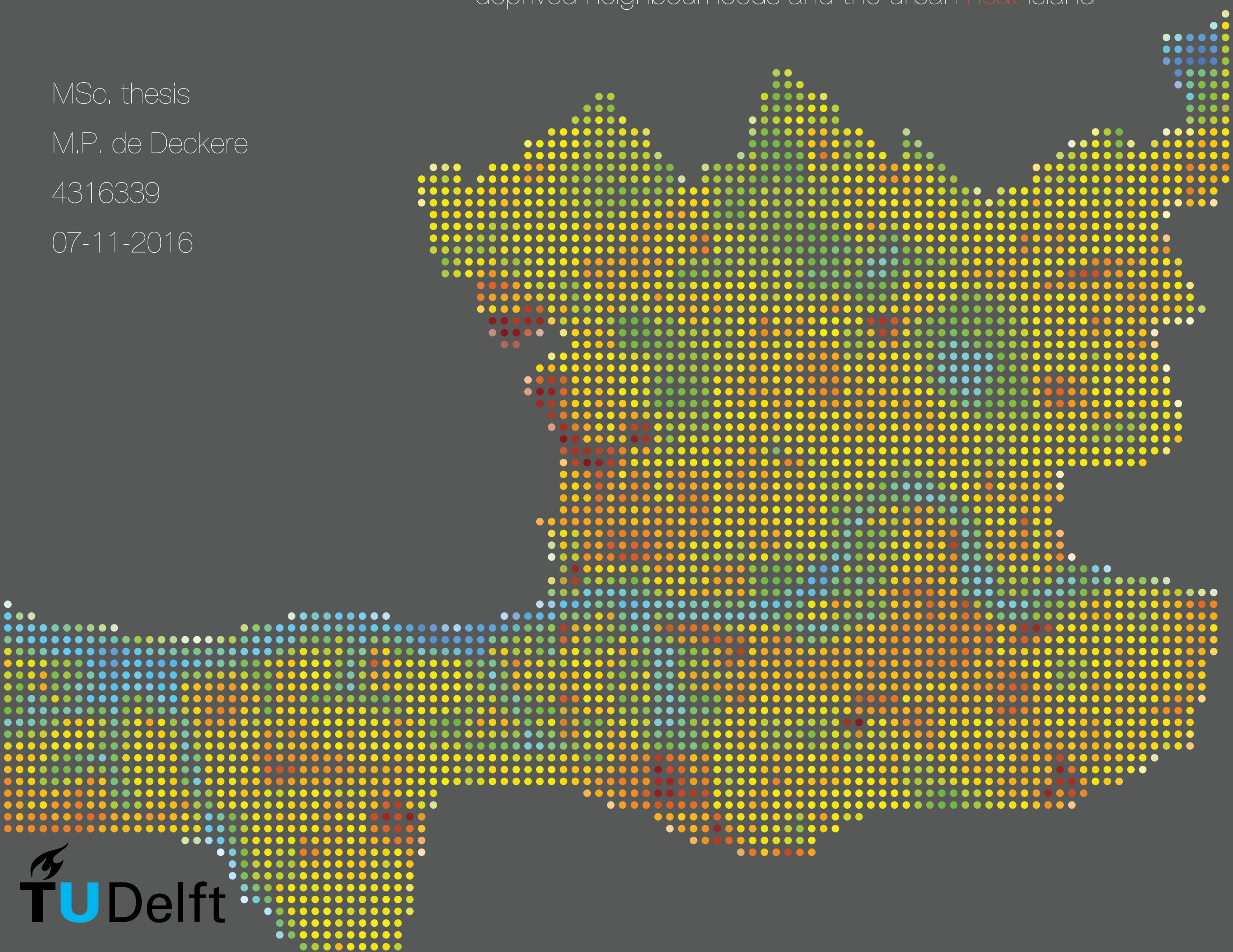
HOT TOWN! SUMMER IN THE CITY

A research into the relation between Rotterdam's South socially deprived neighbourhoods and the urban heat island



MSc. thesis

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TU Delft

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A research into the relation between Rotterdam's South socially deprived neighbourhoods and the urban heat island

By

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In partial fulfillment of the requirements for the degree of Master of Science at the Faculty of Architecture and the Build Environment department Urbanism under the chair of Urban Metabolism at the Technical University of Delft, The Netherlands.

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Preface

This graduation thesis is the result of my master Urbanism at the Delft University of Technology. Such a conclusion is the result of a long journey in higher education which started about 10 years ago. After secondary school, instead of directly going to the university I decided to work and travel for a year. During this year I oriented myself on a study Civil Engineering at the school of applied sciences in The Hague. It was during my final year that I conceived the ambition to continue my education and to do a master urbanism. Such a step from Civil Engineering to Urbanism may not by necessarily a logical continuation. While I am happy that I completed this study I still felt a deep inner urge for personal development with a broader interest for the built environment and society.

Applying for the Rotterdam Academy of Architecture and Urban Design seems a logical choice and while I successfully followed several courses it was due to financial reasons that I had to quit my study. Luckily I quickly found an engineering job at Witteveen+Bos where I worked as an inner-city infrastructure designer. While I enjoyed my time at Witteveen+Bos the unfulfilled ambition of following a master in Urbanism motivated me to quit my job and apply for a bridging program at Delft University of Technology.

After three years of studying my ambition is fulfilled. The master urbanism has given me a deeper insight in the functioning of cities, how they influence and are under influence of processes within society and how urban design influences the ever evolving urban landscape.

In general I believe one of the biggest challenges in urbanism is to gain a better understanding of the relation between the city and its local, regional and global environment. In order to cope with climate change, increasing world population and scarcity of finite resources and raw materials. A better understanding of such relation must lead to a more sustainable way of organizing our cities in relation with our environment. Safe guarding the future and prosperity of mankind today and future generation.

As such my graduation thesis encompasses the relation between the urban heat island and environmental justice. There is plenty of research on the urban heat island and how design can mitigate or adapt the negative effects. However research suggest that limited understanding of the effects of urban heat island connected to socioeconomic and environmental justice dimensions like poverty, inequality and opportunity. My master thesis deal with this issue by researching the relation between Rotterdam's socially deprived neighbourhoods and the urban heat island.

I would not have been able to successfully complete this graduation year with the guidance of my supervisors. I would sincerely like to thank dr. ir. Frank van der Hoeven, dr. ir. Marcin Dabrowski and dipl. ing. Alexander Wandl for their excellent supervision and help. Moreover I would like to thank dr. Ronald Wall and ir. Iris Theunisse for supplying me with their data. I would like to thank my family and friends for their support and finally I would like to thank my girlfriend Anneke for her support and sticking with me through the end.

Abstract

Cities face challenges protecting their population from high air temperatures. In the coming century cities tend to become warmer as a consequence of global warming exacerbating the urban heat island. This affects the liveability of neighbourhoods with negative effects for the population.

The urban heat island is the phenomenon where the city warms up during the day and remains warmer during the evening and night then its surroundings. This is a consequence of urban characteristics like lack of vegetation and use of paved surfaces. However the urban heat island is spatially uneven distributed and some residents are more exposed. These neighbourhoods are often socially deprived neighbourhoods. Residents in these neighbourhoods are of low income and have bad health. In combination with badly insulated houses and a public space that does not provide room for coolness these people are disproportionately exposed. Such exposure to the hazard of high air temperature is considered as an issue of environmental justice.

The city of Rotterdam has a strong urban heat island and above average percentage of people with low income. As such the thesis focuses on if there is a relation between Rotterdam's socially deprived neighbourhoods and the urban heat island. Are people in these neighbourhoods disproportionately exposed to the urban heat island? If so, how can urban design mitigate and adapt to the negative effects of the urban heat island.

With the use of a Pearson correlation analyses a correlation is found between the urban characteristics of neighbourhoods and the averages summer day surface temperature, which acts as an indicator for the urban heat island, fitting urban heat island theory. Interestingly population characteristics also correlate. Neighbourhoods that tend to have a strong urban heat island are also socially deprived. Such a combination is considered as an issue of environmental justice. Residents in these neighbourhoods are more exposed and vulnerable since they also have bad health conditions. Due to urban characteristics of lack of green and high percentage of paved surfaces the neighbourhood does not provide, both in the private and public space, room to escape from the urban heat island.

Such an issue of environmental justice is considered to be the most severe in the city district of Feijenoord. Design interventions are proposed for the neighbourhood of Bloemhof. These range from the introduction of courtyard building blocks, to introducing vegetation in both the public and private space. The introduction of courtyard building blocks provides a typology in which the inner courtyard provides for coolness. The typology also attends to introducing more diversity and population density in the neighbourhoods. With the use of urban heat island mitigating and adapting design principles the building block and its direct surroundings remains relatively cool. More vegetation is introduced in both the public and the private space. A neighbourhood deal is proposed between the residents, the municipality and the housing corporation. In the private space of gardens with a high percentage of paved surfaces the tiles are removed with vegetation. With a careful selection of vegetation these gardens are easy to maintain and not expensive. Firstly the residents are provided with room in their private space to escape from the urban heat island. Secondly such a proposal reduces urban characteristics that contribute to the urban heat island. In the public space on street level vegetation is introduced that covers the facades and tiles along the facades are replaced with vegetation. For squares more vegetation is proposed, with playgrounds and benches in the shade and communal gardens.

In retrospective the thesis introduces the concept of environmental justice on the city scale within the Dutch context. Broadening the scope how the urban heat island affects the population. Future research on the urban heat island should incorporate the concept of environmental justice as it will give a deeper insight in who will be most exposed by the urban heat island.

research and theoretical framework

1. Thesis introduction

This master thesis deals with environmental injustice, caused by high air temperature in parts of Rotterdam. These high air temperatures are a consequences of the urban heat island, which is the phenomenon of urban areas heating up during the day and remaining relatively warm during the night compared to the rural surrounding. Researchers across the globe link high air temperature in urban areas to a broad range of social issues such as of poverty and social deprivation. They argue that these socially deprived neighbourhoods, as a result of their urban characteristics, have a strong urban heat island resulting in a high air temperature. Such link disproportionately affects people who live there. Even without heat stress, these people generally suffer more from health issues and lack the means to shelter from high air temperature. This research concludes that there is environmental injustice because a part of the population is disproportionately exposed to an environmental hazard.

The phenomenon of environmental justice issues in cities has hardly been researched in Europe or more specifically the Netherlands. Since the city of Rotterdam shows a strong urban heat island with social deprivation in specific neighbourhoods. One might wonder to what extend issues of environmental justice can be found in the city of Rotterdam. The combination with expected temperature rise due to climate change motivates this thesis to conduct a research for the city of Rotterdam.

In what follows, firstly three main categories to indicate issues of environmental justice are derived from fourteen sources. These main categories are an environmental hazard, urban characteristics and population characteristics. With the use of statistical analyses fifteen sub categories are used to find whether a correlation exists. A correlation is found between population characteristics and an environmental hazard suggesting an issue of environmental justice. From these results the project area focuses on pre-war expansion areas on the south bank of Rotterdam. Based upon interviews with public officials and micro interviews the results from quantitative analyses the results are verified.

Secondly these results are put in a broader context. Based upon policy documents and analyses of the urban and population characteristics Bloemhof is chosen for a more in depth assessment of overall neighbourhood performance. Urban heat island adapting and mitigating principles are applied to reduce the urban heat island and improve the liveability and overall neighbourhood performances. This results in design interventions and policy proposals in both the public and the private realm of the neighbourhood. In figure 1 on page 11 a diagram shows the content of this thesis with a short description of it's main findings for each chapter.

Content | **Imagery**

Research & theoretical framework

Introduction thesis
Research framework
Theoretical background

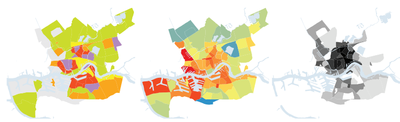
A set of envrionmental justice indicators are derived from research literature and applied on Rotterdam.

Population characteristics | Environmental hazards | Urban characteristics

Statistical anaylses

Statistical analyses of environmental justice indicators
Assessment of vulnerable neighbourhoods

Rotterdam's south pre-war expansion areas score high on indicators of envrionmental injustice.



Rotterdam south general analyses

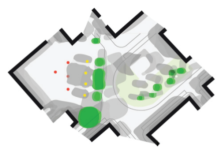
Rotterdam South History
Green structure
Functions
Policy documents
Observations and interviews

In general terms the southern pre-war expansion areas show urban characteristics that postively influence the urban heat island. Overall depriviation is underscribed by observations, interviews and policy documents

Urban characteristics Bloemhof

Floor and ground index
Building year typology
Sunstudy
Public space

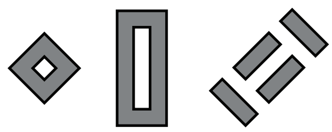
Bloemhof provides for little places to escape from high air temperature both in the public and private as buildings are often badly isolated and the neighbourhood shows little vegatation and lots of paved surfaces



Assessment of three building typologies

Used data
Assessment of three building typologies

Building typpologies of courtyard building block is found to be most benefical in terms of coolness on the inner courtyard.



Urban heat island mitigating and adapting design proposals

Description strategy
Design proposals

The design proposals introduce new building blocks, waterbodies, and adress both the private and public space with the use of a neighbourhood deal.

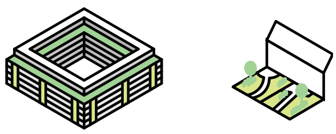


figure 1. Diagram of the thesis structure with a short description of the main findings from each chapter accompanied with an illustrative image (image by author).

2. Research framework

This chapter sets up the research framework, the subsequent research questions and research methodology. Firstly the problem statement concisely states the problem. Secondly the problem is more in depth described in the problem analysis. The phenomenon of the urban heat island, climate change and environmental justice are introduced and how these relate to the city of Rotterdam. Thirdly the chapter concludes with a description of the research methodology goal and scope and relevance is described.

2.1 Problem statement

Cities face challenges related to the urban heat island which cause high air temperature in urban areas. This will become even more challenging with the prediction of global temperature rise in the coming century. In the Netherlands it is predicted that summers become warmer and drier with more frequent and intense heat waves. In the Dutch context Rotterdam experiences a strong urban heat island partly because it's densely built with a high percentage of impervious materials. Besides a strong urban heat island the city also houses many lower income groups who often reside in socially deprived neighbourhoods. Since international research shows a correlation between intense urban heat island and socioeconomic characteristics, stating it as an issue of environmental justice issue, one might wonder to what extend this is the case in Rotterdam. Are lower income group disproportionately exposed to high air temperature and how can urban design mitigate or adapt to reduce exposure to high air temperature?

2.2 Problem analysis

The urban heat island is the phenomenon of relative higher nocturnal air temperature in the city compared to its rural surroundings (Gartland, 2008; Kiesel, Orehounig, Soshtari, & Mahdavi, 2012). With climate change the urban heat island is expected to become more severe since scenarios predict a mean global temperature rise between 0,3 °C and 4,8 °C (Collins et al., 2013). Also the Netherlands will be affected by climate change. Scenarios by the Royal Netherlands Meteorological Institute (KNMI) predict an increase of temperature during summer with a drier and warmer climate. Such a trend will have an intensifying effect on the urban heat island in the Netherlands (KNMI, 2015a). High air temperature can have a negative effect on humans. When the perceived temperature is above 23° C people start to experience mild heat stress and this becomes more severe from 29 °C and above. In the case of vulnerable groups high air temperature can be lethal. For example the elderly are more vulnerable due to their age and ill health condition and during heat waves more elderly decease as mortality rate numbers show. (Dousset et al., 2011; Tian, Chen, & Yu, 2013; van der Hoeven & Wandl, 2015).

However not the city as a whole experiences the same high air temperatures. The intensity of the urban heat island is differently distributed among urbanized areas and closely related to urban characteristics. One might wonder how this different distribution would affect different kind of neighbourhoods and their inhabitants. Within urban heat island related research there is no widespread consensus on the overall relationship between heat related physical issues and socioeconomic characteristics. (Duneier, 2004, 2006; Huang, Caenasso, & Zhou, 2011; Johnson & Wilson, 2009; Klinenberg, 2004; Wilhelmi, Purvis, & Harriss, 2004). However, researchers from the United States and United Kingdom have examined the land surface temperatures pattern at the neighbourhood scale in relation with socioeconomic characteristics of the human population. Outcome is that the built environment of socially deprived neighbourhoods can positively contribute to the urban heat island with negative effects for the well-being of its inhabitants. Such built environment is characterized by a lack of shade, vegetation, high building density resulting in a strong urban heat island with relative high air temperatures. The inhabitants often consist of lower income groups with little resources and a higher percentage with ill health conditions. In combination with a lack of adequate housing the inhabitants are more vulnerable to heat stress. Especially during a heat wave they are more exposed to high air temperature which they are less able to adapt or mitigate to.

Such an issue of environmental justice can be observed on the city scale whereas high air temperature is a hazard that people are unable to shelter from and disproportionate exposed to (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006; Harlan & Ruddell, 2011; Huang et al., 2011; Pearsall & Pierce, 2010; Ruddell, Harlan, Grossman-Clarke, & Buyantuyev, 2010).

Within Europe the urban heat island is a known phenomenon and recognized as a hazard. Studies have investigated the link between heat related death during heat waves and age. Concluding that during a heat wave elderly are a vulnerable group that risk passing away (Dousset et al., 2011; van der Hoeven & Wandl, 2013; van der Hoeven & Wandl, 2015). However there remains limited understanding of the effects of the urban heat island connected to social economic dimensions. Within English written academic research on the urban heat island in Europe such notion is nowhere to be found.

Within the Netherlands the dangers of climate change often relate to the thread of flooding since large urban areas are below sea level and within a river delta. Since the Netherlands has a temperate climate heat related issues is not something that is quickly thought of by the public as a threat. However within the Dutch context the urban heat island is recognized by the academic field and institutions as a hazard that affects vulnerable groups such as the elderly and infants (Climate Proof Cities consortium, 2014; RCP, 2013; van der Hoeven & Wandl, 2013; van der Hoeven & Wandl, 2015). Research shows that Dutch cities experience the urban heat island phenomenon and that this will become more severe due to climate change (Hove et al., 2010; KNMI, 2014; Steeneveld, Koopmans, Heusinkveld, van Hove, & Holtslag, 2011; van der Hoeven & Wandl, 2013; van der Hoeven & Wandl, 2015). A Dutch consortium of public, private and educational partners calls in their final report ‘Climate Proof Cities of 2014’ for strategies to adapt to the consequence of climate change and heat related issues due to urban heat island are specifically mentioned (Climate Proof Cities consortium, 2014). However within the Dutch academic field or institutions there is no notion to be found of the vulnerability to urban heat island by socially-economic deprived groups. Without addressing such as component of the relation of urban heat island and social-economic characteristics there is no clear picture if there is a issue of environmental injustice.

It is precisely this last notion where this master thesis focuses on; if within the Dutch context there is a correlation between the urban heat island and socio-economic characteristics and if this is an issue of environmental justice. The city of Rotterdam will act as the study case as it is one of the most densely populated urban areas in the Netherlands and suffers from a strong urban heat island. In a research on the urban heat island ub the Netherlands concluded was that particularly Rotterdam exceeds the heat stress threshold value for about 15 days per year. (Climate Proof Cities consortium, 2014). The city is vulnerable to climate change which besides these water related challenges also faces heat related challenges (Beumer, Hulsman, & Koning, 2012). Such notion is under scribed by the European Environmental Agency stating that cities in the Benelux will be strongly affected when heat wave intensity increases to the North West of Europe (EEA, 2012a).

Besides a strong urban heat island Rotterdam also has a high share of low income groups concentrated in dense and older parts of the city. The combination of low income, high density, building quality and urban heat island raises the question if there is an issue of environmental injustice. Are lower income groups, living in bad neighbourhoods disproportionately exposed to the urban heat island? What indicators would be applicable to unsubscribe such a relation? And how can the vulnerability of such neighbourhoods be improved? Thus the research goal of this master thesis is to discover how urban heat island is related to social deprivation, why is this an issue in the city of Rotterdam and how urban design can mitigate and adapt to these effects?

2.3 Research questions

As a result the problem statement the main research question is:

How is the urban heat island related to social deprivation, why is such a relation in the city of Rotterdam an issue and how can urban design mitigate and adapt the urban heat island on a neighbourhood scale?

Adding one clarification:

Urban heat island mitigating and adapting solutions and principles are applied to mitigate and adapt to the urban heat island in order to learn how these work on a neighbourhood scale within the Dutch context of pre-war urban expansion areas.

The main research question is related to 5 sub questions:

1. *What is the urban heat island, what are its effects and how are these related to environmental justice?*
2. *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
3. *What are urban heat island adapting and mitigating design principles and how can these be applied to reduce the urban heat island in socially deprived neighbourhoods of Rotterdam?*
4. *What urban typologies in the city of Rotterdam are more exposed to the urban heat island?*
5. *What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?*

2.4 Research methodology

In the course of this thesis report a wide variety of different type of sources and methods are used to support findings in answering the research questions. Each of the used method are described in the subsequent chapters and its paragraphs.

Since the nature of a city resembles that of a complex system one cannot unambiguously assert reality based upon a single type of source or method. Therefore in order to answer the research questions the used research methodology is a methodological triangulation.

Methodological triangulation encompasses the use of multiple qualitative and quantitative methods, theories, data and investigators to study and capture different dimensions of the same phenomenon. Main reason is to come to a more accurate conclusion by minimizing weakness of relying on one particular source or method (Duffy, 1987; Martin & Hanington, 2012). The success of a methodological triangulation lies within the collection of multiple sources aimed at corroborating the same finding. Such success is dependent on the convergence or non-convergence of evidence whereas convergence of evidence leads to findings supported by more than a single source. In figure 2 is depicted convergence and non-convergence of multiple sources of evidence. Convergence leads to evidence from multiple sources. Non-convergence where multiple sources are part of the same study but addressing different findings. The first is considered as true triangulation and the latter as flawed (Yin, 2009).

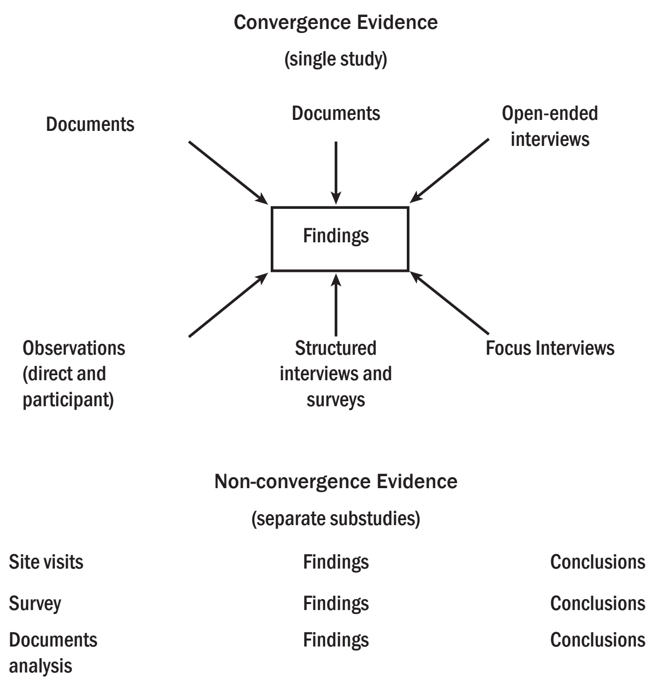


figure 2. Convergence and non-convergence of multiple sources of evidence (Yin, 2009, p. 121).

2.5 Research scope

The scope is to apply environmental justice theory on the Dutch neighbourhood scale and urban heat island mitigating and adapting solutions in an integrated urban design. In order to build the theoretical framework mainly international research on environmental justice in English written reports and papers are used. The context of such research is different from the Netherlands since, for example, income inequality is more severe and the scale of social deprived neighbourhoods is bigger in the United States. This thesis is not judgemental on the scale of environmental justice but rather tries to apply the concept of environmental justice within a Dutch context to discover its applicability. Scope of the urban design is to integrate urban heat island mitigating and adapting design solutions in a wider neighbourhood context of social deprivation and other climate related issues.

2.6 Relevance

The graduation project is relevant for the academic field for four reasons:

Firstly the graduation project connects to the graduation studio of urban metabolism. This studio analyses and visualizes materials and energy flows of the city. Subsequently subdivided by; demographics, air, water, food, biota, mobility, cargo, building materials, waste and energy. The graduation project connects to the topic of energy and water. As urban heat island theory is based upon incoming energy by solar radiation and anthropogenic activities and design solutions will connect to energy and water.

Secondly while environmental justice is an international known concept applying it to a Dutch context of urban heat island is new. A deeper insight will be presented on how researchers link the two and what kind of social and spatial indicators are used.

Thirdly by using similar spatial social and spatial indicators to map environmental justice gives a deeper understanding of such concept. This opens up a discussion of environmental justice in the Dutch context.

Finally the research is relevant for the urban design discipline concerned with climate adapting design solutions. The graduation project implements existing solutions in the context of a pre-war neighbourhood where room is sparse. These lessons learned are valuable for design assignment with a similar framework.

3. Theoretical framework

In this chapter the theoretical framework of environmental justice, urban heat island and climate change are described. The sub questions that are related:

1. ***What is the urban heat island, what are its effects and how are these related to environmental justice?***
2. ***What characteristics of the urban fabric have an exacerbating effect on urban heat island?***
3. ***What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?***

To answer these research questions literature research is conducted. In first instance this has resulted in a literature review paper (appendix "II. Theoretical paper" on page 192).The findings of this literature review paper are used as a basis for this theoretical framework and expanded upon.

Firstly the concept of environmental justice is described and what the relation is with the urban heat island. A set of environmental justice and urban heat island indicators are derived to map the spatial distribution of urban heat island and measure environmental justice. Secondly the theoretical background of the urban heat island is given how it relates to climate change and how it affects the human body. The chapter concludes with how the urban heat island be measured using remote sensed data and GIS.

3.1 Theoretical background of environmental justice

In this paragraph the concept of environmental justice is explained and how it's linked to the urban heat island. The premise of linking the urban heat island to environmental justice is to determine whether certain groups in a city are disproportionally exposed to the environmental hazard of high air temperature as a consequence of the urban heat island.

In what follows firstly the concept of environmental justice is explained. Secondly is described the commonality between research papers on spatial indicators of environmental justice, urban heat island and socio-economic characteristics. Thirdly the indicators to indicators to described issues of environmental justice are described and how they can be applied for the city of Rotterdam.

What is environmental justice?

Environmental justice is characterized as the struggled against the inequitable distribution of environmental hazards and goods and the access to the decision-making process to have a healthy environment in which to live, learn, and work (EPA, 2016). This raises the question if low income groups or minorities are disproportionetely exposed to environmental hazards (Huang et al., 2011; Pearsall & Pierce, 2010). On a global level such effects are often disproportionately left to the poor (Millennium Ecosystem Assessment Board, 2005).

A research on the heat wave in Chicago of 1995 shows that the inequitably distribution of environmental hazards can also be observed on the city scale. The spatial pattern of the land surface temperature within the city shows an inequitable distribution of temperature and this positively correlates with socially deprived neighbourhoods. Such correlation is considered as an issue of environmental justice (Huang et al., 2011).

However such research on the city level is not so plenty. Research papers often stress out the importance for more conclusive spatial correlations with higher resolution and more up-to-date data (Norman et al., 2012). The relative absence of meaningful environmental justice oriented indicators reinforces the need for more theoretical and empirical research on the conceptualization of social sustainability and its relationship to environmental justice on the scale of the city and its neighbourhoods (Pearsall & Pierce, 2010).

Research on environmental indicators and spatial distribution on city scale

There are a few researches that specifically describe environmental justice indicators and are conducted in the United States of America and the United Kingdom. In the cities of Chicago, Phoenix, Baltimore, Birmingham and Arizona researchers conclude that there is a spatial relation between socio-economic characteristics, environmental hazards and urban characteristic. Socioeconomic characteristics are described as low income, low education, ethnic minorities and ill health. The environmental hazards is temperature. Urban characteristics are described as presence of green areas, use of impermeable surfaces, density and bad building quality. The research papers argue that there is a disproportionate exposure to the environmental hazard of temperature by people with a lower socio-economic status. As conclusion is argued that this is an issue of environmental injustice (Harlan et al., 2006; Huang et al., 2011; Norman et al., 2012; Pearsall & Pierce, 2010; Ruddell et al., 2010; Todd & Zografos, 2005; Tomlinson et al., 2011).

For example, a study in Birmingham integrated temperature data, commercial social segmentation data and spatial risk assessment methodology to highlight the potential heat health risk areas (figure 3 on page 19). Concluding that social groups like elderly and people of ill health residing in neighbourhoods with urban characteristics of high population density and high rise living are more vulnerable to heat. The researchers present a map to show the spatial correlation between urban heat island and socio-economic characteristics. Within high-rise neighbourhoods there is a separation between people with low income, living in high rise blocks and well educated young who life in modern or converted apartments (Tomlinson et al., 2011). Consequence is that in these neighbourhoods there is a division between the exposure to heat by different socioeconomic groups.

Research papers on the city of Amsterdam, Rotterdam, Paris and São Paulo describe a correlation between the urban heat island, socioeconomic characteristics and urban characteristics. Notice that these researches do integrate socioeconomic characteristics but do not suggest an issue of environmental justice as this is not a concept integrated in the research. Spatially distributed temperature data is used, like remotely sensed land surface temperature or in situ measurements, for determining the urban heat island. Socioeconomic characteristics are described as age (elderly), mortality rate, infection and income. Urban characteristics are described as building age and low vegetation. Concluding there is a relation between the spatial distribution of the urban heat island, socio-conomic characteristics and urban characteristics (Araujo et al., 2015; Dousset et al., 2011; van der Hoeven & Wandl, 2013; van der Hoeven & Wandl, 2015).

Description indicators to assess issues of environmental justice

In the appendix the literature review paper is added. Within this paper there is a table of different indicators from both environmental justice and the urban heat island papers used for correlating the urban heat island and socio-economic characteristics. These indicators are categorized according to population characteristics, urban characteristics and environmental hazards. The population characteristics are ethnicity, education, health and income. These indicators are used for assessing social deprivation and describe some sort of vulnerability to the urban heat island. The environmental hazard of temperature is used as it can cause heat stress and severe health issues as later described in paragraph "3.4 The effect of air temperature on the human body" on page 26. The urban characteristics are those that correlate with the urban heat island and can either have a mitigating or deteriorative effect on the urban heat island. In table 1 on page 20 an overview is given of these indicators and how they relate to the urban heat island.

This background on environmental justice service as a prelude to conduct a similar research for the city of Rotterdam. With the indicators found the thesis sets out to conduct a similar research with a collection of similar indicators. The data that are used will be described in paragraph "7.1 Used data" on page 39. This chapter continues with a more in depth description of the urban heat island phenomenon.

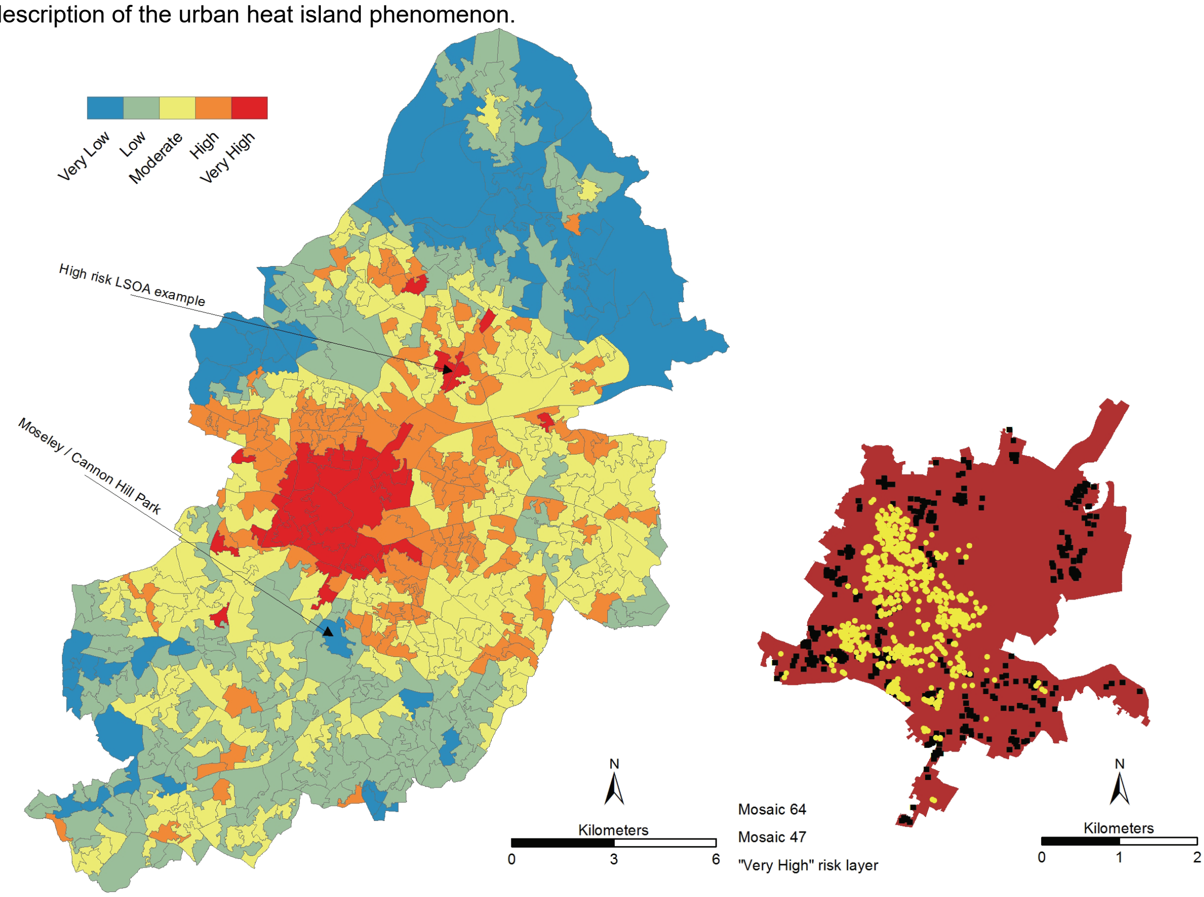


figure 3. The map left displays the heat health risk areas in Birmingham. The map on the right shows that within an area there is a separation of risk to heat (Tomlinson et al., 2011, p. 11 & 12).

table 1. Overview of the indicators to assess environmental justice and how they relate to the urban heat island.

Population characteristics

Age	Ethnicity	Education	Health	Income
The elderly and young are more vulnerable due to physical fragility because of young age or elderly often suffer from diseases such as cardiovascular diseases, respiratory conditions and diabetes	Are more likely to live in warmer neighbourhoods.	Education is linked to socioeconomic status. Lower education limited the ability to understand or access warning or recovery information.	Physical fragile, particular those with renal and cardiovascular conditions and diabetes.	Higher vulnerability due to poorer health status and more likely to live in warmer neighbourhoods with greater exposure to heat stress.

(Cutter, Boruff, & W, 2003; Schauser et al., 2010, p. 33)

Environmental Hazards

Pollution	Temperature
Environmental pollution is defined as the undesirable change in physical, chemical and biological characteristics of our air, land and water.	High temperature is considered a hazard as it negatively influence thermic comfort resulting in misbalancing the thermal body management system also known as heat stress. Effects of heat stress are reduced concentration, learning capacity, labour productivity and sleep problems. Certain groups within a population are more vulnerable (see population characteristics).

(Lenzholzer, 2013; Sharma, 2009)

Urban characteristics

Density	Vegetation	Land use / Land cover	Urban fabric
High density in terms of dense building construction positively correlates with urban heat island.	Vegetation positively relates to the evaporation of energy into the air and provides shade.	Correlation between daytime land surface temperature and land use / land cover.	Physical factors as building quality, canyon like configuration, high building mass, impervious cover or structures that hinder ventilation all correlates to the intensity of the urban heat island.

(EEA, 2012b; Gartland, 2008; Roth, Oke, & Emery, 1989)

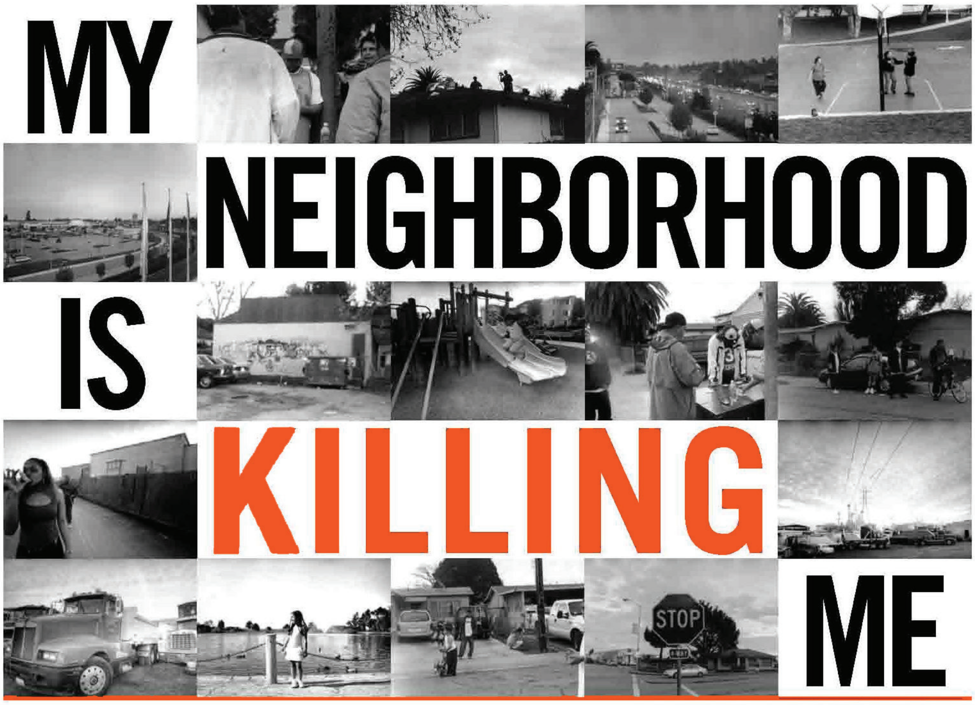


figure 4. Illustrative image of how urban characteristics of a neighbourhood can negatively affect its residents (Wake Forest University).

3.2 The urban heat island

Many cities have the tendency to warm up during the day and remain warm during the night. This is also known as the urban heat island and is the relative higher air and surface temperature in the city compared to its surrounding rural areas (Gartland, 2008).

Due to solar radiation and anthropogenic activities heat the city conserves heat and re-emits this over time. This process can be described with the surface energy balance. The equation of the energy balance explains, based upon the first law of thermodynamics, how energy is transferred from and to the earth's surfaces. The energy from the sun and anthropogenic heat warms the air, is evaporated and or stored in materials.

The equation is:

Net radiation + Anthropogenic Heat = Convection + Evapotranspiration + Heat storage

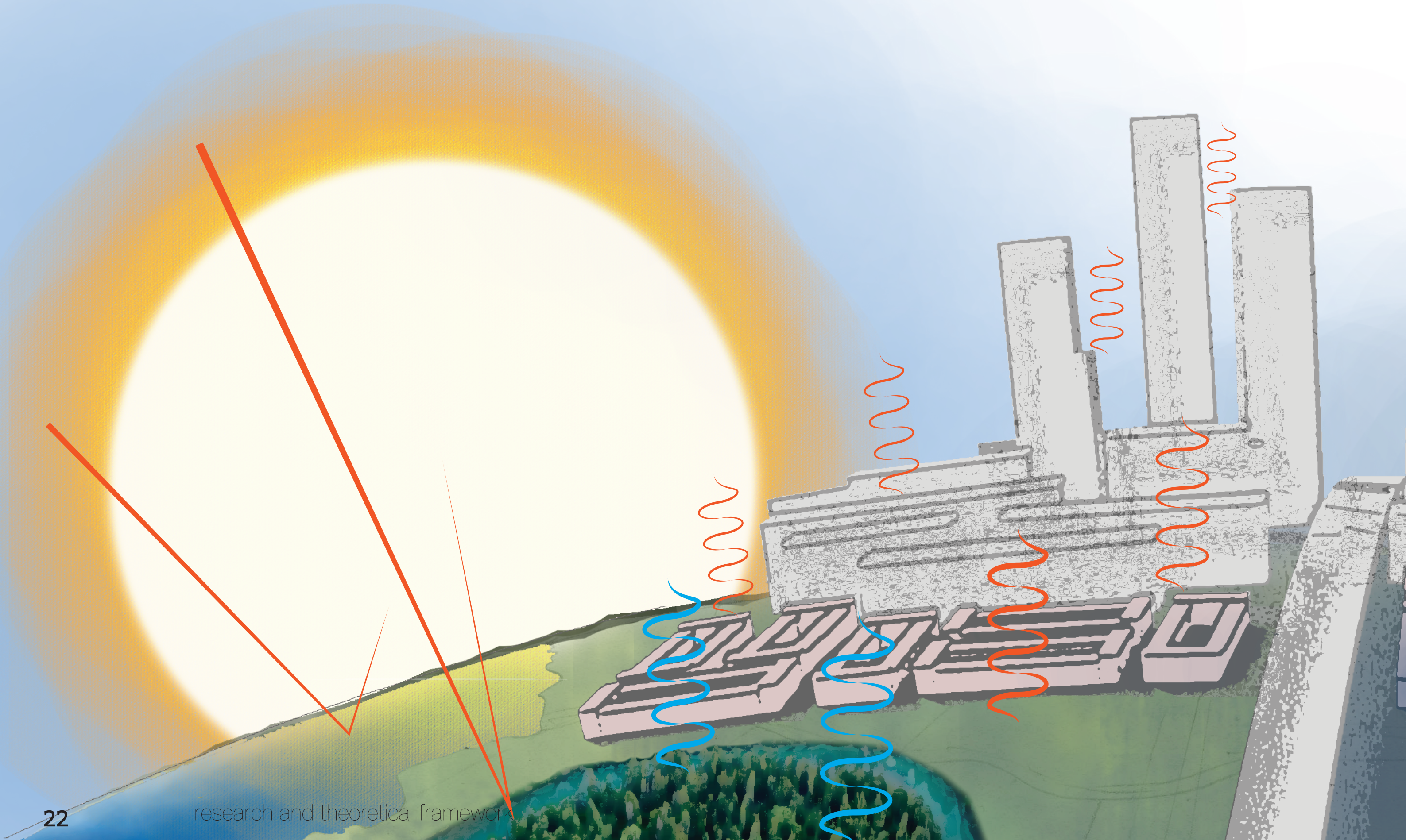
The first part consists of the net radiation and anthropogenic heat whereas the net radiation is made up of four separate radiation processes taking place at the Earth's surface:

- Incoming solar = the amount of energy radiating from the sun.
- Reflected solar = the amount of solar energy that bounces off a surface, based on the solar reflectance of the material.
- Atmospheric radiation = heat emitted by particles in the atmospheres like clouds, pollution and dust.
- Surface radiation = heat radiating from the surface itself.

The equation for the net radiation:

Net radiation = incoming solar – reflected solar + atmospheric radiation – surface radiation.

Incoming solar radiation represents the amount of energy radiated from the sun. The reflected solar radiation represents the amount of solar radiation that is reflected by a surface. Bright materials such as a white roof have a high solar reflectance and dark materials such as black asphalt have a low reflectance. The atmospheric radiation is the energy radiated by particles in the atmosphere. The warmer the atmosphere and the more particles it contains the more energy is emitted. The surface radiation is the heat radiated from the surface itself (Gartland, 2008).



Anthropogenic heat is man-made heat generated by buildings, machinery or people. The anthropogenic heat release is more intense in more dense urban areas and can a have strong influence on the urban heat island formation (Gartland, 2008).

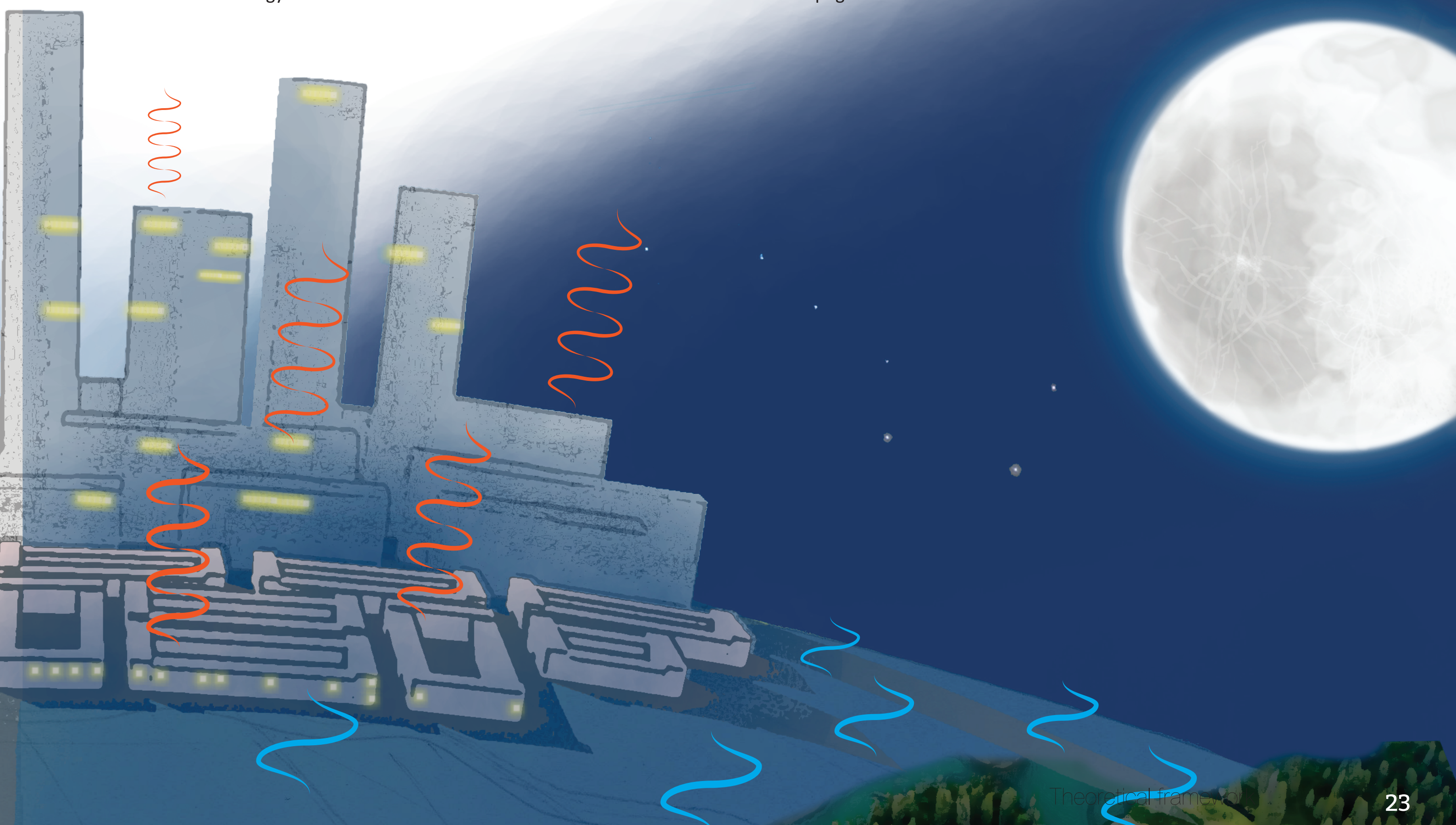
The right part of the equation consists of convection, evapotranspiration and heat storage. Convection is sensible heat where energy is transferred from a solid surface to a liquid or gas and as such heats the air. Evapotranspiration is the latent heat and the combination of energy transmitted away from the Earth's by water vapour and by plants. The water evaporates and rises into the atmosphere taking the sun's energy with it. Evapotranspiration by plants is the process where water is drawn from the soil by the root to keep cool. The heat storage or ground flux depends on the heat capacity of materials. The heat is stored into buildings, soil and water (Gartland, 2008).

In regard to this physical theory the main causes of urban heat island are urban surfaces who reduce evapotranspiration, increase heat storage, increased net radiation, reduced convection and increased anthropogenic heat. As mentioned before asphalt for example is a material that is dark and impermeable and stores a lot of energy and moisture is unable to evaporate this heat (Gartland, 2008). This energy in the asphalt is then overtime radiated. One might have noticed this by putting his hand on asphalt after sunset during a warm summer day and discover that it is still quite warm. This radiation, build up during the ray, and re emitted at night is responsible for the urban heat island effect. In table 2 on page 23 the most important characteristics contributing to the urban heat island are displayed.

The intensity of the urban heat island is strongly determined by the location of a city on the planet and its subsequent climate. In the next paragraph "3.3 Climate change and urban heat island" on page 24 the influence of climate change on the urban heat island will be described.

table 2. Urban and characteristics that are important to heat island formation (Gartland, 2008, p. 16).

Characteristics contributing to the urban heat island	Effect on the energy balance
Lack of vegetation	Reduces evapotranspiration
Widespread use of impermeable surfaces	Reduces evaporation
Increased thermal diffusivity of urban materials	Increases heat storage
Low Solar reflectance of urban materials	Increases net radiation
Urban geometries the trap heat	Increases net radiation
Urban geometries that slow wind speeds	Reduces convection
Increased levels of air pollution	Increases net radiation
Increased energy use	Increase anthropogenic heat



3.3 Climate change and urban heat island

In the 21st century climate change is the most important threat for mankind to deal with. It threatens the environment and societies all over the globe with drought, flooding, famine, water shortage and extreme rainfall or heat waves. The international panel on climate change (IPCC) reports that the global mean temperature will rise this century. The most optimistic scenario predicts an increase between 0,3 °C and 1,7 °C and the least optimistic an increase between 2,6 °C and 4,8 °C. While this temperature change will not be regionally uniform it is virtually certain that there will be an increase of more extreme temperatures (Collins et al., 2013).

The European Environment Agency Climate Change (EEA) reports that climate change will increase temperature extremes in Europe. The report suggests urban heat island will become more aggravated and notes that in climate scenario's the number of tropical nights are underestimated because they don't take in account that the air temperature in cities can be much higher due to the impact of the urban heat island phenomenon (EEA, 2012a, 2012b).

In the Netherlands the predictions are that the country will experience more warm summer days. The national meteorological institute (KNMI) has developed 4 climate scenarios to predict development of the climate in the Netherlands for the coming century. Variables are change of air flow pattern and global temperature rise. A temperature rise of 1 °C is labelled with G and a rise of 2 °C with label W. Second label is the value of change in air flow pattern. The influence of change in air flow pattern in scenario L is low. In scenario H the change in air flow pattern causes more easterly winds during the summer which results in warmer and drier weather. The table 3 on page 25 shows for the year 2050 and 2085 the outcome of the four scenarios. Referring to the period 1981 – 2010 with an average of 21 (≥ 25 ° C) summer days measured for rural areas. The favourable scenario G_L adds an additional 4,6 summer days for 2050 and 6,3 summer days for 2085 is predicted. In the least favourable scenario W_H an additional 14,7 and 27,3 summer days for 2050 and 2085 is predicted. It must be noted that these prediction apply to rural areas and don't take into account the effect of the urban heat island on the number of tropical nights. Expected is that in urban areas the heat stress threshold is more often exceeded than in rural areas (KNMI, 2014, 2015a). Heat related problems will become more severe in the city as is under scribed by the EEA who note that cities will be strongly affected when heat wave intensity increases (EEA, 2012a). In figure 5 on page 24 the increase of number summer days are displayed according to the KNMI climate scenario's for 2050. How these prediction apply to Rotterdam is discussed in the introduction of the chapter part "Statistical analyses of environmental justice indicators" on page 39.

The urban heat island in combination with expected temperature increase due climate change this century will affect humans. In the next paragraph "3.4 The effect of air temperature on the human body" on page 26 the influence of high air temperature on the human body will be further described.

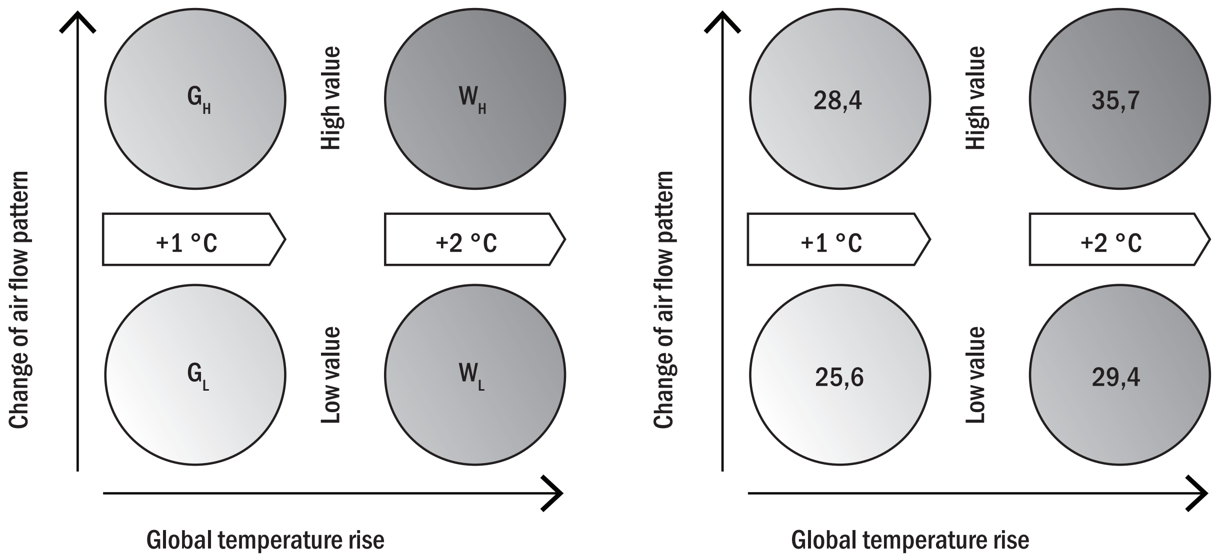


figure 5. Diagram of the KNMI climate scenarios for 2050 with on the y-axis change of air flow pattern and on the x-axis the global temperature rise of one or two degrees couple coupled with the expected number of summer days (KNMI, 2014).

table 3. Overview of the different climate scenarios and the predicted increase of mean temperature, summer days and tropical nights (KNMI, 2014).

	Ref.	**Scenario (2036-2065)**				**Scenario (2071-2100)**			
		2050				**2085**			
		G_L	G_H	W_L	W_H	G_L	G_H	W_L	W_H
mean temperature	24,7	26,1	26,6	27,0	28,0	26,7	27,3	28,3	29,6
number of summer days (max ≥ 25 ° C)	21,0	25,6	28,4	29,4	35,7	27,3	31,5	39,9	48,3
number of tropical nights (min ≥ 20 ° C)	0,1	0,5%	0,6%	1,4%	2,2%	9,0%	1,2%	4,5%	7,5%

3.4 The effect of air temperature on the human body

High air temperature as a result of the urban heat island has effects on humans. These effects have been quite extensively researched. For example high air temperature leads to more energy use for cooling by air conditioning because dense urban areas remain warm during the evening and night. (EEA, 2012a; Li, Shang, & Cao, 2010; van der Hoeven & Wandl, 2013). In São Paulo urban areas with overall high air temperature show more infection cases of dengue fever then relatively cooler areas in figure 6 (Araujo et al., 2015). Higher air temperatures due to urban heat island have a positive effect on formation of ozone which leads to health complains (Stone, 2005).

Health issue due to high air temperature can even be deadly. This relation between mortality due to extreme heat can be found across all continents (Harlan & Ruddell, 2011). Within the European context across different countries there is an increase of the number of casualties during the heat wave of 2003 (table 4). During this heat wave of 2003 and 2006 a significant amount of elderly died during the heat waves of 2003 in Paris and 2006 in Rotterdam. Researchers directly link this to the this to high air temperature as a result of the urban heat island (Dousset et al., 2011; van der Hoeven & Wandl, 2015).

Human health is affected by high air temperature as it influences the human system of thermoregulation. A system of processes that keeps the humans core body temperature between 36,8 °C and 37,7 °C. In figure 7 on page 27 all heat inputs and outputs from the body are presented. The distribution of the land surface temperature and dengue cases among the population is shown in figure 6.

For the body to lose heat convection and evaporation are the major ways with a minor role for respiration, radiation and conduction. With higher air temperature the human body is less able to lose heat by convection, conduction and radiation. The difference between human body temperature and the air temperature becomes smaller limiting the ability to lose heat. When the air is saturated with moist and thus has a high humidity the body is less able to lose heat through evaporation because the air is less able to absorb the perspiration. This combination of high air temperature and high humidity separately and in combination can lead to heat stress (Havenith, 2005).

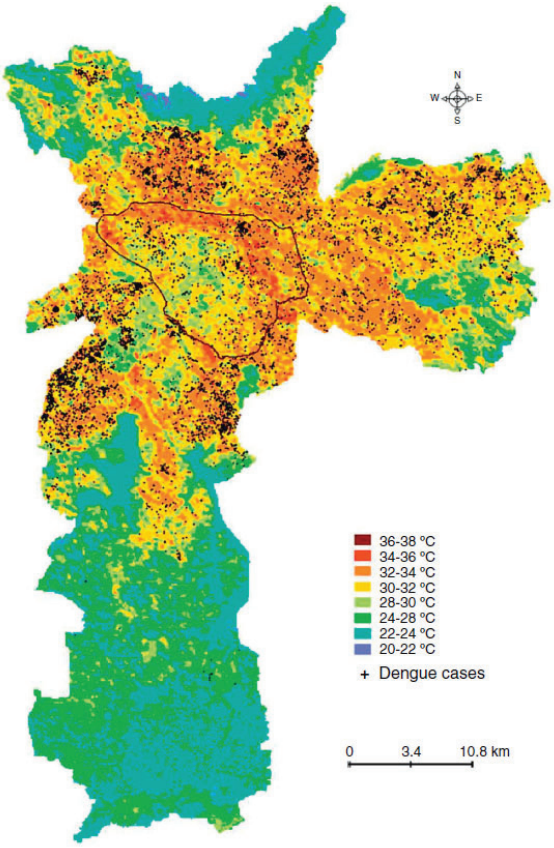


table 4. Extra casualties during the heat wave of 2003 in different European countries (Lenzholzer, 2013, p. 24).

Location	Additional causalities	Increase (%)
England and Wales	2091	17
France	14802	60
Germanu	1410	-
Italy	3134	15
The Netherlands	1400-2200	-
Portugal	1854	40
Spain	4151	11
Switserland	975	7

figure 6. An example of how land surface temperatures correlates with dengue cases and slum-like areas in the city of São Paulo (Araujo et al., 2015, p. 148).

Heat stress is the threat of body functions failing as a result of exposure to heat (RIVM), 2012). This heat stress reduces sleep quality, concentration, learning capacity and labour productivity. More severe health problems are heat -rash, -cramps, -exhaustion, -stroke, kidney falling or respiratory problems. Groups such as children, elderly and people with obesities or chronically heart diseases, cardiovascular and respiratory problems or pregnant women are extra vulnerable (Climate Proof Cities consortium, 2014; Lenzholzer, 2013). In table 5 an overview is given of the consequences of heat stress.

Since the urban heat is unevenly spatially distributed across the city the effects on the population varies. Therefore the urban heat island need to be mapped. By measuring the land surface temperature an indication can be given of the urban heat island. In paragraph "3.5 Calculating land surface temperature using remote sensed data and GIS" on page 29 will be described how, with the use of remote sensed data, land surface temperature, maps can be created in ArcGIS.

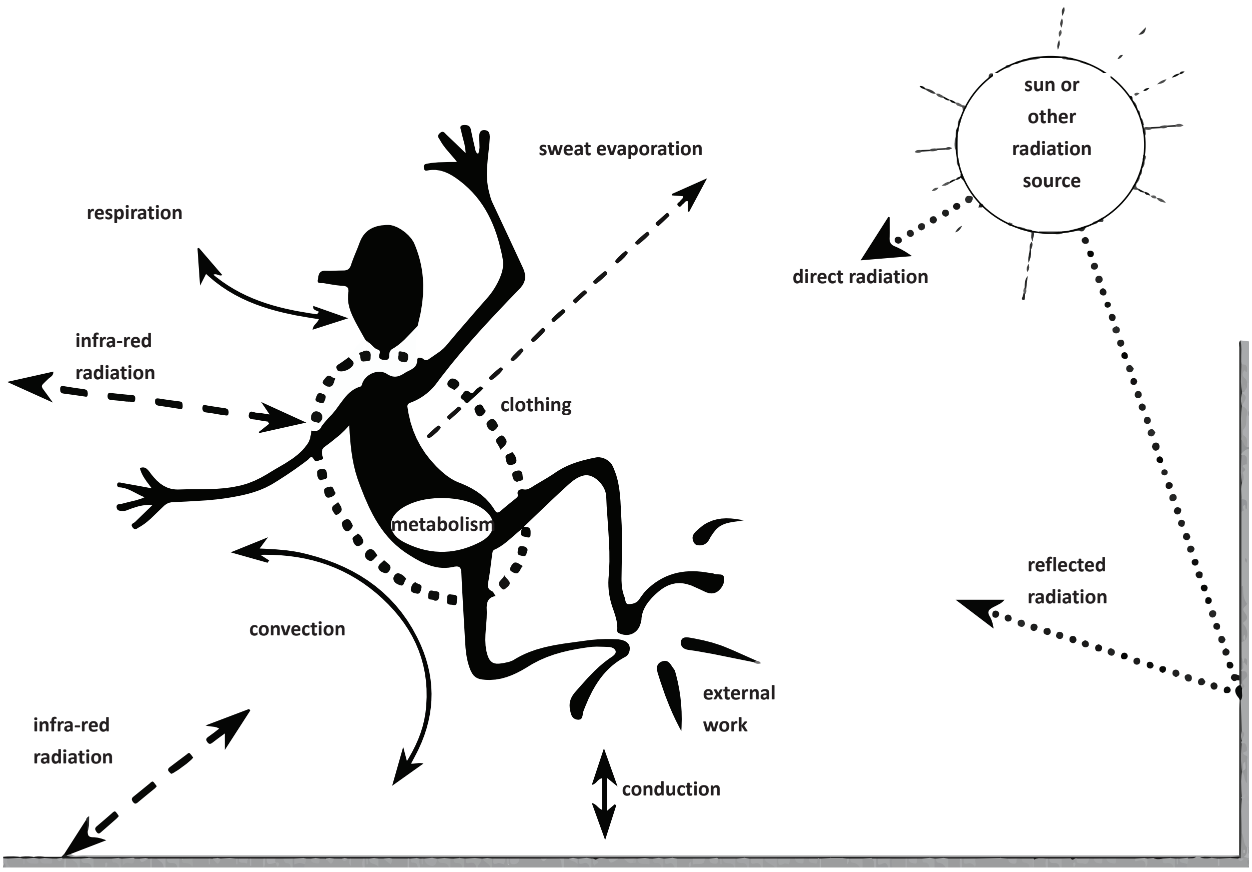


figure 7. A graphical representation of all the heat inputs to and outputs from the body (Havenith, 2005, p. 72).

table 5. Consequences of heat stress (based upon ((RIVM), 2012, p. 33)

Effect	Symptoms	Mechanism
Nuisance	Irritable, lethargic, reduced alert, sleep disturbance, headache, dizziness, concentration problems , anxiety, muscle pain	Change of psychological functioning and social interaction with others
Sleep disturbance	Loss of concentration , tired, listless, irritable	Decrease in sleep quality that results insufficient recovery
Edema	Non painful swelling of ankles in which a well can be pushed	Withdrawal of fluid from the bloodstream by dilating blood vessels Blockage of sweat glands
Rash	Itchy blisters and redness	Blockage of sweat glands
Heat exhaustion, heat syncope , heat exhaustion	General: dry mouth, tired, dizziness , headache Skin: red , sweating Body temperature to 40 ° C	Moisture loss through transpiration and dilation of blood vessels
Heat Cramps / muscle Cramps	Skin warm and dry	Extreme loss of fluid and salts through sweating at effort
Heat stroke	General : confused, drowsy , Unconscious Body temperature above 40 ° C	Skin warm and dry Extreme loss of fluid and salts by perspiration

3.5 Calculating land surface temperature using remote sensed data and GIS

In this paragraph is described how land surface temperature maps are calculated from USGS Landsat 8 satellite dataset (USGS, 2013). The dataset for 5 September of 2013 has been chosen. In Rotterdam this day had a maximum temperature of 31,6°C and minimum of 15,6 °C (KNMI, 2013). In the month July of 2013 there was a heat wave in the Netherlands and such Landsat 8 data would be more significant to show urban heat island. However the datasets from this period all fully clouded. The dataset from 5 September has the least amount of clouds. The dataset was also used to get a sense for the work around for calculating land surface temperature.

The remote sensed data are recorded during the daytime. Important notion is that the method calculates the land surface temperature. While the land surface temperature by radiation and conduction warms the human body it is air temperature that influences the human body the most. However land surface temperature data can be used as it causes the nocturnal urban heat island and influences the air temperature (van der Hoeven & Wandl, 2015). Secondly there is a close relationship between the satellite derived land surface temperature and air temperature (Mallick, Rahman, & Singh, 2013). Therefore measuring the land surface temperature is used as an indicator for the urban heat island intensity.

Landsat 8 data conversion
Landsat 8 data will be used to calculate the land surface temperature. Landsat 8 satellite images the entire Earth using the two instruments Operational Land image (OLI) and Thermal infrared sensor (TIRS). The spectral bands of the OLI consist of 9 bands with and the TIRS of two bands 10 and 11 with a spatial resolution size of 30 by 30 m.

These images can be processed using GIS software (ArcGIS in this case). First the normalized difference vegetation index (NDVI) is calculated. Then the digital numbers for Band 10 and 11 where converted into radiance. Radiance is converted into at-satellite brightness temperature. Land surface emissivity is derived and finally the land surface temperature is derived. The following bands are used to calculate NDVI:
Band 2; Blue
Band 3; Green
Band 4; Red
Band 5; Near Infrared

The equation for the NDVI is: $NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$

The radiance rescaling factors are provided in the meta-data file of the downloaded Landsat 8 dataset.

$$L_\lambda = M_L Q_{cal} + A_L$$

Where:
L_λ = TOA spectral radiance (Watts/(m² * srad * μm))
M_L = Band-specific multiplicative rescaling factor
A_L = Band-specific additive rescaling factor
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

Conversion to At-Satellite Brightness Temperature
TIRS band data can be converted from spectral radiance to brightness temperature using the thermal constants.

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Where:
T = At-satellite brightness temperature (K)
L_λ = TOA spectral radiance (Watts/(m^2 * srad * µm))
K_1 = Band-specific thermal conversion constant
K_2 = Band-specific thermal conversion constant
Deriving LSE (Land surface emissivity)
P_v = $(NDVI - NDVI_{min} / NDVI_{max} - NDVI_{min})^2$
P_v = Proportion of vegetation
E = $0.004P_v + 0.986$

Deriving land surface temperature

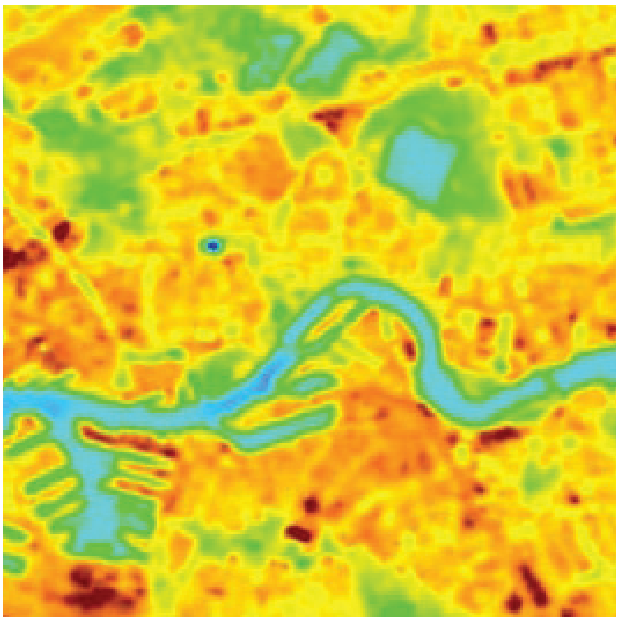
$$Land\ surface\ temperature = BT \div 1 + w \times ((BT \div p) \times \ln(e))$$

BT = At satellite temperature
w = wavelength of emitted radiance (11.5 µm)
p = h * c/s (1,438 * 10^{-2} m K)
h = Planck's constant (6,626 * 10^{-34} Js)
s = Boltzmann constant (1,38 * 10^{-23} J/K
c = velocity of light (2,998 * 10^8 m/s)

Atmospheric correction
An atmospheric corrections needs to be applied because of the interference of the reflectance of the atmospheric that is different from day to day. It must be noted that such a correction has not been done for this calculation.

Result
Calculating the Landsat data results in a map with the land surface temperature as presented in figure 9. The darker red the higher the surface temperature, the more green or blue the lower the surface temperature. A quick glance on the surface temperature map and the Urban Atlas map of Rotterdam shows how open water and green areas are cooler and urban an industry areas warmer.

figure 8. Artist impression of the NASA-USGS Landsat 8 Satellite (NASA's Goddard Space Flight Center, 2014).



LEGEND
Land surface temperature

47,0 °C

0,0 °C

LEGEND
Category of different land uses

- Continuous Urban fabric (S.L. > 80%)
- Discontinuous Dense Urban fabric (S.L.: 50% - 80%)
- Discontinuous Medium Urban fabric (S.L.: 30% - 50%)
- Discontinuous Low Density Urban fabric (S.L.: 10% - 30%)
- Discontinuous Low Density Urban fabric (S.L.: < 10%)
- Isolated Structures
- Industrial, commercial or public
- Fast transit roads and associated land
- Other roads and associated land
- Railways and associated land
- No data
- Airports
- Mineral extraction and dump sites
- Construction sites
- Land without current use
- Green urban ares
- Sports and leisure facilities
- Agricultural Areas, semi-natural areas and wetlands
- Forests
- Water
- Port areas

figure 9. Result of calculating the Landsat data for 9 September 2013 aligned with the Urban Atlas from the European Environment Agency (EEA, 2006).

4. Conclusion

The urban heat island affects life of people in the city and shows a wide range of negative effects on the population. A disproportionate exposure of different social groups to high air temperature can be seen as an issue of environmental justice. Due to climate change an increase of mean temperature is expected and the urban heat island will intensify with higher air temperatures.

In this chapter the three research questions that were discussed are:

1. *What is the urban heat island what, are its effects and how are these related to environmental justice?*
2. *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
3. *What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?*

Relating to the first question the urban heat island is the phenomenon where the city warms up during the day and remains relatively warmer compared to its rural surroundings. The high air temperature affects people in the city and shows a wide range of negative effects on the population. People can experience heat stress causing
- reduced sleep quality,
- concentration,
- learning capacity, and
- labour productivity.

Regarding the second research question. Since the urban heat island shows a diverse spatial distribution across a city the question rises if all city dwellers experience the same negative effects. On the scale of a city the relation between socio-economic characteristics and the urban heat island can be seen as an issue of environmental justice where certain groups suffer more from high air temperature then others. The characteristics of the groups are linked to social deprivation whereas people of low income and ethnicity often live in deprived neighbourhoods and due to urban characteristics there is a strong urban heat island with high land surface temperature suggesting high nocturnal air temperatures. Residents of these neighbourhoods and in general because of bad health suffer more from heat stress as the neighbourhood does not offer any opportunity to escape high air temperature as there is no green, shaded places and houses are of bad quality.
In relation to the second research question urban characteristics of the urban fabric that have an exacerbating effect on the urban heat island are
- a lack of vegetation,
- widespread use of impermeable surfaces,
- increased thermal diffusivity of urban materials,
- low solar reflectance of urban materials,
- urban geometries the trap heat,
- urban geometries that slow wind speeds,
- increased levels of air pollution, and
- increased energy use.

These characteristics either reduce evapotranspiration or convection or increases heat storage, net radiation and anthropogenic heat.

In answer of the third research question indicators that are used to measure environmental justice on the neighbourhood scale are based upon three categories; population and urban characteristics and an environmental hazard. The population indicators are

- age,
- ethnicity,
- education,
- health and
- income.

These can be used to describe vulnerability to the environmental hazard of high air temperature. This chapter did not extensively focus on the city of Rotterdam only partly answering the sub question of how environmental justice applies to the city of Rotterdam. A more in depth analysis of the findings in this chapter in relation to Rotterdam will be described in paragraph “Statistical analyses” on page 35

Statistical analyses

5. Introduction

The theoretical framework described how the urban heat island can be an issue of environmental justice. People in socially deprived neighbourhoods can be disproportionally exposed to high air temperature. Firstly those who live in these neighbourhoods are often more exposed to the urban heat island as it can be more intense. Secondly people are more vulnerable because the population is characterized by bad health and little means to shelter from these high temperatures. To discover whether the concept of environmental justice is applicable in the Netherlands, Rotterdam is chosen for further analysis as it has a strong urban heat island and neighbourhoods which are considered socially deprived.

This chapter will continue with an analyses of Rotterdam and deals with the research questions of:

2. What characteristics of the urban fabric have an exacerbating effect on the urban heat island?
4. What urban typologies in the city of Rotterdam are more exposed to the urban heat island?
5. What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?

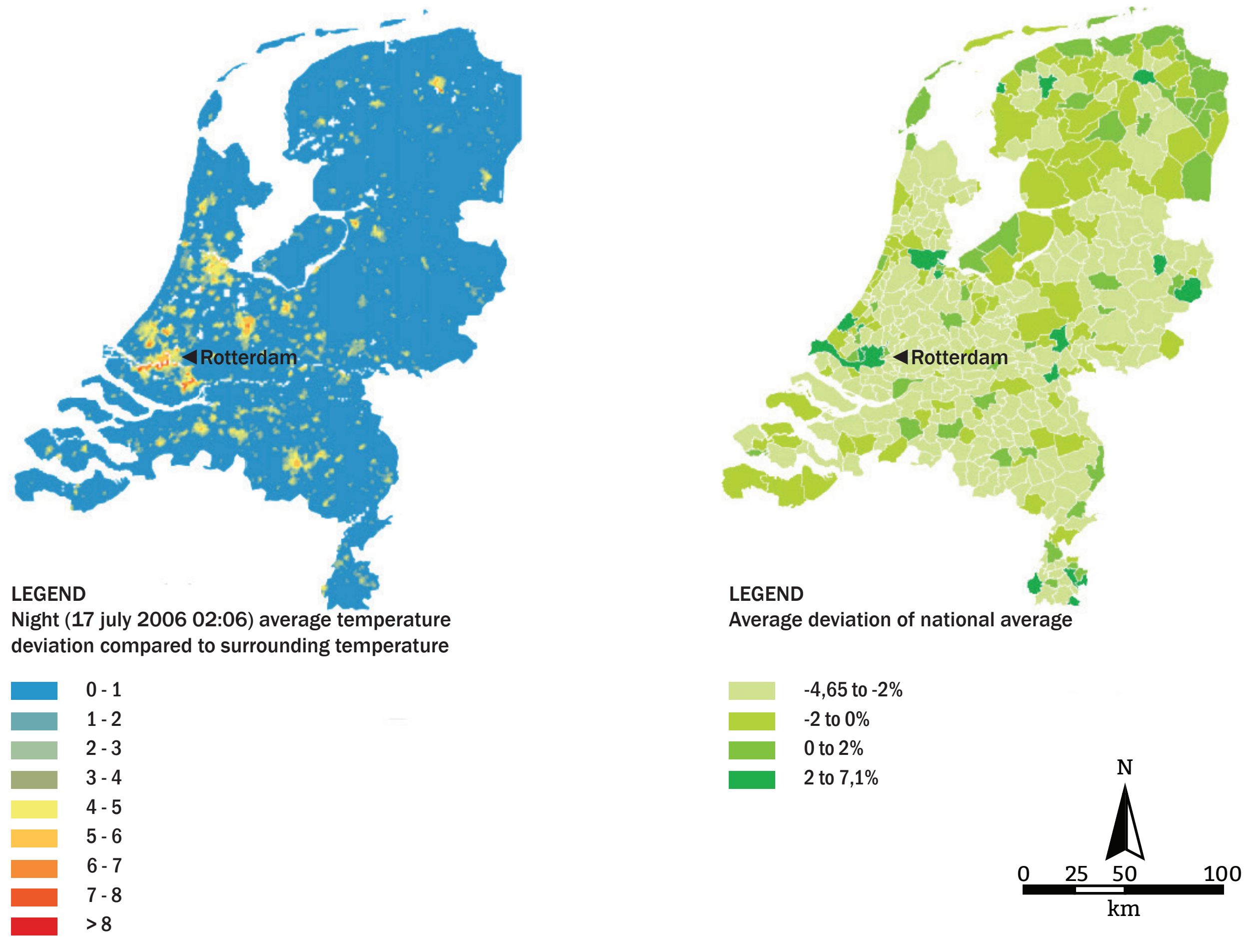


figure 10. On the left the nocturnal urban heat island during the heat wave of July in 2006 and on the right the deviation of the national average of house hold incomes are shown (CBS, 2014, p. 84; Klok, Zwart, Verhagen, & Mauri, 2012)

6. Rotterdam within the Dutch context

The city of Rotterdam suffers from an intense urban heat island and has a high share of households with a low income. In figure 10 on the left the intensity of urban heat island is given during the heat wave of July in 2006 showing a strong urban heat island for the city of Rotterdam. In figure 10 on the right the deviation of the national average of household incomes within each municipality are shown. Rotterdam scores below average and has a high percentage of households with low income.

To get a better sense of how the different neighbourhoods in Rotterdam preform in regard to the urban heat island and social characteristics three maps are displayed in figure 11 the 'leefbaarometer' or liveability meter, the annual income per household and the land surface temperature map.

In the 'leefbaarometer' is displayed which neighbourhoods are characterized according to their liveability. The western, northern and southern part of Rotterdam show neighbourhoods with a negative score. The annual income per household is displayed based upon CBS data showing that some inner city, eastern and north parts of Rotterdam deviate from the rest with higher annual income. The distribution of the land surface temperature shows more intense temperatures for industrial and dense neighbourhood areas (also see: figure 9 on page 31). On figure 12 on page 38 the urban heat island of Rotterdam is displayed with the number of summer days (> 20 °C) and how this is spatially distributed across the city. This calculating has been done for the current situation and KNMI scenario W_H and W_L (TNO, 2011). The current situation and the two scenarios show how the urban heat island is differently distributed across different neighbourhoods.

In the next chapter "7. Statistical analyses of environmental justice indicators" on page 39 the data that is used as indicators for the analyses of such relation will be further described. The result will be used to choose neighbourhoods for a deeper analyses.

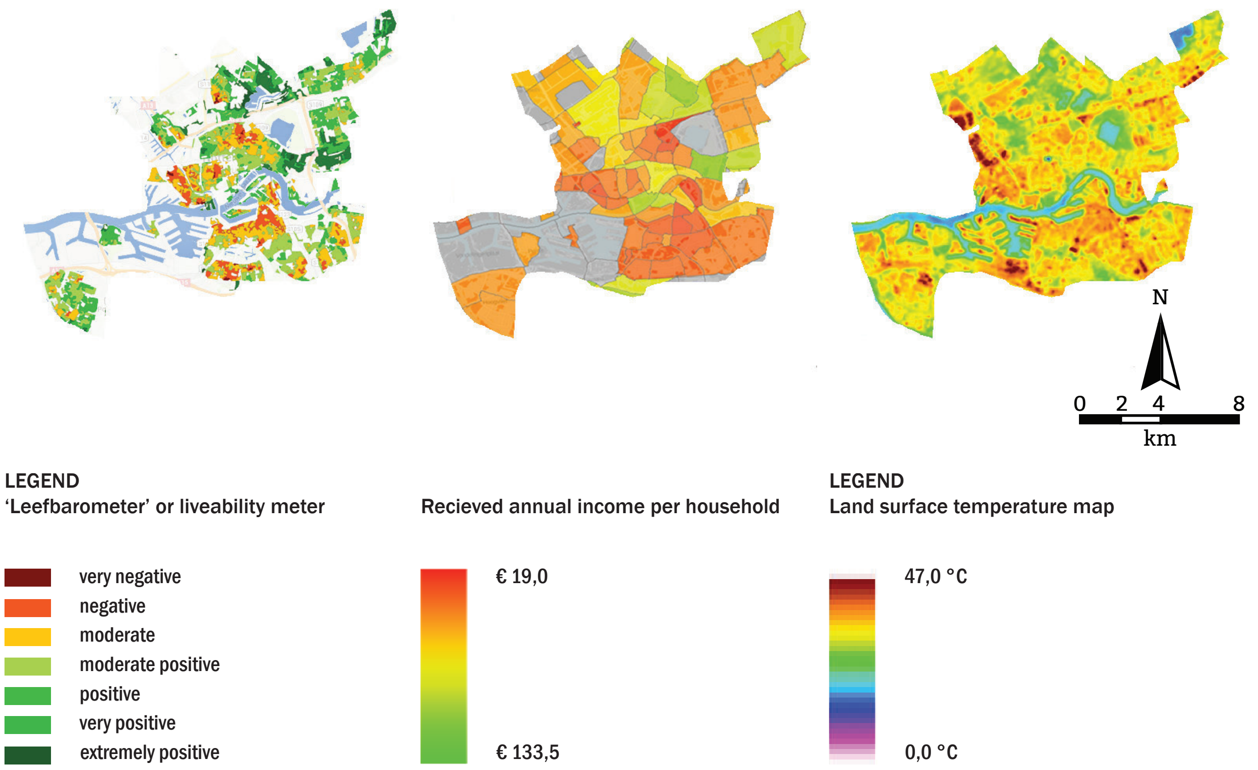


figure 11. Above left to right, the leefbaarometer, CBS data on income per household and the land surface temperature map of the heat wave of July 2006 (CBS, 2013; Leefbaarometer, 2012; van der Hoeven & Wandl, 2015).

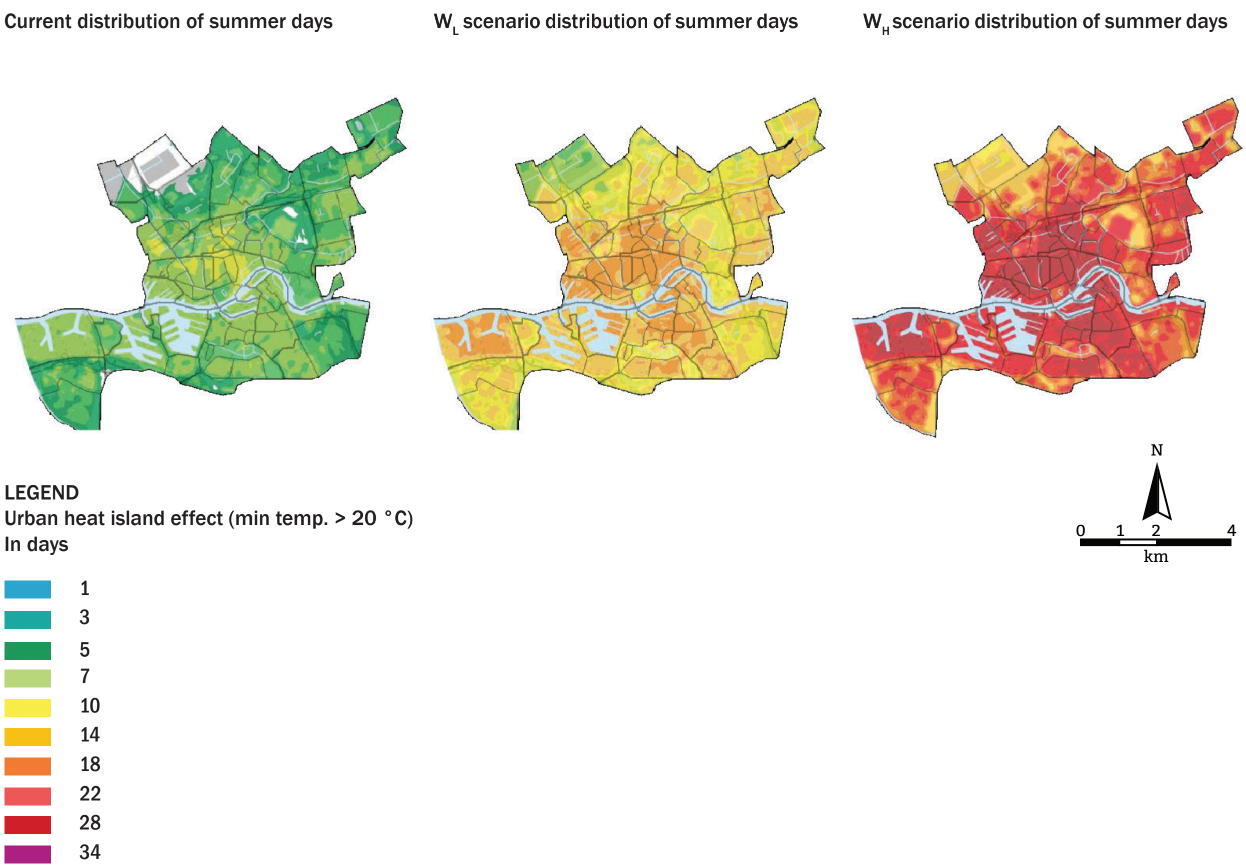


figure 12. The current, W_L and W_H scenario show the expected increase of the number of summer days across the city (TNO, 2011).

7. Statistical analyses of environmental justice indicators

Data on the neighbourhoods scale is used to discover if there is a disproportionate exposure to high air temperature by residents in socially deprived neighbourhoods. To assess of an issue of environmental justice is applicable for Rotterdam a set of indicators on the neighbourhood scale are used categorized according to an environmental hazard, urban characteristics and population characteristics as is summarized in table 1 on page 20. With these indicators statical analyses is conducted.

7.1 Used data

The data that is used on the neighbourhood scale is provided by dr. ir. Ronald Wall of the Erasmus University Rotterdam. Ronald Wall is economic geographer and urban planner and part of the senior academic stage and head of the study urban competitiveness and resilience. In table 7 on page 40 the indicators are shortly described and the source of each dataset.

The environmental hazard of temperature is the average summer day surface temperature based upon data by TNO. This data comes from the research 'Ruimtelijke verdeling en mogelijke oorzaken van het hitte-eiland effect'. In this research fifteen Landsat remote sensed imagery of summer months from 1984 to 2007 are used to derive the average summer day surface temperature.

The municipality of Rotterdam produces every few years the report 'Rotterdam sociaal gemeten' or Rotterdam socially measured. In this report a social index is presented that provides insight in the performance of each neighbourhood with four categories and several sub categories (table 6). Sub categories that are complimentary with those in table 1 on page 20 are the population characteristics education, health and income. The scores of the social index are used as population characteristics that indicate social deprivation in a neighbourhood. The scores are provided on a scale of 1 to 10, with 1 being the lowest and 10 the highest. These scores are based upon survey among the population and registrations. The scores are grouped into 5 categories (table 8).

This chapter continues with the statistical analyses of the data in the next paragraph to discover which indicators correlate with the average day time temperature of a summer based on data by TNO.

table 6. The social index and its subsequent categories for the Rotterdam area.

Living environment	Capacities	Participation	Social Cohesion
• Pollution an nuisances	• Sufficient language proficiency	• Experienced connection	• Employment and school
• Adequate services	• Sufficient income	• Mutations	• Social contacts
• Fitting houses	• Good health		• Social and cultural activities
• Lack of discrimination	• Education level		• Social commitment

(Gemeente Rotterdam, 2012)

table 7. Each indicators that is used with a short description, what unit is used and from what source in originates.

	Indicator	Description	Unit	Source
Environmental hazards	Temperature	Average summer day surface temperature	Temperature	TNO, 2010
	Excess air quality	Excess air quality standard (PM10, NO2) to location	Percentage	DCMR
Urban characteristics	Paved open space	Share of paved open space	Percentage	GBKR
	Open space	Open space	Ratio	GBKR
	Open water	Share of total surface area of open	Ratio	GBKR
	Floor space index	Floor space index	Ratio	SO
	Building year	Average building year	Year	Woningbestand
	Total green	Share of total	Percentage	SO
	Dwellings per hectare	Dwellings per hectare	Number per hectare	Woningbestand
	Sealed soil ratio	The share of sealed soil	Ratio	SO
Population characteristics	Income	Average per capita income	Euro	CBS, 2013
	Property value	Average property value housing	Euro	Gemeente Rotterdam, 2012
	Social index - Capabilities	Social index - Capabilities	Index	Gemeente Rotterdam, 2012
	Social index - Social cohesion	Social index - Social cohesion	Index	Gemeente Rotterdam, 2012
	Social index - Participation	Social index - Participation	Index	Gemeente Rotterdam, 2012
	Social index - Living environment	Social index - Living environment	Index	Gemeente Rotterdam, 2012

table 8. The score categorization of the social index.

Score	Category
≤ 3,9	Socially very weak
3,9 - 4,9	Problematic
5,0 - 5,9	Vulnerable
6,0 - 7,0	Socially sufficient
7,1 ≥	Socially strong

7.2 IBM SPSS Statistics

IBM SPSS Statistics is used to run a stepwise linear regression analysis to predict the effect on land surface temperature by income, paved open space, open space, open water, floor space index, total green, dwellings, sealed soil and property value.

The stepwise linear regression is a semi-automated process of building a model by adding or removing variables to estimate their significance (Duke University, 2016). It used to find what variables have a significant effect on the variable temperature.

A significant regression equation was found ($F(5, 39) = 39{,}960$, $p < .000$), with an R^2 of 0,837.

As a result of the stepwise correlation analyses 5 variables are significant for temperature (see table 9). These variables are total green, property value (Woz), number of dwellings, paved open space and open water. Each of these variables has statistically significant effect on the dependent variable temperature. The variable total green is the most significant variable. The other four are also significant but add little to the explained significance. In the coefficient table the beta scores for total green, property value, open water and space follow the logic when these variables increase the land surface temperature decreases. However when the number of dwellings go up the temperature goes down which does not seem so logical since the number of dwellings would suggest a higher density which is correlated with higher land surface temperatures.

The notion that the amount of total green is most significant fits the theory that green has a big impact on reducing the urban heat island as it provides for shade and evapotranspiration (Gartland, 2008; Huijbers & Dobbelsteen, 2012; Lenzholzer, 2013; Taleghani, 2014). Apart from such logic the statistical significance of the property value on the land surface temperature raises the question what characteristics of this indicator influences the land surface temperature. This thesis restrains itself of suggesting that low property value correlates with urban characteristics that have an exacerbating effect on the urban heat island. However since the thesis uses a methodological triangulation week findings are strengthened by stronger ones as the Pearson's correlation analysis will provide for in the next paragraph.

table 9. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F	
1	,819a	,670	,663	1,02397	,670	87,442	1	43	,000	
2	,852b	,726	,713	,94480	,056	8,509	1	42	,006	
3	,875c	,766	,748	,88420	,040	6,954	1	41	,012	
4	,895d	,801	,781	,82542	,035	7,047	1	40	,011	
5	,915e	,837	,816	,75679	,036	8,584	1	39	,006	2,202

a. Predictors: (Constant), Total_green
b. Predictors: (Constant), Total_green, Woz
c. Predictors: (Constant), Total_green, Woz, Dwellings
d. Predictors: (Constant), Total_green, Woz, Dwellings, Paved open_space
e. Predictors: (Constant), Total_green, Woz, Dwellings, Paved_open_space, Open_water
f. Dependent Variable: Temp

table 10. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	91,684	1	91,684	87,442	,000[b]
	Residual	45,086	43	1,049		
	Total	136,770	44			
2	Regression	99,279	2	49,639	55,610	,000[c]
	Residual	37,491	42	,893		
	Total	136,770	44			
3	Regression	104,716	3	34,905	44,647	,000[d]
	Residual	32,054	41	,782		
	Total	136,770	44			
4	Regression	109,517	4	27,379	40,185	,000[e]
	Residual	27,253	40	,681		
	Total	136,770	4			
5	Regression	114,433	5	22,887	39,960	,000[f]
	Residual	22,337	39	,573		
	Total	136,770	44			

a. Dependent Variable: Temp

b. Predictors: (Constant), Total_green

c. Predictors: (Constant), Total_green, Woz

d. Predictors: (Constant), Total_green, Woz, Dwellings

e. Predictors: (Constant), Total_green, Woz, Dwellings, Paved_open_space

f. Predictors: (Constant), Total_green, Woz, Dwellings, Paved_open_space, Open_water

7.3 Pearson correlation analysis

With the use of Microsoft Excel a Pearson's product-moment correlation coefficient or short Pearson correlation is computed and analysed. The Pearson correlation is a measure of the linear correlation or strength and direction of association that exist between two variables (Laerd statistics, 2016).

The Pearson correlation analysis was computed to assess the relationship between the average day summer surface temperature and the environmental hazard indicator of excess air quality, 8 indicators of urban characteristics and 6 indicators of population characteristics as presented in table 7 on page 40. In figure 13 on page 44 the distribution of each indicator among the different neighbourhood is displayed with for each a graph the formula and R^2 value that indicates how well the data is correlated.

Firstly it must be noted that within the field of statistics the interpretation of the R^2 depends on the academic field the statistics apply for. In social and behavioural sciences a R^2 value of above 0,3 is accepted for claiming a correlation between two variables. Secondly must be noted that the computed Pearson correlation uses data on both population and urban characteristics. One could argue that when statistics are applied on population characteristics data, claiming a correlation requires a lower R^2 value then for urban characteristics. The correlation between average day summer surface temperature and urban characteristics is one of physical nature rather than societal and might require a higher R^2 to claim a correlation.

The indicators with significance R^2 are:

- Social index: social bonding,
- Social index: living environment,
- Dwellings per hectare,
- Property value,
- Floor space index,
- The share sealed soil ratio, and
- Total green.

Such results fit the theory that urban characteristics of density, green and the use of impervious surfaces correlate with the land surface temperature (EEA, 2012b; Gartland, 2008; Harlan et al., 2006; Tomlinson et al., 2011; van der Hoeven & Wandl, 2013). The correlating indicators from the category of population characteristics are social bonding, living environment and property value. This suggests that neighbourhoods that score low on these indicators, indicating some sort of deprivation, correlate with high land surface temperatures.

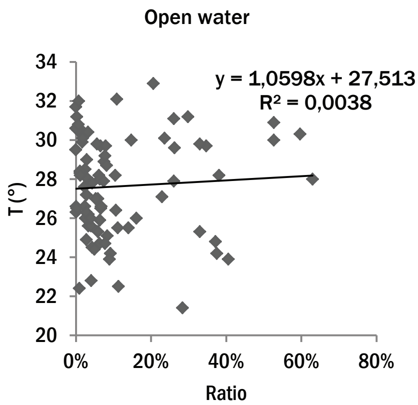
To gain a deeper understanding of how each neighbourhoods scores the correlating variables of social characteristics are grouped in terms of social vulnerability and temperature. This will be described in the next paragraph "7.4 Analyses of the population characteristics indicators" on page 48.

figure 13. The distribution of each indicator among the different neighbourhood.

Urban characteristics

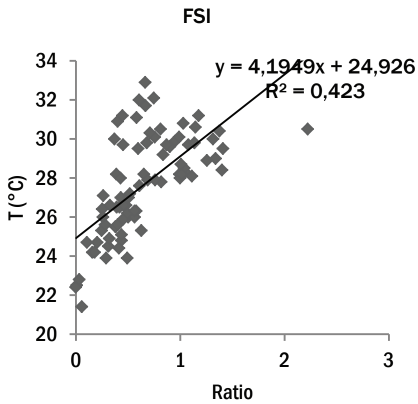
Open water ratio

- < 0,007
- 0,007 - 0,017
- 0,017 - 0,033
- 0,033 - 0,055
- 0,055 - 0,083
- 0,083 - 0,113
- 0,113 - 0,205
- 0,205 - 0,297
- 0,297 - 0,464
- 0,464 - 0,749



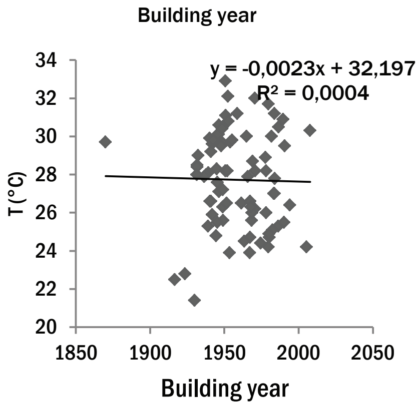
Floor space index

- 0,00 - 0,05
- 0,05 - 0,20
- 0,20 - 0,32
- 0,32 - 0,43
- 0,43 - 0,51
- 0,51 - 0,62
- 0,62 - 0,75
- 0,75 - 0,95
- 0,95 - 1,25
- 1,25 - 2,22



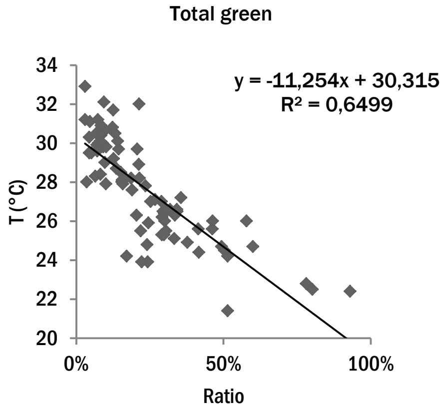
Building year year

- < - 1870
- 1870 - 1932
- 1932 - 1946
- 1946 - 1955
- 1955 - 1964
- 1964 - 1972
- 1972 - 1982
- 1982 - 1994
- 1994 - 2007

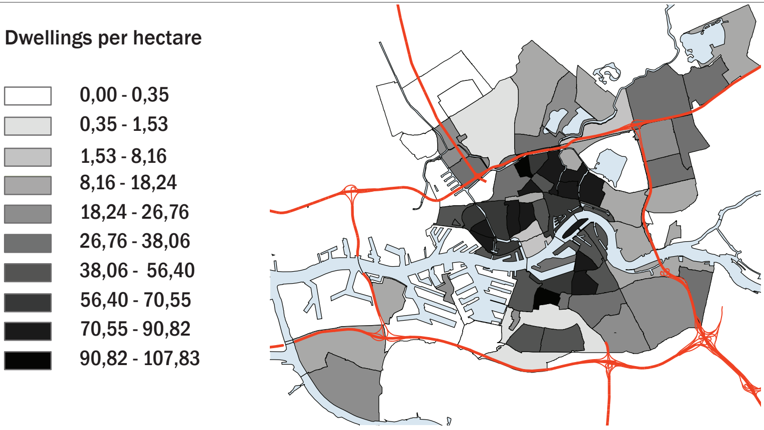


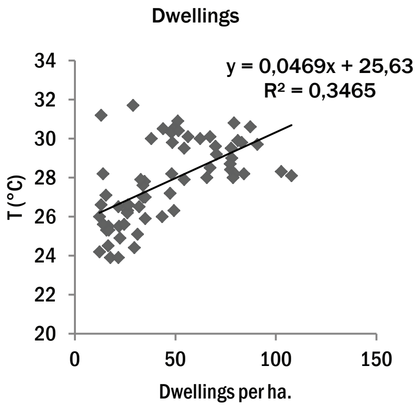
Total green ratio

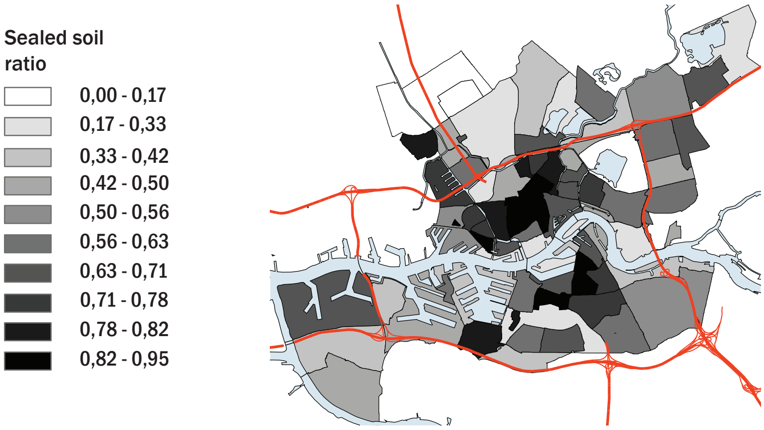
- 0,02 - 0,05
- 0,05 - 0,08
- 0,08 - 0,10
- 0,10 - 0,14
- 0,14 - 0,18
- 0,18 - 0,25
- 0,25 - 0,33
- 0,33 - 0,41
- 0,41 - 0,60
- 0,60 - 0,92

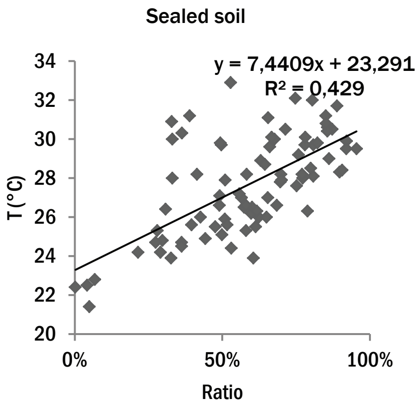


Urban characteristics

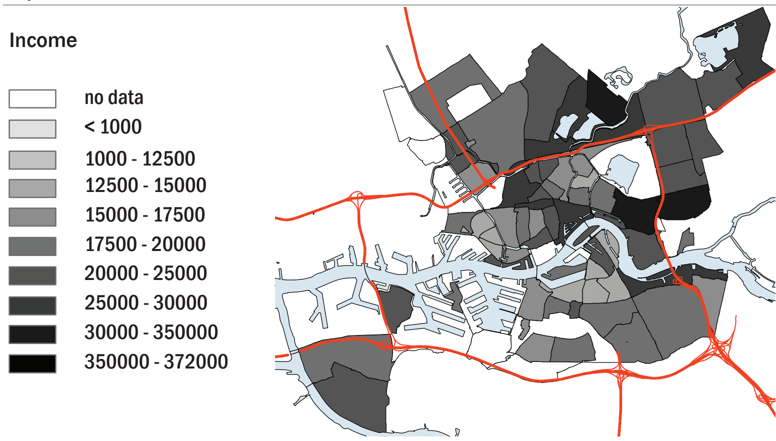


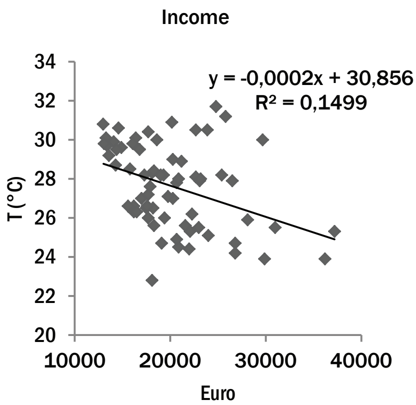


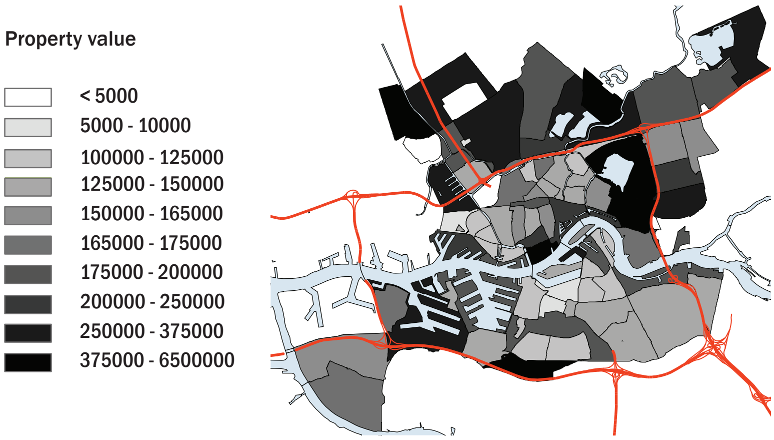


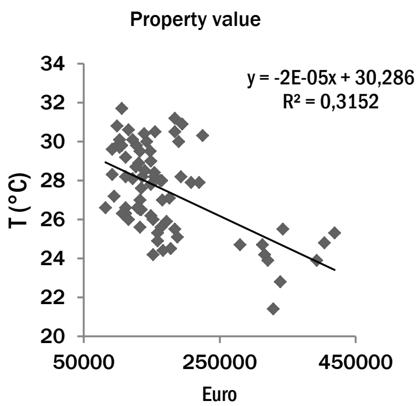


Population characteristics



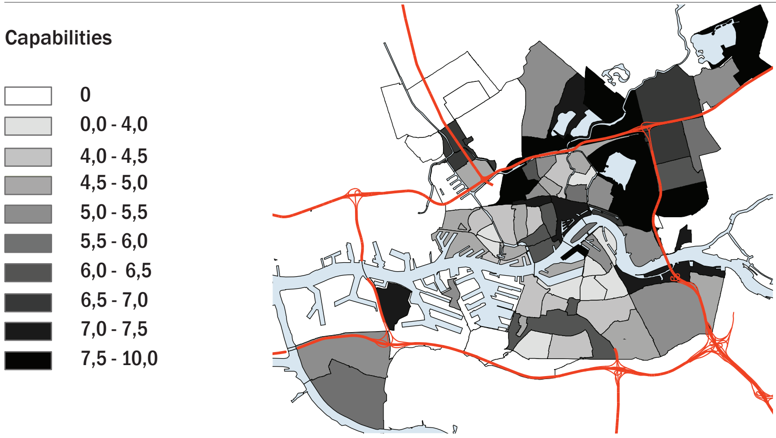


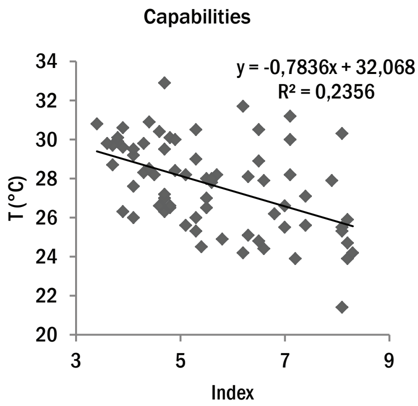




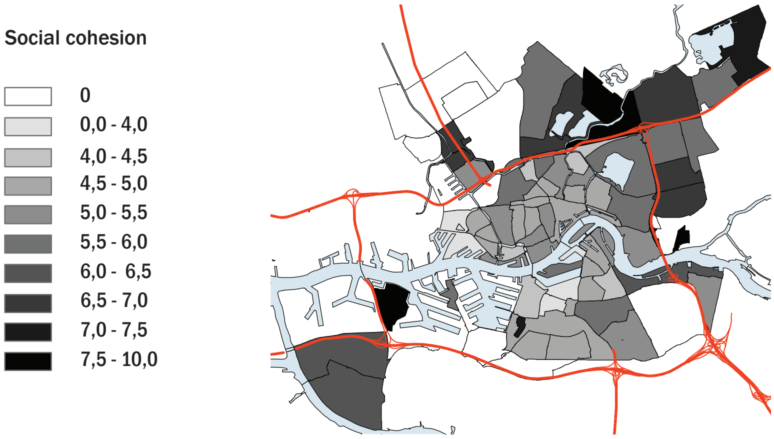
Population characteristics

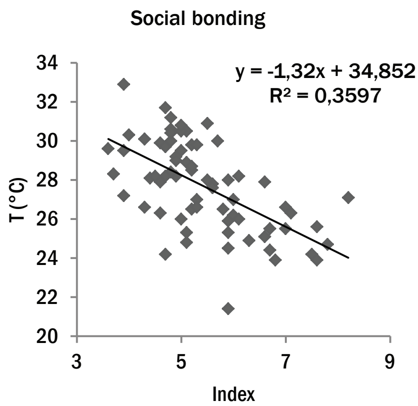
Capabilities



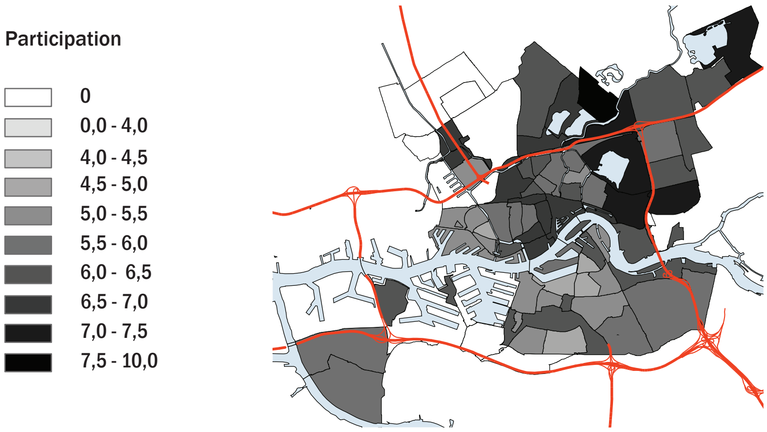


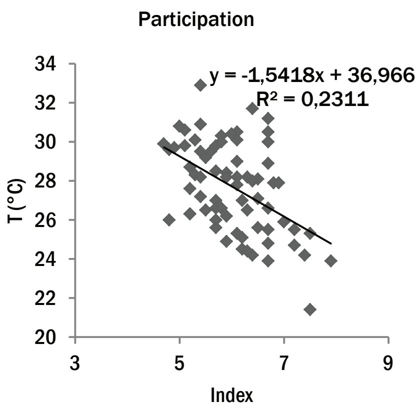
Social cohesion



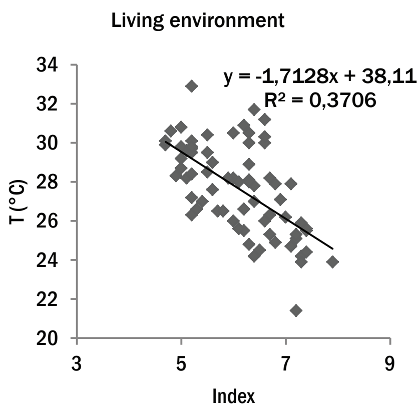


Participation





Living environment



7.4 Analyses of the population characteristics indicators

To get a better understanding of what neighbourhoods score high on average summer day surface temperature and on the three population characteristics of property value, living environment and social cohesion the neighbourhoods are grouped in terms of social vulnerability and temperature. In figure 14 a diagram is displayed that deals with how to categorize a neighbourhood score according to its relation between the population indicator and the summer days land surface temperature.

Each neighbourhood in each of the three Pearson's correlation diagrams is categorized in one of the five categories. In figure 15.a on page 49 the map of this categorization is presented and in figure 15.b on page 49 each neighbourhood is presented on the graph with temperature and the average property value in euro's. This continues in figure 16.a and figure 16.b on page 50 and figure 17.a and figure 17.b on page 51.

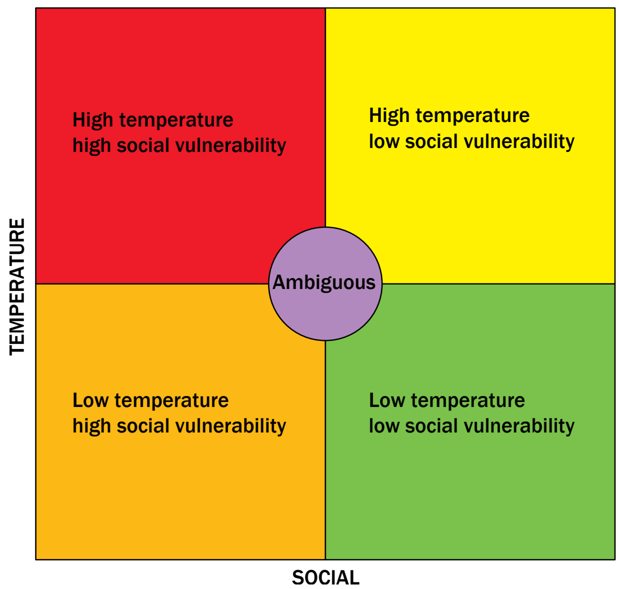
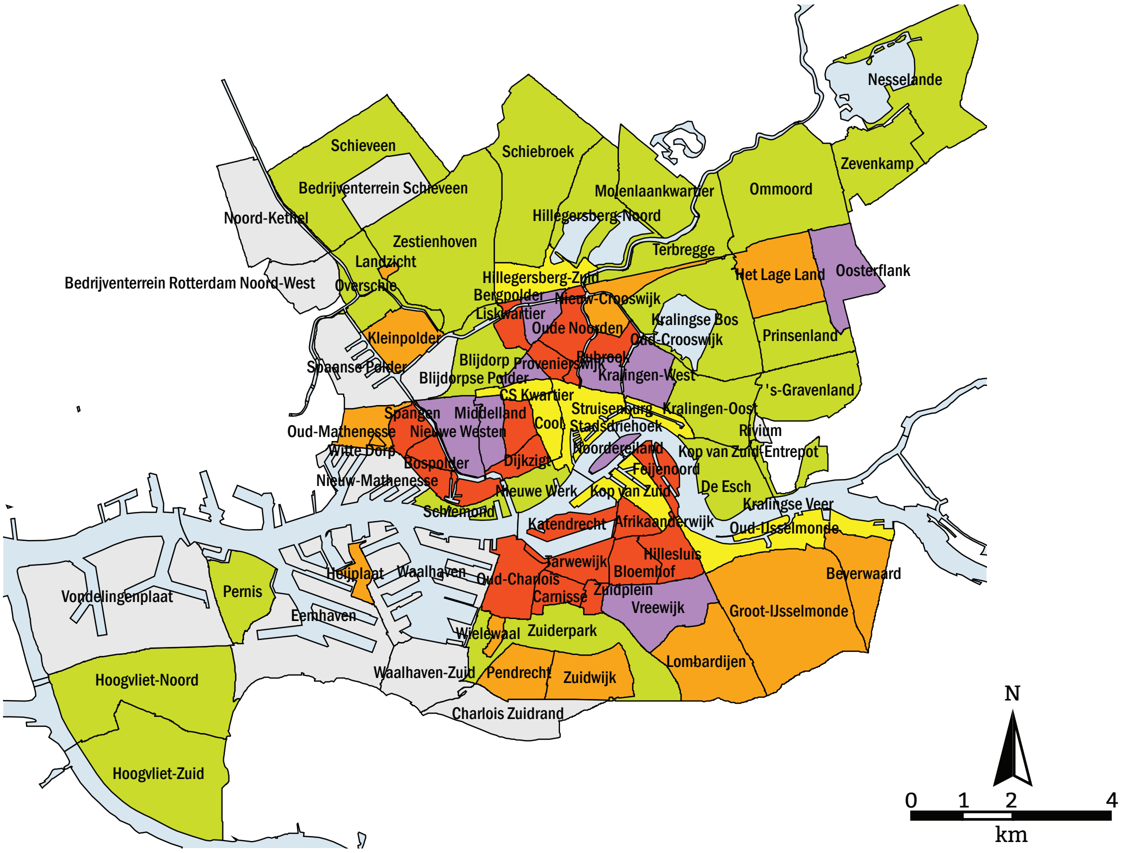


figure 14. Diagram of the principle to judge each neighbourhood upon its temperature and social vulnerability.



LEGEND
Neighbourhoods score on temperature and social vulnerability

- High temperature high social vulnerability
- High temperature low social vulnerability
- Low temperature high social vulnerability
- Low temperature low social vulnerability
- Ambiguous

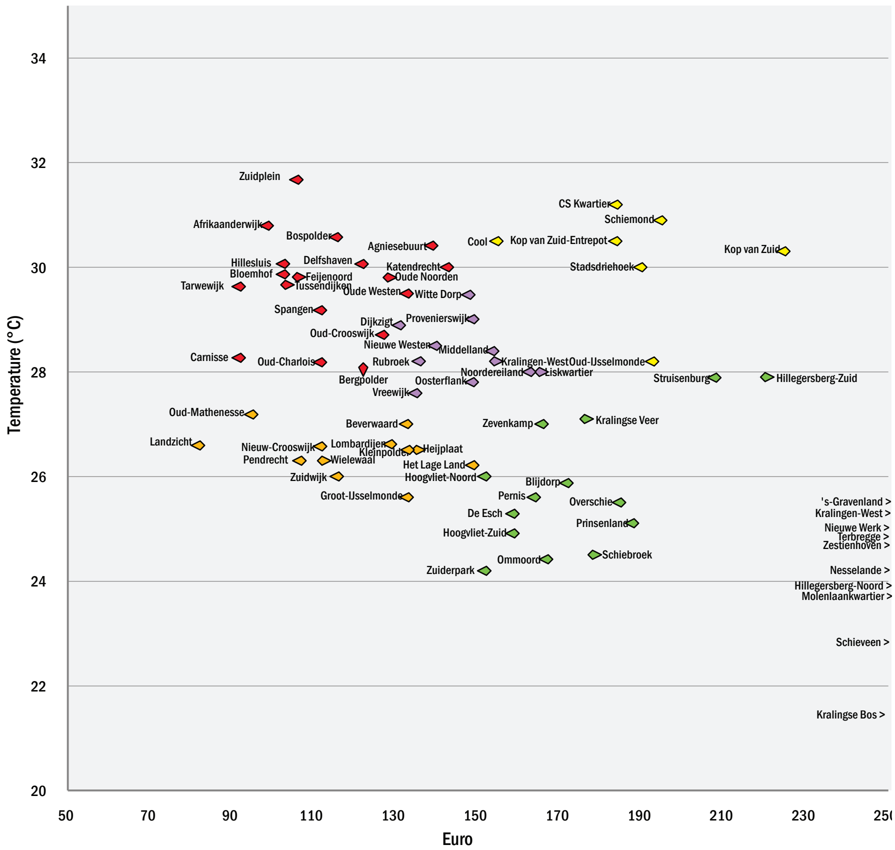
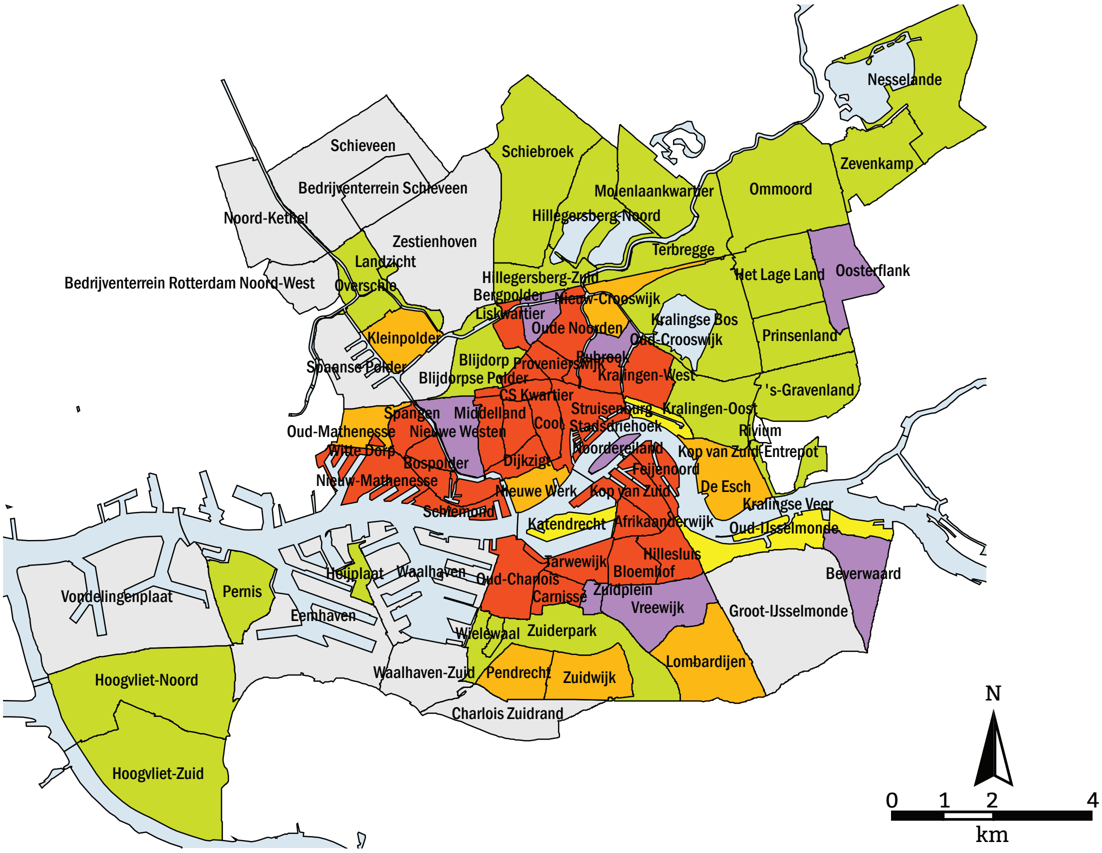


figure 15.a.Above the map for the indicator of property value per neighbourhood in relation between social vulnerability and temperature.
figure 15.b.Below the graph of the score of each of the neighbourhoods is displayed and how they range on vulnerability diagram.



LEGEND

Neighbourhoods score on temperature and social vulnerability

- High temperature high social vulnerability
- High temperature low social vulnerability
- Low temperature high social vulnerability
- Low temperature low social vulnerability
- Ambiguous

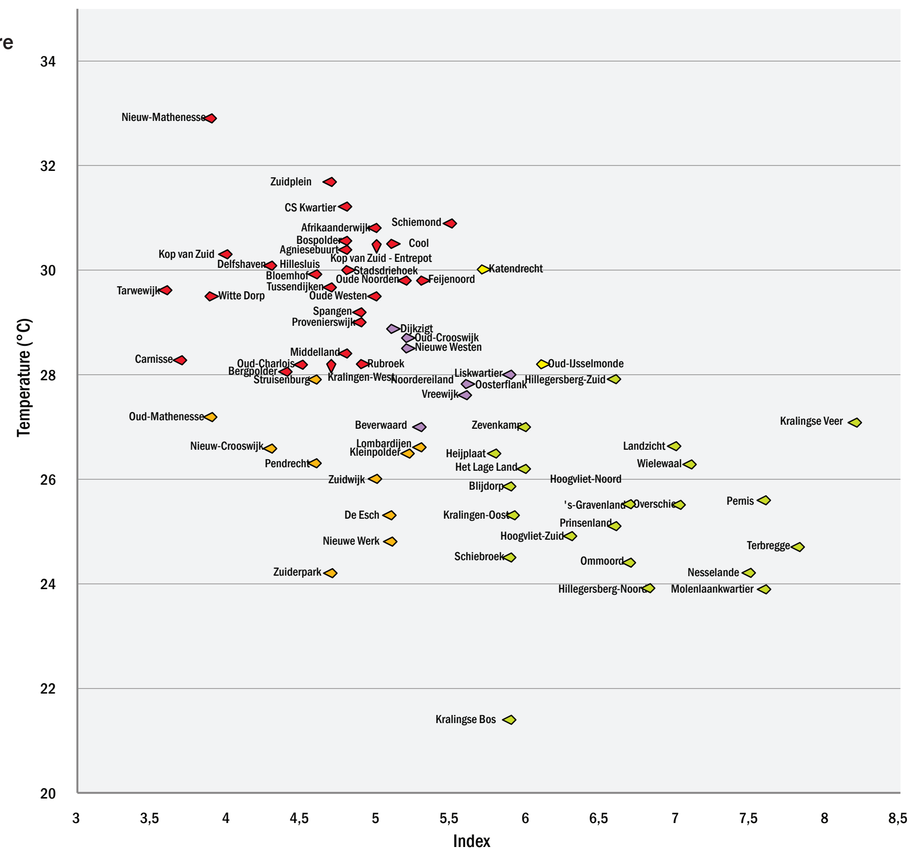
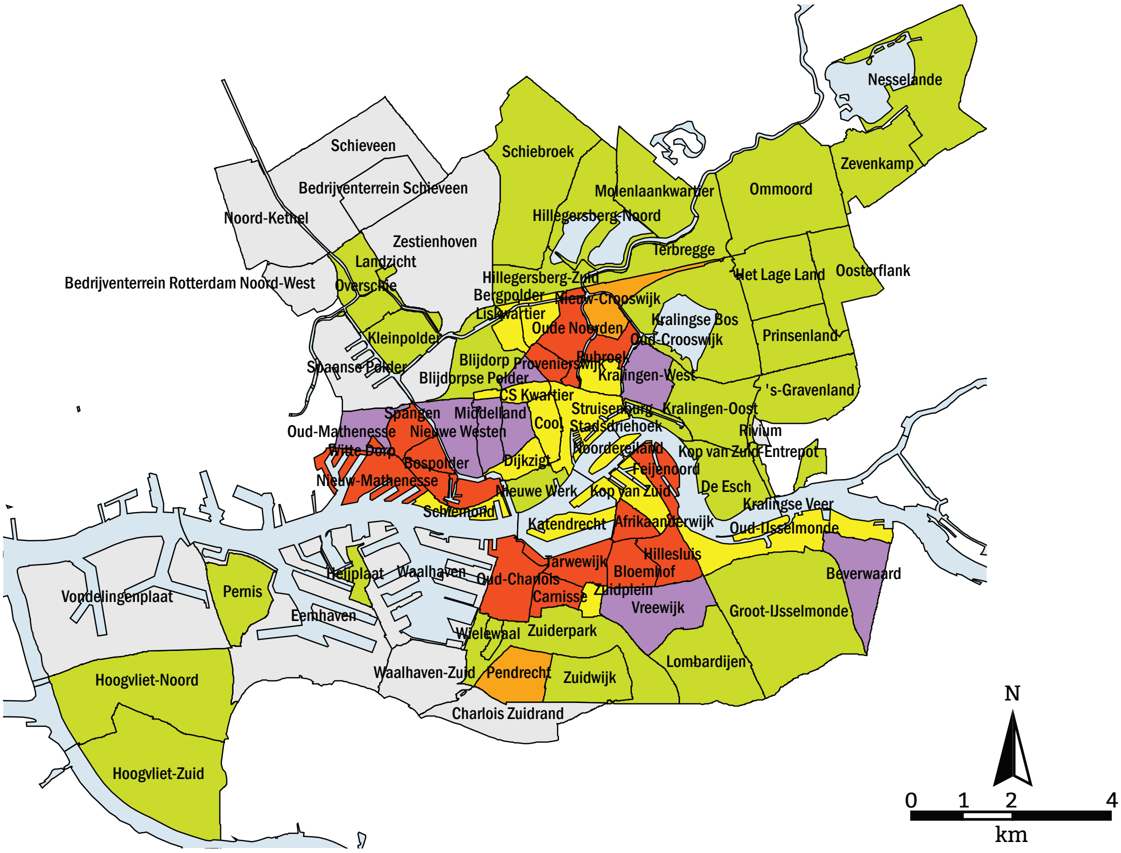


figure 16.a. Above the map for the indicator of social cohesion with the value per neighbourhood in relation between social vulnerability and temperature.

figure 16.b. Below the graph of the score of each of the neighbourhoods is displayed and how they range on vulnerability diagram.



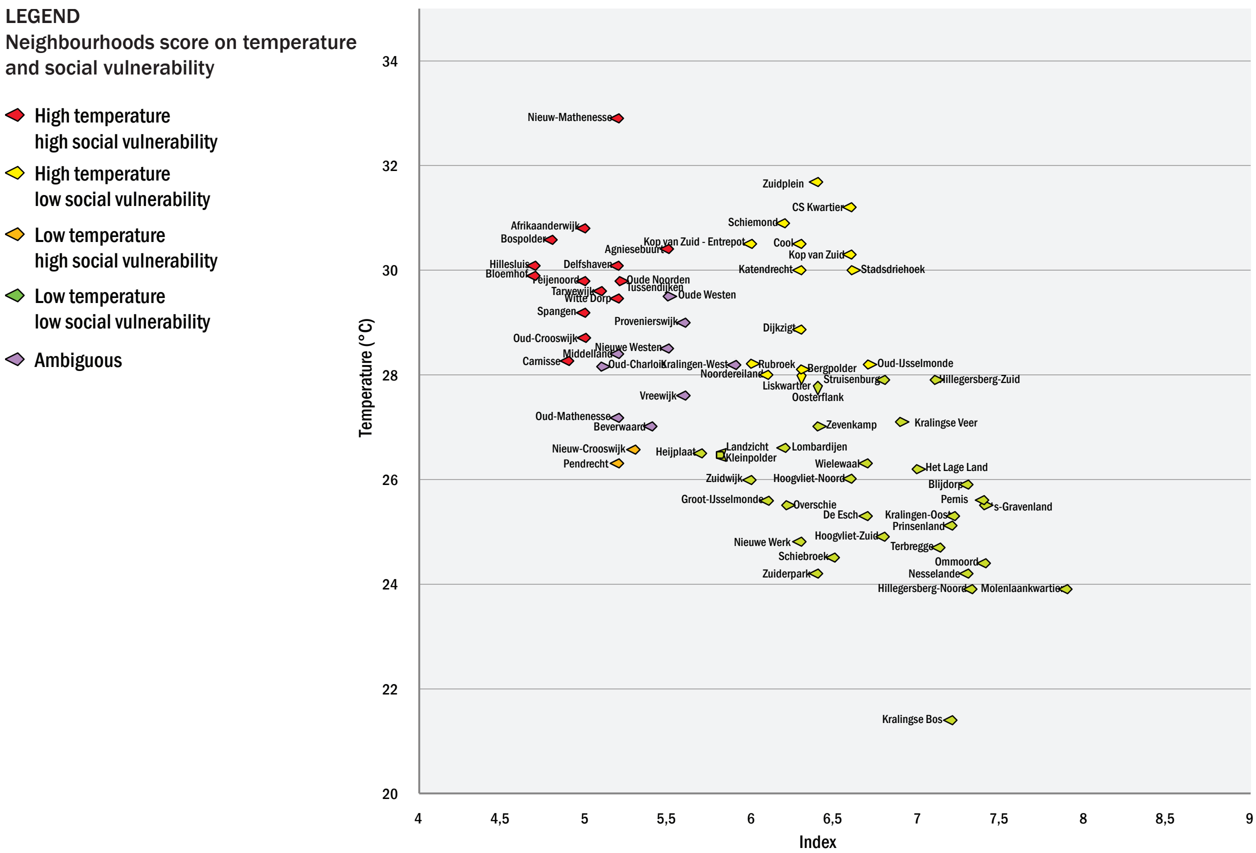


figure 17.a. Above the map for the indicator of living environment with the value per neighbourhood in relation between social vulnerability and temperature.

figure 17.b. Below the graph of the score of each of the neighbourhoods is displayed and how they range on vulnerability diagram.

8. Assessment of vulnerable neighbourhoods

In figure 18 on page 53 and in table 12 on page 54 the fourteen neighbourhoods are presented that are considered vulnerable. These neighbourhoods all score high on both social vulnerability and high average summer day surface temperature. Also the non-correlating indicators are shown for each neighbourhood. To come to a more narrow selection the choice is made that neighbourhoods with an average income per household of € 15.000 euro or less are most socially deprived. Such threshold is based upon the lower income threshold by the central bureau for statistics and the 'not much but adequate'-threshold of the social cultural plan bureau and presented table 11 (SCP & CBS, 2014).

As a result of choosing this threshold the selection is narrowed down. The eight neighbourhoods that score high on social vulnerability and average summer day surface temperature and below an average income threshold are Spangen, Tussendijken Bospolder, Afrikaanderwijk, Hillesluis, Bloemhof, Feijenoord and Tarwewijk and displayed in figure 19 on page 53.

These neighbourhoods are rougly part of Rotterdam West and South. In order to choose which neighbourhoods are more severely deprived in relation to the environmental indicators of health they are compared with the aid of the health index by the municipality of Rotterdam (figure 20 on page 55). The three indicators from the health index that are used are quality of life, loneliness and health. Loneliness is chosen as an indicator as residents in neighbourhoods that suffer from loneliness are considered as vulnerable. In a research on the heat wave of July 1995 in Chicago the researchers concluded that those vulnerable to heat waves are, among people with a medical condition or elderly, those who live alone and do not have networks of social contacts (Duneier, 2006; Semenza et al., 1996). Argued is that people with bad health suffer more from the high air temperature then more healthy people and as such the neighbourhoods that score worst on this health index should be addressed for further analyses. The indicator of health compromises of medical conditions related to heart, blood pressure and respiratory conditions.

table 11. The threshold for lower income and ´not much but adequate´.

	single	couple			parent family		average
2013		**no children**	**1 child**	**2 children**	**1 child**	**2 children**	
Lower income threshold	10.100	13.900	16.900	19.000	13.500	15.000	14.800
'not much but adequate'-threshold	10.600	14.500	17.700	19.900	14.100	16.000	15.500

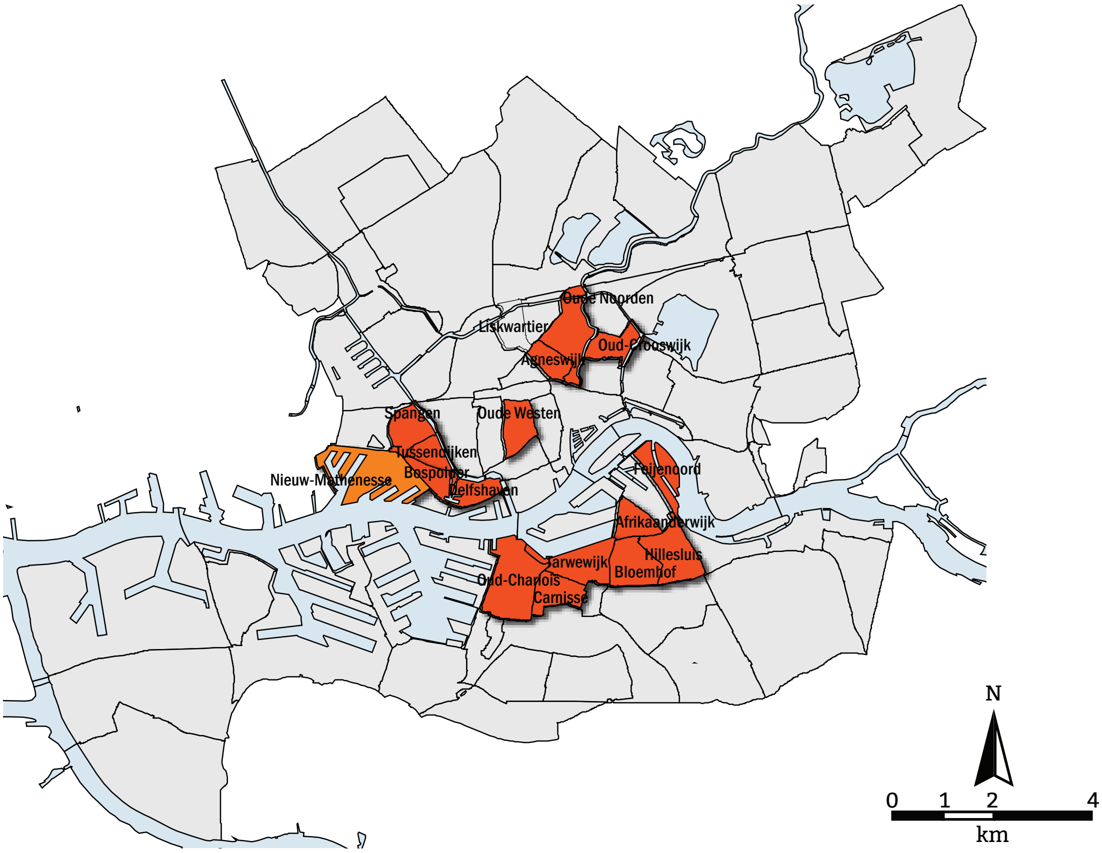


figure 18. Map of the neighbourhoods that are considered problematic.

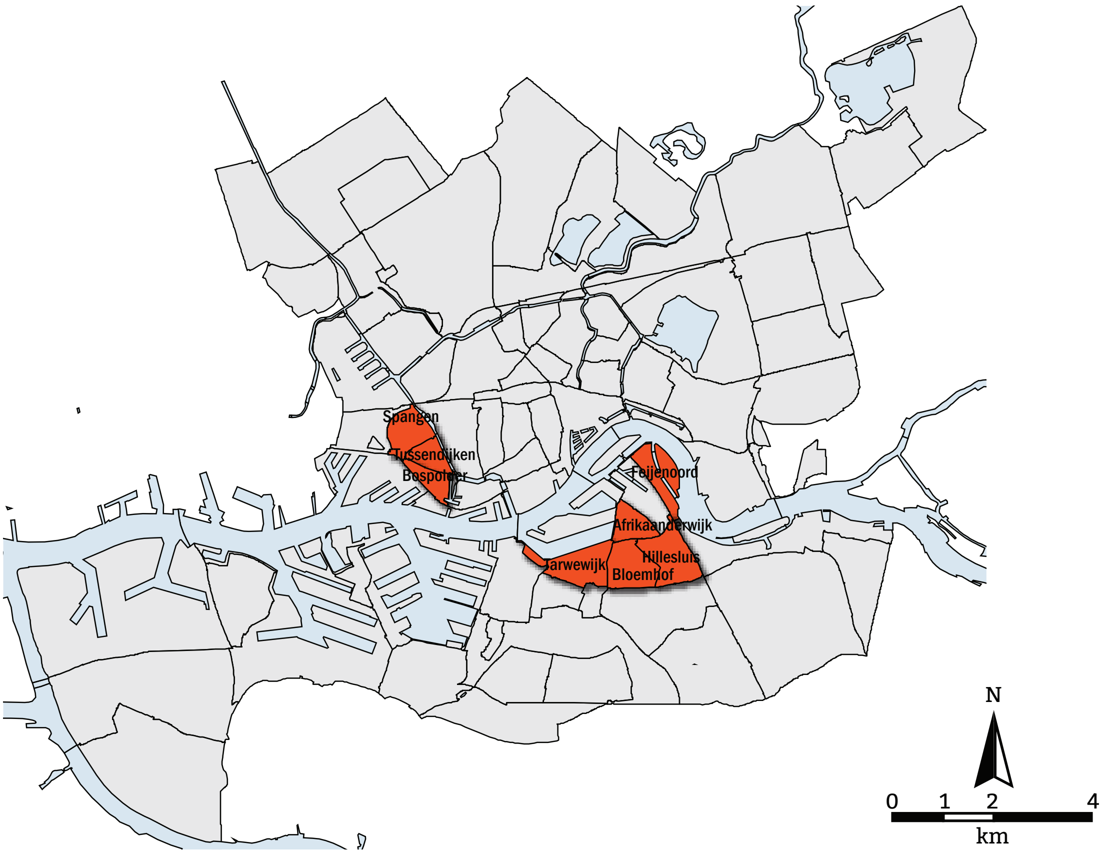


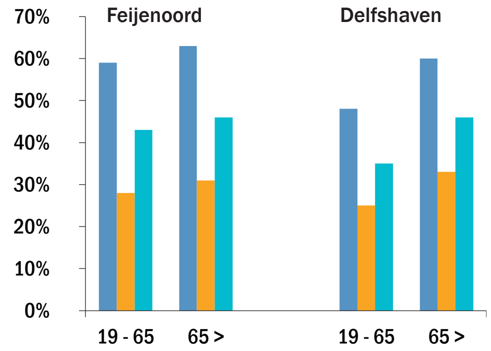
figure 19. Eight neighbourhoods that score high on social vulnerability and land surface temperature and below an average income threshold.

table 12. Fourteen neighbourhoods that are considered vulnerable to the high average day surface temperature.

Neighbourhoods	Temperature	Income	Total green	Dwellings per hectare	Sealed soil ratio	Property value	Excess air quality	Capabilities	Social cohesion	Participation	Living environment
Afrikaanderwijk	30,8	13000	0,12	79	0,85	99		3,4	5	5	5
Feijenoord	29,8	13100	0,1	49	0,49	106	0,003	3,6	5,3	5,1	5
Hillesluis	30,1	13300	0,14	56	0,78	103		3,8	4,3	5,3	4,7
Tussendijken	29,7	13400	0,08	91	0,78	103	0,019	3,7	4,7	4,9	5,2
Spangen	29,2	13600	0,13	71	0,76	112	0,002	4,1	4,9	5,5	5
Bloemhof	29,9	14100	0,07	81	0,92	103	0,001	3,8	4,6	4,7	4,7
Oud Crooswijk	28,7	14300	0,14	77	0,64	127	0,054	3,7	5	5,6	5
Bospolder	30,6	14600	0,09	87	0,86	116	0,009	3,9	4,8	5,1	4,8
Tarwewijk	29,6	14900	0,07	70	0,66	92	0,012	3,9	3,6	4,8	5,1
Oude Noorden	29,8	16100	0,09	83	0,82	128	0,053	4,3	5,2	5,7	5,2
Delfshaven	30,1	16400	0,08	67	0,67	122	0,012	4,8	4,3	6,1	5,2
Oude Westen	29,5	16800	0,05	78	0,92	133	0,055	4,1	5	5,6	5,5
Oud Charlois	28,2	17300	0,21	48	0,58	112	0,007	4,5	4,5	5,4	5,1
Agniesebuurt	30,4	17700	0,08	52	0,86	139	0,068	4,6	4,8	6	5,5
Carnisse	28,3	18100	0,06	103	0,9	92	0,003	4,3	3,7	5,3	4,9
Nieuw Mathenesse	32,9	-	0,03	-	0,53	-	-	4,7	3,9	5,4	5,2

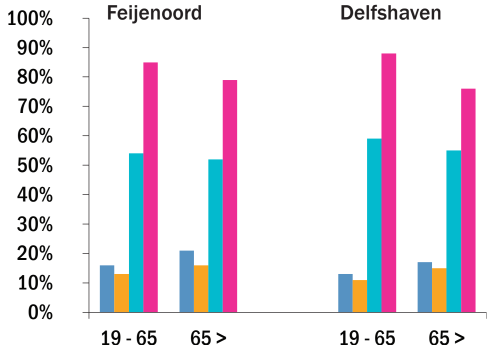
LEGEND
Loneliness

- Moderate to severly lonely
- Emotional loneliness
- Social loneliness



LEGEND
Quality of life

- Mildly or fully unhappy
- Satisfaction of life (-6)
- Satisfaction of life (+8)
- Feeling of being in control of ones own life



LEGEND
Medical conditions

- Heart conditions
- High blood pressure
- Respitory illness
- Suffered from stroke or heart related failure

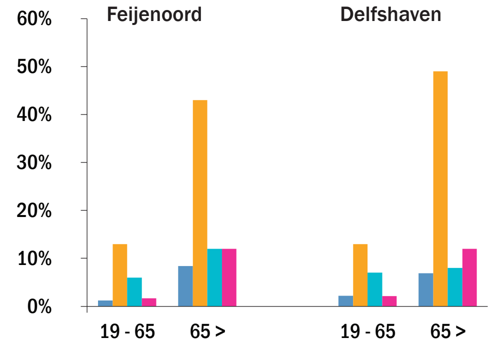


figure 20. Three graph of scores of the districts of Feijenoord and Delfshaven on loneliness, quality of life and medical conditions (GGD Rotterdam Rijnmond, 2014).

8.1 Perceived liveability and quality of life

In “8. Assessment of vulnerable neighbourhoods” on page 52 the city district Feijenoord and it’s subsequent neighbourhoods score low on the indicators of loneliness, quality of life and medical conditions. The health atlas by the ‘Gemeentelijke Gezondheidsdienst’ (GGD) or municipal health service and the safety index based upon ‘wijkprofiel’ or neighbourhood profile by the municipality of Rotterdam are used o get a better understanding of how these different neighbourhoods score on these indicators.

These indicators are important to assess as these are an indication of the overall liveability of a neighbourhood. In the book ‘Transformatie strategieën voor Verouderde Stadswijken‘ or transformation stategies voor aged neighbourhoods co-author dr. ir. van Dorst describes perceived liveability in neighbourhoods. The author notes that it cannot be determined unambiguously on the manner in which the physical environment contributes to the well-being of people as such relation is to complex. However the author notes that from a collection of both social and physical indicators the perceived quality of life can derived (Rooij, 2012). The authors offer indicators that attribute to the perceived quality of life and refer to other authors who do the same. These indicators are in displayed in table 13. The positive relation of greenery and health can mainly be attributed to the stress reducing effects of green. Green in a neighbourhood can stimulate physical activity and social contact as they are attractive spaces to be active or to socialize. The physical activity of children, elderly and lower income is positively correlated with the availability of green in there direct surroundings as these groups spend more time in their direct living environment (Hoeymans, Melse, & Schoemaker C.G., 2010; Maas, 2008).

In the next two paragraphs both the health index and safety index are presented and assessed to described to percieved liveability of a neighbourhood.

table 13. Indicators to assess perceived liveability and happiness for a neighbourhood.

Neighbourhood indicators that attribute to happiness	Perceived liveability by residents
• Health	• Attractive and well maintained and neat neighbourhood
• Safety	• Spacious and green
• Social relations	• Street noise and nuisance
• Material wealth	• Neighbour rumour
• Perceived freedom	• Heterogeneous and relocation
• Income inequality	
• Identity	
• Contact with natural surroundings	
(Rooij, 2012)	(Wardt & Jong, 1997)

8.2 Health index

The health numbers are based upon the health monitor of 2012. The indicators that are presented are extracted from the 'gezondheidsatlas Rotterdam Rijnmond' or the health atlas Rotterdam Rijnmond (GGD Rotterdam Rijnmond, 2016). In 2012 a health research was conducted among residents of age 17 and above. The figures are presented at the neighbourhood level. Out of 37.730 who were asked to participate in the research a total of 14.113 people has responded and returned the inquiry.

The number of response for the respective neighbourhoods:

- Feijenoord (149) (respons percentage: 33,0%)
- Afrikaanderwijk (195) (respons percentage: 27%)
- Hillesluis (210) (respons percentage: 30%)
- Bloemhof (207) (respons percentage: 30%)
- Tarwewijk (204) (respons percentage: 29%)

On figure 20 on page 5579 the indicators that are presented are:

- Moderate to severe loneliness is when someone experiences a strong lack of an intimate relationship, an emotionally close relationship with a partner or friend (s).
- Difficulty making ends meet: ability of an individual to buy all basic and necessary monthly needs.
- Experience health as really good: Perceived health is not only about illnesses or disabilities. Own judgment about the state of health is also about things like fitness, depression, nutrition, social support, smoking and physical activity.
- Residents with overweight based upon body mass index (BMI)
- Mildly or fully happy; percentage of people of feeling mildly or fully unhappy.
- Socially loneliness; social loneliness is when someone lacks meaningful relationships with a wider group of people such as friends , colleagues, neighbours or people with similar interests (Nationaal Kompas, 2016).
- Quality of life.
- Mildly or fully unhappy: the number of people that consider them self as mildly or fully unhappy.
- Obese; the amount of people that suffer from obesity.
- Sufficient for green in the neighbourhood; the percentage of people who grade green with a sufficient score.

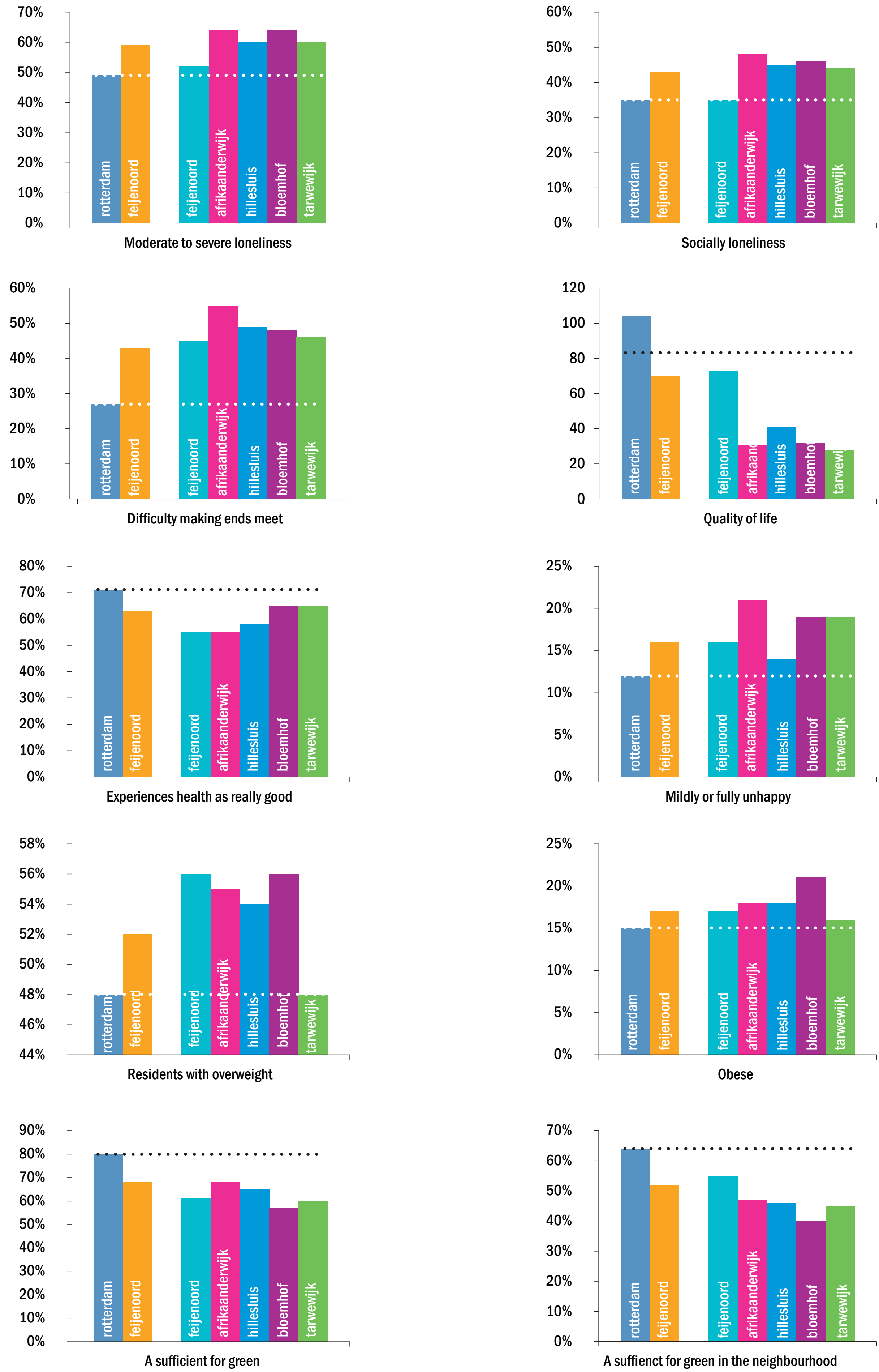


figure 21. Indicators that attribute to the perceived quality of life for each neighbourhood (GGD Rotterdam Rijnmond, 2014).

8.3 Safety index

The safety index presented is based upon 'wijkprofiel' or neighbourhood profile by the municipality of Rotterdam. The scores on the topics are displayed as an index score, the average of Rotterdam in the baseline (2014) is set at 100. The scores of the districts calculated relative to this city average. The themes indicators presented and their background are:

- Theft:
  Objective: the recorded amount of thefts per 1,000 inhabitants in the district.
  Subjective: to what extent residents perceive theft as a problem in their neighbourhood.

- Violence:
  Objective: registered violent crimes per 1,000 residents in the district.
  Subjective: to what extent residents perceive violence as a problem in their neighbourhood.

- Burglary
  Objective: registered burglaries per 1,000 residents in the district.
  Subjective: to what extent residents perceive burglary as a problem in their neighbourhood.

- Vandalism
  Objective: the degree to which vandalism is carried out in the neighbourhood.
  Subjective: to what extent vandalism perceive burglary as a problem in their neighbourhood.

- Nuisance
  Objective: describes the degree to which place in the neighbourhood nuisance in public space.
  Subjective: to what extent vandalism perceive nuisance as a problem in their neighbourhood.

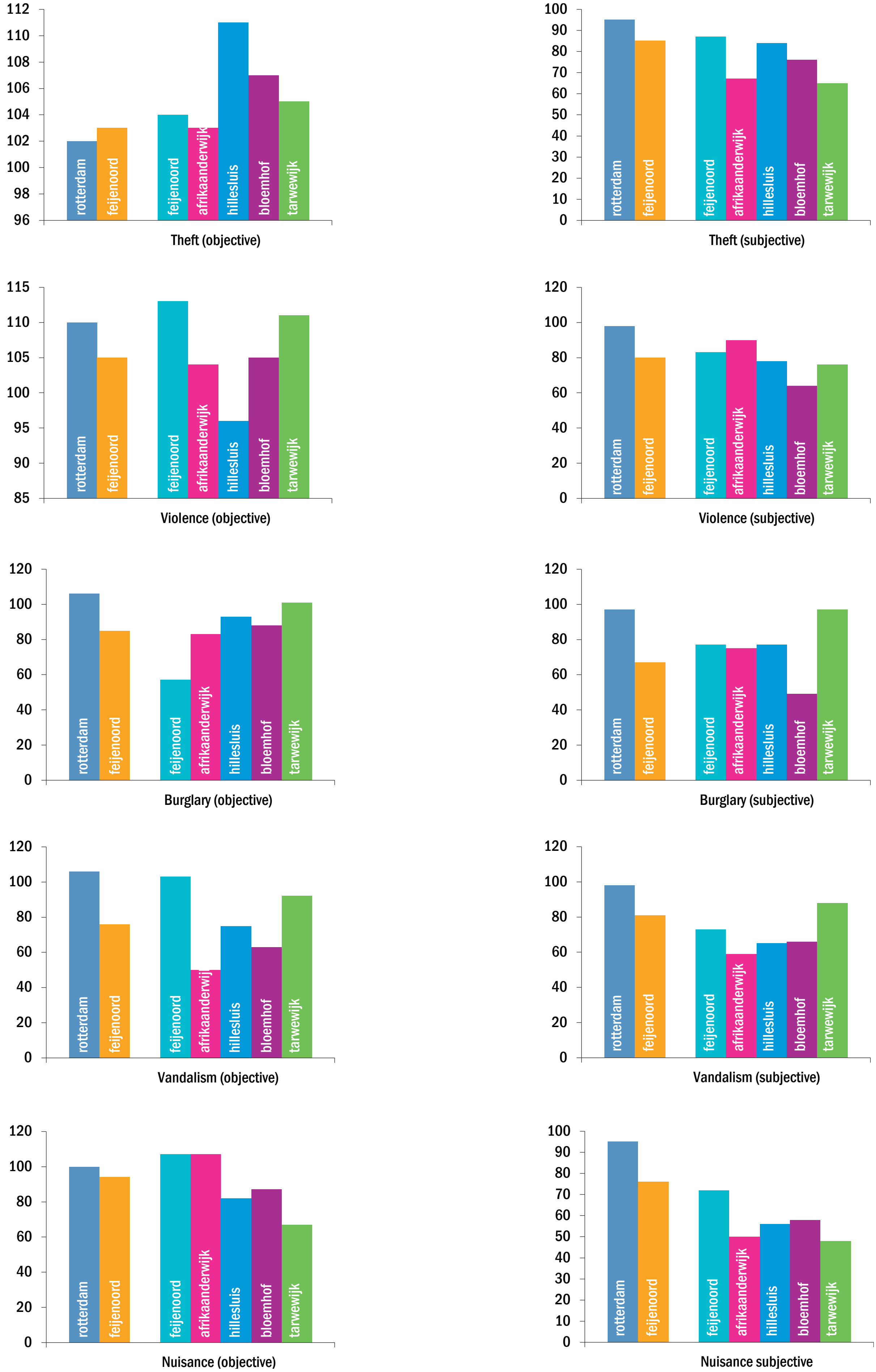


figure 22. The indicators from the safety index (Rotterdam & OBI, 2016).

9. Conclusion

This chapter set out to discover if people in socially deprived neighbourhoods in Rotterdam are inequitable exposed to the urban heat island. Rotterdam suffers from an intense urban heat island and shares a high amount of people with a low income. Based upon the dataset provided by dr. ir. Ronald Wall of the Erasmus University of Rotterdam and the social index by the municipality of Rotterdam statistical analyses has been conducted. With the use of indicators from the health index on loneliness, quality of life and medical conditions the neighbourhoods are selected and chosen for deeper analyses. The chapter is related to the research questions:

2. *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
4. *What urban typologies in the city of Rotterdam are more exposed to the urban heat island?*
5. *What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?*

In regard to research question 2 based upon the results of the step wise linear regression analyses and Pearson correlation analyses it found that the indicators that have a significant impact on the average summer day surface temperature are

- green,
- property value,
- density,
- paved open space,
- open water,
- floor space index, and
- share of sealed soil ratio.

The amount of green is the strongest correlating indicator with the average summer day surface temperature and together with the other urban characteristics, disregarding the property value, fits the theory that describes urban characteristics of density, vegetation and the use of impervious surfaces correlate (EEA, 2012b; Gartland, 2008; Harlan et al., 2006; Tomlinson et al., 2011; van der Hoeven & Wandl, 2013). Therefore in answer of the research question of what characteristics of the urban fabrics have an exacerbating effect on urban heat island are indicators of density, vegetation and impervious surfaces. As this under scribes the theory the notion is made that in regard to the indicator of open water seems to have a significant impact on the land surface temperature. This would fit research on Vienna and Rotterdam that argue that the temperature of open water, build-up during the spring and summer, can have a negative effect on the nocturnal urban heat island as the water body is warmer then it surroundings heating the air above it (Steeneveld, Koopmans, Heusinkveld, & Theeuwes, 2014; Žuvela-Aloise, Koch, Buchholz, & Früh, 2016). However such significance only comes forth from the step wise linear regression and not by the Pearson Correlation analyses. As such there remains some ambiguity concerning a strong statement regarding to relation between the indicators of open water and the urban heat island in Rotterdam.

Concerning research question 4 what urban typologies in the city of Rotterdam are more exposed to the urban heat island remains somewhat ambiguous. Such ambiguity comes forth from the lack of a clear definition of each neighbourhood accompanied by meaningful indicators. The selected neighbourhoods that come forth from the paragraph 'analyses of the population characteristics indicators' are all pre-war expansion areas. However this is too meagre to build a clear answer for the research question. Therefor in part "Assessment of three building typologies" on page 121 a closer analyses is performed on the typology in the city district Feijenoord

Relating to the research question 5 what environmental justice indicators are on a neighbourhood level and how these apply to the city of Rotterdam it is found that indicators of property value and social index indicators of social cohesion and living environment show a correlation. Neighbourhoods that score worst upon the social index indicators score high on average summer day surface temperature. Such a correlation is similar for the property value. One should be aware that a social indicator does not influence the land surface temperature as it is not a physical property related to the urban heat island. However such a finding does follow research on environmental justice in relation to the urban heat island as socially deprived neighbourhoods are often neighbourhoods with a strong urban heat island. From the statistical analyses of the health index it is learned that the city district scores low on the indicators

- health,
- quality of life,
- medical conditions, and
- social index indicators of capabilities.

The latter comprises of the indicator of good health and scores low for each neighbourhood. Therefore the general health of these neighbourhoods is considered below average and not sufficient. The indicators of the health index for each neighbourhoods under scribes such notion. Statically data from the safety index shows that the indicators

- theft,
- violence,
- burglary,
- vandalism, and
- nuisance score below average.

The results from statistical analyses suggest at least that people in socially deprived neighbourhoods of Feijenoord are more exposed to the urban heat island by average summer day temperatures. The indicators of population characteristics show a correlation. A closer look show the re-occurrence of neighbourhoods that score low on the social index and on the indicator for high temperature. With the use of additional indicators of income threshold and the health index the neighbourhoods Feijenoord, Afrikaanderwijk, Tarwewijk, Bloemhof and Hillesluis are designated as neighbourhoods that are most socially deprived.

Rotterdam south general analyses

10. Introduction

From the statistical analyses in "7. Statistical analyses of environmental justice indicators" the neighbourhoods in the city district Feijenoord and the neighbourhood Tarwewijk in Rotterdam South are designated for closer analyses. These neighbourhoods score the highest on the environmental hazard of high average summer day surface temperature and on social vulnerability indicators of property value and the social and health index. This chapter starts with a short description of the history of Rotterdam South to put the city in a historic context from the end of the 20th century. Secondly a closer analysis on these neighbourhoods is performed on urban characteristics of the green structure and distribution of functions and on population characteristics with the health and safety index. Secondly the chapter asses what findings come forth from policy documents. Thirdly interviews transcripts with official from the municipality of Rotterdam and housing corporation Woonstad are presented and the findings from the three sight visits. The chapter concludes with a triangulation on the findings from these different sources and how they relate to the research questions.

The chapter as whole applies to the research questions of:

2 What characteristics of the urban fabric have an exacerbating effect on urban heat island?

5 What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?

figure 23. Illustrative image of a pergola at Orleanderplein in Bloemhof (image by author).

11. Rotterdam South History

The city of Rotterdam is founded on the north bank of the Meuse close by to the North sea. At the end of the 19th century Rotterdam grew faster than other Dutch cities. The harbour activities expanded to the south bank focused on the transit of goods to the German hinterland. A lack of fitting houses for the labour class and expected population growth motivated the construction of new neighbourhoods. The southern part of Rotterdam was chosen as there was enough room without the infrastructural barriers of its northern counterpart. Both civil engineer Witteveen and architect Grandpré Molière have been concerned with the planning of this development. The southern part of the city was intended to develop into an independent district with its own city centre with hotels, restaurant, theatre and cinema (Jaarsveld, 2004; Rutte & Abrahamse, 2014; Wagenaar, 2011).

The urban typology of the neighbourhoods of Afrikaanderwijk, Hillesluis, Bloemhof and Tarwewijk mainly consist of close building blocks with a maximum of five floors and pre-war row housing. Afrikaanderwijk was developed at the beginning of the 20th century and mainly consist of closed building blocks. Bloemhof's consist of a mixture of different pre-war urbanism with street pattern based upon the polder structure. Hillesluis consist of mainly four layer closed building blocks with symmetric street pattern. Tarwewijk is a mixture of four layer closed building blocks and large industrial complex alongside the harbour (Lörzing, Harbers, & Schluchter, 2008).

In figure 24.a and figure 24.b on page 67 two plans from 1903 and 1926 are displayed of the envisioned expansion of Rotterdam.

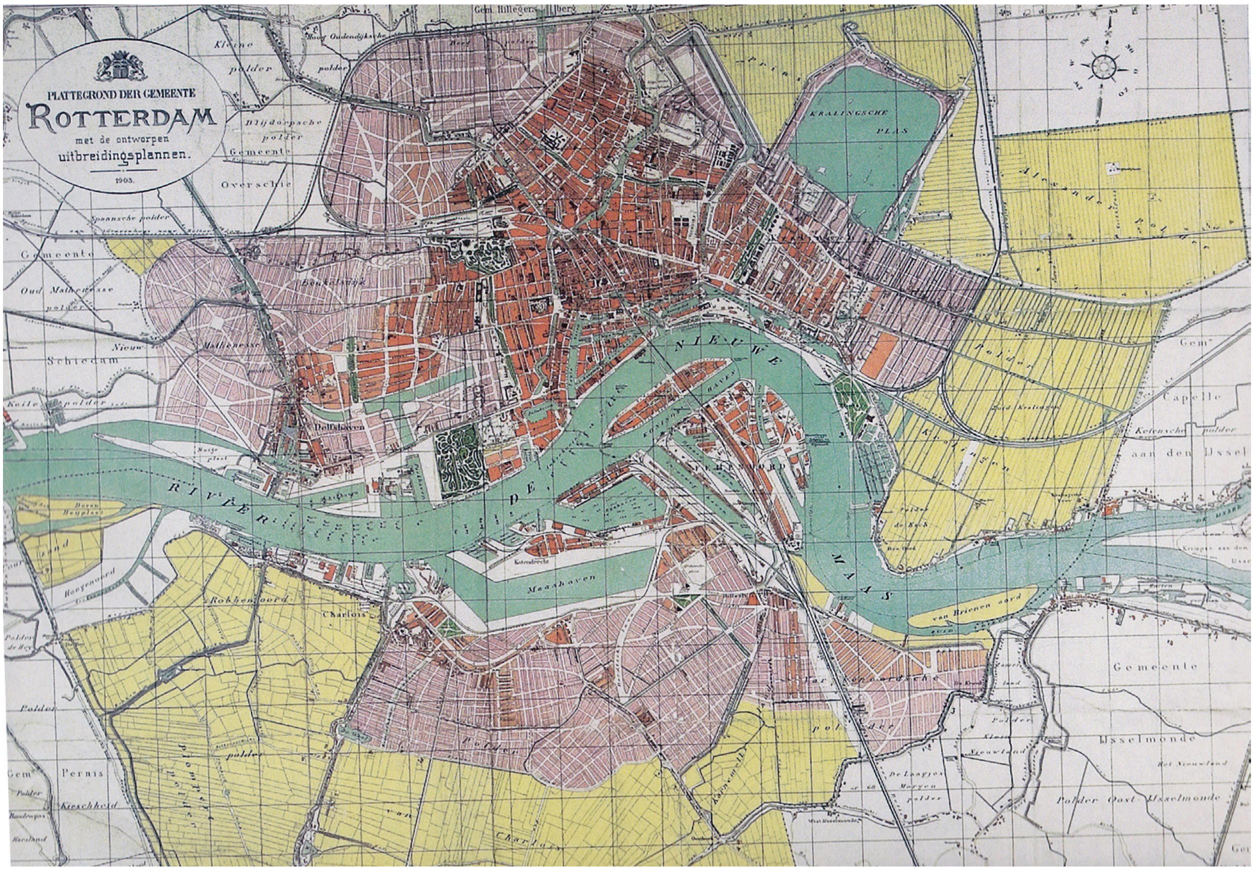


figure 24.a. Expansion plan from 1903 envisioned by De Jongh. Essentially this expansion plan is a collection of different sub-plans (Jaarsveld, 2004, p. 42).

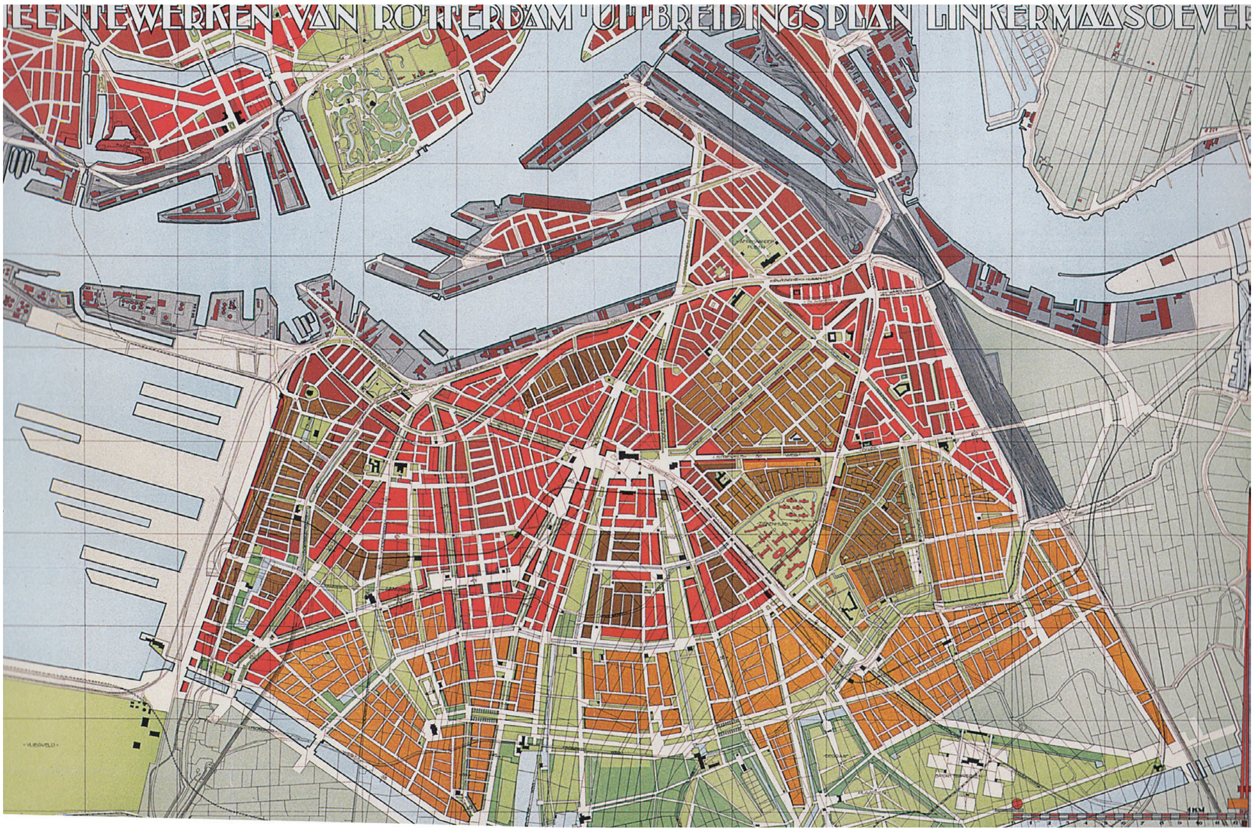


figure 24.b. Witteveen's plan in 1926 for the expansion on the south bank. Witteveen used the concept of the bounded town with a clear border of a 100 m wide canal between the city and its rural surroundings. The plan was rejected as was argued that Rotterdam needed an opener concept with room for harbour development and green neighbourhoods (Jaarsveld, 2004, p. 49).

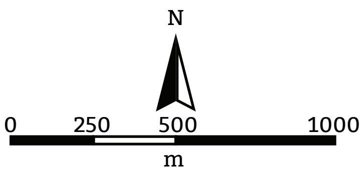
12. Green structure

In figure 26 on page 69 the green structure of the city district of Feijenoord is presented with parts of Charlois and Ijsselmonde and build from three data sources. The map is based on the layer 'blokplan' or block plan obtained by the municipality of Rotterdam. The layers of buildings, grassland and water are used to act as a under layer and to present the green structure of the grassland. The layer tree plant boxes are used from the 'grootschalige basiskaart' or scale base map obtained by the TU Delft's Map Room. It must be noted that the GBKN does not cover the entire area of the city district of Charlois and Ijsselmonde and does also no contain data on private property. The third layer of the trees is obtained through Gisweb with the layer height file trees. This dataset is derived from the height file 2014 and includes Light Detection And Ranging of Laser Imaging Detection And Ranging (LIDAR) measurements that represent in most cases trees. The third layer is loaded in ArcGIS where it is exported as an image. This image is processed in Adobe Photoshop and Illustrator. It therefore does not contain attributes of height. However the layer is used as to illustrate the distribution of trees and big bushes. It must be noted that the dataset misses out on small trees as some of the trees are too small (figure 25). Therefore combination with the data from the GBKN shows the smaller trees that height file tree misses out on.

In general terms the green structure shows lots of green in the form of big trees along side the main axis of the city district. However the green stucture inside each neighbourhood is much less.

figure 25. An image of Google Street view looking into the south western direction of Putsebocht and a cut out of the green structure map. Notice how the high file map misses out on some of the trees because of their small size but take into account that this data is based on 2014 and the street view map on 2015 (Google maps, 2015).

LEGEND
Green structure of Rotterdam South



- Building
- Building island
- Grasland
- River
- Water
- Tree plant boxes
- Tree crowns

figure 26. Overview of the vegetation in Rotterdam South (image by author).

13. Functions

In this paragraph the distribution of functions of the city district Feijenoord is on display. The data is derived from the cadastre's basic registration addresses and building viewer.

Such a map does not necessarily follows from previous chapters or the theoretical framework. However the presence of services for the neighbourhood is linked to the liveability of neighbourhoods. In the book publicized by the Delft University for Technology 'transformation strategieën voor verouderde stadswijken' one of the aspects that attributes to the liveability of a neighbourhood is the presence of services like shops, educational facilities, health care services and community centres as such services provide for social control (Rooij, 2012). Jane Jacobs describes in The Death and Life of Great American Cities how social control provides for safety in the streets. Such safety is effectuated by local supervisors who live in the street, use the street or who run a shop or work in one of the describe services. Jacobs describes how for example shop owners prefer an orderly and safe surrounding as its beneficial for them to do business (Jacobs, 1961). Therefore knowledge on the distribution of the functions can provide for valuable information why certain streets are considered more deprived then others.

On the right page the distribution of functions in the city district Feijenoord is shown. The map is based upon the basic registration of addresses and buildings by the national cadastre. Buildings can be filtered according to their purpose. From the web application data is extracted and processed in Adobe Illustrator and Photoshop. In the "Appendix I" on page 174 each individual function is displayed.

figure 27. Overview of the different functions except residential in Rotterdam South (image by author).

14. Policy documents

To get a notion how, from the viewpoint, Rotterdam South and city district Feijenoord should develop according to different institution an overview is presented of their main points. These notions are part of the methodological triangulation and considered as qualitative data.

Firstly an important notion is that the neighbourhoods of Rotterdam South are designated as 'oud zuid' or old south and considered as socially deprived by the national government. These neighbourhoods have been given extra attention and as such the policy documents may provide valuable information for the thesis to confirm earlier findings or to provide for new leads. When reading the policy documents extra attention is given to remarks on indicators of social deprivation of income and health and urban characteristics related to the urban heat island indicators vegetation, density, building quality and use of impermeable surfaces. The policy documents that are used, translated to English, National Program Rotterdam South, Chart of the city and Area plan city District Feijenoord.

Secondly the city of Rotterdam has a water issue in regard to transport and capacity. Since water potentially provides for either mitigating or exacerbating effects on the urban heat island integrating water policy in further stages of the thesis might prove valuable as a design component. The policy documents that are used are Waterplan 2013 and Waterplan Feijenoord and Charlois.

Thirdly the document Rotterdammer make the city is a design research and is part of the 5th International Architecture Biennale Rotterdam, a platform created to investigate and together with residents and entrepreneurs how a sustainable inner-city might look like. As the subtitle is called 'densifying and greening is a sustainable city' the research might provide, regardless of its focus for the inner city of Rotterdam, valuable design solutions.

Fourthly the general prognosis for population growth in Rotterdam is adjusted upwards in regard to earlier prognosis (figure 28). This will lead to a changing population demographics with a greater demand for more commercial rental property and owner-occupied property in middle and higher segment. Within the middle and higher income group there is a greater demand for diverse accommodation ranging from student apartments, big studio's, child friendly apartments, elderly friendly apartments and single-family houses (Gemeente Rotterdam, 2015).

In table 14 on page 73 is presented with the main points selected from the different policy documents.

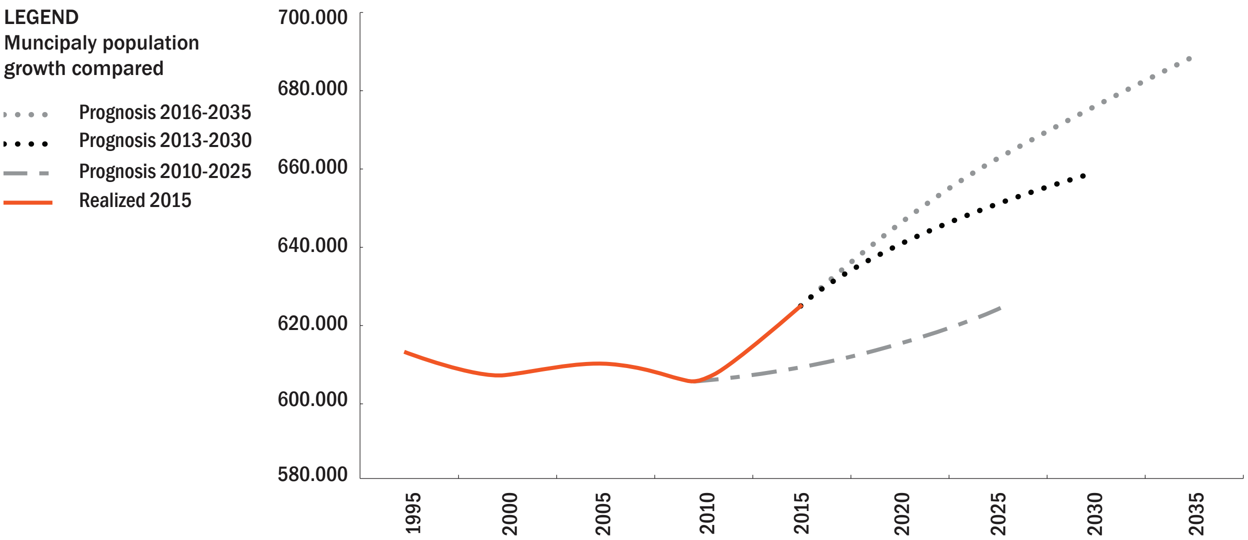


figure 28. Three prognosis for different time ranges (Gemeente Rotterdam & OBI, 2015).

table 14. An overview of the main points selected from the different policy documents.

Topic	Scale	Policy document	Main points	Source
Housing	Rotterdam South	National program Rotterdam South	• Need for critical mass in housing and services for a diverse target audience. • Need for quiet residential areas to create more diversity in housing to attract different groups. • Private owned small apartments are worrisome.	(programmabureau NPRZ, 2015)
Population	Rotterdam	Chart of the city	• Population of Rotterdam is growing with 40.000 more in 2025 according to the prognosis of 2015-2035 then a previous prognosis of 2010-2015.	(Stadsontwikkeling Rotterdam, 2015)
varied	Afrikaanderwijk	Area plan city district Feijenoord	• Streets have high percentage of pavement. • Afrikaanderwijk needs improvement of its shopping street. • Improvement of the facades • Parking pressure is high.	(Gebiedscomissie Feijenoord, 2014)
varied	Bloemhof	Area plan city district Feijenoord	• High burglar percentage. • Small and bad insulated houses. • Lack of green; no small parks or green with quality. • Youth hang out at squares with nuisance. • Diversity of houses.	(Gebiedscomissie Feijenoord, 2014)
varied	Hillesluis	Area plan city district Feijenoord	• Transition neighbourhood: people don't stay long. • Homogenous type of housing. • Create room for meeting, playing and relaxing. • More diverse houses. • Improvements public space and facade of the boulevard.	(Gebiedscomissie Feijenoord, 2014)
Water	City district Feijenoord	Waterplan 2013	Afrikaanderwijk, Bloemhof and Hillesluis do not meet the requirements for the norm for water nuisance.	(Gemeente Rotterdam, Waterschap Hollandse Delta, Hoogheemraadschap van Schieland en de Krimperenerwaard, & Hoogheemraadschap van Delfland, 2013)
Water	Afrikaanderwijk, Tarwewijk, Hillesluis and Bloemhof	Waterplan Feijenoord and Charlois	With a high percentage of paved surfaces, lack of green and insufficient transport capacity there is a need for open water to give the water system a quantitative and qualitative new impulse. However due to a high density, a higher ground surface and limited capacity in its surrounding water system there is a need for innovative solutions.	(Gemeentewerken, 2010)
Density and greenery	Rotterdam	Rotterdammers maken stad verdichten + vergroenen = duurzame stad	• Higher density stimulates walking and cycling. • Higher improves employment as the demand for services increase. • Higher density intensifies the use of greenery.	(Tillie, 2012)

15. Observations and interviews

In this chapter qualitative data that is acquired through observations and micro interviews with resident's. Also interviews with an official of the municipality of Rotterdam and housing corporation Woonstad are presented in "II. Interviews" on page 188. These have moved to the appendix since this thesis does not clearly defined a method on interviewing and are to meagre to use as qualitative data.

15.1 Mental maps

In the book publicized by the Delft University for Technology 'transformation strategieën voor verouderde stadswijken' describes how the mental map and both long and short interviews in combination with statistical data are a good way to map the daily experience and important social issues (Rooij, 2012). It must be noted that the mental maps described is one made by the residents. In this case the mental map is made by the author and inspired by 'de zachte atlas van Amsterdam' or 'the soft atlas of Amsterdam' by Jan Rothuizen. The author is an artist who describes his drawings a 'written maps' or 'drawn report'. On his turn he is inspired by the Soft City by Jonathan Raban who claims that the city manifests itself where the 'hard' city meets the 'soft' subjective experience and expectations of the users of the city (Rothuizen, 2010). From observation and micro interviews a mental map has been drawn and is presented on page 76 as a spread.

In regard to the micro interview the notion that people made are:

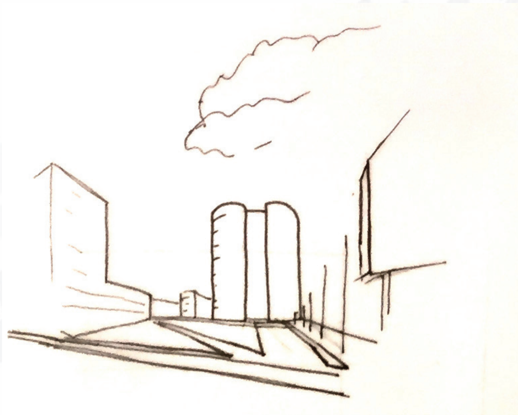
Micro interview with Dutch-Hindustan women (40+), lives in a apartment in Tarwewijk:
• During the summer it gets really warm or stuffy in the neighbourhood and my house.
• I keep the windows closed for the mosquito or drug addicted burglars.
• There has been some renovation of the inner-walls but it only helps for sound.

Micro interview retired Dutch man in the Roggestraat Tarwewijk:
• It gets quit hot in the summer, when I have the grand kids I let them sleep on the east side.

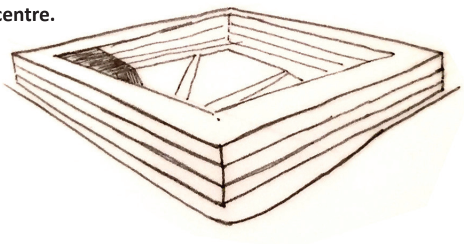
Micro interview with Moroccan women (40+), lives in a maisonette apartment in Tarwewijk:
• It gets really warm in my apparent, however the ground flour is much cooler.

This seemingly would fit the notion that residents experience high temperature as a nuisance. However this thesis restrains in itself in making strong claims from such findings. In relation with the statistical data and policy documents such findings serve supportive. However from a methodological point of view the academic background on micro interviews presented here is somewhat to shallow and should need more elaborative work in both the research framework and the fieldwork. A suggestion would be to set up a broader survey for the city as a whole. This would present a stronger representation of how temperature is perceived per neighbourhood.

such a dull open space.



Hillekopplein (Kop van Zuid-Entrepot); such a dull open space.



Violierstraat (Bloemhof); new building block 'In de Roos', no trees in the centre.

Market
Market
this square is off scale!

School Putselaan (Bloemhof); a lot impervious surfaces.

De kleine Seinpost; a mixed crowd accoring to the bartender

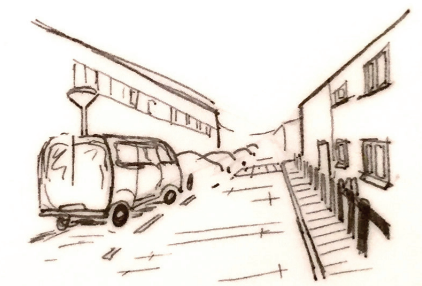
Very unsafe according to women (50+)

Patrion

New block dull public space

Lively square

Courtyard has no trees



Hyacintstraat: lack of green and a lot paved surfaces.

Could be these blocks she mentioned (1930)

DOCK

Had tuna wrap at a bakery

Dock communal centre (Tarwewijk); a lively centre and well kept.

Lack of green in these streets

Micro interview with Dutch-Hindustan women (40+), lives in a apartment in Tarwewijk:

- During the summer it gets really warm or stuffy in the neighbourhood and my house.
- I keep the windows closed for the musquitos or drug addicted burglars.
- There has been some renovation of the inner-walls but it only helps for sound.

Syrian refugees caught in at Dock; highly educated and already speak some Dutch.

Lively street

Thrift shop >

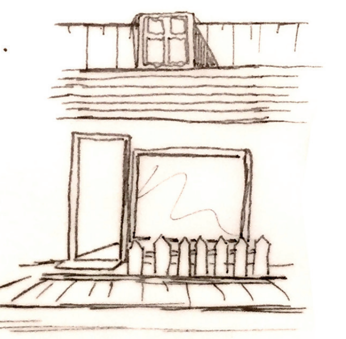
Such a lovely street, intimate scale and nice small green.

Micro interview with Maroccan women (40+), lives in a maisonette apartment in Tarwewijk:

- It gets really warm in my apartment, however the ground flour is much cooler.

Cafe 't Lanterntje

Cannabis plantage



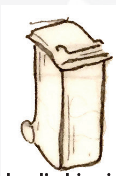
Rijsoordpad (Tarwewijk) Dull courtyard lack of trees

Micro interview with a women (50+) and Man (70+) near the thrift shop Resedastraat (Bloemhof):

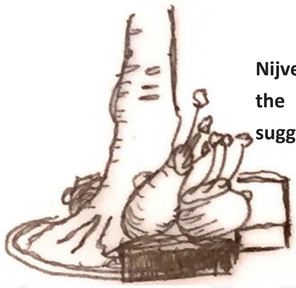
- It has gotten worse last years with drugs, crime and slumlords.
- They have broken up twice a cannabis plantage (Pointing across the street).
- Putseplein is very unsafe during the night
- There are alot of people adolecents living Marocan adolecents living in these houses, I don't know if thats allowed (Pointing across the street).
- During the summer, when I am outside, I hear nuisance of their ethnical music, but when I play Americana music they get mad.
- My daughter punshed a guy once in the face during an argument.

Micro interview retired Dutch man in the Roggestraat Tarwewijk:

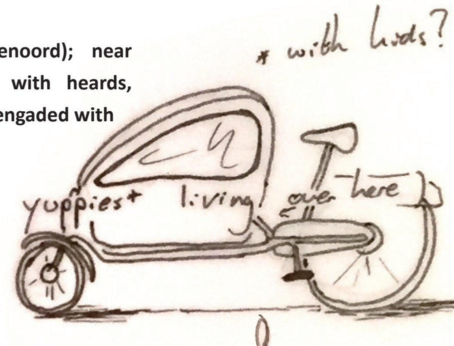
- Life is good here in Tarwewijk.
- The postal code 3081 has a bad reputation.
- It gets quit hot in the summer, when I have the grand kids I let them sleep on the east side.
- A few weeks ago they rolled up a cannabis plantation.



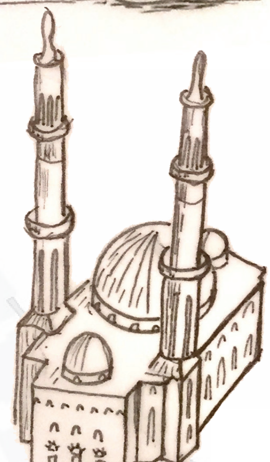
A lot of wheelie bins in Bloemhof.



Nijverheidsstraat (Feijenoord); near the tree old pottery with heards, suggesting someone is engaded with



Nijverheidsstraat (Feijenoord); a type of bike that suggest people with kids and a higher education are living here.



Essalam mosque (Hillesluis); a landmark clearly visible from afar.

Market at Afrikaanderplein (Afrikaanderwijk):
I would consider this as a big market, dominated by;

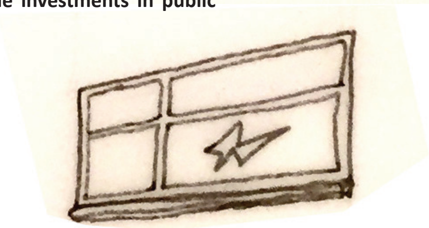
- Vegetable stalls
- Fish stalls
- Clothes stall
- Phone accessories tall
- Jewellery stall

Mostly run by people other than Dutch.

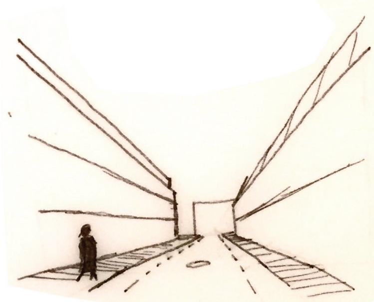
Woonstad neighbourhood office; spoke with Yvonne and Diane.

- There was a city trainer Rick Moonen but he is long gone
- We only help the people and don't know that much; you should go to DOCK.
- People are unable to speak the language, that the problem.

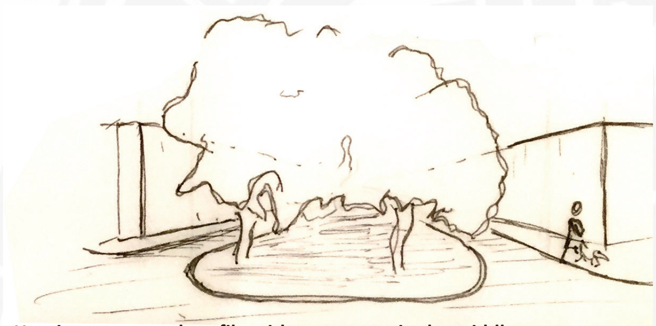
Blokweg (Hillesluis); clearly there has been some investments in public space.



Colosseumweg (Hillesluis); a broken window.



Brabantsestraat (Hillesluis) no green in the street.



Heerjansweg: good profile with green zone in the middle

Two Afghan (?) women sitting in the front of the door looking somewhat depressed.

15.2 Photo's from city walk straight through Tarwewijk

In this paragraph a photo collage is provided of a city walk straight through Tarwewijk, this provides for a close up look in the inner courtyard of apartment blocks and the linear building block's private gardens that are normally unavailable to reach as they are fenced off for the public. In

In general the observation is made that the visited courtyards and linear building block show a high percentage of paved surfaces with little to not green. The gardens are not well maintained and overall impression is somewhat depressing.

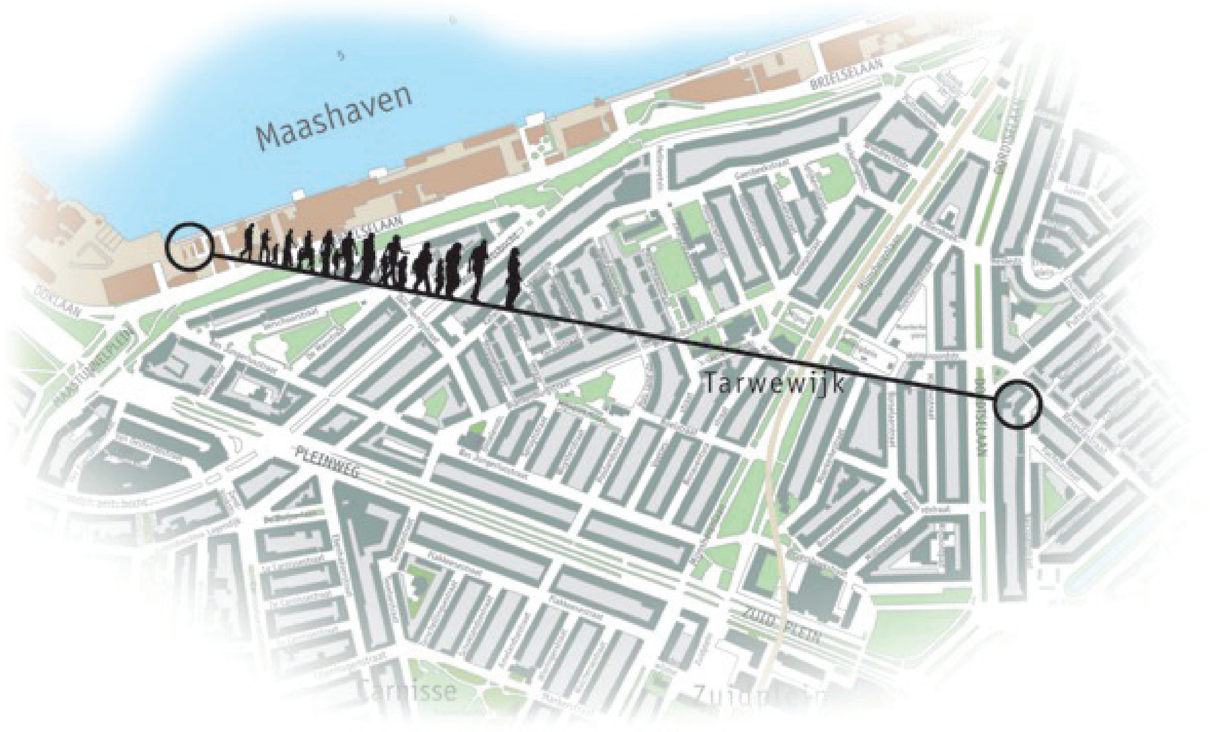


figure 30. Route taking through Tarwewijk. The straight line is the actual route that is taken with minor detours. As such one is able to visit the inner courtyard to are normally unavailable to reach.

16. Conclusion

This chapter set out to submit the neighbourhoods in the city district of Feijenoord and Tarwewijk to a closer analysis. Firstly the main aim is to gain more understanding of how the indicators of population characteristics and urban characteristics from the previous chapters relate to each neighbourhood. How do policy documents describe the different neighbourhoods and how is the neighbourhood perceived by residents? Secondly such closer analysis should provide for qualitative data and support the methodological triangulation. The related research questions are:

2 *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
5 *What are environmental justice indicators on a neighbourhood scale and how do these apply to the city of Rotterdam?*

This conclusion will first describe how the findings from the different paragraph interrelate and what can be concluded in regard to the above research questions.

In regard to the second research questions as is learned from the statistical analyses the neighbourhoods of city district Feijenoord and Tarwewijk shows a low amount of total green, have a low open space ratio and to some degree a high ratio of open space. Both from the green structure analyses, policy documents and the mental map such a notion is under scribed. There are some 'nice' green axis that border neighbourhoods with canals or big trees the inside of the neighbourhoods in general lack vegetation and there is a high ratio of paved surfaces. Policy documents subscribe the notion of lack of vegetation with remarks like: 'streets have high percentage of pavement' and 'lack of green; no small parks or green with quality'. In terms of water management documents make similar claims: 'with a high percentage of paved surfaces, lack of green and insufficient transport capacity…'. Observation as displayed in the mental map under scribe these findings with notions of streets that lack vegetation or high percentage of pavement. These findings support the statistical analyse.

Again from the statistical analyses it is learned that the city district scores low on indicators of health, quality of life, medical conditions and social index indicators of capabilities. Qualifying such data remains difficult as residents were not willing to openly speak about their medical condition. In terms of safety the quantitative and qualitative data seemingly triangulate. Statically data from the safety index shows that indicators of theft, violence, burglary, vandalism and nuisance score below average. Such notion is under scribed by policy documents as they make remarks of: 'high burglary percentage' and 'youth hangs out at squares with nuisance'. The interview with drs. Susanne Buijs made the remark how elderly are afraid to open the door. Short interviews with residents make similar remarks related to crime. A Dutch-Hindustan women made the remark that while her dwelling got warm during the summer, opening the windows is not an option as she fears burglary by drug addicts. Others make comments on crime or vandalism in the form of cannabis plantations or other shady practices, nuisance by youth or loud music during the summer. In regard to research question 5 the population characteristics on the neighbourhood level score below average and with the triangulation between both quantitative and qualitative data indicate issues of environmental injustice.

However there is a problem with the methodological triangulation. Firstly the statistical analyses was conducted on the city as a whole. The qualitative data is generated on the level of the city district. As such one can not unambiguously claim that the findings from the policy documents or observations support the findings from the statistical analyses. Secondly the micro interviews or observations are to few and there is an unsystematic approach reducing the scientific value. A survey on the city scale for each neighbourhood of how people experience their dwelling or direct surroundings in regard to air temperature is recommended to generate qualitative data from a stronger scientific methodology.

The chapter described interrelation between population and urban characteristics in combination with growth ambition and the design strategy in relation with the distribution of functions provides for interesting leads on how the neighbourhoods could be improved to meet growth ambitions, improve on water transport and capacity and to improve on perceived liveability or neighbourhood indicators of happiness of the neighbourhoods. Before such step is made first the neighbourhood of Bloemhof is analyses on how it preforms on the density, public spaces, building typology and sun and shade.

The choice for Bloemhof is based upon the fact that the neighbourhoods firstly preforms bad on the population characteristic indicators of loneliness, quality of life, obesity, burglary. Secondly on the urban characteristics of the lack of green, the notion of small and bad insulated houses. In the next part Bloemhof will be assessed upon urban characteristics of density and building age and typology. The public spaces in combination with a sun-study of the neighbourhood as a whole will be assessed upon quality and ability to provide shade.

Urban characteristics Bloemhof

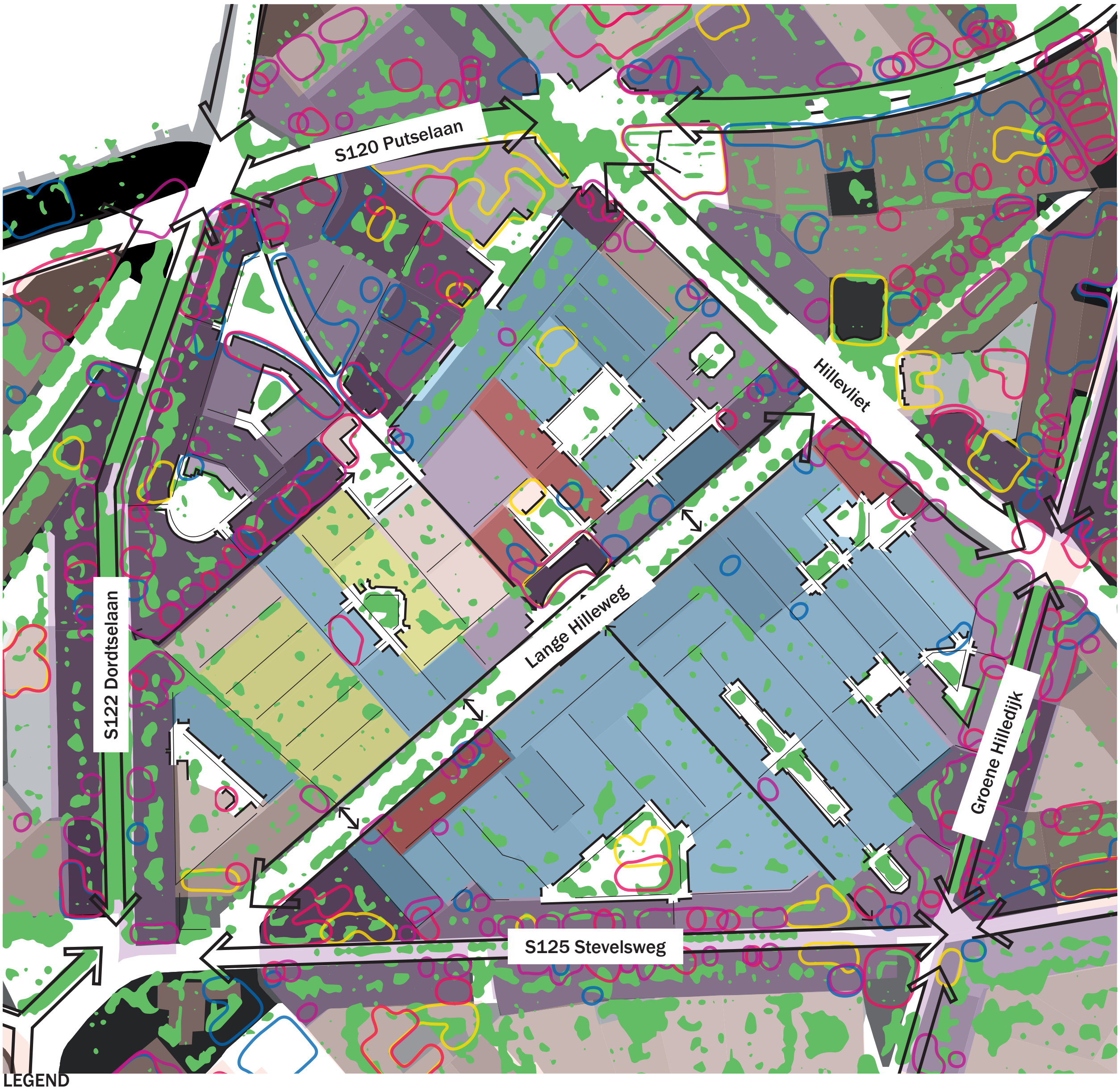
17. Introduction

In this chapter the neighbourhood Bloemhof is analysed on its urban characteristics of floor and ground space index, building year and building typology, sun study and an evaluation of the green spaces.

The chapter as whole applies to the research questions of:
2 What characteristics of the urban fabric have an exacerbating effect on urban heat island?
4 What urban typologies in the city of Rotterdam are more exposed to the urban heat island?

Such assessment provides for an insight in where and what kind of design interventions are viable and necessary. The chapter starts with the value map in which a combination is made of the function map from paragraph "13. Functions" on page 70 with, the green structure, building typology and infrastructure. Secondly the ground and floor space index of the neighbourhood is presented with the use of ArcGIS. Thirdly the building year and typology is presented. Fourthly the assessment of each public space is presented. The findings will lead up to the final chapter in which the design interventions will be presented.

On the next pages the value map is on display combing the analyses from building typology, green structure and public spaces. In general terms the neighbourhood has a diamond shape surrounded by the Dordtselaan, Putselaan, Hillevliet, Groene Hilledijk and Strevelweg. Bloemhof is divided by the Lange Hilleweg. These axis are often quite green with a diversity of functions however the inner part of Bloemhof lack green. The coloured areas represent what the dominate urban typology is and the darker they are the more dense. In paragraph "18. Floor and ground space index" on page 88 the density with the use of the ground and floor space index is individually presented. In paragraph "19. Building year and typology" on page 91 the building typology and year are presented.



LEGEND
Combination of building typology, functions, green and infrastructure. Building typology in combination with floor space index: darker means higher density.

- Apartment
- Duplex
- Terraced houses
- Maisonette
- Communal
- Industry
- Education
- Shops
- Trees
- Street
- Street and direction
- Main street

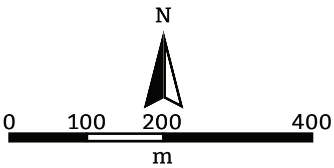


figure 31.Value map based upon the building typology, green structure and public spaces.

18. Floor and ground space index

The floor and ground space index (FSI and GSI) gives an indication of the land use and density of a neighbourhood. As the floor space reflect the building intensity and the ground space the relationship between built and non-built space (Meta Berhauser Pont & Per Haupt, 2010). The formula for calculation the floor and ground space index are:

$$FSI = \frac{F_x}{A_x}$$

F_x = gross floor area
A_x = area of aggregation
x = aggregation

$$GSI = \frac{B_x}{A_x}$$

Bx = footprint
Ax = area of aggregation
x = aggregation

For calculating the floor and ground space index the dataset of ir. Iris Theunisse and the TOP10NL are used. See table 15 for the workflow. In figure 32a on page 89 and figure 32.b on page 89 two graphs are presented from the book Spacematrix by Meta Berghauser Pont en Per Haupt. The graphs describe how a building typology can be categorized according to its ground and floor space index. In figure 33.a figure 33.b on page 90 the ground and floor space index is presented for Bloemhof. In general terms the FSI of building blocks alongside the main axis has a high FSI and within the Bloemhof the FSI remains quite low. These building blocks with a high FSI often consists of mid-rise block types between 4 to 6 floors. Such typology persists along the northern part of Bloemhof. More south the building blocks often show a FSI of low-rise block and strips. In paragraph "19. Building year and typology" on page 91 the building blocks are individually assed according to their typology and age.

table 15. Work flow for calculating the floor and ground space index per building block island.

TOP10NL	Dataset Theunisse
Autocad: building block island built from road heart line	ArcGIS: F_x is the number of stories times shape area per building F_x = max_aantal × shape area
+	
ArcGIS: Spatial joint Calculate sum of the F_x per building within each building block island shape.	
FSI = Sum F_x / building block island shape	

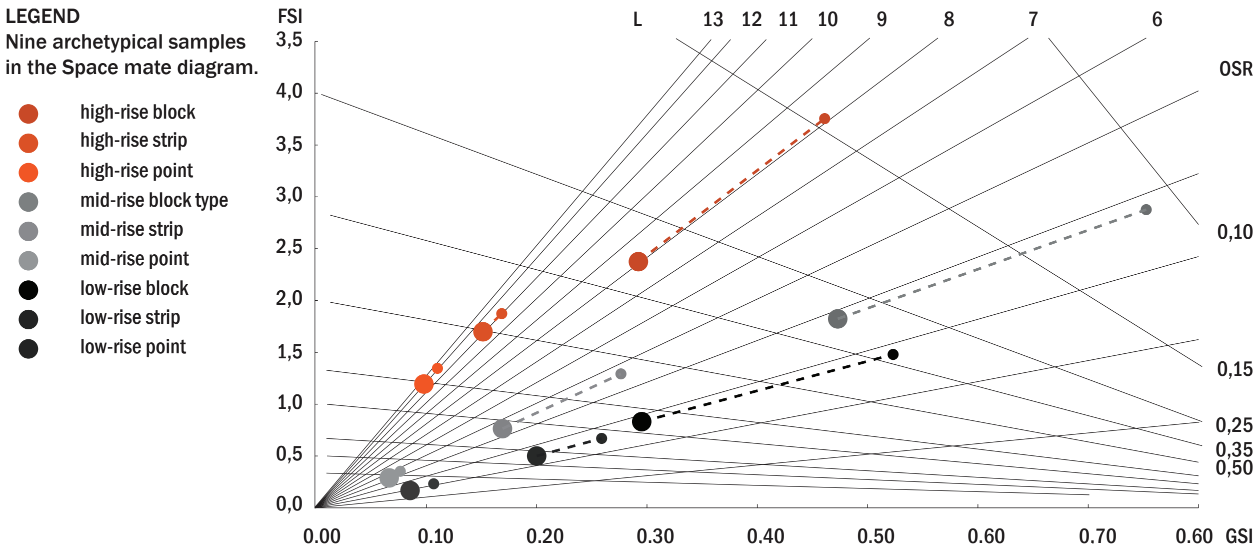


figure 32a Building types according to their GSI, FSI in the Spacemate diagram on the scale of the fabric (Berhauser Pont & Haupt, 2010, p. 191).

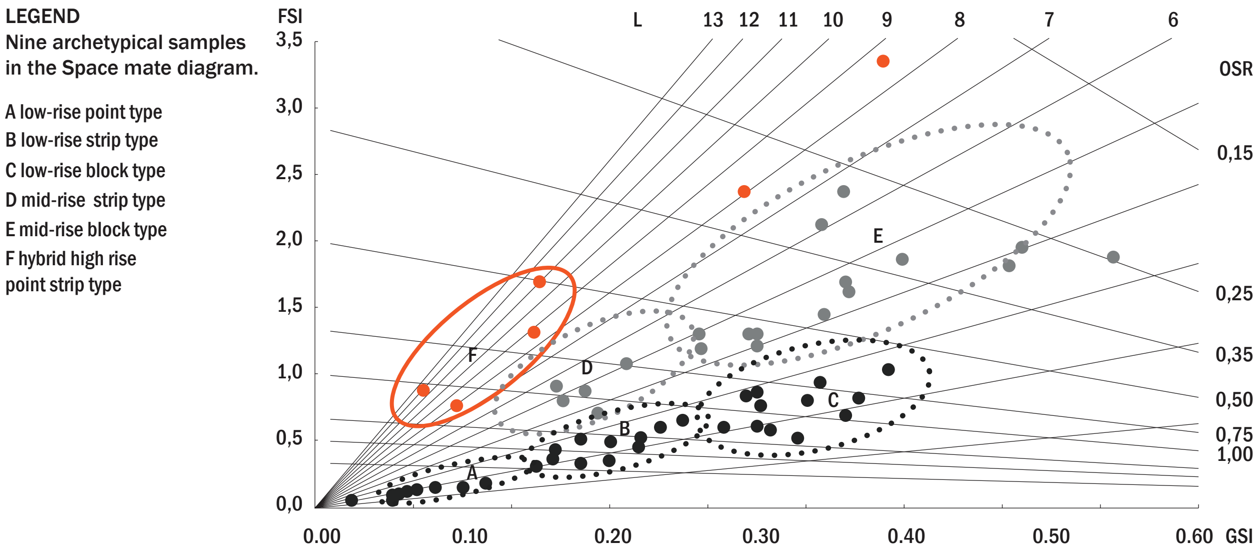


figure 32.b.Building types in the Spacemate diagram on the scale of the fabric (Berhauser Pont & Haupt, 2010, p. 191).

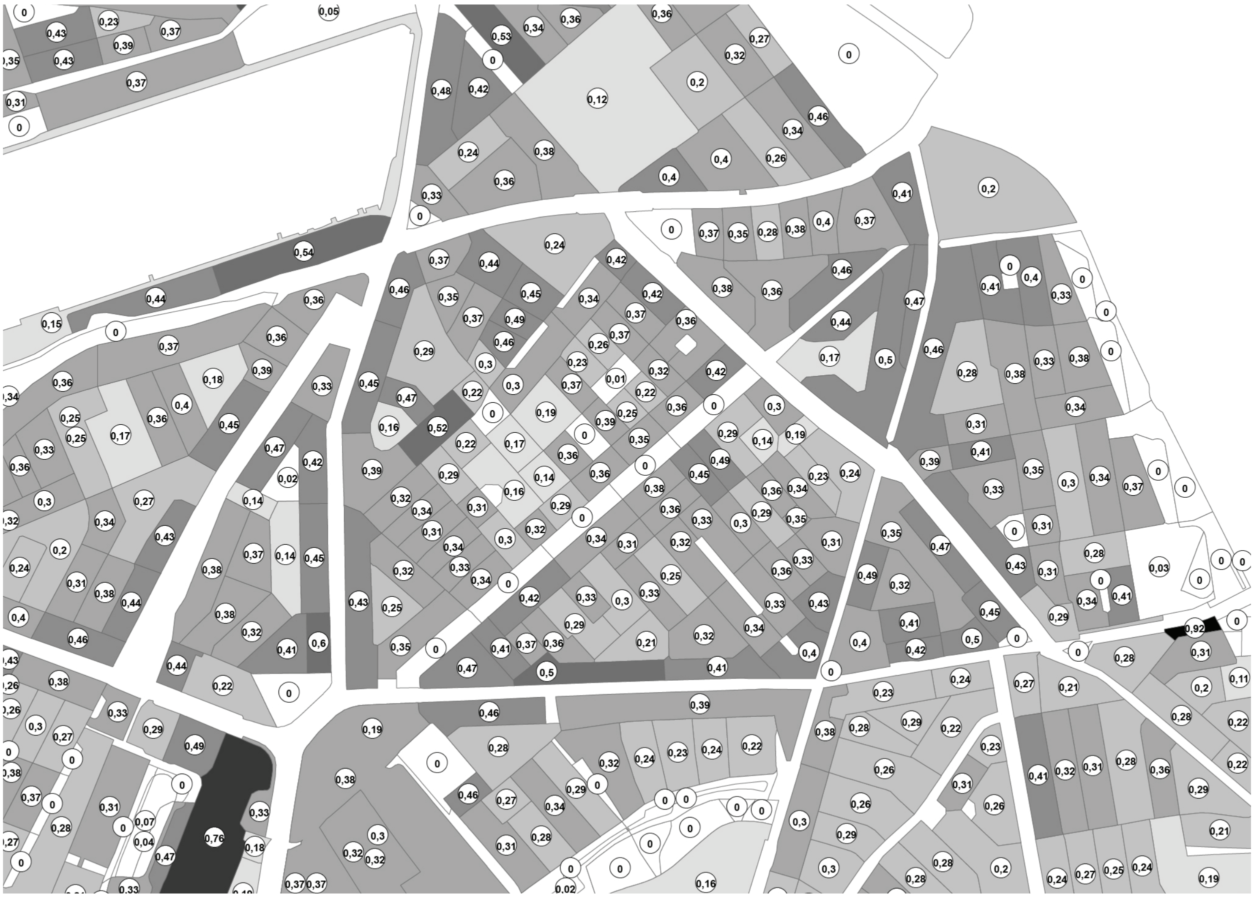


figure 33.a.Map of Bloemhof with the ground space index for each individual urban island.

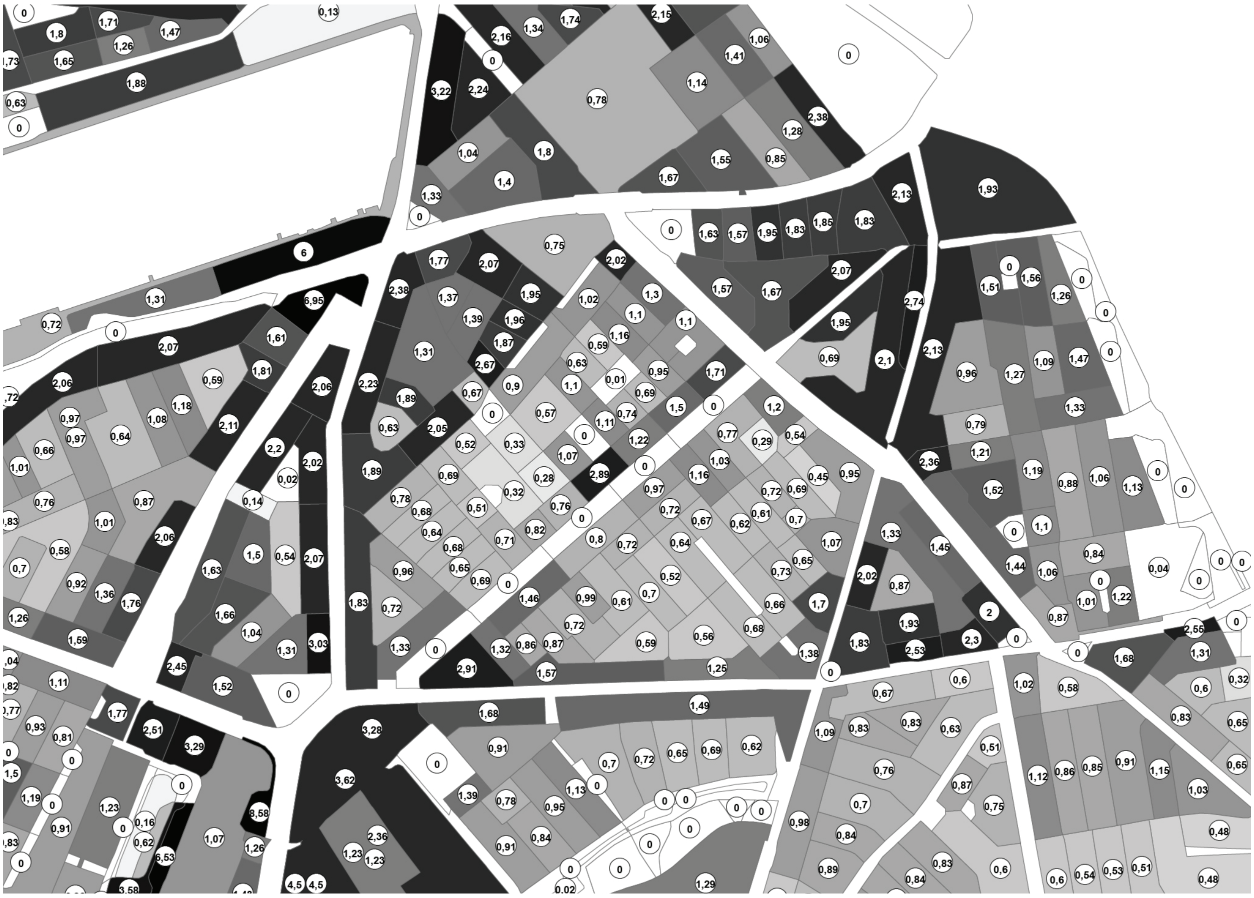


figure 33.b. Map of Bloemhof with the floor space index for each individual urban island.

19. Building year and typology

In figure 34 and figure 35 on page 92 the building year per building block is displayed and an overlay of the building typology per building block for Bloemhof and partly its surrounding neighbourhoods.

The map of the building year is based upon the dataset made by ir. Iris Theunisse. Since Bloemhof is part of pre-war expansion the neighbourhood for a large part consists of building from the period 1910-1940 presented in the colour range orange to yellow. As Rotterdam south was not bombarded there are almost no building from the build-up area from 1945 – 1965. New building emerges during urban renewal period from 80's till mid 90's which are presented in the colour range light blue. Darker blue blocks represent buildings build after 2000. In general terms Bloemhof for a large part still consist of buildings from the period 1910-1940. Mainly at the north western part there has been some urban renewal projects which is less so the case for the south eastern part.

Based upon an optical analyses each building block is categorized according typology; apartment, duplex, terraced houses and maisonette. A building with two floors with a dwelling on each floor is called a duplex. A building of more than two floors a no more than four floors with two dwellings which either one or both have two floors is called a maisonette. The map with the building typologies is an overlay over the building year map in black and white and indicates the building typology and its age. For example in the south eastern part the light blue building blocks are renovated terraced building blocks and the dark blue are pre-war terraced houses.

The north eastern part of Bloemhof consists in the northern part and an along the axis of apartments block varying in building age. The southern part consists of mainly terraced houses, duplex and apartments mainly pre-war but with some renewal. The south western part mainly consists of pre-war terraced houses and along the axis apartments.

figure 34.a.Map of Bloemhof with building year per building block (image by author).

figure 35.a.Map of Bloemhof with the building typology per building block (image by author).

20. Sun study

In this paragraph the sun study is presented. The municipality offers a 3d model for Rotterdam in xml format. The model is processed with Globalmapper into dwg vector format. In Rhino 5 by Rhinoceros the 3D model is processed and meshes are built from the vector file. Other than the green structure map are the trees based upon the Gisweb layer 'Bomen naar ontwikkelingsfase en kroon projectie', or 'tree development phase and tree crown projection'. These are processed in Photoshop and AutoCAD and combined with the 3d model in Rhino. Since the tree layer does contains trees on private property trees from the height file trees are selected and merged in AutoCAD. The trees are categorized according to their crown diameter and extruded. With the Rhino 5 solar one-day sun study option a sun study is executed for summer equinox of 21-06-2015 at 0900, 1300 and 1600 o' clock. The sun study provides three separate renders which are processed and combined in Illustrator. The sun study shows how during the summer the buildings and vegetation cast their shadow. The darker the area the more shadow is cast during a summer day. In the next paragraph the public spaces in combination with the sun study are assessed according to how much protection they provide from the sun during summer days.


N
0
100
200
200
m

21. Public spaces

In the policy documents of the area plan city district Feijenoord there is the commented on the lack of small parks or green with quality and a high percentage of paved surfaces (Gebiedscomissie Feijenoord, 2014). In relation to the water management system the neighbourhood does not meet the requirements for water nuisance because of lacking temporal storage capacity partly caused by the lack of green (Gebiedscomissie Feijenoord, 2014; Gemeentewerken, 2010). As described in “9. What is the urban heat island and it effects?” on page 47 the intensity of the urban heat island is closely related to the presence of vegetation as this provides for evapotranspiration and a shade (Gartland, 2008). The findings from “19. Building year and typology” on page 91 describe how Bloemhof consist largely of prewar dwellings with little vegetation in both the private en public space. Such combination with notion that these houses are badly insulated (Gebiedscomissie Feijenoord, 2014) that the residents in the neighbourhood have little opportunity to escape from high air temperature both in the public and the private space.

However to under scribe the notion of the lack of small parks or green with quality an assessment is done for all the available public spaces in Bloemhof. Each public space in Bloemhof is assessed on shading, the amount of trees, accessibility, shade for coolness during heat waves, what kind of facilities they provide for physical activities, what there service area is and in general how they are distributed.

Firstly for each public space a close up is presented with bordering buildings based upon the sun study as presented in “20. Sun study” on page 93. The edging of the infrastructure is generated from the GBKN for the city district Feijenoord. Grassland and the playgrounds are based upon the basis map layer in Gisweb.

Secondly each public space is assessed on size, the availability of playground for children under and above 10, the amount of trees and in what development phase they are, the amount of benches and those who are within the shade during one of the periods during the day morning midday and the afternoon and if the playground is fenced off. Each indicator is graded with a score, see table 16 on page 97 for the valuation of the scores.

Thirdly to get a sense for the ratio of the public space, trees and the surrounding buildings sections are presented with the use of the Rhino 5 plugin SectionTools. And finally what the service area is within a certain distance is calculated with urban network analysis. The method and work flow is described in the next paragraph. By combining these different analyses the quality of the public space, its value to the neighbourhood and the overall distribution of the public spaces is assessed.

Urban network analysis

With the urban network analysis the service of each public space to its neighbourhood is assessed. The urban network analysis is a toolbox developed by City Form Lab at the Harvard University Graduate School of design. The toolbox is developed to analyze spatial network on reach, gravity, betweenness, closeness and straightness and works with ArcGIS and Rhino3D (City Form Lab, 2016).The Rhino 3D toolbox is currently in a beta stage and used because of the ease of use, compatibility with collected data and the option of commuting the service area from a specific location.

The data by the Kadaster’s TOP10NL digital topographic basic file is used as it consists of center line for road for automobiles, cyclist and pedestrians. Isolating this center line gives a continuous network of lines which the urban network analyst can easily analyze. However it must be noted that TOP10NL file misses out on some specific pedestrian roads and thus the network needs to be verified and adjusted. In figure 36 an example is given of an omission in the TOP10NL file of the a pedestrian route between Putsebocht and Asterstraat.

A service area of 240 m is chosen as it represents access to public spaces within 5 minute travel time. The Dutch Knowledge center for traffic, transport and infrastructure (CROW) defines the average walking speed of 0,8 m/s. In the past there was a distinction for between children, adults, elderly and people with a handicap (CROW, 2004). To determine the service are of a park this walking speed 0,8 m/s are used. A service area within 240 m fits the notion from the rapport ‘Rotterdammers maken de stad’ that states a 250 m for daily activities.

table 16. Valuation of the scores.

Score	0	1	2	3
Area (m²)	-	< 1000	2000 - 3000	> 3000
Playground facilities age ≤ 10	0	1	2 - 3	≥ 4
Playground facilities age ≥ 10	0	1	2	≥ 3
Trees young	3 ≤	4 - 10	11 - 19	≥ 20
Trees adult and old	2 ≤	3 - 5	6 - 10	≥ 11
Trees end phase	4 ≤	3 - 2	1	0
Benches	0	1 - 3	4 - 5	≥ 6
Benches in shade	0	1 - 3	4 - 5	≥ 6
Fenced	YES	-	-	NO

The assessment of each public space begins with figure 37 on page 98 with each public space is identified. Subsequently each public space per page is assessed. This paragraph concludes with the findings from the assessment.

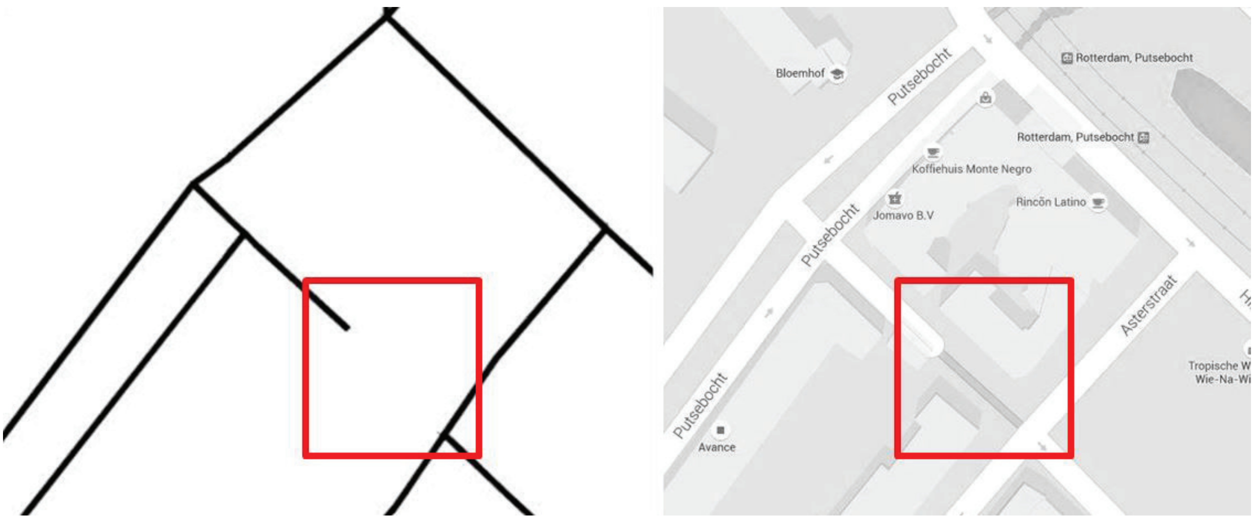
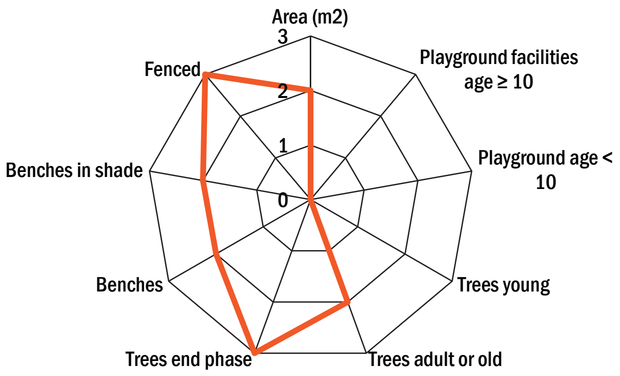


figure 36. Omission of the pedestrian axis in the TOP10NL and verification with google maps (Google maps, 2016).

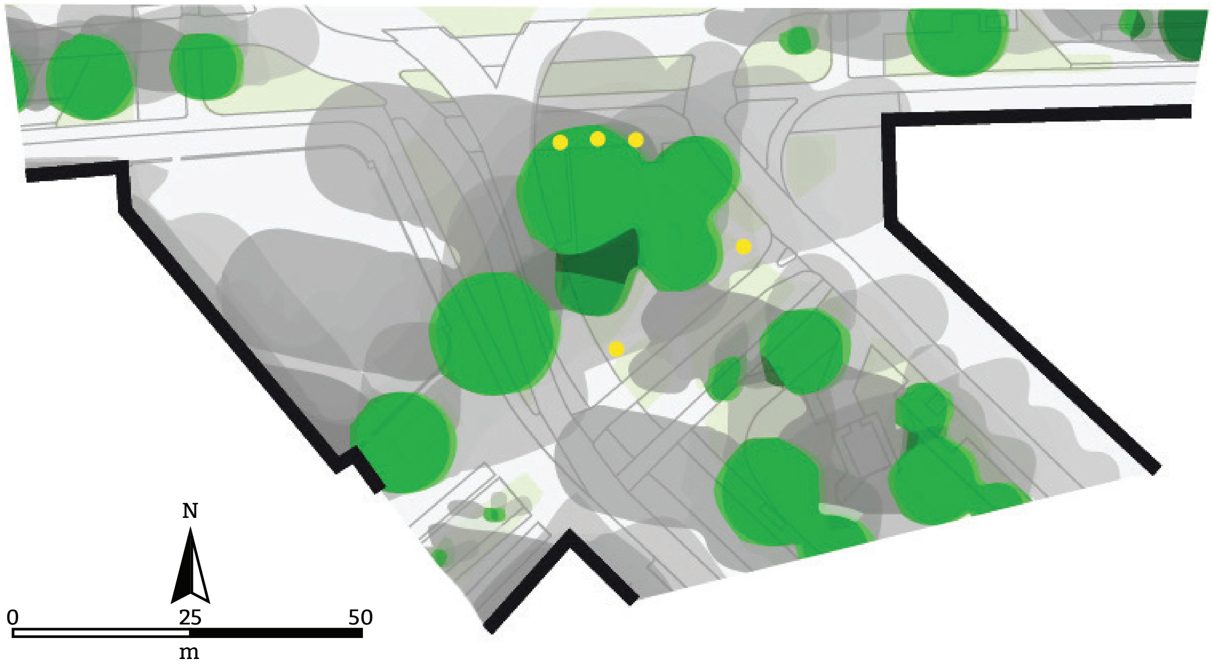
figure 37. Map with the building blocks and vegetation and an identification of each public space.

1. Slaghekstraat

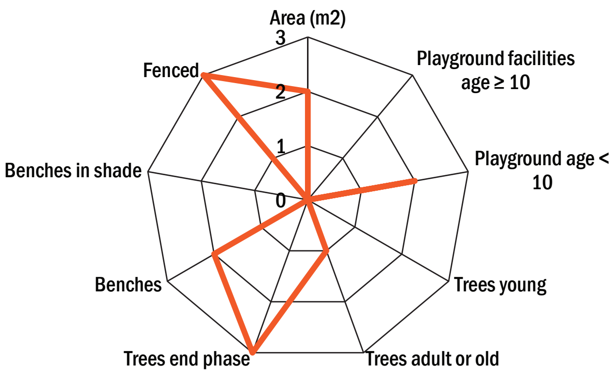


Valuation of public space

Service area public space within 240 m

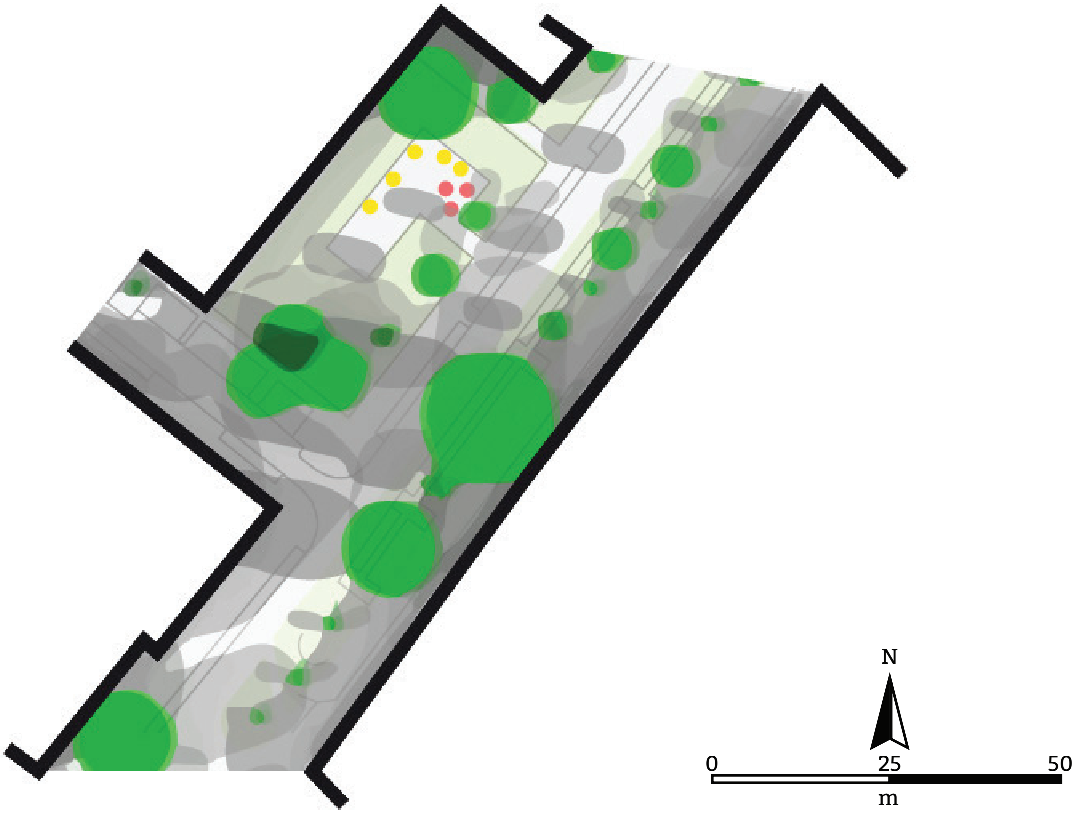


2. Putseplein

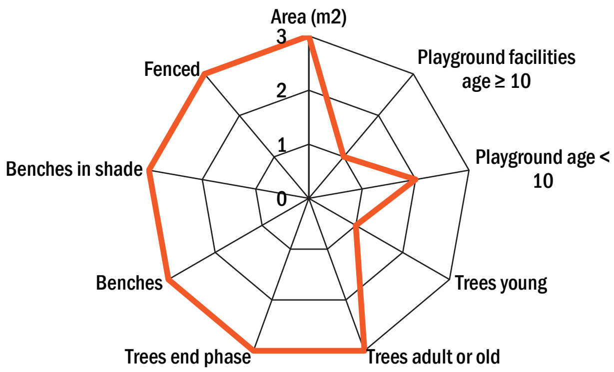


Valuation of public space

Service area public space within 240 m

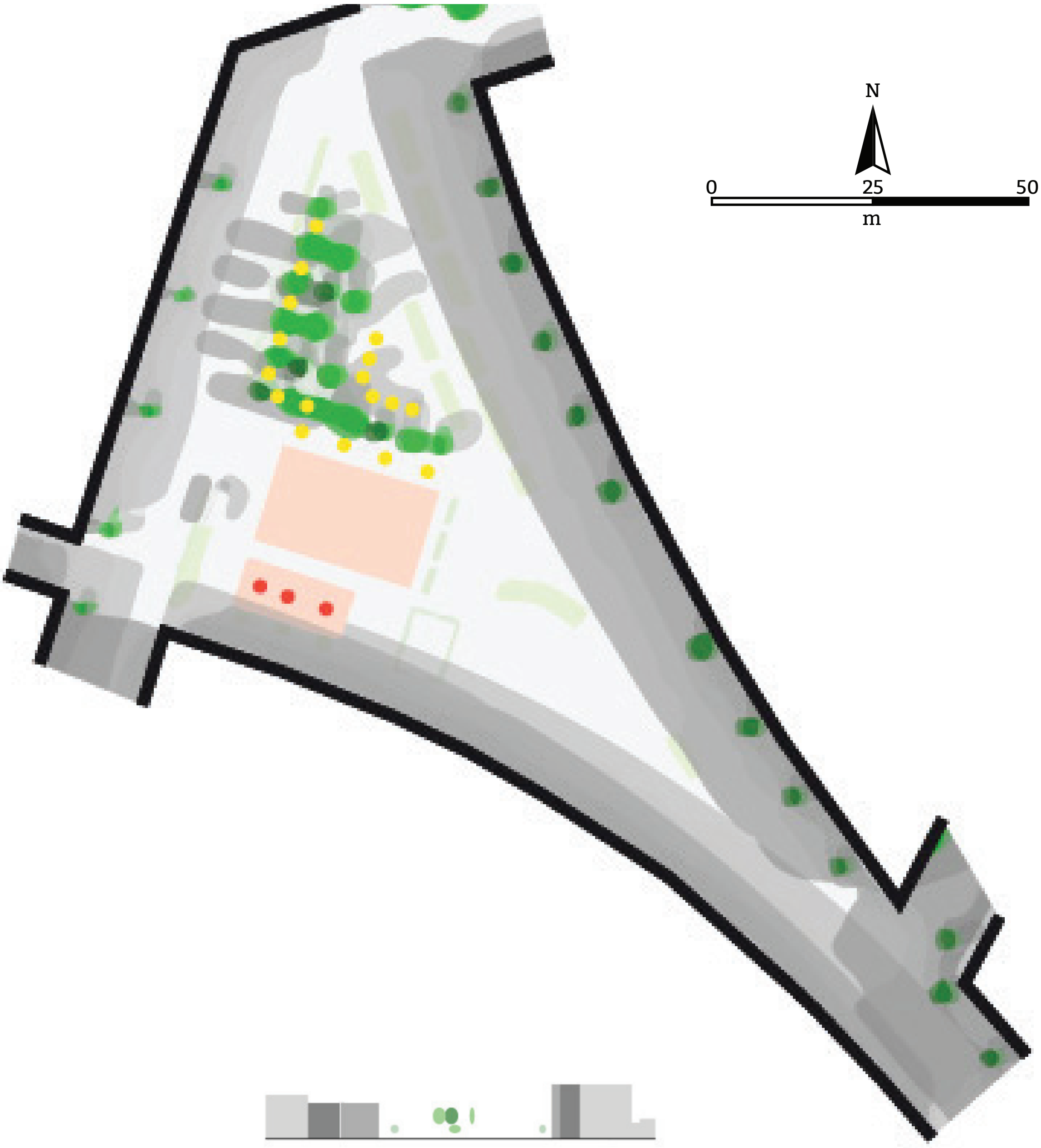


3. Orleanderplein

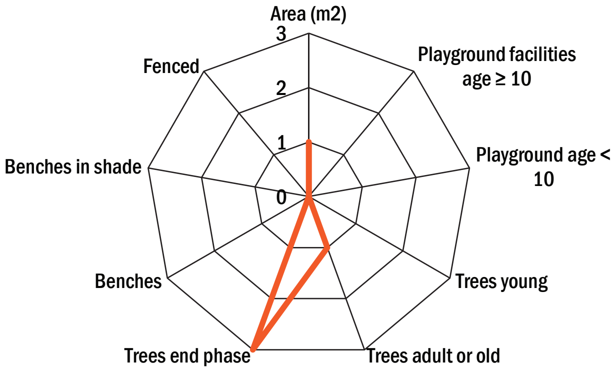


Valuation of public space

Service area public space within 240 m

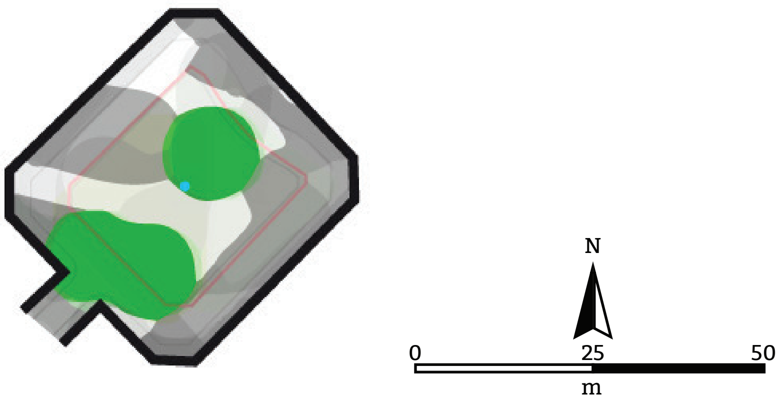


4. Patrimoniumhof

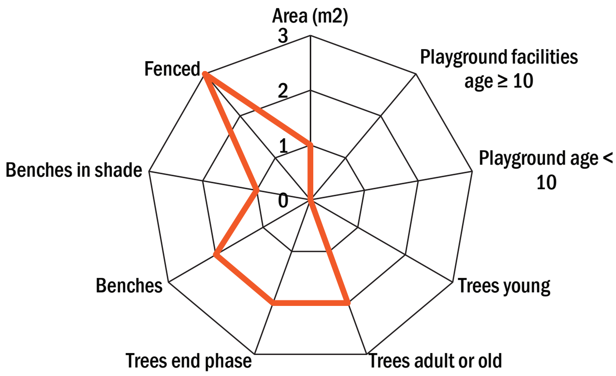


Valuation of public space

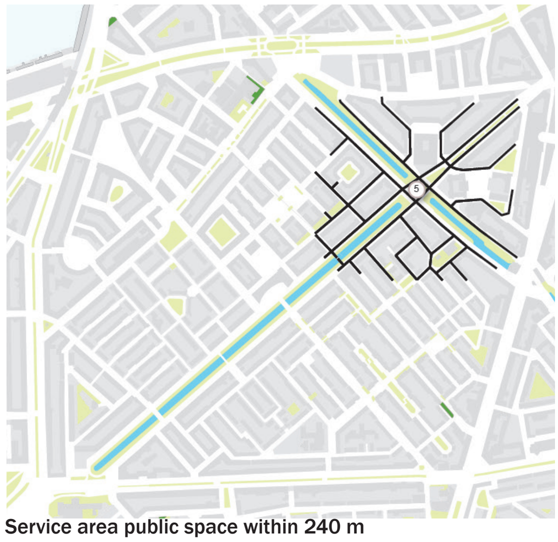
Service area public space within 240 m



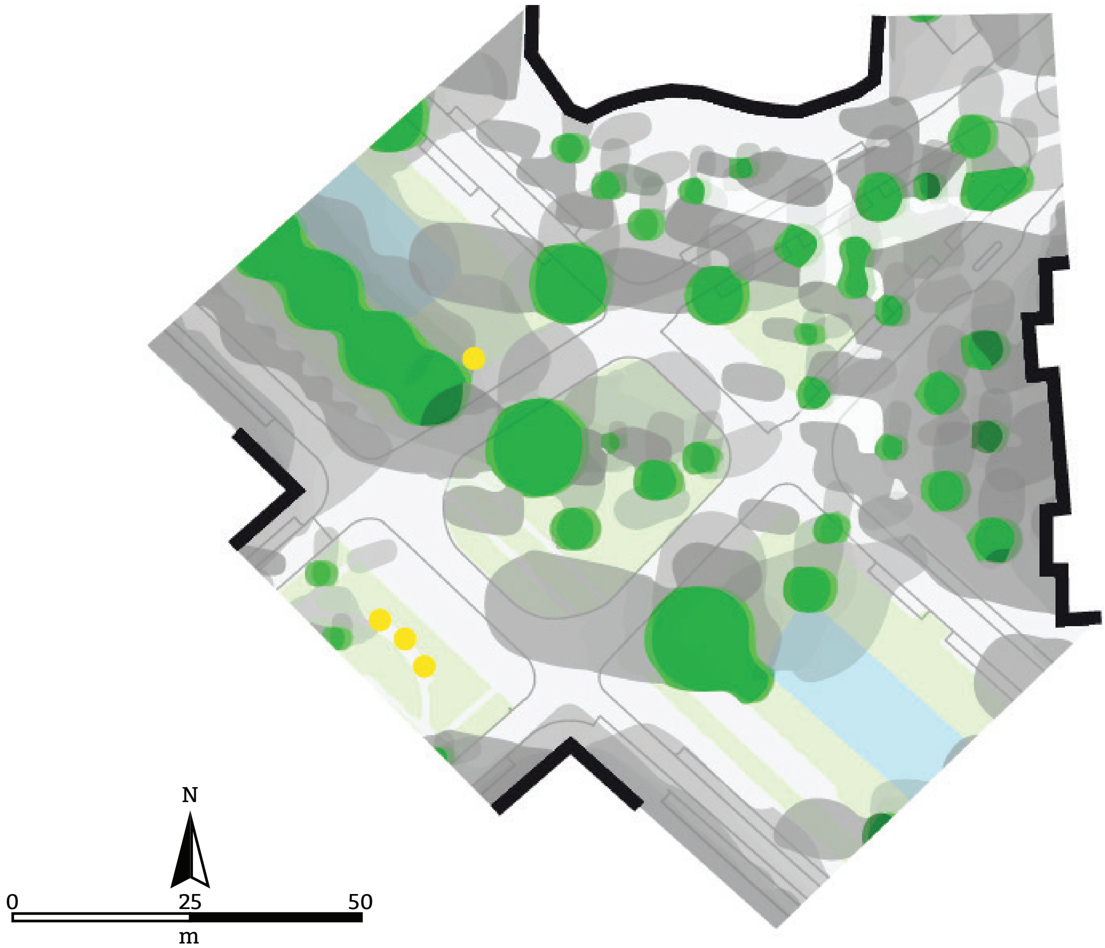
5. Hillebrug



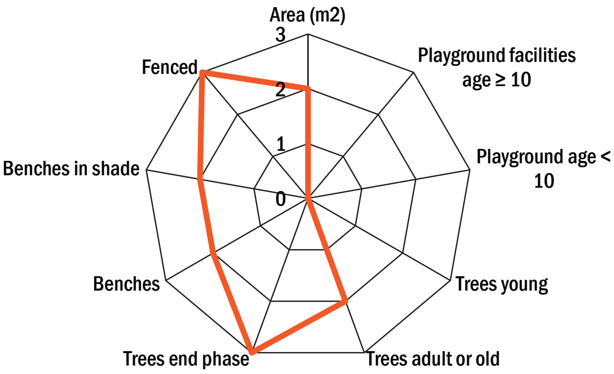
Valuation of public space



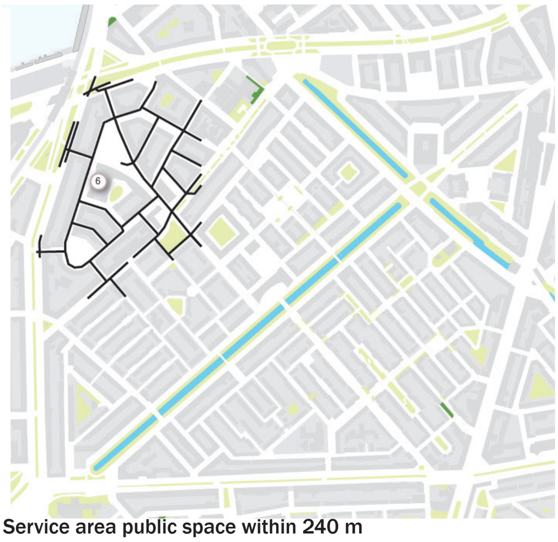
Service area public space within 240 m



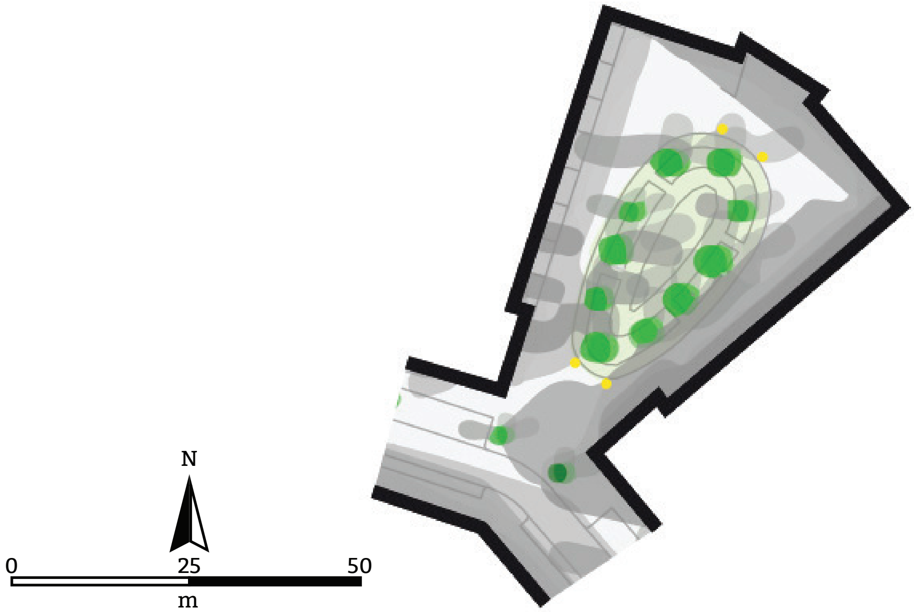
6. Salviahof



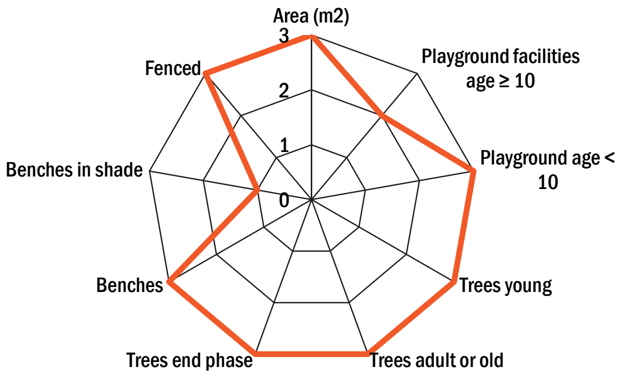
Valuation of public space



Service area public space within 240 m

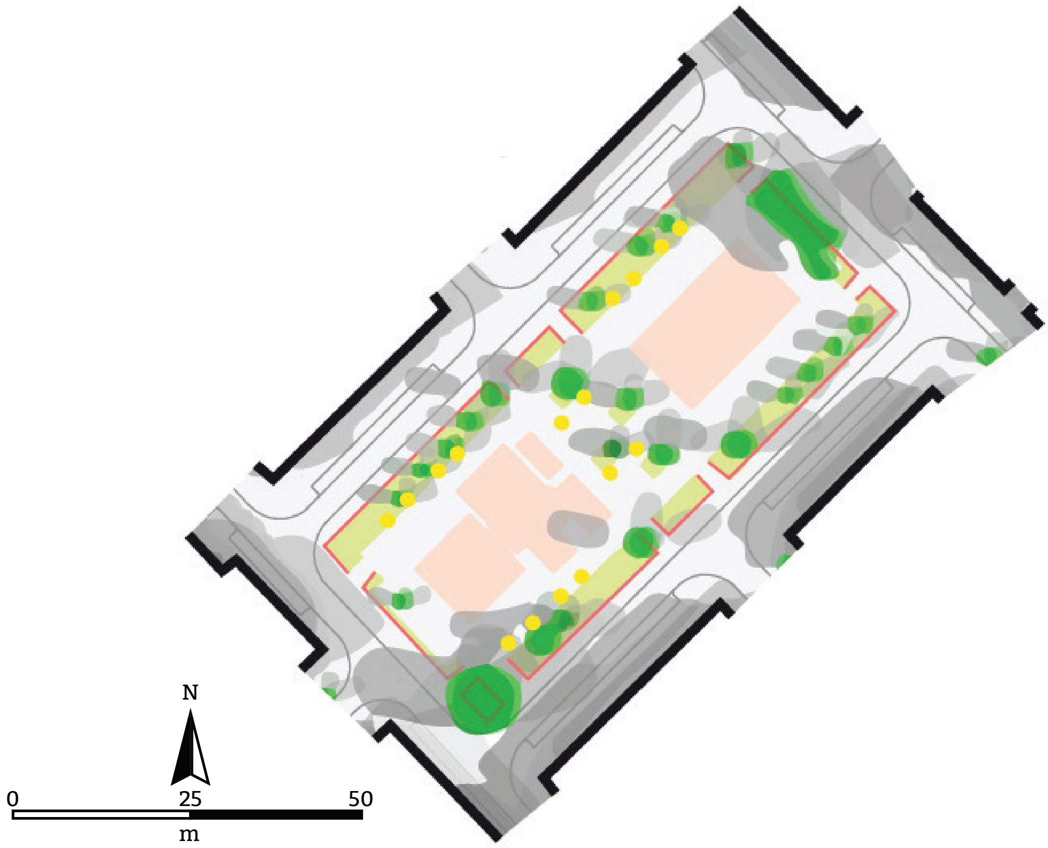


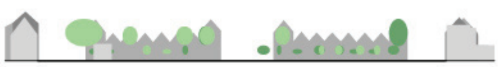
7. Bloemhofplein



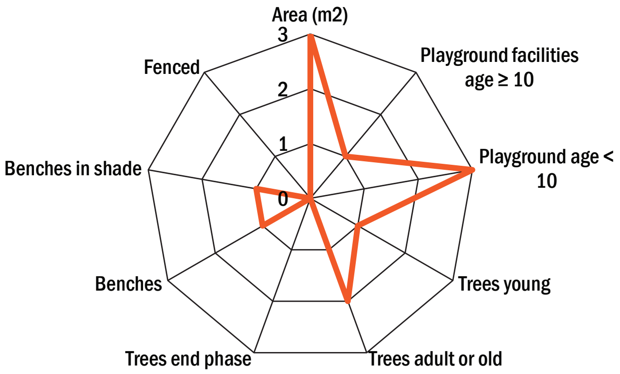
Valuation of public space

Service area public space within 240 m



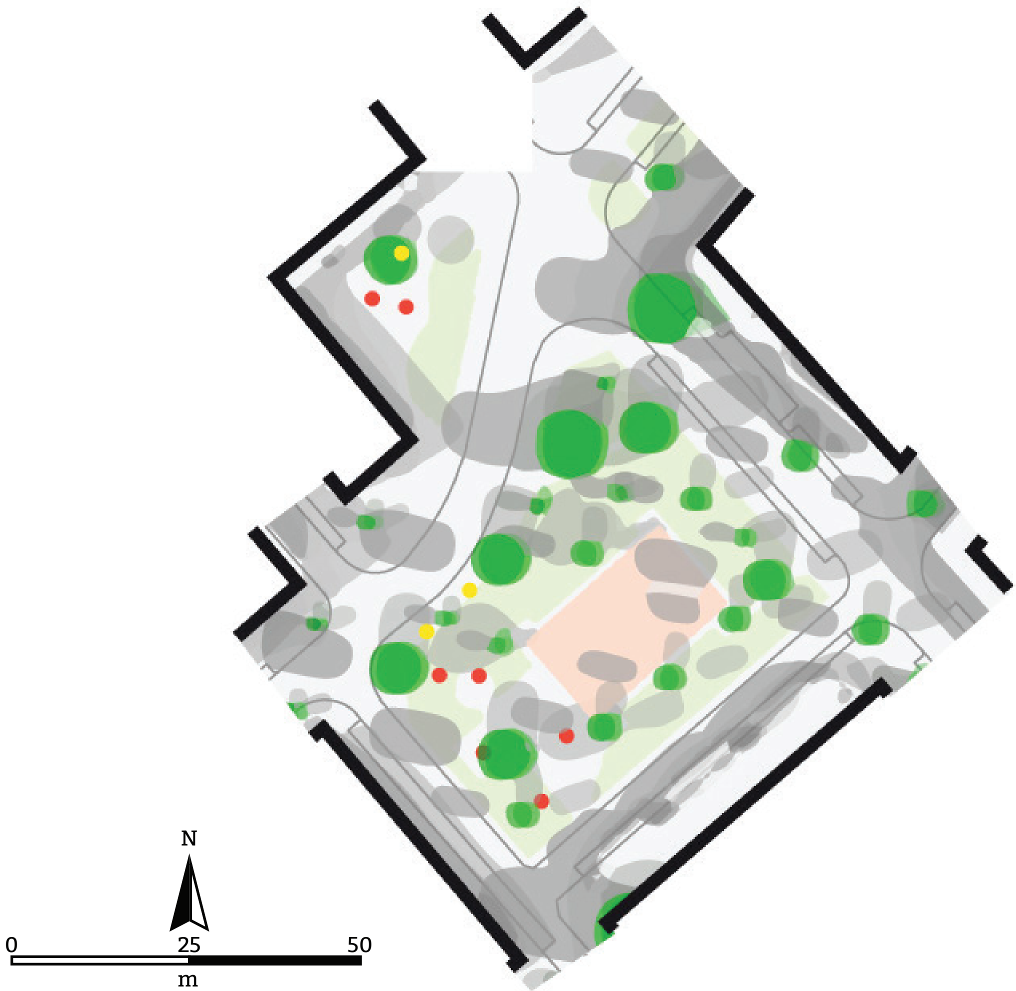


8. Putsebocht

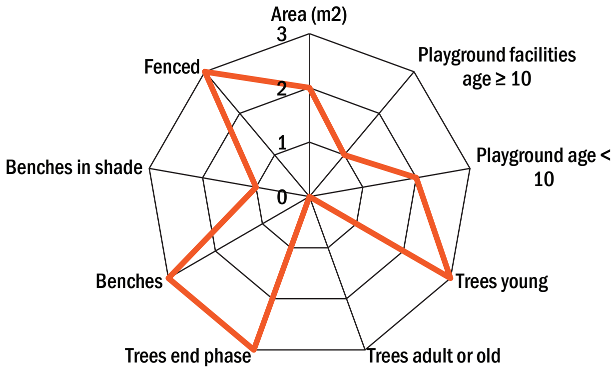


Valuation of public space

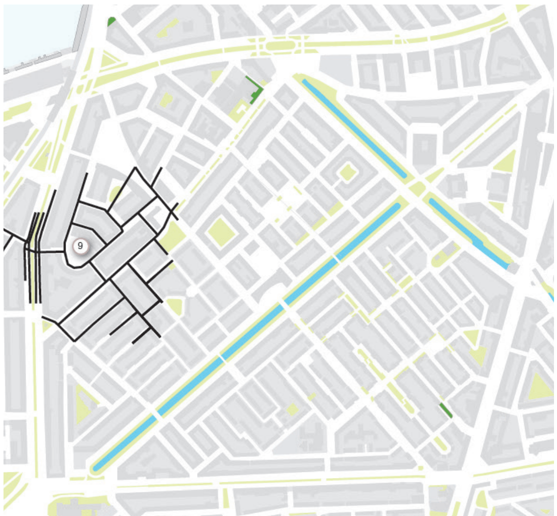
Service area public space within 240 m



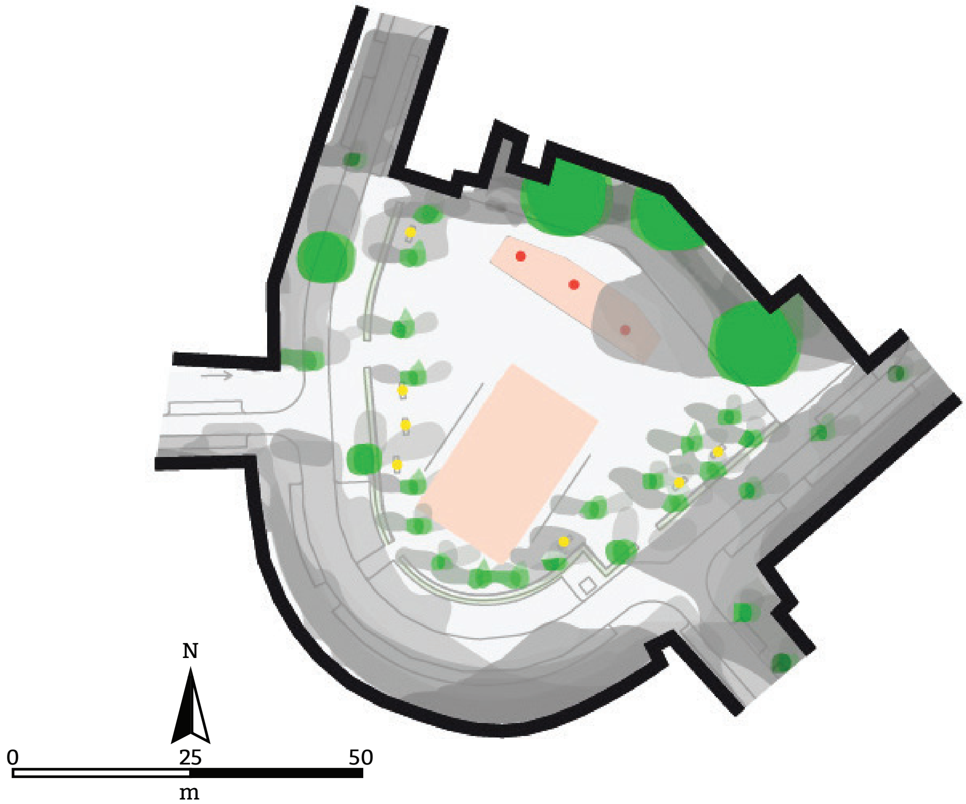
9. Ericaplein



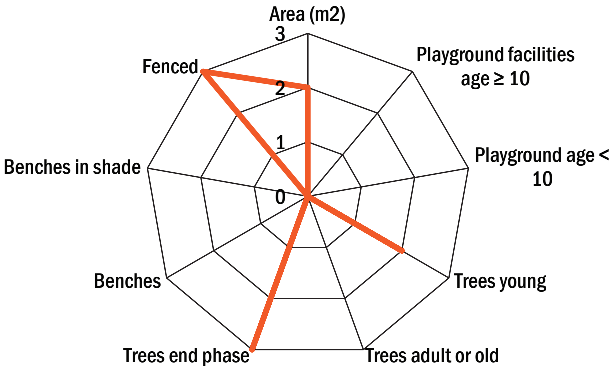
Valuation of public space



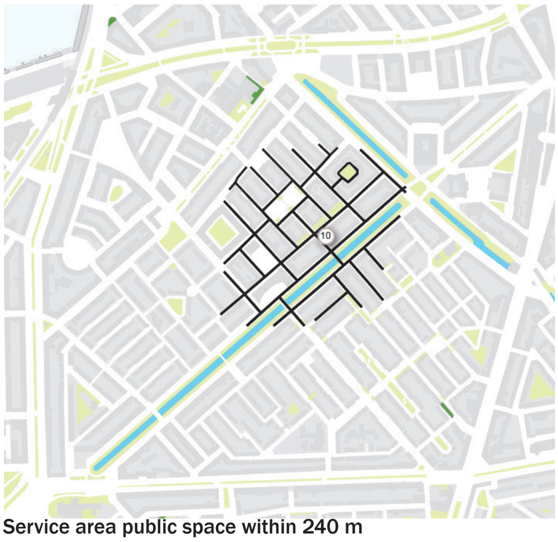
Service area public space within 240 m



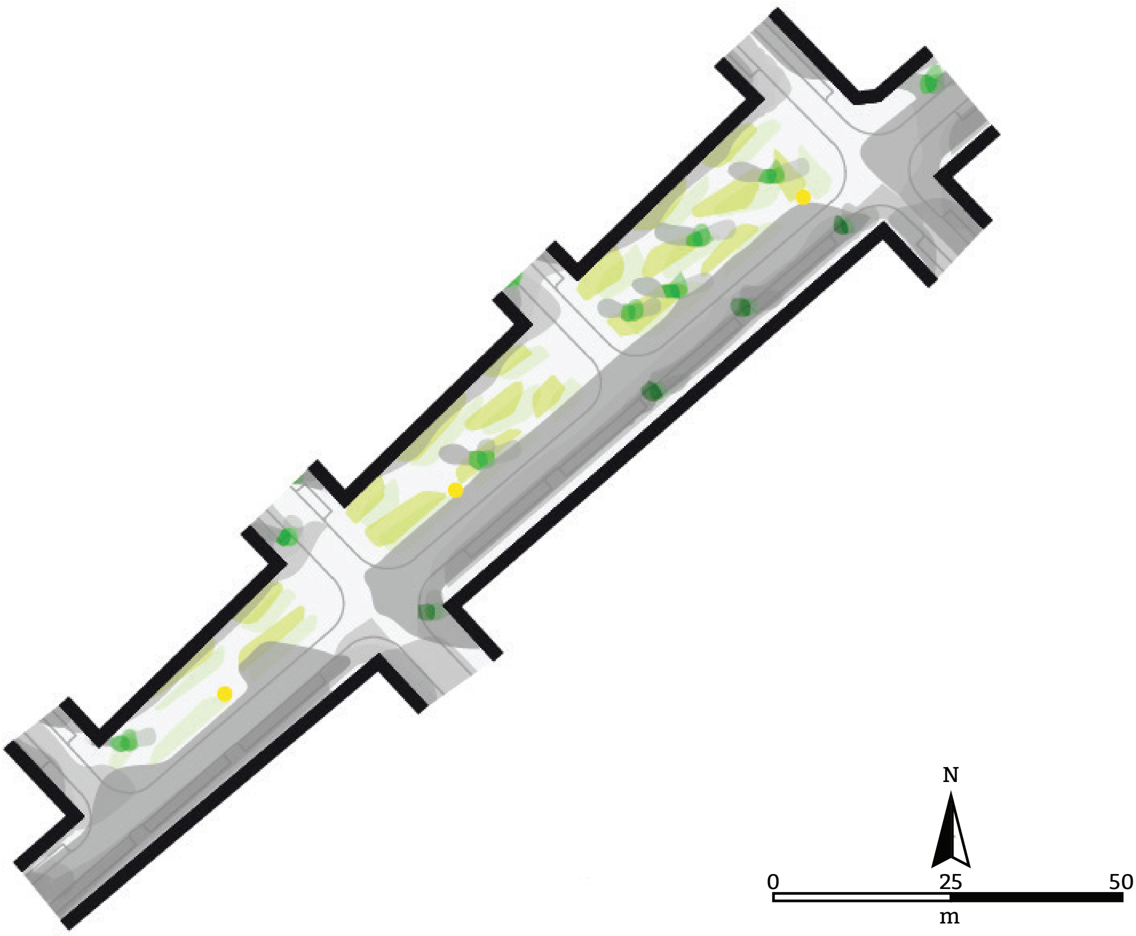
10. Dahliastraat



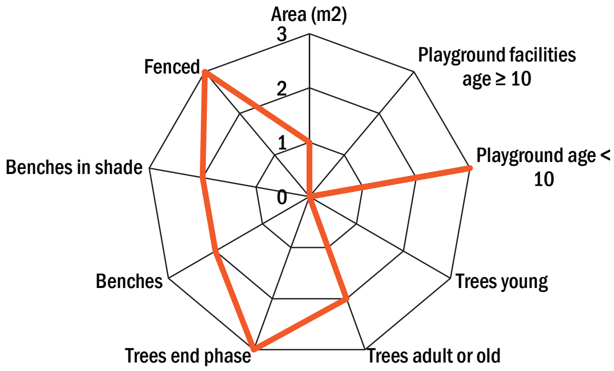
Valuation of public space



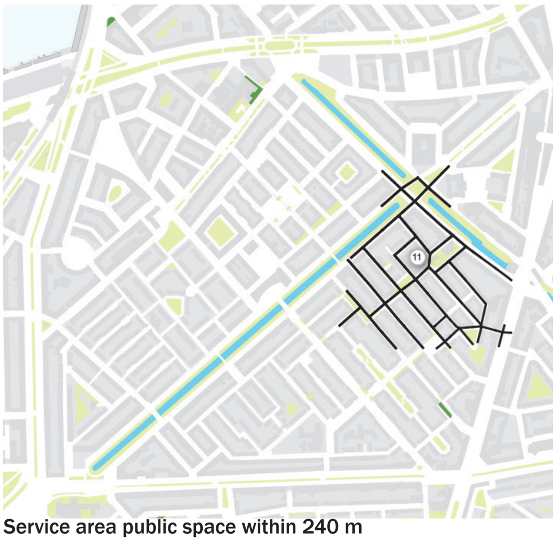
Service area public space within 240 m



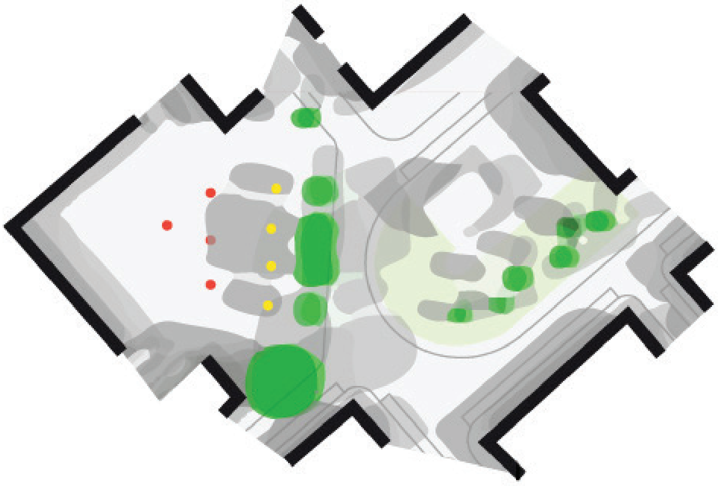
11. Eemstein

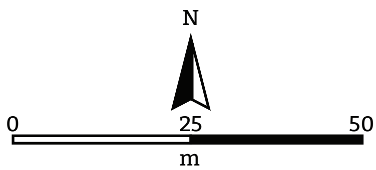


Valuation of public space

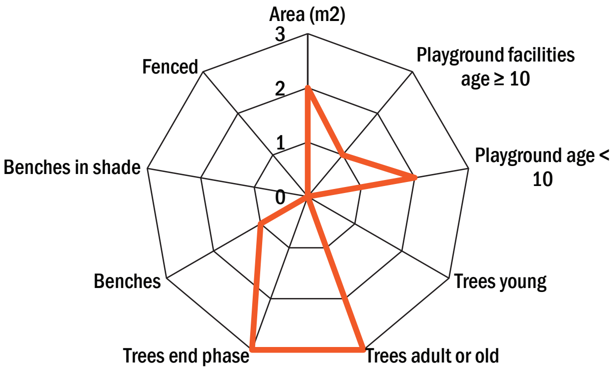


Service area public space within 240 m



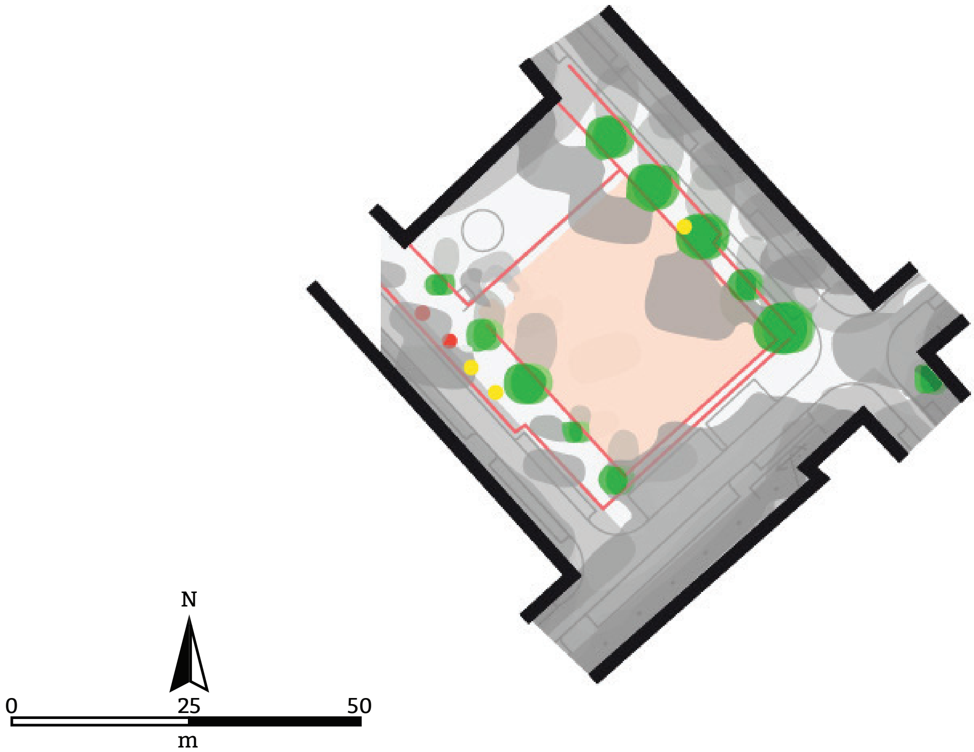


12. Rozemarijnstraat

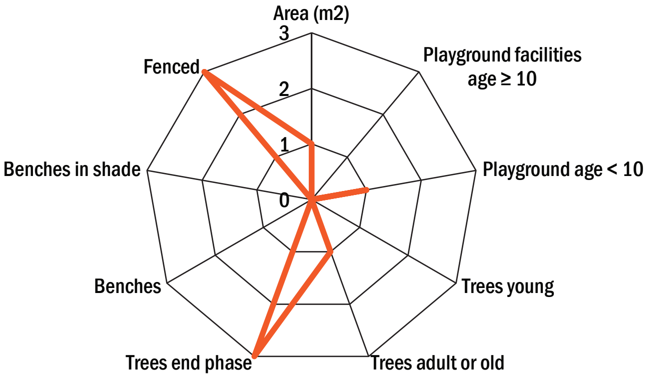


Valuation of public space

Service area public space within 240 m

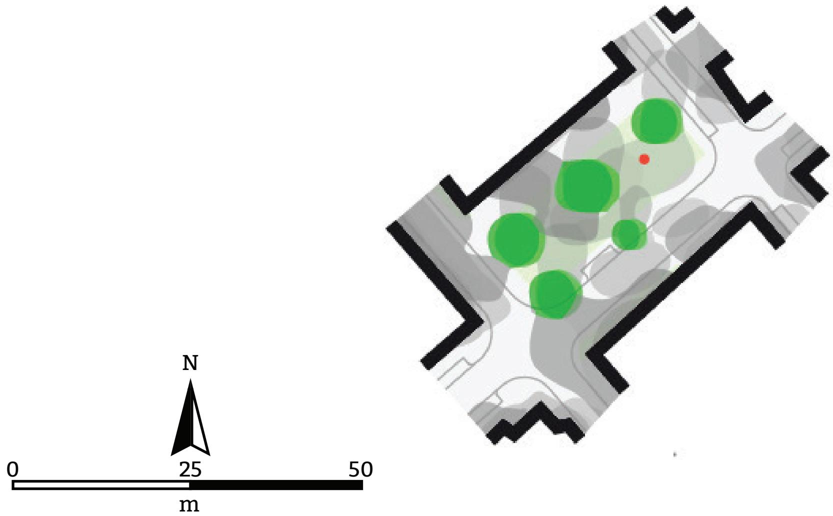


13. Groote Lindtstraat

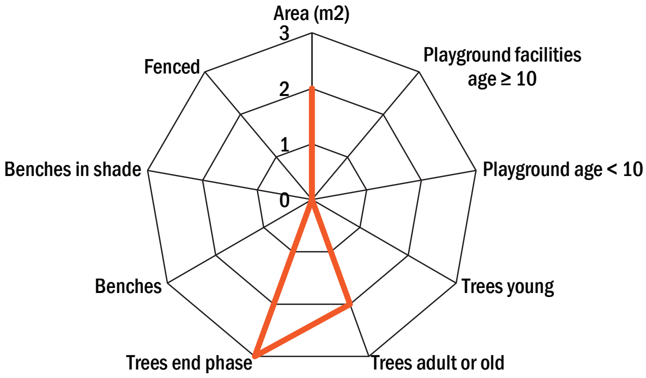


Valuation of public space

Service area public space within 240 m

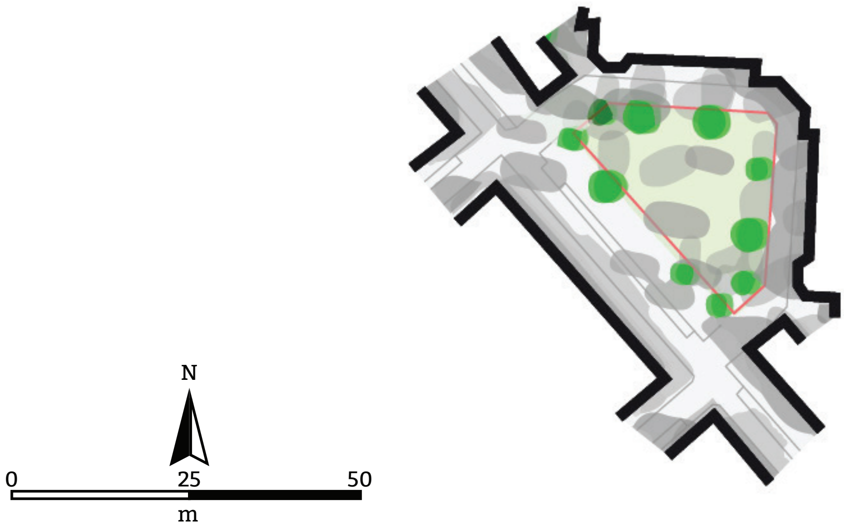


14. 2e Balsiemstraat

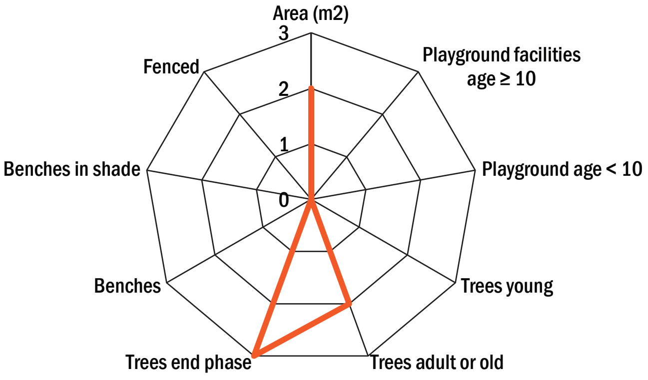


Valuation of public space

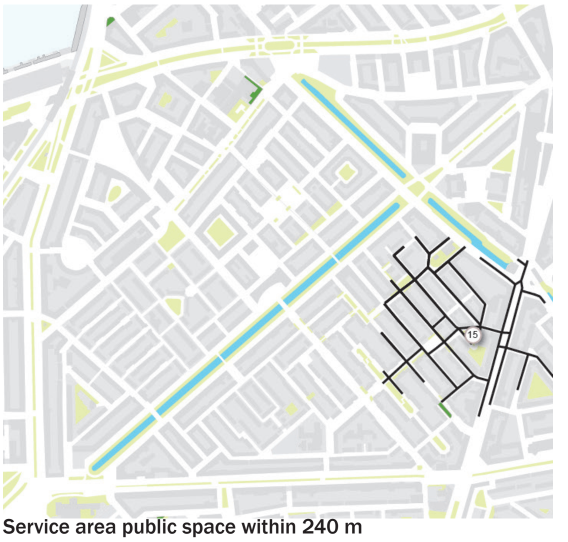
Service area public space within 240 m



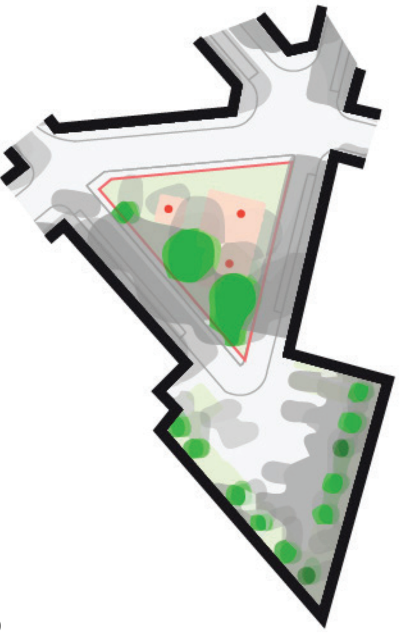
15. Hendrik Idoplein

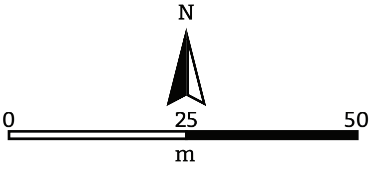


Valuation of public space

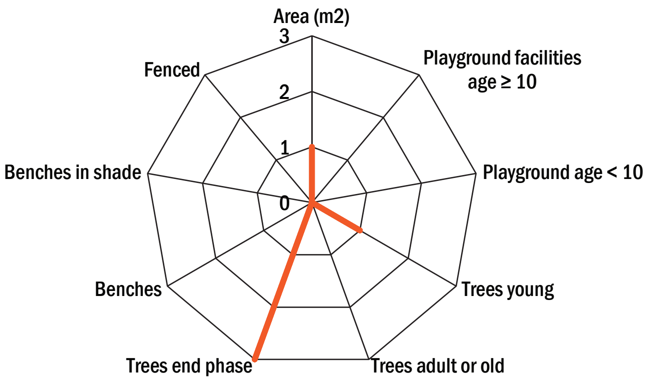


Service area public space within 240 m



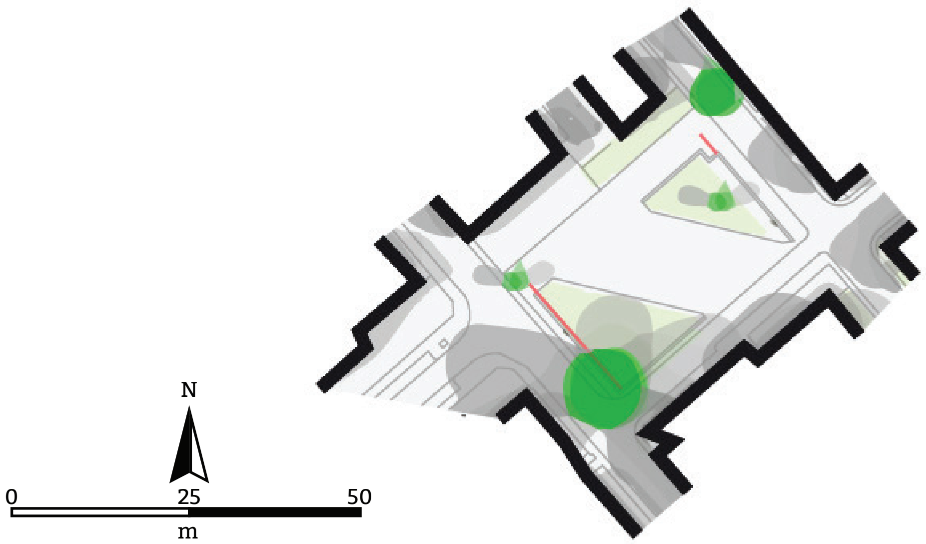


16. Zwijndrechtseplein

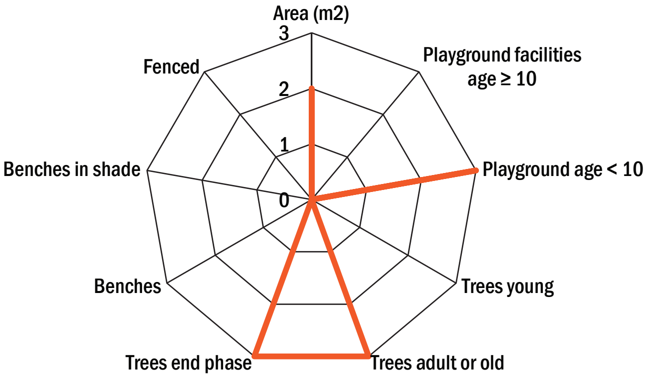


Valuation of public space

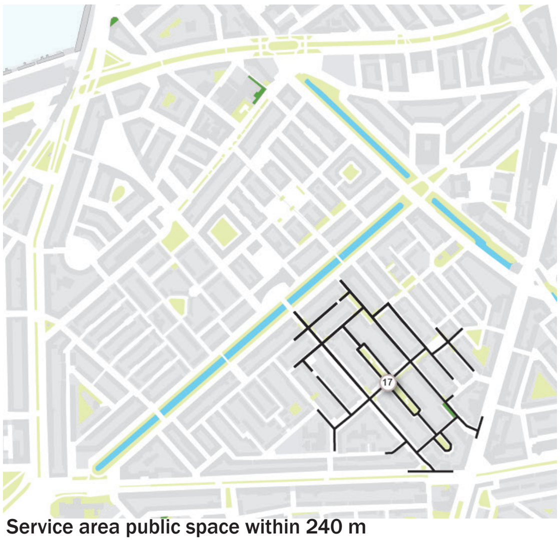
Service area public space within 240 m



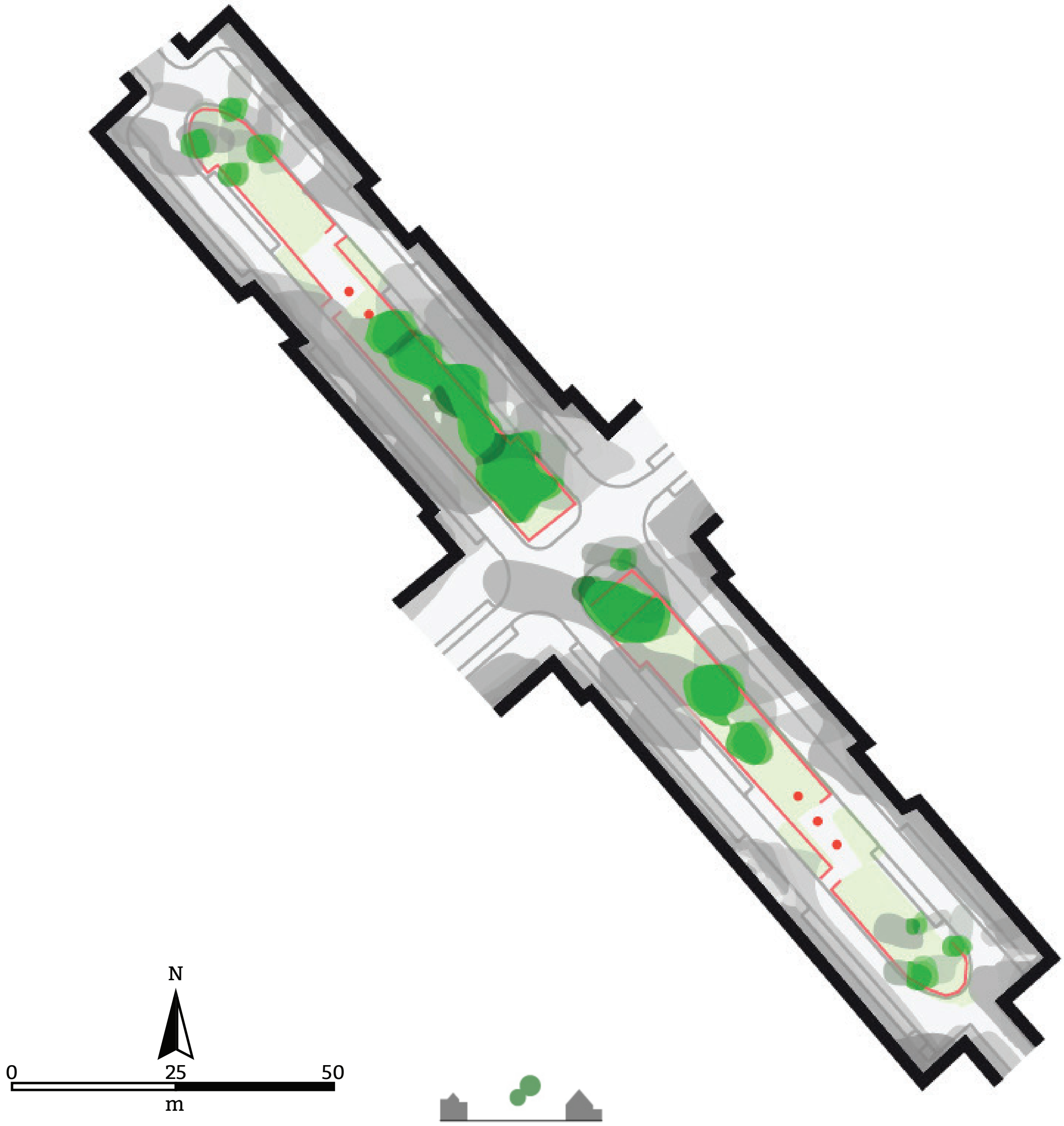
17. Heerjansweg



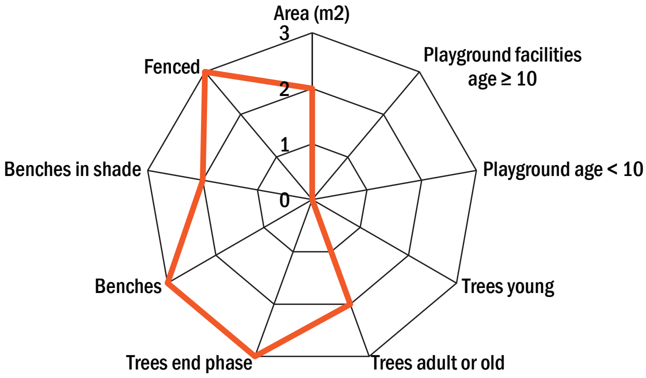
Valuation of public space



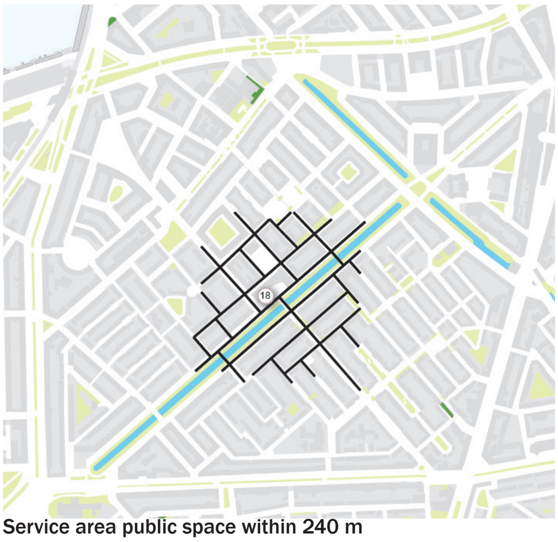
Service area public space within 240 m



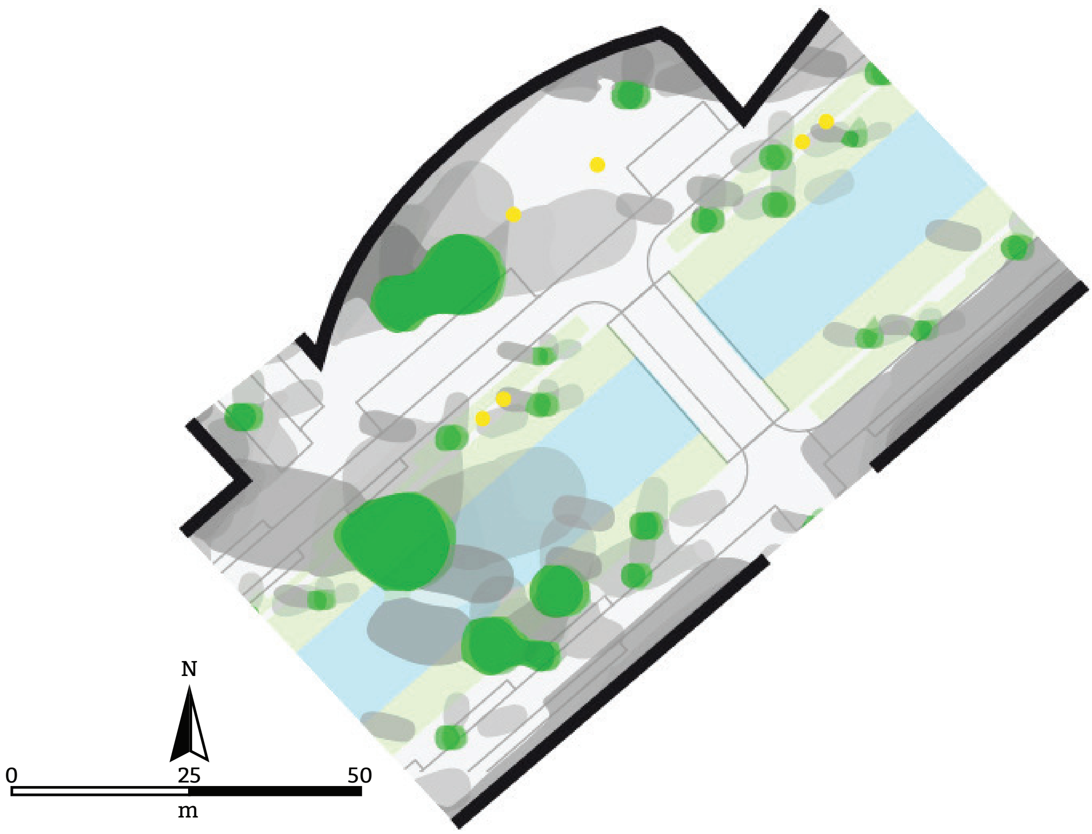
18. Lange Hille



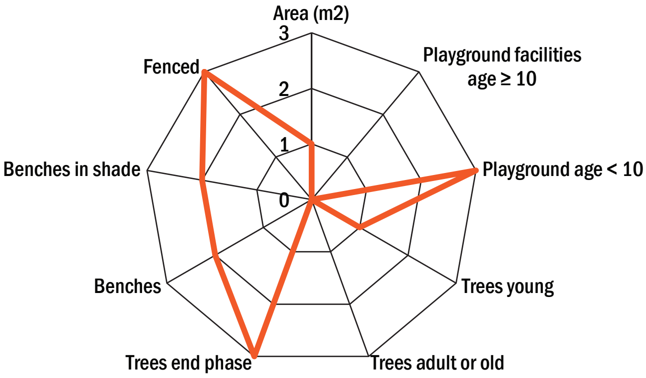
Valuation of public space



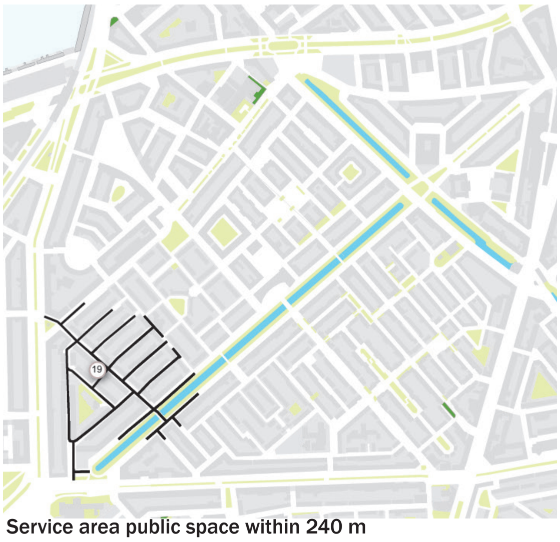
Service area public space within 240 m



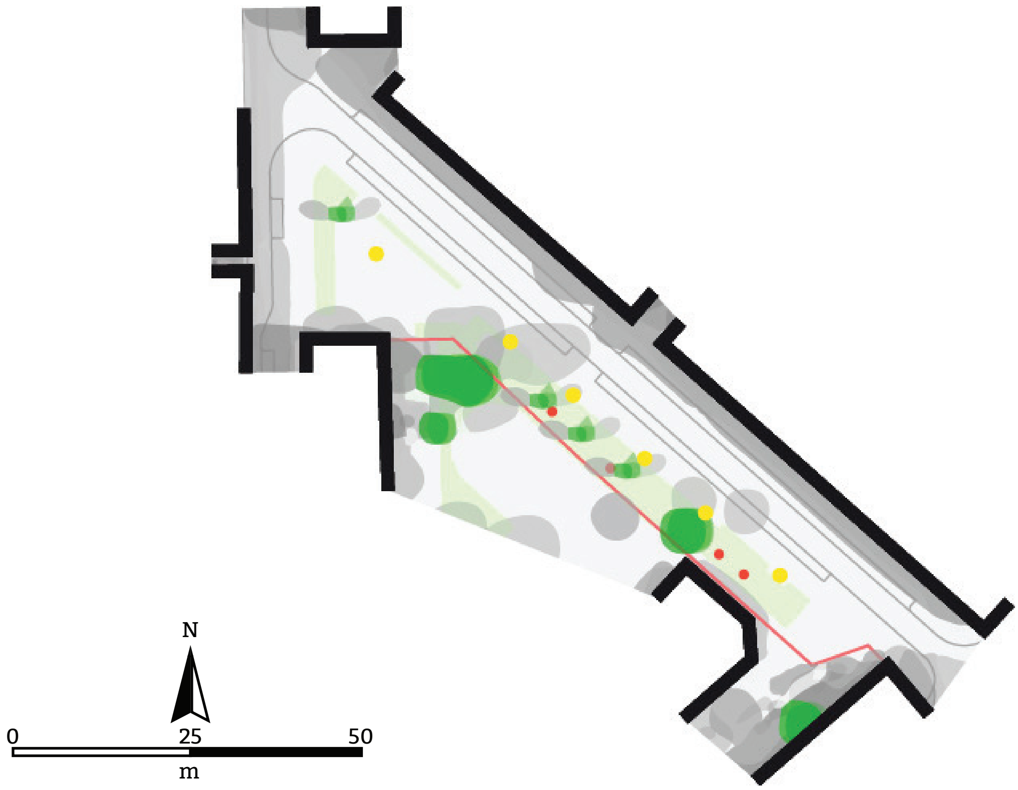
19. Fuchsiastraat



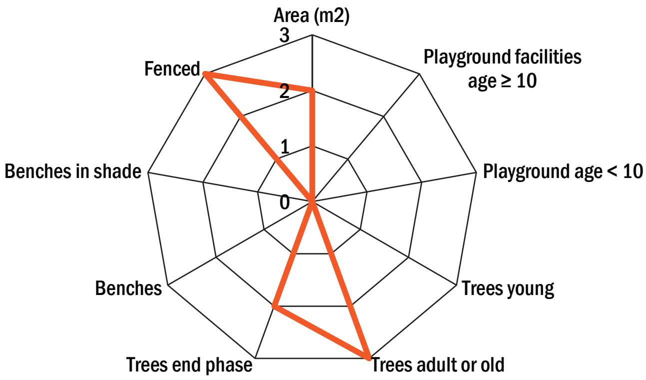
Valuation of public space



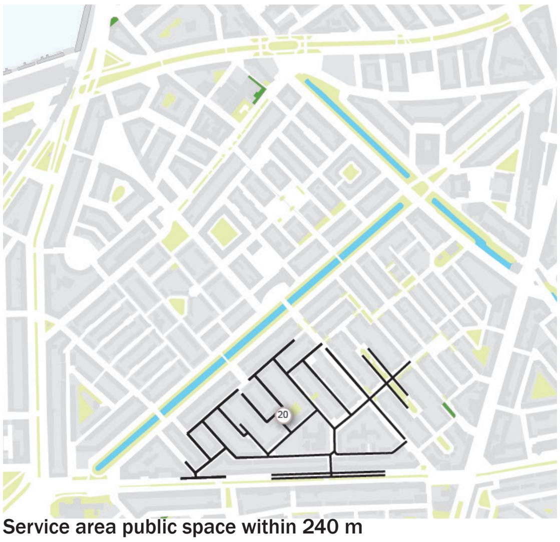
Service area public space within 240 m



20. Dubbelstraat



Valuation of public space



Service area public space within 240 m

The assessment of the public space for Bloemhof learns that the neighbourhood comprises of few public space that provide a combination of shade, vegetation, enough benches and playgrounds. Orleanderplein (3) in the northern part of Bloemhof (7) is in this regard considered as a good public space. Orleanderplein is surrounded by buildings constructed around 1996 and with the construction of an underground parking lot in 2010 the public space provide for many shade casting trees with benches underneath. The square provides for a soccer square and playground equipment. While the use of paved surfaces is quite abundant there is some smaller vegetation with a shade providing pergola stretching from one end to the other end of the square and plantation defines the borders of the square without the use of fences. The public square provides for all elements that are beneficial for residents of different ages to recreate. In terms of the urban heat island the use of many trees in combination with benches provide room to escape high air temperatures. However the use of paved impermeable surfaces is considered as to abundant.

In regard of good public spaces the public square of Bloemhofplein is considered as a second best. The public square provides for many benches, a soccer field and wide variety of playground equipment. Unfortunately the trees in the square provide for little shade as they are too young. The medium sized trees do not cast shadow over the benches as these are, in regard of shade, not well placed. In the fencing in combination with plantation fences off the square as it provides for 8 access points. Public spaces such as Putsebocht, Lange Hille or Ericaplein and to some degree Groote Lindtstraat score at sub elements but none of these score on high on broad range of the indicators.

Remarkable the southern part of Bloemhof comprises of few less public spaces whereas Heerjansweg is to some degree a good public space as it provides for some medium sized trees and playground equipment but lacks shade and is fenced off. The fewer amount of public spaces in this part of Bloemhof in relation to the predominantly presence of terraced houses with a private garden might explain this absence.

22. Conclusion

In this chapter the neighbourhood of Bloemhof is analysed on its urban characteristics of floor and ground space index, building year and building typology, sun and shade and the public spaces are assessed.

The chapter as a whole applies to the research questions of:
2 *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
4 *What urban typologies in the city of Rotterdam are more exposed to the urban heat island?*

As a whole the neighbourhood of Bloemhof comprises of few public spaces with vegetation, shade, enough benches or playgrounds. This under scribes the conclusion from part “Green structure” on page 68 and paragraph “13. Policy documents” on page 72 see table 14 on page 73. Only a few public space in northern part of Bloemhof are considered to have some quality. As such firstly is argued that there is little to no space for residents to use the public space for cooling during hot summer days. It is argued that as there is a lack of vegetation there is little evapotranspiration that would mitigate the urban heat island.

Along the borders the neighbourhood shows reasonable high density but inside the neighbourhood there are many building blocks that score low on density. Most of these building blocks are duplex or terraced building block typology and constructed between 1910 and 1930. A low density is favourable in terms of the urban heat island, as it provides for a high sky view factor and a lower ground flux with less building mass. These typologies in combination with the lack of vegetation in both the private and public space provide for little shade in both spaces. In regard to the shade map of the Hotterdam publication such notion is under scribe as this map shows for the inner part of Bloemhof short hours of shade per hectare. Due to the north-east to south-west orientation of the terraced building blocks which, according to Taleghani, is the least favourable for the micro-climate inside of two opposing blocks. It is argued that these suffer the most from high land surface temperatures as they are under constant radiation by the sun.

When looked at terraced building blocks that are orientated from north-west to south-east such conclusion is somewhat nuanced since during midday to sunset the south-western part of a building block provides for shade in the private space. Nonetheless in regard to the research question 4 it is argued that the typology of terraced houses with a low FSI, considered according to Berghauser Pont and Haupt as low rise block type. The orientation from either north-east to south-west or north-west to south-east are the most exposed to the high land surface temperatures.

Based upon the assessment of both the public space and the urban form it is concluded that Bloemhof has little to no possibilities for a large part of the residents to shelter from high air temperature during hot summer days in both the public nor the private space.

Assessment of three building typologies

23. Introduction

In this chapter an assessment is given of the three building typologies of low rise terraced houses, three floors apartment block and a closed building block as these are the predominate typology in the neighbourhoods of Afrikaanderwijk, Hillesluis, Bloemhof and Tarwewijk. The aim is to gain an understanding how each of these three building blocks preform in relation to the urban heat island and what lesson can be derived. The chapter will first describe the different types of data that is used, the three assessed building typologies are presented and concluded is what lesson can be learned for the urban design proposals.

This chapter refers to the research questions:

3. What urban typologies in the city of Rotterdam are more exposed to the urban heat island?

In paragraph "9. Conclusion" on page 61 there was the notion that from the statistical analyses there was no clear answer to this research question as the indicators from the used dataset were, in regard to this research question, not usable. Therefore new indicators are used to assess the building block typologies:

The building blocks are assessed based on four indicators:

1. **Based upon the 3D data provided by the municipality of Rotterdam, GBKN of city district Feijenoord and Bing maps urban characteristics as paved surfaces, impervious surfaces, grass fields amount of green (trees), objects in public space, building configuration.**
2. **With the 3d model sun and shading for the time 9:00, 13:00 and 16:00 during summer equinox are shown in combination with the inner door temperatures model of Iris Theunisse.**
3. **The building block is assessed on urban fabric from according to the dissertation of dr. Mohammad Taleghani.**
4. **The location of the building block in relation to ground flux, sensible heat, sky view factor and latent heat.**

24. Used data

24.1 Dwelling on Courtyards

Dr. Mohammad Taleghani formed his dissertation ‘Dwelling on Courtyards: Exploring the energy efficiency and comfort potential of courtyards for dwellings in the Netherlands’ on the urban heat island phenomenon and the dependency of buildings on fossil fuels. Taleghani studied low-rise residential courtyard buildings among different urban block types in the Netherlands. The three urban forms singular, linear and courtyard with north south and east west orientation are studied with ENVI-met on their micro-climatic performance during a hot day of 19th June 2000 with a maximum air temperature of 33 °C. In the graph the temperature progression of five models is shown; one courtyard, two linear and two singular models in combination with psychological equivalent temperature (PET) range. Taleghani concludes that the urban form courtyard preformed best with the most protected micro-climate, less solar radiation during summer and lowest air temperature. Singular shape preforms worst and then linear form with W-W orientation. In figure 36 on page 124 these urban forms and there performance are presented.

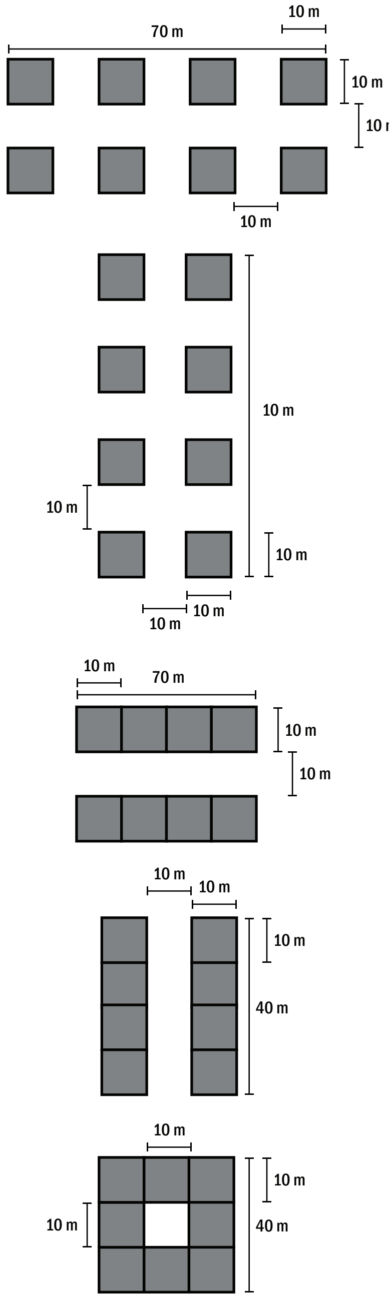
In further study the courtyard urban form is more extensively researched. Different ratio of urban form of length and width and orientation are modelled in ENVI-met and tested. Taleghani concludes that N-S oriented courtyard provide the shortest period of sun in the centre of the courtyard. E-W direction provides a long duration of direct sun. NW-SE oriented received sun mostly in the morning and NE-SW oriented courtyard in the afternoon. In figure 37 on page 125 the graph describdes the temperature progression at the centre point during the day per courtyard building block.

Furthermore Taleghani modelled with ENVI-met the performance of three different mitigations strategies. He concludes that both green and water areas inside a courtyard are most effective as a heat mitigation strategy. He rightfully notes that reducing the albedo of façades would reduce indoor temperature. With this last remark he touches upon the boundary of his research. He is primarily focused of micro climate performance within the center point of a courtyard and not with the inner door temperature. However his findings can be used in considering orientation and urban form if one wants to provide micro climate comfort outside a residents direct surrounding.

The three building typology are assessed according to Taleghani research on urban fabric form. As Taleghani notes that his research did not focus on the inner door temperature. In ir. Iris Theunisse Master Thesis research is done on modelling inner door temperatures by ir. Iris Theunisse and is therefor used.

24.2 The visualisation of urban heat island indoor temperatures

The Master Thesis of ir. Iris Theunisse starting point is that urban heat island effect assessment is currently predominantly done by remote sensing. This does not allow for understanding indoor temperatures in relation to the urban heat island effect. Based upon data from approximately 1300 temperature sensors ir. Theunnisse has created a model that estimates indoor temperatures for the city of Rotterdam. The output of her research is a 3d model that functions as a tool for urban planners and designers to help them understand local differences in the urban temperature. The model will be used for each of the thee building typologies.



24.3 Hotterdam

The publication Hotterdam by dr. ir. Frank van der Hoeven and dipl. ing. Alexander Wandl aims to get a better understanding of urban heat. As it uses Rotterdam as a study area it concludes that the pre-war neighbourhoods (North, West and South) are warmer and more vulnerable than other parts of the city. Part of this publication is the presentation of heat maps that show the distribution of urban heat related topics of, ground flux, sky view factor and latent and sensible heat on 100 m by 100 m grid. These map are used to depict how each of the three urban typology are exposed to each of these topics. Each typology is assessed on whether it is for example in area with a high ground flux compared to the rest of the neighbourhood.

This chapter continues with the assessment of three building typologies.

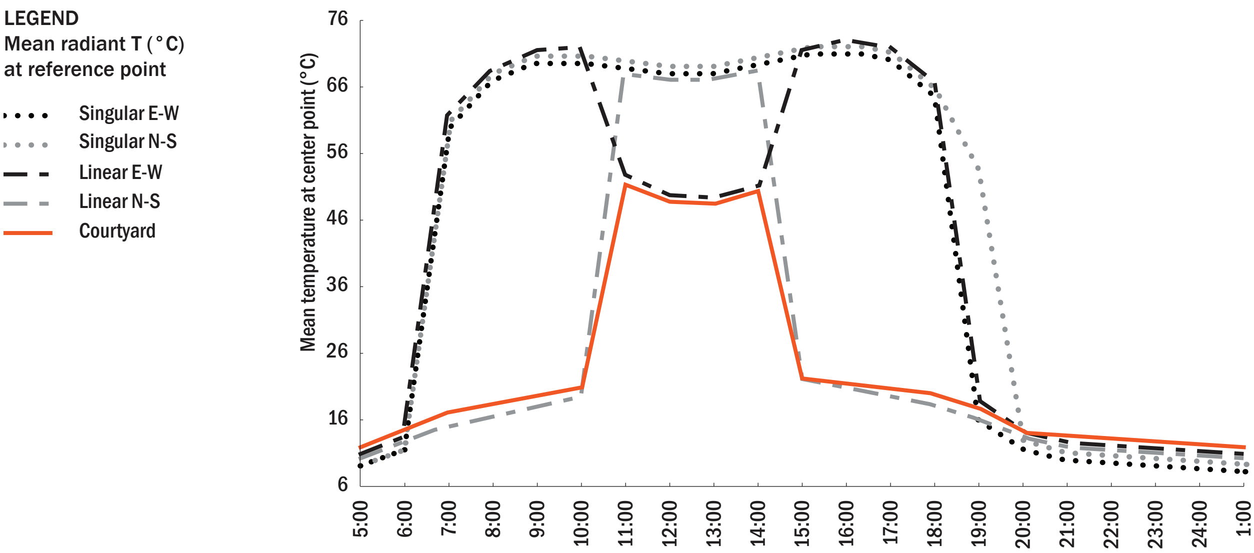


figure 38. The 5 studied urban fabric forms and how they preform on mean radiant temperatures at the reference point during a day. Notice how the courtyard urban fabric forms holds the lowest radiant temperature at the reference point during the whole day (Taleghani, 2014, pp. 220, 234).

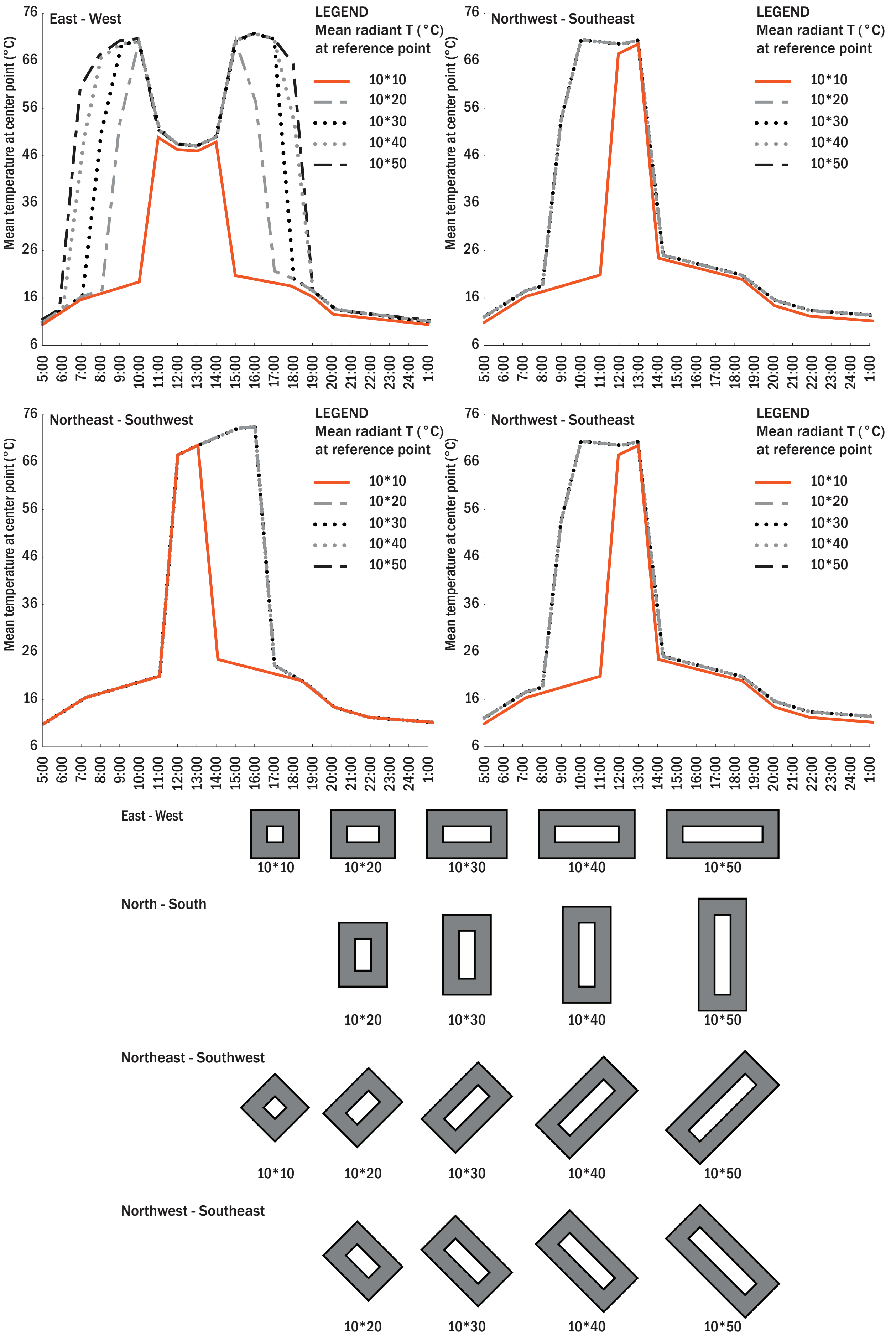


figure 39. An overview of the basic models of courtyard urban forms with different orientations. The graphs correspond with these models depicting different mean radiant temperatures over the course of the day. (Taleghani, 2014, p. 253 & 268)

25. Assessment of three building typologies

25.1 Patrimoniumhof

The building block Patrimoniumhof is constructed in 1915 and has a courtyard with a closed square urban form with houses on the in- and outside. Inside there is a square with a fountain acting as a small park. The space between the houses consists of some green but also shows areas with only paved surfaces. The square urban form of the courtyard is according to Taleghani optimal and in relation to the inner door temperature model shows few houses that score high on temperature. As the building block is quite dense the building block scores quite high on floor space index of 1,1 as is described in “18. Floor and ground space index” on page 88. In terms of ground flux Patrimoniumhof is an area that scores high which suggests higher nocturnal air temperatures, however this is the case for Bloemhof as a whole. In terms of latent heat Patrimoniumhof is in an area where more latent heat is available for evapotranspiration in comparison to the rest of the neighbourhood. The sky view factor the courtyard block is in is part the lowest as it indicates more exposure to the sky which is beneficial for nocturnal cooling. Also in terms of sensible heat Patrimoniumhof is in a cooler area.

In the conclusion the outcome of the assessment for Patrimoniumhof will be compared to the two other typologies.

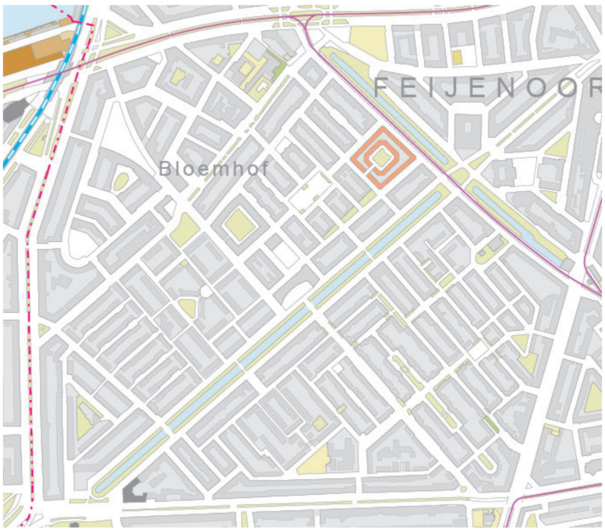


figure 40.a. Location of Patrimoniumhof.

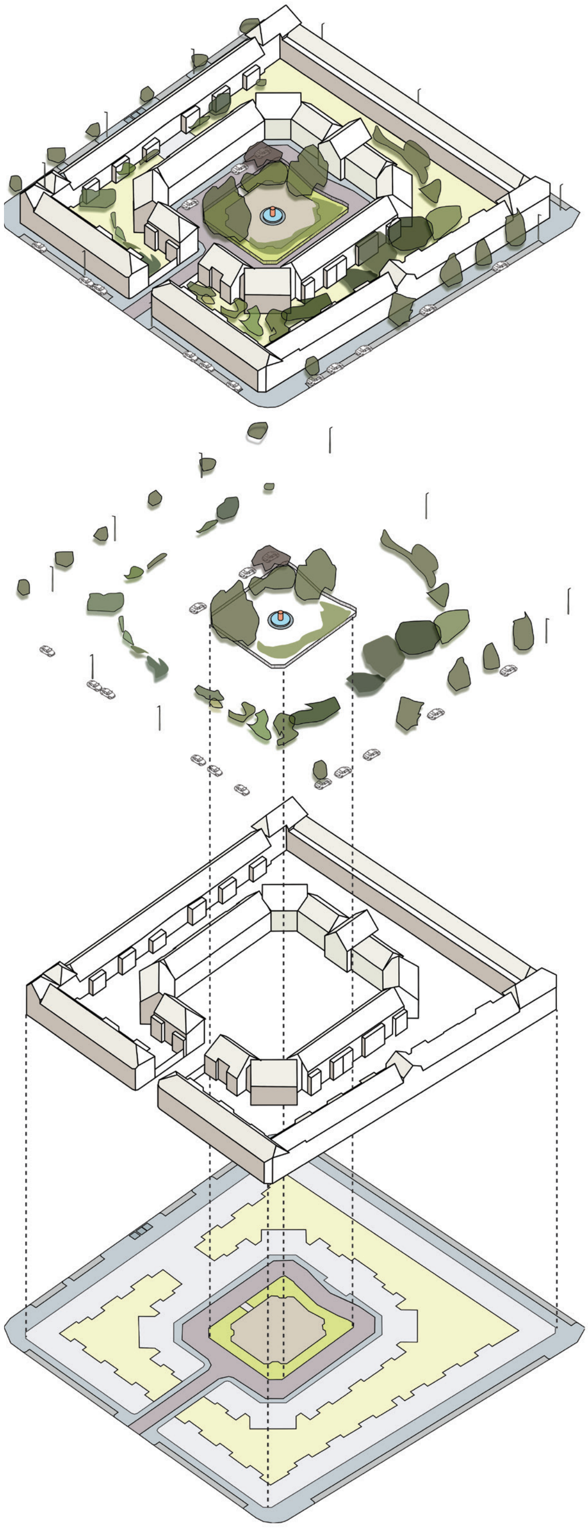


figure 40.b. Exploded view of building block Patrimoniumhof.

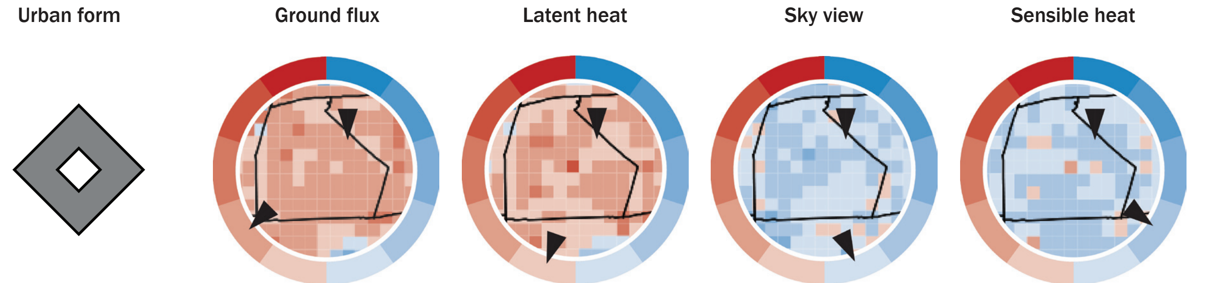
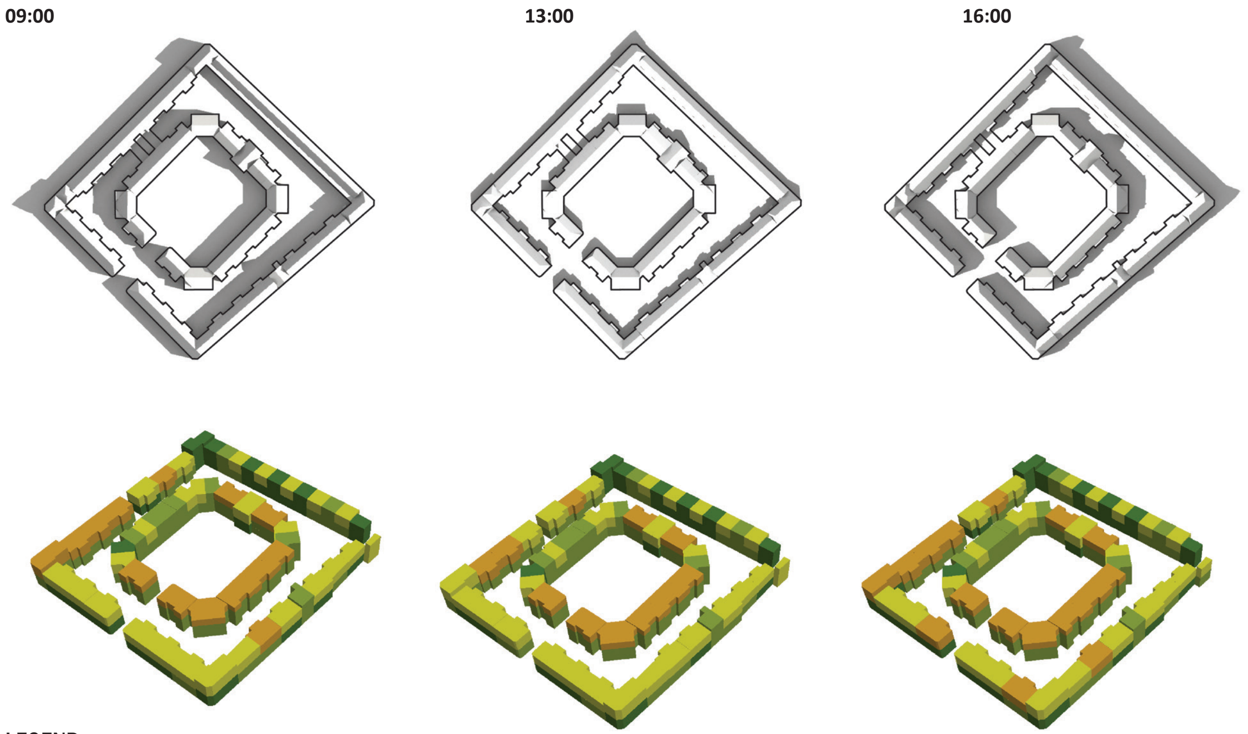


figure 41.a. The assessment of the building block Patrimoniumhof and how it compares to the urban form study done by Taleghani. The assessment of the location of Patrimoniumhof in regard to the Rotterdam study results of ground flux, latent heat, sky view and sensible heat.



LEGEND
Inner door temperature in (°C)

- 22,00 - 24,13
- 24,14 - 24,59
- 24,60 - 24,82
- 24,83 - 25,09
- 24,10 - 25,47
- 25,48 - 25,96
- 25,97 - 28,00

figure 41.b. Sunstudy of Patrimoniumhof and inner door temperature based upon model by ir. I. Theunisse.

25.2 Rendierstraat courtyard block

Rendierstraat block is constructed in 1924 and situated in the neighbourhood of Hillesluis. The building is 3 stories high and has a long stretch courtyard urban form oriented north to south similar to the 50*10 NS block in Figure. On the inner courtyard there are private gardens for residents on the ground floor and only accessible from the inside. These gardens consist of some green in the form of small trees but are mainly made up of paved surfaces. The urban form of a long stretch courtyard with a north to south orientation provides for shade during the morning and the end of the afternoon but does not provide shade during 11:00 till 14:00 midday according to Taleghani. Such notion would be under scribed by the sun study. The model by Theunisse show notable diference between the top floor, which is warmer than the other floors. Arguably these top floors are warmer as they have a flat roofs radiated by the sun throughout the day. In terms of density Rendierstraat block scores 0,88 on floor space index as it the building block only has three floors. In terms of ground flux Rendierstraat is in an area that scores high, which suggests high nocturnal air temperatures, however there are some areas in Hillesluis that have a higher ground flux. In terms of latent heat Rendierstraat is in an area with, in regard to its surrounding, little energy for evapotranspiration. The sky view factor in regard to the surrounding areas of the neighbourhood Hillesluis is somewhat higher which is beneficial for nocturnal cooling. In terms of sensible heat Rendierstraat is in an cooler area.

In the conclusion the outcome of the assessment for Rendierstraat will be compared to the two other typologies.

figure 42.a. Location of Rendierstraat.

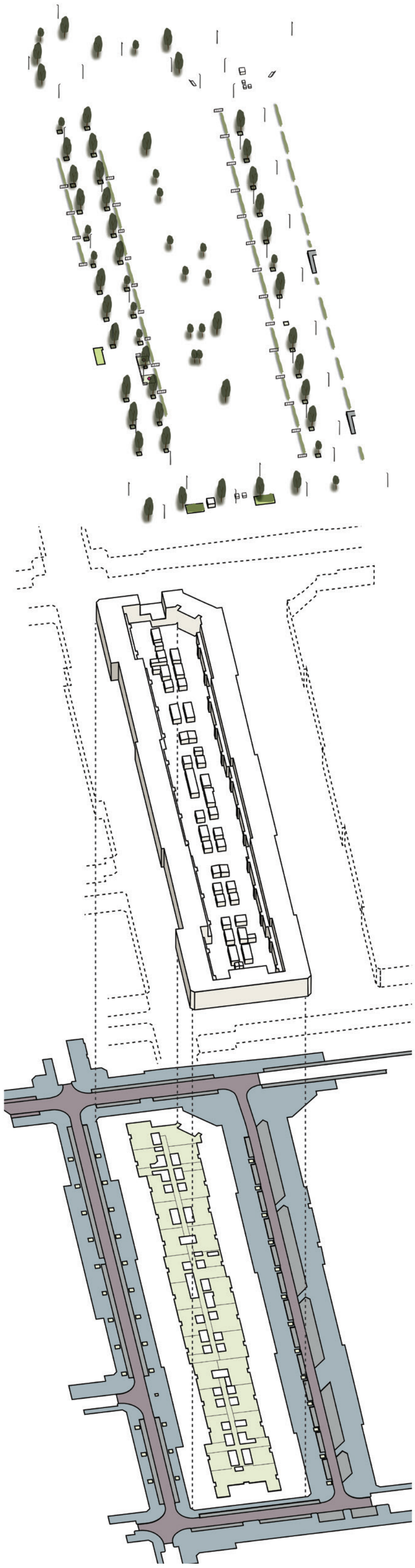


figure 42.b. Exploded view of building block Rendierstraat.

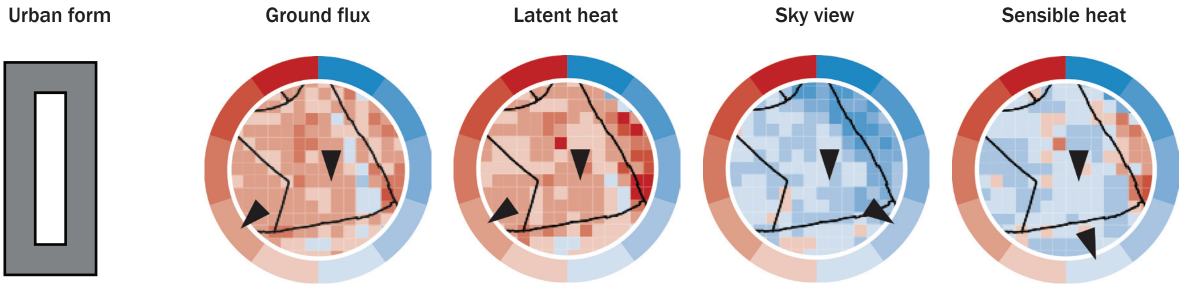
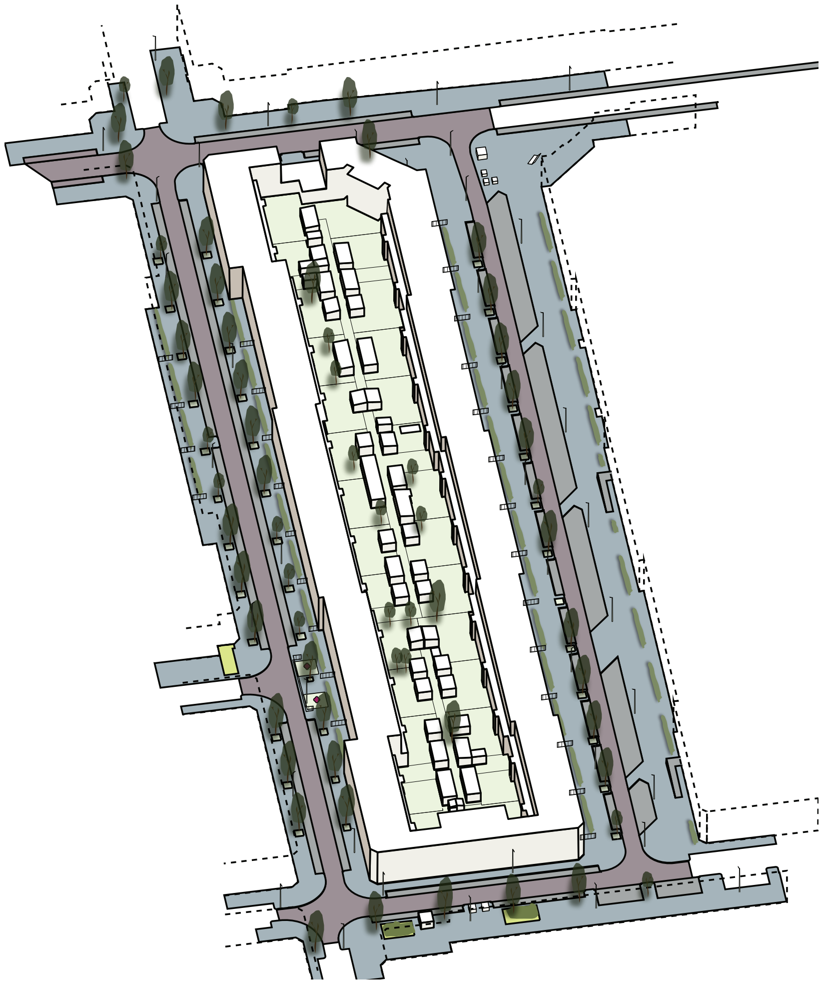
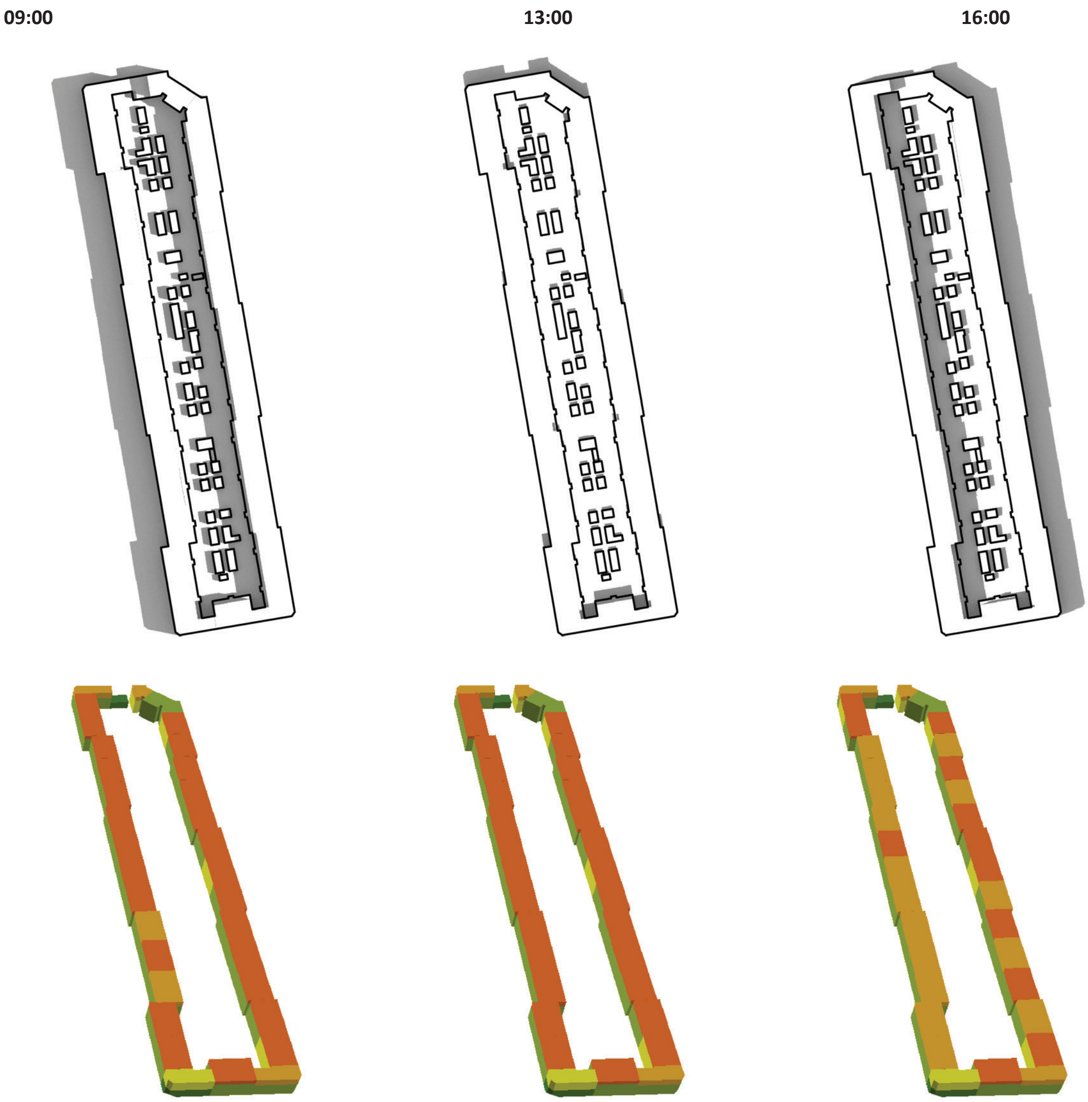


figure 43. The assessment of the building block Rendierstraat and how it compares to the urban form study done by Taleghani. The assessment of the location of Rendierstraat in regard to the Rotterdam study results of ground flux, latent heat, sky view and sensible heat.





LEGEND
Inner door temperature in (°C)

- 22,00 - 24,13
- 24,14 - 24,59
- 24,60 - 24,82
- 24,83 - 25,09
- 24,10 - 25,47
- 25,48 - 25,96
- 25,97 - 28,00

figure 44. Sunstudy of Rendierstraat and inner door temperature based upon model by ir. I. Theunisse.

25.3 Geraniumstraat linear block type

Geraniumstraat linear block type is constructed in 1925 and situated in the neighbourhood Bloemhof. The block type could be considered as a long stretch open courtyard block as the head ends are open. However due to its low rise of only two floors the block could be considered as a linear block type. Such a configuration of orientation and linear building block typology has not been assessed by Taleghani. The building block has private gardens with little to no green and mostly consists of paved surfaces. These gardens are accessible through an alley. The building block is orientated from north east to south west. Therefore in this case the block is assessed as a courtyard typology. This suggests rising radiant temperatures from end of the morning till the end of the afternoon. Such notion is under scribed by the sun study as it shows how south west and south east facing façade and inner gardens are directly radiated by the sun during midday and the afternoon. The model for inner door temperature partly fits such notion as most of the building blocks have a high inner door temperature. Arguably this is also caused by the flat roofs that are under constant radiation by the sun. The block scores low on density with 0,68 which is unsurprising as the building block only consist of two floors. In terms of ground flux Geraniumstraat linear block is an area with a high ground flux but so is the rest of Bloemhof. Geraniumstraat is situated in an area with little energy for evapotranspiration. The sky view factor in the area of the building block is high compared its surroundings which beneficial for nocturnal cooling. In terms of sensible heat the area is significantly high compared the adjacent areas.

In the conclusion the outcome of the assessment for Garaniumstraat will be compared to the two other typologies.

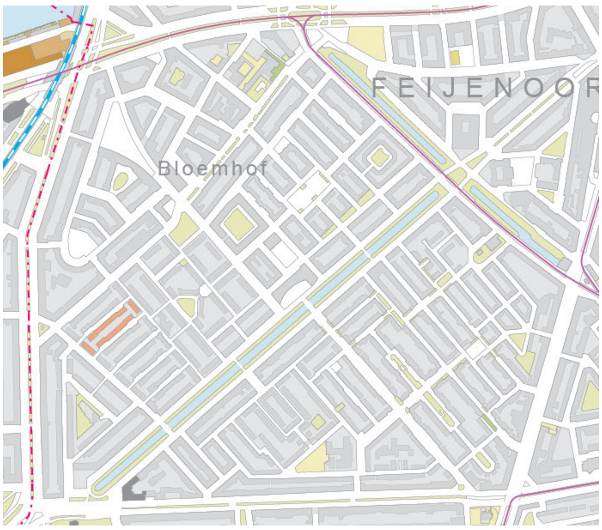


figure 45.a. Location of Geraniumstraat.

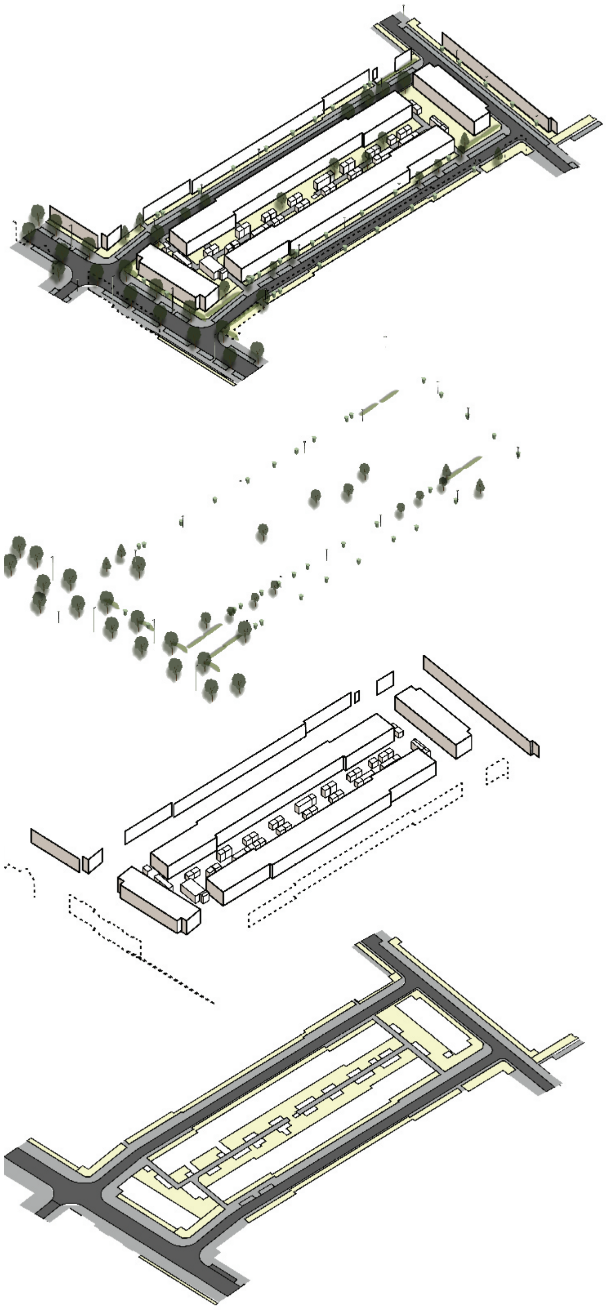


figure 45.b. Exploded view of building block Geraniumstraat.

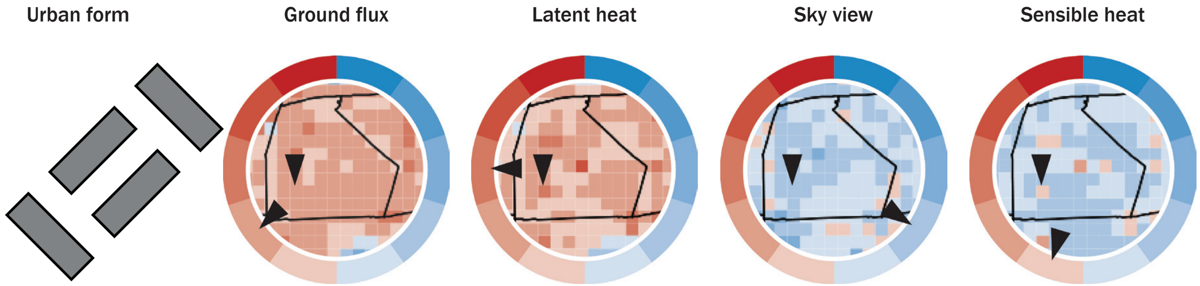
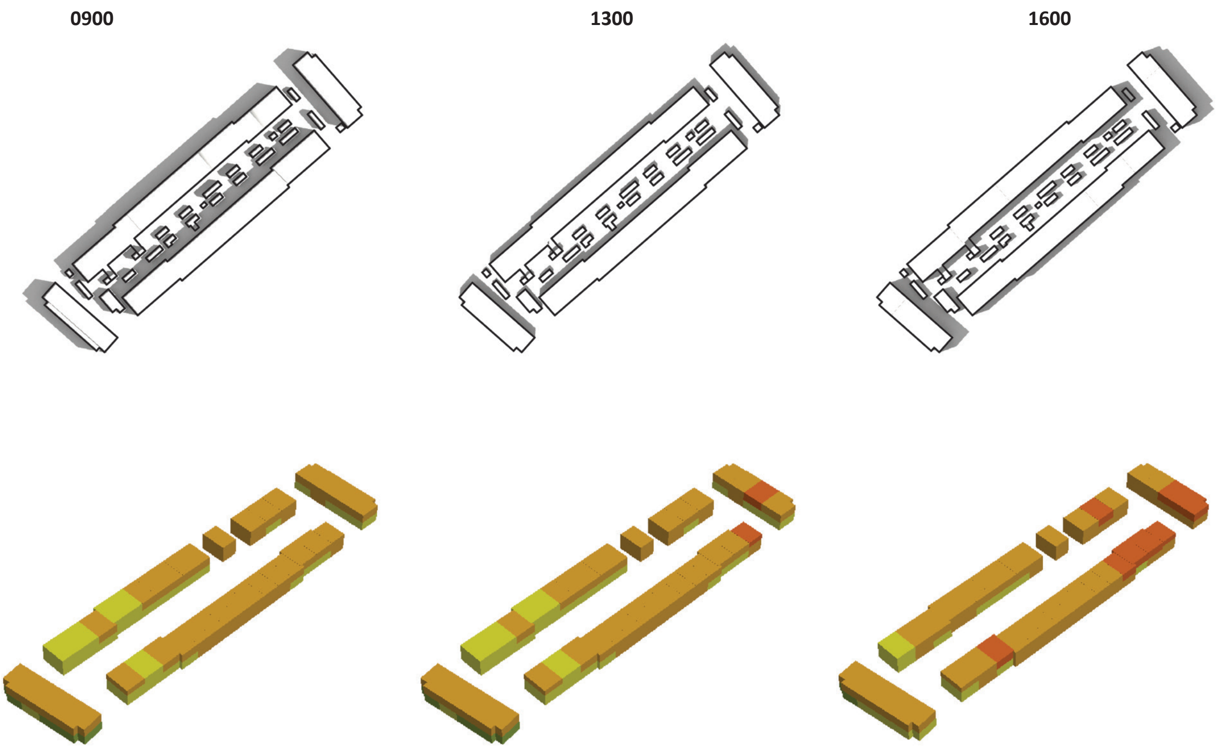


figure 46.a.The assessment of the building block Geraniumstraat and how it compares to the urban form study done by Taleghani. The assessment of the location of Garaniumstraat in regard to the Rotterdam study results of ground flux, latent heat, sky view and sensible heat.



LEGEND
Inner door temperature in (°C)

22,00 - 24,13
24,14 - 24,59
24,60 - 24,82
24,83 - 25,09
24,10 - 25,47
25,48 - 25,96
25,97 - 28,00

figure 46.b. Sunstudy of Geraniumstraat and inner door temperature based upon model by ir. I. Theunisse.

26. Conclusion

This chapter assessed the three building typologies of Patrimoniumhof courtyard in Bloemhof, Rendierstraat long stretch courtyard in Hillesluis and linear building block in Bloemhof. The building blocks have been assessed on urban characteristics of use of materials and green, urban form based upon dr. Mohammad Taleghani's dissertation, inner door temperature model by ir Iris Theunisse, a sun study based upon a 3d model provided by the municipality of Rotterdam and the Hotterdam study by dr. ir. Frank van der Hoeven and dipl. ing. Alexander Wandl. This in order to answer the research question of:

3. What urban typologies in the city of Rotterdam are more exposed to the urban heat island?

In regard to answering the research question first the findings from the analyses of the three typologies are compared and discussed.

From the three typologies the courtyard Patrimoniumhof preformed best in terms of urban from, the use of greenery, inner door temperature and the indicators by Hotterdam. According to dr. Taleghani a square like inner courtyard is a beneficial urban form for outdoor micro-climate comfort measured in the centre of the block. In regard to the indicators from the Hotterdam maps Patrimoniumhof is within a little less warm areas, with little more latent heat and lower sensible heat. Distinct difference from the other two typologies is the fact that Patrimoniumhof consists of sloping roofs. Since ir. Theunisse did not take into account such factor it is assumed that the indicators from the Hotterdam study depict more cooler surroundings that would benefit inner door temperature.

When the thee urban typology are compared in terms of urban form and drop shadow by the sun study the analyses would confirm research conclusions by dr. Taleghani as he argues that a courtyard form is most beneficial for outdoor microclimate. The urban form of Rendierstraat, considered as a 50*10 NS block has little to no drop shadow between 11:00 – and 14:00 when sun radiation reaches its maximum. The urban form of Geraniumstraat is arguable the least favourable as figure 36 on page 124 depicts whereas the mean radiant temperature peaks between 11:00 and 17:00. However from the model made by ir. Theunisse the Rendierstraat shows high temperatures in the model by ir. Theunisse.

However there are some considerations in regard with to the use of the Hotterdam maps since these have a grid size of 100m by 100m. This makes strong correlation with urban form or urban characteristics somewhat less credible as the grid size is too high. Therefore the thesis restrains itself in unambiguously claiming strong correlations with urban typologies or vulnerability to exposure is taken into account. This somewhat debunks this method of a close up look on urban typologies in relation to exposure to factors of the urban heat island. The scale of the Hotterdam maps and the scale on block level do not match.

However in regard to the research question of what urban typologies are more exposed to the urban heat island it is argued, based upon dr. Taleghani, that urban from influences the micro-climate. Typologies of courtyard, linear and singular form, based upon orientation, either provide comfortable micro-climate or uncomfortable micro-climate. Whereas from the analysis a courtyard typology provides for the best micro-climate performance.

Urban heat island mitigating and adapting design proposals

27. Introduction

The chapter presents design interventions for the neighbourhood Bloemhof. Such interventions are based upon the analyses described in previous chapters and a invertaris ofdesign principles. Firstly the general strategy for Bloemhof will be described as this comes forth from the findings and conclusions from the previous chapters. Secondly the background of the main sources used for the design principles are described. Thirdly each design interventions and design principles are described accompanied by an assessment graph. This chapter as whole applies to the research question of:

4. ***What are urban heat island adapting and mitigating design principles and how can these be applied to reduce the urban heat island in socially deprived neighbourhoods of Rotterdam?***

28. Description strategy

The neighbourhood of Bloemhof, part of the city district Feijenoord, is considered as socially deprived and considerably exposed to high average summer day temperatures. In terms of the urban heat island, based on figure 12 on page 38, it shows that for the neighbourhood of Bloemhof the expectancy is that the urban heat island will intensify. The neighbourhood is characterized by urban characteristics that are beneficial in terms of the urban heath island and population characteristics indicate social deprivation. In terms of social deprivation the neighbourhoods scores bad on income and the 'leefbarometer'. A more in depth analyse found that the neighbourhood lacks vegetation and public spaces that provide for cooling, the inner parts of the neighbourhood are low in density with old terraced houses of bad quality. As such the neighbourhood does not provide for cooling during hot summer days. Apart from these issues related to the urban heat island and social deprivation firstly the neighbourhood also deals with a lack of water transport and temporal capacity as the cause of lack of green and the use of paved surfaces. The city of Rotterdam is expected to grow with 50,000 residents in 2030. The national program Rotterdam South calls out for the need for more critical mass of housing to support services and more diversity which is under scribed by the area plan city district Feijenoord.

To give an insight of how each design interventions applies to the findings and conclusions from the previous chapters and assessment graph is made based upon table 17 that describes how each score is valued.

table 17. Overview of to what each indicator applies and how the scores are defined.

Indicator	Applies to	Score			Source
		Negative -1	Neutral 0	Positive 1	
Heat storage / ground flux	Heat storage or ground flux depends on the heat capacity of materials and is the biggest factor for the nocturnal urban heat island.	Increases the amount of impervious surfaces or mass that collects energy from the sun re-emitted during the evening or reduces the amount of evapotranspiration.	-	Reduces the amount of impervious surfaces or mass that collects energy from the sun re-emitted during the evening / or evapotranspiration.	(Gartland, 2008; van der Hoeven & Wandl, 2015)

Evapotranspiration / Latent heat	Evapotranspiration is the latent heat and the combination of energy transmitted away from the Earth's by water vapour and by plants.	Decreases the amount of greenery and shallow water available for evapotranspiration.	-	Increases the amount of greenery and shallow water for evapotranspiration.	(Gartland, 2008; van der Hoeven & Wandl, 2015).
Sun / shade	Direct radiation by the sun a strong influence on the experience of heat by the human body.	More exposure to direct sun light due to lack of shade.	-	Less exposure to direct sun light due to shade.	(Gartland, 2008; Havenith, 2005).
Density	Density of urban fabric in terms of FSI and GSI are beneficial as it provides critical mass in terms of inhabitants for services and the need for more dwelling because of expected growth.	Density decreases	-	Density increases	(Tillie, 2012; programmabureau NPRZ, 2015; Stadsontwikkeling Rotterdam, 2015)
Urban form	Urban form, defined by Taleghani, that is beneficial for providing thermal comfort at reference point.	Singular	Linear	Courtyard	(Taleghani, 2014)
Housing mix	The housing mix is perceived as problematic as its to homogeneous with houses of bad quality in terms of isolation, maintenance and size.	The housing mix becomes more homogeneous.	-	The housing mix becomes more heterogeneous.	(Gebiedscomissie Feijenoord, 2014; programmabureau NPRZ, 2015)
Parking	Reducing the parking pressure on the streets, as these are often narrow, as this is perceived as nuisance by the residents.	The parking pressure increases due to reasons of increased population density without providing sufficient parking places.	-	New parking solutions that reduce parking pressure on the street.	(Gebiedscomissie Feijenoord, 2014)
Public squares	The quality of public spaces in terms of greenery, playgrounds and benches.	The quality of a public space declines caused by reduction in one of the indicators that were used to judge the public spaces.	-	The quality of a public increases as one of the indicators increases and or new public spaces are introduced.	(Gebiedscomissie Feijenoord, 2014)
Water storage capacity	The capacity of a neighbourhood to temporal store water as a cause of heavy rainfall.	The amount of water capacity reduces.	-	The amount of water capacity increases.	(Gemeentewerken, 2010)
Water transport	Transport capacity to water bodies like 'singels'.	The transport capacity to water bodies decreases.	-	The transport capacity to waterbodies increases.	(Gemeentewerken, 2010)

-

As the design proposal are linked to the findings and conclusion of the previous chapters the design principles that connect are based upon 5 main sources who act as references and inspiration. These references are:

- The publication 'Duurzame ideeën & DCBA Methodiek' is published by Architecture SMART Architecture, department of Architecture, faculty of Architecture, TU Delft and provides the DCBA-method for possible sustainable building measures divided into four different levels rising in ambition level. These measures are subdivided in: sustainable construction, ambition, energy, water, green, mobility, materials, living environment, waste, pollution, liveability, process and raising awareness (Teeuw & TU Delft Faculteit Bouwkunde SMART Architecture, 2010).

- The book 'Het weer in de stad' or 'the weather in the city' by dr. Sanda Leznholzer (Lenzholzer, 2013) contains a catalogue of design principles to influence the micro-climate of the city. Lenzholzer describes how the experience of temperature by humans is influenced by sun/shade, radiation of materials and air temperature. The design principles she proposes ranges from very effective to somewhat less as she argues that influencing sun and shade on a small scale is very effective but reducing air temperature through evapotranspiration works less well and needs to be applied on a larger scale of at least a neighbourhood.

- Dr. Lisa Gartland has written the book Heat Islands: understanding and mitigating heat in urban areas. The design principles she proposes are classified according to roofs, pavement and trees and vegetation (Gartland, 2008). Gartland design principles are described in a more general way with less practical applications. However these solutions prove their value as they are supported with scientific theory on the physical performances.

- The book 'Architectuur als klimaat machine' or Architecture as climate machine by architect Vera Yanovshtchinsky, ir. Kitty Huijbers and prof. dr. ir. Andy van den Dobbelsteen is the result of the collaboration between Vera Yanovshtchinskt architect and the TU Delft. The book offers theory and practical applications for both passive and active systems that improve comfort of building and especially residential buildings (Huijbers & Dobbelsteen, 2012).

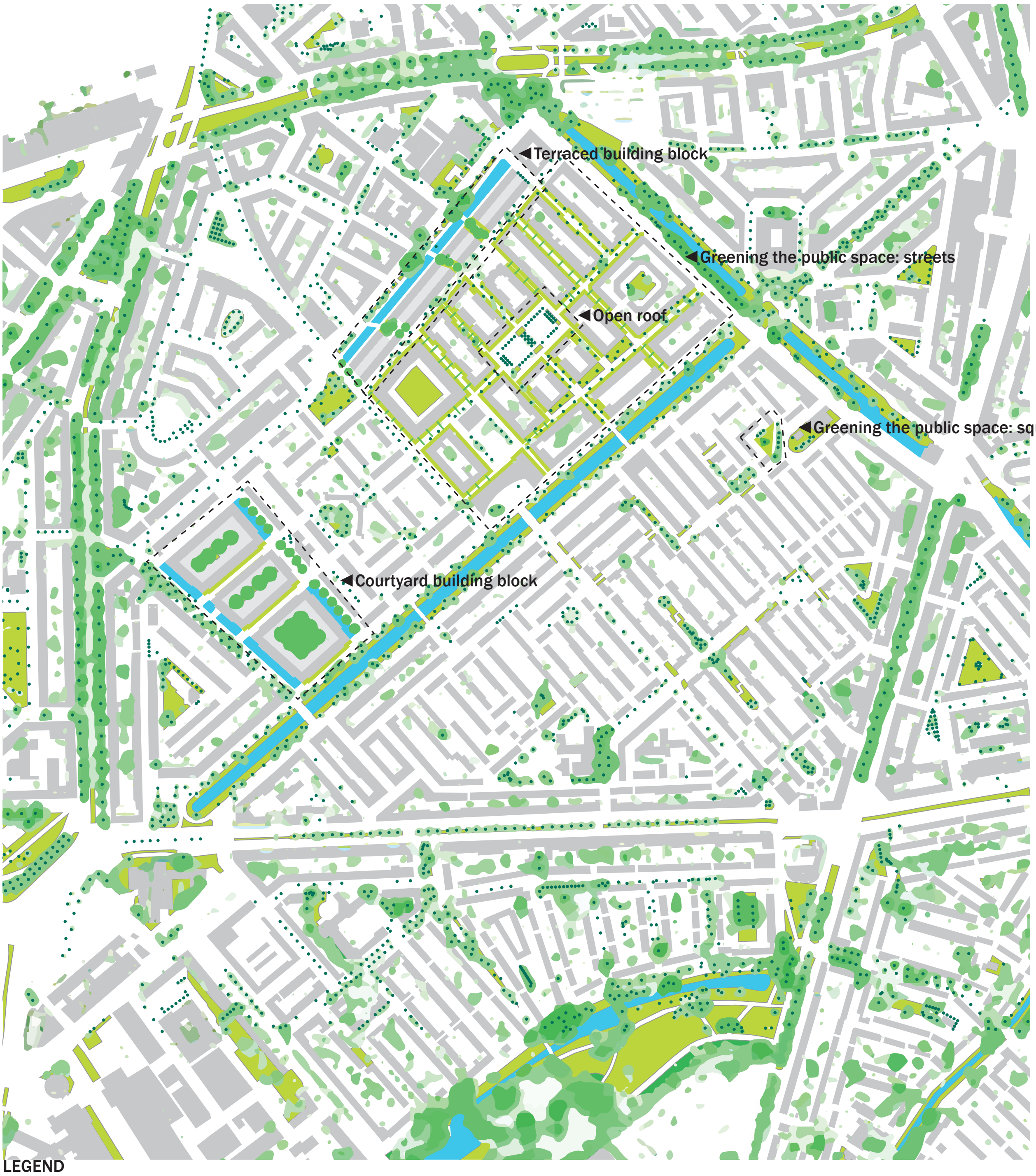
- Sponge City Water: resource management – Ville permeable: L'eau resource urbaine is a book that brings together French examples of water management solutions on urban scale. The solutions deal with reversing the use of impervious surfaces and abandoning the all pipe system. The book offers a broad range of design solution for both landscape architects and urban planners. These are subsequently divided in: landscape and site, (Eco-) neighbourhoods and development zones, urban public spaces, public parks and gardens and private gardens and landscaped spaces. (ICI Consultants, 2015)

29. Design proposals

The design proposals firstly focus on replacing some building blocks with blocks that are more beneficiary for the neighbourhood in adapting and mitigating to the urban heat island and addressing issues of water storage, improving diversity in housing mix and increasing population density. Secondly interventions are proposed that address both the existing private and public space and there where these two meet. Addressing the private space provides for more coolness during hot summer days and water storage capacity. An similar aim is envisioned for addressing the public space sub devided by streets and squares. Addressing these two creates a network in which a neighbourhood resident is able to use streets and squares that provide more comfort in terms of air temperature.

On the next page in figure 48 an overview map is presented for the design proposals in Bloemhof.

figure 47. Illustrative image of how there are some nice places in terms of vegetation in Bloemhof. The picture shows overarching vegetation with underneath a few chairs to sit on (image by author).



LEGEND
Greenstructure

- Building
- Building island
- Grasland
- River
- Water
- Tree plantboxes
- Tree crowns
- Vegetation on and along side facade. Also represents semi-paved parking surfaces.
- Tree crowns
- Project borders

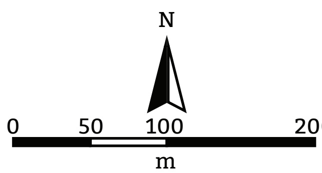


figure 48. An overview of the design proposals for Bloemhof (image by author).

29.1 Courtyard building block

The courtyard building block typology shows characteristics that meet the requirements for Bloemhof as it provides for an increase in density, more comfort in terms of micro-climate and the inner courtyard can both be filled with greenery and parking places.

The introduction of the courtyard building block follows a trend of an earlier courtyard building block ‘in de roos’ completed in 2007. However ‘in de roos’ (figure 51.a on page 144) is considered as somewhat mediocre. Firstly as the opportunity to add a higher density in the neighbourhood’s, as ‘in de roos’ only provides for three floors, seems to have been missed .This results in a low ground space index and floor space index as the calculation from part “Floor and ground space index” on page 88figure 33.b on page 90 shows. However is must be noted that a closer look at the used model used for ground space index and floor space index misses out precisely upon some of the floors of ‘in de roos’. When the building block is assessed on ground space index and floor space index with AutoCAD the ground space index would be approximately 0,35 and the floor space index 0,95. Which would be considered according to Spacemate’s building types by Berghauser Pont and Haupt as low rise block type (Berhauser Pont & Haupt, 2010). A new building block should have a density that fits the category of a mid-rise block type. As the diagram in depict the mid-rise block type as having partly a similar GSI but often twice or three times the floor space index. A higher quality of greenery and shade providing design solutions seems to be missed. The greenery inside the building block is somewhat dull and lack quality as the young trees provide for no shade with no alternative. On the positive side, the solution of parking within the courtyard is considered as sufficient. As such the building technology of the building should implement design solution of greenery on the building and inside the courtyard, shade to prevent direct inner door radiation from the sun during the summer inside. The building should be configured in such a way that it provides for eyes on the street and a clear distinction between the private and the public space to improve social control. The parking inside the courtyard provides reduces the parking pressure on the street. In the appendix III on page 190 a cross section is presented of the courtyard building block.

As ‘in de roos’ is seen as a missed opportunity the courtyard building block of ‘De Hofdame’ by Klunder Architecten (figure 51.b on page 144) next yo the Laurenskerk alongside Blaak in Rotterdam acts as a reference and inspiration of how a courtyard block can reach a high density with greenery in the courtyard and parking solution inside the courtyard block.

Location and description design intervention

The location chosen to implement the courtyard building block lays between Resedastraat en Hyacintstraat. The building originate from 1920-1930 and is of duplex typology. Apart from a few large trees the location lacks vegetation. Based upon the property value figures of housing corporation Woonstad table 18 on page 143) the property is one of the lowest in Bloemhof. From micro-interviews the location in opinion of some residents is considered as very deprived with lots nuisances and crime.

The principle of the building block and its sub components are shown in figure 49 on page 142 and its performance in figure 50 on page 143. The courtyard block should be made up of at least 5 floors. This increases density and provides for more dwellings of different sizes to improve the diversity in housing mix in the neighbourhood. Answering to the need of expected population growth and wish for more population pressure on services and public spaces. Such an increase the building mass increases which is disadvantageous for the urban heat island as the ground flux / heat storage increases.

The design consists of three courtyard building blocks each of 5 storey high. The inner courtyard is used for parking and vegetation in the form of large trees. Large trees take decades to grow but there is a option to plant Plantanus Hispanica with a length of 6,5 m to 10,0 m ranging from a price class between € 330 - € 1.500 (Tenhoven-Bomen, 2016). The Plantanus Hispanica is also considered a tree who is ‘climate proof‘ as it is very well able to withstand long periods of drought (Lenzholzer, 2013, p. 132). With the introduction of these three courtyard blocks a total of 143 dwellings are removed. In return a total of 318 dwellings of different sizes are added. The resulting floor space index and ground space index is 1,16 - 1,32 and 0.27 - 0,32.

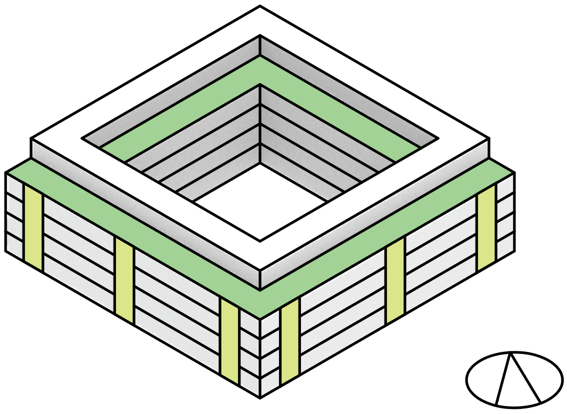
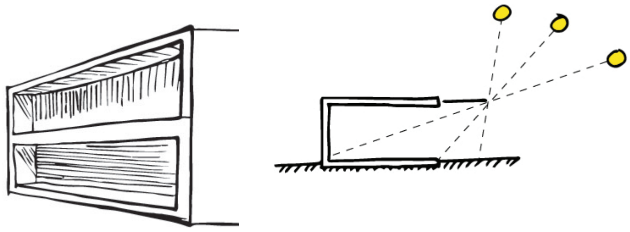
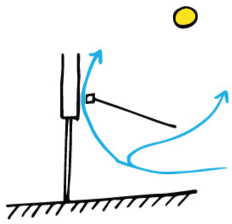


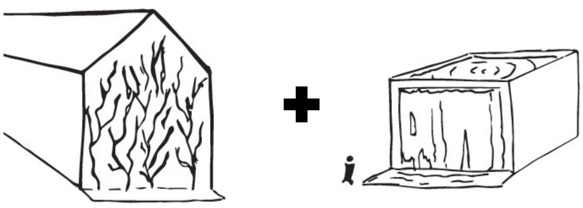
figure 49. Principle of courtyard building block.



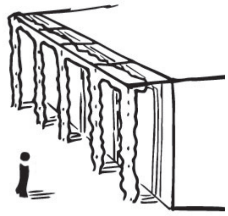
The principle of a loggia is to protect the inside of a building from intense sunlight during the day while providing sunlight during the evening and morning and the winter (Huijbers & Dobbelsteen, 2012, p. 84; Lenzholzer, 2013, p. 118)



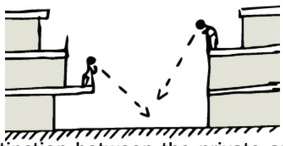
When solar blinds are introduced they should be installed in such a way that they is some space left between the blind to provide for ventilation and the façade to prevent the air underneath the blind to warm the façade (Huijbers & Dobbelsteen, 2012).



A green facade provides shading for the wall behind the green reducing the temperature of the outer wall and the inner temperature. Providing the plants with water can be troublesome and needs consideration (Lenzholzer, 2013, p. 123).

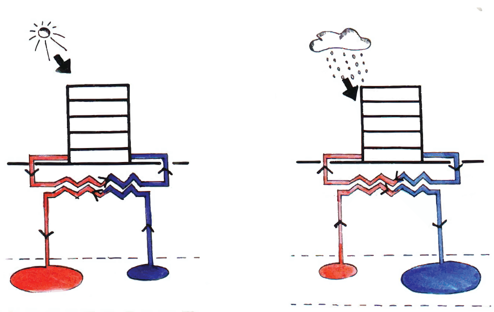


A pergola offers shade and cooling by evapotranspiration. Requires regular maintenance which can be an opportunity for communal effort and responsibility (Lenzholzer, 2013, p. 121).



With a clear distinction between the private and public realm residents recognize their own territory creating involvement in their neighbourhood. Eyes on the street provide for social control creating a feeling of safety for both residents as visitors. (Polman, 2009; Teeuw & TU Delft Faculteit Bouwkunde SMART Architecture, 2010, p. 87)

Roofs with intensive green provide for shade, reduce inner door temperature, reduce air pollution, storm water reduction, and provide green to its direct surroundings. It must be noted that green roofs need a strong construction, a minimum thickness of at least 25 cm, during drought irrigation and intensive maintenance (Gartland, 2008; Lenzholzer, 2013, p. 162).



With the introduction of a heat and cold storage system the energy in the form of heat is collected and stored in an acquifer in the subsoil layers. The stored heat is available during the winter for heating. The system also works the other way around. During the summer the cooler water in the subsoil acquifer provides for cooling. Such a system would reduce energy costs and mitigated to high air temperature (Climate Proof Cities consortium, 2014).

table 18. Property value of building blocks between Resedastraat en Hyacintstraat scoring below average of Bloemhof.

Complex nr.	Street	Average property value	Nr. units
81004	Geraniumstraat	€ 60.560,98	41
	Narcissenstraat		
81005	Lobeliastraat	€ 62.465,12	43
81008	Sneeuwbalstraat	€ 60.620,69	29
81009	Goudenregenstraat	€ 67.100,00	30
Average of Bloemhof		€ 99.312,30	

(Woonstad, 2016)

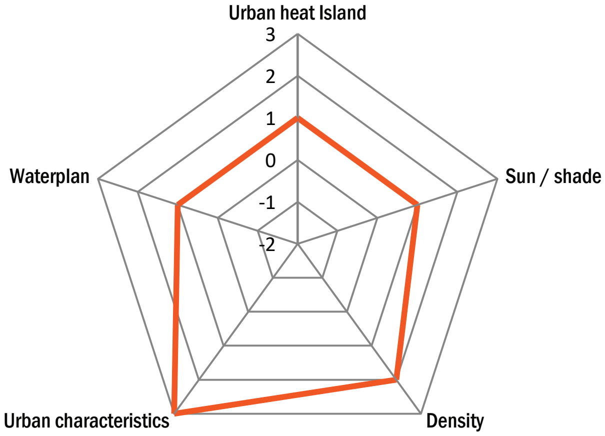
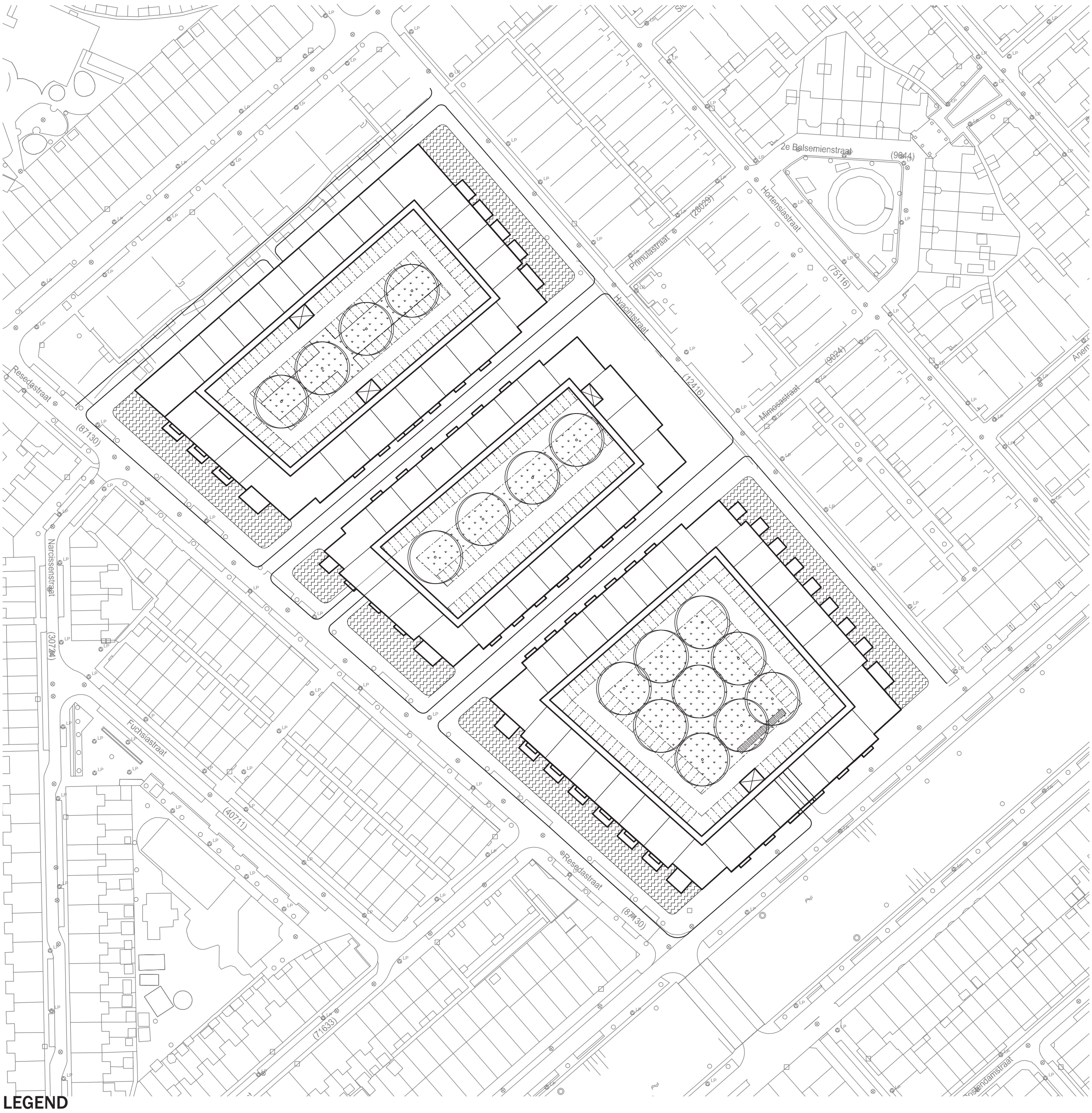


figure 50. Valuation of the courtyard building block typology.

figure 51.a. Courtyard block ´In de roos´ with the lack of additional floors and higher quality vegetation opportunities have been missed.

figure 51.b. 'De Hofdame' with the inner courtyard with greenery, provides, as the architects claim: a green oasis in the city centre (Realworks, unkown).



LEGEND
Courtyard building block

- Water
- Grass
- Grass roof in combintaion with water and PV
- Parking lot 2,30 m by 4,50 m
- Tree 16 m diameter
- Elevator and staircase

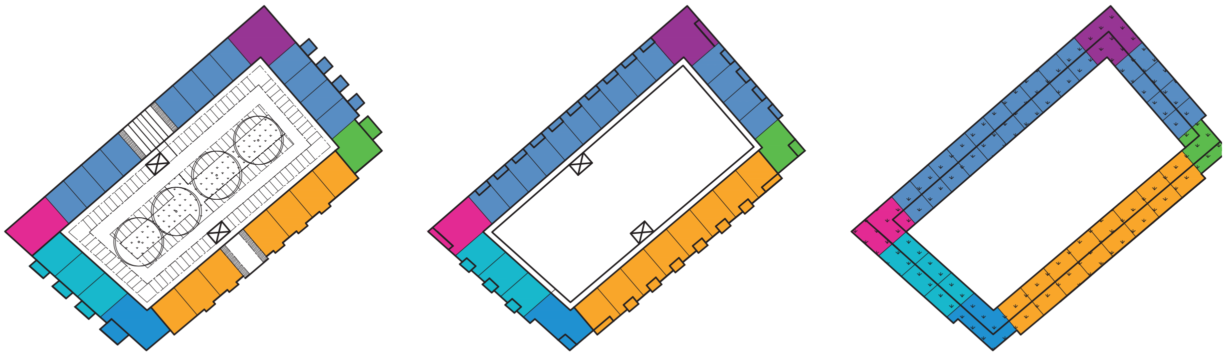
figure 52. Design proposal for introducing the courtyard building block (image by author).

LEGEND
Building block I
Total apartments 108

Indoors (i.), Balcony (b.), Maisonette (m.)
FSI: 1,17 GSI: 0,32

Parking lots: 116

- Type A: 86 - 96 m^2 (i.) 10 m^2 (b.) 134 m^2 (m.)
- Type B: 112 - 124 m^2 (i.) 12 m^2 (b.) 172 m^2 (m.)
- Type C: 113 - 121 m^2 (i.) 12-18 m^2 (b.) 173 m^2 (m.)
- Type D: 184 - 202 m^2 (i.) 18 m^2 (b.) 287 m^2 (m.)
- Type E: 186 - 201 m^2 (i.) 15-38 m^2 (b.) 280 m^2 (m.)
- Type F: 220 - 240 m^2 (i.) 20 m^2 (b.) 376 m^2 (m.)
- Type G: 137 - 152 m^2 (i.) 15-28 m^2 (b.) 221 m^2 (m.)

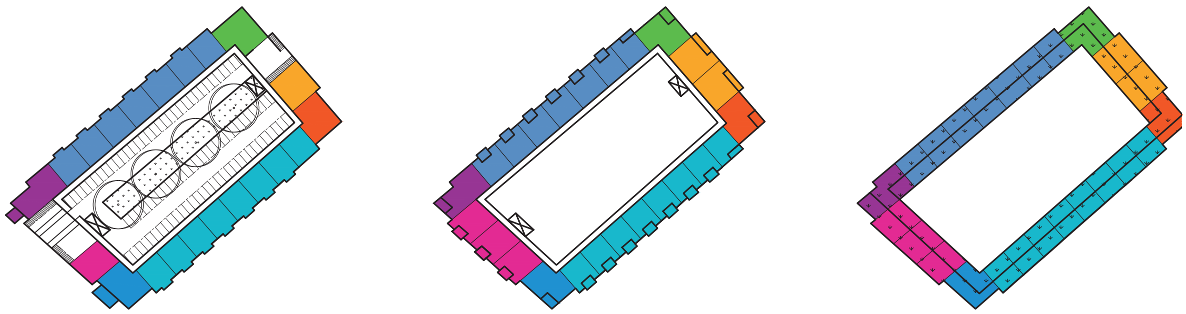


LEGEND
Building block II
Total apartments 90

Indoors (i.), Balcony (b.), Maisonette (m.)
FSI: 1,33 GSI: 0,30

Parking lots: 90

- Type A: 92 - 104 m^2 (i.) 12 m^2 (b.) 130 - 142 m^2 (m.)
- Type B: 127 - 143 m^2 (i.) 16 m^2 (b.) 172 m^2 (m.)
- Type C: 90 - 94 m^2 (i.) 10 - 12 m^2 (b.) 139 m^2 (m.)
- Type D: 112 - 120 m^2 (i.) 12 m^2 (b.) 162 m^2 (m.)
- Type E: 129 - 144 m^2 (i.) 15 m^2 (b.) 189 m^2 (m.)
- Type F: 143 - 158 m^2 (i.) 15 - 16 m^2 (b.) 224 m^2 (m.)
- Type G: 143 - 158 m^2 (i.) 15 - 16 m^2 (b.) 233 m^2 (m.)
- Type H: 143 - 158 m^2 (i.) 15 - 16 m^2 (b.) 233 m^2 (m.)

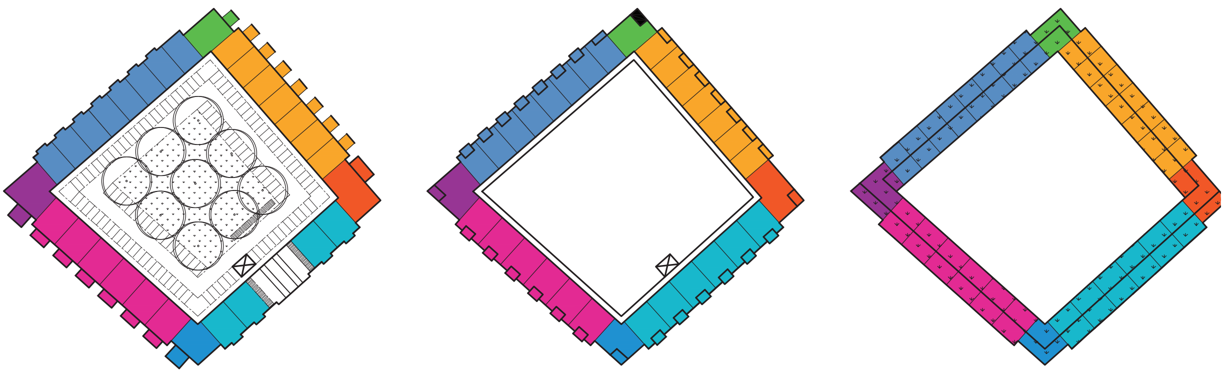


LEGEND
Building block III
Total apartments 120

Indoors (i.), Balcony (b.), Maisonette (m.)
FSI: 1,20 GSI: 0,28

Parking lots: 124

- Type A: 86 - 100 m^2 (i.) 12 m^2 (b.) 134 - 136 m^2 (m.)
- Type B: 86 - 96 m^2 (i.) 10 - 16 m^2 (b.) 134 - 136 m^2 (m.)
- Type C: 112 - 124 m^2 (i.) 12 m^2 (b.) 172m^2 (m.)
- Type D: 111 - 120 m^2 (i.) 12 - 18 m^2 (b.) 171 m^2 (m.)
- Type E: 116 - 131 m^2 (i.) 15 - 30 m^2 (b.) 173 m^2 (m.)
- Type F: 160 - 175 m^2 (i.) 15 - 30 m^2 (b.) 257 m^2 (m.)
- Type G: 119 - 143 m^2 (i.) 15 - 16 m^2 (b.) 196 m^2 (m.)
- Type H: 177 - 191 m^2 (i.) 14 - 32 m^2 (b.) 276 m^2 (m.)



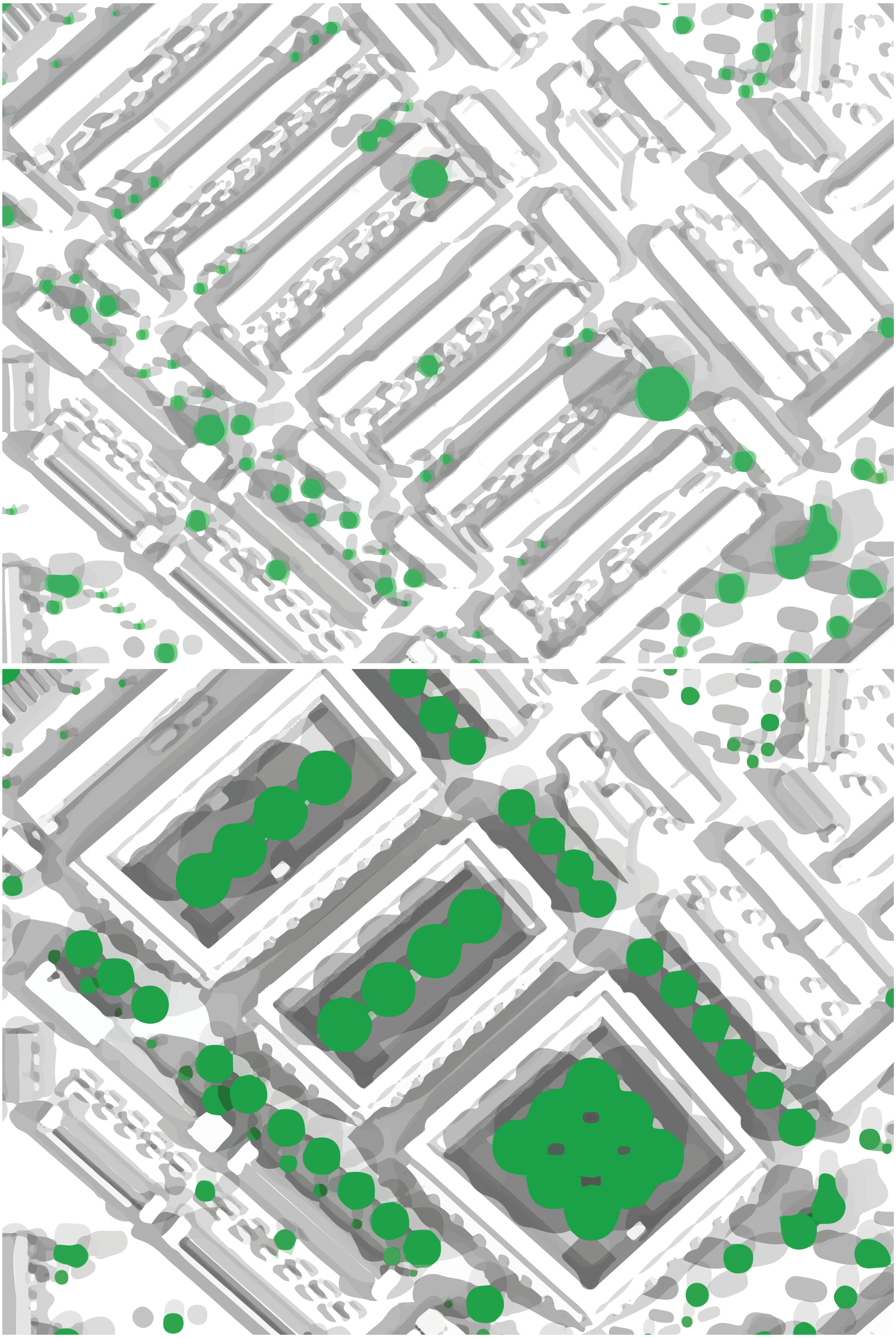


figure 53. Before and after of sun study of the introduction of three courtyard Building blocks (image by author).

29.2 Introducing a singel with terraced building blocks

With the introduction of a terraced building block and a 'singel' alongside Putsebocht a new water body with rich vegetation is introduced. Such a water body has the potential to mitigate the urban heat island as it provides for water for evapotranspiration and is beneficial for the water capacity of the neighbourhood. However there are some nuances to be noted.

Researchers on Vienna and Rotterdam argue that the temperature of open water, build-up during the spring and summer, can have a negative effect on the nocturnal urban heat island as the water body is warmer then it surroundings heating the air above it (Steeneveld, Koopmans, Heusinkveld, & Theeuwes, 2014; Žuvela-Aloise, Koch, Buchholz, & Früh, 2016). However the authors seem to be addressing open water bodies of lakes and open water within harbours. In the publication of Hotterdam van der Hoeven and Wandl both note that implication of un deep water body's in the form, un deep basins, ponds and fountains evaporated relatively much but are less able store heat (van der Hoeven & Wandl, 2015). Lenzholzer notes that in general terms water bodies are little of effect but in combination with vegetation prove their efficiency as is provided for water for evapotranspiration by vegetation and shade on the water surface by the same vegetation (Lenzholzer, 2013). As such implementing a water body in the neighbourhood of Bloemhof needs thoughtful design decisions, consideration and is go together with the introduction of vegetation.

In terms of social safety the introduction of vegetation and a water body should create ordered public space with maximal lines of inter visibility and clarity who owns such space. Such a situation would increase the potential for social control and clarity on the distinction between the private and the public space. Residents should be given room to actively get involved in their neighbourhood as they are allowed to claim small part of vegetation or add small beautification as they see fit. This provides for involvement and maintenance of the public space creating more social control and cohesion (Rooij, 2012; Teeuw & TU Delft Faculteit Bouwkunde SMART Architecture, 2010).

The chosen location for implementing the principles of introducing vegetation and water body is the street 'Putsebocht'. Such implementation requires additional room and therefor replacement of building blocks which roughly ranges from Putsebocht nr. 80 to nr. 16 and Asterstraat nr. 91 to nr. 13. Based upon that dataset of housing corporation 'Woonstad' the average property value of 'Putsebocht' is around € 80,000 and for the Asterstraat around € 100,000 (table 19 on page 150). However it must noted that the Asterstraat is only partly in possession by housing corporation 'Woonstad'.

In figure 55 on page 149 the design principle for the terraced building block is shown. The principle consist of two three storey high rows of opposing terraced dwellings with in between a parking garage where the roof acts as a balcony for each dwelling. The urban structure as a whole is sub divided in which a connection is created between different parts of Bloemhof allowing residents to easily move from one part to another (figure 54). At the northernside of the buidling block a 10 m wide 'singel' is introduced. The building block partly provide for shadow on the 'singel' southern bank. On the northern bank water vegetation is introduced as it provides for shade and evapotranspiration.

With the introduction of these terraced housing blocks a total of 77 dwellings are removed. In return a total of 88 dwellings of different sizes are added. The resulting floor space index and ground space index is 0,82 - 0,99 and 0.23 - 0,28.

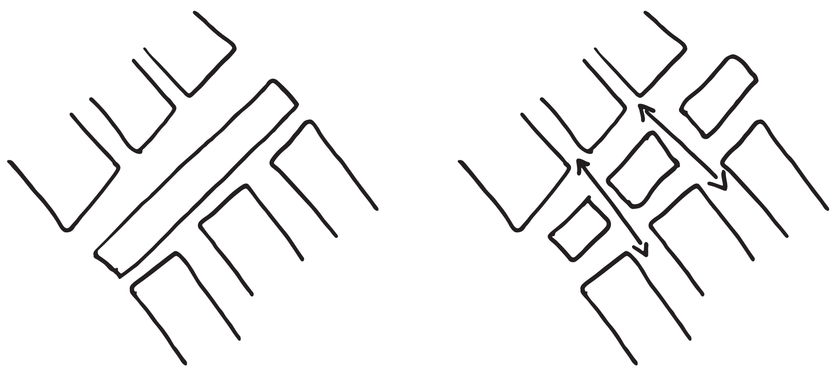


figure 54. Explanatory diagram of how the sub dividing the urban form to provide for more interconnectivity in the neighbourhood.

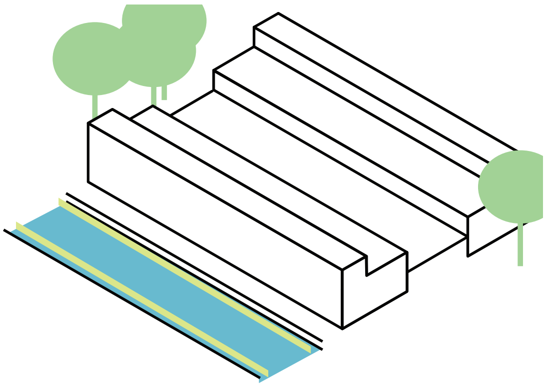
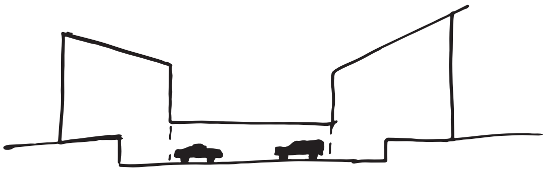
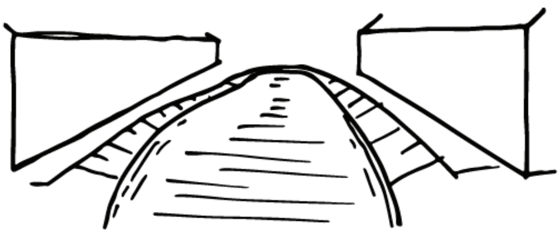


figure 55. Principle of terraced building block.



Parking solution in where the parking garage is part of a terraced building block. The parking garage acts as a public space accessible from the dwellings.



The introduced water body provides for water capacity and vegetation. The label singel is used as it not only is part of the water management system it also provides for public spice with parkish greenery and pedestrian routes. As such a singel is a urban design element that can provide for greenery and surface water capacity (Meyer, 2012).

The introduction of large trees provides for evapotranspiration and shade which enables a reduction of 50% of radiation within the drop shadow of the tree (Lenzholzer, 2013). In the street 'Putsebocht' there are already some big trees and these should be integrated in the design.

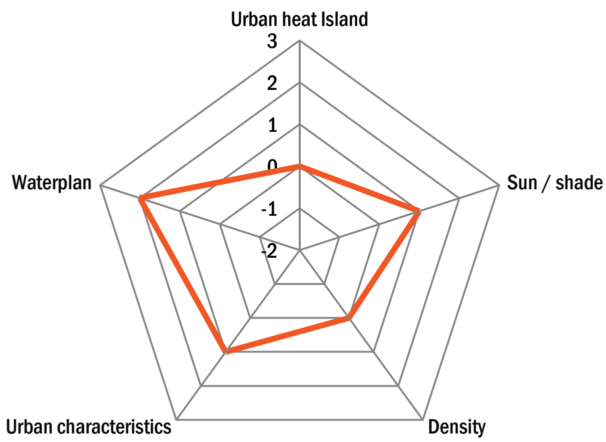
A mixture of bigger and smaller plants provide for shade, evapotranspiration and esthetical value. Within the urban design there are two considerations. Firstly smaller plants can dry and therefore should be placed within the drop shadow of the large trees. Secondly larger plants my obstruct inter visibility and have a deteriorating effect on social control (Lenzholzer, 2013, pp. 134, 165).

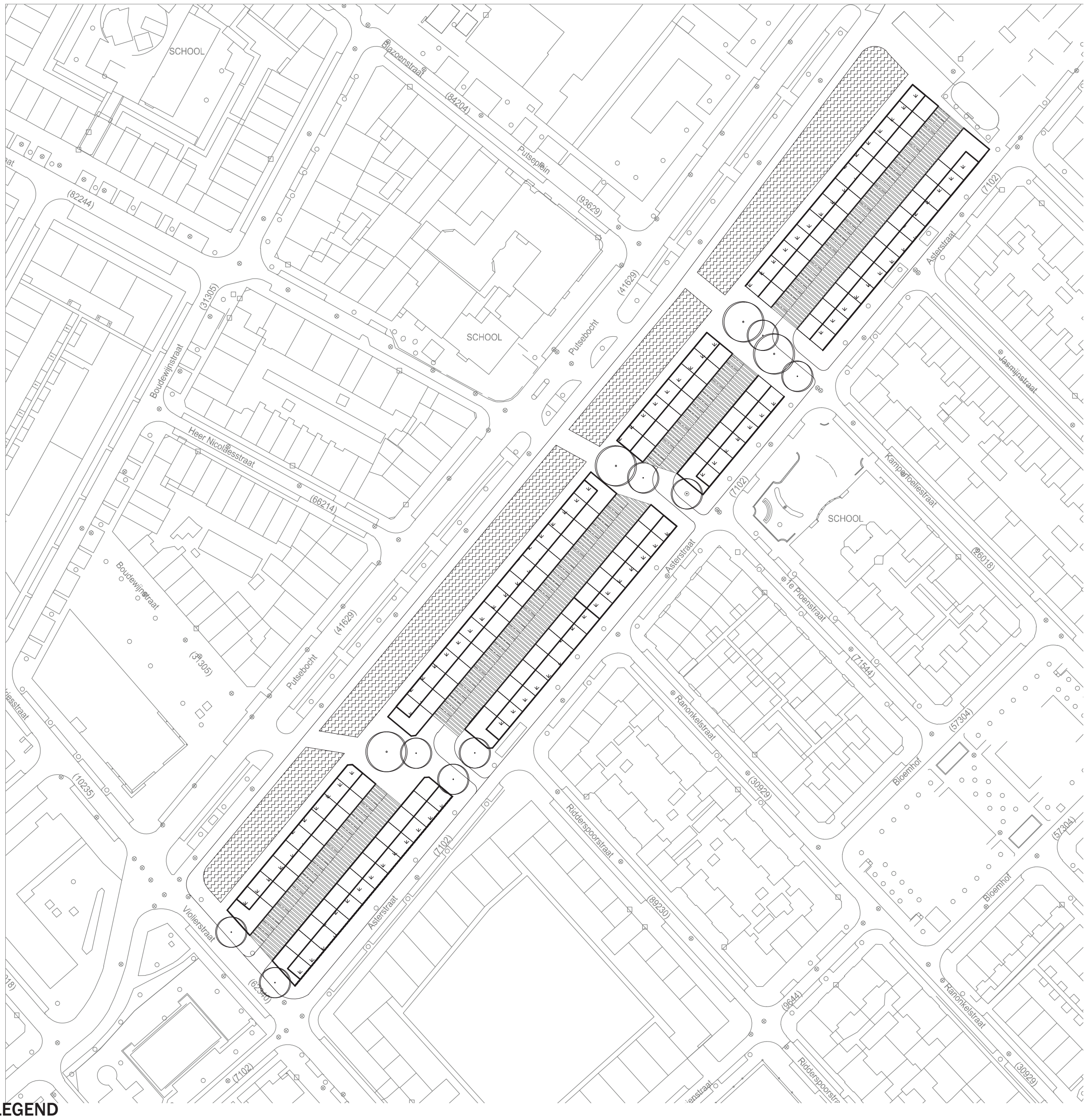
The effectively of the water body increases with vegetation as these provide shade, evapotranspiration of heat is beneficial for bio diversity (Lenzholzer, 2013, p. 169).

table 19. Property value of building blocks on Putsebocht and Asterstraat scoring somewhat below average of Bloemhof.

Complex nr.	Street	Average property value	Nr. units
81002	Putsebocht	€ 83.647,06	34
81003	Putsebocht	€ 78.260,00	50
81073	Asterstraat	€ 103.272,73	33

(Woonstad, 2016)





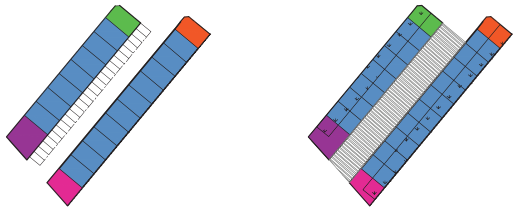
LEGEND
Terraced housing building block

- Water
- Balcony
- Grass roof in combintaion with water and PV
- Parking lot 2,30 m by 4,50 m
- Tree 9 m diameter
- Tree 12 m diameter

figure 56. Design proposal for introducing terraced building blocks (image by author).

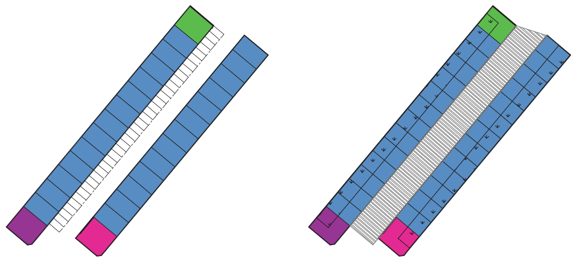
LEGEND
Building block I
Total apartments 21
Parking lots: 25
Indoors (i.), Balcony (b.)
FSI: 0,94 GSI: 0,29

- Type A: 150 m^2 (i.) 60 m^2 (b.)
- Type B: 224 m^2 (i.) 130 m^2 (b.)
- Type C: 161 m^2 (i.) 77 m^2 (b.)



LEGEND
Building block II
Total apartments 29
Parking lots: 37
Indoors (i.), Balcony (b.)
FSI: 1,09 GSI: 0,30

- Type A: 150 m^2 (i.) 60 m^2 (b.)
- Type B: 201 m^2 (i.) 63 m^2 (b.)
- Type C: 185 m^2 (i.) 77 m^2 (b.)
- Type D: 205 m^2 (i.) 125 m^2 (b.)



LEGEND
Building block III
Total apartments 13
Parking lots: 18
Indoors (i.), Balcony (b.)
FSI: 0,82 GSI: 0,24

- Type A: 150 m^2 (i.) 60 m^2 (b.)
- Type B: 275 m^2 (i.) 115 m^2 (b.)

LEGEND
Building block IV
Total apartments 25
Parking lots: 34
Indoors (i.), Balcony (b.)
FSI: 1,00 GSI: 0,28

- Type A: 150 m^2 (i.) 60 m^2 (b.)
- Type B: 195 m^2 (i.) 145 m^2 (b.)

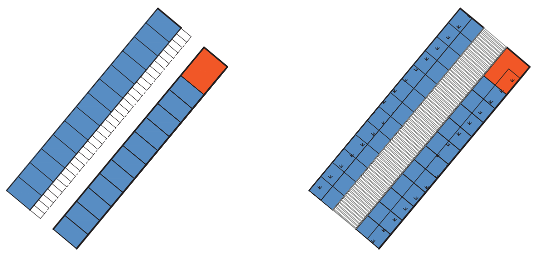


figure 57. Design proposal with the sun and shade for the introducing of terraced building blocks (image by author).

29.3 Greening public space and private gardens

In paragraph "7. Statistical analyses of environmental justice indicators" on page 39 was found that Bloemhof has little green and lots of paved surfaces both in the public and the private space in regard to other neighbourhoods. Such notion is under-scribed with the analyses of the green in the neighbourhoods paragraph "12. Green structure" on page 68, policy documents in paragraph "14. Policy documents" on page 72 and from observation in paragraph "15. Observation and interviews" on page 74. This paragraph deals with how both the public and the private space will be addressed. In the case of Bloemhof greening private space is divided in two categories: one where the private meets the public space and second he private garden. For the first a greening process is proposed where the neighbourhood in close collaboration with the municipality engage in a 'wijkdeal' or neighbourhood deal. The second category deal with the private garden.

Greening semi-private space

The question arises how to intervene in the private space. One could not force residents to start a greening process in their own private sphere. However one could initiate a greening process in which the municipality, housing corporation and residents engage in a 'wijkdeal' or neighbourhood deal. For example the municipality of Schiedam and Breda have made such a deal with neighbourhood residents. Such deals revolving around greening often provides neighbourhood residents the freedom to maintain vegetation in their street to their own liking. The municipality provides tips, material and money. Both commit them-self to keep their end of the bargain in which the 'wijkdeal' acts as sort of contract. In figure 58 an example is given of a brochure how to plant an vertical garden with tips and requirements the residents should meet. Such solution of more green in the street is the realm where both the private and public space meets. A housing municipality plays an active role since it is reasonable for the public space. The benefit of a vertical garden is that it provides for less paved surfaces, more green for evapotranspiration and shade. However such intervention, helpful as they may be, remain a small one. Bigger impact on the high share of paved surfaces lies with the private gardens and inner courtyards.

figure 58. Brochure of a 'wijkdeal' or neighbourhood deal in which the municipality provides a step roadmap to plant a vertical garden. Apart of these tips the residents the brochure also notifies the residents with a few requirements they should meet (Gemeente Schiedam, 2015).

The issue of private gardens with lack of green and lots of paved surfaces needs a slightly different approach as the private space of these garden is private property or property of the housing corporation. Aside the argument of the urban heat island and water storage capacity there are more arguments to convince both parties to spend time and money on greening the gardens. Brochures (figure 59) in regard of greening gardens claim that with clever design and choice of green a green garden does not necessarily needs more time or money to maintain then paved gardens. Only a small part of the garden needs to be paved to sit or walk on. With the use of ground covering plants weed gets no chance to grow and require little maintenance. These plants do not require additional watering as their roots grow deep enough to provide them-self with water. Between the ground covering plants one should plant shrubbery in combination with naturalizing bulbs (Gemeente Vlaardingen, Groei en Bloei Waterweg Noord, & Stichting Boombehoud Vlaardingen, 2016; Haags Milieucentrum, 2011).

The means for an effort to improve private gardens is partly money related as plants and a gardener are needed to provide for advice. But the success of such an improvements is mainly a social effort by residents in the neighbourhood and their willingness to commit themselves to greening their own garden. As such socially mobilizing the residents is key of greening private property. This thesis restrains itself in the methods and theoretical background on social mobilization in neighbourhoods. However from own experience greening proposals start with creating enthusiasm among the residents and municipality or housing corporations convincing them with a good plan and montages to show how a current location could look like after a greening process has taken place. Guiding the communication between different stakeholders and conducting pre-work for a specific location lowers the bar for stakeholders to commit themselves to a greening process. In figure 60 and figure 61 on page 156 is presented from the author's own work a poster on greening a street in the city of Vlaardingen (derived from a own made folder) and how early adapters respond to such ideas.

figure 59. Brochures of greening gardens with relative little means and maintenance. On the left ´meer groen minder tegels! Goed voor het milieu en voor uw gezondheid´ or more green less tiles! Beneficial for the environment and your health. On the right ´Weinig werk en toch een groene tuin!´ or little effort but still a green garden! (Gemeente Vlaardingen, Groei en Bloei Waterweg Noord, & Stichting Boombehoud Vlaardingen, 2016; Haags Milieucentrum, 2011)

figure 60. Poster for greening a street in the city of Vlaardingen to show neighbourhoods residents and the municipality the potential for greening a street (image by author).

figure 61. On the left early adapters who on their own initiative start right away with greening (photo by author). On the right early adapters who create their own montage of their property of how greening would look like (image by UrbinDesign Vlaardingen).

Greening private garden

Greening the private gardens is both an effort by the residents as the housing corporation. With the aid of a gardener private gardens are redesigned to a low maintenance garden. Such an effort provides for the resident a relative easy to maintain garden that gets less warm during hot summer days and are more enjoyable. With removing titles the water storage capacity of the soil increases as water is more able to infiltrate in the surface. In figure 62 the principle of greening the private space. In figure 63 on page 158 an montage is presented of how a paved garden could look like when a low maintenance garden is landscaped

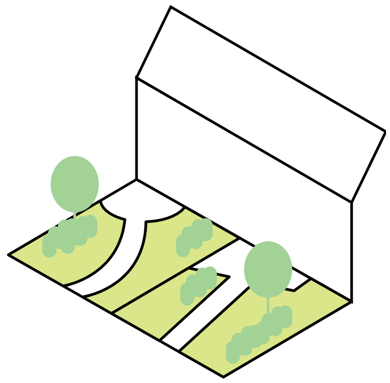
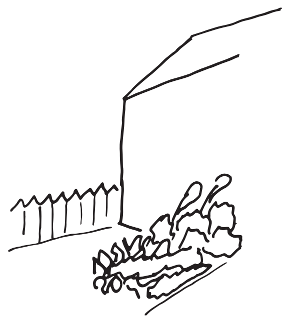


figure 62. Principle of greening the private space (image by author).



Ground covering plants reduce the ground flux of surfaces and provide for evapotranspiration. However during long periods of hot summer days the plants can wither. The chance is reduced when ground covering plants are combined with shade providing small trees (Lenzholzer, 2013, p. 165).

Small trees provide for shade and evapotranspiration. Since the roots of the tree grow deeper the chance of withered is much lower (Lenzholzer, 2013, p. 130).

LEGEND
Description of plants

(GC) Ground covering plants

(UP) Unpaved path

(SH) Shubbery

(NB) Naturalizing bulbs

(TR) Trees

figure 63. Montage of a landscaped garden (image by author).

29.4 Greening public space: streets

The greening of the public space is realized with the use of a neighbourhood deal. The main goal is to provide for more vegetation in both the public space and the border between the public and private. Firstly the vegetation provides for more evapotranspiration, shade, isolation and water-storage capacity. Secondly vegetation creates a more inviting and attractive surrounding in the neighbourhood. In figure 64 on page 159 the principles that are applied are shown with for each a short description. On figure 65 on page 160 and figure 66 on page 161 two montages are made in which the principles are applied. The location to implement these principles revolves around 'Bloemhofplein' and side streets. The sun study from chapterpart "Sun study" on page 93 does not directly suggest additional attention for improving shade as the narrow streets provide for some more shade. However this part of Bloemhof has little vegetation in the street and shows a high percentage of paved surfaces. In figure 48 on page 140 a schematic map of where the design interventions should take place. Such representation would be an ideal situation in which all residents together with the housing corporation and municipality engage in an neighbourhood deal. The design proposal is part of creating a network of more green intensive steers, with more shade interconnected with shade providing squares.

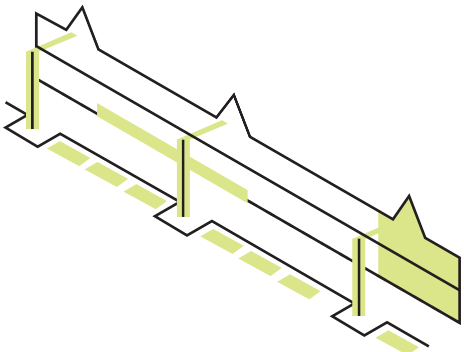
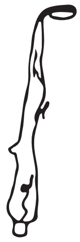
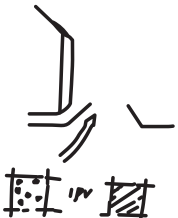


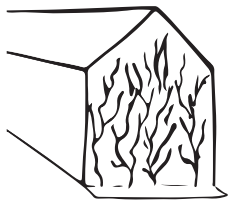
figure 64. Principle of greening a street (image by author).



When there is a lack of space greening street lanterns can provide for an alternative for trees. The effect is less then a full grown tree but should not be neglected. (Lenzholzer, 2013, p. 172).

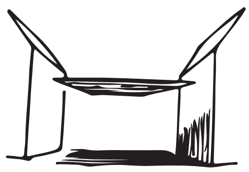


Replacing the paved surfaces of parking spaces in the public space with semi paved tiles provides for more water storage as water is more able to infiltrate in the soil and reduces the ground heat flux (Lenzholzer, 2013, p. 179, ICI Consultants, 2015, p. 154).



A green facade provides shading for the wall behind the green reducing the temperature of the outer wall and the inner temperature (Lenzholzer, 2013, p. 123).

Conscious community takes care of maintenance in the neighbourhood with support of the municipality. The neighbourhood provides for communal services that are managed by the community (Teeuw & TU Delft Faculteit Bouwkunde SMART Architecture, 2010).



An interpretation of build shade elements in the street. In this case overarching climbing plants provide for additional shade on the surface below (Lenzholzer, 2013, p. 140).

figure 65. Montage of the street 'Volierstraat' with on the right the building block 'in de roos' (image by author).

figure 66. Montage of the street 'Kampfoeliestraat´ (image by author).

29.5 Greening public space: squares

As described in part “Public spaces” on page 96 Bloemhof consists of few public spaces that provide for shade or vegetation. In combination with greening the streets and neighbourhood axis a network is created that enables residents in ‘Bloemhof‘ to find cooling in their direct surrounding during hot summer days and to be engaged in outside activities. The design interventions that are proposed range from easy catches like adding a bench in the right spot to square overarching roof. Some squares have already been redesigned but may still score low on the quality of shade providing trees. As these are often already planted and need time to grow and such intervention are left out.

In figure 67.a figure 67.b on page 163 two montages are displayed of ‘Patrimoniumhof‘ and Eemstein. Both are public spaces or courtyards that show quality in the form of well maintained vegetation. However there is a lack of use for coolness as their are no benches that catch shade during midday. Adding benches is a small intervention. Nonetheless such addition small as it may increases the potential to provide a public space to escape from heat during hot summer days.

In figure 68 on page 164 the public square of Eemstein is redesigned. The square is currently very much paved and in general has a saddening appearance. However the square does over few benches within shade cast by trees and a small playground. The design intervention removes the pavement and replaces these with grass. Additional vegetation is introduced in the combination with a communal garden maintained by the neighbourhood residents. The playground is expanded upon and additional benches are added.

Patrimoniumhof

2e Balsiemstraat - Hortensiastraat

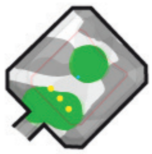


figure 67.a. Montage of ´Patrimoniumhof´ with benches positioned when the shadow is casted by the trees around midday (image by author).

figure 67.b. Montage of courtyard between ‘2e Balsiemstraat‘ and ‘Hortensiastraat‘ positioned when the trees cast their shadow around midday (image by author).

Eemstein

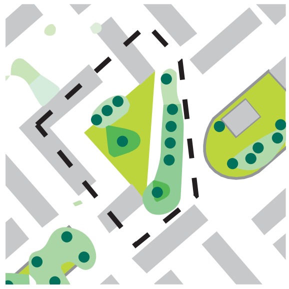
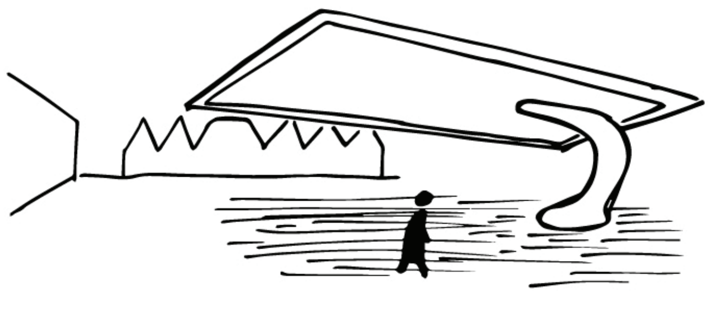


figure 68. Montage of Eemstein with the introduction of more unpaved surfaces, vegetation and a communal garden the public square provides for a more diverse program (image by author).

29.6 Open roof 'Bloemhofplein'

The public square 'Bloemhofplein' provides for lots of benches, playgrounds and trees and is regarded as one of the better public spaces. However many trees are of young age and as such provide for little shade. It is therefore argued that a temporal or permanent solution in the form of an open roof that provides for shade on the playground and benches. Such roof would also provide for protection from rain and could act as a collector of the water temporally storing it. In consideration should be taken that protection from rain might attract youth that dominates the square with might cause nuisance to their direct surroundings. In figure 69 on page 166 a reference is shown of a shade providing roof. In figure 70 on page 166 a montage is presented of how such a design could look like.



The benefit of a shadow roof that rests on few columns is that it provides for shade while it does not block the overview of the square or the ability to move. When such a roof is well designed it can provide for identity of a public space. It should be taken into account that the roof storages some heat which can contributing to the nocturnal urban heat island (Lenzholzer, 2013; van der Hoeven & Wandl, 2015).

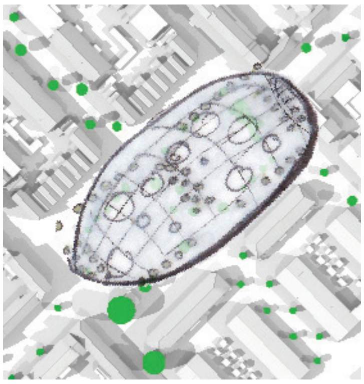


figure 69. Forest of hope by El Equipo De Mazzanti is a centre in the outskirts of Bogotá where the community can take part in sports and academic activities (Loreto, unkown).

figure 70. Below an impression of the open roof construction providing shade for the playground and benches (By author).

30. Conclusion

This chapter presented design interventions for the neighbourhood Bloemhof based upon the analyses of urban and population characteristics a general strategy is described. The design interventions that are implemented work on constructing new building blocks and the private and public space. The aim of this chapter was to answer the research question of:

4. *What are urban heat island adapting and mitigating design principles and how can these be applied to reduce the urban heat island in socially deprived neighbourhoods of Rotterdam?*

The main aim in regard to the research question of the design interventions are to both address the urban heat island with adapting and mitigating design proposals while at the same time address other issues in regard to social deprivation, water storage capacity and future development. As such the design interventions range from small proposals in which a few benches carefully placed to replacing building blocks.

The design principles that are used attribute to the physical theory of the urban heat island of evapotranspiration and heat storage. In regard to evapotranspiration the design principles in general terms revolve around introducing more vegetation and water. The design principles that address heat storage reduce building mass and the use of dark and impervious materials. Within the context of Bloemhof combining these aspects firstly address reducing the paved public and private realm and replacing them with unpaved materials. This reduces the heat storage capacity of materials. The replacement consists of different forms of vegetation that provide for evapotranspiration and additionally shade to block direct radiation from the sun reducing the heat storage process. With the design principle of introducing water one should be aware the water can have an exacerbating effect on the urban heat island. As such water bodies should receive enough shade and should be combined with vegetation.

However the aspect of reducing building mass is in opposition of future development of Bloemhof. As increased building mass provides for more residents that can maintain services in the neighbourhoods. As such when more building mass is introduced urban heat island adapting and mitigating design principles must be an integral part of the design. Within this chapter the use of a courtyard building typology in combination with vegetation on the facade and in the inner courtyard is the general principle applied here as it reduces the negative effect of increased building mass.

The introduction of new building blocks with higher density improves upon the diversity within the neighbourhood. An range of dwellings of different sizes accommodates to people of different income and family composition. The existing building blocks are in possession by the housing corporation and covers demolishing an reconstruction costs. Firstly is argued that such a investments provides the benefit of improving the liveability of the neighbourhood as a whole. Secondly with almost doubling the amount of dwellings the rent paid by tenants increases, generating more income for the housing corporation. By demolishing existing houses the current tenants should be accommodated in the newly building block without increasing the current rent they pay.

The improvement of both the private and the public space in terms of urban heat island is at the same time an improvement of the liveability of the neighbourhood. Vegetation can help building the community as communal gardens can provide for more social cohesion, part of new building blocks design is social control and residents can become more engaged with their direct surroundings. Aside from this social aspects residents in the neighbourhood are more able to escape heat during hot summer days since both the public and private outer space provides for coolness. As such the severity of the environmental hazard of high air temperature becomes much less reducing disproportionate exposure and diminishing issues of environmental injustice.

Research conclusions

31. Introduction

This thesis focused on the question:

How is the urban heat island related to social deprivation, why is such a relation an issue in the city of Rotterdam and how can urban design mitigate and adapt to the urban heat island on a neighbourhood scale?

In short answer to the main research question it is argued that the urban heat island is related to social deprivation as the spatial distribution of the urban heat island is intense in socially deprived neighbourhoods. These neighbourhoods show urban characteristics that have an exacerbating effect on the urban heat island and population characteristics that indicate social deprivation. People who live in these neighbourhoods are more exposed and vulnerable to high air temperature during hot summer days. Firstly the neighbourhood, due to it's urban characteristics, lack any room to find coolness during hot summer days in both the public as the private. Secondly these people are more vulnerable as they suffer from bad health and lack the means to protect themselves from high air temperature. As such the statement is made that these people are disproportionately exposed to the urban heat island and such an exposure is an issue of environmental justice. With the introduction of urban heat island mitigating and adapting design principles the urban characteristics that have an exacerbating effect on the urban heat island are reduced. At the same time firstly these design principles provide in both the public as the private space room to escape from high air temperature. Secondly the principles attribute to improving social cohesion through a neighbourhood deal. Thirdly the introduction of new building blocks and water bodies answer to trends in population growth, the wish to attract more higher educated residents, housing diversity, improving pressure on shops and services and water storage and transportation capacity.

To support such a conclusion 5 sub question were defined all contributing to a final answer.

In order to answer this research question 5 sub questions were defined all contributing to a final answer:

1. *What is the urban heat island what are its effects and how are these related to environmental justice?*
2. *What characteristics of the urban fabric have an exacerbating effect on urban heat island?*
3. *What are urban heat island adapting and mitigating design principles and how can these be applied to reduce the urban heat island in socially deprived neighbourhoods of Rotterdam.*
4. *What urban typologies in the city of Rotterdam are more exposed to the urban heat island?*
5. *What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?*

32. Research conclusions

1. What is the urban heat island what are its effects and how are these related to environmental justice?

The urban heat island is the phenomenon where the air temperature in the city warms up during the day and remains relatively warmer during the night compared to its rural surroundings. The urban heat island can be explained with the energy balance. This is an equation that describes how energy is transferred from and to the earth's surface. The factors that provide the energy are the sun and anthropogenic activities. Through convection, evapotranspiration and heat storage the energy is then transferred back into the atmosphere. The factor heat storage is responsible for the nocturnal air temperature as energy is remitted from materials over time heating the atmosphere.

The heat, or high air temperature, effects human well beings thermal comfort, air pollution, organic life and air pollution. In regard of thermal comfort, high air temperature influences the human system of thermo regulation. When temperature rises to high the human body is unable to lose heat which causes:

- heat stress,
- sleep disturbance,
- decreased ability to concentrate,
- decreased learning capabilities, and
- decreased labour productivity.

The urban heat island is unevenly distributed among the city, differently affecting the population. The relation between socio-economic characteristics of the population and the urban heat island can be an issue of environmental justice where certain groups suffer more from the urban heat island then others. The characteristics of the groups are linked to social deprivation whereas people of low income and ethnicity often live in deprived neighbourhoods and due to urban characteristics there is a strong urban heat island with high air temperatures. Residents in these neighbourhoods suffer from heat stress as the neighbourhood does not offer any opportunity to escape high air temperature as there are no parks, shaded places and houses are of bad quality. Such relation is a disproportionate exposure to the environmental hazard of temperature and as such an issue of environmental justice.

2. What characteristics of the urban fabric have an exacerbating effect on urban heat island?
Urban characteristics that have an exacerbating effect are;

- a lack of vegetation,
- widespread use of impermeable surfaces,
- increased thermal diffusivity of urban materials,
- low solar reflectance of urban materials,
- urban geometries that trap heat,
- urban geometries that slow wind speeds, and
- increased levels of air pollution and increased energy use.

These characteristics either reduce evapotranspiration or convection or increases heat storage.

3. What are urban heat island adapting and mitigating design principles and how can these be applied to reduce the urban heat island in socially deprived neighbourhoods of Rotterdam?

The design principles that are used attribute to the physical theory of the urban heat island of evapotranspiration and heat storage. In regard to evapotranspiration the design principles in general terms revolve around introducing more vegetation and water. The design principles that address heat storage reduce building mass and the use of dark and impervious materials. Within the context of Bloemhof combining these aspects firstly address reducing paved materials in the public and private space and replacing them with unpaved materials. This reduces the heat storage capacity of materials. The replacement consists of semi-paved surfaces and different forms of vegetation that provide for evapotranspiration and shade to block direct radiation from the sun reducing the heat storage. With the design principle of introducing water one should be aware the water can have an exacerbating effect on the urban heat island. As such water bodies should receive enough shade and should be combined with vegetation.

4. What urban typologies in the city of Rotterdam are more exposed to the urban heat island?

Three building typologies of a courtyard, three floor apartment and linear building block are assessed on urban characteristics of use of materials, vegetation and urban form and inner door temperature model. The outcome remains ambiguous in claiming a correlation between a specific urban typology and vulnerability to the urban heat island. Such an analyses requires a quantitative methodology to analyse the relation between the urban heat island and urban typology.

However it is argued that the use of urban form and its influence on the micro climate follows research conclusion by dr. ir. Taleghani whereas the courtyard typology provides for the best micro climate performance. This conclusion is taken into account as part it is implemented in the design to private for adapting design principles for the neighbourhood of Bloemhof.

5. What are environmental justice indicators on a neighbourhood level and how do these apply to the city of Rotterdam?

The indicators of environmental justice are categorized according to an environmental hazard, urban characteristics or population characteristics. Indicator for the environmental hazard is temperature subdivided by air and land surface temperature. The urban characteristics are:

- density,
- vegetation,
- land use / land cover, and
- urban fabric indicators.

The population characteristics are

- age,
- ethnicity,
- education,
- health, and
- income.

The indicators that apply for Rotterdam is dependent on the data available. The data used is based upon the dataset provided by dr. ir. Ronald Wall and the social index by the municipality of Rotterdam. The first mainly provides indicators for environmental hazard indicators and urban characteristics and the second population characteristics. The environmental justice indicators that are applicable for Rotterdam are:

With the use of a Pearson's Correlation analyses and stepwise linear regression these indicators are statically analysed. The outcome is that the relation between the environmental hazard of temperature and urban characteristics follow urban heat island theory. Correlating indicators are:

Floor space index (R^2 = 0,423)
Total green (R^2 = 0,650)
Sealed soil ratio (R^2 = 0,429)

The population characteristics of property value and social index indicators of social bonding and living environment show the strongest correlation with temperature.

table 20. Overview of the environmental justice indicators that are applicable for Rotterdam.

Environmental hazard	Urban characteristics	Population characteristics
• Temperature • Excess air quality	• Paved open space • Open space • Open water • Floor space index • Building year • Total green • Dwellings per hectare • Sealed soil ratio	• Income • Property value • Social index – capabilities (sufficient language proficiency, sufficient income, good health, education level) • Social index – social bonding (employment and school, social contact, social and cultural activities, social commitment) • Social index – participation (experience connection, mutations) • Social index – living environment (pollution an nuisances, adequate services, fitting houses, lack of discrimination)

Social bonding (R^2 = 0,315)
Living environment (R^2 = 0,358)
Property value (R^2 = 0,371)

For each of these three indicators the neighbourhoods are identified that score high on temperature and low on property value, social bonding and living environment. A low score is considered as social vulnerable. There are fifteen neighbourhoods that are considered social vulnerable for each of the three indicators. This combination indicates an issue of environmental justice as these are disproportionately exposed to the environmental hazard of temperature.

However to make a stronger case, the environmental justice indicators of capabilities (R^2 = 0,236) should also strongly correlate as it consists of indicators of health and education. It is therefore argued that the identified neighbourhoods that do not meet the threshold of income and score low on indicators of loneliness, quality of life and medical conditions are the neighbourhoods that are most exposed to the urban heat island with a population that is most vulnerable. As a result the city district of Feijenoord with five neighbourhoods are considered as most exposed to the urban heat island and as such in these neighbourhoods the issue of environmental justice is most severe.

33. Applicability of environmental justice and addition to academic knowledge

The concept of environmental justice in relation with the urban heat island phenomenon is a previously unknown theme within national academic body of knowledge. The researchers van der Hoeven and Wandl explored the spatial relation between social and physical characteristics and the urban heat island. In their research 'Hotterdam' the researchers proved how concentrated groups of elderly (age > 75) in combinations with building age are more vulnerable to the urban heat island as mortality rates show. Firstly the thesis expanded on the spatial relation by using a wider set of social characteristics per neighbourhood. Secondly the introduction of the concept of environmental justice on the city scale, in relation with the urban heat island, was prior to this thesis a non-researched concept within the national context.

Reviewed research from the perspective of the spatial correlation between urban heat island and socio-economic factors don't consider such a correlation as an issue of environmental justice. The results of these researches fit the element of environmental justice that describes the disproportionate distribution of an environmental hazard, in this case the exposure of urban heat island to vulnerable groups (Araujo et al., 2015; Dousset et al., 2011; van der Hoeven & Wandl, 2013; van der Hoeven & Wandl, 2015). Introducing the concept of environmental justice in combination with the relation between the urban heat island and socio-economic conditions broadens the scope of what such relationship means.

In regard of climate change it is argued, based upon reports of the European Environmental Agency (EEA), International Panel on Climate Change (IPPC) and United Nations, that climate change, increasing urbanization and rise of mean temperature and temperature extremes will have an worsening effect on the urban heat island and social consequences (Collins et al., 2013; EEA, 2012; United Nations, 2014). This thesis dealt with how the social consequence of the hazard of urban heat island is an issue of environmental justice on the city scale. The notion that climate change has worsening effects on the population would be embraced. Temperature rise would be felt by the population of Rotterdam as a whole. However the negative effects of rising temperature would be disproportionately felt by those who dwell in socially deprived neighbourhoods.

In the literature research was found that researchers argued that more conclusive spatial correlations need to be produced, with higher resolution and more up-to-date data. (Bulkeley, Carmin, Castán Broto, Edwards, & Fuller, 2013; Bulkeley, Edwards, & Fuller, 2014; Huang, Caenasso, & Zhou, 2011; Pearsall & Pierce, 2010). In practical terms the environmental justice concept on the city scale provides on such a notion. Both data on population characteristics and urban characteristics are easily accessible and of high resolution. By finding a correlation between population characteristics and an environmental hazard this thesis provides for additional knowledge for within the Dutch context. The addition are more conclusive spatial correlations between the urban heat island and population characteristics with higher resolution data. Admittedly similar research uses similar indicators and on this matter this thesis provides nothing new other than that the concept of environmental justice is applicable in a Dutch context.

34. Recommendation for further research

This thesis does not deal as much with urban form theory as available theory would allow for. The notion that urban form could trap heat or slow wind speeds could have more extensive research as it could influence design decision. One could argue that certain orientation of building block is beneficial as dominant wind direction may cool a building block. The use of urban land climate zones or in general deeper analyses of the urban form for Rotterdam South and its relation to urban heat island theory could have some more extensive work. A more extensive analyses combing in the urban land climate zone theory, urban heat island theory of urban form and its relation for Rotterdam South would give a better idea of how these different form preform in terms of urban heat island.

The thesis deals with firstly environmental justice and, among other indicators, use indicators of health. With the use of spatially related data regarding specific conditions that are related to heat stress, cardiovascular conditions or high blood pressure on the building block level would allow for more precise analyses where problems in relation to high air temperature might arise. Secondly conducting a survey city wide among residents how they perceive there house and direct surrounding in regard to high temperature might provide for a clearer picture on the severity of such environmental hazard. As it remains somewhat the question; how bad is high air temperature a certain number of days during the year really? Thirdly regarding the latter recommendation gaining data on the cause of death and analyses of this data in relation to high air temperature provides for insight on the severity of high air temperature.

A nation wide research could be conducted on the relation between environmental justice and the urban heat island. This would provide insight if there are more neighbourhoods where an issue of environmental justice exists. If this is the case these neighbourhoods could be compared with questions like; are there commonalities between different neighbourhood, do they share diverse on urban characteristics and population characteristics?

The urban heat island is a phenomenon that manifests itself for one part during nocturnal hours. However the used data for land surface temperature by remote sensing provides only an indication for the nocturnal urban heat island. As such knowledge of hourly nocturnal air temperature with a high resolution provides for data to assess neighbourhood performance during the evening and the night. While there is some data available these are mainly based on local weather stations and provide data for its direct surroundings. Therefore measuring the nocturnal urban heat island needs a dense network of measure points to gain a clear picture of how the nocturnal urban heat island is distributed.

35. Process Reflection

During the course of the thesis choosing a research location took considerable time. In first instance the aim was to conduct a research for a city within Europe. This was refrained because lack of data availability and ease of traveling. A travel to Warsaw learned that, while there is research on the urban heat island, the city is considered as quite egalitarian. Therefore a disproportionate distribution of the urban heat island among lower income groups was not expected to be found.

Therefore Rotterdam was chosen as a research location as two of the three mentors already did research on Rotterdam regarding the urban heat island. This would indicate more knowledge and data to build upon and the city is easy to travel to.

Main issue of this thesis in terms of process is the choice of a clear research aim and methodology on the level of a city district. During the P2 presentation and in the thesis plan it was somewhat unclear what part of Rotterdam the thesis was about to address. Not knowing the location was not a problem, but rather not knowing what research methods the thesis would use when the location was found. As a result the thesis moved back and forth in analysing the city on the scale of the building block and the city district. However this should not have been a problem if closer attention was given to different research method to either analyse the city on district scale, neighbourhood or block level in an earlier stage. When the choice for a city district or part was made it would be easier to apply research methods for each scale level. However there was quite a good guess that the thesis would address on of thee three pre-war exapansion area. As such picking up the book ‘Transformatie strategieën voor verouderde stadswijken’ in an earlier stage would prove beneficial as it gives leads for sources on theoretical background and methods. Therefore with hindsight the used analyse method of networks and density according to Berghauser Pont and Haupt and assessing public spaces would have been conducted across multiple neighbourhoods for the city district Feijenoord. Especially the work by Berghauser Pont and Haupt provides for a clear categorization of building typologies according to ground and floor space index. When used a fuller picture could be given of how different urban typologies preformed in regard to the urban heat island or what difference there could be found among building blocks of similar typology.

36. Reflection

The relationship between research and design

The phenomenon of the urban heat island is something one can separable study and research with attention for the urban fabric but little related to social components. This graduation thesis shows how the relationship between the research and design is embedded within the study of both urban and population characteristics. Firstly the factors that influence the urban heat island are the lack of vegetation, the use of paved and impermeable surfaces, the configuration of buildings and high building mass and low reflective of used materials. Such factors are part of the urban language the urban designer has to his disposal. Secondly the population and social characteristics of a neighbourhood in terms of demographics and social issues are defining factors whether the urban heat island is an issue of environmental justice. Such a issue would be a theme for the urban designer to address.

The graduation research shows that within the context of the Netherlands the urban heat island is an emerging phenomenon and makes a case for the existence of environmental justice. However one could still question its severity. As such when proposing urban design principles and intervention that would mitigate and adapt to the urban heat island and at the same time improve a neighbourhood liveability and functioning in broader terms. Therefor the graduation thesis took a broader look at the neighbourhood. As such the design principles are linked to both the urban heat island and other issues and opportunities.

The relationship between the theme of the graduation lab and the subject/case study chosen by the student within this framework (location/object)

The graduation lab of smart cities and urban metabolism is connected with the understanding of the metabolism of urban environments, the relationship to landscape systems theory, and the performance of different elements, infrastructure and systems, in reality to the spatial quality, environmental sustainability and social wellbeing of future cities. The flow of materials and energy are analysed subdivided by; demographics, air, water, food, biota, mobility, cargo, building materials, waste and energy.

The urban heat island is related to this because it’s all about energy. The city by warms up due to the sun’s energy and anthropogenic activities. This increases the temperature of the city surface and air temperature compared to its rural surroundings. There is plenty of research on the urban heat island and how through design the negative effect can be mitigated or adapted. But the graduation thesis is also about social wellbeing. Since literature suggests that their remains a limited understanding of the effects of urban heat island connected to social-economic and environmental justice dimensions like poverty, inequality and opportunity.. The graduation thesis deals with this issue by researching the relation between Rotterdam’s socially deprived neighbourhoods and the urban heat island.

The relationship between the methodical line of approach of the graduation lab and the method chosen by the student in this framework.

The urban designer deals with the complex reality of the city through research and design. The methodological line of approach is one of designing through the layers and the visualization of flows of energy and materials. The chosen methodological line is one of methodological triangulation as it tries to conduct research by using both quantitative and qualitative research methods. As a result of this method quantitative data could be verified by qualitative and vice versa from which design interventions were proposed.

The relationship between the project and the wider social context

The relationship of the master thesis and the wider social context is translated through the concept of environmental justice in relation to the urban heat island. The urban heat island is recognized as a hazard that potentially can harm city dwellers. A distinction is made that city dwellers with lower income living in socially deprived neighbourhoods are more exposed and more vulnerable to high surface temperatures. Such an issue is proclaimed as an issue of environmental justice and opens a broader societal discussion. The wide encompassing trends of climate change and an increase of inequality due to the current political economic reality of both neoliberalism and globalisation, disproportionate exposure by environmental hazard to lower income groups within the city needs a political answer on a regional and local level. (RIVM), R. v. V. e. M. (2012). GGD-richtlijn medische mileukunde.

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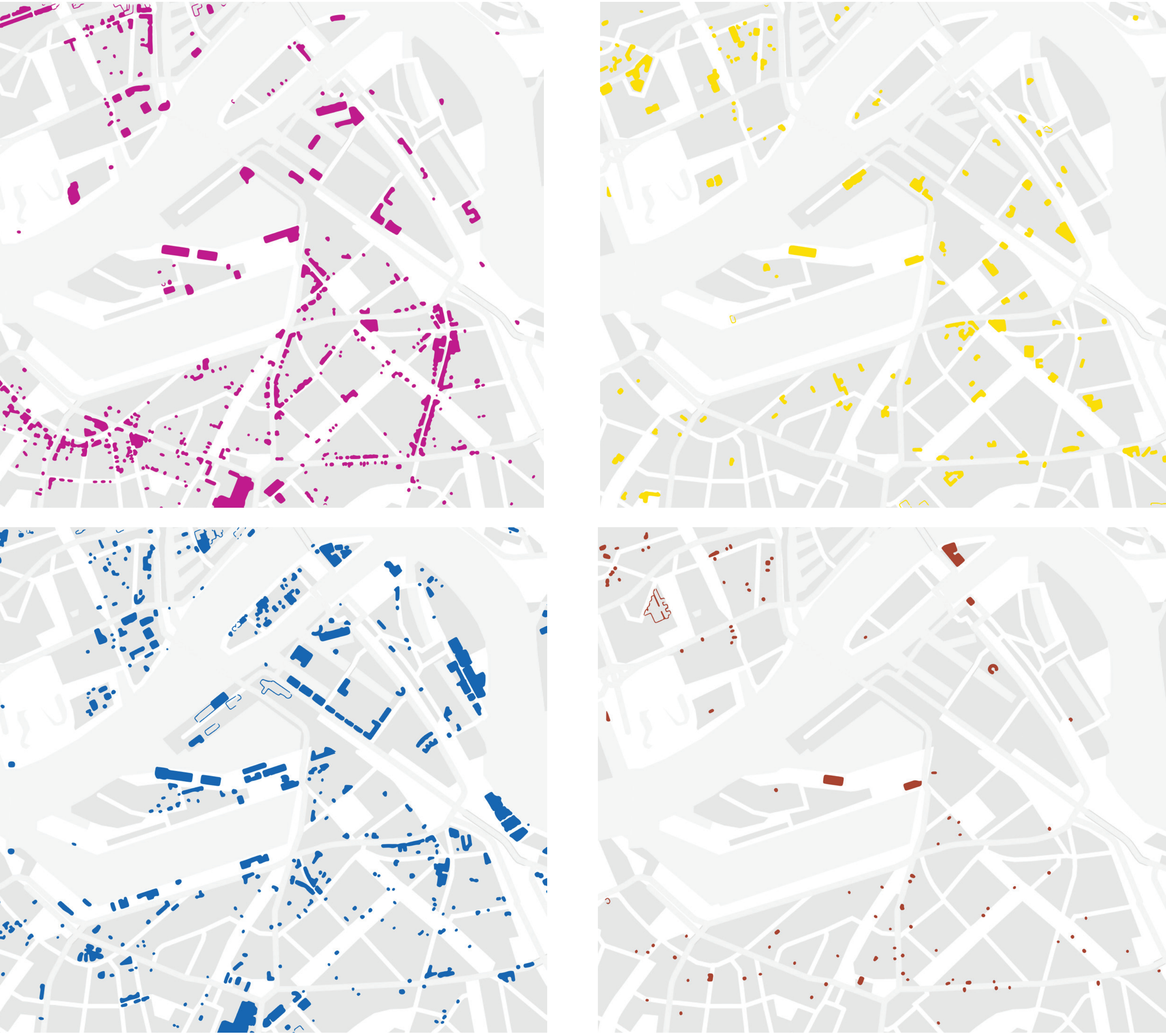
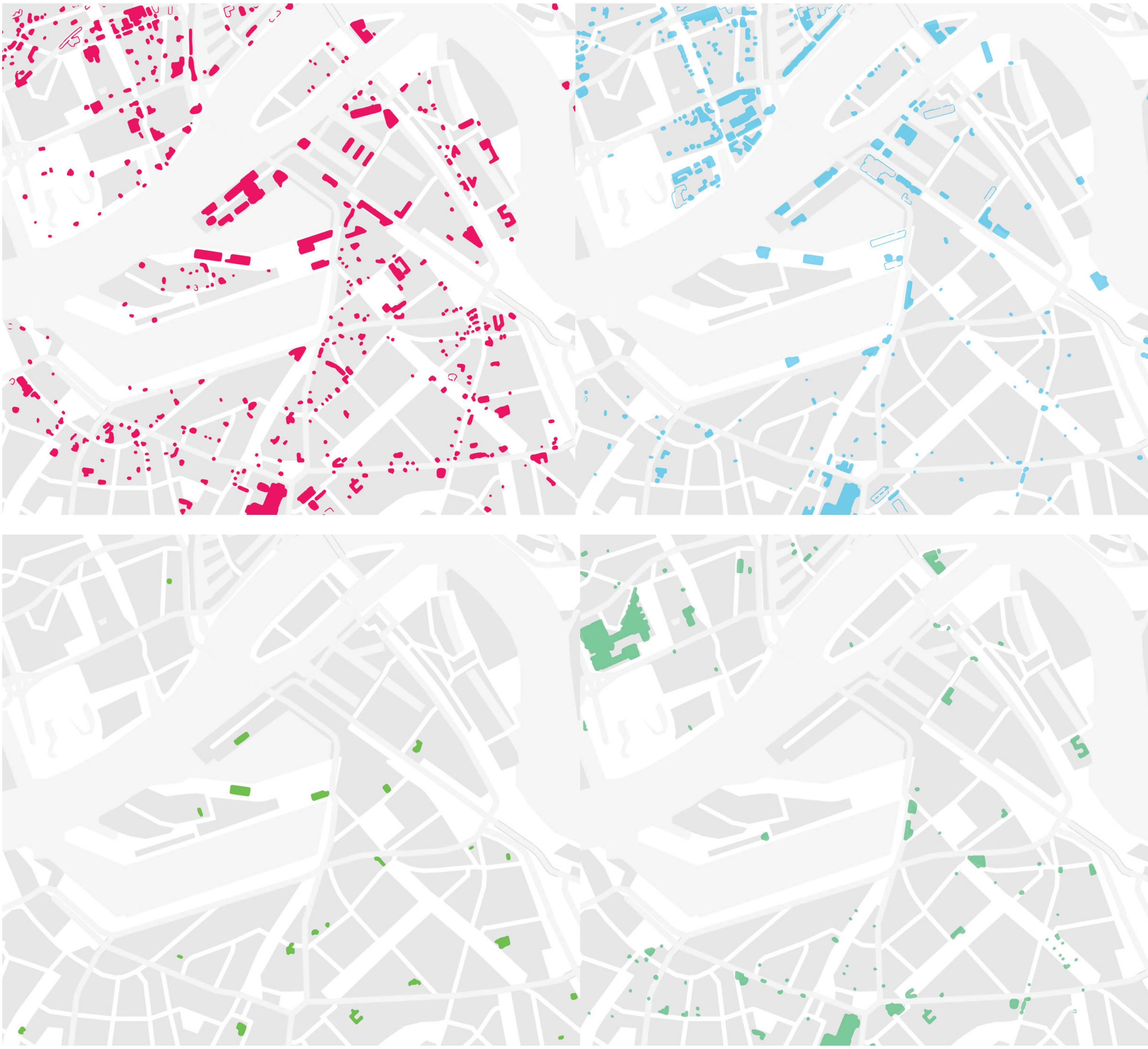
Appendix

I. Functions





II. Interviews

Interview with drs. Susanne Buijs

Interview with drs. Susanne Buijs on 31 March at municipal office of Rotterdam cluster city development in 'De Rotterdam' Galvanistraat 15, 3029 AD Rotterdam. Drs. Susanne Buijs is in the transcript shortened to S.B. and the interviewer to Int.

S.B. makes the general remark: 'the municipality has the wish to attract higher educated people to the city as the education level is considered as to low.'

Int. Can you describe how people are affected by high air temperature and to what extend this relates to social issues in a neighbourhood?
S.B. 'Elderly don't open the windows as they think the air draught makes them ill. Neither do they easily open the door as they are afraid they will be robbed'.

Int. What do you think are good urban heat island adaptation or mitigation measurement for the urban heat island.
S.B.: 'Adaptation measures to the urban heat island that are proven to be efficient are those on a social level such as raising awareness of the dangers of high air temperatures and social control in the neighbourhood that people tend to watch each other'

Int. Can you give an example?
S.B. 'Neighbourhood gardens are good activators of the neighbourhood and therefore recommended. However there will always remain people who are unwillingly to participate or almost impossible to reach.'

Int. And apart from the social are there also physical examples you can give?
S.B. 'Simple solution are remove a tile and replace it with greenery'

Interview ir. Annemarie Nolson
Interview with asset manager ir. Annemarie Nolson on 13 May at housing corporation office Woonstad in Rotterdam at Rochussenstraat 21 3015EA Rotterdam. ir. Annemarie Nolson is in the transcript shortened to A.N. and the interviewer to Int.

Int. What is the vision of Woonstad in general terms with neighbourhoods of Bloemhof.
A.N. ‘An important notion is that many of the terraced houses have shallow foundation. This causes issues, but for the coming decade we don’t have any plans to restructure the terraced houses but we are considering after this period of time to have closer look at how to adjust to housing stock. In general terms we consider the low density as a quality that we would like to preserve. However there are areas with small streets and a high parking pressure. The notion of the national program for Rotterdam South in terms of increase in number of houses we interpreted as adding more diversity to the neighbourhood. We are not considering increasing density.’

Int. Since the thesis is concerning with urban heat island. Have you heard that people experience their house as to warm, or their surroundings?
A.N. ‘I have not heard of such concept nor that people suffer from high air temperature during the summer.’

Int. Which houses are renovated and what kind of renovations were these.
A.N. ; We have renovated some of the houses of the Kossel I en II in terms of fencing off the alleys and to improve the locks and doors. In general the houses, are since they are not old, not so well renovated. In terms for courtyard block the inner courtyard is considered renovating in collaborations with the residents.‘

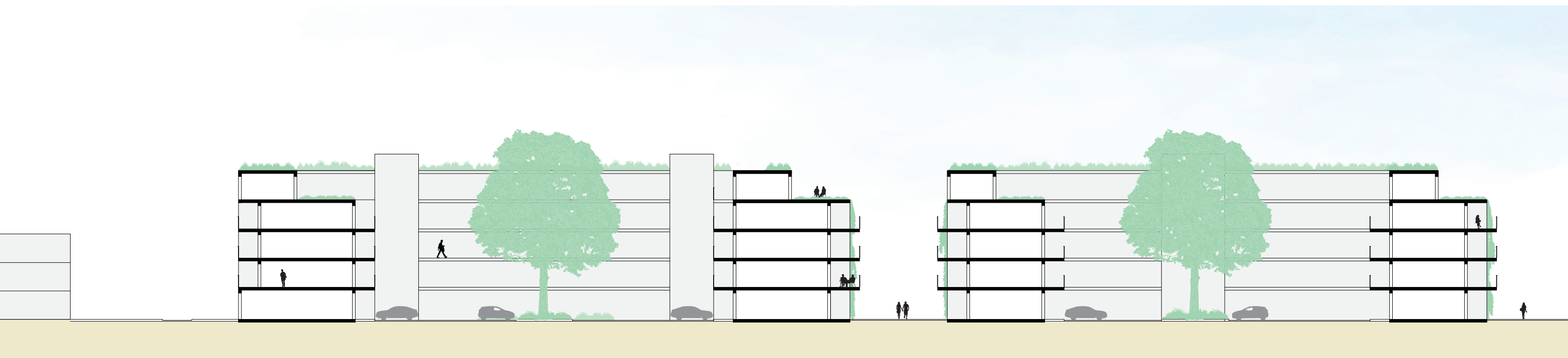
Int. The neighbourhoods, according to policy documents and statistics seem to suffer from burglary, vandalism, or nuisance youth. What do you think of such notions?
A.N. ‘I would under scribed such notion.’

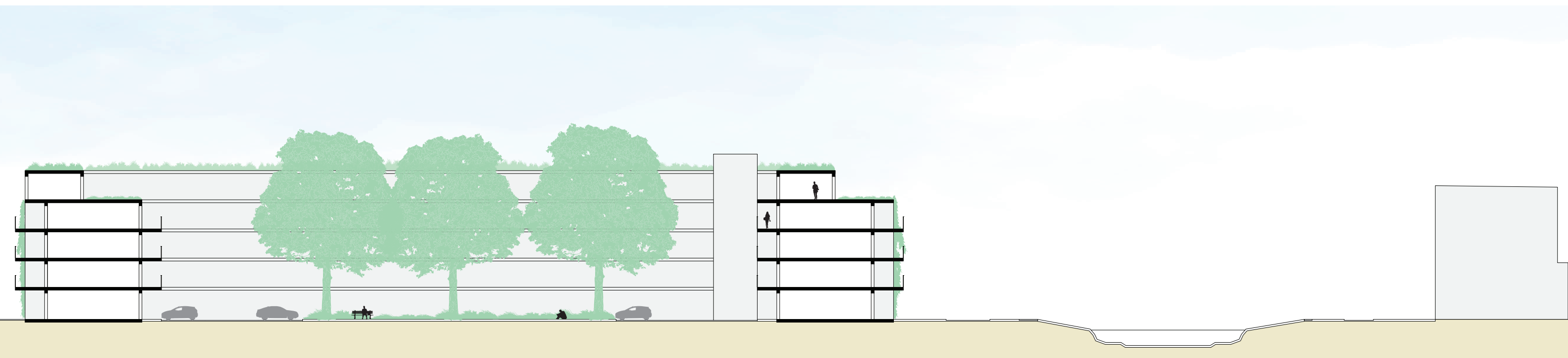
Int. Are there any social program initiatives like collective gardening?
A.N. We are somewhat sceptic of such programs. It is hard to find people who are willing to commit themselves and when such rather become a threat then an opportunity.

Int. Public spaces are fenced off, is there an explanation for why?
A.N. The public space indeed lacks some quality, however there are some quite beautiful spaces which. The fencing off of these public spaces has to do with nuisance youth.

Int. Other comments?
A.N. Shops are under pressure as it is a national phenomenon. The Putsebocht is currently be restructured with terraced houses.

III. Cross section courtyard building block





IV. Theoretical paper

Is the urban heat island an issue of environmental justice?

A literature review on the relationship between the spatial distribution of urban heat island and environmental justice on the neighborhood scale.

This literature review paper investigates the relationship between the urban heat island (UHI) and environmental justice. The UHI is the phenomenon of cities warming up during the day and staying warmer at night then its rural surroundings. The two main causes are the usage of impermeable and dark materials. UHI causes higher energy demand for cooling, health issues, heat stress and higher mortality rate among elderly. Expected is the increase of UHI due to the globally rise of mean temperatures. Environmental justice is the struggle against the inequitable distribution of environmental hazards and goods and secondly efforts to increase access of all populations to the environmental decision-making process. Both UHI and environmental justice can be correlated with socio-economic characteristics on the neighborhood scale. Researches on such correlation define indicators who can be accommodated in the categories population and urban characteristics and environmental hazard. In answer of the question the relation is that the UHI is an environmental hazard that is uneven spatially distributed on the city scale and more intense in neighborhoods where vulnerable groups such as the elderly, low income and ethnic groups reside. Such a disproportionate exposure to environmental hazards to certain groups meets the definition of environmental justice and thus UHI and environmental justice can be related to each other.

Key words – urban heat island, environmental justice, indicators, and climate change

A3U022, Theory of Urbanism

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01, 2016

Introduction

The purpose of this paper is to investigate if there is a relation between the urban heat island (UHI) and environmental justice. Both spatially manifest themselves on the city and neighborhood scale and can correlate with the urban population and urban characteristics. The main question is: what is the relation between the concept of UHI and environmental justice and how does this relation spatially coincide?

To answer this question a literature review is conducted on research on both concepts by scanning the internet in both English and Dutch on related key words as urban heat island and environmental and social justice indicators.

First the paper introduces the UHI and its effects without going to much in detail on technical and physical aspects. Secondly the concept of environmental justice is introduced. The paper raises the question whether exposure to the UHI is an issue of environmental justice. Expanded is what indicators research on both concepts use to spatially represent any correlation. How are these indicators different and comparable to each other? In the discussion this comparison is being discussed and argued that the UHI could be an issue of environmental justice.

This paper does not touch upon the political context within each country the reviewed research paper was conducted. The reader should be aware of this since the reviewed research has a strong social component to it. The U.S.A. is regarded as a much less inequitable society and Europe as more equitable. Thus research on the relation between the UHI and social components probably brings different results.

Urban heat island

In this paragraph the UHI will be described, how it affects city dwellers life and how this can be an issue of environmental justice.

Many cities have the tendency to warm up during the day and remain warm during the night. This is also known as the urban heat island effect (UHI) and is the spatial distribution of relative higher nocturnal near ground air temperature in a city compared to its rural surroundings (Gartland, 2008; Kiesel, Orehounig, Soshtari, & Mahdavi, 2012). Main causes of the UHI are the use of impermeable and dark materials. With the use of impermeable materials moisture is not available to evaporate the sun’s heat. Dark materials with a low albedo can reach temperatures up to 88 °C in contrast to vegetated surfaces who only reach 18 °C. Besides these causes there are other urban characteristics that contribute to the urban heat island. In table 1 an overview is given of the main factors contributing to urban heat island (Gartland, 2008). The UHI is often positively correlated with city size (Oke, 1973). This heat affects human well beings in respect of thermal comfort, heat stress, air pollution, organic life and energy consumption (Rahola, Oppen, & Mulder, 2009).

Table 1. Urban and suburban characteristics important to heat island formation (Gartland, 2008, p. 16).

Characteristics contributing to the urban heat island
Lack of vegetation
Widespread use of impermeable surfaces
Increased thermal diffusivity of urban materials
Low Solar reflectance of urban materials
Urban geometries the trap heat
Urban geometries that slow wind speeds
Increased levels of air pollution
Increased energy use

The effects of UHI have been quite extensively researched. Intense UHI leads to more energy use for cooling by air conditioning (EEA, 2012b; Li, Shang, & Cao, 2010; F. van der Hoeven & Wandl, 2013). During heat waves of 2003 in Paris and 2006 in Rotterdam a significant amount of elderly died. Researchers directly link this to the UHI (Dousset et al., 2011; FD van der Hoeven & Wandl, 2015). In Sao Paulo urban areas with intense UHI show more infection cases of dengue fever then relatively cooler areas figure 1 (Araujo et al., 2015). Higher air temperatures due to UHI have a positive effect on formation of ozone which leads to health complains (Stone, 2005). The relation between mortality due to extreme heat can be found across all continents (Harlan & Ruddell, 2011).

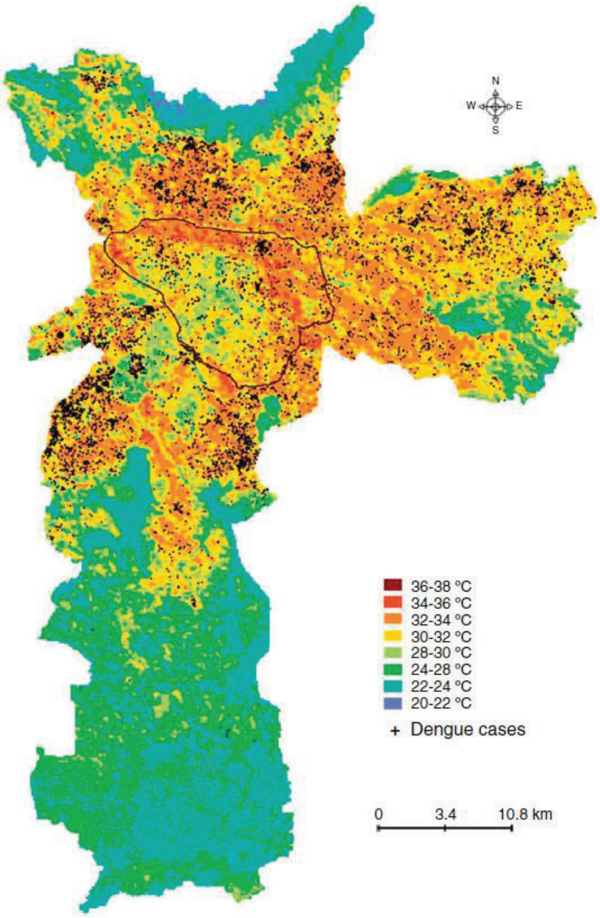

Figure 1. An example of how land surface temperatures correlates with dengue cases and slum-like areas in the city of São Paulo (Araujo et al., 2015, p. 148).

In reports of the European Environmental Agency (EEA), International Panel on Climate Change (IPPC) and United Nations remarks are made that climate change, increasing urbanization and rise of mean temperature and temperature extremes will have an worsening effect on UHI and social consequences (Collins et al., 2013; EEA, 2012a; United Nations, 2014). Globally the UHI will become increasingly intense and thus potentially a serious problem.

Studies in sociology, health, and epidemiology have investigated the link between the spatial distribution of heat related deaths and the UHI (Dousset et al., 2011; F. van der Hoeven & Wandl, 2013; FD van der Hoeven & Wandl, 2015). Few of them have examined the UHI at the neighborhood scale in relationship with the socio-economic characteristics of the human population and argue that such a relation is an issue of environmental justice (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006; Huang, Caenasso, & Zhou, 2011; Pearsall & Pierce, 2010; Ruddell, Harlan, Grossman-Clarke, & Buyantuyev, 2010).

The UHI affects life of people in the city and shows a wide range of negative effects on the population. Due to climate change an increase of mean temperature is expected and the UHI will worsen. Since the UHI shows a diverse spatial distribution across a city the question rises if all city dwellers experience the same negative effects. On the scale of a city the relation between socio-economic characteristics and the UH could be an issue where certain groups suffer more from the UHI then others. Such an issue could be an issue of environmental justice. The next paragraph will dwell on this concept.

WHAT IS ENVIRONMENTAL JUSTICE?

In this paragraph the concept of environmental justice is described and how research has related this to the concept of the UHI.

Environmental justice is often characterized as comprising of two elements. Firstly one is the struggle against the inequitable distribution of environmental hazards and goods and secondly efforts to increase access of all populations to the environmental decision-making process. This raises the question if low income groups or minority residents are disproportionately exposed to environmental hazards (Huang et al., 2011; Pearsall & Pierce, 2010). On a global level such affects are often disproportionately left to the poor (Millennium Ecosystem Assessment Board, 2005). Such an inequitably distribution of environmental hazards can also be seen on the city scale. In a research on the heat wave in Chicago in 1995 the relation between urban heat, poverty and age proofed higher risk due to socio-economic conditions (Huang et al., 2011).

In an evaluation on environmental justice in policy plan the authors note that while environmental justice is often part of broader sustainable efforts, there is often a lack of understanding of the specific spatial distribution of environmental inequity on the city scale. Meaningful environmental justice indicators are needed to get a better grasp on such a distribution (Pearsall & Pierce, 2010). In the relation between UHI and environmental justice recommended is that more conclusive spatial correlation need to be produced on the scale of the neighborhood (Norman et al., 2012). However, as described in the previous paragraph, there is research that confirms such a correlation between the UHI and socio-economic aspects. The more intense UHI parts of urban areas spatially coincide with socio-economic characteristics such as income, age or ethnicity (Harlan et al., 2006; Huang et al., 2011; Pearsall & Pierce, 2010; Ruddell et al., 2010).

For example, a study in Birmingham integrated temperature data, commercial social segmentation data and spatial risk assessment methodology to highlight the potential heat health risk areas. Concluding that social groups like elderly people and ill health in combination with urban characteristics like high population density and high rise living are more vulnerable to heat. The researchers present a map to show the spatial correlation between UHI and socio-economic characteristics. The researchers show that within high-rise neighborhoods a separation between poor people, living in high rise blocks and well educated young who life in modern or converted apartments exists figure 2 (Tomlinson, Chapman, Thornes, & Baker, 2011).

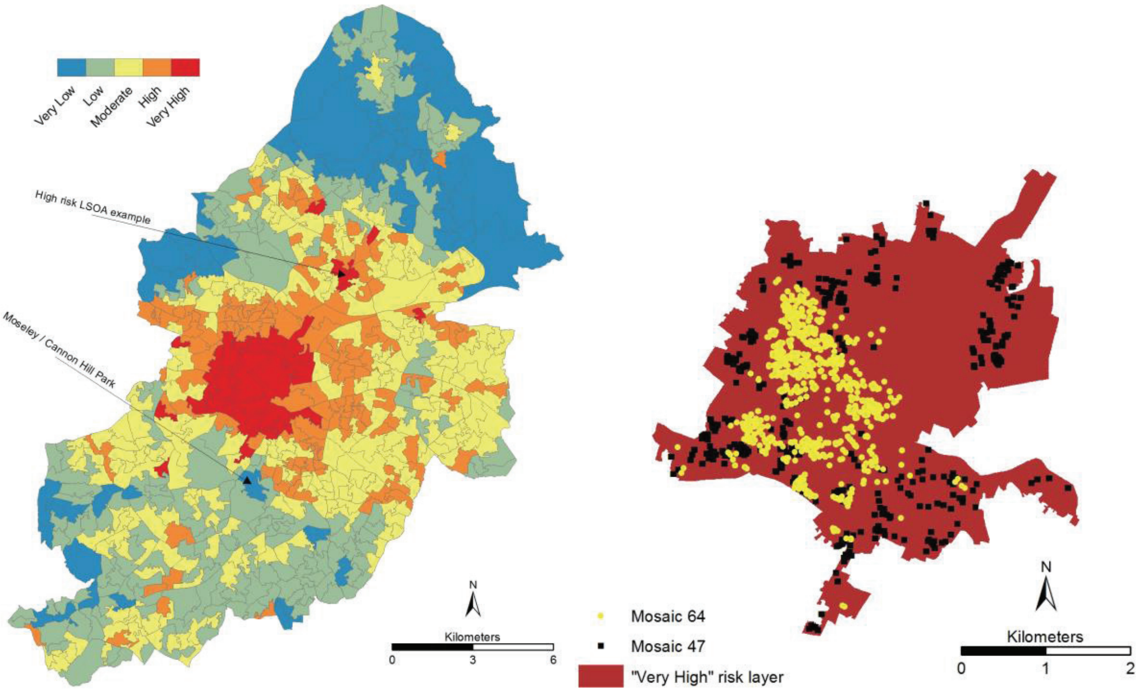

Figure 2. The map left displays the heat health risk areas in Birmingham. The map on the right shows that within an area there is a separation of risk to heat (Tomlinson et al., 2011, p. 11 & 12).

In the case of Birmingham the UHI is an environmental hazard where socio-economic groups are disproportionate exposed to. Such an unevenly spatially distribution raises questions who are more exposed to UHI. Such an issue would fit the first definition of environmental justice; the disproportionate exposure to environmental hazards to certain groups. In the next paragraph a more in-depth description is given on how research on both UHI and environmental justice spatially correlate with socio-economic and urban characteristics and what kind of indicators are used.

THE SPATIAL CORRELATION BETWEEN UHI, SOCIO-ECONOMIC AND URBAN CHARACTERISTICS

In this paragraph research on the spatial distribution of UHI or environmental justice and socio-economic characteristics on the city scale is reviewed. An overview is given on what indicators are used and described.

First below the overview table 2 is displayed.

Table 2 Overview of the indicators used by researches on both environmental justice and UHI that research the correlation with socio-economic characteristics.

Research papers on the spatial distribution on city scale of environmental justice			
1. (Huang et al., 2011)	2. (Todd & Zografos, 2005)		3. (Pearsall & Pierce, 2010)
Social variables • Economic status (% & $) • Education (%) • Ethnicity (%) • Age (#) • Lifestyle (p/hh)[1] • Crime (#) *Pollution* • Land surface temperatures	*Pollution* • Noise pollution • Air quality • Water pollution • Land pollution • Visual pollution *Neighborhood characteristics* • Access to public green space • Access to private green space	*Procedural* • Local control • Power-sharing • Access to information • Consultation • Environmental groups	• Mean income level ($) • Proportion of environmental pollution • Participation in the decision making process
4. (Harlan et al., 2006)	5. (Ruddell et al., 2010)	6. (Tomlinson et al., 2011)	7. (Norman et al., 2012)
Neighborhood population characteristics • Median income ($) • Poverty rate (%) • Educational attainment (%) • Ethnicity (%) • Age (#) *Outdoor temperature* • Neighborhood microclimate (T) *Neighborhood characteristics* • Distance from the central city (km) • Population settlement density (# / km^2) • Amount of open space (%) • Vegetation density (SAVI)	*Neighborhood demographics* • Population per square mile • Median income ($) • Poverty rate (%) • Ethnicity (%) • Age (#) *Land use/Land cover* • Land use/Land cover *Heat model* • Air temperature (T) at a 2 m height *Extreme heat* • Criteria for identifying heat waves (t)	*Land surface temperature* • Landsat ETM+ and ASTER (T) *Social data* • Elderly people (#) • Ill health *Urban fabric* • High rise • Density of households (# / km^2)	*Population characteristics* • Economic dependency (%) • No high school diploma (%) • New resident (%) *Urban characteristics* • Incomplete plumbing (%) *House hold assets* • One bedroom (%) Occupancy (%)

[1] Person(s) per household.

Research papers on the UHI and its relation with temperature, physical and social indicators			
(Gartland, 2008)	(F. van der Hoeven & Wandl, 2013)	(EEA, 2012c)	
Neighborhood physical indicators • Impermeable and watertight materials • Dark material in canyon like configuration • Reduced evapotranspiration • Increased heat storage • Increased net radiation • Reduced convection • Increased anthropogenic heat	*Physical Indicators* • Impervious and watertight surfaces (%) • Shade (#) • Vegetation index (0-1) • Percentage of surface water (%) • Building envelope (area / ha.) • Sky-view (0-1) • Albedo (0-1) • Energy use *Social indicators* • Leefbarometer	*Physical indicators* • Geographical location and topography • Vegetation and water areas • High building mass • Presence of impervious cover • Structures that hider ventilation • Little shadowing • Insufficient building insulation • Urbanization with a high share of built-up land and impervious areas.	*Vulnerable groups (Schauser et al., 2010)* • Elderly • Sick • Young • Low income groups • Ethnic minorities *Human factors* • Population density • Additional heat production due to production processes, transport, heating etc.
(FD van der Hoeven & Wandl, 2015)	(Dousset et al., 2011)	(Araujo et al., 2015)	(Tian, Chen, & Yu, 2013)
Temperature indicators • Inner house temperatures (t) • Surface temperature (t) • Surface energy balance (var.) *Social indicators* • Elderly (≥ 75) *Physical indicators* • Building age (#) • Impervious surfaces (0-1) • Percentage of water (%) • Albedo (0-1) • Vegetation index (0-1) • Shade (T / ha) • Leaf area index • Sky-view (0-1) • Building volume (m3) • Building shell (m2 / m3)	*Temperature indicators* • Land surface temperature AVHRR (T) • In situ meteorological data (T) *Physical indicators* • Land use / land cover • Housing conditions *Social indicators* • Mortality (#) • Age(#) • Sex (m/f) • Socio-economic conditions • Family entourage • Behavior during the heat wave • Mobility • Health status	*Population data* • Geocoded denque cases (#) • Population density (# / km2) • Household income ($/mth.) • Land use (cat.) *Temperature data* • Land surface temperatures LANDSAT 5 (T) *Physical indicators* • Normal difference vegetation index • Slum like areas	*Built-up over types (LANDSAT TM)* • Urban land • Bare ground • Water area • Grassland • Shrub land • Urban forest *Climatic database* • Mean temperature change (T) • Minimum temperatures • Diurnal temperature range • Relative temperature change

RESEARCH ON THE ENVIRONMENTAL JUSTICE INDICATORS AND SOCIO-ECONOMIC CHARACTERISTICS

This paragraph gives a description of research on the spatial distribution on city scale of environmental justice based on the overview in table 2 What kind of indicators are used and what is concluded?

Two researches by Scottish Agricultural College and Temple University department Geography and Urban Studies in Philadelphia give definitions of environmental justice indicators. In an exploration of the context of environmental justice in Scotland 7 distributive indicators of environmental justice were defined from literature. Indicators like access to public green and air quality were ranked based on interviewees. Secondly procedural attributes were defined like access to information and local control (Todd & Zografos, 2005). For San Francisco three indicators were defined to monitor environmental justice overtime. Mean income level, proportion of environmental pollution and participation in decision making process. (Pearsall & Pierce, 2010)

In the United States and United Kingdom researchers[2] show a correlation between socio-economic aspects, the built environment and the UHI. In the cities of Chicago, Phoenix, Baltimore and Birmingham the urban fabric is often dense with lots of impermeable surfaces, lack green spaces and houses are of bad building quality. Residents in these neighborhoods are often poor, unhealthy, part of an ethnic minority and lack education. This combination make theses deprived neighborhoods more vulnerable to the effects of UHI and extreme weather events such as heat waves. These groups tend to live in hotter places and are more exposed to heat waves which are considered a natural hazard. Such an unequal distribution of environmental hazard is described as an issue of environmental justice (Harlan et al., 2006; Huang et al., 2011; Ruddell et al., 2010; Tomlinson et al., 2011).

In a research[3] in Arizona, USA and Sonora, Mexico the researchers couple data from flood and erosion models and socio-economic data to identify socio-economic vulnerable populations. Research paper on the spatial distribution of environmental justice analyses the correlation between vulnerability to environmental hazards. By using spatial socio-economic datasets in correlation to environmental hazards spatial vulnerability maps are produced that spatially show how the poor are disproportionately exposed to environmental hazards (Norman et al., 2012).

The research papers by (Harlan et al., 2006; Norman et al., 2012) identify socio-economic groups of low income, ethnicity and lack of education are more vulnerable to UHI. Refereeing to research that describes the background of such vulnerability (Cutter, Boruff, & W, 2003; Schauser et al., 2010, p. 33). Low income groups are more likely to live in warmer neighborhoods with a greater exposure to heat stress. Socio-economic groups considered ethic have a higher vulnerability due to poorer health status. Socio–economic groups with limited education lack the ability to understand or access warning or recovery information.

Within the reviewed literature of environmental justice the UHI is recognized as a hazard which is disproportionate spatially distributed among neighborhoods. The UHI is more intense in neighborhoods with urban characteristics with high percentage of impervious materials, lack of green areas, high density and bad building quality. Socio-economic groups of low income, ethnicity and lack of education often life in such neighborhoods. These groups are more vulnerable due to bad health and are due to greater exposure to UHI more exposed toheat stress. Recommendations are made for more up to date socio-economic data sets on the neighborhood scale which are not always easily accessible (Norman et al., 2012; Tomlinson et al., 2011).

RESEARCH ON UHI AND SOCIO-ECONOMIC CHARACTERISTICS

This paragraph gives a description of research from the perspective of UHI and the spatial distribution on the city scale.

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[2] Harlan et al., 2006: Arizona State University, Image Science and Analysis Laboratory, NASA Johnson Space Center & University of Michigan
Huang et al., 2011: Center for Regional Change, University of California & Department of Plant Sciences, University of California
Ruddell et al., 2010: University at Albany, the State University of New York & Arizona State University
Tomlinson et al., 2011: School of Civil Engineering, University of Birmingham
[3] Norman et al, 2012: U.S. Geological Survey, Western Geographic Science Center
University of Arizona, School of Natural Resources and the Environment
Arizona State University, School of Transborder Studies

The UHI is strongly related with the urban characteristics of use of impervious, dark materials and a lack of green. Research on Amsterdam show that the city has a strong UHI and a relation with land use or land cover, vulnerability of the population and the energy efficiency of workplaces. The researchers concludes that the use of impervious surfaces is the strongest factor, albedo cools dense neighborhoods, elderly in socially deprived are vulnerable and workplaces situated in older parts of the city are energy inefficient (F. van der Hoeven & Wandl, 2013). In a research on how Shenzhen has warmed up during the past decades the researchers conclude that land use / land cover is the most important factor on UHI (Tian et al., 2013). In Sao Paulo both slum areas with high LST and areas with higher socio-economic status show higher dengue infection rates. Confirming that low vegetation sites with higher LST has higher dengue incidence rates (Araujo et al., 2015).

Two researches on the heat waves on Paris 2003 and Rotterdam 2006 show a correlation of mortality rate among elderly and UHI. This is the result of the higher risk of heat stress on elderly, the concentration of elderly and the age of buildings they life in (Dousset et al., 2011; FD van der Hoeven & Wandl, 2015).

In a report by the European Environment Agency the authors state that extreme weather events result in hazards such as heat waves, floods and droughts putting cities under risk. The report states that heat waves are influenced by the urban fabric and design. Local urban characteristics play an important role in the severity of heat waves and the intensity of the UHI reflects this. The authors note that beside the sensitivity of elderly to heat other socio-economic aspects such as low incomes and ethnic minorities are also determine vulnerability (EEA, 2012c).

The correlation between UHI with socio-economic and urban characteristics is under scribed in the reviewed literature. However this is not directly acknowledged as an issue of environmental justice. In the next paragraph the overview and description will be discussed.

Discussion

In this paragraph the overview and description of the research papers on UHI and environmental justice are being discussed and compared in their use of indicators.

Reviewed research on the spatial distribution on the city and neighborhood scale of both UHI and environmental justice are concept who shares similar indicators. Both concepts correlate socio-economic and urban characteristics and the environmental hazard of UHI. The concept of environmental justice recognizes UHI as a hazard which is disproportionate spatially distributed among vulnerable groups. Four of reviewed the environmental justice research papers show a spatial correlation between UHI and socio-economic factors which can be spatially recognized on the city scale. The research strongly argues the effects of UHI as an issue of environmental justice. The researcher uses this as a motivation for their research (Harlan et al., 2006; Huang et al., 2011; Ruddell et al., 2010; Tomlinson et al., 2011). Reviewed research from the perspective of the spatial correlation between UHI and socio-economic factors research don't consider such a correlation as an issue of environmental justice. The results fit the element of environmental justice that describes the disproportionate distribution of environmental hazards, in this case UHI to vulnerable groups (Araujo et al., 2015; Dousset et al., 2011; F. van der Hoeven & Wandl, 2013; FD van der Hoeven & Wandl, 2015). However, since the concept of environmental justice is not a component that researches tried to measure one can only guess to what extend there are issues of environmental injustice.

Many reviewed research papers address the issue of climate change, arguing that vulnerable groups such as elderly, low income and ethnic minorities will be disproportionately exposed. These vulnerable groups often live in socially deprived neighborhoods which have a higher UHI and people are more vulnerable due to bad building quality and unhealthy life style (Harlan et al., 2006; Huang et al., 2011; Pearsall & Pierce, 2010; Ruddell et al., 2010). Such a disproportionate exposure leads to more heat stress which they can't or barely escape and as such is issue of environmental injustice (Huang et al., 2011; Millennium Ecosystem Assessment Board, 2005; Pearsall & Pierce, 2010).

From the overview table 2 the use of indicators for the spatial distribution of either environmental justice or UHI can be summarized in three main categories; population characteristics, urban characteristics and environmental hazards (table 3). Research papers on the relation between environmental justice and UHI all contribute to categories of population characteristics and environmental hazards. This is much less so the case for research from an UHI perspective that focuses more on the relation between the UHI and urban characteristics. Population characteristics age, ethnicity, education and health are used as indicators for vulnerability to an environmental hazard. Most papers address urban characteristics as an indicator that has either an worsening or softening effect on an environmental hazard. Others call for such research. They argue that more conclusive spatial correlations need to be produced, with higher resolution and more up-to-date data. (Bulkeley, Carmin, Castán Broto, Edwards, & Fuller, 2013; Bulkeley, Edwards, & Fuller, 2014; Huang et al., 2011; Pearsall & Pierce, 2010). This is interestingly, in terms of time, stated after research papers that do claim such a spatial correlation. This could be partly due to the fact that there some researcher seems to assume that environmental justice is recognized on an international scale but less on the national or city scale (Bulkeley et al., 2013; Bulkeley et al., 2014).

Table 3. Three main categories; population characteristics, urban characteristics and environmental hazards derived from table 1.

Population characteristics	Environmental hazards	Urban characteristics
Age	Temperature	Density
Ethnicity	Pollution	Vegetation
Education		Land use land over
Health		Urban fabric.
Income		

This paper did not touch upon the political context within the country each research paper was conducted. The U.S.A. is much less an inequitable society and the scale and impact of UHI is probably much bigger. Europe is considered as a much more equitable society. However voices are heard that claim that from the political concept of neo-liberalism Europe can expect an increase in inequality and segregation in the cities of Europe (EEA, 2012c; Tammaru, Marcinczak, Ham, & Musterd, 2015). This in relation with climate change would cause more intense UHI that may be hard to deal with in socially deprived neighborhoods.

Reviewed research papers that correlate environmental justice and UHI are all conducted in the U.S.A. and U.K. However to claim that these are the only two countries where such linkage is researched would be too bluntly since the literature review is mainly conducted for papers in English language. However in the English language research on environmental justice in relation to UHI on the city is scale not so plenty. This literature review paper suggests that their remains limited understanding of the effects of UHI connected to social-economic and environmental justice dimensions like poverty, inequality and opportunity in continental Europe. This based upon the lack of such research within the Dutch language and no research papers from European Universities in the English language.

A few reviewed research papers use population density as an indicator of urban or socio-economic characteristic in relation to the UHI (Araujo et al., 2015; Harlan et al., 2006; Harlan & Ruddell, 2011; Schauser et al., 2010; Tomlinson et al., 2011). Population density is often associated with variables such as building density, share of green and blue areas (Steeneveld, Koopmans, Heusinkveld, van Hove, & Holtslag, 2011). It must be noted that density does not directly relate to the UHI since it does not directly represent any physical condition. One should be careful using this indicator since population density might represent whole different kind of urban typologies and thus building configuration with each his own worsening or softening effect on the UHI (Figure).

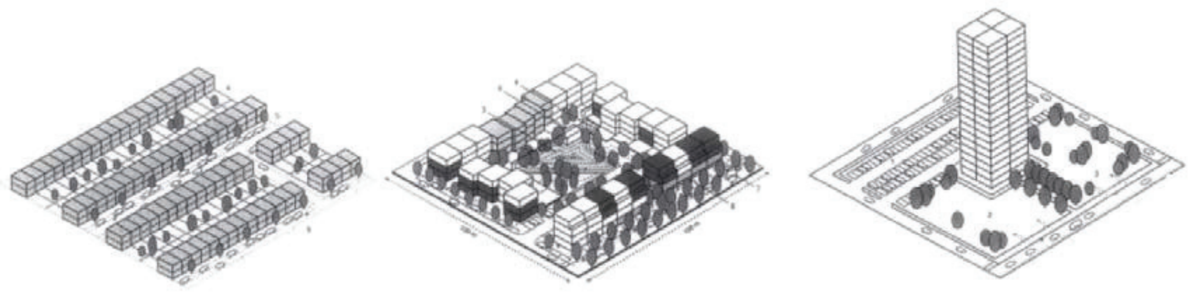

Figure 3. Three types of parceling with all a density of 75 dwellings per acre (Haupt, 2010).

Conclusion

This paper asked the question: what is the relation between the concept of UHI and environmental justice and how does this relation spatially coincide? The relation is that the UHI is an environmental hazard that is uneven spatially distributed on the city scale and more intense in neighborhoods where vulnerable groups such as the elderly, low income and ethnic groups reside. Such a disproportionate exposure to environmental hazards to certain groups meets the first element of the concept of environmental justice. The struggle against the inequitable distribution of environmental hazards and goods. The UHI is often the most intense in such neighborhoods because of urban characteristics like little to no vegetation, a high population density, high building mass, lack of shade and bad building quality. Socially deprived neighborhoods share such characteristics and people, due to their social-economic status, are more vulnerable to effects of UHI and more exposed to intense UHI because of the same urban characteristics.

Recommendations

Discussed is that research on the link between environmental justice and the UHI is not so plenty in English written research papers. To get a better overview of the current state of the academic field on this correlation another literate review could be conducted for different languages.

The research paper started out with the notion of the difference between equality in different societies such as the U.S.A. and Europe. However voices are heard that claim that from political concept of neo-liberalism Europe can expect increase in inequality and segregation in the cities of Europe (EEA, 2012c; Tammaru et al., 2015). In combination with climate change, which has an worsening effect on UHI, the academic field in Europe would do well to continue research on the impact of UHI in correlation with socio-economic characteristics.

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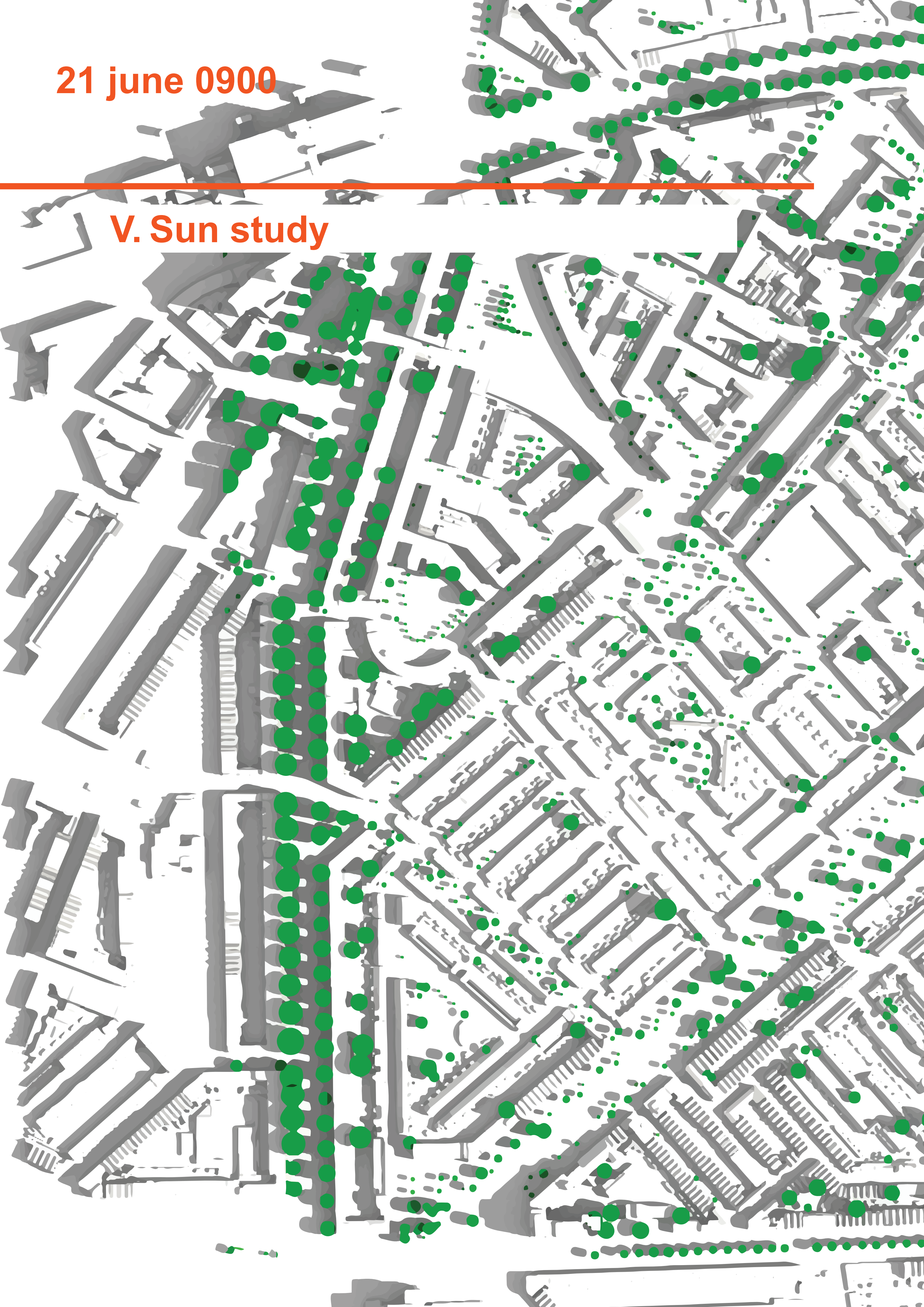

V. Sun study

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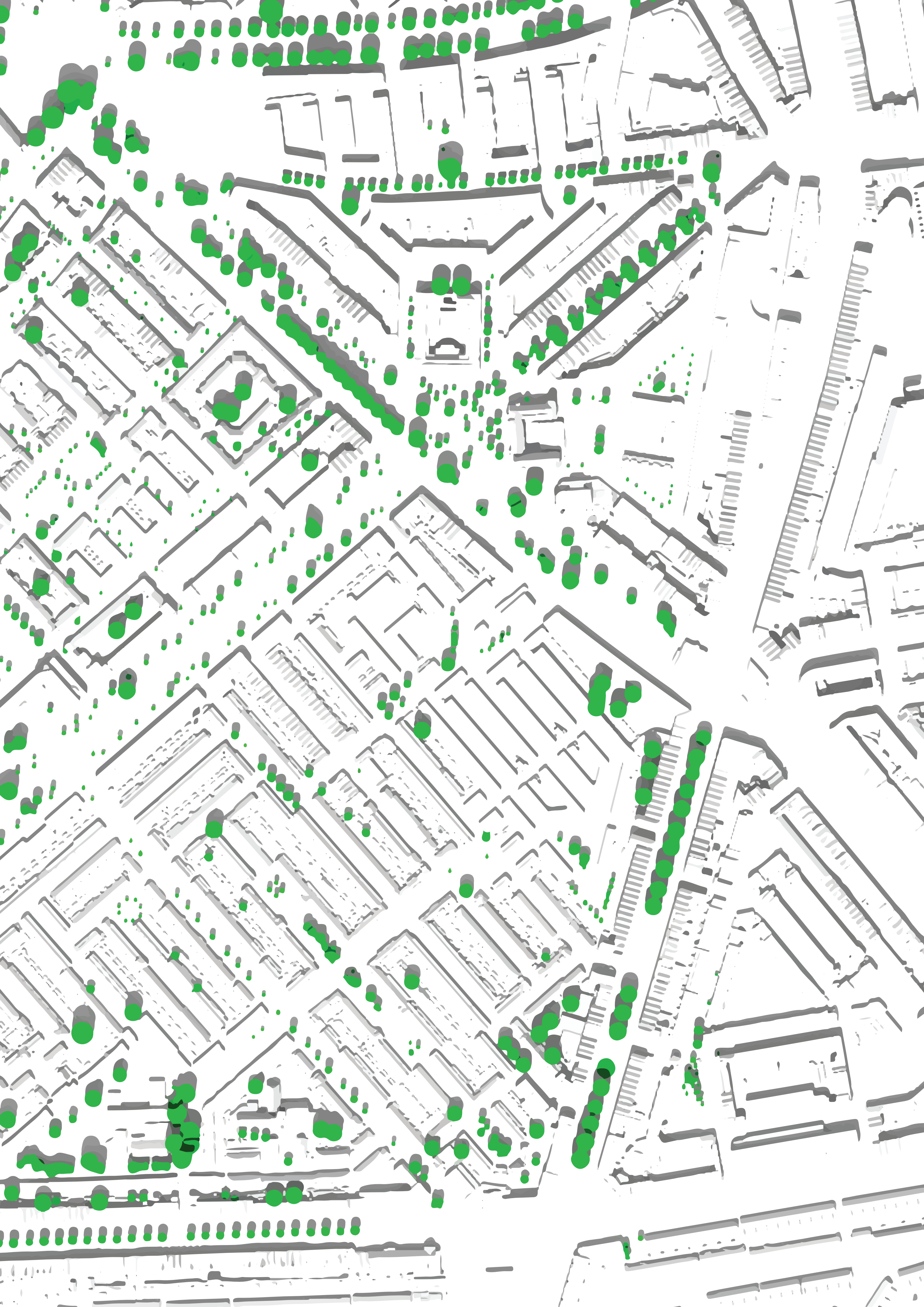

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