. The maps used indicate various aspects of heat. Using all of these maps does not only provide insight in the specific presence of heat in urban areas, but also provides insight into how people perceive this heat and what effects this has on people. Furthermore, it shows one aspect of the ability of people to cope with heat. Therefore, the combination of the various maps provides a more complete overview of the issues present and the areas policymakers should focus on when considering interventions. Potentially combining the currently present maps with maps regarding other effects might further improve the overview the KEA offers with regards to heat in urban areas. Overall, improvements to this tool could be the aspects mentioned above, as well as the aggregation of the data on neighborhood levels, as was done in this report.

In conclusion of this chapter, the results have shown that the proposed intervention is a useful way for mitigating heat in urban areas. In order to gain more understanding of the potential effect of other, less extreme, interventions, more scenarios should be calculated. As discussed, this will take time and effort due to the heterogeneity of input data and models used. Tools such as the Green Benefit Planner (GBP) can therefore provide promising solutions for these issues, which can help gain important insights into the effects that different interventions can have, leading to better decision-making when deciding on climate change mitigation.

5.2 Conclusion

The goal of this report was to assess the effect that the addition of greenery to (semi-)private areas could have, specifically with regard to more vulnerable neighborhoods. Following the goal of the research, the following research question was formulated:

What is the role of private gardens and housing corporation greenery in mitigating adverse heat effects in urban neighborhoods?

The city of Eindhoven was used as a case study in order to answer this question on the basis of maps relating to urban heat, available on the *Klimaateffectatlas*. These maps were firstly analyzed on a neighborhood level to come to a certain heat value for each heat topic. This preliminary analysis distinctly showed the presence of the green 'wedges' in Eindhoven, which greatly reduce heat values in these areas. Additionally, heat values were found to be much higher in neighborhoods located in areas that are characterized as green-deficient. These results clearly indicate the opportunity for the mitigation of heat by adding greenery, which can be done in (semi-)private areas, as these neighborhoods are often largely residential neighborhoods. Besides these findings, this analysis has shown that while the *Klimaateffectatlas* does provide multiple maps relating to urban heat, the additional step of aggregating the available data on a neighborhood level provides extra information regarding the presence of issues throughout the city. This information can be especially useful for policymakers that want to make informed decisions regarding what areas of the city should receive their attention first when it comes to applying proposed interventions.

Another aspect that should be taken into account in this regard is the presence of inequalities in socio-demographic and socio-economic aspects and their relation to the calculated heat values. A correlation analysis was performed in order to assess whether certain socio-demographic and socio-economic aspects significantly correlate with the calculated values. Results show that there are indeed multiple significant correlations to be found. Substantial positive correlations were found for share of one person households in neighborhoods, as well as for the share of people with a Western migration background in neighborhoods, indicating higher heat values in these areas. These correlations were found between the socio-demographic variables and both the original heat values and the recalculated UHI values, indicating that the proposed scenario does not address inequality simultaneously with heat issues. These findings stress the need for addressing the most vulnerable neighborhoods when it comes to urban heat, in order to address inequalities simultaneously with the mitigation of urban heat issues. These findings, however, only relate to a few of the socio-demographic factors, as no clear correlations were found between the heat values and the other socio-demographic and the socio-economic variables.

Finally, the effect of adding greenery in areas was tested by the modeling of a proposed scenario which involves the replacement of paved areas in private gardens and housing corporation greenery in order to achieve a threshold of only 25% paved areas, on average, in these areas throughout Eindhoven. Clear results were found after implementing the scenario. In conclusion, thereby answering the research question, it can be stated that the addition of greenery in these areas significantly reduces multiple heat effects, and provides inhabitants the opportunity to better cope with heat during hot periods. As expected, positive effects were mainly found in residential neighborhoods, once more indicating the advantages of focusing such interventions so close to people's homes.

Regarding the KEA, this has proven to be a useful tool for policymakers that want to gain more insight into the current state of an area with regard to one or several climate aspects. However, even though the tool provides a nice overview of maps containing this information, this data has to be processed in order to gain better insights on a neighborhood level. On top of that, using the models underlying these maps in order to gain more insight into the effect a particular intervention can have has proven to be very time-consuming and faces issues of intellectual property and unavailability of data. Therefore, tools such as the Green Benefit Planner might prove to be a suitable solution for these issues in the future.

Recommendations and future work

Following the results of this research, but also the limitations regarding the used methods and resources, several courses of action have become clear in order to improve ways of working concerning climate mitigation policies.

First of all, there are several technical aspects which can be worked on in order to reduce efforts needed to calculate certain scenarios. Adding new scenarios to the current maps displayed in the *Klimaateffectatlas* has proven to be very time-consuming, as input maps should often be provided in different configurations. On top of that, models underlying the maps are not always available to everyone and might require expert knowledge and specific software or tools in order to use them. These issues can partially be overcome by use of the GBP tool. Therefore, expanding functionality of the GBP tool can significantly reduce time and effort needed for calculating multiple scenarios on a certain area. On top of that, governments should consider making spatial data from their city available for researchers if the research supports governmental policymaking.

Regarding the *Klimaateffectatlas*, efforts should be made towards making the models underlying the available maps match with regard to input data and (intermediate) output of models. This, however, requires either collaboration between companies working on separate models, or guidelines from the overarching institution managing the KEA.

As the results have shown, adding greenery to (semi-)private areas can be a very effective strategy for the mitigation of urban heat issues. There are already certain initiatives, an example being *Steenbreek*, in place for the addition of greenery in these areas. Furthermore, the municipality of Eindhoven already has an extensive policy plan in place regarding greenery. In this policy plan, however, no clear strategies are in place for the addition of greenery in (semi-)private areas, besides the involvement with *Steenbreek*. Therefore, the municipality should have more decisive policy plans regarding this topic, especially following the results from this study.

As cooperation in initiatives such as *Steenbreek* is voluntary, governments should consider an increase in incentives for private individuals in order to reach policy goals in these areas. Financial incentives might reduce barriers relating to the costs that are involved with removing tiles and other paved areas from gardens and replacing them with greenery. Furthermore, there could be other barriers regarding the implementation of greenery that is holding back private individuals from adding more greenery to their gardens. More research is needed to identify these barriers and construct strategies for overcoming them. Additionally, more research is needed with regard to people's preferences of layout of their gardens, as people might simply prefer paved areas over greenery in their gardens. Such aspects will also have to be dealt with accordingly.

Regarding housing corporations, better results might be achieved through legislation. In this way, housing corporations might be forced, with support from the government, to only have a certain percentage of their property be paved. This way, governments will have more control on the amount of greenery present in areas that are not in the public domain. In order to actually achieve the greening of these areas, governments should work together with housing corporations, as well as inhabitants, in order to share knowledge and ideas regarding what types of greenery is best suited for climate mitigation and how this greenery should be put into place. This is also stressed by Klostermann et al. [64], who state that corporations lack expertise in this aspect, and that cooperation with inhabitants is often lacking. Additionally, there are multiple types of (semi-)private greenery that are either completely or partially controlled by housing corporations. For these areas, different strategies are needed. First, there are areas surrounding apartment buildings and other large housing estates that are controlled by housing corporations. Here, corporations have full control over these areas and legislation can be used to eventually add more greenery to these areas. Other areas include private gardens of residential homes owned by housing corporations. For these areas, corporations should be encouraged or forced to add clauses in their rental agreements with regard to the amount of greenery present in these gardens, so that residents cannot simply pave these areas. In order to achieve this, corporations can assist in the maintenance of greenery in these areas.

The potential of heat mitigation by the addition of greenery in (semi-)private areas has become clear. It is now up to governments to prioritize such interventions in their policies and work together with relevant stakeholders to make this policy a reality.

Besides deciding where to implement greenery and how to achieve this, policymakers also face the issue of deciding which neighborhoods to prioritize when it comes to providing both guidance and incentives to involved parties. Results have shown that implementing the same measure city-wide does not decrease inequalities between neighborhoods. Therefore, individual neighborhoods should be analyzed to see how well inhabitants can cope with heat, and how this relates to the heat values present in that neighborhood. For example, if the largest heat value for PET is found in a neighborhood with inhabitants of a high socio-economic status, this neighborhood might not need priority, as inhabitants have more funds for measures such as air-conditioning, but also for the addition of greenery on their parcels. In such a case, neighborhoods with slightly lower heat values, but containing inhabitants that are not able to cope with heat well might require policymakers' attention first. Besides taking neighborhoods as a whole as the level of intervention, the option of addressing heat issues by targeting individual households might also prove to be an effective option. Such a policy can lead to an increase in ability to cope with heat of less affluent people, who would be prioritized regarding subsidies and other incentives for the greening of their parcel. The effectiveness of these different types of policy interventions does require additional research.

Finally, it must be noted that even though the addition of greenery in (semi-)private areas has proven to be a successful way of heat mitigation, there are still other strategies to be explored. In densifying cities, the presence of (semi-)private areas might become less and less. In these dense areas, the concept of 'greenification' [7] might be applied. This concept offers other solutions, such as green roofs and façades, but also additional greenery in the public domain, to offer heat mitigation solutions in more densely built-up areas. Also, the implementation of public greenery should remain an important policy point, as this has proven to be an important solution to heat issues as well.

Future work on this topic includes the further development of tools such as the GBP, so that more scenarios can be tested and better decisions can be made.

Also, scenarios should be tested in various forms, and should be applied for the whole city, instead of only a specific region, which was partly done in this report.

Next, findings of these report indicate that more greenery in (semi-)private areas can be an effective way to reduce heat issues, but ways of implementation are unsure. Therefore, there is a need for more research regarding potential strategies of doing so. For this, research is needed regarding barriers of such implementation for both private individuals and housing corporations. Furthermore, preferences of people should be researched, so that strategies can be adjusted regarding these preferences. This research provides the next step in the implementation of more greenery in urban areas and subsequently the mitigation of heat issues.

Finally, the use of more accurate data regarding socio-demographics and spatial layout of the city will help to obtain more accurate results.

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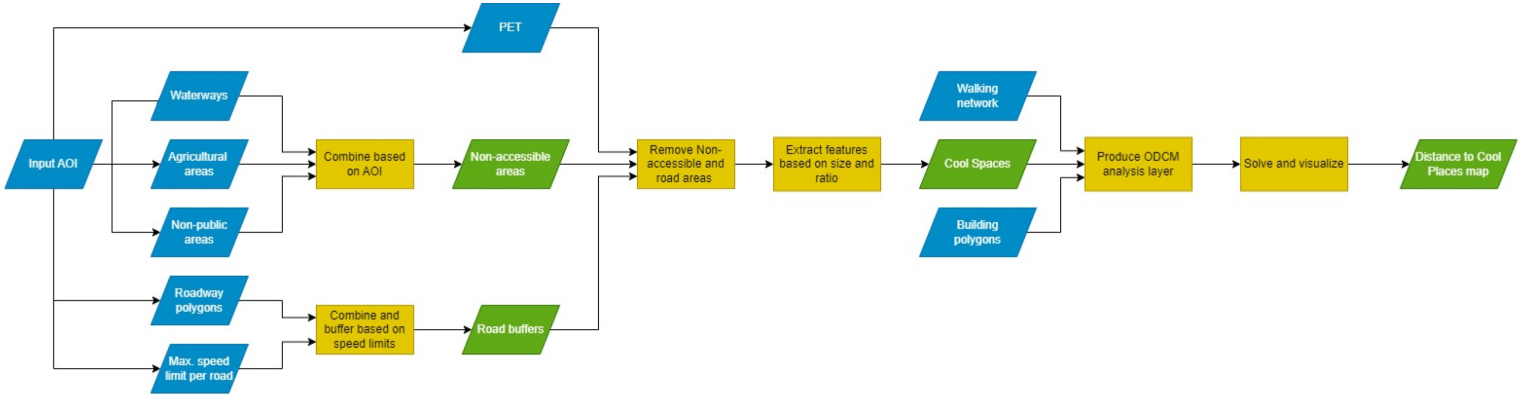
Appendices

Appendix A: Methodology

Distance to Cool Places model



Conceptual representation of Distance to Cool Spaces model, based on [40]

UHI reproduction QGIS syntaxes

Here, the specific syntaxes relating to equations 3.19 and 3.20 are shown.

$$\begin{aligned} &if(\text{"}Greenery\_combined\_layer\text{"} < y_{<75\%}, \text{"}Greenery\_type\_layer\text{"} + ((y_{<75\%} - \\ &\qquad \text{"}Greenery\_type\_layer\text{"}) * [Coefficient\_greenery\_type]), \text{"}Greenery\_type\_layer\text{"}) \end{aligned}$$

This syntax indicates the code that was entered in QGIS to obtain the individual recalculated input maps for each of the greenery types specifically. The exact functioning of this syntax is explained in section 3.6.

$$\begin{aligned} &\text{"}Greenery\_type\_layer\text{"} - \text{"}Greenery\_type\_garden\_layer\text{"} \\ &\qquad + \text{"}Recalculated\_Greenery\_type\_garden\_layer\text{"} \end{aligned}$$

This syntax represents the final step in the recalculation of the UHI input map. Here, the combined greenery layers are added to the original map by replacing the cells that are recalculated. Again, for further reference, please review section 3.6.

Appendix B: Results

Original heat values

Neighborhood name	UHI rank	UHI value	PET ranking	PET value	Heat stress rank	Heat stress value	AtK rank	AtK value	Average ranking
Bokt	3	2.22	13	12.71	7	3.94	1	0.00	6
Herdgang	6	2.53	4	11.34	42	5.50	1	0.00	3
Grasrijk	46	6.41	64	15.30	22	4.90	109	86.69	82
Meerbos	12	3.08	10	12.42	1	0.00	1	0.00	5
Tempel	66	8.00	38	14.52	55	5.70	77	29.38	80
Achtse Barrier-Gunterslaer	62	7.44	61	15.21	60	5.78	40	6.97	67
Poeijers	61	7.41	24	13.81	44	5.56	1		33
Prinsejagt	51	7.04	54	15.00	51	5.67	39	6.90	58
Esp	26	4.66	22	13.63	50	5.67	1	0.00	15
Karpen	15	3.59	15	12.90	11	4.32	31	3.52	24
Het Ven	86	9.74	75	15.60	66	5.88	100	57.00	112
Wielewaal	2	2.01	3	11.27	1	0.00	1	0.00	2
Hurk	102	10.35	63	15.28	71	5.98	27	2.08	84
Bergen	104	10.50	96	16.50	110	7.39	111	96.49	97
t Hool	71	8.57	40	14.61	73	6.00	37	6.12	47
Engelsbergen	83	9.57	48	14.88	40	5.47	69	23.43	53
Limbeek-Noord	100	10.26	94	16.44	95	6.37	84	33.63	92
Genneperzijde	41	6.03	44	14.70	58	5.78	38	6.35	26
Eliasterrein, Vonderkwartier	114	10.90	112	17.21	101	6.72	107	81.91	114
Strijp S	99	10.23	109	17.09	113	7.60	106	77.06	102
Kruidenbuurt	70	8.52	110	17.15	102	6.75	83	33.47	88
Oude Toren	69	8.45	73	15.57	93	6.35	36	5.77	42
Barrier	75	8.94	115	17.64	78	6.04	86	38.40	102
Woenselse Watermolen	84	9.57	80	15.67	100	6.67	87	39.30	68

Neighborhood name	UHI rank	UHI value	PET ranking	PET value	Heat stress rank	Heat stress value	AtK rank	AtK value	Average ranking
Muschberg, Geestenberg	52	7.10	49	14.89	48	5.65	28	2.40	49
Achtse Barrier-Hoeven	35	5.63	62	15.22	36	5.37	51	11.32	45
Eckart	57	7.38	51	14.95	86	6.08	44	7.51	52
Bennekel-West, Gagelbosch	54	7.23	68	15.43	41	5.49	76	29.10	64
Genderdal	82	9.43	78	15.66	62	5.84	25	0.98	69
Sportpark Aalsterweg	19	4.12	32	14.27	18	4.85	1	0.00	18
Vlokhoven	74	8.88	53	14.98	88	6.21	45	7.86	61
Oude Gracht-West	50	6.96	57	15.13	59	5.78	23	0.63	35
Doornakkers-Oost	77	9.03	67	15.42	56	5.72	65	18.58	73
Burghplan	81	9.43	70	15.49	65	5.88	30	2.66	70
Fellenoord	111	10.82	92	16.43	115	8.82	99	56.67	88
Schouwbroek	105	10.55	99	16.68	73	6.00	85	37.70	105
Elzent-Noord	88	9.77	74	15.58	103	6.79	70	23.53	55
Limbeek-Zuid	112	10.85	102	16.72	111	7.47	61	15.95	73
Bloemenplein	92	9.87	114	17.39	105	6.80	105	76.73	92
Leenderheide	1	1.74	1	9.36	1	0.00	1		1
Riel	8	2.62	9	12.38	1	0.00	24	0.92	10
Vaartbroek	38	5.83	35	14.33	54	5.70	59	15.73	50
Roosten	14	3.33	11	12.47	14	4.48	1	0.00	11
Lievendaal	42	6.10	71	15.51	68	5.92	54	13.24	65
Eindhoven Airport	7	2.61	21	13.58	33	5.33	1	0.00	9
Koudenhoven	5	2.38	6	11.86	20	4.88	55	13.68	21
Gennep	17	3.79	18	13.22	9	3.95	1	0.00	22
Puttense Dreef	49	6.91	25	13.93	25	5.12	33	4.58	28
Blaarthem	78	9.13	103	16.77	73	6.00	62	16.66	98
Hagenkamp	85	9.70	82	15.78	77	6.04	49	10.39	62

REFERENCES

Neighborhood name	UHI rank	UHI value	PET ranking	PET value	Heat stress rank	Heat stress value	AtK rank	AtK value	Average ranking
Generalenbuurt	79	9.21	81	15.71	90	6.26	66	20.93	96
Woenselse Heide	65	7.54	69	15.48	83	6.07	34	4.80	71
Driehoeksbos	39	5.99	46	14.82	31	5.27	46	8.11	44
Hanevoet	47	6.51	47	14.83	64	5.86	48	9.86	54
Doornakkers-West	87	9.76	76	15.61	49	5.66	73	26.56	94
Woensel-West	72	8.60	100	16.69	69	5.96	96	50.53	113
Kronehoef	97	10.18	89	16.33	97	6.47	82	33.44	108
Meerrijk	21	4.17	41	14.67	17	4.58	101	67.77	58
Oude Gracht-Oost	30	5.33	23	13.76	34	5.34	43	7.39	34
Schrijversbuurt	73	8.78	77	15.65	67	5.91	91	42.82	85
Gijzenrooi	23	4.33	26	13.93	19	4.85	58	15.18	30
Bennekel-Oost	44	6.33	42	14.67	61	5.80	74	27.66	51
Villapark	90	9.83	66	15.34	73	6.00	104	72.80	111
Irisbuurt	106	10.59	72	15.55	82	6.06	78	30.01	103
Lakerlopen	107	10.62	98	16.61	84	6.07	102	68.04	116
Tongelresche Akkers	34	5.60	31	14.24	23	4.94	71	24.59	37
Mensfort	91	9.86	86	16.01	79	6.05	81	32.15	109
Gerardusplein	68	8.33	88	16.13	89	6.23	88	39.92	86
Tuindorp	93	9.90	52	14.98	80	6.05	98	54.76	83
Drents Dorp	59	7.40	104	16.86	30	5.23	56	14.05	59
Schutterbosch	25	4.50	2	11.19	21	4.90	21	0.17	14
Rapelenburg	58	7.39	65	15.31	62	5.84	41	7.09	41
Kertsroosplein	76	8.99	101	16.71	99	6.61	52	11.74	60
Witte Dame	116	10.95	113	17.31	116	11.13	110	96.34	107
Nieuwe Erven	98	10.22	84	15.84	84	6.07	35	5.25	56
Joriskwartier	103	10.39	111	17.17	107	6.93	113	104.56	107
Beemden	13	3.16	17	13.17	1	0.00	1	0.00	7
Blixembosch-Oost	45	6.35	60	15.20	37	5.40	112	99.27	94
t Hofke	27	4.81	30	14.21	47	5.57	60	15.81	38

Neighborhood name	UHI rank	UHI value	PET ranking	PET value	Heat stress rank	Heat stress value	AtK rank	AtK value	Average ranking
Flight Forum	37	5.79	58	15.15	72	5.99	1	0.00	40
Kerkdorp Acht	63	7.45	50	14.94	26	5.12	63	17.13	78
Vredeoord	16	3.78	5	11.62	12	4.39	1	0.00	16
TU-terrein	60	7.41	29	14.14	96	6.42	1	0.00	31
Achtse Barrier-Spaaihoef	48	6.75	56	15.06	38	5.44	90	41.96	74
Genderbeemd	80	9.26	59	15.19	52	5.68	50	11.13	81
Park Forum	9	2.62	27	14.02	10	4.13	1	0.00	19
Mispelhoef	33	5.42	28	14.08	81	6.05	26	1.67	40
BeA2	4	2.29	14	12.71	1	0.00	1	0.00	4
Urkhoven	11	2.90	12	12.61	7	3.94	22	0.32	12
Zandrijk	28	4.94	97	16.61	35	5.36	114	141.73	80
Eckartdal	10	2.78	7	11.94	13	4.47	1	0.00	9
Hemelrijken	115	10.92	116	17.87	98	6.53	103	69.87	115
Bosrijk	18	3.90	19	13.42	43	5.52	1	0.00	14
Oude Spoorbaan	95	10.09	108	17.09	94	6.36	108	82.96	105
Sintenbuurt	96	10.17	90	16.36	69	5.96	75	27.99	90
Ooievaarsnest	32	5.42	34	14.32	28	5.18	42	7.37	37
Kapelbeemd	43	6.22	55	15.02	57	5.75	94	47.33	75
Castiliëlaan	29	5.31	20	13.50	15	4.52	1	0.00	23
Eikenburg	24	4.34	8	12.33	24	5.02	67	21.38	25
Blixembosch-West	40	6.02	37	14.47	29	5.22	93	46.34	47
Binnenstad	113	10.88	91	16.37	114	8.42	92	44.93	100
Luytelaer	20	4.16	16	13.11	32	5.29	64	18.30	28
Waterrijk	22	4.22	45	14.78	16	4.56	29	2.42	32
Jagershoef	67	8.30	79	15.67	91	6.28	47	9.15	77
Rapenland	94	10.02	83	15.82	104	6.80	95	50.07	95
Zwaanstraat	55	7.29	85	15.86	46	5.57	68	23.34	64
Heesterakker	36	5.66	43	14.68	45	5.56	72	24.84	43
Philipsdorp	110	10.80	95	16.50	108	7.05	79	30.28	89
Hondsheuvels	31	5.38	36	14.42	39	5.46	1	0.00	17
Schoot	101	10.33	105	16.97	92	6.30	89	41.61	110

Neighborhood name	UHI rank	UHI value	PET ranking	PET value	Heat stress rank	Heat stress value	AtK rank	AtK value	Average ranking
Looiakkers	56	7.37	33	14.30	87	6.20	57	14.68	29
Gildebuurt	108	10.67	106	16.97	106	6.89	80	31.16	100
Tivoli	64	7.46	107	16.99	53	5.69	32	3.81	48
Winkelcentrum	89	9.81	87	16.02	112	7.60	97	54.74	77
Rochusbuurt	109	10.77	93	16.43	109	7.18	53	12.93	66
Elzent-Zuid	53	7.17	39	14.53	27	5.17	1	0.00	20

Socio-demographic analysis

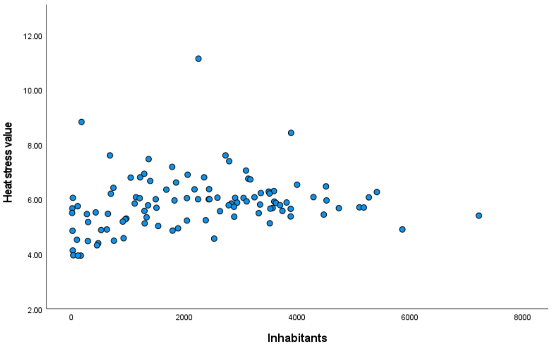
P-values linearity assessment

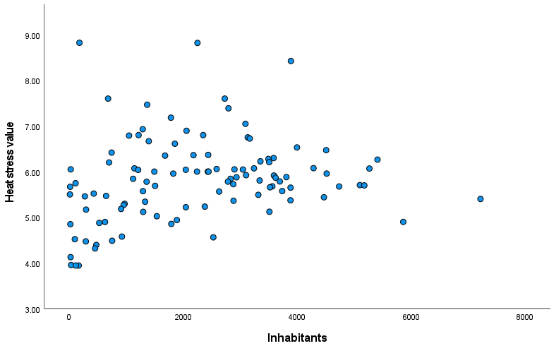
	UHI value	UHI value recalculated	PET value	Heat stress value	AtK value
Inhabitants	0.058	0.070	0.031	-*	-*
Total households	0.003	<0.001	<0.001	<0.001	0.051
% One person households	<0.001	<0.001	<0.001	<0.001	0.074
% Households without children	<0.001	<0.001	<0.001	<0.001	0.002
% Households with children	<0.001	<0.001	<0.001	<0.001	0.412
% Native	<0.001	<0.001	<0.001	<0.001	0.027
% Western migration background	<0.001	<0.001	<0.001	<0.001	<0.001
Number of dwellings	<0.001	<0.001	<0.001	0.01	<0.001
% Corporation dwellings	0.006	0.036	0.004	0.375	0.1
% Rental dwellings	<0.001	<0.001	<0.001	<0.001	0.574
Experiences a limited social network	0.034	0.026	0.021	0.009	0.442
Feels not so happy or unhappy	<0.001	<0.001	<0.001	0.004	0.632
Considers own health moderate or poor	0.184	0.815	0.207	0.405	0.007
% People in individual households with low income	0.002	0.013	0.001	0.068	0.069
% People in individual households with long-term low income	0.166	0.377	0.13	0.994	0.013
Has trouble making ends meet	<0.001	<0.001	<0.001	<0.001	0.662
Average personal income per income collector	<0.001	<0.001	<0.001	0.004	0.582
Average disposable household income	<0.001	<0.001	<0.001	0.025	0.849
% High household income	0.002	0.004	0.018	0.03	0.855
UWV registered job seekers without employment relative to number of 15-74 year olds	0.936	0.544	0.685	0.401	0.001
% Sometimes feels unsafe in own neighborhood	<0.001	<0.001	<0.001	<0.001	0.772
Proportion of people who have the perception that there is a lot of crime in their neighborhood	<0.001	<0.001	0.001	0.011	0.936
% Physical degradation	<0.001	<0.001	<0.001	<0.001	0.288
% Social nuisance	<0.001	<0.001	<0.001	<0.001	0.027

* Some p-values regarding linearity could not be calculated by SPSS. In these cases, the scatter plots were checked for linearity. After doing so, outliers were dealt with and the variables were deemed linear enough to be taken into account for the correlation analysis.

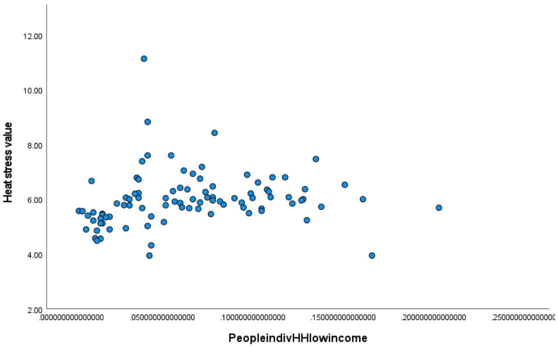
Scatterplots winsorized variables

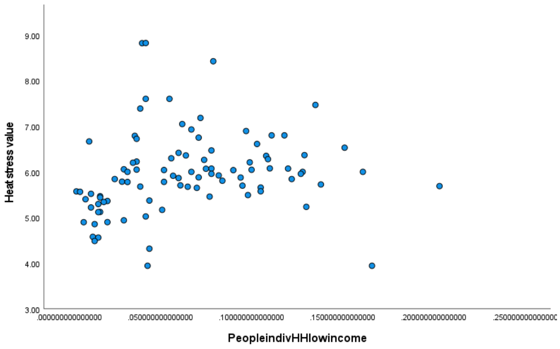
Heat stress value & Inhabitants



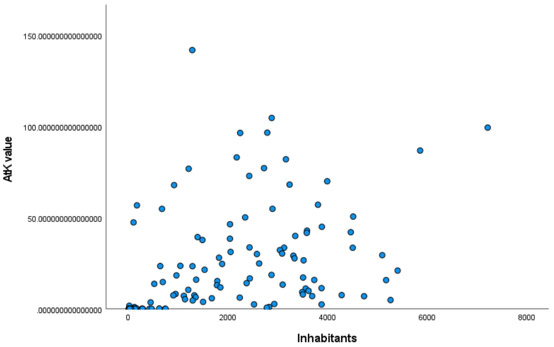


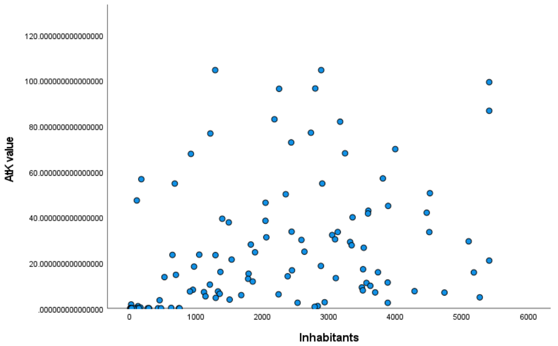
Heat stress value & % People in individual households with low income





Distance to Cool Places value & Inhabitants





Updated heat values

Neighborhood name	UHI rank	UHI value	PET rank	PET value	AtK rank original + gardens	AtK value original + gardens	AtK rank new	AtK value new
Bokt	5	2.25			1	0.00		
Herdgang	7	2.32			1	0.00		
Grasrijk	64	5.96			111	69.19		
Meerbos	10	2.58			1	0.00		
Tempel	62	5.88			74	16.60		
Achtse Barrier-Gunterslaer	60	5.69			49	5.77		
Poeijers	66	6.24			1	0.00		
Prinsejagt	49	5.23			46	4.84		
Esp	22	3.52			1	0.00		
Karpen	14	2.81			1	0.00		
Het Ven	96	7.83			104	43.00		
Wielewaal	2	1.71			1	0.00		
Hurk	113	9.63			33	0.52		
Bergen	110	9.02			112	78.44		
t Hool	73	6.60			48	5.35		
Engelsbergen	88	7.51			82	19.83		
Limbeek-Noord	106	8.34			73	15.85		
Genneperzijde	36	4.57			44	3.35		
Eliasterrein, Vonderkwartier	109	8.97			110	68.93		
Strijp S	102	8.21			79	18.90		
Kruidenbuurt	67	6.26			94	31.67		
Oude Toren	75	6.67			40	2.47		
Barrier	71	6.46			96	33.92		
Woenselse Watermolen	100	8.16			29	0.04		
Muschberg, Geestenberg	44	5.06			36	1.49		

Neighborhood name	UHI rank	UHI value	PET rank	PET value	AtK rank original + gardens	AtK value original + gardens	AtK rank new	AtK value new
Achtse Barrier-Hoeven	31	4.29			58	8.21		
Eckart	55	5.49			50	5.85		
Bennekel-West, Gagelbosch	51	5.30			80	19.16		
Genderdal	84	7.32			30	0.28		
Sportpark Aalsterweg	26	3.87			1	0.00		
Vlokhoven	74	6.65			43	3.33		
Oude Gracht-West	46	5.18			31	0.32		
Doornakkers-Oost	76	6.72			54	6.50		
Burghplan	80	7.11			35	1.35		
Fellenoord	114	9.64			1	0.00		
Schouwbroek	101	8.18			102	40.34		
Elzent-Noord	89	7.51			67	11.54		
Limbeek-Zuid	112	9.43			57	8.03		
Bloemenplein	81	7.20			107	52.31		
Leenderheide	1	1.34			1	0.00		
Riel	3	1.90			32	0.33		
Vaartbroek	32	4.37			52	6.07		
Roosten	15	2.85			1	0.00		
Lievendaal	38	4.66			64	10.79		
Eindhoven Airport	9	2.48			1	0.00		
Koudenhoven	4	2.11			61	9.34		
Gennep	21	3.50			1	0.00		
Puttense Dreef	52	5.35			42	3.08		
Blaarthem	78	6.79			72	15.42		
Hagenkamp	90	7.66	19	13.29	37	1.95	61	9.29
Generalenbuurt	79	6.94			66	11.21		
Woenselse Heide	58	5.54			45	3.92		
Driehoeksbos	41	4.72			56	7.98		
Hanevoet	43	5.01			62	9.36		

Neighborhood name	UHI rank	UHI value	PET rank	PET value	AtK rank original + gardens	AtK value original + gardens	AtK rank new	AtK value new
Doornakkers-West	82	7.27			85	20.50		
Woensel-West	72	6.57			103	42.42		
Kronehoef	97	7.86			77	17.67		
Meerrijk	23	3.70			59	9.05		
Oude Gracht-Oost	28	4.10			53	6.12		
Schrijversbuurt	77	6.73	13	12.70	100	35.69	63	9.80
Gijzenrooi	18	3.16			63	10.27		
Bennekel-Oost	40	4.68			90	24.20		
Villapark	99	7.93			108	53.85		
Irisbuurt	104	8.26			89	23.99		
Lakerlopen	103	8.21			109	54.55		
Tongelresche Akkers	37	4.64			84	20.38		
Mensfort	85	7.45			87	22.16		
Gerardusplein	65	6.09			98	34.83		
Tuindorp	86	7.48			99	35.42		
Drents Dorp	56	5.50			55	7.26		
Schutterbosch	20	3.41			1	0.00		
Rapelenburg	54	5.48			51	5.86		
Kertsroosplein	70	6.44			1	0.00		
Witte Dame	116	9.73			113	86.73		
Nieuwe Erven	87	7.48			38	2.35		
Joriskwartier	95	7.81			114	86.96		
Beemden	13	2.74			1	0.00		
Blixembosch-Oost	39	4.67			115	89.02		
t Hofke	24	3.71			69	11.89		
Flight Forum	50	5.30			1	0.00		
Kerkdorp Acht	63	5.92			71	12.73		
Vredeoord	16	3.07			1	0.00		
TU-terrein	69	6.37			1	0.00		
Achtse Barrier-Spaaihoef	47	5.21			101	40.20		
Genderbeemd	98	7.91			60	9.09		

Neighborhood name	UHI rank	UHI value	PET rank	PET value	AtK rank original + gardens	AtK value original + gardens	AtK rank new	AtK value new
Park Forum	12	2.73			1	0.00		
Mispelhoef	42	5.00			1	0.00		
BeA2	6	2.28			1	0.00		
Urkhoven	11	2.68			1	0.00		
Zandrijk	27	3.94			116	116.67		
Eckartdal	8	2.43			1	0.00		
Hemelrijken	111	9.02			105	46.04		
Bosrijk	17	3.12			1	0.00		
Oude Spoorbaan	92	7.73	23	13.67	106	49.61	101	39.48
Sintenbuurt	83	7.29			91	25.15		
Ooievaarsnest	45	5.11			47	5.10		
Kapelbeemd	57	5.53			93	27.45		
Castiliëlaan	29	4.13			1	0.00		
Eikenburg	25	3.84			68	11.77		
Blixembosch-West	34	4.54			95	32.34		
Binnenstad	115	9.69			97	34.21		
Luytelaer	19	3.41			65	10.90		
Waterrijk	35	4.55			39	2.40		
Jagershoef	68	6.32			41	2.96		
Rapenland	91	7.68			81	19.82		
Zwaanstraat	61	5.77			92	25.76		
Heesterakker	30	4.25			88	23.15		
Philipsdorp	107	8.70			83	20.06		
Hondsheuvels	33	4.40			1	0.00		
Schoot	94	7.80			86	20.95		
Looiakkers	59	5.57			76	17.56		
Gildebuurt	108	8.73			75	16.96		
Tivoli	48	5.22			34	1.22		
Winkelcentrum	93	7.75			78	17.84		
Rochusbuurt	105	8.30			70	12.05		
Elzent-Zuid	53	5.47			1	0.00		