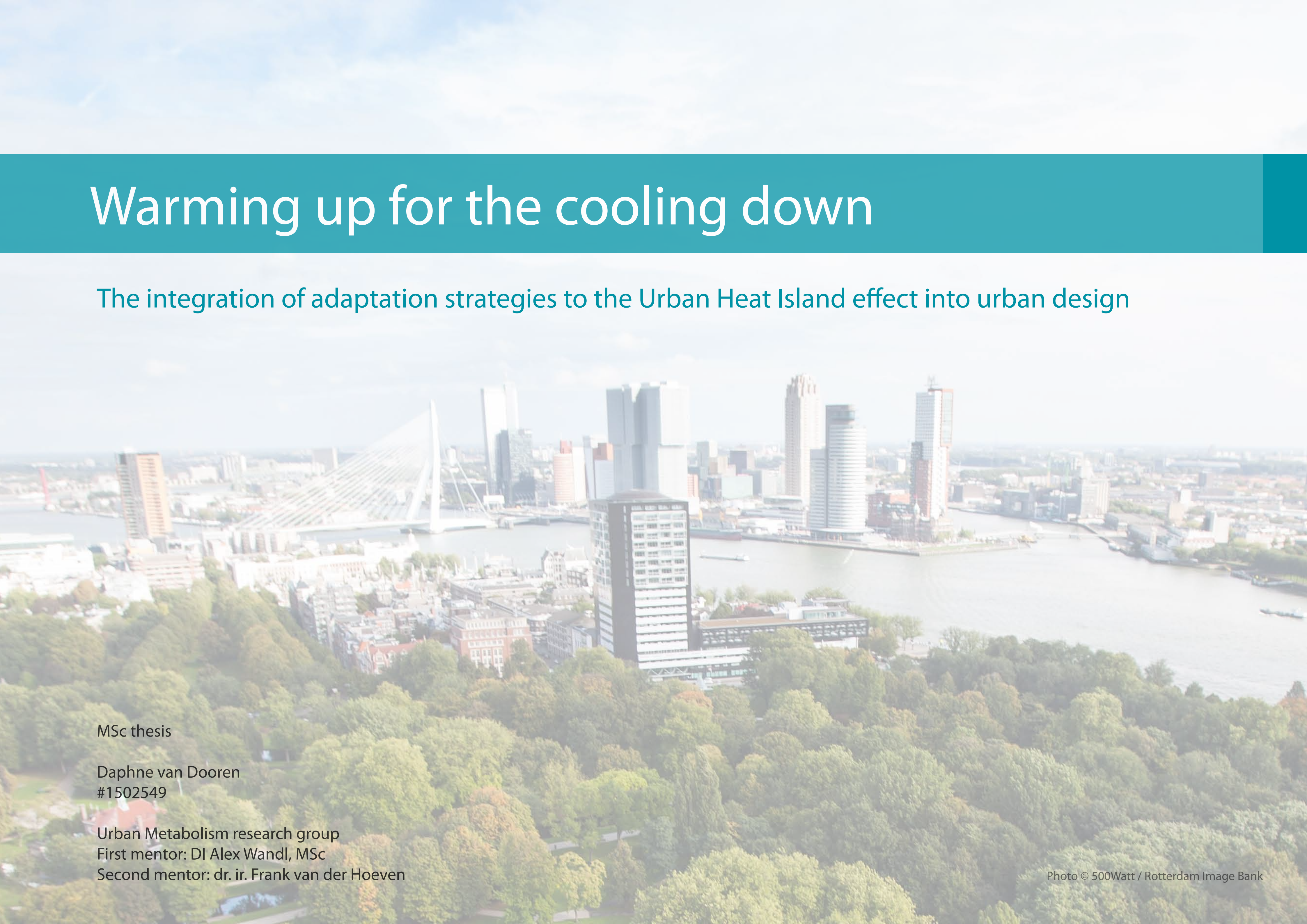
Warming up for the cooling down

The integration of adaptation strategies to the Urban Heat Island effect into urban design



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MSc thesis

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Urban Metabolism research group
First mentor: DI Alex Wandl, MSc
Second mentor: dr. ir. Frank van der Hoeven

Colophon

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June 20, 2015

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Summary

Predictions from the Royal Netherlands Meteorological Institute (KNMI 2014a) show that high temperatures and heat waves will occur more frequently in the future. Warm weather leads to even higher temperatures in the city, because of the Urban Heat Island (UHI) effect. This is not without risks, since heat can affect the health of people. Especially among elderly, poor, and minorities many extra deaths are reported because of heat. Heat does not only have a negative effect on people, but also on the economy and environment of a city.

When the UHI effect is present, there is a temperature difference between the city and its surroundings. This is caused by the structure of the city, in which five characteristics play an important role. Together the amount of shadow, reflection (albedo value), perviousness, openness to the sky (sky-view factor), and fraction of vegetation/water, determine whether a city retains much heat or not. Since these heat related characteristics can be measured, an indication can be given of how heat proof a certain area is. Also, measuring these characteristics can give insight in how effective an adaptation strategy to heat can be. This is done in a case comparison for two locations in the cities of Antwerp, London and Copenhagen. In this case comparison, the heat related characteristics are estimated for before and after a given development. From the comparison of these results, it has become clear that interventions on a small scale and large scale both can have a positive effect on the local environment.

The existing body of knowledge on adapting to the UHI effect, shows a gap in how to integrate adaptation strategies into urban design. Therefore, design elements are used in this graduation project to make this integration possible. The design elements combine the heat characteristics and adaptation measures, which can become part of a design. This leads to a design that is both good for the city and against heat. The mentioned design elements are described in a pattern language. The pattern language focuses on adaptation to heat, and is generically applicable in (Dutch) cities.

In the Netherlands the UHI effect occurs in many cities, from which Rotterdam shows one of the largest temperature differences. The air temperature difference can be up to 8°C (Heusinkveld et al. 2010), while the surface temperature difference is 4,9°C (E. J. Klok et al. 2012). When looking closer at the temperatures, it becomes clear that the UHI effect of Rotterdam is mainly present in the central, western and southern part of the city. Two neighbourhoods in this area, called Bospolder-Tussendijken and Cool, are chosen as design locations for the implementation of the patterns. They both are vulnerable to heat, but in a different way. In Bospolder-Tussendijken there are many young children, and it is a poor neighbourhood with a weak social cohesion. In Cool we can find many working people, who are influenced by heat in terms of labour productivity.

The developed patterns are implemented as test cases in urban designs for Bospolder-Tussendijken and Cool. It has become clear that focusing on the weaker heat related characteristics of the design location, has more effect than implementing patterns without focus on specific characteristics. Furthermore, it is not important how many patterns are used in a design, but the fraction of implementation should be as large as possible. Integrating adaptation strategies against heat in urban design, with the use of patterns, helps to create spots in the urban environment where people can cool down.

Part 1: Project description

Photo © Claire Droppert / Rotterdam Image Bank

Preface

This thesis is the result of my work during the graduation year, at the department of Urbanism at the TU Delft. The present document describes what the graduation project is about, how research is done, and the outcomes of this research.

The graduation project is done under the guidance of the research group 'Urban Metabolism', which is part of the chair Environmental Technology & Design. This research group uses the metaphor of the city as a living organism, and studies the flows that are connected to this dynamic city. This project is focusing on one of these flows: heat.

Motivation

When we look at cities, people and nature bring the urban environment to life. If urban structures only existed of pavements and buildings, cities were much less pleasant to live in. People give vibrancy to a place, and nature makes a place more dynamic as well. But there is more to urban design than only creating a pleasant environment for the people. Since the cultural layer of the city merges together with the natural layer underneath it, the city structures also become part of the natural ecosystem. As a result, we have to act like the city is part of nature, and be as dynamic as nature is. This means that we have to adapt to the changing conditions of the environment, which especially includes climate change. Because people can have a lot of influence on the environment, we need human intervention to adapt to the problems occurring from the climate change.

Sustainability means in my opinion that a city should be part of the flows of the environment. As a result, it is important to positively influence these flows, instead of counteract to nature. On the contrary, human beings treat nature in a bad way in the present day, by producing polluted air and wasting the earth's resources. The negative effects of our acting clearly starts to get visible in our everyday life's. This demonstrates that currently human beings do not influence nature in a positive way.

The Urban Heat Island effect

The weather is changing through the decades, and extreme weather conditions occur on a regular basis. This is also visible because of changes in the city. Problems like water nuisance are clearly visible in the streets, but there are also less visible problems. When I discovered that heat could actually be a problem in the Netherlands, it caught my attention. This is an issue I wanted to know more about, and for that reason I decided to do research on the subject of the Urban Heat Island effect for my graduation project.

As an (future) urban designer I have the possibility to contribute to a better environment. Using nature in urban design is one of the key factors in how we can achieve that, since the ecosystem exists of natural processes. As mentioned before, the city has to become a dynamic and natural process on its own. According to me, it is the task of human beings, and especially the urban (landscape) designer to contribute to that.

Acknowledgements

I would like to thank Alex and Frank for their enthusiasm for my project, and the knowledge and confidence they gave me in the many meetings we had. Furthermore, I enjoyed sharing findings about urban heat with Klaas and Iris, from the different perspectives of our projects. I am also grateful for the many interesting conversations I had with family and friends about my graduation project. Finally, I thank Johannes for his support and the loving care he gave me, not only the last year, but during my whole time in Delft. It was really invaluable to have people around me who gave me the motivation to achieve something good.

Daphne van Dooren
June 20, 2015

Introduction

This project concerns the flow of heat in cities, and especially focuses on the Urban Heat Island (UHI) effect. According to Oke (1995) the Urban Heat Island can be defined as "[...] the characteristic warmth of a town or city", which can be identified "[...] on the basis of temperature differences between urban and rural stations". From this it can be concluded that a city can heat up, while the rural areas have a lower temperature.

The project elaborates on the UHI effect, while also considering adaptation strategies and the integration of it in urban design. As a result, the main important subjects addressed in this document are:
- The Urban Heat Island effect itself.
- Adaptation strategies to climate change in general, as well as to adapt to the UHI effect.
- The integration of these adaptation strategies into the profession of urban design.
- The integration of these adaptation strategies in two neighbourhoods in Rotterdam.

The aim of the project is to design adaptation strategies to adapt to the Urban Heat Island effect in the Netherlands, and especially in two neighbourhoods in Rotterdam. The focus is on how these adaptation strategies can be integrated in urban design. Therefore, more general 'patterns' will be created, which are made of design elements that can be used by Dutch cities to implement in their city plans. For the concerning neighbourhoods in the city of Rotterdam, design elements are made, based on these generic patterns.

It should be noted that in this document the term 'adaptation' is used, and not 'mitigation'. This is a choice that has been made to avoid confusion. The measures which are taken, in the context of climate change, focus on adaptation to the changing circumstances. Eventually, this could lead to the mitigation (reduction) of the Urban Heat Island effect, but mitigation is not always the result. For that reason, the term 'adaptation' is used in this document.

Urban Metabolism

The graduation project takes place in the context of the research group on Urban Metabolism. According to Van Timmeren & Icibaci (2014), the research group focuses on the flows of materials and energy in the city. From this perspective, the city is seen as an ecosystem, that is as a dynamic system consisting of flows. Also, they focus on the integration of the social perspective with the technical perspective of the environment. Research is done on adapting human behaviour and its settlements to the environmental conditions. This is something that is done in this graduation project as well. In this case the flow of air heat is the main environmental condition that is considered, and this is done from both a technical and social perspective. The city has to adapt to the environmental conditions by using adaptation strategies to heat, as demonstrated in the problem analysis.

Collaboration

During the development of this project, several meetings have taken place in which thoughts, knowledge and research findings were shared. These meetings involved Alex Wandl (researcher, urbanism), Frank van der Hoeven (associate professor, urbanism), Klaas Akkerman (graduation student, urbanism) and Iris Theunisse (graduation student, geomatics). As a result, this project is influenced by the participants and their work.

Problem analysis

For a project dealing with a complex problem such as climate adaptation, it is essential to start with a proper problem analysis. It is meant to understand what is at stake, to guide the research and set priorities. At first, an explanation is given on why heat is a rising problem in the Netherlands. Then it is pointed out which groups and neighbourhoods are vulnerable to heat. Furthermore, it is discussed how adaptation strategies should be implemented. And finally, it is demonstrated why Rotterdam is an appropriate city to use as test case for adaptation strategies.

Heat is here to stay

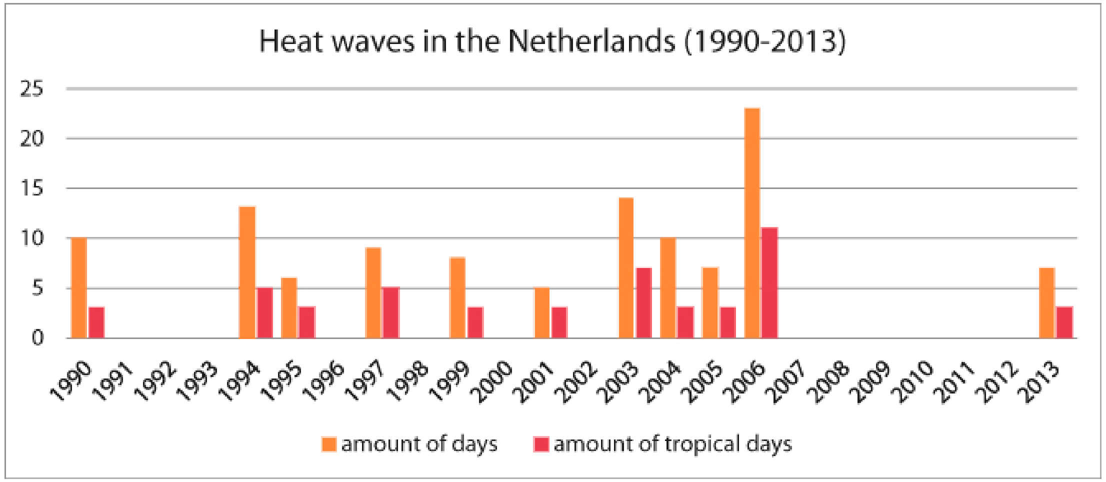
There are various reasons why the UHI effect occurs in cities, but one of the elements that is always part of the causes is warmth. As the definition of the UHI effect determines (see 'Introduction'), heat remains present in the city, while the rural areas cool down after a hot day. So, if the city was able to cool down as well, there would have been less heat remaining there.

As Figure 1 shows, heat waves are not an exception anymore in the Netherlands. They do not occur every year, but they show up regularly, and sometimes even several times during one summer. It is investigated by the Royal Netherlands Meteorological Institute (KNMI 2014a) that due to climate change temperatures will rise in the future, and that there will be an increase of hot periods during the summer. For the UHI effect in the Netherlands, this means that the chance the effect occurs rises. So, there will be more heat as a consequence of the changing climate, as well as more heat because of the UHI effect.

Heat is a problem

The presence of heat in a city, can be seen as a problem because of the consequences it has. Marcel Olde Rikkert, professor in geriatrics (health care of elderly), describes in Figure 2 the consequences heat has on the health of especially elderly people. He says that elderly have problems with keeping their body temperature in balance when there are large temperature differences. Also, they experience difficulties with sweating, with a higher body temperature as a result. According to Olde Rikkert this sometimes leads to heart and blood vessel problems. Eventually, there is even a higher mortality rate because of these health problems. Not only elderly people have to deal with health problems because of heat, but they are considered a vulnerable group.

Besides the fact that heat can have a bad influence on the health of people, it also has an influence on the environment and economy of a city. Since these many negative effects are often attached to heat periods, the Urban Heat Island effect is



Overview of the amount of days heatwaves occured in the Netherlands between 1990 and 2013.

Figure 1.
Image by author, based on: KNMI, 2013. Klimatologie: Hittegolven sinds 1901 ., 2014(September 18). Available at: www.knmi.nl/klimatologie/lijsten/hittegolven.html.

part of this problem as well. This means that these problems can partly be solved by adaptation, mitigation, or even taking away the UHI effect.

Vulnerability

As said before, elderly people are not the only people who are vulnerable to heat stress. As pointed out by Harlan et al. (2006), more deaths because of heat occur especially in temperate climates, like the Netherlands, because they are not used to the heat. Besides, under the poor, minorities and elderly people the most deaths are reported. Because i.e. poor people mostly live in certain specific types of neighbourhoods, a correlation between living conditions of a neighbourhood and heat stress is expected. Therefore, a study on this aspect was performed by Harlan et al. (2006). A positive correlation is found between poor inhabitants in a neighbourhood and the exposure to heat. High-income neighbourhoods were rather comfortable from this perspective, middle-income neighbourhoods altered, and low-income neighbourhoods showed the highest mortality rate.

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Meer 80-plussers dood door hittegolf

RIJSWIJK - Er sterven veel meer ouderen tijdens een hittegolf dan tijdens een normale zomerse week. Dat blijkt uit een data-analyse van het ANP op basis van cijfers van het Centraal Bureau voor de Statistiek en het KNMI. Voor mensen onder de 65 geldt niet of nauwelijks dat er meer doden vallen tijdens een hittegolf.

In de afgelopen 20 jaar hebben we in Nederland tien hittegolven meegemaakt. Dat zijn perioden van minimaal vijf dagen waarop de temperatuur boven de 25 graden is en minimaal drie dagen daarvan boven de 30 graden. Tijdens die hittegolven stierven per week gemiddeld 202 mensen van boven de 80 meer, dan in de week voor en na de extreem warme periode. In 2006 was het verschil zelfs 400 meer sterfgevallen.

Foto: ANP

Hetzelfde is overigens te zien in de winter.
Tijdens de koude eerste 18 weken van het jaar overlijden gemiddeld 235 80-plussers per week meer dan tijdens de zomerperiode van eind mei tot halverwege september. Een gemiddelde week tijdens de winterperiode eist ongeveer evenveel levens van de oudste ouderen als een week met een hittegolf.

Volgens Marcel Olde Rikkert, hoogleraar Geriatrie aan het Nijmeegse UMC St Radboud, hebben oudere mensen gemiddeld meer moeite om hun lichaamstemperatuur op peil te houden bij sterkte temperatuurstijgingen of -daling. Het vernauwen of verwijden van hun aderen gaat namelijk niet meer zo gemakkelijk als vroeger. „Dat geldt ook voor zweten en rillen, dat lukt minder goed en minder snel. De kerntemperatuur van het lichaam gaat daardoor meer mee met de buitentemperatuur", legt Olde Rikkert uit. Dat kan zorgen voor problemen met het hart en de bloedvaten van de ouderen.

In de winter telt ook mee dat ouderen vaak minder bewegen, waardoor hun spieren het lichaam minder opwarmen. In Nijmegen worden dan ook met grote regelmaat ouderen opgenomen met een te lage lichaamstemperatuur. Verder zijn ouderen in de winter gevoelig voor ziekten als de griep en het norovirus, die snel in een instelling om zich heen kunnen grijpen.

Bejaarden kunnen zich volgens Olde Rikkert wapenen tegen de plotse temperatuurstijgingen door in zomer veel te drinken. Dat bevordert het zweten en voorkomt uitdroging. In de winter helpt uiteraard warme kleding. „En zorg vooraf dat iemand langskomt om activiteiten te ondernemen, om de spierverwarming te bevorderen", adviseert Olde Rikkert.

Newspaper article addressing the amount of deaths, under people above 80 years old, because of heat waves.

Figure 2.
De Telegraaf, 2013. Meer 80-plussers dood door hittegolf. , 2014(September 30). Available at: http://www.telegraaf.nl/binnenland/21746964/__Meer_80-plussers_dood__.html.

Furthermore, it has become clear that heat exposure is very specific to the place, and not a gradual transition between the rural areas and the city core. The places with a high level of exposure to heat, showed similarities in the density of vegetation and open space. Also, the vulnerable neighbourhoods demonstrated a lack of social networks. We see that heat vulnerable neighbourhoods show both economic and social issues. According to Harlan et al. (2006) this underlines the 'environmental justice hypothesis': "[…] risks incurred from environmental hazards are greater for marginalized populations." As a result, their recommendation is to focus on these neighbourhoods at first, when addressing the climate change adaptation strategies.

Implementation and effects of adaptation strategies

The National Programme for Spatial Adaptation to Climate Change (VROM 2007) is a document that focuses on how the Netherlands can be made climate proof. According to this programme, from research it has become clear that prevention of climate change is not possible. As a result, we have to deal with what this change is bringing us. On the other hand, there are things that we can do to minimize the change of the climate. By the use of strategies for adaptation we can make the consequences 'acceptable'. That will be the approach in the Netherlands (VROM 2007).

According to IPCC (2014), adaptation strategies are in some cases added to the planning processes of existing programmes. Unfortunately, this is still done with a limited view on the strategies: "Most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions (medium evidence, high agreement)." (IPCC 2014)

From this conclusion it can be derived that there is a demand for looking at how the adaptation strategies can be implemented in the best possible way. Besides, there is not much knowledge on the effects of the implemented adaptation strategies. So, this is something that still should be investigated.

Rotterdam as urgent case

As demonstrated by E. J. Klok et al. (2012), Rotterdam has significant temperature differences between the city and the rural areas (4,9 °C), as measured in July 2006. Rotterdam is the only city in the Netherlands that is in the top 5 of the highest Surface Heat Island (SHI) temperatures during both day and night time. Besides, it is remarkable that the temperature at night is the same as at day:

Average SHI at day:
1. 's-Gravenhage (8,6 °C)
2. Waalwijk (5,9 °C)
3. Amersfoort (5,2 °C)
4. Tilburg (5,1 °C)
5. Rotterdam (4,9 °C)

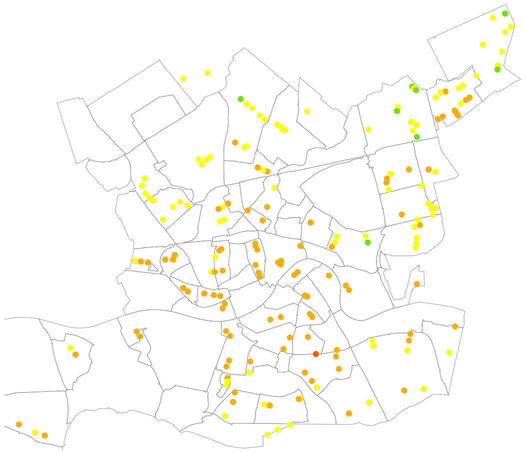
Average SHI at night:
1. Dordrecht (5,0 °C)
2. Delft (4,9 °C)
3. Utrecht (4,9 °C)
4. Rotterdam (4,9 °C)
5. Zwijndrecht (4,8 °C)

Besides the surface temperatures, the air temperatures are measured as well in Rotterdam. This was done by Heusinkveld et al. (2010), using a mobile platform for making measurements along a certain route. From the results it has become clear that the air temperature difference can be up to 8 °C. Remarkably, the industrial areas did not show higher temperatures than the inner city, while this was the case for the surface temperature measurements from satellites. From this it can be concluded that there is a difference between air temperatures and surface temperatures.

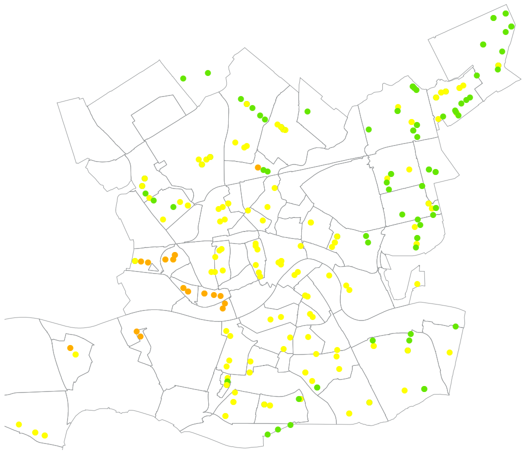
In the study of Steeneveld et al. (2011), it is also demonstrated that Rotterdam has a significant Urban Heat Island. It is pointed out that the city crosses the threshold value for heat stress (27,7 °C) for 15 days a year, while 50% of the cities from the study only passes this temperature for 7 days a year. The study is done by measurements from hobbyists, as well as the use of three meteorological stations from the Wageningen University, located in Rotterdam City, East and West. According to Steeneveld et al. (2011) these stations represent different area characteristics, and the measurements from these stations are compared with a meteorological station in the rural areas of Rotterdam. The results show that Rotterdam is a 'particular case', in comparison to the other cities, because the city shows 'substantial heterogeneity'. This means that the UHI effect strongly varies throughout the city. The highest values of the UHI were measured in the city centre.

Recently, the project 'Hotterdam' started as an cooperation between the universities of technology in Delft and Eindhoven. This is an ongoing project on the Urban Heat Island effect in Rotterdam, and is a spin-off from the Climate Proof Cities research programme. The focus of this project is on temperature differences, housing characteristics, liveability of neighbourhoods, and the vulnerability of certain groups (Van der Hoeven & Wandl 2014). In Figure 3, air temperatures in Rotterdam are shown as measured by means of sensors in the summer of 2014. Since the 2nd of August was a hot day, this date is used to analyse where the hot spots of the city are. This is done by making maps on different moments during the day, with an interval of 6 hours. When we look at the maps with measurements that are made in the evening or night, it becomes clear that the heat especially remains in the city center, as well as the western and southern part of the city. Additionaly, there are some smaller areas where heat is present. It can be concluded that this larger part with high temperatures, represents an Urban Heat Island.

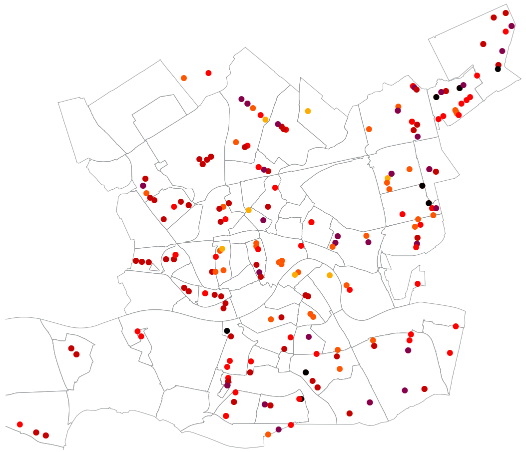
The city of Rotterdam is chosen as design location for this project, because of three reasons. The first reason is that, according to the indicated measurements, Rotterdam has one of the most present UHI of the Netherlands. Furthermore, the city is focusing on climate change adaptation (Rotterdam Climate Initiative), and is therefore willing to use adaptation strategies in the city. Finally, it is useful that there is detailed and recent data available on the spatial temperature profile of Rotterdam. These measurements provide data and maps that can be used for this research project.



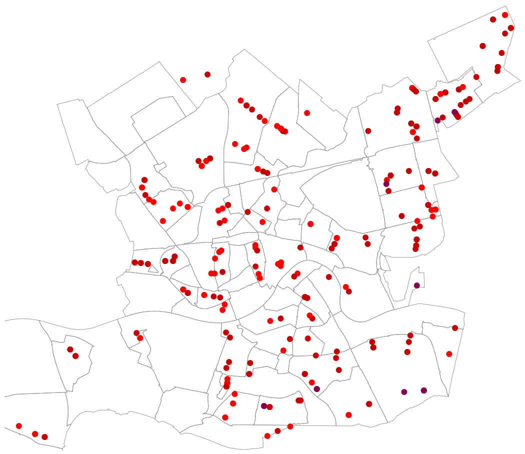
Outdoor temperatures on August 1, 2014 23:00h.



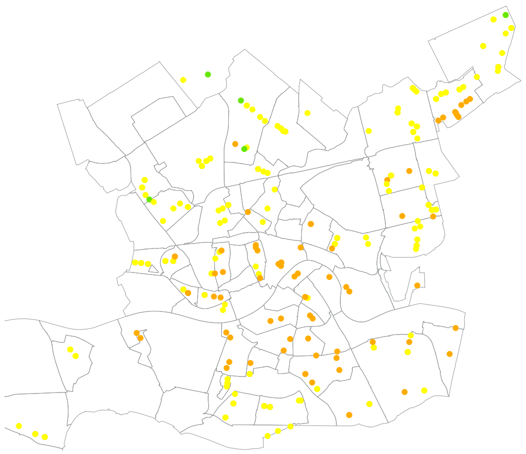
Outdoor temperatures on August 2, 2014 05:00h.



Outdoor temperatures on August 2, 2014 11:00h.



Outdoor temperatures on August 2, 2014 17:00h.



Outdoor temperatures on August 2, 2014 23:00h.

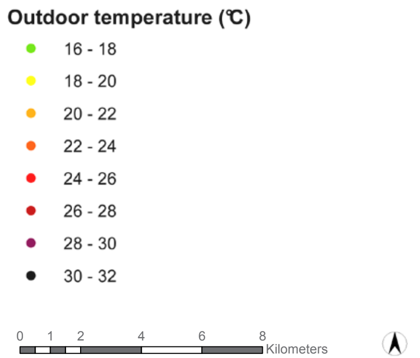


Figure 3.
Image by author, based on data from Hotterdam.

Relevance of the project

In order to show the importance of doing research on the topic of the Urban Heat Island effect, the relevance of it should be clear. On the one hand it should be relevant to society, which means in this case that people need to be able to see that there is a problem with heat that needs a solution. On the other hand there should be an scientific demand for the project. If there is no need to investigate more about a certain subject, the project would be useless for the academic world. This section describes the societal relevance at first, followed by the scientific relevance of the project.

Societal relevance

During the two heat waves in July 2006, there were approximately a thousand extra deaths in the Netherlands (CBS 2006). It was an exceptional situation, since it was the warmest month in three centuries. Although this was an extreme case, the CBS (2006) found in general a positive correlation between heat and the amount of deaths. For every degree the temperature rises there will be an average raise of 31 people who die in one week. From this it can be concluded that heat is a serious threat in terms of death cause. The CBS (2006) also looked for correlations between deaths because of heat and various population groups in the Netherlands. Elderly women especially turn out to be a vulnerable group, since there are more elderly women than elderly man, and elderly are vulnerable to heat generally (see also 'Problem analysis'). There will be more elderly people in the future; the aging population will increase. This directly means that the most vulnerable group for heat will increase too.

Besides the prediction that this vulnerable group grows, the amount of heat itself is likely to increase as well. The KNMI (Royal Netherlands Meteorological Institute) has made predictions about how the weather will develop in the future. From these predictions, among others, it has become clear that the average temperature will slowly rise, and that the summers will be more hot in the future. Also, it is predicted that the amount of solar radiation close to earth will increase a bit (KNMI 2014a), which means that surfaces warm up more easily. The consequence of the three mentioned events is that we have to deal more with heat in the future, and that the chance the Urban Heat Island effect occurs increases. As a result, the problem becomes more and more relevant in the coming years.

Scientific relevance

According to Van Hove et al. (2011), it was not expected a decade ago that the UHI effect would be a serious issue in Dutch cities. The assumption that the Netherlands does not have to deal with heat stress, comes from the fact

App geeft weersvoorspelling voor eigen tuin

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Stadsbewoners kunnen in de toekomst het weerbericht voor de eigen straat opvragen op hun mobieltje. Wetenschappers werken aan een speciaal programmaatje (app) dat dit mogelijk maakt. Onderzoekers van Wageningen Universiteit zijn al langer bezig de temperatuur en luchtvochtigheid van Nederlandse steden gedetailleerd in kaart te brengen. Als voorbeeld: in het centrum van Rotterdam is het vaak aanzienlijk warmer dan in de buitenwijken en het havengebied.

'Het temperatuurverschil binnen de stadsgrenzen kan soms wel 7 à 8 graden bedragen,' zegt hoogleraar Meteorologie Bert Holtslag. 'Het algemene weerbericht noemt dit in veel gevallen niet.'

Bakfiets
Studenten en onderzoekers van Wageningen Universiteit kwamen in 2009 groot in het nieuws toen ze voor het eerst weermetingen deden in Rotterdam. Ze onderzochten met behulp van meetstations en een bakfiets vol meetapparatuur waar het in de stad het warmst was. Het onderzoek leverde de gemeente een schat van informatie op die nuttig is bij het maken vanplannen voor de ruimtelijke ordening.

Daarop voortbordurend zijn de wetenschappers bezig met het ontwikkelen van een 'hittekaart' die voor iedereen toegankelijk moet worden. 'Daarvoor hoeft de stad niet te worden volgehangen met meetstations,' zegt Holtslag. 'De meeste Rotterdammers hebben een weerstationnetje in hun broekzak: hun mobiele telefoon.

Het mobieltje geeft om de paar seconden een signaal af aan de telefooncentrale. De sterkte van dat signaal hangt af van de temperatuur en de luchtvochtigheid. Met wat trucs kunnen we mogelijk uit die informatie een uiterst plaatselijke weervoorspelling maken.'

Gadget
De voortdurende stroom data zijn meer dan een leuke gadget, benadrukt Holtslag. De gegevens zijn relevant voor bijvoorbeeld overheden en gezondheidsdiensten om de gevolgen van hittestress bij mensen te voorkomen. Ook stedelijke ontwerpers hebben belang bij de gegevens, omdat zij beter rekening kunnen houden met de leefbaarheid tijdens warme zomers. Holtslag: 'Toepassingen te over. Organisatoren van festivals kunnen er ook hun voordeel mee doen.'

Holtslag hoopt in 2016 met een prototype van het programmaatje te komen. 'Ons streven is dat we tot op de 100 meter nauwkeurig het weer in kaart kunnen brengen. De huidige weermodellen rekenen met een resolutie van 25 kilometer. Dus als alles volgens plan verloopt, is het straks mogelijk een weersverwachting voor de eigen tuin te krijgen.'

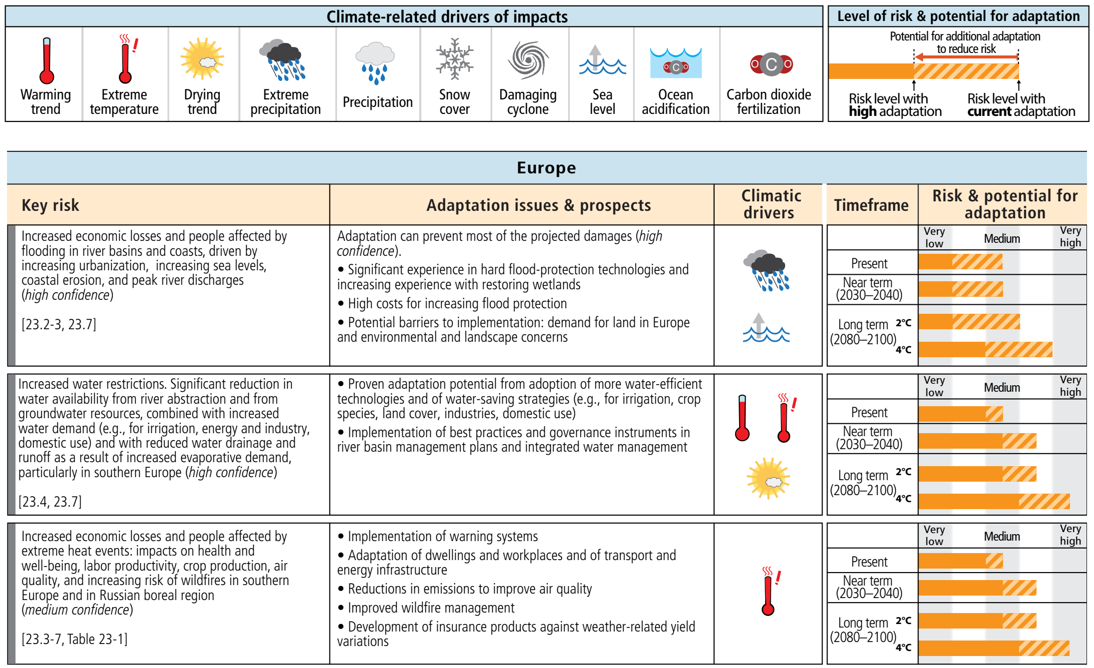
Newspaper article, which introduces a cell phone application that measures the temperature in your own garden, because the temperatures in the city can vary heavily.

Figure 4.
AD, 2014. App geeft weersvoorspelling voor eigen tuin. , 2014(September 17). Available at: http://www.ad.nl/ad/nl/1012/Nederland/article/detail/3721760/2014/08/20/App-geeft-weersvoorspelling-voor-eigen-tuin.dhtml.

that it is a country with a 'mild oceanic' climate (Steeneveld et al. 2011). However, predictions on the climate show that hot days will occur more often in the future. This already became clear when the Netherlands had to deal with heat waves during the summers of 2003 and 2006. When comparing measurements from these time periods with those from other European countries, it became clear that the UHI effect was also present in Dutch cities (Van Hove et al. 2011).

During the heat wave of 2006, measurements were performed by satellites in order to quantify the significance of the UHI in the Netherlands. As described by Klok et al. (2012) the average surface temperature difference between the city and its countryside was 2,9 °C during the day, and 2,4 °C during the night. When looking at the cities with the highest impact of the UHI effect, it can be concluded that there is a difference in heat stress at day and at night. Remarkable is that Den Haag is by far the city with the highest average (8,6 °C) and maximum (15,4 °C) temperature difference during the day, while at night the city ends up at number 36 of the ranking list. During the night, the cities of Dordrecht, Delft, Utrecht and Rotterdam are the cities on top of the list, with an average temperature difference of 4,9 °C.

Studies demonstrate that heat causes problems, and that the Urban Heat Island effect also exists in the Netherlands. At the moment, the subject slowly becomes known among the people as well. Figure 4 describes the development of a cell phone application that shows the weather forecast, and additionally takes heat differences into account. In the article, Bert Holtslag, professor in meteorology at Wageningen University, demonstrates measurements that have been done in the city of Rotterdam, from which the results show that temperature differences can be up to 8 °C in this city. Holtslag mentions, that information derived from measurements like these is relevant to different groups: governments, health care organizations, and urban designers. The first two groups can prevent the consequences of heat stress, while urban designers are able to enhance the liveability of the urban environment during periods of heat. From this is becomes clear that urban design can play an important role in reducing the heat, and with that the problems caused by heat.



Risks of climate issues and potentials for adaptation.

Figure 5.
IPCC, 2014. Summary for policy-makers. In C. B. Field et al., eds. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdon and New York, USA: Cambridge University Press, pp. 1–32.

Risks and the need for adaptation

Figure 5 is a schedule made by IPCC (2014), and shows the possibilities for adaptation and risks related to climate change issues for Europe. The 'climate-related drivers of impacts' that are related to the Urban Heat Island effect are the 'warming trend' and 'extreme temperature'. Besides the water restrictions, in Europe this leads to "increased economic losses […]" and "[…] impacts on health and well-being, labo[u]r productivity, crop production, air quality […]" (IPCC 2014). Possible adaptation strategies only focus for a small part on the change of urban structures. It is mentioned that dwellings and infrastructure can be adapted, while the other adaptation strategies focus on things like warning systems and the reduction of emissions.

From the schedule it becomes clear that it is not possible to reduce the risks because of extreme temperatures to a low level. Also, the risks will increase through time, whether we use adaptation strategies or not. On the long term it is possible to keep the risks close to the medium level, while without adaptation the level would have been up to very high. It should be noted that these risk levels are only related to the extreme temperatures, and not the warming trend. This means that these levels of risk could not be translated to the UHI directly. Still it can be derived that adaptation strategies could reduce the risks related to climate change, which makes it convenient to choose for adaptation instead of not acting at all.

Aim and research questions

From the problem analysis and the relevance of the project, important issues in the field of the UHI effect can be derived. These issues are used to determine the problem statement. Furthermore, the question is asked: What should be achieved after doing research? The answer to this question leads to the aim of the project. For the present project this aim is explained in this section. The additional aims are explained as well, which are related to the main aim. The research questions are based on the problem statement and the aim(s) of the project. Research questions are specifically important for the project, because they lead the research in a certain direction. This direction is derived from the gap in the body of knowledge about the UHI effect.

Problem statement

As discussed in the problem analysis, as well as in the relevance of this project, heat forms a serious threat for certain people in the Netherlands. This threat appears in warmer periods in the summer, and especially during heat waves. Since it is predicted that these conditions will appear more often in the future, the threat becomes more serious. As a result of these heat periods, there are many more deaths than the average numbers. It can be stated that the Urban Heat Island effect is a serious threat as cause of death for vulnerable groups. Especially elderly people, poor people and minorities are vulnerable groups in this case.

When looking at the body of knowledge, we see that a lot of theories about the Urban Heat Island effect are discussed. There is knowledge on how heat acts in the city, what causes the UHI effect, and also what the consequences are for the people in the city. Besides, theories about possible adaptation strategies are already there. It is known that some large cities even tried to implement these possible adaptation strategies, all in their own way. On the other hand, what is not investigated yet, is how effective these implemented strategies are.

Attached to the effectiveness of the adaptation strategies, is the question whether the adaptation strategies are implemented in urban design in the right way. Investigation is needed on how the strategies can be implemented, without changing the other focuses for the design. Therefore, this project needs to focus on the integration of adaptation strategies with social and economic issues in urban design. Often the aspect of vulnerability is attached to the neighbourhood characteristics. In neighbourhoods where social and economic issues are present at the moment, the exposure to heat increases.

Aim of the project

The main aim of the project can be described as follows:

To integrate adaptation strategies to the Urban Heat Island effect into urban design in general, and into urban designs in Rotterdam.

As described in the problem analysis, there is a demand for a better integration of adaptation strategies into urban design. Also, in the section about the relevance of the project, it is pointed out that urban designers are able to have a role in enhancing the living environment in periods of heat. The adaptation to climate change in general, and in this case to the problem of heat specifically, helps to reduce the risks that are related to this phenomenon. By integrating adaptation strategies into the profession of urban design, it becomes more accessible for cities to apply adaptation strategies in project development.

To test whether the application of adaptation strategies works out well in the proposed way, it is needed to use a location with its context, as an example. This can help to improve the application, and shows that it is possible to actually integrate adaptation strategies in urban design.

Additional aims

Because of the subdivision of the project into four themes, additional aims can be formulated for these themes.

1. The aim of the project, regarding the Urban Heat Island effect, is to to reduce the consequences of the UHI effect to an acceptable level in the example designs.

In the process of adapting to the UHI effect, the focus is on making the consequences acceptable. This has to do with human comfort in the living environment, and the reduction of the negative effects attached to heat. Because the health of people is one of the most vulnerable elements to heat, and heat even leads to an increasing amount of deaths, it is important that people are protected against the heat. This can be done by providing places for people where they can escape from the heat. In that case, the heat has no chance to attack the health of people. It is not needed to mitigate the UHI effect at every place in the city, as long as people do not have to stay in hot areas for a long time.

2. The aim of the project, regarding adaptation strategies, is that it should clarify which adaptation strategies are effective to apply.

The effectivity of the adaptation strategies is determined by means of criteria for the strategies, based on literature. Certain adaptation strategies work well, and others not, for certain cases, because the UHI effect is related to the characteristics of a location. When an adaptation strategy makes it possible to remove these characteristics, or to counteract them, the strategy is considered effective. It is therefore needed to determine what characteristics an adaptation strategy should have, and in which cases this works out well.

3. The aim of the project, regarding the creation of an integrated design, is to make designs which include adaptation strategies, with attention to the social, economic and environmental issues of the location.

Since this project is focusing on adaptation to the UHI effect, adaptation strategies should be developed in a way that it can be used in urban design. Measures against heat are translated into generic design elements, which can be used in different contexts. This does not mean that these design elements only have a focus on adaptation. On the contrary, they can be applied in a way that they take all the aspects concerning the given location into account. By looking at all the circumstances, it can be considered as urban design, instead of technical solutions to the problem of heat in a city. The application of the design elements is done on the neighbourhood scale, with a focus on the UHI effect, and the social and economic issues that are present at the location.

4. The aim of the project, regarding the case of Rotterdam, is to integrate adaptation strategies in the existing development plans for two different types of neighbourhoods.

Two various neighbourhoods in Rotterdam are taken as example cases for implementing adaptation measures against heat. The patterns, which are the translation of adaptation measures into generic design elements, are applied while considering the existing plans for the neighbourhoods. By looking at the visions for the neighbourhoods, made by the city of Rotterdam, the patterns can be part of the development plans. As a result, adaptation measures are applied at the same time that development takes place in certain locations in the city. This is an efficient way to take measures against heat, without making seperate development plans.

Research questions

With the problem statement and aim as a base, it is possible to formulate questions for the research. In order to give guidance to the project, research questions are needed at the beginning of the project. The formulated questions determine the framework for what topics should be investigated during the research, and where the design should be focused on. The main research question is the guideline for the project. In order to structure the project properly, the sub research questions are useful means. Together these sub questions lead to the answer of the main question.

Main research question

The main research question can be derived from some key words, which are related to the issues discussed in the problem analysis and relevance of the project. These key words are: Urban Heat Island (UHI) effect, adaptation strategies, integrated urban design, neighbourhoods in Rotterdam. In combination with the chosen locations for the design, the following main research question can be formulated:

How can adaptation strategies to the Urban Heat Island effect be integrated in urban design, and how can this be done in two exemplary neighbourhoods in Rotterdam?

Sub research questions

Considering the key words again, the sub research questions divide the main question into parts that are researched:
1. What is the Urban Heat Island effect, and what are the causes and consequences of it?
2. What are the possible adaptation strategies to the Urban Heat Island effect, and how effective are they?
3. How can adaptation strategies be integrated in urban design?
4. How can adaptation strategies be integrated in two exemplary neighbourhoods in Rotterdam?

These research questions all have a different character. The first question has a focus on theory, and gives an overview of what is already known about the UHI effect. In the second question, existing implementations are discussed. The last two questions can be seen as the design assignments of the project. The third question focuses on how generic design elements can be used, while the last question has to deal with the context of two different neighbourhoods in Rotterdam.

Research approach and methods

By means of a research approach, methods are defined to answer the main research question. At first, the approach to the research is described, followed by an explanation of important terms.The use of methods is explained further in an overview with the related techniques, questions, keywords and literature.

Research approach

The knowledge about adaptation strategies to the Urban Heat Island effect should be applied in the field of urban design. Since urban design always addresses issues from various perspectives (social, economic, environmental), the application should be placed within the context of these perspectives. As a result, the design is an integrated design, taking all the circumstances and problem fields into account. This is considered in the development of the methods, which eventually lead to the research outcomes. Although the project exists of a research and a design part, it does not mean that research and design are seen as separate parts. On the contrary, they have a reciprocal influence, with the result that the process is not linear but iterative. Figure 6 shows the research approach with the relations between the methods.

Literature review

As stated by Webster & Watson (2002) "a successful literature review constructively informs the reader about what has been learned." In other words, it is an overview of the body of knowledge of the research subject, which explains the reader relevant information, in order to understand the subject. According to Webster & Watson (2002), important characteristics of a literature review are that it provides the development of theory, it selects the important information from a large amount of sources, and makes clear where research is still needed.

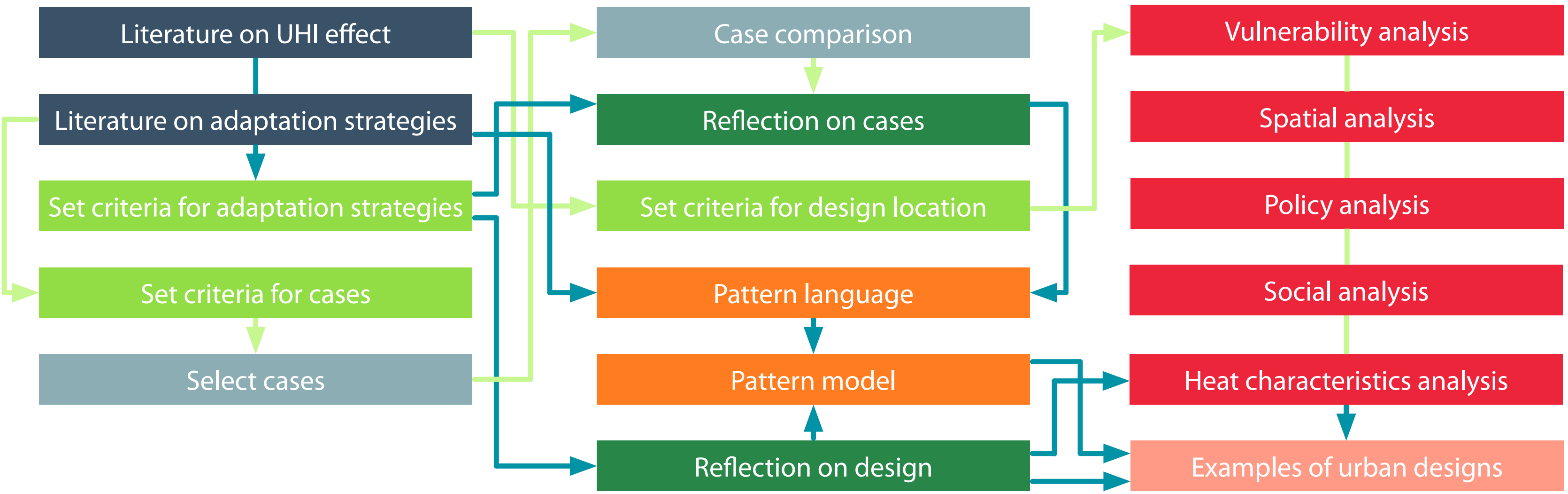


Figure 6.
Image by author.

Overview of the research approach, explaining the relations between the methods.

Case comparison

In this project a few reference cases are compared, which is referred to as a case comparison. Because adaptation strategies are applied in different ways, it is important to look at different cases. By using various reference cases, various types of measures are shown, as well as various ways to implement adaptation strategies. These cases are compared on the same values (qualitative) and entities (quantitative). This leads to conclusions on the similarities and differences between the cases, as well as an indication of which cases can be considered effective or not.

Adaptation strategies

The function of an adaptation strategy, in this case, is to reduce the consequences of the UHI effect. This is done by the use of strategies, because a strategy is always used for a certain purpose. The definition of a strategy is "a plan of action designed to achieve a long-term or overall aim" (Oxford Dictionaries 2014b). In this project the aim is to adapt to the UHI effect. The plans of action are made in the form of measures that are developed into design elements. The configuration of the design elements is based on the neighbourhood dynamics. In the process of positioning the design elements, it is taken into account at what places the design elements have the highest impact on the UHI effect.

Environmental science & design

The approach of Midgley, described in Müller et al. (2005), is used for the integration of the adaptation strategies in urban design. It is described that the knowledge generation processes of science and design can be compared, in order to make an integrated design. Examples of theories, methods, and applications to a context, are mentioned by Müller et al. (2005). For the design cycle the theory about pattern languages of Alexander (1995) is used to produce patterns, sketches and design principles. These patterns can be turned into a plan for the concerning location. For the science cycle the system dynamics theory of Forrester is used as an example. As stated by Ford (1999) this theory can be used for analysing problems, in the framework of a socio-economic system. Because of this it can be useful to make models, similar to the theory of Forrester, in which location specific parameters can be used.

Patterns

In his book 'A Pattern Language', Christopher Alexander (1995) introduces a way to structure the different elements that are needed to make a design. He calls the elements 'patterns', which represent a solution to a regular problem. Besides, the relation between the patterns is shown in order to use them to make a design. Important in the way Alexander describes patterns are physical and social relations, which are the key elements of the solution.

The book of Alexander (1995) shows a pattern language for cities, buildings and constructions, which he developed himself. This can be seen as an example of how a pattern language can be made, based on elements and their relations. By structuring and describing elements in the same way as Alexander, it is possible to create a pattern language for other domains than cities, buildings and constructions. During the design process of this project, a pattern language is used to describe the various adaptation measures.

Methods & techniques

On the following pages, an overview is given of the methods that are used for every research question. The left column explains the methods and their techniques, the column in the middle is in some cases used as clarification of which questions, key words or themes are addressed. The last column shows the used references. A reference to the concerning section and page is given in this last column as well.

Sub research question 1: *What is the Urban Heat Island effect, and what are the causes and consequences of it?*

Literature review on the Urban Heat Island effect

In order to understand the Urban Heat Island effect, there should be a theoretical framework that addresses certain aspects of this phenomenon. Therefore a few questions are asked that need an answer in this literature review.

- What are the causes of the UHI effect?
- How does the process work?
- What is the result of this process?
- How could the UHI effect be measured?

causes, effects, urban climate, remote sensing, meteorological observations, Urban Heat Island (UHI) effect

- Memon et al. (2008)
- Döpp et al. (2011)
- Van der Hoeven & Wandl (2013)
- Mills (2007)
- Mirzaei & Haghighat (2010)
- Oke (2004)
- Oke (1995)
- Taha (1997)

>>> On the Urban Heat Island effect, p. 27

Sub research question 2: *What are the possible adaptation strategies to the Urban Heat Island effect, and how effective are they?*

Literature review on adaptation strategies

An overview is needed on the various possibilities for adaptation to the UHI effect. The pattern language can be created from this overview, with possible strategies for different situations.

- Which adaptation strategies are mentioned in literature?
- What is known about the effectivity of these adaptation strategies?
- Which adaptation strategies are already implemented?
- How could the effectivity of adaptation strategies be measured?

adaptation strategies, implementation, impacts, effectivity, case comparison, Urban Heat Island (UHI) effect

- Arup (2014)
- IPCC (2014)
- Rense (2007)
- Shashua-Bar et al. (2006)
- Shaw et al. (2007)
- VROM (2007)

>>> On adaptation strategies, p. 31

Set criteria for selecting relevant cases for the case comparison

A list of selection criteria is made before the case comparison is done. For these criteria it is important that different kinds of implemented adaptation strategies are addressed. This means that the cases should focus on different ways of adapting, and on different measures.

- Gerring (2007)

>>> Case comparison, p. 43

Set criteria for testing implemented adaptation strategies and design elements

Some of the adaptation strategies which were found in literature are already implemented. In order to be able to test whether these strategies were effective or not, criteria are needed. In these criteria, aspects like impact of the measure on the temperature, and the social and economic impact are taken into account. These criteria are not only used for the implemented adaptation strategies, but also for the design elements.

- Arup (2014)
- Van der Hoeven & Wandl (2013)
- Shashua-Bar et al. (2006)
- Stathopoulos et al. (2004)

>>> On adaptation strategies, p. 31

Case comparion of cases related to implemented adaptation strategies

The selected cases are compared on the subject of adaptation strategies. The formulated questions are used to make the framework in which the cases are compared.

- What are the probable causes of the UHI effect in this case?
- With what kind of adaptation strategies did they try to tackle it?
- What where the goals of these adaptation strategies?
- What was the impact of these strategies on the UHI effect?
- What was the impact of these strategies on the social and economic conditions at the given location?

- Lauwaet et al. (2013)
- Greater London Authority (2008)
- Nickson et al. (2011)
- City of Copenhagen (2011)

>>> Case comparison, p. 43

Reflection on the implemented adaptation strategies

For the reflection the criteria for testing implemented adaptation strategies are used. The information provided by the case comparison is compared with these criteria. This leads to conclusions about the effectivity of all the cases, and eventually to the conclusion which adaptation strategies are effective. By deducing the characteristics of effective adaptation strategies, it is possible to come up with other strategies than which are used in the cases.

>>> Case comparison, p. 47

Sub research question 3: *How can adaptation strategies be integrated in urban design?*

Create a pattern language by using adaptation strategies (see Figure 7)

At first, effective adaptation strategies are selected. This is done on the basis of the reflection on the cases. Then, the effective adaptation strategies are translated into patterns, based on the pattern language of Alexander. In the description of the patterns it is important to mention the social and economic benefits, because it shows a broader view than only a technical solution.

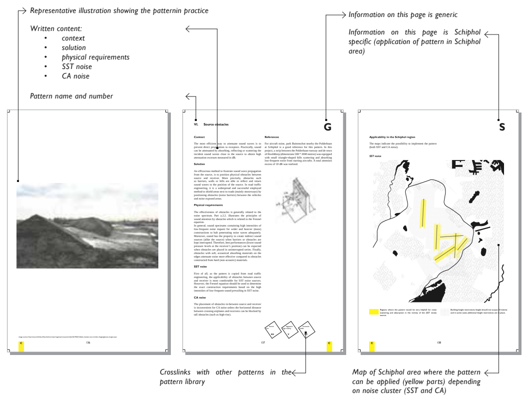


Figure 7.
Lugten, M., 2014. Re-sil(i)ence: design patterns for an aircraft noise abating spatial environment. TU Delft.

- Alexander (1995)
- Bruin (2010)
- Mentink et al. (2013a)
- Lugten (2014)

>>> Patterns, p. 52

Create a pattern model by showing the context of implementation (see Figure 8)

From the reflection on the cases, it has become clear for which aspects the patterns function well, and could improve local circumstances. The benefits are summarised in a 'pattern model', by showing important relations of the patterns. This pattern model can be useful for cities to implement in certain situations. Eventually the pattern model is used to create design elements for the areas of development.

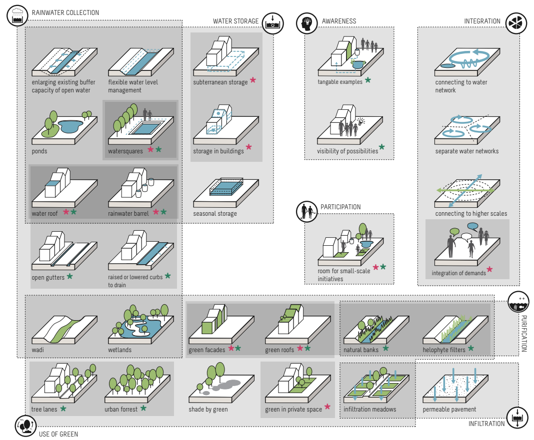


Figure 8.
Van Lohuizen, J., 2014. Climate Adaptive Solutions for the Neighbourhood: A strategy of small-scale interventions to facilitate adaptation to impacts of climate change on the neighbourhood scale. Delft University of Technology.

- Van Lohuizen (2014)
- Salingaros (2008)

>>> Pattern model, p. 50

Sub research question 4: *How can adaptation strategies be integrated in two examplary neighbourhoods in Rotterdam?*

Set criteria for selecting the most representative neighbourhood

For the urban design two neighbourhoods are chosen which have to deal with the UHI effect. A list of selection criteria is provided, based on the problem analysis. From the problem analysis it can be derived what kind of characteristics the neighbourhoods should have, and which part of the inhabitants belongs to a vulnerability group.

- Daanen et al. (2010)
- Van der Hoeven & Wandl (2014)

>>> Research approach & methods, p. 25

Vulnerability analysis for selecting design locations

With the drawn criteria, neighbourhoods are selected for the design implementation. The selection considers the UHI effect, but also the vulnerability of people who live in the concerning neighbourhoods.

- outdoor temperatures
- vulnerability maps
- demographic numbers
- social indices
- construction periods

- CBS (2014)
- Gemeente Rotterdam (2012)
- Van der Hoeven & Wandl (2014)

>>> Vulnerability analysis, p. 91

Spatial analysis of the design locations

To make it possible to implement adaptation strategies in the chosen neighbourhoods, an understanding of the local structure is needed. This is done by mapping information of different aspects. Not only the neighbourhood itself is analysed, but also its position in the city of Rotterdam.

- infrastructure
- public transport
- water structure
- green structure
- functions
- public and private space
- vision of Rotterdam
- SWOT analysis

>>> Spatial analysis, p. 94

Social analysis of the design locations *This part of the analysis is focusing on other characteristics of the neighbourhood than the physical structure. It is investigated who uses the public space, and which activities are done there.*	- Who uses the public space, and how crowded is it? - What activities are done in public space?	>>> Social analysis, p. 105
Heat characteristics analysis of the design locations *An indication of the performance of the five heat characteristics is given for the present situation of the neighbourhoods. This is done for the different design locations.*	- Are the heat characteristics weak, moderate or strong for the various design locations?	>>> Urban design implementation, p. 108
Urban designs based on the research outcomes *The urban designs are made for the neighbourhoods in Rotterdam. As basis for the designs, the pattern model is used. As a result, the adaptation measures are part of the design, because they are part of the patterns. The urban designs address solutions for the local problems as well, and are created as part of existing development plans.*		- Mentink et al. (2013b) >>> Urban design implementation, p. 108
Reflection on the example designs *At the end of the project the outcomes of the research are implemented in the design elements. In order to test if this is the case, the design elements in Rotterdam are tested. This is done in the same way the adaptation strategies are tested after the case comparison; the criteria are the base for this reflection. The reflection helps to give a conclusion on how other cities can use the patterns and pattern model to adapt to the consequences of the UHI effect in their city.*		>>> Urban design implementation, p. 108

Criteria for selecting representative neighbourhoods

Before design elements can be made for the city of Rotterdam, a specific location is needed. Two representative neighbourhoods are selected by means of the following criteria:
- The neighbourhoods are situated in the city of Rotterdam.
- The neighbourhoods have to deal with a significant amount of heat, due to the UHI effect.
- The neighbourhoods consist of a relative large amount of vulnerable inhabitants, with the focus on elderly and poor people.
- The neighbourhoods are in need for change, according to the policies of Rotterdam.
- The neighbourhoods are different from each other in terms of building typologies, functions and inhabitants.

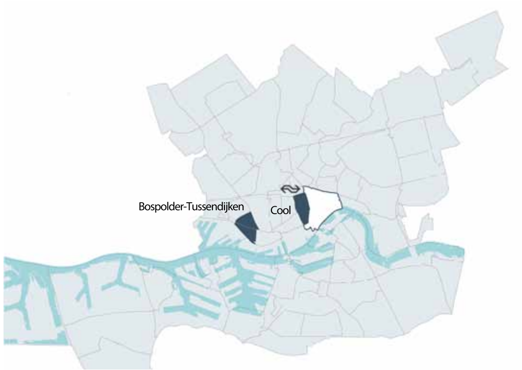
The selection of the neighbourhoods is done by the use of temperature and vulnerability maps, and information from policies for Rotterdam. By combining this information, two neighbourhoods are found, which meet the criteria described above. The vulnerability of the neighbourhoods, combined with the UHI effect, show the urgency to implement adaptation measures in the concerning neighbourhoods. By looking for neighbourhoods for which developments are planned in the nearby future, there is an opportunity for implementing the desired measures against heat. In this way implementation can be done, without doing interventions only as a measure against the UHI effect. The two different neighbourhoods show the possibility to apply the adaptation measures in different situations.

Main actors related to the project

The following actors are specifically taken into account during the project:
- Municipality of Rotterdam. This is the actor that is able to provide information about the city, and also has certain visions which need to be considered. Besides, the project is made for the city of Rotterdam, and this is the actor that eventually could realise the designs.
- Climate Proof Cities Consortium. This research programme of Knowledge for Climate provides a lot of useful information on measurements in the city of Rotterdam.
- Inhabitants of the chosen neighbourhood in general, and of the city of Rotterdam. They are the people for who the design elements are made. For this reason the designs should fit the people who live there.
- Vulnerability groups of the chosen neighbourhoods. Since the neighbourhood are (partly) selected on the base of the vulnerability groups, the design elements should be suitable for these groups.

Location analysis

The chosen neighbourhoods in Rotterdam are Bospolder-Tussendijken and Cool (see Figure 9). These neighbourhoods are investigated further in the location analysis. The location analysis exists of four elements:
- vulnerability analysis, focusing on selecting two exemplary neighbourhoods
- spatial analysis, focusing on understanding the structures of the neighbourhoods
- social analysis, focusing on the activities, and what kind of inhabitants can be found in the neighbourhoods
- heat characteristics analysis, focusing on the weak, moderate or strong status of the different heat related characteristics.



Position of Bospolder-Tussendijken and Cool in Rotterdam.

Figure 9.
Image by author.

Part 2: Background information

Photo © Plaswijckpark, Unit10 Fotografie / Rotterdam Image Bank

On the Urban Heat Island effect

The first part of the literature review is described in this section. After a short introduction of the Urban Heat Island (UHI) effect is given, the process behind it is explained. Furthermore, this section elaborates on what the causes and consequences are of the UHI effect, and how this effect can be measured.

Introduction

Luke Howard is a pioneer in the field of climate, and also the person who first mentioned the theory behind the Urban Heat Island effect. In 1833 he wrote the book 'The Climate of London', in which he describes his findings on the climate. He based the conclusion that the city has a higher temperature than the countryside on measurements in the city of London and in the nearby villages of Plaistow, Stratford and Tottenham Green. He concludes: "[…] the temperature of the city is not to be considered as that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fires […]" (Mills 2007). Howard noticed that heat is produced in the city and remains there.

The process

The process of the production and conservation of heat in a city, can be described by the Surface Energy Balance (SEB) equation (Oke 1988 in Memon et al. 2008):

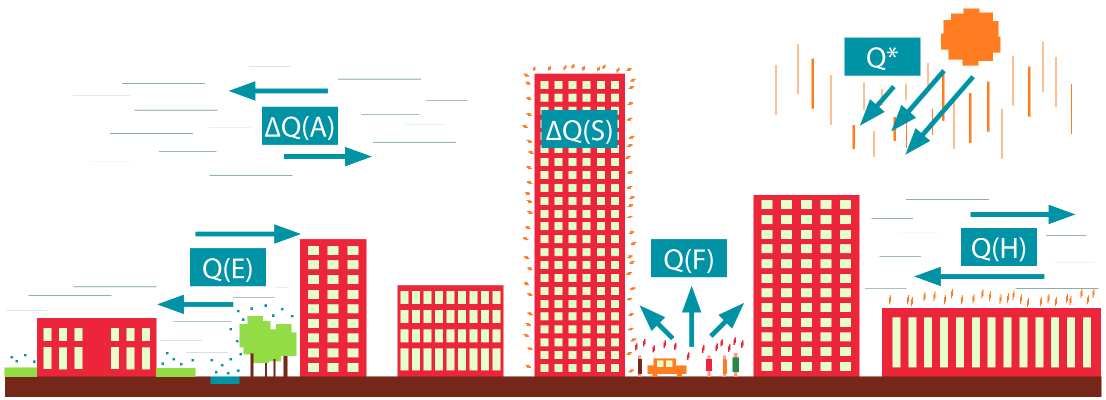
$$Q^* + Q(F) = Q(H) + Q(E) + \Delta Q(S) + \Delta Q(A)$$

All the parameters that are part of this equation are explained here (see Figure 10).

The net all-wave radiation (Q*) is a combination of long wave and short wave radiation, mainly caused by the sun. The amount of radiation that can be captured by the surfaces is influenced by a few things. At some areas the short wave radiation is mitigated by large amounts of polluted air. This leads to less radiation on the surface. The decrease of the radiation is offset by the albedo, because albedo leads to extra radiation. Long wave radiation increases as a result of radiation from high temperature surfaces. The difference in radiation between the city and the countryside can vary up to 5% (Memon et al. 2008).

Anthropogenic heat is heat "originating in human activity" (Oxford Dictionaries 2014a). Memon et al. (2008) state that this heat comes from stationary and mobile sources. It could be described as heat produced by buildings, vehicles and people, or as the remaining part of all the produced heat. There is a strong variability in the amount of anthropogenic heat release Q(F), since it depends on the energy use of people.

The turbulent sensible heat flux density Q(H) is related to eddy (a circular movement of air), as well as the heating of surfaces. The height of this parameter is positively correlated to the amount of built



Representation of the process of production and conservation of heat in a city, called the Surface Energy Balance (SEB).

Figure 10.
Image by author, based on: Van der Hoeven, F.D. & Wandl, A., 2013. Amsterwarm. Gebiedstypologie warmte-eiland Amsterdam, Delft: TU Delft, Faculty of Architecture.

surface, because in general these surfaces heat up easily. Other influences can come from the net all-wave radiation Q*, thermal admittance, and the presence of moisture in the ground (Memon et al. 2008).

The turbulent latent heat flux density Q(E) is related to evaporation and eddy, and varies heavily. Especially vegetation has influence on evaporation, with the result that high vegetated areas have a high latent heat flux, while it could be very low in less vegetated areas (Memon et al. 2008).

The before mentioned parameters are all measurable, which is not the case for the sensible heat storage ΔQ(S). This parameter is related to surface materials and the orientation of (building) structures, as well as the interaction between those two. A strong correlation is found between the net all-wave radiation Q* and the sensible heat storage. In other words: when the radiation of the sun is less strong, less heat will be absorbed by materials and buildings. Since it is not possible to measure the heat storage, usually ΔQ(S) is calculated by considering it as the only unknown variable of the Surface Energy Balance (Memon et al. 2008).

According to Memon et al. (2008) the net heat advection ΔQ(A) can be neglected in the SEB, because it is considered as an inaccuracy in the measurements of all the parameters. It is caused by the transport of air, which is dependent on the combination of temperature, humidity and wind.

The causes

As described by Taha (1997) it is difficult to get grip on the complexity of what causes the UHI effect. In his paper he focuses on three important elements that have to do with the causes: albedo, evapotranspiration and anthropogenic heat. These terms will be explained further here.

'Albedo' is a number that is used for the "hemispherically- and wavelength-integrated" (Taha 1997) reflection of a certain surface. A lower (than the average building surface) temperature could be reached by the use of materials with a high albedo, because it reflects solar radiation. With that, the materials of among others the buildings, will absorb less heat. As a result, there will also be less use of mechanical cooling systems in the buildings, which indirectly contributes to less heat in the city.

The term 'evapotranspiration' could be described as the combination of evaporation and transpiration. Places that contain soil and vegetation can be cooler because of these phenomena, and can approximately reduce the temperature with 2-8 °C (compared with the surroundings of the soil/vegetation area). A reduction of 8 °C will only occur in extreme situations, while a reduction of 2 °C can be expected in more general situations. An important factor which should be taken into account in this case is the availability of water for the evapotranspiration. When there is no water within reach, the soil and vegetation will not make a lot of difference to the temperature (Taha 1997).

As mentioned before, 'anthropogenic heat' is heat that comes from human activities. It was already described by Luke Howard (Mills 2007) that there was a kind of 'artificial heat' in the city, which caused a temperature difference between city and countryside. In the paper of Taha (1997) it is demonstrated that the UHI effect caused by anthropogenic heat can be 2-3 °C in a large city core. The combination of this heat with factors like an area with a low amount of vegetation or a high amount of dark surfaces (which means low albedo), creates an increase of the UHI effect.

Memon et al. (2008) point out that we live in times of urbanisation and industrialisation, which has a lot of consequences for the world we live in. The paper demonstrates global problems like

“[…] global warming, industrial waste, and air pollution”, and the negative effects they have on the environment and its ecology. One of the mentioned phenomena on a smaller scale is the Urban Heat Island effect, which is in their eyes caused by more or less the same things as pointed out by Taha (1997). Another thing that is related to the cause of the UHI effect, according to the paper of Memon et al. (2008), is the ‘high roughness structure’ urban areas have. This makes it difficult for the heat to get away from the urban structures, because the convection decreases.

From the explanations of Taha (1997) and Memon et al. (2008) it can be derived that the following elements in a city can contribute to the cause of the UHI effect:
1. Materials with a low albedo.
2. Mechanical cooling systems.
3. Lack of vegetation and soil.
4. Lack of water structures (close to vegetation and soil).
5. Production of heat by buildings, vehicles and people.
6. High roughness structure of the buildings.

In the process of applying adaptation strategies, these elements should be taken into account for the making of design elements. By focusing on this, the measures can contribute to the prevention or reduction of heat stress.

The consequences

In literature we can find a lot of consequences of the Urban Heat Island effect. As described by Memon et al. (2008) there will be a negative impact on the living environment, more demand for energy, increase of exposure to ozone, and in the end also more deaths. Döpp et al. (2011) point out the same consequences, while adding some nuances and sometimes be more precise. They name some additional problems that human beings can have, namely health problems and a negative influence on the productivity at work. The negative consequences the heat has for the living environment can be linked to thermal comfort, air quality and ecology.

Another consequence, which is not mentioned by the other authors, has to do with economic issues. According to the Intergovernmental Panel on Climate Change (IPCC 2014), extreme temperatures can lead to an increase of economic issues. Issues that were mentioned related to this are i.e. impacts on labour productivity and crop production. In addition to this Mirzaei & Haghighat (2010) mention the increase of energy use because of air conditioning systems. According to them this could even lead to power outage in a city. It can be concluded that the UHI effect not only has an influence on the well-being of people, but also on the well-being of the city, in terms of the environment and economy.

Measuring the Urban Heat Island

When we want to measure the UHI effect, there are two kinds of approaches. The first one is making measurements on site, while taking all the dynamics into account. The second method is to measure from a far distance, by the use of satellites or airplanes. Both the measurement methods are explained.

In one of the many articles about the UHI effect of Oke (2004) an explanation is given on how to measure temperatures and climate conditions on site. One of the first things mentioned are the dynamics on various scales (see Figure 11). In the article it is pointed out that normally measurements are done on the local scale. Since the dynamics vary heavily at the micro scale, it should be taken into account that this could influence the results. In an ideal situation there is no micro scale influence, but this is difficult to achieve. Therefore it is good to choose a location for measurements by typical circumstances. Next to these horizontal scales, Oke (2004) mentions the vertical scales as well. In a city the vertical scale occurs as the 'urban canopy layer' (UCL). In this layer the dynamics are determined by a combination of a micro climate on the scale of a surface, and the turbulent eddies. Furthermore, the vertical scale has to deal with the 'roughness sub layer' (RSL). Because of the micro climates and eddies, a process of blending occurs. The RSL is determined by the height of this part of air where the blending takes place. For the measurements it is, as another method for measurement, a possibility to locate the sensors above the RSL. This method works best in terms of wind and precipitation. For the other method, the one where a typical situation is used, it is important to locate the sensors at the same heights as in the rural areas. This method works best in terms of air temperature and humidity.

Another often used method is to measure temperatures from a far distance. This method is called 'remote sensing', and is done by the use of satellites or airplanes, according to Döpp et al. (2011). A positive element of this method is that you are able to make maps of a certain area with all the temperatures. However, the difficulty of this method is that other information than temperatures cannot be obtained normally. Also, the interpretation of the gained information is complicated. In both the case of on-site measurements and remote sensing, it is important to clarify how the methods were used, and how this led to the interpretations that has been done.

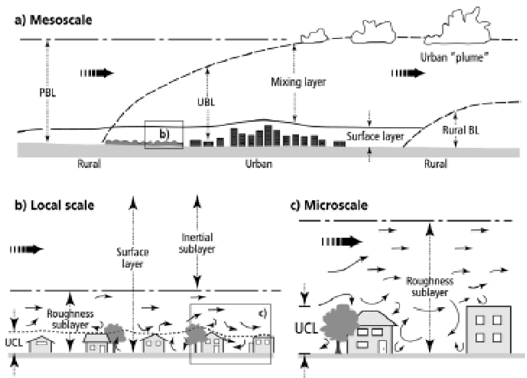


Figure 11.
Oke, T.R., 2004. Initial guidance to obtain representative meteorological observations at urban sites. World Meteorological Organization, (81), p.51.

The dynamics of different scales should be taken into account when measuring the Urban Heat Island.

An introduction and a literature review is given on climate change and adaptation strategies. This review addresses the possibilities and effectivity of adaptation strategies. By means of setting criteria, implemented strategies are assessed on their impacts on both the UHI effect and the social and economic conditions. This assessment takes place in the case comparison, which is described in 'Part 3: Research outcomes'.

It should be noted, that in this project adaptation strategies which focus on changing or constructing certain building structures, do not get a lot of attention. This choice is made, because this project focuses on how the existing urban form can be used as a basis for adapting to the UHI effect. In other words, at many locations it is not desirable to build up the entire urban environment again. As a result, the project focuses on changing public space, private outdoor areas, and in some cases adds some elements to an existing building structure.

Climate change adaptation

In the Netherlands, a lot of knowledge about climate change is developed in the last year. At the moment we are at the point where adaptation is needed. Especially in the case of the UHI effect the application of knowledge is still lacking. This graduation project has the aim to be part of climate change adaptation in the Netherlands. Therefore, the body of knowledge about this subject is given on the scale of this country. This means that not only the problem of heat is addressed, but also other manifestations of climate change.

Effects of climate change

According to the factsheet about Spatial Adaptation to Climate Change by Rense (2007) there are several effects of climate change. These effects are related to the subjects of security, living environment, biodiversity and economy. Based on this factsheet, the following summary can be given:

Security – Both the sea level rise and the increasing amount of water in rivers, ask for measures to prevent the Netherlands from flooding.
Living environment – Extreme temperatures and extreme rain showers lead to heat stress and water nuisance.
Biodiversity – Because of changing temperatures and water conditions, certain species disappear.
Economy – Extreme weather conditions can cause problems for transport and energy, which has an negative influence on the economy. Also, the agricultural business could perceive problems due to draught or a lack of sweet water.

The before mentioned effects are all negative effects because of climate change. A positive effect is mentioned by Rense (2007): Warm summers positively influence the economy in the fields of agriculture, tourism and recreation. Indirectly there are more positive effects because of climate change. The Netherlands is known for its innovative water management, which is developed due to the threat of floods. Also, the agricultural sector is forced to come up with solutions to draught and water shortage, which also leads to innovative technologies.

Adaptation and mitigation

Although there are some positive effects to the climate change in the Netherlands, there is an urgency to reduce the negative effects. Without acting, human beings will only have a negative influence on the environment, and climate change will have more impact than it has now. Therefore, negative effects should be fought. This could be done by using adaptation or mitigation strategies. According to Rense (2007), adaptation strategies focus on the creation of the best possible circumstances, because it is not possible to stop the change itself. Mitigation is used to actually reduce climate change. As said before, it is not possible to stop climate change, but at some points strategies can lead to mitigation. This is especially the case for CO_2 emissions and greenhouse gasses. Only on the long term, adaptation strategies could possibly have an effect on the mitigation of climate change. Because it is impossible to mitigate climate change on the short term, we have to focus on adaptation for the other cases now (Rense 2007). When we talk specifically about the Urban Heat Island effect, it could be pointed out that measures are called adaptation strategies, because they try to reduce the consequences, while these measures eventually could lead to the mitigation of the UHI effect.

As defined by IPCC (2014) adaptation is: "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." From this explanation it can be derived that human acting can cause mitigation, but that is not a necessary effect of the adjustment. Adaptation is used to minimize the impact of climate change, and if it benefits to natural systems it is a welcome effect. As a conclusion, it can be said that adaptation is needed now, and that mitigation could be a positive side effect to it.

Possible adaptation strategies in urban design

Shaw et al. (2007) show in Figure 12 possible adaptation strategies, which can be used as measure against the UHI effect in urban design. They handle three scales on which these strategies, or 'actions and techniques' as they call it, can be implemented. The division of different strategies per scale is as follows, according to them:
Conurbation scale – A network of high quality green space, bodies of water, protection against solar radiation by using shadow/orientation, ventilation based on building orientation/structure.
Neighbourhood scale – Green structures with the possibility to evaporate, use of ponds and similar water structures, protection against solar radiation by orientation, cool reflective/permeable pavements, cool roof networks.
Building scale – Protection against solar radiation by plantings/shading/glass, cool building materials and green roofs/walls, innovative water cooling systems, mechanical cooling systems, fresh and cold air ventilation, thermal heat storage.

There are many possibilities, as demonstrated by Shaw et al. (2007) , and they are implementable on different scales. It is a positive thing that there are many things we could do, but on the other hand it makes decision making in this case very complicated. It raises questions like: What scale should be taken into account? What are the most effective adaptation strategies? And how many should be implemented at the same time? These questions need to be investigated further.

Impact of conditions and measures on heat

Little is known about the effectivity of adaptation strategies, because only a few measures are implemented until the present day. Fortunately, in literature some studies can be found, which address the impact of conditions ans measures on heat in the city. Knowledge in this field can be used, to indicate the effectivity of adaptation strategies on the UHI effect.

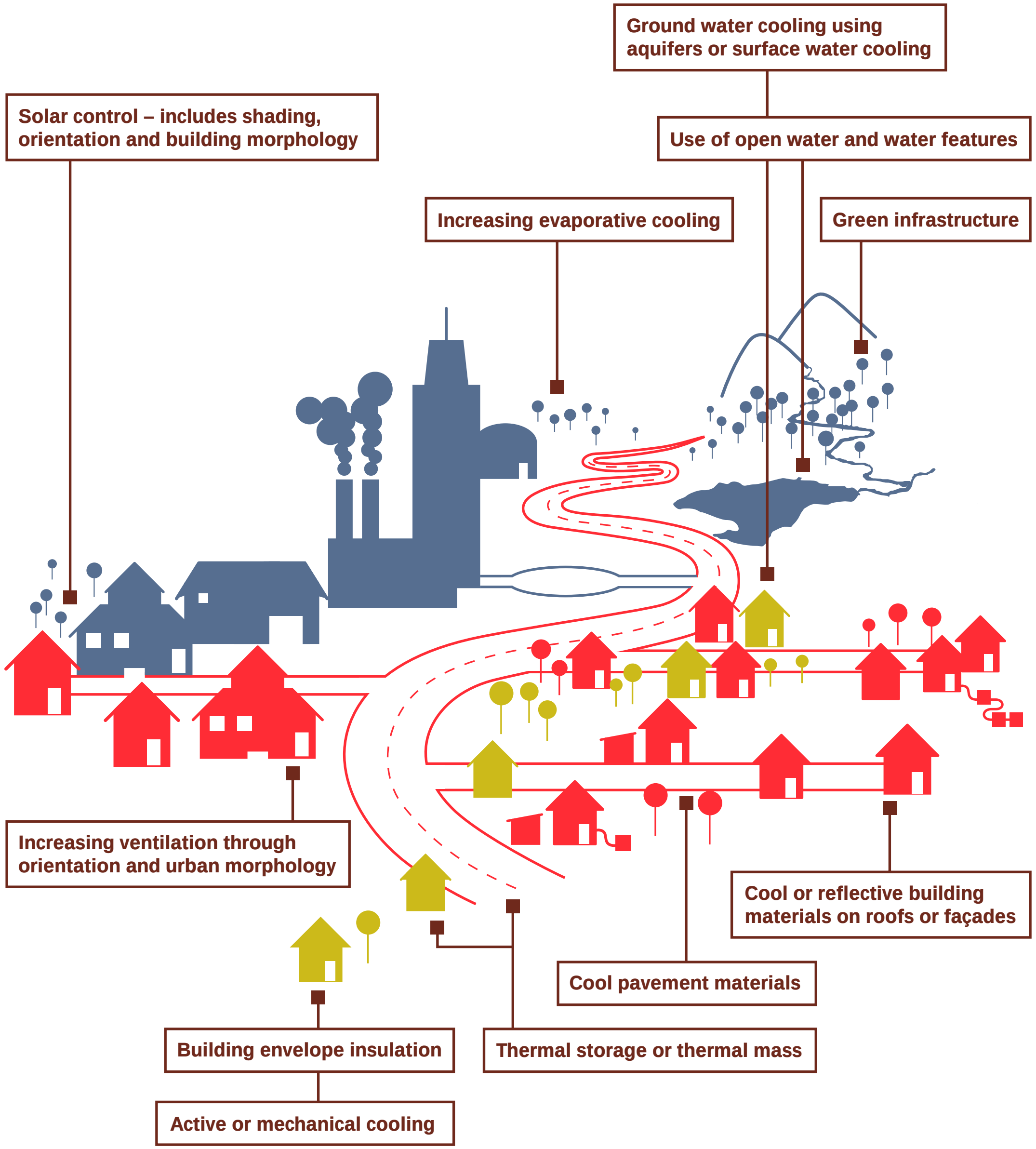
Environmental conditions

In a study, done by Shashua-Bar et al. (2006), the thermal effects of built form, trees, and colonnades, are simulated. As a result of this study, a few important conclusions can be drawn:
- "The smaller the envelope ratio, the cooler the built-up unit."
- "The tree effect is stronger, the larger

is the envelope ratio (as in shallow open spaces)."
- "Preliminary analysis of in situ measurements shows that the lawn's evaporative effect [...], was about half that of shade trees."
- "The UCL in closed courtyards is cooler than that of street houses."
- "The colonnade effect is stronger in closed courtyards than in the streets, due to the added area under the colonnades. [...] The cooling effect is especially strong in shallow (low H/W) open spaces."
- "The correlation between the built-form and the trees effects is negative—the warmer the built-up unit, the stronger the tree cooling effect." (Shashua-Bar et al. 2006)

In this case the envelope ratio can be described as "the ratio of the open ground area to the envelope area" (Shashua-Bar et al. 2006). The UCL represents the 'Urban Canopy Layer', which is an often used term referring to the air temperature, measured at a quite low point in the city. 'H/W' refers to the height/width ratio of the open space between buildings.

The thermal effects are related to some characteristics that are mentioned in the conclusions, in particular building envelope, open space, evaporation and shade. These characteristics can contribute



Representation of the possible adaptation strategies in urban design.

Figure 12.
Shaw, R., Colley, M. & Connell, R., 2007. Climate change adaptation by design: a guide for sustainable communities, London.

to a lower temperature in the built environment.

Measures

Arup (2014) has composed a document which focuses on reducing heat risks. In this document there is an appendix, in which measures for addressing the risks of urban heat are demonstrated. This appendix is a collection of information from several sources. The measures that are related to the environment outside or the modification of dwellings, will be pointed out here.

Measures for the modification of dwellings:
- 'Internal wall insulation': Reduces the risk of overheating, especially useful for vulnerable users of the building. External shading is more effective than internal shading.
- 'Ventilation': This is useful for human comfort. Natural ventilation only works when the outside temperature is lower than inside, but is negative in terms of air quality. Air-conditioning is needed in some cases, but is negative in terms of emissions and waste heat.
- 'Trees': A natural way of shading, with positive effects on air quality and surface water runoff. Species which are deciduous and with broad leaves are preferred, because of shade in summer and light in winter.
- 'Flat roof refurbishment': Green roofs are positive for water management and ecology. Also white roofs help to reduce overheating of the building.
- 'External environment / landscaping': A well designed area can provide shade and evapotranspiration, which reduces the local temperature.

(Arup 2014)

Measures related to urban trees and green infrastructure:
- 'Evaporative cooling and transpiration of plants': Water is converted into vapour by the sun, which leads to lower temperatures.
- 'Reflectance / albedo of greenery': Dark and matt surfaces absorb heat, which leads to a warmer environment. Therefore light and reflective surfaces can help to do the opposite, including greenery.
- 'Shading from urban trees': Shade protects surfaces from heating up, buildings from having the greenhouse effect, and people from direct exposure to the sun.
- 'Spatial scales of cooling by urban green spaces': Green spaces show significant lower temperatures than other parts of the city. As a result, the surrounding areas of a green space are cooler as well.
- 'Right tree, right place': Species and the location of trees influence the cooling effect. The tolerance of the trees should be addressed as well. Water irrigation can help to ensure evapotranspiration.
- 'Green roofs, walls and bio-shade': Useful for locations with no room for green spaces. Surfaces can be protected from heating up by direct solar radiation, and the plants can evapotranspirate. They have positive effects on biodiversity and air quality.
- 'Water bodies': Cooling effect particularly works well on the leeward side (protected from the wind) of the water body. Provides evaporation, and a reflective surface retains less solar energy.

(Arup 2014)

Important characteristics of these measures are that they provide shade, insulation, ventilation, reflection and/or evaporation. Shade and evaporation were mentioned by Shashua-Bar et al. (2006) as well, and open space can be related to ventilation. The reflection (albedo) of surfaces is something that was not pointed out particularly by Shashua-Bar et al. (2006), as well as insulation. What is not mentioned by Arup (2014) is the building envelope. For the measures and environmental conditions it is useful to look at the characteristics of the (altered) environment, to see if it is a convenient situation for heat risks.

On integrated urban design

Before adaptation strategies can be integrated into urban design, it is important to know the ways in which this could be achieved. Therefore, the theory of Midgley is described, because this theory is applied during the project.

Science and design

Since climate change and environmental issues can be seen as part of science, theories about combining science and design are relevant to this project. In the article of Müller et al. (2005) about converging design, science and deliberation in urban planning, some relevant activities in science and design are described. They mention that communication, the development of design principles, observation, and calculation are all part of science and design. A major difficulty in combining these two (science and design), is how they could be considered on an equal level. The approach of Midgley, as discussed by Müller et al. (2005), is an effective way to combine science and design, and in the case of the article combining these two with deliberation as well. Midgley suggests in his approach to make a shift from comparing the knowledge fields to comparing the knowledge generation processes. This can be done by using the learning cycles of these processes.

From the approach of Midgley, described in Müller et al. (2005), a few relevant things can be derived. In the first place, every learning cycle exists of interpretation, design and effects. In the design cycle the focus is on the (spatial) design, and in the science cycle the focus is on the effects. Secondly, a few useful examples of theories, methods, and applications to a context, are mentioned (see Figure 13). For the design cycle it is possible to use the theory about pattern languages of Alexander (1995), to produce patterns, sketches and design principles. These can be turned into a plan for the concerning location. For the science cycle the system dynamics theory of Forrester could be used. As stated by Ford (1999) this theory could be used for analysing problems, in the framework of a socio-economic system. Because of this it could be useful to make models, based on this theory of Forrester, in which location specific parameters can be used. According to Forrester (1969) the system dynamics theory leads to the conclusion that solving the social, economic and environmental problems at the same time is not possible. However, it is possible to choose different plans for improvement, which all have another effectivity in the social and economic context.

It can be stated that finding a balance between social, economic and environmental issues is quite difficult, although sustainable development becomes more part of urban design nowadays. According to Müller et al. (2005), the strategy of Midgley can be used to focus on the relation between environmental science and design. By

Table 1. Three levels of the basic learning cycles illustrated with examples

	Design cycle	Science cycle	Deliberation cycle
Theories	Pattern language (Alexander *et al.*, 1977), Ecopolis (Tjallingii, 1996)	Material flow analysis (Baccini and Brunner, 1991), system dynamics (Forrester, 1961)	Process management (de Bruijn *et al.*, 1998), gaming theory
Methods, tools	Patterns, sketches, design principles	Models	Delphi, games, design principles for process management
Applications of methods in specific context	Plans for local space	Simulations using model parameters of local situation	Process with local actors

Examples of theories, methods, and application to the context for the different learning cycles.

Figure 13.
Müller, D.B., Tjallingii, S.P. & Canters, K.J., 2005. A Transdisciplinary Learning Approach to Foster Convergence of Design, Science and Deliberation in Urban and Regional Planning. Systems Research and Behavioral Science, 22(3), pp.193–208.

considering the common ground between the processes of these two, instead of looking at similarities in knowledge, they can be considered as equal in the design process. Theories like the pattern language of Alexander (1995) and the system dynamics theory of Forrester (1969) can be used to achieve this.

For the urban design elements, which are developed during this project, the theory of Midgley will be involved. The principle of making patterns will be used, in combination with looking at the dynamic system in a similar way as Forrester did.

Sustainable design

According to Carmona et al. (2010), there is regularly a tension between the long-term and short-term needs in urban design. It is stated that when we talk about human needs and desires, it effects mostly the short-term. On the other hand, environmental issues are addressing the long-term needs of the urban areas. Besides, it is pointed out by Carmona et al. (2010) that the long-term includes the short-term as well, while the short-term does not include the long-term. From this point of view it is important for environmental issues (long-term) to address the short-term issues as well. Besides making an urban design environmentally sustainable, it should be also socially and economically sustainable (Carmona et al. 2010). In order to be able to do this, knowledge is needed about what the human needs are(short-term), from a social and economic perspective.

In general in urban design, according to Carmona et al. (2010), the focus is on the combination of economic gains and the social well-being of the people who live in the concerning environment. It is pointed out that only occasionally the design focuses on the well-being of the environment itself in addition to social and economic circumstances. Fortunately, as pointed out by Carmona et al. (2010), there is a shift towards more sustainable design, with the result that environmental issues are becoming more attached to urban design nowadays. As suggested by Carmona et al. (2010) there is also critique on addressing environmental issues in local urban design. Additionally, they suggest that in literature it is discussed whether the environmental strategies really work out well for the global scale. This is something that should be taken into account when making a design for the local scale.

Part 3: Research outcomes

Photo © Peter Schmidt / Rotterdam Image Bank

Effectivity of adaptation strategies

The criteria for measuring how effective a certain adaptation strategy can be understood, addresses the Urban Heat Island effect, as well as social and economic conditions. A method is developed to assess the influence of the urban environment on heat. For the social and economic conditions, the impact is measured in terms of added value.

Impact adaptation strategies on the UHI effect

From the studies done by Shashua-Bar et al. (2006) and Arup (2014), it has become clear that shade, building envelope, insulation, ventilation, albedo and evapo(transpi)ration are important features to take into account when adapting to heat.

Furthermore, it is demonstrated by Van der Hoeven & Wandl (2013) that shadow, sky-view factor, albedo, vegetation, surface water, pavements, infrastructure and building surface are factors that are related to heat in the city. In order to make the urban environment 'acceptable' for heat, human comfort should be addressed as well. According to Stathopoulos et al. (2004) a few conditions are related to outdoor human comfort. It is pointed out that "wind speed, air temperature, relative humidity and solar radiation" (Stathopoulos et al. 2004) influence the comfort of human beings in the urban environment. Since the adaptation strategies focus on heat, related to human comfort, these factors could be related to each other. By making relations between heat and human comfort, a convenient way of assessing the effectivity of an adaptation strategy can be created.

As a result, the most important mentioned characteristics of outdoor space, can be used as an indicator to estimate the heat flows in a certain urban environment. By the use of shadow, albedo, pervious surfaces, sky-view factor, vegetation and water, five heat flows are determined. This does not lead to exact numbers, but it indicates how sensitive the concerning area is to heat. The determined heat characteristics have the following effect: it reduces radiation, reflects radiation, does not store heat, releases heat, or evapo(transpi)rates. These heat flows combine several elements that are mentioned before by Shashua-Bar et al. (2006), Arup (2014), Van der Hoeven & Wandl (2013) and Stathopoulos et al. (2004). The effects on heat are combined with indicators and related to characteristics in the following way:

Reduces radiation
Indicator: shadow
Related to: shadow, solar radiation

Reflects radiation
Indicator: albedo
Related to: albedo, surface water, pavements, infrastructure, building surface, solar radiation

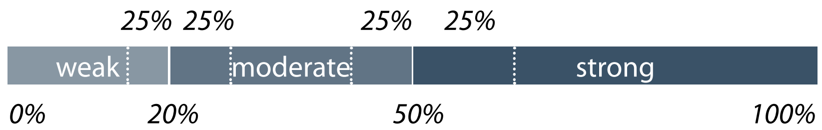
Does not store heat
Indicator: pervious surfaces
Related to: pavements, infrastructure, building surface, building envelope, air temperature, solar radiation

Releases heat
Indicator: sky-view factor
Related to: sky-view factor, wind speed, air temperature, relative humidity

Evapo(transpi)rates
Indicator: evaporative vegetation, water
Related to: vegetation, surface water, ventilation, evapo(transpi)ration, wind speed, air temperature, relative humidity

For both private and public outdoor space, the five mentioned heat characteristics are addressed. In that case, the indicators area estimated or calculated for the ground surface of the area of intervention. For buildings the focus is on three characteristics, because the surfaces of a building structure are concerned. This means that the estimations or calculations are done for the total surface of the roof and the facades. In the case of building calculations of heat characteristics, only the reduction of radiation, reflection of radiation, and evapo(transpi)ration are determined. Heat storage and heat release are eliminated, because the total building structure stores heat and is open to the sky.

In order to use these outdoor and building characteristics as indicators for evaluating the effectivity of adaptation measures, an evaluation system with set values is needed. The method which is used in this case, is inspired by the book 'Urban green-blue grids for sustainable and dynamic cities' (Pötz & Bleuzé 2012). In this book all kinds of features of urban designs are rated by 1-3 blocks. The idea of using a simplified system as such, is translated to this project. In this case, every indicator has three categories, which can be seen as weak, moderate and strong. For every adaptation measure, the characteristics can be valued both before and after the implementation, which presumably leads to a value difference. This difference can be defined by means of points that are related to the values. For every weak feature 1 point is given, for every moderate



a. Image for the explanation of how to deal with the boundaries of the value system, example for 'reduces radiation'.

Public / private outdoor space	*measured for surface of area of intervention*			
Reduces radiation	< 20 %	20 - 50 %	> 50 %	average % covered with shade in Jun-Aug
Reflects radiation	< 0,10	0,10 - 0,30	> 0,30	average albedo
Does not store heat	< 33 %	33 - 66 %	> 66 %	% covered with pervious surfaces
Releases heat	< 0,33	0,33 - 0,66	> 0,66	average sky-view factor
Evapo(transpi)rates	< 20 %	20 - 30 %	> 30 %	% covered (evaporative) vegetation/water

Buildings	*measured for surface of concerning buildings*			
Reduces radiation	< 20 %	20 - 50 %	> 50 %	average % covered with shade in Jun-Aug
Reflects radiation	< 0,10	0,10 - 0,30	> 0,30	average albedo
Evapo(transpi)rates	< 20 %	20 - 30 %	> 30 %	% covered (evaporative) vegetation/water

b. Method for indicating the heat flows, based on characteristics related to the UHI effect, for outdoor space and buildings.

Figure 14.
Image by author.

value 2 points, and for every strong value 3 point. The sum of the points after the implementation, is reduced by the sum of the points before the implementation.

When we look at Figure 14b, it seems that the boundaries of the value system are quite strict. However, these should be treated in a more flexible way. In some cases the values change considerably, while there is no change from one category to the other - or the other way around. In a situation as described, the weak, moderate or strong value can be changed, provided that at least one of the values is part of the first or last 25% of a category (see Figure 14a). For example, when the value for shadow changes from 5% to 18% because of an adaptation measure, the allocated category can be changed from weak to moderate.

All the characteristics are calculated or estimated for the area that is changed because of the intervention. It is important to note that the value system is based on assumptions. For some of the characteristics, the categories are based on the results of studies, but even then assumptions are made. An explanation follows, for every characteristic, on how the characteristics can be valued.

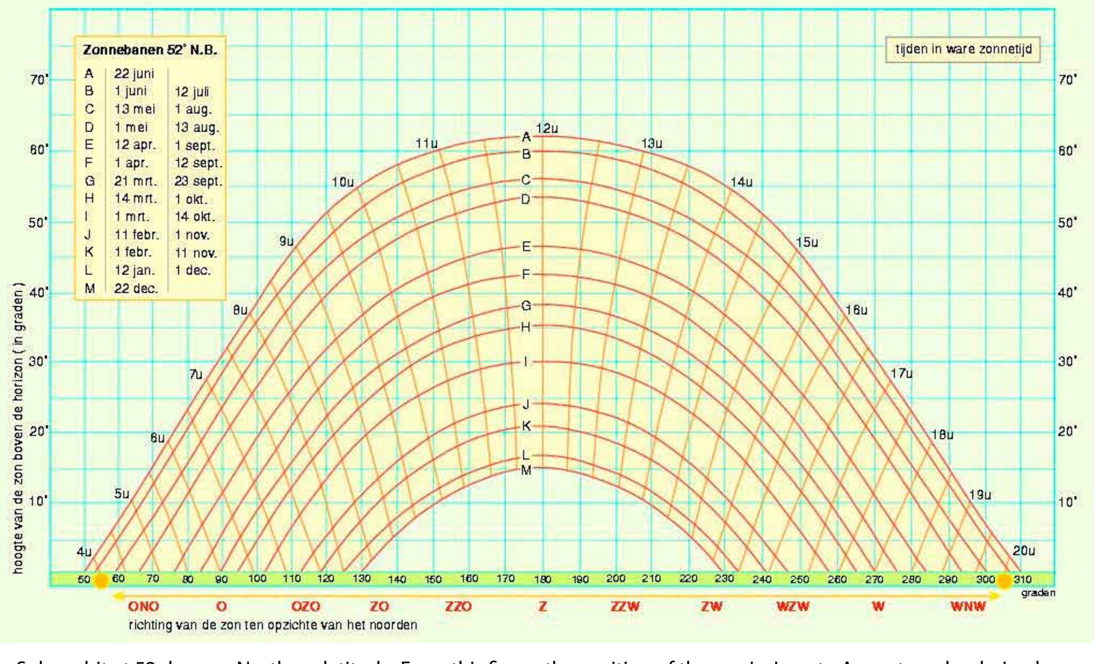
Shadow: reduces radiation

For this heat characteristic, the part of the surface that is covered with shadow is estimated. This is done on the basis of the position of the sun in the months June, July and August. The average amount of shadow is calculated for these months, between sunrise and sunset. In these months it is most likely that a heat

Figure 15.

a:
KNMI, 2014b. Zonnebanen 52° Noorderbreedte, De Bilt.

b:
Taha, H. et al., 1988. Residential cooling loads and the urban heat island—the effects of albedo. Building and Environment, 23(4), pp.271–283.



a. Solar orbit at 52 degrees Northern latitude. From this figure the position of the sun in June to August can be derived.

Cover	Albedo (α)	Source
Water (large altitude)	0.09	[17]
Desert	0.34 0.52	[13]
Fresh snow	0.80	[25]
Old snow	0.40–0.70	[2]
Moist soil w/grass	0.16	[2]
Bare, dry soil	0.30	[2]
Deciduous forest	0.10–0.20	[2]
Coniferous forest	0.05 0.15	[2]
Crops	0.15 0.25	[2]
Concrete/buildings	0.10–0.35	[2]
Streets	0.14	[2]
Asphalt pavement	0.10	[4]
Land use	**Albedo (α)**	**Source**
Low-density residential	0.20	[17]
Medium-density residential	0.23	[17]
Heavy density residential	0.25	[17]
Schools	0.15	[17]
Shopping Centers	0.20	[17]
Office buildings	0.22	[17]
Park/green area	0.16	[17]
Urban areas	0.10–0.27	[2]
Industrial	0.26	[17]
Freeway/streets	0.30	[17]
Open green surfaces	0.35	[2]
Seasonal parks	0.15	[17]

b. Albedo values which will be used as an indication.

wave occurs. As shown in Figure 15a, the sun is at a quite high position in the concerning months. As a result, there is not as much shadow as in the winter months. Furthermore, the assumption is made, that the addition of shadow is more important when there is almost no shadow, compared to cases in which already a moderate amount of shadow is present. Therefore the categories have an increasing scope.

Albedo: reflects radiation

As indicator for the reflection of radiation, albedo values are used. The albedo value of an area can be calculated as the average of the albedo values of the various surfaces. The distribution of the categories is based on the categories used in the Amsterwarm project (Van der Hoeven & Wandl 2013). In this project, it has become clear that an albedo value above 0,3 leads to significantly lower temperatures than beneath 0,3. Therefore this is used as the strongest category. The albedo value of each surface will be determined according to Figure 15b.

Pervious surface: does not store heat

For determining the heat storage, the pervious surfaces in the area are used. In other words, the percentage pervious surfaces of the total surface is calculated. Pervious surfaces are used as indicator for surfaces which does not store heat, because impervious surfaces have the capability to absorb the heat and store it (Mills 2007). Vegetation and soil are considered pervious, while materials like asphalt, pavement, stone and roofs are considered impervious to a large extent. It should be noted, that in the case a new neighbourhood is built, the calculations are done for the total ground surface (built area included).

Sky-view factor: releases heat

The ability for surfaces to cool at night is strongly related to the openness to the sky. This allows surfaces to release heat, while the wind contributes to cooler surfaces as well. Therefore, the sky-view factor is used to estimate the passive heat release. Since calculations can only be done by the use of fish-eye photographs or remote sensing, rough estimations are done for the cases. Figure 16 can be used as a framework to estimate the factor. The categories are equally divided, because there is a linear correlation between the maximum heat island intensity and the sky-view factor (Oke 1982).

Vegetation and water: evapo(transpi)rates

Heat can be released in a passive way, but also in an active way. This is the case when evapo(transpi)ration takes place. Because evapo(transpi)ration is caused by water and vegetation, the percentage of present water bodies and vegetation can be calculated. The categories are based

Author(s)	Sky view interval	Number of stations	Number of occasions	Season	$r_{x,y}$	R^2	Method	Type of environment
Bärring et al. (1985)	0.52–0.98	75	1	cold	−0.54	0.29	car meas.	urban
Bärring et al. (1985)	0.52–0.98	75	5	cold	−0.48	0.23	car meas.	urban
Yamashita et al. (1986)	0.55–0.90	9	1	cold	−0.68	0.46	car meas.	urban
Yamashita et al. (1986)	0.55–0.90	21	1	cold	−0.62	0.38	car meas.	urban
Eliasson (1996)		10–30	6	cold	–[a]	–	car meas.	urban
Upmanis (1999)	0.38–1*	7	1	cold	−0.54	0.29	perm. stations	central city
Upmanis (1999)	0.60–0.80*	6	10	summer	−0.87	0.76	perm. stations	central park
Karlsson (2000)	0.42–0.99	13		cold	–[b]	–	perm. stations	forest
Postgård (2000)	0.26–0.98	–	1	spring	–	0.44	car meas.	forest
Postgård (2000)	0.26– 0.98	–	1	cold	–	0.45	car meas.	forest
Svensson (2004)	0.34–0.98*	16	36	all year	−0.76	0.58	perm. stations	built-up
Svensson (2004)	0.70–0.98*	8	36	all year	−0.63	0.39	perm. stations	multi-family
Svensson (2004)	0.78–0.94*	6	36	all year	−0.73	0.53	perm. stations	single houses
Svensson (2004)	0.22–0.82*	13	1	cold	−0.75	0.57	car meas.	open and dense canyons
Svensson (2004)	0.22–0.60*	9	1	cold	−0.88	0.78	car meas.	dense canyons

Notes: * Sky view factor from images captured at ground level (SVFg); [a] no significant correlation; [b] strong correlation presented graphically

Table that could be used to estimate the sky-view factors of different types of environments.

Figure 16.
Svensson, M.K., 2004. Sky view factor analysis – implications for urban air temperature differences. Meteorological Applications, 11(3), pp.201–211.

on the fact that the largest influence of evapo(transpi)ration on heat is visible by changing the percentage of vegetation/ water from 20% to 30% (Myrup 1969). According to Van den Hurk (2010), very low vegetation evaporates more than trees, on the short term and in periods of heat. On the other hand, it is pointed out that on the long term vegetation (like grassland) dries out more quickly than trees. To remain the positive influence of vegetation for evaporative cooling, either there should be water available to avoid dry soil, or grasses (and other very low vegetation) should not be considered as contributory to evaporative cooling. Therefore, in this project the very low vegetation types (ca. under 100 mm) will not be included for evapotranspiration, unless there is enough water available. This is also the case for extensive green roofs.

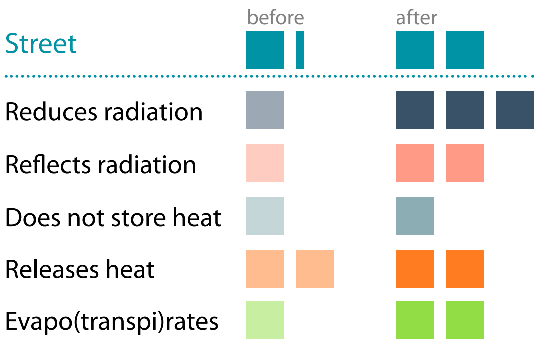


Figure 17.
Image by author.

Example of how effective a certain adaptation measure is.

To clarify how this method is used, an example is given of an adaptation strategy which is implemented hypothetically. The example uses a measure in which a lane of trees is added to a quite open street with a lot of impervious surface.

Figure 17 demonstrates that implementing a lane of trees, leads in this case from 1,2 points to 2 points. The measure reduces radiation, reflects radiation, and evapotranspirates more than before the development. The heat storage and passive heat release remained (nearly) identical to the previous situation.

Impact adaptation strategies on social and economic conditions

In contrast to the impact on the UHI effect, the impact on social and economic conditions only focuses on the qualitative values of the adaptation strategies. Therefore, it is not possible to make a measuring model similar to the one that is used for the impact on the UHI effect. However, a way of assessing the impact on social and economic conditions is needed.

Since a positive influence on social and economic circumstances is desired, it is possible to assess this influence in terms of added value. For the cases and design elements, the added value can be demonstrated by pointing out what the added values are of the concerning measure. When applying a measure to a certain location, these added values can be taken into consideration. The descriptions of the added values can be approached as a solution to social and economic problems at a certain location. For example, in a case where the social cohesion can be improved, a measure that provides an environment in which public gatherings can take place is suitable to apply. Thus, added values are described for all the adaptation strategies, to provide information on how these strategies can influence the social and economic conditions.

Case comparison

Selection of the cases

The criteria for selecting the cases for the comparison are based on the technique of Gerring (2007) in which the most different cases are chosen. Important for this technique is that there are similarities in the cases as well.

Criteria used for the selection of cases:
- The plans for the city should include the ambition to adapt to the Urban Heat Island effect.
- The cities should have an oceanic climate, like the Netherlands has.
- The plans should be concrete enough to make assumptions on how it (might) look(s) like.
- The plans should be concrete enough to make assumptions on the scale on which the interventions take place.
- The plans should be concrete enough to relate them to a certain location in the city.
- The cases should address different measures and adaptation strategies.

Introduction to the cases

The three cities that are part of the case comparison had all different strategies. Antwerp looked at vulnerable neighbourhoods, and tried to match adaptation strategies to the characteristics of the location. London uses an adaptation strategy for the city as a whole, and

Antwerp

- Green roof
- Trees along river
- Green waterfront
- Green façade
- Pergola
- More green / water in public space
- Green tile parking lot
- Water storage for dry periods
- Water structure
- Shadow walking route
- Shadow gathering place
- Shadow playground
- Leefstraat (living street)
- Building NW-SE orientation
- Asphalt > reflective material

London

- Green roof
- Street trees
- Good quality green space
- Greenery
- Cool roof technology
- Low-carbon, energy-efficient cooling
- Improve building insulation
- Adapted building (less cooling)
- Decentralised energy

Copenhagen

- Green network
- Trees
- Green wall
- Rain garden
- Storm water basin
- Pond
- District cooling of buildings

Concrete adaptation measures, as mentioned in the documents about the Urban Heat Island effect in Antwerp, London and Copenhagen.

Figure 18.

Antwerp:
Lauwaet, D. et al., 2013. Opmaak van een hittekaart en analyse van het stedelijk hitte-eiland effect voor Antwerpen, Mol.

London:
Greater London Authority, 2008. The London Climate Change Adaptation Strategy: Summary draft report, London: Greater London Authority.

Nickson, A. et al., 2011. Managing risks and increasing resilience: the mayor's climate change adaptation strategy, London: Greater London Authority.

Copenhagen:
City of Copenhagen, 2011. Copenhagen Climate Adaptation Plan, Copenhagen.

determined quantified goals that they want to achieve in a certain time period. Copenhagen only has general plans for different scales, which can be implemented in urban developments. Where or how much they want to implement is not clearly determined. The approaches and probable causes for Antwerp, London and Copenhagen are described in this section. An example case description of Scheldekaaien (Antwerp) follows, while the other cases are described in the appendix.

Because the approaches to the adaptation strategies are different in the three cities, they are all three interesting examples to look at. It demonstrates how cities can deal with all the different measures from which they can choose. In the case comparison the cities are investigated, by analysing whether or not the adaptation strategies had a convenient contribution to the adaptation to the UHI effect.

In Figure 18, an overview is made of all the mentioned adaptation measures for Antwerp, London and Copenhagen. The colours correspond with where the measure is related to:

- Vegetation
- Water
- Other measures for public spaces
- Buildings
- Materials

In the addressed projects from the three cities, it is pointed out which of these measures are used. Since it is not possible to look at all the measures, because they are not all in the projects that are demonstrated, some general conclusions are given after the case comparison. This information is used in the development of the patterns and the pattern model.

Antwerp

Approach (Lauwaet et al. 2013)
The city of Antwerp made a thorough analysis of the Urban Heat Island effect in the city. The vulnerability of neighbourhoods is taken into account, which has resulted in a selection of vulnerable neighbourhoods. The selected neighbourhoods are used to generate ideas related to the problems at that specific location. Unfortunately, the recent projects do not link to these vulnerable neighbourhoods yet.

Probable causes (Lauwaet et al. 2013)
- Low sky-view factor
- Low amount of vegetation
- High amount of water
- High amount of paved surfaces

London

Approach (Nickson et al. 2011)
In a combined adaptation strategy, the city of London adapts to the consequences of climate change. The risk of overheating, which concerns the UHI effect, will be reduced by an increase of green space, green roofs and tree cover throughout the city. Goals are constructed for these specific actions, including numbers and time periods. In this way the city aims to reduce the heat through the whole city.

Probable causes (Hamilton et al. 2014)
- Dense urban form
- Little green space
- Hard surfaces
- Anthropogenic heat emission

Copenhagen

Approach (City of Copenhagen 2011)
By focusing on the development of a network of green structures, the city of Copenhagen tries to combat the UHI effect. Elements such as water, shade and air circulation will be taken into account in this approach. Green structures will be integrated in city developments.

Probable causes (City of Copenhagen 2011)
- Lack of water and vegetation
- Dense and high building development
- Large covered (impervious) areas

Current situation of the Scheldekaaien, Antwerp.

Scheldekaaien, Antwerp

The waterfront of the river Schelde in Antwerp will be redeveloped, with as main objective to enhance the water protection.

Initial goals (Meijsmans & Peelaerts 2011)
- Security: Reduction of floods by the use of dikes and controlled flood areas.
- Natural quality: Recovery of a healthy ecosystem, good water quality, and unique flora and fauna.
- Economy: Accessability for ships stimulates the inland navigation.
- Recreation: The dikes are a recreational area, and therefore attractive to people and animals.

Adaptation measures
Although the problem of heat is not mentioned in the masterplan description of the Scheldekaaien, there are some measures implemented indirectly. When looking at the possible adaptation measures, like mentioned by Lauwaet et al. (2013), the following elements can be found in the Scheldekaaien project:

Trees along river

More green / water in public space

Shadow playground

Impact on the UHI effect

Explanation (see Figures 19 and 20):
Along the waterfront of Antwerp, mainly trees and grass are added. This leads to more shadow, evapotranspiration and perviousness of the waterfront.

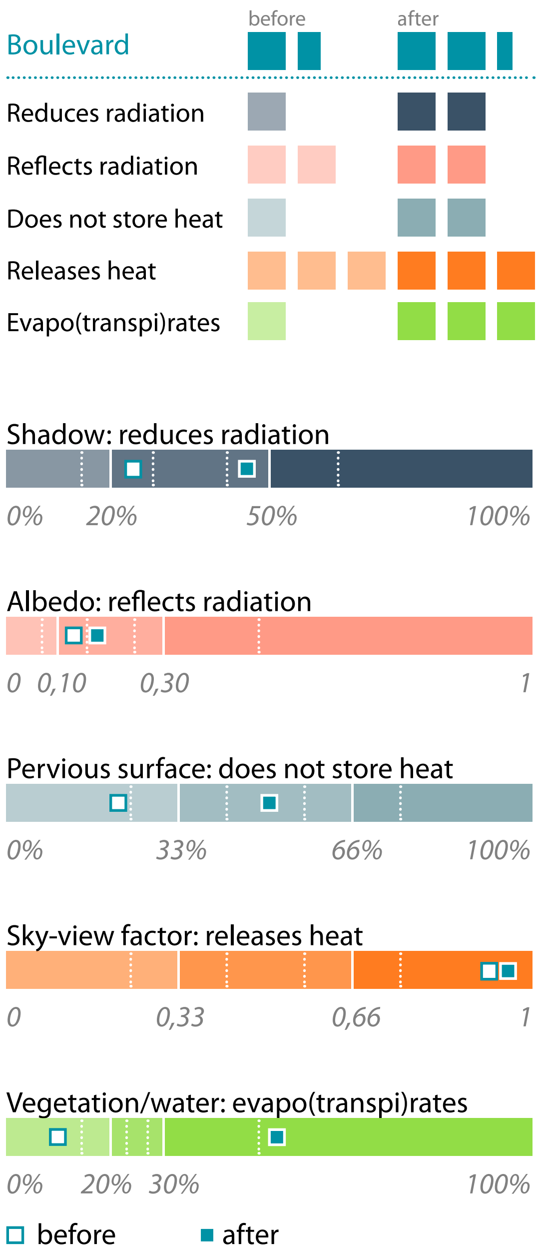
Recommendation for improvement:
There are many open spaces, partly because of the possibility to organize festivities. These open spaces can be improved by creating a higher surface albedo, and by the addition of shadow. In order to keep flexibility, other measures than trees can be used to create shadow.

Impact on social and economic conditions
- Recreation along the waterfront attracts people to the river area.
- Functions and temporary activities give the environment a dynamic character.
- Economic damage is prevented by the protective function of the waterfront.

Figure 19.

Above:
Borret, K., 2010. Toelichting door stadsbouwmeester Kristiaan Borret. Masterplan Scheldekaaien.

Under:
Google Maps.




Design and visualisations of the Sint-Andries & Zuid part of the Scheldekaaien in Antwerp.

Figure 20.
Borret, K., 2010. Toelichting door stadsbouwmeester Kristiaan Borret. Masterplan Scheldekaaien.

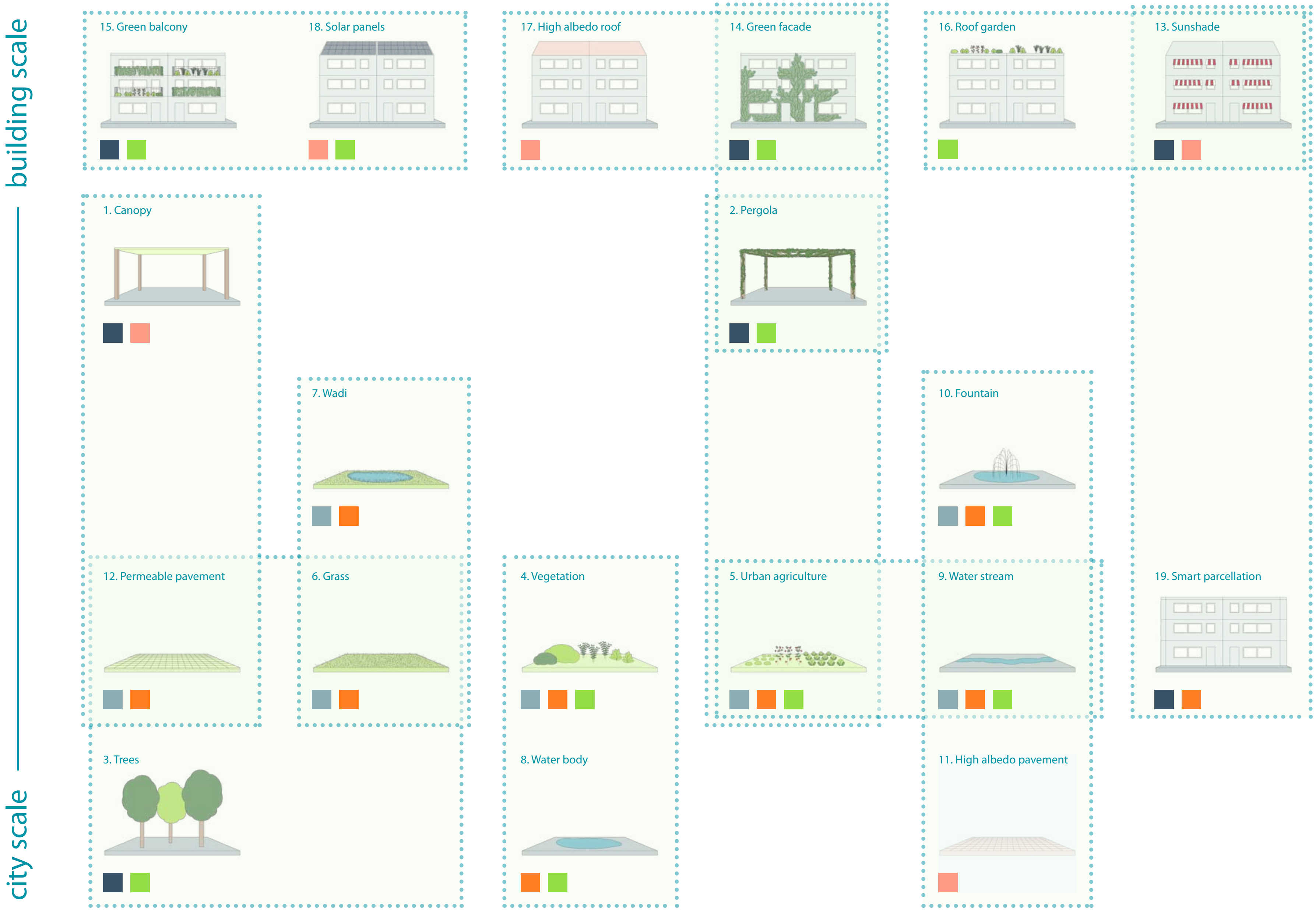
Reflection on the cases			
Scheldekaaien, Antwerp *Boulevard:* *- Trees along river* *- More green / water in public space* *- Shadow playground*	Reduces radiation Reflects radiation Does not store heat Releases heat Evapo(transpi)rates	+ 0 + 0 ++	- Recreation attracts people. - Dynamic character because of functions and activities. - Protective function of the waterfront.
Theater square, Antwerp *Square:* *- More green / water in public space* *- Shadow gathering place*	Reduces radiation Reflects radiation Does not store heat Releases heat Evapo(transpi)rates	++ + 0 0 +	- Possibility to stay attracts people.
Olympic Park, London *Park district:* *- Green roof* *- Street trees* *- Good quality green space* *- Greenery* *- Cool roof technology* *- Low-carbon, energy-efficient cooling* *- Improve building insulation* *- Adapted building (less cooling)* *- Decentralised energy*	Public / private outdoor space: Reduces radiation Reflects radiation Does not store heat Releases heat Evapo(transpi)rates Buildings: Reduces radiation Reflects radiation Evapo(transpi)rates	 ++ - - - ++ + + 0	- Sustainable living conditions. - Building a new community. - Vibrant parkland. - Impuls to the economy by new functions. - Many new jobs are provided.
Jubilee Gardens, London *Park:* *- Good quality green space*	Reduces radiation Reflects radiation Does not store heat Releases heat Evapo(transpi)rates	+ 0 - 0 +	- Intensive use, because of many seatings.

Ørestaden, Copenhagen	Public / private outdoor space:		- Necessary functions are nearby.
	Reduces radiation	+	- Fast connection to the central city.
Green district:	Reflects radiation	0	
- Green network	Does not store heat	-	
- Trees	Releases heat	0	
- Storm water basin	Evapo(transpi)rates	+	
	Buildings:		
	Reduces radiation	+	
	Reflects radiation	+	
	Evapo(transpi)rates	0	
Nordhavnen, Copenhagen	Public / private outdoor space:		- Sustainable living conditions.
	Reduces radiation	+	- Close to the inner city.
Water district:	Reflects radiation	+	- Short distances stimulate walking and cycling.
- Green network	Does not store heat	++	- Room for social interaction.
- Trees	Releases heat	-	
- Green wall	Evapo(transpi)rates	+	
- Rain garden			
- District cooling of buildings	Buildings:		
- Storm water basin	Reduces radiation	+	
- Pond	Reflects radiation	+	
	Evapo(transpi)rates	+	

Part 4: Pattern language

Photo © Jan van der Ploeg / Rotterdam Image Bank

Pattern model



Use of patterns

In the pattern model an overview is given of all the patterns, which are developed as measures against heat. For every pattern the name, number and the related heat characteristics are given in this model. Furthermore, the scale of application is pointed out. It should be noticed that the patterns for the building scale cannot be applied on the city scale, but the city scale patterns can be applied on smaller scales as well. The blue frames show which patterns can be used together very well. This is related to the effectivity against heat, but also to the use in urban design. Now it is explained how the different heat characteristics are able to reinforce each other, or when they can have a negative effect.

Reduces radiation

In case there is shade on a high albedo surface, the reflection does not have much effect anymore. Therefore, often the reduction of radiation and reflection of radiation do not work well together.

Reflects radiation

This heat characteristic works well when the radiation is reflected to the sky. If it reflects to other parts of the urban environment, it does not have a positive effect anymore. In some cases the reflection can even be disturbing for inhabitants. This can be the case for high albedo facades, or for high albedo roofs when high rise buildings are nearby.

Does not store heat

The application of this heat characteristic works well in almost every case. Only shadow can make the effect a bit less, because the surface warms up less anyway.

Releases heat

It should be noticed that the sky-view factor, which is related to heat release, cannot always be changed because of the existing conditions of the built environment. Also, this characteristic has an opposite effect on the reduction of radiation. This means that when there is a lot of shade, the sky-view factor is quite low in many cases. As a result, it is not possible for all the heat characteristics to have a strong position at the same time.

Evapo(transpi)rates

A combination of vegetation and water reinforces the effect of active heat release. This is because vegetation is only able to evapotranspirate when there is enough moisture.

On the following pages the library with pattern descriptions can be found. This includes a hypothesis, context, solution for the heat problem, physical restrictions, the related heat characteristics, application scale, typologies of space for which it can be used, possible combinations with other patterns, and the possible applications for Bospolder-Tussendijken and Cool. It should be noticed that, when there are many possible locations for application, only locations are marked in the areas of development within the neighbourhoods.

1. Canopy

A canopy provides shade and reflects sunlight, which leads to an increase of shadow and albedo.

Reduces radiation

Reflects radiation

Context

Canopies can be used in several circumstances. It can be constructed to a building or above the street between the buildings. Also, it is possible to have a separate construction. In the last case it can be placed anywhere. The canopy is mostly used as an element to walk underneath. It provides shade and, in case the canopy is waterproof, it also gives shelter when it rains. It should be remarked that a negative effect of a canopy can be that it takes away light in winter. Canopies can be made of all kinds of materials, like wood, steel or polyester. The size of the canopy can differ a lot, and it can also be used as a temporary element.

Solution

Underneath the canopy, shadow is created. When sitting or walking underneath the canopy, people can avoid direct sunlight. If the position of the canopy is right, buildings can have advantage of its shadow. Also, there is a possibility to give the canopy a high albedo, with the result that it reflects sunlight. In that case, less heat will be absorbed by the canopy. It is possible to combine the canopy with a garden on its roof as well, which adds evapotranspiration as additional positive effect of the canopy.

Physical restrictions

- Minimum height of 2,5m needed.
- The height of the canopy determines the maximum height of traffic which is able to pass.
- When the canopy is attached to a building, the building should be able to carry the weight of the canopy.
- The positioning of the construction poles is depending on the materialisation, size and shape of the canopy.
- Underground space is needed for the construction of the poles.

Figure 21.
EcoDynamic, 2014. Aanleg O & O terrein UT Twente. Available at: http://www.eco-dynamic.eu/nl/referenties/aanleg-o-en-o-terrein-ut-twente.

Heat characteristics
- reduces radiation:
shadow from the roof of the canopy
- reflects radiation:
the material of the roof can have a high albedo

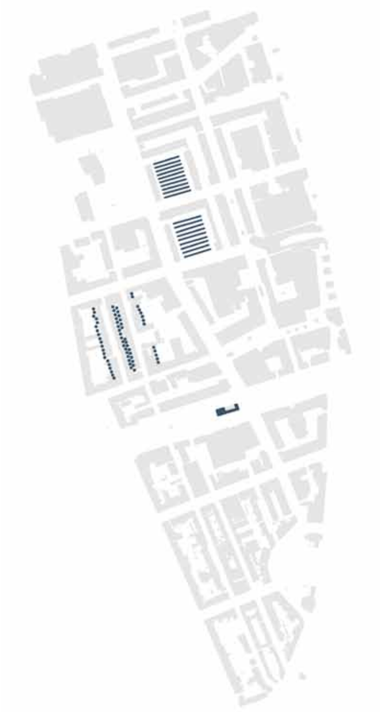
Application scale
- building scale
- street scale

Typologies of space
- private garden
- cultural street
- shopping center
- square
- park
- green zone

Combination with other patterns
- grass
- permeable pavement

Bospolder-Tussendijken
In Bospolder-Tussendijken, Park 1943 and the Visserijplein can be improved by adding a canopy. In the park, the canopy can be used as a stage for festivals. On the square, several canopies can be created for the market stalls. In both cases the canopies can be temporary.

Cool
A canopy can be allocated to the Lijnbaan area and Westblaak. In the case of the Lijnbaan, the green inner courtyards can have a canopy, for a terrace or walking route. At Westblaak, this pattern can be used for the terrace of the café.



2. Pergola with climbing plants

The climbing plants on the pergola provide shadow and evapotranspiration.

Reduces radiation

Evapotranspirates

Context

An open roof construction, overgrown by climbing plants. The construction exists of poles with a slatted roof construction. In some cases the sides are used as overgrown walls as well. A pergola can be constructed against a building. This is usually done in private gardens. People can sit in the shadow underneath the leaves. Because people like to sit in a sheltered place, terraces are often used in addition to these kind of pergolas. A pergola can also be built in an open space, above a terrace or walking route. In the last case a walking path is constructed underneath the pergola. This application often takes place in a park, or for example in a rose garden.

Solution

Direct sunlight gives the opportunity for both surfaces and people to warm up easily. By creating shadow by means of a pergola the air can still be warm, but it creates an environment that is better for human comfort. Additionally, surfaces warm up less fast. The air temperature will decrease because of the evapotranspiration of leaves. Preferably the plants are deciduous plants, because they have leaves in summer for shadow, and no leaves in winter. As a result, the pergola provides the maximum amount of sunlight in winter.

Physical restrictions

- Minimum height of 2,5m needed.
- Construction poles can have a maximum distance of 5m.
- Underground space is needed for the construction of the poles.

Figure 22.
La Pergola, 2014. Foto van La Pergola: View of our hotel pool from La Pergola. TripAdvisor LLC. Available at: http://www.tripadvisor.nl/LocationPhotoDirectLink-g635892-d2177195-i66003346-La_Pergola-Santa_Susanna_Catalonia.html#35348744 [Accessed December 18, 2014].

Heat characteristics
- reduces radiation:
creates shadow underneath the pergola
- evapotranspirates:
evapotranspiration takes place by the climbing plants

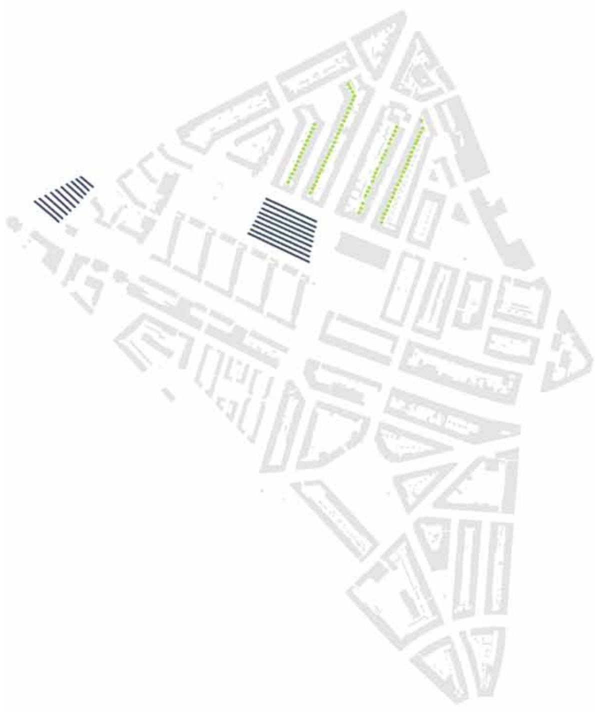
Application scale
- building scale
- street scale

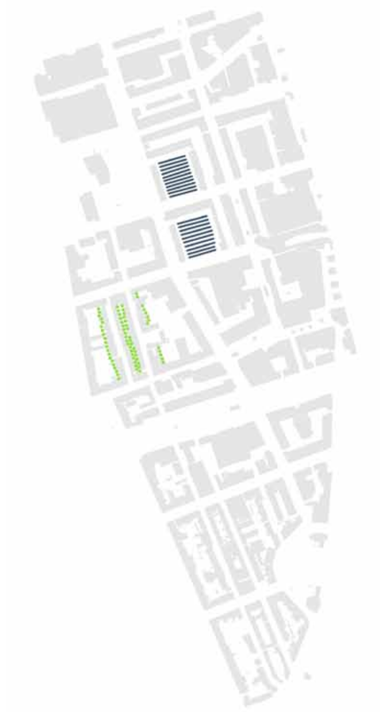
Typologies of space
- private garden
- park
- green zone

Combination with other patterns
- grass
- permeable pavement

Bospolder-Tussendijken
A pergola with climbing plants can among others be located in a private garden. The Marconiplein already has a lot of shade and vegetation, but a pergola fits well in a green zone like this. In Park 1943, the shadow can be reduced further by creating pergolas.

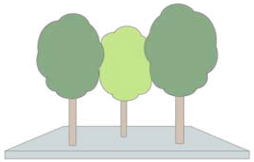
Cool
The green zones in the Lijnbaan can use pergolas to create more shadow. Also, the private gardens of the Jacobusstraat and Mauritsstraat can have more green, and are therefore suitable for pergolas with climbing plants.





3. Trees

Underneath trees it can be relatively cool because of shadow and the evapotranspiration of the leaves.



Reduces radiation
Evapotranspirates

Context

Because of their shape, trees are able to structure urban spaces. A solitary tree can stand out on its own, while a group of trees creates a sheltered area with a lot of shade. Furthermore, a line of trees gives direction or divides different areas. Underneath tree crowns people can walk or sit in the shadow or the sun. Usually it is possible to look underneath the tree crowns. There are additional benefits to trees for health and ecology. Many species are available. Some trees are almost the same in every season, while other trees develop a lot during the year. In winter deciduous trees are bald, and colours change in some cases during spring or autumn.

Solution

Depending on the species, trees provide a various amount of shadow. When the tree crown is not that dense, sunlight will partly come trough the leaves. This leads to a preference of a high density of leaves in summer. Not every tree will be a good choice if shadow is needed. Furthermore, evapotranspiration takes places by the tree, leading to lower temperatures and more vapour in the air.

Physical restrictions

- The soil should be appropriate for the tree to grow on.
- There should be enough space in the subsoil for the roots of the tree. The size of the tree crown can be used as indication for the size of the roots.
- There should be enough space for the crown of the tree.

Figure 23.
Rijnboutt, 2012. Bomen bepalend voor garage onder Lange Voorhout. Available at: http://rijnboutt.nl/articles/648 [Accessed March 11, 2015].

Heat characteristics
- reduces radiation:
the leaves create partly shadow underneath the trees
- evapotranspirates:
evapotranspiration comes from the leaves

Application scale
- street scale
- neighbourhood scale
- city scale

Typologies of space
- city road
- neighbourhood road
- singel
- private garden
- residential street
- cultural street
- shopping center
- square
- park
- green zone

Combination with other patterns
- vegetation
- grass
- permeable pavement

Bospolder-Tussendijken
In many of the design locations of Bospolder-Tussendijken it is possible to plant trees. In Park 1943 and the Visserijplein trees can add shadow, while at other places the addition of vegetation is needed. Trees can further be added to the Schiedamseweg, Haringpakkersstraat and Kleine Visserijstraat where it is possible in terms of space and subsoil.

Cool
In Cool there is less room for trees. In the green zones in the Lijnbaan ensemble, extra trees can be added to create shadow. In streets like the Jacobusstraat and Mauritsstraat, and Downtown, it can be figured out whether there is space for more trees. Also, at the Eendrachtsplein there is room for trees to add vegetation.

4. Vegetation

Vegetation cools down the air by evapotranspiration, and does not store heat because of the open soil underneath it.

- Does not store heat
- Releases heat
- Evapotranspirates

Figure 24.
Bomenbuur, 2013. Uitslag van de wedstrijd: "Wie heeft het mooiste geveltuintje van de Bomenbuurt in 2013?" Available at: https://bomenbuur.wordpress.com/2013/09/06/uitslag-van-de-wedstrijd-wie-heeft-het-mooiste-geveltuintje-van-de-bomenbuurt-in-2013/ [Accessed March 12, 2015].

Context

The many colours, species and sizes of vegetation can create a flourishing environment. Because vegetation is often very low, it does not help that much in dividing spaces. The low layout provides the possibility to look out over the area. Since it is not possible to walk on the vegetation, pedestrians are directed by the layout of the vegetation. For vegetation the seasonal differences are clearly visible, especially when the flowers are colourful, or when the leaves fall off in winter. Sometimes the leaves change colours in autumn as well. Plants can also be planted in boxes, which gives flexibility to place them in various arrangements.

Solution

Vegetation releases heat in both a passive and active way. The passive heat release occurs because of its openness to the sky. The active heat release is caused by the possibility to evapotranspirate. The transpiration of the vegetation evaporates, which cools down the air. In the area around the vegetated spot it will be a bit cooler than the surroundings for this reason. Also, the soil underneath the plants does not store that much heat, because it is an open surface.

Physical restrictions

- The soil should be suitable for the vegetation to grow on.
- Most vegetation species need a certain amount of sunlight.
- In dry periods, vegetation needs to have additional water.
- Certain vegetation species need a lot of maintenance, like trimming.

Heat characteristics

- does not store heat:
the soil is pervious and does not store that much heat
- releases heat:
the air above the vegetation is open and makes it possible to release heat
- evapotranspirates:
the leaves and flowers evaporate heat actively

Application scale

- street scale
- neighbourhood scale

Typologies of space

- singel
- private garden
- residential street
- cultural street
- shopping center
- square
- park
- green zone

Combination with other patterns

- trees
- grass
- wadi

Bospolder-Tussendijken

Vegetation can be planted in the private gardens and residential streets. This can also be done along the Schiedamseweg, to increase the perviousness. The Marconiplein can be more pervious and have a higher sky-view factor by adding vegetation. The Visserijplein needs to have room for the market. Therefore, vegetation can only be added to a certain extent. Park 1943 can have vegetation instead of grass, in order to increase the evapotranspiration, but already has much other vegetation like grass and trees.

Cool

The green zones in the Lijnbaan area can be used to add vegetation. When some trees are replaced by this, the sky-view factor increases. The Jacobusstraat, Mauritsstraat and Eendrachtsplein can benefit from vegetation in terms of active heat release. Westblaak is very impervious, so when vegetation is included in the design for this part, the area can be more pervious.

5. Urban agriculture

The crops cause active and passive heat release, while the open surface prevents heat storage.

Does not store heat

Releases heat

Evapotranspirates

Context

Small scale urban agriculture is generally meant for local purposes, and has nothing to do with general food production. For children it has an educative element, and you can meat other people from the neighbourhood while gardening. The spatial structure is always layed out in a way that people can walk between the crops, so that it is possible to reach to every part of the garden. The seasons play an important role in the garden, because it determines the phases of the cultivation process. Also, urban agriculture can look very colourful when the fruit and vegetables are ripening.

Solution

Crops can have a similar effect on heat as other vegetation. They release heat in an active way by means of evapotranspiration, and they loose heat in a passive way as well. Also, the soil has to remain wet enough for the plants to grow on, which provides enough water to make cooling possible. The soil underneath the plants is pervious, which leads to a low amount of heat storage.

Physical restrictions

- The soil should be suitable for the crops to grow on.
- Most of the crops need a certain amount of sunlight.
- In dry periods, crops need to have additional water.
- To produce a reasonable amount of food, a lot of space is needed.

Figure 25.
Poptahof Delft, 2011. Moe'sTuin, Delft. Atelier GROENBLAUW. Available at: http://www.groenblauwenetwerken.com/projects/moestuin-delft-the-netherlands/ [Accessed March 11, 2015].

Heat characteristics
- does not store heat:
soil does hardly store heat
- releases heat:
heat is released to the air above the crops
- evapotranspirates:
crops evapotranspirate and cool the surrounding air

Application scale
- street scale
- neighbourhood scale

Typologies of space
- park
- green zone

Combination with other patterns
- high albedo pavement
- permeable pavement

Bospolder-Tussendijken
By creating a place for urban agriculture at the Marconiplein, both the sky-view factor and perviousness can be improved. Such a place can also be created in Park 1943, but there is almost no demand for the benefits of this pattern at this location.

Cool
In the Cool area the green zones can be used for urban agriculture, which increases the sky-view factor. It should be noted that in that case the shadow will be reduced.

6. Grass

An area covered in grass does not store that much heat, and releases heat at the open spaces.

Does not store heat

Releases heat

Context

Since it is possible to walk on grass, there are many activities that can take place. Besides walking, it is possible to play sports on it, or to sit or lie down. Therefore, a lawn can be lively at certain moments, especially when the weather is good. When there are no people on the grass, it still gives a green look. Furthermore, grass can be planted underneath a tramline, or in strips between roads. There are many grass species, but for lawns always soft and short green grass is used. In some cases small flowers are growing between the grass. Maintenance is needed to keep the grass short. This is usually done with a mower, but it is also possible to let sheep graze on the grass.

Solution

Grass grows on soil, which creates a pervious surface. This grass land is able to let water in and out, and therefore helps to cool the air with this water. When the soil gets dry, it has not much of a cooling effect anymore, but the soil never stores as many heat as impervious surfaces. Also, the grass releases heat to air above it, and therefore is able to cool down as well. This can be less effective in the case that there are trees above the grass, because the air stays underneath the crowns of the trees.

Physical restrictions

- The grass should be maintained regularly.
- The soil should be suitable for the grass to grow on.
- In dry periods, grass needs to have additional water.

Figure 26.
Cool, T., 2010. Westbroek Park, juli 2010. Available at: http://thomascool.eu/Thomas/Nederlands/Publiek/Westbroek/index.html [Accessed April 10, 2015].

Heat characteristics
- does not store heat:
the soil with grass does not store a lot of heat
- releases heat:
the grass releases heat to the air above it

Application scale
- street scale
- neighbourhood scale

Typologies of space
- city road
- neighbourhood road
- singel
- square
- park
- green zone

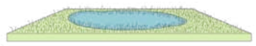
Combination with other patterns
- canopy
- pergola
- trees
- vegetation
- wadi
- permeable pavement

Bospolder-Tussendijken
The addition of grass can be used to increase the perviousness of an area. In Bospolder-Tussendijken it can be applied at the tramline of the Schiedamseweg, on the small soccer field in Park 1943, and instead of the paved area at the Marconiplein.

Cool
The only useful application of grass to Cool, is to make the tramline pervious. For other areas the use does not fit a surface covered with grass.

7. Wadi

A lower area where water can be stored after a rain shower, while the water slowly sinks into the ground.



Does not store heat

Releases heat

Context

Usually a wadi is part of a lawn. The ground has a slope which creates a lower area in which water can be stored temporarily. This happens after a rain shower. The layer of water slowly drains into the ground. In dry periods there is no water in the wadi. A wadi can be constructed for functional and decorative reasons, but can also be used to play with. Elements can be made to walk above the water, or children can play with the water itself. To create a wadi, enough space is needed to store a certain amount of water and to create the slope.

Solution

A wadi can play the same role in the cooling process as a flat area with grass. The soil does not store a lot of heat, and the heat can be released into the air. Because the lower parts can get full of water, trees cannot be planted above the wadi. This means that there is no shelter to keep the heat between the trees and grass. This makes the passive heat release possible. The water in a wadi can only be benificial in the cooling process when the water is still present when a period of heat arrives.

Physical restrictions

- The soil should be suitable for grass to grow on.
- In dry periods, the grass needs to have additional water.
- Enough space in the subsoil is needed to create a lower area than its surroundings.
- Enough space in the area is needed to create a slope, and to store a certain amount of water.

Figure 27.
Marijke, 2010. WATER, Doetinchem Dichteren, Wadi / Hemelwaterafvoer. Panoramio. Available at: http://www.panoramio.com/photo/39900107 [Accessed March 16, 2015].

Heat characteristics
- does not store heat:
the soil with grass does not store a lot of heat
- releases heat:
the grass releases heat to the air above it
(- evapo(transpi)rates:
this only happens when it is hot in a short period of time after a rain shower)

Application scale
- street scale

Typologies of space
- park
- green zone

Combination with other patterns
- vegetation
- grass

Bospolder-Tussendijken
A part of the playground part of Park 1943 can be replaced by a wadi, in which can be played, to improve the perviousness. The Marconiplein can be improved with a wadi, because it increases the perviousness and sky-view factor.

Cool
In Cool a wadi can be part of the green inner courtyards of the Lijnbaan.

8. Water body

Water evaporates and cools the area when the water moves, and when the water body is shallow.

Releases heat

Evaporates

Context

Water bodies are in some cases used for boats, but are mostly meant to create a better environment. It can have the shape of a pond or like a stretched out water element. Water bodies can be seen as a barrier, because in some cases bridges are needed to cross the water. On the other hand, the water can mark a transition area between a road and a residential area, or between different streets. Often there are paths along the water, so people can walk in the presence of water, and vegetation can be found along the water. Sometimes there are facilities like benches and small boulevards to sit at the waterfront.

Solution

The use of a water body for cooling down does not work in every case. In fact, it can have an opposite effect when it is not applied in the right way. The water can only be shallow, because otherwise it will store too much heat and radiates it to the air later on. This is also the case for stationary water. Therefore a shallow water body, which also moves, is the only way in which it can help to cool the area. Then the heat is released both in a passive and active way. The active heat release takes place by means of evaporation.

Physical restrictions

- Enough space in the subsoil is needed to create a lower area than the surroundings.
- The water body should be shallow, which means that it can have a maximum depth of about 50 cm.
- Water structures should be connected in order to keep the water moving.
- The water body should not be a barrier for the surrounding area.

Figure 28.
Noud, 2008. Amsterdam - Vondelpark - Panorama. Panoramio. Available at: http://straatkaart.nl/1071AK-Vossiusstraat/media_fotos/amsterdam-vondelpark-panorama-3Yi/ [Accessed April 10, 2015].

Heat characteristics
- releases heat:
heat is released to the air above the water
- evaporates:
by means of evaporation, the water can cool the air

Application scale
- street scale
- neighbourhood scale
- city scale

Typologies of space
- singel
- park

Combination with other patterns
- fountain

Bospolder-Tussendijken
In Bospolder-Tussendijken, a water body can be located in Park 1943. This can lead to a higher sky-view factor or to more evapotranspiration, because there is always water available.

Cool
Along the singel at the Eendrachtsplein, a water body can be placed at the location where a part of the water structure used to be in the past. The addition of water leads to more evaporation. This is also the case for the inner courtyards, where this pattern can be applied as well.

9. Water stream

A water stream is very shallow and moves, which does not allow heat to be stored, and helps to release heat both passively and actively.

Does not store heat
Releases heat
Evaporates

Context

Water streams can be constructed in a formal or informal way. When it is done in an informal way, it often looks like a natural water stream. Formal designs are more often used in an urban context. Moving water is attractive for children to play with, and because the water stream is very shallow, it is safe to do this. Also, it is possible to make crossings over the water stream, with the result that it is not a barrier. Sometimes the stream is small enough to reach the other side by taking only one step. Besides the dynamic effect of the streaming water, it also creates a calm sound.

Solution

By creating a water stream, the temperature can be lowered in different ways. Besides the fact that the streaming water does not store heat, it also releases heat in a passive and active way. The air above the water cools down, because the heat goes up to the open sky above it. Also, the water evaporates, which leads to lower temperatures. An extra effect the water stream can have, is that people can touch the water to cool themselves.

Physical restrictions

- The water body should not be a barrier for the surrounding area.
- It should be possible to construct a height difference and a water pump system.

Figure 29.
Rots maatwerk, 2009. Waterstrip Amersfoort. Available at: http://fonteinopmaat.nl/projecten/Amersfoort_Waterstrip.html [Accessed March 11, 2015].

Heat characteristics
- does not store heat:
the small layer of streaming water does not store much heat
- releases heat:
heat is released to the air above the water
- evaporation:
by means of evaporation, the water can cool the air

Application scale
- street scale
- neighbourhood scale

Typologies of space
- shopping center
- square
- park
- green zone

Combination with other patterns
- fountain
- high albedo pavement

Bospolder-Tussendijken
For a water stream it is an advantage when there is a natural height difference. This can be found in the area along the Dakpark. Some other larger areas have a slight difference in height, but then an extra height difference should be added. The water stream is mainly helpful against heat in terms of perviousness and evaporation.

Cool
In the Lijnbaan area some height differences can be found. Therefore, it is possible to create a very small waterstream in the shopping streets. The inner courtyards are also suitable to construct a waterstream. In the southern part of the area, there is a height difference as well.

10. Fountain

The moving water in a fountain evaporates and does not store heat, which leads to a cooler environment.

Does not store heat

Releases heat

Evaporates

Context

Fountains are usually located in lively public areas. It has a decorative function, but is also seen as a cool spot for warm days. Sometimes it is possible to sit on the edge of the fountain. They are often placed in the middle of a broad pedestrian zone, as a central element, or as part of a visual line. There are also small fountains on ground level, in which children can play. Furthermore, fountains can be placed in a water body or water stream. Movement is created by a pump underneath the water, which pushes the water up. When a fountain is not in movement, because the pump is not at work, the water structure remains.

Solution

Because of the movement, the water barely stores heat. Also, the cooler water drops in the air cool down the surrounding air. Evaporation has an additional effect for the cooling process. There is another advantage of a fountain, namely that people can touch the water, or feel the cold drops in the air. In this way people are able to cool down more easily.

Physical restrictions

- It should be possible to create a water pump system.
- Enough space is needed to walk around the fountain when located in a pedestrian zone.

Figure 30.
Carl030nl, 2010. CK Fontein Plein van Berllage. StraatKaart. Available at: http://straatkaart.nl/3553JL-Van-Egmondkade/media_fotos/ck-fontein-plein-berllage-hLk/.

Heat characteristics

- does not store heat:
the small layer of moving water does not store much heat
- releases heat:
heat is released to the air above the water
- evaporates:
the air is cooled by the water drops in the air, and the evaporation of water

Application scale

- street scale

Typologies of space

- singel
- cultural street
- shopping center
- square
- park

Combination with other patterns

- water body
- water stream
- high albedo pavement

Bospolder-Tussendijken

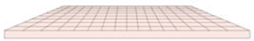
At the central side of the Visserijplein, a fountain can be placed. The rest of the square needs to be open for the market. Especially the evaporation helps to cool down the square. At the Marconiplein, a fountain can be added to create a landmark.

Cool

Small fountains can be placed in the middle of the pedestrian zones of the Lijnbaan. This causes evaporation. The perviousness of the Eendrachtsplein can be improved by adding a fountain there.

11. High albedo pavement

Pavement with a high albedo colour reflects a lot of sunlight.



Reflects radiation

Context

Bricks or tiles made out of stone or clay can be used as high albedo pavement. The result of this is that only slower traffic can use these kind of paved areas. The colours, structures, patterns, and especialy the different combinations of these, can give various looks to the environment. When a space contains high albedo pavement, this gives a very bright and clean feeling. At the same time, it can easily look dirty when it is not well maintained. Regular cleaning is needed, also because the high albedo will not remain by itself.

Solution

Because sunlight is reflected more when it reaches ground coloured with a high albedo, there is less radiation to heat up the area. This leads to cooler pavement, and therefore a cooler environment.

Physical restrictions

- Regular cleaning is needed to keep the pavement in a good condition for reflection.
- High albedo pavement cannot be used for roads meant for fast traffic.

Figure 31.
Straategie, Wandelen over uitnodigende bestrating in Breskens. Available at: http://www.straategie.nl/beeldbank-met-bestratingsprojecten/wandelen-over-uitnodigende-bestrating-in-breskens [Accessed March 20, 2015].

Heat characteristics
- reflects radiation:
the high albedo pavement reflects much of the incoming radiation

Application scale
- street scale
- neighbourhood scale
- city scale

Land use allocation
- residential street
- cultural street
- shopping center
- square

Combination with other patterns
- urban agriculture
- water stream
- fountain

Bospolder-Tussendijken
Many public spaces in Bospolder-Tussendijken can strongly be improved by replacing existing pavement with high albedo pavement. It is not desirable to add more pavement to the neighbourhood. Therefore, locations like the Marconiplein and Park 1943 are not completely suitable for this pavement, but only for the parts which are paved right now.

Cool
Almost all the public space in Cool is suitable for high albedo pavement. Only green zones or traffic roads are not suitable for this pattern.

12. Permeable pavement

Pavement with an open (inner) structure helps to prevent heat storage to a large extent.

Does not store heat

Releases heat

Context

This surface can be used in many situations, depending on how open the structure is. A half open surface with grass can be used to a limited extent, since the rough structure makes it not suitable for faster traffic. Then this pavement is often used for parking lots. There are also permeable bricks, which can be used in residential streets as well. Other permeable street surfaces, like gravel or shells, are mainly used for pedestrian areas. These materials will mostly be found in parks or green structures.

Solution

The open structure of the pavement makes it possible to let heat go through the surface, without storing all the heat. Also, the moisture underneath the surface can evaporate through the pavement. This helps to cool the surface itself, and also the air above the surface.

Physical restrictions

- The soil underneath the pavement should be permeable as well.
- In some cases the weed that grows through the pavement should be taken away.
- In some cases the structure changes because of its use, and should be brought back in the original state occasionally.
- In some cases the vehicles on the pavement cannot be very heavy.

Figure 32.
Leefmilieu Brussel, G_NAT01 Biodiversiteit in de stad maximaliseren. Gids duurzame gebouwen. Available at: http://gidsduurzamegebouwen.leefmilieubrussel.be/nl/g-nat01-biodiversiteit-in-de-stad-maximaliseren.html?IDC=26&IDD=4784 [Accessed March 20, 2015].

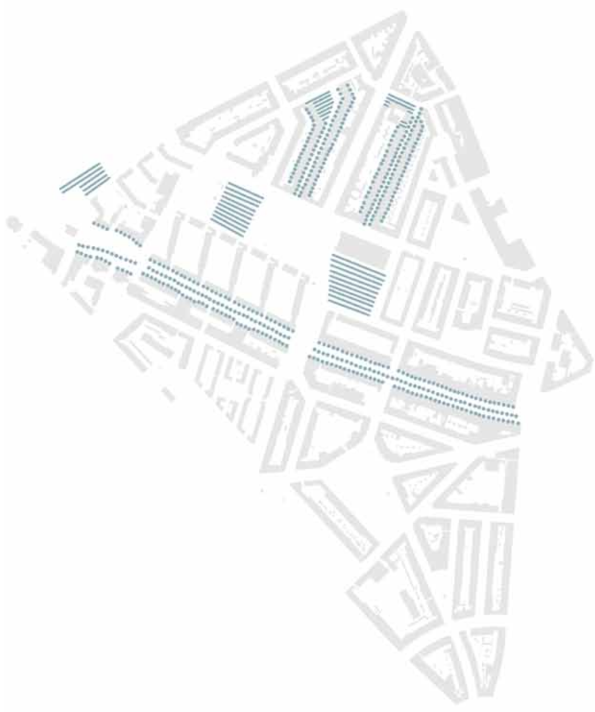
Heat characteristics
- does not store heat:
heat is not stored in the pavement but goes through to a large extent
- releases heat:
heat is released by means of the soil underneath the pavement

Application scale
- street scale
- neighbourhood scale

Land use allocation
- private garden
- residential street
- cultural street
- shopping center
- square
- park

Combination with other patterns
- canopy
- pergola
- trees
- urban agriculture
- grass

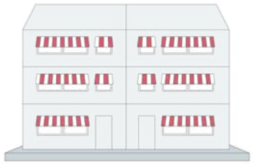
Bospolder-Tussendijken
Existing pavement can be replaced by permeable pavement in many cases. Only green structures and traffic roads are not suitable for this type of pavement. The perviousness of the pavements can vary strongly. For private gardens it can be good to replace impervious pavements with a permeable version.



Cool
For Cool it is the same case as in Bospolder-Tussendijken: many impervious surfaces can be replaced by permeable pavement.

13. Sunshade

Sunshades create shadow in a building, which leads to a lower indoor temperature.



Reduces radiation

Reflects radiation

Context

Sunshades are often placed above a window, to create shadow in the house. It is also possible that the sunshades create shadow on the facade. The position of the sunshades is depending on the orientation of a building towards the sun. The southern side of a building captures sunlight the most, but the sun has a lower position when it stands in the east or west. The position of the sun also differs during the seasons. Therefore, the angle of the sunshades should depend on the building orientation. Often sunshades have a light colour, in order to reflect as much sun as possible.

Solution

Since less solar radiation enters the building through the windows, the indoor temperature will be less high than without sunshades. This leads to a lower outdoor temperature as well. In addition, the solar radiation is reflected by the sunshades. This means that there is less radiation left in the urban environment to heat up the area.

Physical restrictions

- Sunshades are only useful when they have the right position with respect to the sun. The southern facade has to deal with solar radiation the most, and the eastern or western facade has to deal with a lower position of the sun.

Figure 33.
Welzon, Brustor B-2100 Uitval zonnescherm. Available at: http://welzon.nl/contents/nl/d14_welzon-best-referentie_02.html [Accessed April 10, 2015].

Heat characteristics
- reduces radiation:
the sunshade takes away solar radiation from the windows
- reflects radiation:
the light colour of the sunshade reflects the solar radiation

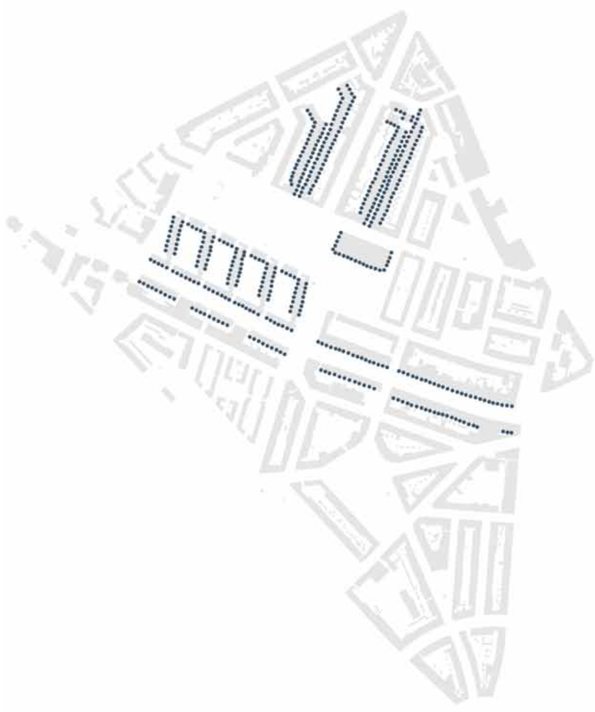
Application scale
- building scale

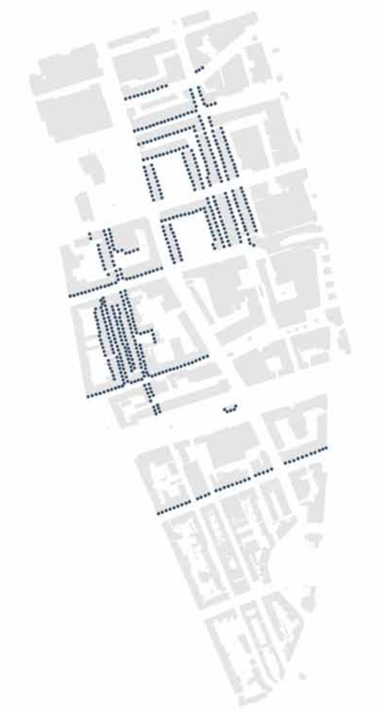
Typologies of space
- public building
- row houses
- apartments

Combination with other patterns
- green balcony
- roof garden
- high albedo roof
- solar panels
- smart parcellation

Bospolder-Tussendijken
Buildings with windows orientated to the east, south or west, are suitable for sunscreens. This can be added to all types of buildings. For some buildings it is less useful to use sunscreens, because there is almost no sun on the facade during the day.

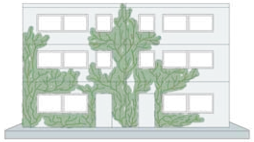
Cool
For Cool it is the same case as Bospolder-Tussendijken: the windows directed at the east, south or west can have sunscreens.





14. Green facade

A green facade protects the building from heating up, and at the same time cools the outdoor air by evapotranspiration.



Reduces radiation

Evapotranspirates

Context

Vegetation can be placed directly on the facade, or as an extra facade in front of the building. In summer the plants have leaves and create shadow on the facade and windows. A construction should be made against the facade, or on its own, to hang the plants. It is possible to use all kinds of plants, colourful or not. In some cases climbing plants are used, which slowly overgrow the facade. In other cases the plants are small, and directly placed in the right position.

Solution

The leaves of the plants cause evapotranspiration, which actively cools down the surrounding air. In this way the outdoor environment is cooled. The indoor environment is cooler because of the shadow that is created by the green facade.

Physical restrictions

- It should be possible to create a construction in/on which the plants can grow.
- It should be possible to give the plants additional water in times of drought.
- The plants on the facade should be maintained, among others to keep the view through the windows.

Figure 34.
La Citta Vita, 2010. Copenhagen, Denmark. Green Business Watch. Available at: http://greenbusinesswatch.org/blog/stunning-green-wall-pictures/copenhagen-denmark [Accessed April 10, 2015].

Heat characteristics

- reduces radiation:
depending on the position of the plants, shadow is created on windows and the facade
- evapotranspirates:
the plants evapotranspirate and cool down the surrounding air

Application scale

- building scale

Typologies of space

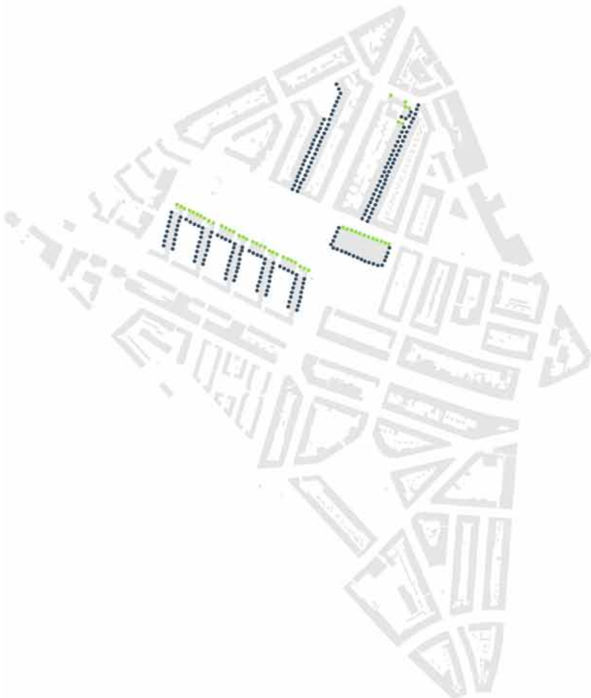
- public building
- row houses
- apartments

Combination with other patterns

- green balcony
- roof garden
- high albedo roof
- solar panels

Bospolder-Tussendijken

Green facades can be useful for shadow and greening in different areas. Especially at the Gijsingflats, green facades will suit well as an extra facade. For the community building at the Visserijplein, and for the Haringpakkersstraat and Kleine Visserijstraat, the green facades can be made on the existing walls.



Cool

The high rise buildings of the Lijnbaan can have a green facade, just as the dwellings in the Jacobusstraat and Mauritsstraat. For the Lijnbaan a separate facade is recommended, while for the streets a green facade on the wall is more suitable. The last option is also suitable for the supply streets of the Lijnbaan.

15. Green balcony

A green balcony creates a cool outdoor spot attached to the house, by means of shadow and evapotranspiration.

Reduces radiation

Evapotranspirates

Context

Balconies in the Netherlands are often very empty or used as place for storage. By placing vegetation on the balcony, additional benefits can be created for the local climate. The vegetation can be placed in boxes. Also, climbing plants can be used for the fence of the balcony. This gives a green look at the balcony, as seen from the perspective of the street. It should be noted that the vegetation cannot be planted directly into the subsoil, but only in a box. As a result, the size of plants is limited to the size of the boxes.

Solution

The air around the vegetation cools down because of evapotranspiration. This can have a very local effect, because a balcony is a quite closed outdoor space. The balcony itself will also create shadow underneath it, and there will be some shadow from the vegetation.

Physical restrictions

- The size of the boxes limits the size of the vegetation.
- The vegetation needs additional water in times of drought.
- The vegetation should be maintained, because they cannot grow too big.
- Additional space is needed to walk (and sit) on the balcony.

Figure 35.
Acquire Publishing, No Title. Available at: http://www.acquirepublishing.nl/static/site/img/module/content/article/20879/xheader.jpg.pagespeed.ic.5EuKHD_z-Z.jpg [Accessed April 10, 2015].

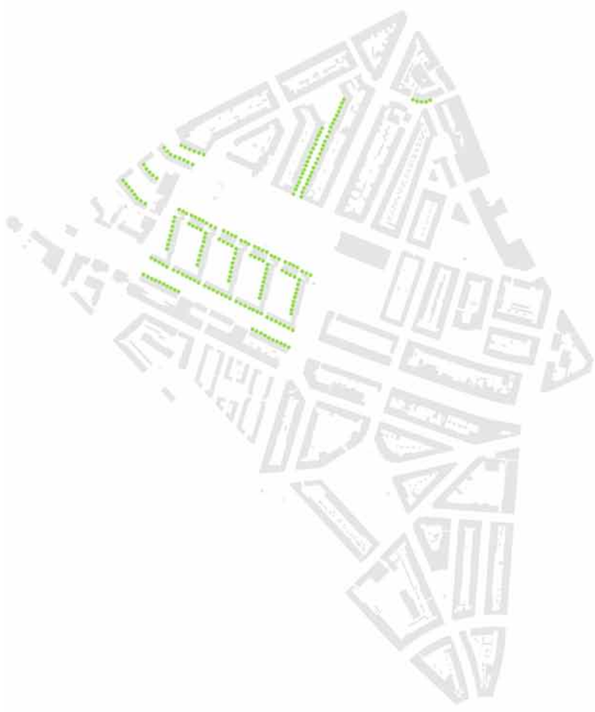
Heat characteristics
- reduces radiation:
shadow is created mainly underneath the balcony
- evapotranspirates:
the vegetation on the balcony decreases the air temperature by means of evapo-transpiration

Application scale
- building scale

Typologies of space
- apartments

Combination with other patterns
- sunshade
- green facade
- roof garden
- high albedo roof
- solar panels

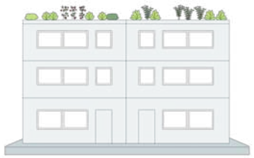
Bospolder-Tussendijken
In this neighbourhood, balconies can be found mostly in the high rise buildings. Also, lower apartment buildings sometimes have balconies. For the areas of development, the balconies are marked. This concerns the Schiedamseweg, Park 1943 and the Haringpakkersstraat.



Cool
Also in Cool the balconies can be found in high rise buildings and apartment buildings. Especially the Lijnbaan ensemble has many balconies. Other balconies can be found in the Jacobusstraat and Mauritsstraat.

16. Roof garden

A roof garden releases heat in an active way because of evapotranspiration.



Evapotranspirates

Context

A roof garden consists of all kinds of vegetation, planted on a special roof construction. This roof construction should be made in a way that it can carry the weight of the garden itself, and of people as well. Often there is also a terrace on the roof. An important difference with a regular garden, is that there is no subsoil for the vegetation. Therefore, vegetation is planted in boxes, which can be moved and therefore placed in other positions. It is also possible to construct a layer of soil on the entire roof, but this layer has a limited height because it is heavy.

Solution

Roof gardens should not be confused with an extensive green roof, which exists of small plants that can bare heat and draught. To benefit from the cooling possibility of the green roof, evapotranspiration is needed by the vegetation. This can only be provided by species which are able to evapotranspirate a lot.

Physical restrictions

- The roof construction of the building should be able to carry the weight of the garden and people that walk on the roof.
- The roots of vegetation cannot go deeper than the limited height of the soil layer.
- The roof should be accessible and flat.

Figure 36.
Oozo, Woning Bastiaansplein 21 Delft. Available at: http://www.oozo.nl/woningen/delft/binnenstad/zuidpoort/woning/158145/woning-bastiaansplein-21-delft [Accessed April 10, 2015].

Heat characteristics
- evapotranspiration:
the air temperature is lower above the roof garden because of evapotranspiration

Application scale
- building scale

Typologies of space
- public buildings
- row houses

Combination with other patterns
- sunshade
- green facade
- green balcony

Bospolder-Tussendijken
There are many buildings with flat roofs in Bospolder-Tussendijken, which creates the opportunity to make roof gardens. In that case it is important that an access to the roof is added to the concerning building. The flat roofs in the areas of development are marked on the map.

Cool
In Cool there are even more flat roofs. Especially the lower ones, which people from higher buildings are able to see, are interesting for roof gardens. This can be a way to make this paved area greener. Since there are many public areas in this neighbourhood, it is also possible to make some roofs accessible for visitors.

17. High albedo roof

A roof with a high albedo prevents the building from heating up, by means of its reflection.

Reflects radiation

Context

There are two ways to create a high albedo roof. It is possible to paint an existing roof with a colour that has a high albedo. The other option is to replace the roof with another material which has a high albedo by itself. Because of weathering, the reflection will slowly get less. Therefore, it is important to clean the roof regularly, which makes the reflection possible.

Solution

High albedo colours reflect a lot of sunlight. When this reflection happens on a roof, this leads to less solar radiation on the level where people are located. As a result, the temperature is lower than without the light roof.

Physical restrictions

- It is important to clean the roof regularly, in order to remain the high albedo.

Figure 37.
Nebiprofa, 2014. Woningen - Krimpen aan den IJssel. Available at: http://www.nebiprofa.nl/over-nebiprofa/portfolio/view/woningen-krimpen-aan-den-ijssel [Accessed April 13, 2015].

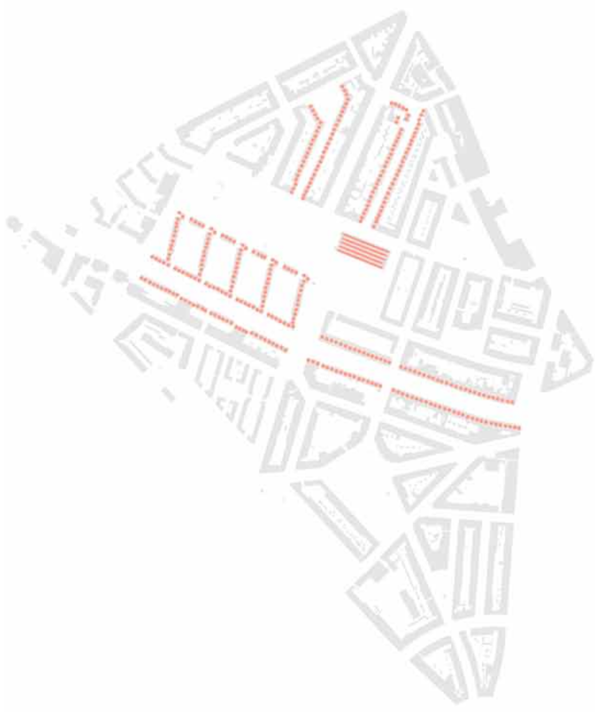
Heat characteristics
- reflects radiation:
the high albedo of the roof reflects a lot of solar radiation back to the sky

Application scale
- building scale

Typologies of space
- public buildings
- row houses
- apartments

Combination with other patterns
- sunshade
- green facade
- green balcony

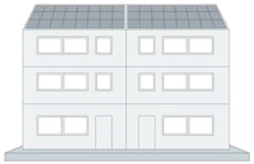
Bospolder-Tussendijken
For each roof it is possible to transform it into a high albedo roof. Therefore, all the roofs that are part of the areas of development are marked.



Cool
In this case, all the roofs of the areas of development are marked as well, for the same reason as mentioned for Bospolder-Tussendijken.

18. Solar panels

Solar panels reflect sunlight, and are able to extract heat in an active way.



Reflects radiation

Active heat release

Context

Often solar panels are placed on a rooftop of a building. This is done because the panels should be able to catch the maximum amount of solar radiation. Preferably they are lifted in a small angle, and directed towards the south. Solar panels can also be placed in a field or other open space, but this is not preferred because it takes away valuable space. There are standard sizes available for the panels, but they can also be applied in smaller sizes. The small size solar panels can be integrated in glass structures i.e.

Solution

Solar panels reflect and absorb a lot of solar radiation. This leads to less heat in the air above the panels, and inside the concerning building. An additional effect can be achieved when energy is extracted from the solar panels during the day. In that case the panels are cooled at the same time. Although solar panels do not exist of water or vegetation, this pattern can have the effect of active heat release, like evapo(transpi)ration does. Therefore, an exception is made for this pattern to see it as part of the evapo(transpi)ration / active heat release.

Physical restrictions

- The roof construction of the building should be able to carry the weight of the solar panels.
- While positioning the panels, the amount of solar radiation that can be captured should be taken into account.
- Preferably the roof has a small slope directed towards the south.

Figure 38.
Vastgoedjournaal, Sterrenberg. Available at: http://www.vastgoedjournaal.nl/uploads/images/gemeenten/Sterrenberg.jpg [Accessed April 10, 2015].

Heat characteristics
- reflects radiation:
the solar panels reflect solar radiation
- active heat release:
when energy is taken from the panels they cool down in an active way

Application scale
- building scale

Typologies of space
- public buildings
- row houses
- apartments

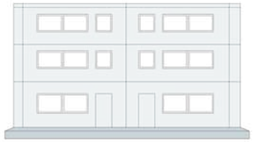
Combination with other patterns
- sunshade
- green facade
- green balcony
- smart parcellation

Bospolder-Tussendijken
Since roofs with a slope in the southern direction are most suitable for solar panels, these roofs are marked for the whole neighbourhood. These are often older types of buildings with gabled roofs. These roofs can be found, among others, along the Schiedamseweg and Grote Visserijstraat.

Cool
Also in Cool the gabled roofs can be found in the parts with older buildings. These buildings are part of the southeastern part of the neighbourhood. To a large extent this concerns the dwellings along the Westersingel.

19. Smart parcellation

Smart orientation and dimensioning of streets and buildings can lead to lower temperatures in the street and inside the buildings.



Reduces radiation

Releases heat

Context

When a new parcellation can be created in a neighbourhood, the building orientation and height/width ratio (H/W ratio) of the streets can be determined. Especially the H/W ratio is related to the desired building typology, so there is not always a possibility to have a choice in this. For this pattern, in relation to heat protection, it is smart to make the following choices: an orientation from northwest to southeast, and a H/W ratio between 1/2 and 1/1. In case this cannot be achieved, it is helpful to try to reach this as much as possible.

Solution

The northwest-southeast orientation of a street or building block leads to a lot of shadow at the hottest part of the day, less heating up of buildings, and a cooling wind in the street. In this way, radiation is reduced and heat is released. Also the mentioned height/width ratio leads to a cooling wind in the streets, and a sky-view factor that allows the street to release heat.

Physical restrictions

- The desired building typology should allow to determine the height/width ratio.
- The new building orientation and height/width ration should fit into the existing building structure.

Figure 39.
Wek Dordrecht, Bagijnhof Dordrecht met schaduw postkantoor. Available at: http://www.wekdordrecht.nl/oud-dordrecht-visstraat-bagijnhof/ [Accessed May 8, 2015].

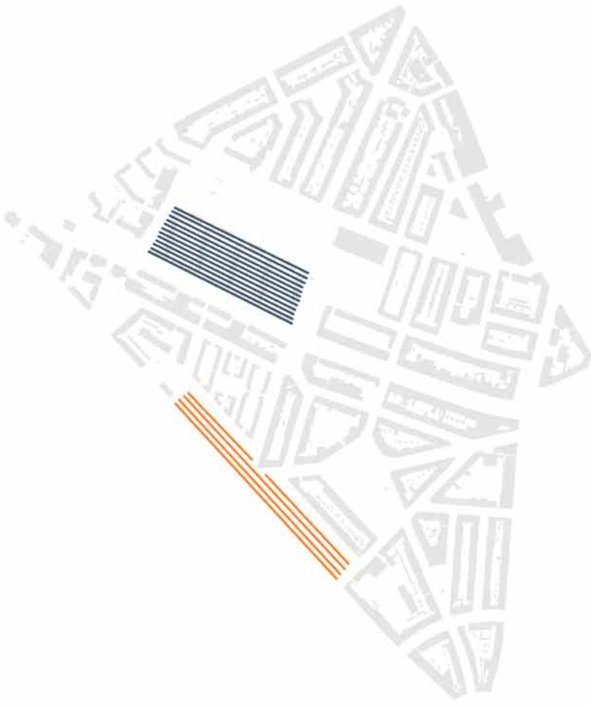
Heat characteristics
- reduces radiation:
because of the building orientation, shadow is created in the street
- releases heat:
the orientation and sky-view factor lead to heat release

Application scale
- street scale
- neighbourhood scale

Typologies of space
- residential street
- cultural street
- shopping center
- row houses
- apartments

Combination with other patterns
- sunshade
- solar panels

Bospolder-Tussendijken
In this neighbourhood the Gijsingflats can be replaced by new dwellings. Since there is a northwest-southeast orientation in the adjacent street, it is very suitable to create a smart parcellation here. Also, the vacant space along the Dakpark can be used for this pattern.



Cool
There are no spaces availabe in Cool to build new streets. Also, the building orientation is mostly directed north-south and east-west in this neighbourhood. Therefore, this pattern cannot be applied in the current layout of the neighbourhood.

Part 5: Rotterdam

Photo © Ossip van Duivenbode / Rotterdam Image Bank

Vulnerability analysis

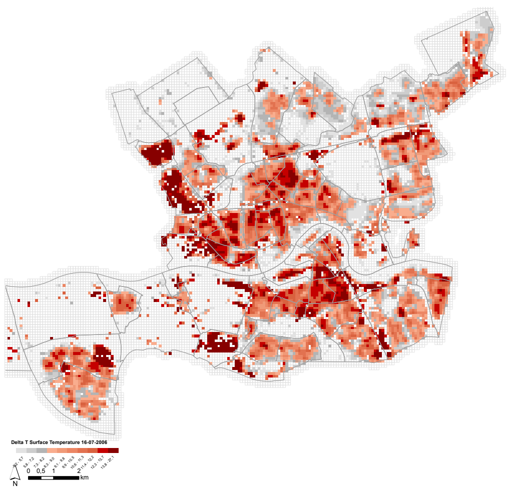
When we look at maps produced in the Hotterdam project, we can analyse the surface temperatures and vulnerabilities of elderly and babies (see Figure 40). The surface temperatures confirm that the heat is mostly present in the central, west and south part of the city. Bospolder-Tussendijken and Cool are also part of the hottest surface areas in Rotterdam. In Cool the vulnerability of elderly is very high, while in Bospolder-Tussendijken the vulnerability is more present for babies. This makes the neighbourhoods representative for the heat and the vulnerability in terms of ages.

Kwetsbaarheid - 75 plussers

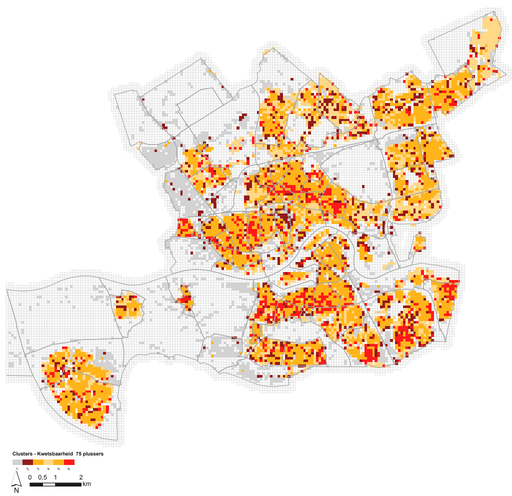
	Warmte-eiland oppervlakte temperatuur	leefbaarometer 2012	Gemiddeld energielabel	Gemiddeld 75+/ha
kwetsbaarst C2	9.4	zeer negatief	D	21.8
kwetsbaarder C6	10.0	matig	geen/D	3.7
kwetsbaarst C3	10.5	matig	C	5.6
kwetsbaarst C5	9.8	matig positief	D	5.3
matig kwetsbaar C4	8.7	matig positief	geen	2
overig C1	-	-	-	-

Kwetsbaarheid - Babies

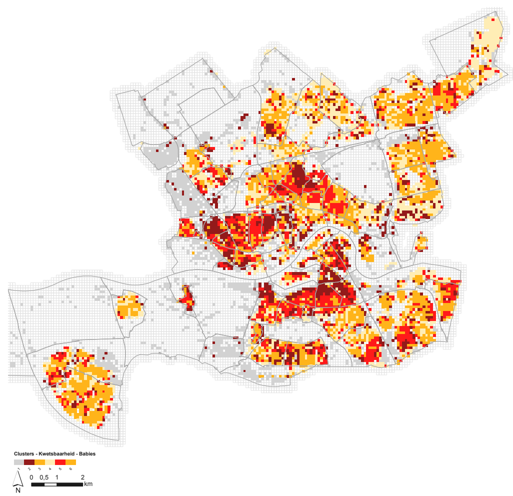
	Warmte-eiland oppervlakte temperatuur	leefbaarometer 2012	Gemiddeld energielabel	Gemiddeld 75+/ha
kwetsbaarst C2	10.5	negatief	C	1.5
kwetsbaarder C5	10.0	matig	geen/D/C	1.7
kwetsbaarst C3	9.6	matig positief	D	1.1
kwetsbaarst C6	9.6	matig positief	C	1.3
matig kwetsbaar C4	8.6	matig positief	geen	0.6
overig C1	-	-	-	-



a. Surface temperature differences of the inhabited parts of Rotterdam, compared to its rural surroundings.



b. Vulnerability of people aged above 75 in the inhabited parts of Rotterdam.



c. Vulnerability of babies in the inhabited parts of Rotterdam.

Figure 40.
Van der Hoeven, F. & Wandl, A., 2014. Hotterdam (ongoing project).

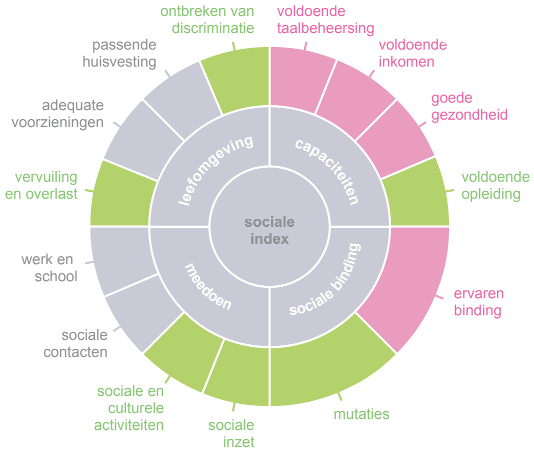
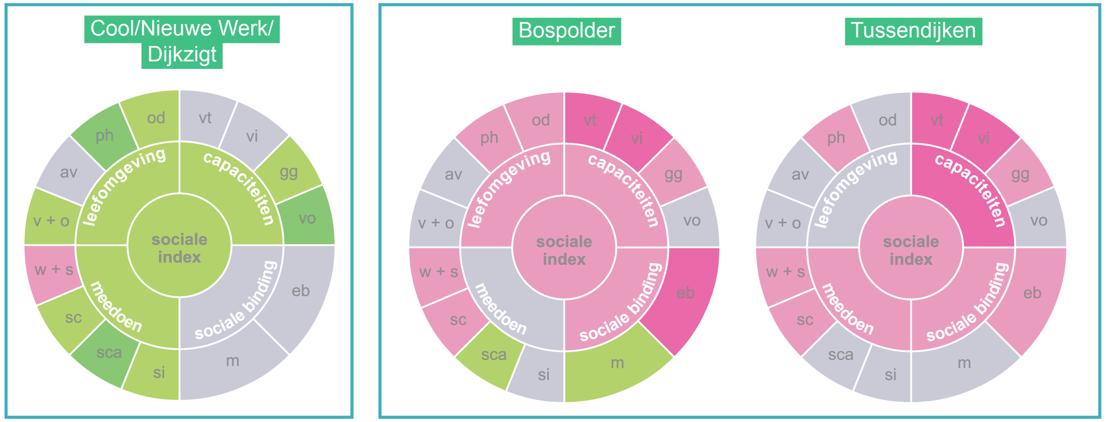


Figure 41.
Gemeente Rotterdam, 2012. Rotterdam sociaal gemeten: 4e meting Sociale Index, Rotterdam.

Social index of Rotterdam.



Left: social index of Cool (together with Nieuwe Werk and Dijkzigt). Right: social indices of Bospolder and Tussendijken.

From the demography of Cool, Bospolder-Tussendijken and Rotterdam, the following conclusions can be drawn:
- Although the size of the two neighbourhoods is quite similar, the amount of inhabitants is almost three times as much in Bospolder-Tussendijken.
- In both the neighbourhoods, the percentage of males is higher than females, while in Rotterdam the percentage of females is higher.
- Remarkably, there are many people in the working age (25-45 yr) in Cool. The people in Bospolder-Tussendijken are younger than the average in Rotterdam.
- The largest part of the inhabitants is unmarried, in both neighbourhoods.
- In Cool there are almost no households with children, while in Bospolder-Tussendijken there are more than the average of Rotterdam.
- In Cool and Rotterdam in general, natives and immigrants are almost equally divided. In Bospolder-Tussendijken 80% of the inhabitants are immigrants.
- In Cool, immigrants come from Western or other origin. In Bospolder-Tussendijken there are many people from Morocco and Turkey as well.

The graphics and numbers of the demography are based on CBS (2014), and can be found in the appendix (see Figure 98).

When we compare Cool and Bospolder-Tussendijken, it can be concluded that the social index of Cool is much better than the one of Bospolder and Tussendijken (see Figure 41). Although the social cohesion of Cool is weak, and not many people go to school or work, the social index is not bad. On the other hand, Bospolder-Tussendijken has a lot of negative social aspects, especially when it comes to capacities. Therefore, Bospolder-Tussendijken is vulnerable in terms of economic and social issues.

Figure 42 demonstrates that Bospolder-Tussendijken is in general a bit older than Cool. Both neighbourhoods exist of buildings from many different time periods. A large part of Cool is reconstructed after the bombardments in the Second World War. This is also the case for a smaller part of Bospolder-Tussendijken, which was destroyed after a bombardment in 1943. The presence of old buildings makes some parts of the neighbourhoods more vulnerable than others as well.

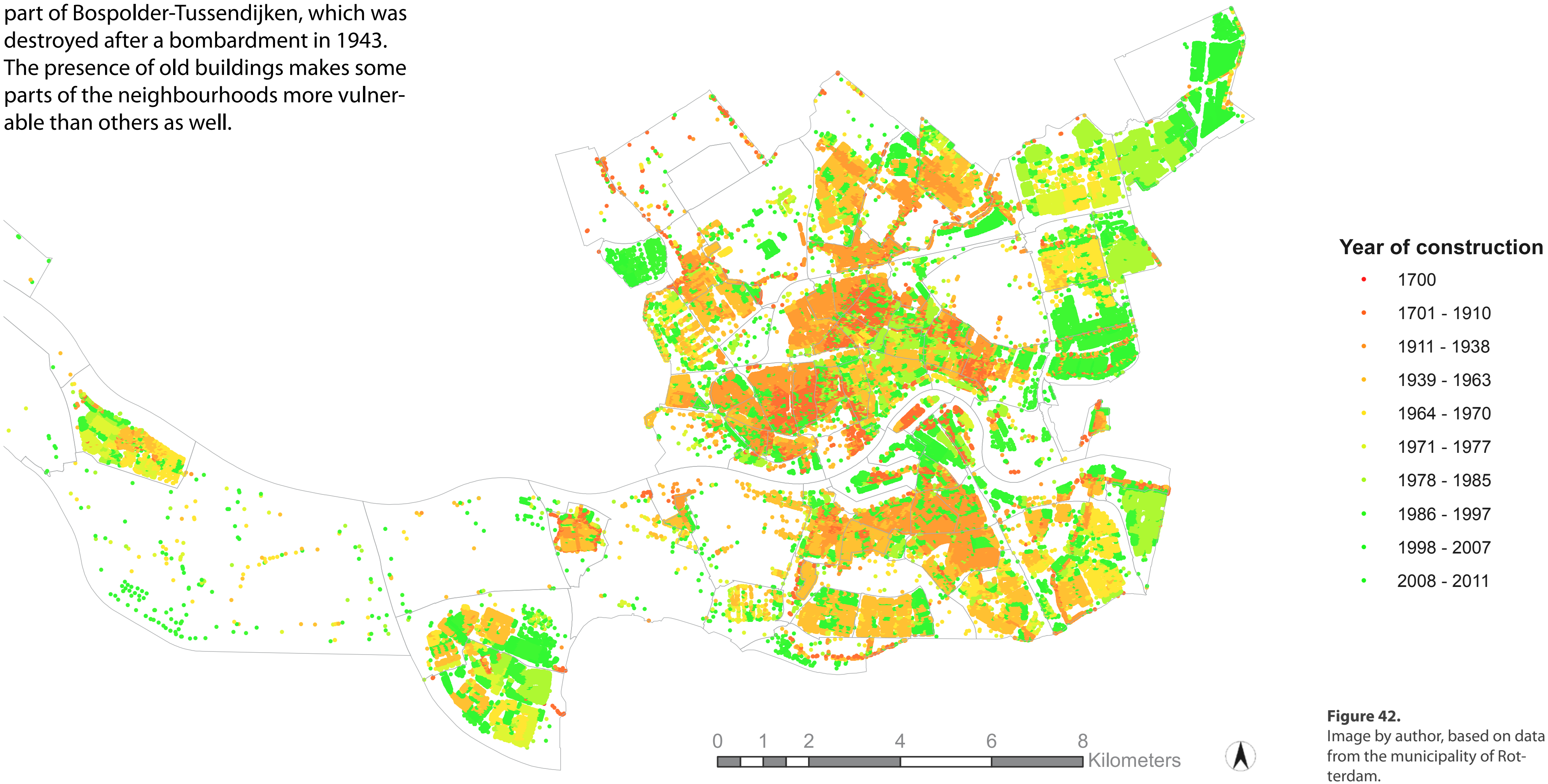


Figure 42.
Image by author, based on data from the municipality of Rotterdam.

Spatial analysis

The spatial analysis focuses on the urban structures. Analysis maps of additional subjects related to the urban structure can be found in the appendix of the present document.

Green and water structure

In the central, western and southern part of the city, large green structures are missing (see Figure 44). Remarkably, these are also the hottest parts of the city. For Bospolder-Tussendijken, Park 1943 is the only larger green spot of the neighbourhood (see Figure 43a). Therefore, the Dakpark, which is a rooftop park on a shopping mall, along the border of the neighbourhood is very important. Inside the building blocks green can be found in private gardens. In Cool there is even less green (see Figure 43b). Vegetation can be found in some inner courtyards i.e. For Cool the closest large green structure is the Museumpark, which is located at the southwestern side of the neighbourhood. The river Maas is an important water structure for Rotterdam, but at the same time a source of heat in summer. The neighbourhoods are not directly located at the river, but they are close to the harbours. Bospolder-Tussendijken could have higher temperatures because of the harbour industry as well. Along Bospolder-Tussendijken a branch of the Maas can be found: the Delfshavense Schie. The border of Cool is marked by the Westersingel, this is a water structure with grass and trees.

a. Green and water structures of Bospolder-Tussendijken.

b. Green and water structures of Cool.

Green structure
Water structure
Buildings

scale 1:25.000

Figure 43.
Image by author.

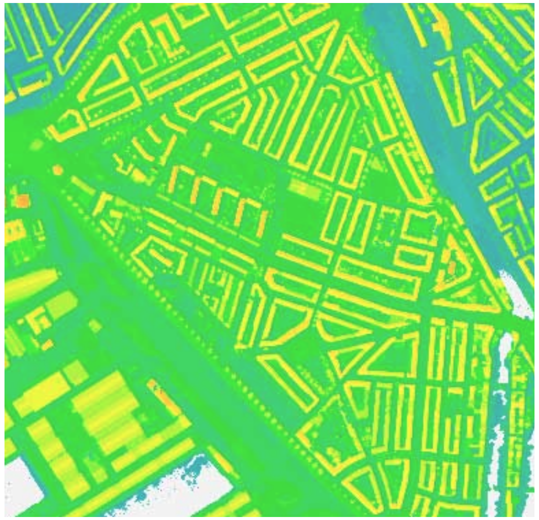
Figure 44.
Image by author.

Heat characteristics

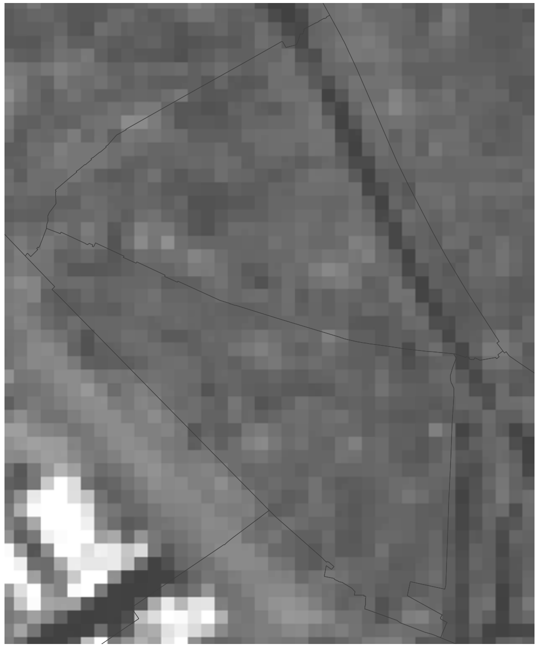
These maps are used to determine the current values of the heat characteristics. The height map (Figure 45b and 46b) is used to estimate the sky-view factor. In ArcGIS (Esri 2015), the albedo, perviousness and amount of vegetation is estimated by means of average values for the design areas. The outcomes of the estimations can be found in the assessment of the heat characteristics for the design variants.

Bospolder-Tussendijken

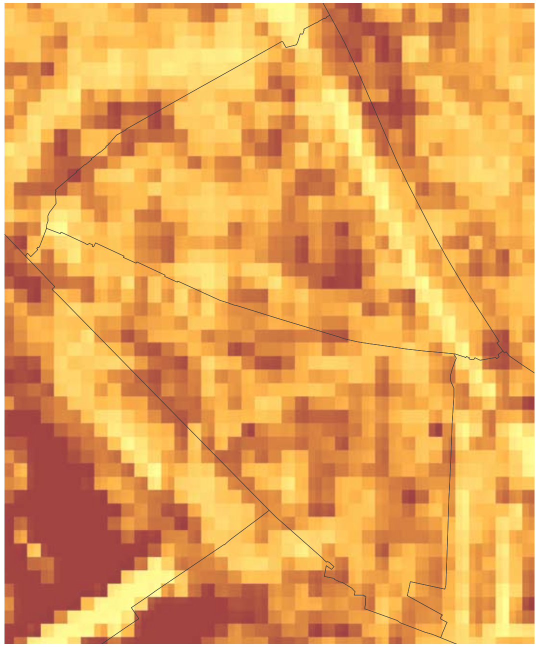
a. Shadow based on height map of Bospolder-Tussendijken.



b. Height map of Bospolder-Tussendijken.



c. Albedo values of Bospolder-Tussendijken.



d. Perviousness of Bospolder-Tussendijken.

e. NDVI (vegetation index) of Bospolder-Tussendijken.

Figure 45.

a & b:
Esri Nederland & AHN, 2015. Actueel Hoogtebestand Nederland. Available at: http://ahn.maps.arcgis.com/apps/webappviewer/index.html?id=c3c98b8a4ff84ff4938fafe7cc106e88 [Accessed June 8, 2015].

c, d & e:
Based on data from Hotterdam.

Legend for ArcGIS maps:

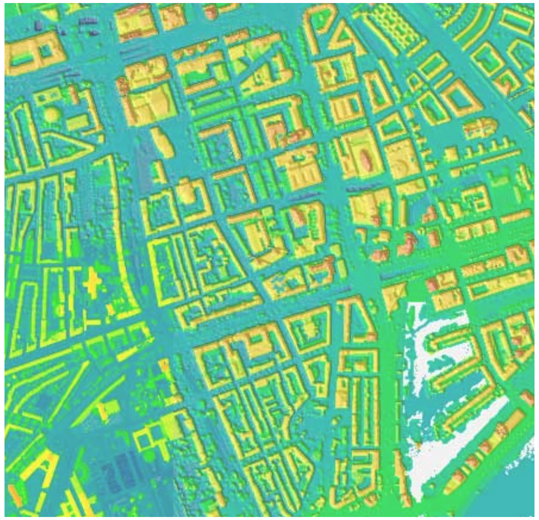
high albedo value
low albedo value

impervious
pervious

much vegetation

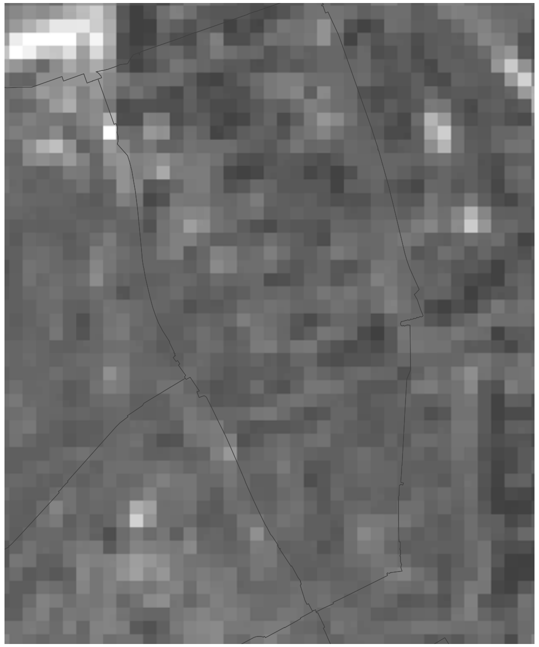
little vegetation

a. Shadow based on height map of Cool.

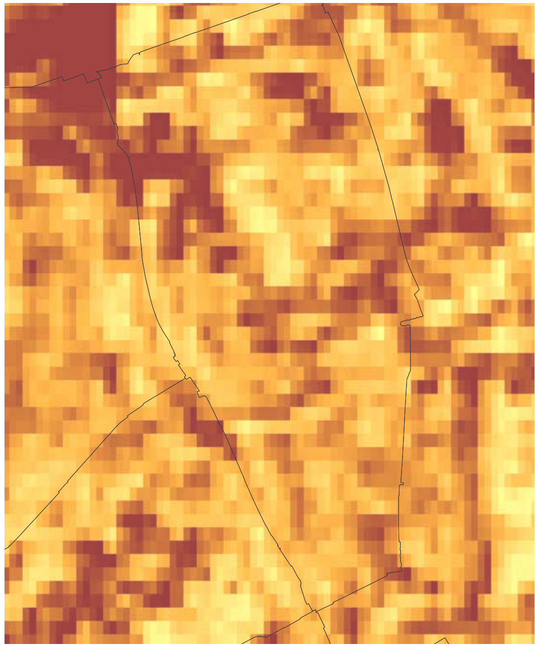


b. Height map / sky-view factor of Cool.

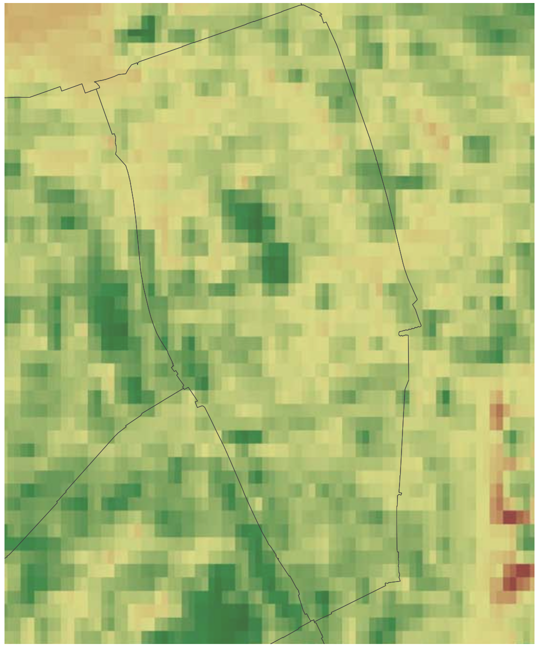
Cool



c. Albedo values of Cool.



d. Perviousness of Cool.



e. NDVI (vegetation index) of Cool.

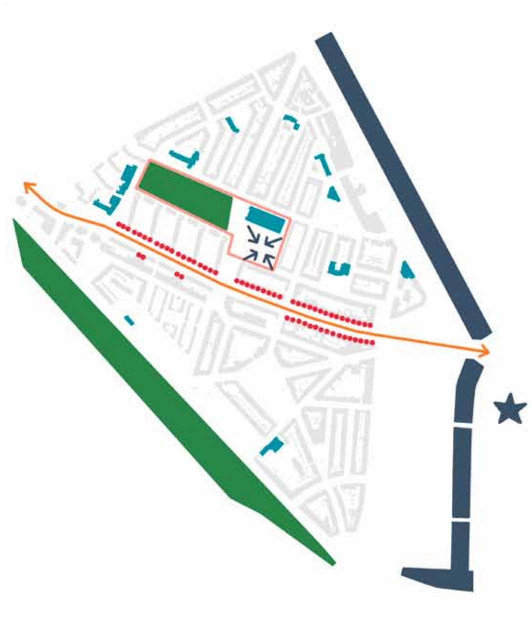
Figure 46.

a & b:
Esri Nederland & AHN, 2015. Actueel Hoogtebestand Nederland. Available at: http://ahn.maps.arcgis.com/apps/webappviewer/index.html?id=c3c98b8a4ff84ff4938fafe7cc106e88 [Accessed June 8, 2015].

c, d & e:
Based on data from Hotterdam.

SWOT analysis

The SWOT analysis describes the strengths, weaknesses, opportunities and threats of the design locations. In the appendix an elaborated version of this analysis can be found. There, analyses are demonstrated for the locations which can be developed, but are not part of the design areas. Here, an overview is given of the most important results (see Figure 47). The SWOT of both neighbourhoods is followed by the SWOT analyses for the design locations.



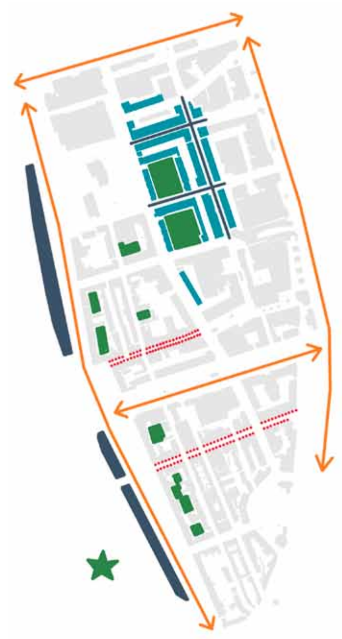


Figure 47.
Image by author.

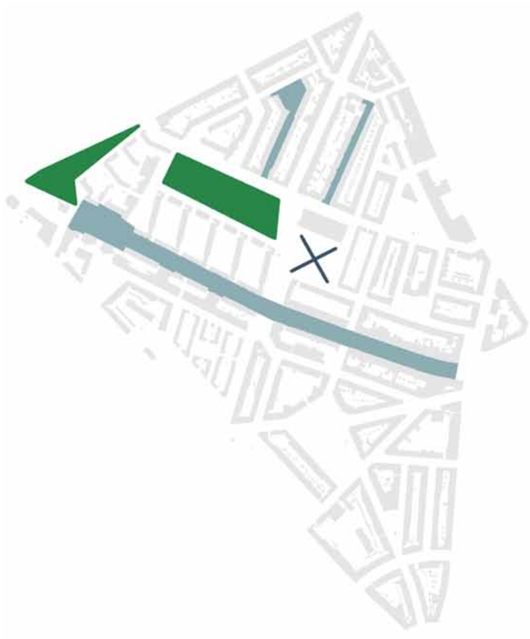
- Spot with additional value
- Spot with lack of quality
- Public space
- Road
- Retail
- Building
- Green structure

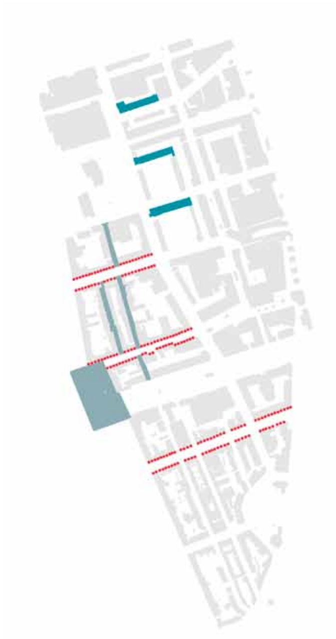
Strengths Bospolder-Tussendijken

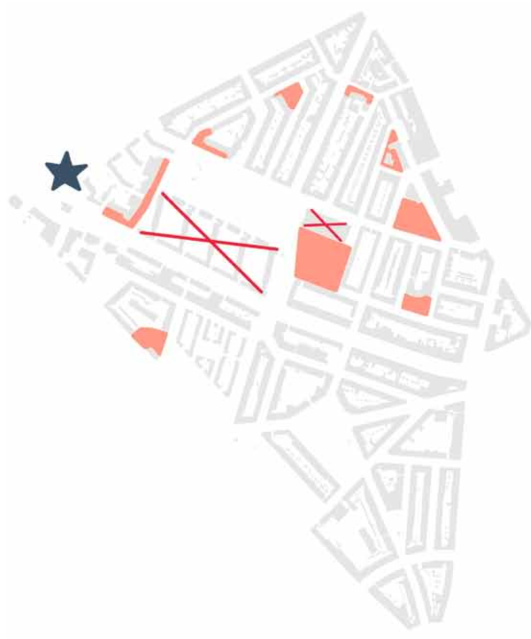
- Schiedamseweg: good accessible by car and public transport (metro and tram)
- Schiedamseweg: lively street with shops
- Visserijplein: attracts people from outside to market, from inside the neighbourhood to community building
- Park 1943 & Visserijplein: core of the neighbourhood, because of public functions and its central location
- Many public buildings (mainly schools) are closely located to the park and square
- Dakpark is a large green structure nearby
- Historical harbour of Delfshaven with its water structure is nearby

Strengths Cool

- Lijnbaan: high monumental value
- Lijnbaan: intensively used public space
- Witte de Withstraat & Oude Binnenweg: lively streets with many terraces
- Good accessible by car and public transport (train, metro, tram and bus)
- Green inner courtyards in between paved areas
- Singel at western border of the neighbourhood
- Museumpark is a large green structure nearby



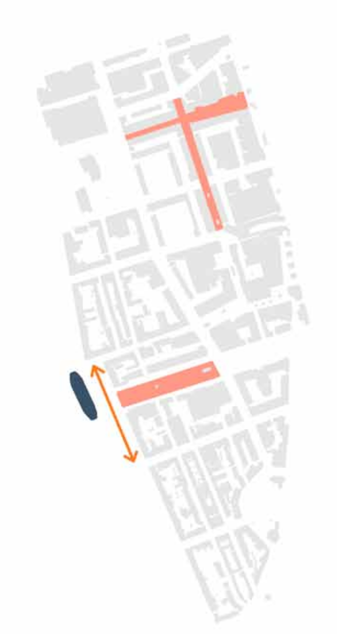


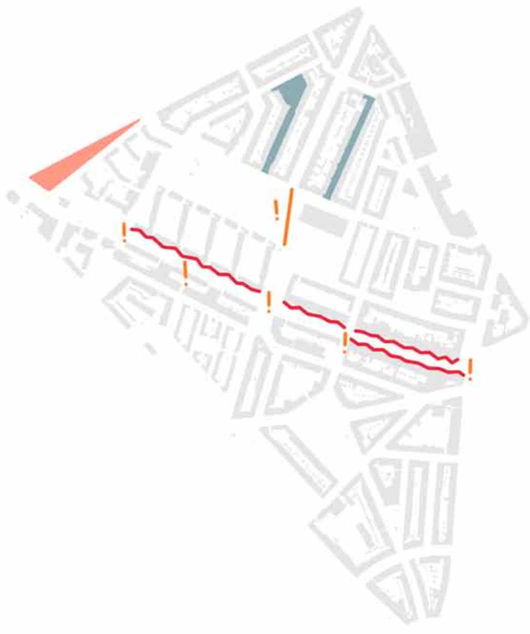


Weaknesses Bospolder-Tussendijken
- Schiedamseweg, Kleine Visserijstraat & Haringpakkersstraat have a grey look, because of stone and pavement, and absorb a lot of heat
- Visserijplein: empty when there is no market and out of proportion
- Park 1943 & Marconiplein: monofunctional

Weaknesses Cool
- Lijnbaan: high rise buildings look mainly towards roofs and pavements
- Jacobusstraat & Mauritsstraat: narrow and dominated by cars
- Eendrachtsplein: paved to a large extent, and therefore absorbs a lot of heat
- Downtown: streets are not located close to each other

Opportunities Bospolder-Tussendijken
- Visserijplein: flexible layout
- Park 1943 & Visserijplein: Gijsingflats & community building can be replaced by new buildings
- Marconiplein: can be an iconic entrance of the neighbourhood
- Small open spaces next to the schools: can be developed into playgrounds





Opportunities Cool
- Lijnbaan: car free zone creates flexibility for the layout
- Westblaak: can be redeveloped to an integrated skatepark design
- Eendrachtsplein: water structure can be brought back
- Eendrachtsplein: can be used as a connective zone

Threats Bospolder-Tussendijken
- Schiedamseweg: cluttered streetscape along the shops at the Schiedamseweg
- Schiedamsweg & Grote Visserijstraat: crossings can be unsafe, especially for children
- Grote Visserijstraat: can be an obstruction between Park 1943 & Visserijplein
- Kleine Visserijstraat & Haringpakkersstraat: can have a monotonous look
- Marconiplein: border of the neighbourhood where people don't stay

Threats Cool
- Lijnbaan: cluttering because of advertisement signs and various looks of the stores
- Lijnbaan: empty area at night can become a place for criminality
- Westblaak: can be a barrier to cross
- Eendrachtsplein: can become monofunctional

Visserijplein

Strenghts:
- Close to Schiedamseweg with public transport connection and shops
- Next to a public building, consisting of a library and community center
- Next to a neighbourhood park
- Well connected with other parts of the neighbourhood

Weaknesses:
- When there is no market the square is empty
- The square in combination with the surrounding buildings is out of proportion
- The large paved area looks grey and absorbs a lot of heat

Opportunities:
- The market attracts many people to the neighbourhood
- The shape of the square creates flexibility for the layout
- Possibility to redevelop the community building

Threats:
- Grote Visserijstraat can obstruct the direct connection to the park

Figure 48.
Image by author, based on Bing Maps.

Figure 49.
Image by author, based on Google Maps.

Figure 50.
Image by author, based on Bing Maps.

Park 1943

Strengths:
- Surrounded by public buildings and functions (schools, library, community center, market)
- Combination of playground and green structure
- Well connected with other parts of the neighbourhood

Weaknesses:
- Limited possibilities for use of the park

Opportunities:
- Gijsingsflats will be demolished and replaced by other dwellings
- Community building can be replaced

Threats:
- Safety of crossings for school children
- Grote Visserijstraat can obstruct the direct connection to the square

Figure 51.
Image by author, based on Google Maps.

Marconiplein

Strengths:
- Large amount of mature trees

Weaknesses:
- Unclear function of the area

Opportunities:
- Creation of an iconic point for the neighbourhood
- Attract people with a new function

Threats:
- Border between different areas is only used to pass by and not to stay there

Figure 52.
Image by author, based on Bing Maps.

Figure 53.
Image by author, based on Google Maps.

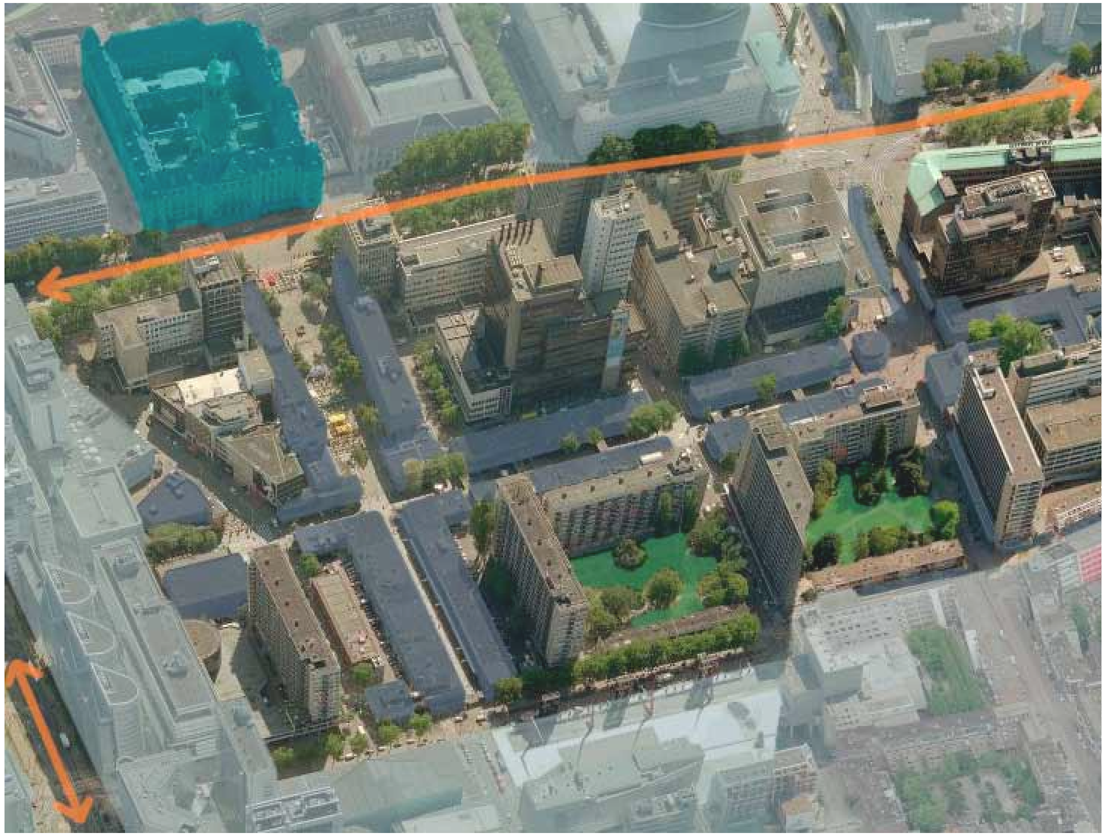


Figure 54.
Image by author, based on Bing Maps.

Figure 55.
Image by author, based on Google Maps.

Lijnbaan

Strengths:
- Intensively used public space
- Building ensemble is of high monumental value on national level
- Good accessibility by public transport (train, metro, tram and bus) and by car

Weaknesses:
- High rise buildings look towards roofs and pavement (with exception of the inner courtyards)

Opportunities:
- Car free zones create flexibility for the layout of the shopping streets
- Functions can be added to the inner courtyards

Threats:
- Empty shopping streets can stimulate criminality during the night
- Advertising signs can create cluttering

Since urban spaces are designed for people, some background information is needed on how a place functions well for them. According to the demographic numbers, and the fact that there are many schools, there are a lot of children in Bospolder-Tussendijken. This group is especially taken into account in the designs for this neighbourhood. The social analysis demonstrates how and by what kind of people the different locations are used in the present situation.

Urban spaces for people

According to Carmona et al. (2010), urban design is about creating places for people. In the book 'Public Places - Urban Spaces' is referred to seven objectives of urban design. These objectives state that a place should contain (Carmona et al. 2010):
- Character: own identity.
- Continuity and enclosure: distinguishing public and private space.
- Quality of the public realm: attractive outdoor areas.
- Ease of movement: easy to get and move there.
- Legibility: understandable and with a clear image.
- Adaptability: easy to change.
- Diversity: variety and choice.

These objectives are used as a framework for good urban design in this project. For every area where design elements are created, it is questioned whether this contributes to enhancement of these objectives. For the patterns it is difficult to say something about these objectives, since it depends on the application. In some cases a certain design element will add value to an urban space, while in another context it will not work. Therefore, this framework is only used for the design context, and not in general for every pattern.

Children in urban space

According to Gleeson & Sipe (2006), there is a relation between the health and well-being of children and the quality of urban development. When the state of urban development is poor in residential areas, this leads to limited possibilities for recreation and self-expression. As a result, children cannot completely establish their "key environmental and behavioural dynamics that shape the well-being of children" (Gleeson & Sipe 2006). This demonstrates the importance to take children in account in urban development of residential areas.

For children it is important to have freedom to move, and to have diverse environmental resources to play with, as stated by Tranter (2006). According to him, it is especially for children in the age of 8-12 years old, necessary for parents to give the children this freedom. By stimulating children to move, the risks for overweight and a lack of cognitive, social and emotional development', will decrease. Thus, children should be encouraged to play.

When focusing on the design of urban spaces for children, the possibility to play should be considered. According to Walsh (2006), the following play opportunities should be offered:
- explore the natural environment (cognitive development);
- move with speed (gross motor development);
- share robust play with other children (social development).

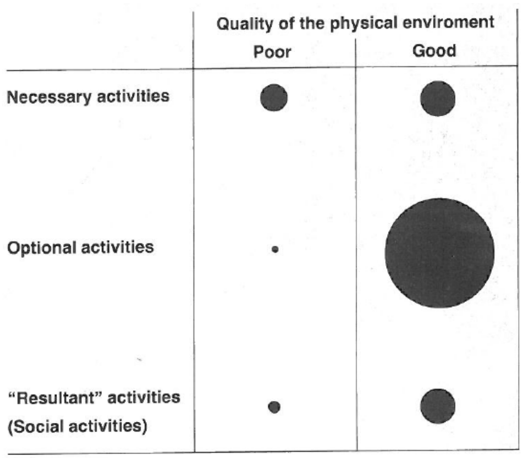
It should be mentioned that this goes beyond playing only in playgrounds and parks, because it needs to have a spontaneous element. Walsh (2006) offers some guidelines for formal and informal playspaces:
1. Dedicated space: enough space to play.
2. Access: availability of adults can be necessary for playing outside.
3. Variety: different types of playspaces.
4. Invitation: consideration of what is stimulated by a certain design.
5. Ambience: climate of the play environment and presence of natural elements.

While addressing the UHI effect, the last point is considered automatically. It can be concluded that it is also important to consider the other aspects of a playspace.

Urban spaces for activities

As said before, urban spaces are places for people. As mentioned by Gehl (1987), the quality of these spaces depends on the activities that can take place. A poor quality urban space only focuses on necessary activities, while good quality spaces also pay attention to optional and social activities. In figure 56, it becomes clear that especially optional activities play an important role in the quality of the physical environment.

For Bospolder-Tussendijken and Cool, analysis is done on which activities took place in the urban environment. These activities are written down for all the locations in the neighbourhoods that will be changed (see Figure 57). This was done on a site visit, which took place on a regular Friday, a sunny day in March. In this way, it can be determined if a certain urban space has much quality or not. Also, it becomes clear whether the area is used by different age groups, or needs to focus more on children for example.



a. Cohesion between activities and quality of public space.

Driving
Necessary activity

Cycling
Necessary activity

Walking
Necessary activity

Waiting for public transport
Necessary activity

Grocery shopping
Necessary activity

Enter or leave the house
Necessary activity

Walk the dog
Necessary activity

Throw away the garbage
Necessary activity

Construction or maintenance
Necessary activity

Smoke
Necessary / optional activity

Sit and watch
Optional activity

Walk with a baby car
Optional activity

Shopping
Optional activity

Eat or drink on a terrace
Optional activity

Eat or drink
Optional activity

Use a mobile phone
Optional activity

Have a conversation
Social activity

Play sports
Social activity

Play
Social activity

b. Necessary, optional and social activities which can be found in Bospolder-Tussendijken and Cool.

Figure 56.

a:
Gehl, J., 1987. Life between buildings: using public space, New York: Van Nostrand Reinhold Company.

b:
The Noun Project, 2013. The Noun Project collection. Available at: http://thenounproject.com/.

Activities of people

Bospolder-Tussendijken

As mentioned by Gehl (1987), optional activities play an important role in the quality of the physical environment. In Bospolder-Tussendijken we can see that there are many necessary activities, and only a few optional and social activities.

- At the Marconiplein, 6 of the 9 activities were necessary activities. There were a few people in a very small playground who were sitting there to watch their children play. These were an optional and social activity. Another optional activity was walking with a baby car.
- The only optional activity which happened at the Schiedamseweg was shopping. On the other hand, a large part of all the present people was doing this activity.
- Àt the Visserijplein, there were 5 necessary and 3 optional activities, and 1 social. The necessary activities all happened along the road, where people passed quite fast. The optional and social activities happened more at the square itself.
- In Park 1943 the activities were mostly necessary and social. The only optional activity was sit and watch.
- The Haringpakkersstraat and Kleine Visserijstraat existed of necessary activities, except for playing children. In the Kleine Visserijstraat only a few children were playing, while in the Haringpakkersstraat a complete school class was playing outside.

Cool

In the Cool area, the activities are analysed as well. Since this is a more central area, the activities are a bit different than in Cool. It is remarkable that activities like eating, sitting on a terrace, and using a phone are done more here.

- At the Lijnbaan, a lot of optional activities are done. The only necessary activities were walking and smoking.
- The Mauritsstraat and Jacobusstraat showed different activities, while they seem to have the same kind of character. An explanation for this is that there were not that much people, and therefore they were doing different things.
- At the Eendrachtsplein, the activities were either a certain way of transportation, or an optional activity. On the square itself, the activities were (almost) only optional.
- Also at the Westblaak, the activities focused on transportation or optional activities like shopping and eating. The part of the street that is in between the roads was not used, because the skatepark was made empty for construction.
- As part of Downtown, the Oude Binnenweg was analysed. Almost all the people who where here, were doing optional activities.

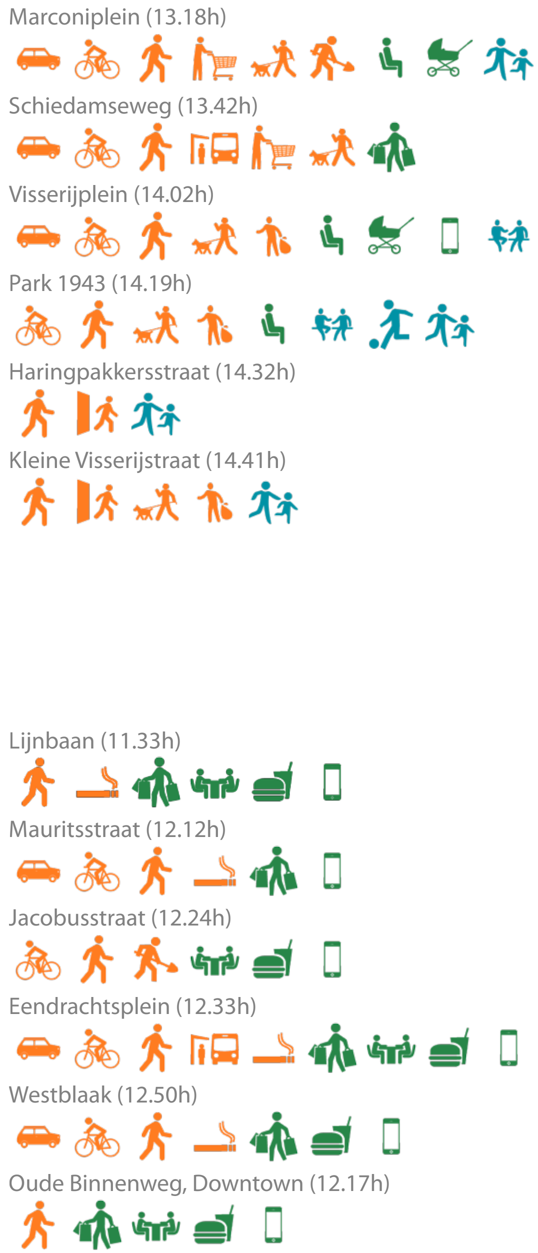


Figure 57.
The Noun Project, 2013. The Noun Project collection. Available at: http://thenounproject.com/.

Urban design implementation

The role of design in the project

The aim of the project is not to make urban designs with the focus on heat adaptation, but to develop a method to integrate adaptation measures against heat in urban design. In order to make sure that this can be done in general, it had to be tested in exemplary situations. Therefore, in this project multiple designs are used to show how the patterns can be used, and what the expected effect is on heat. They can be seen as examples and test cases for the developed pattern language.

During the design process, findings are used to improve the patterns and the pattern model. In this way, designing was a helpful mean to improve the pattern language. This has led to an iterative process between design and the research outcomes. Also, from the variants it becomes clear what the different influences can be on heat when different approaches are used. This is demonstrated in the conclusion of the thesis.

City development

The present project shows designs for the neighbourhood scale, while applying the patterns on the city scale can have even more effect. In the graduation thesis of Klaas Akkerman (2015), which is conducted within the Urban Metabolism research group, the integration of heat mitigation strategies into policies for the city of The Hague is addressed. The method described in his thesis can be used as starting point for the city scale application in Rotterdam. Existing policies can be adapted in a way that heat is integrated in the large scale development plans. Based on Akkerman (2015), it is expected that it is useful to look at green structures, neighbourhoods with elderly people, and densities to implement heat mitigation strategies. The patterns can be used when designs are made, which are based on the altered policies.

Design areas

From the future development areas of Bospolder-Tussendijken and Cool, as mentioned in the neighbourhood policies, a few parts are chosen for making the mentioned urban designs. These parts of the neighbourhoods are the most representative areas to show the application of patterns in various typologies of space. For every design area two design variants are shown, which are made with a different approach. Although the designs are always a combination of using the goals for the neighbourhood and the application of patterns, the focus is on one of these aspects in the variants. This is described in the explanation of the designs. The second variant is described in a more elaborative way, because the focus is on the heat characteristics.

The designs are demonstrated in a similar way as in the case comparison. It contains the following elements:

- The goals from Deelgemeente Delfshaven or Gemeente Rotterdam Stadsontwikkeling.
- 3D image of the current situation.
- 3D image of both variants.
- Description of both variants.
- Impression/section of the second variant.
- Related actors and their responsibilities for the second variant.
- Design principles of the second variant.
- Review of the heat characteristics for both variants.
- Image of the heat characteristics for the second variant.
- An overview of all the used patterns for both variants.

Urban development is not the only way in which adaptation measures can be applied. Inhabitants can do a lot in their living environment themselves. Therefore, on the next page, an explanation is given of what inhabitants can do to make it cooler in summer. This is followed by the designs for the different areas.

What can you do to make your living environment cooler?

1. Keep windows closed when it is warmer outside than inside. At night, when the outdoor temperature becomes lower than the indoor temperature, open the windows to cool the house.

2. Keep the sun out of the house. This can be done by adding sunshades in front of windows that are directed to the east, south or west. In some cases, a tree in front of the house can provide shade to the windows of the house.

3. Make your house as much heat proof as possible. The roof can be improved by adding solar panels, a roof garden or a high albedo material. Since the top floor is the hottest space in the house, it is advised not to sleep there. Furthermore, greening your balcony or facade can help to keep your house cool as well.

4. Make your garden as much heat proof as possible. Remove pavement to a large extent, and replace the remaining pavement with high albedo pavement. Add vegetation, and take care of it by providing for enough watering by collecting rain water. Also a pond can be useful as part of your new heat proof garden.

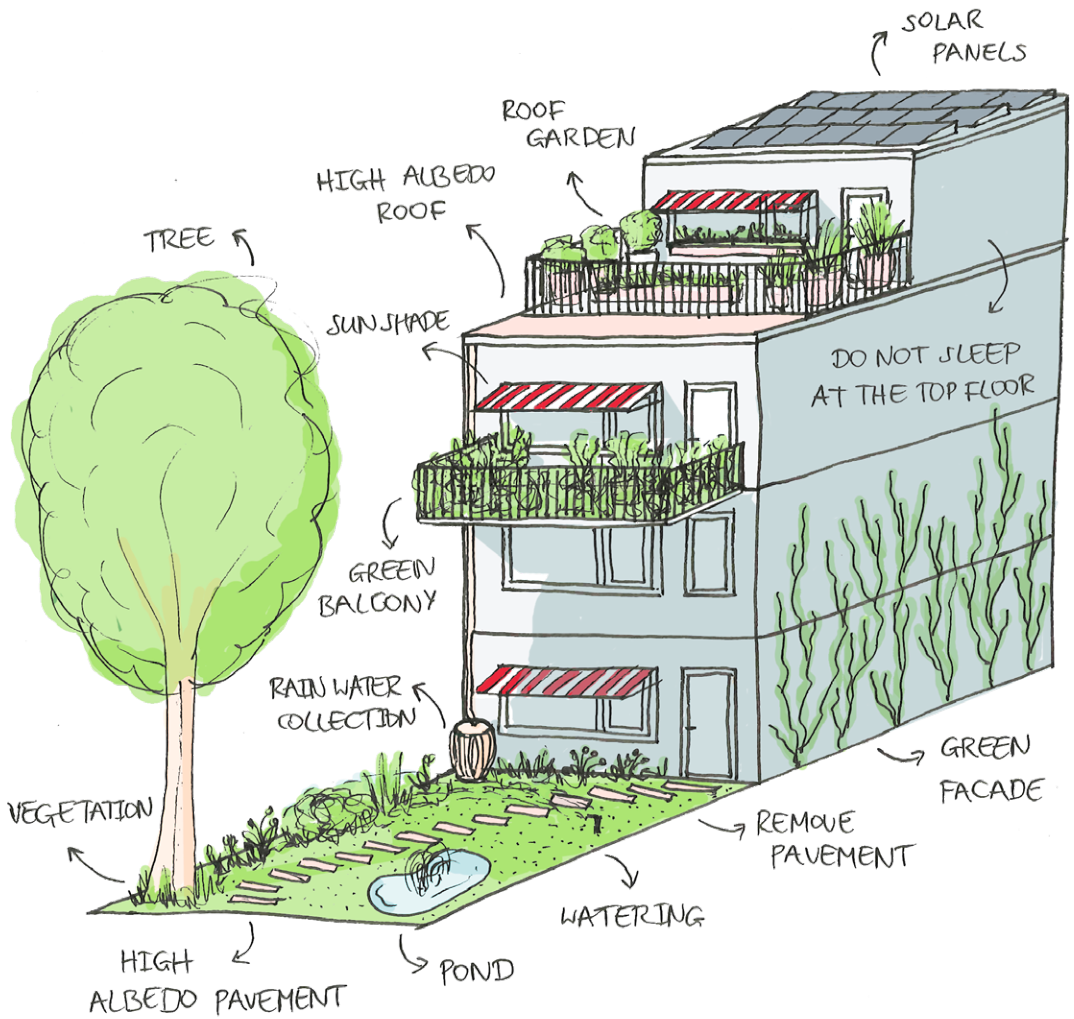


Figure 58.
Image by author.

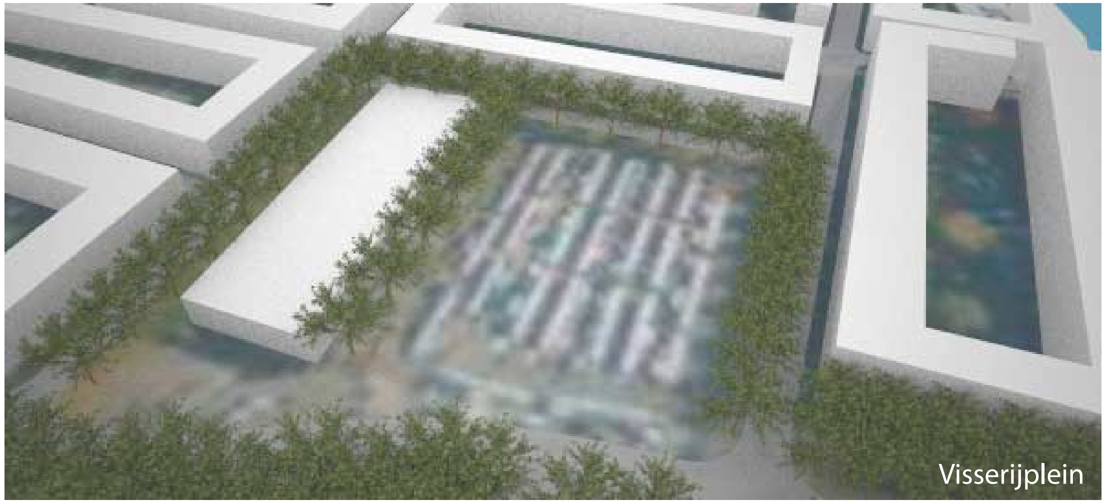
Visserijplein

Goals (Deelgemeente Delfshaven et al. 2009)
- reduction and redevelopment of the square for multifunctional use, with maintenance of the market
- improved connection between the shops at the Schiedamseweg and the market
- market is a determinative element for the multicultural neighbourhood
- multifunctional accommodation for functions like Pier 80, library, school activities, small scale sport activities, elderly care and a supermarket

Recommendation for improvement:
When the market stalls are present, the shadow and albedo improve immediately. If they can be made multifunctional, it can permanently improve the situation. Also, another pavement can be used to increase perviousness and/or albedo. A new community building can be constructed in a way that it is good for heat.

Park 1943

Goals (Deelgemeente Delfshaven et al. 2009)
- redevelopment for increased utility value for inhabitants
- enhancement of public space and green structure for playing, meeting and relaxing
- replacement of Gijsingflats by houses with ground floor access, meant for families and elderly:



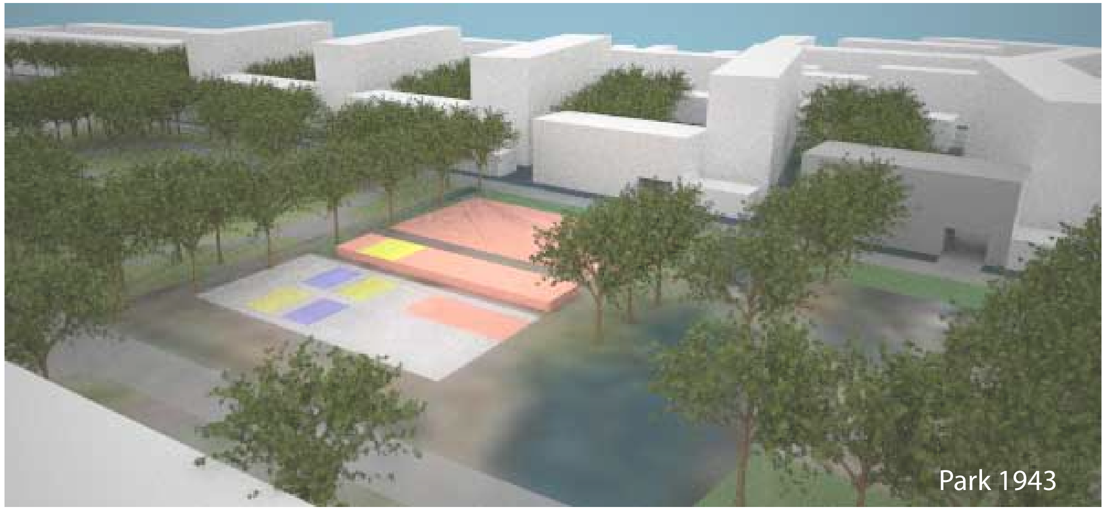
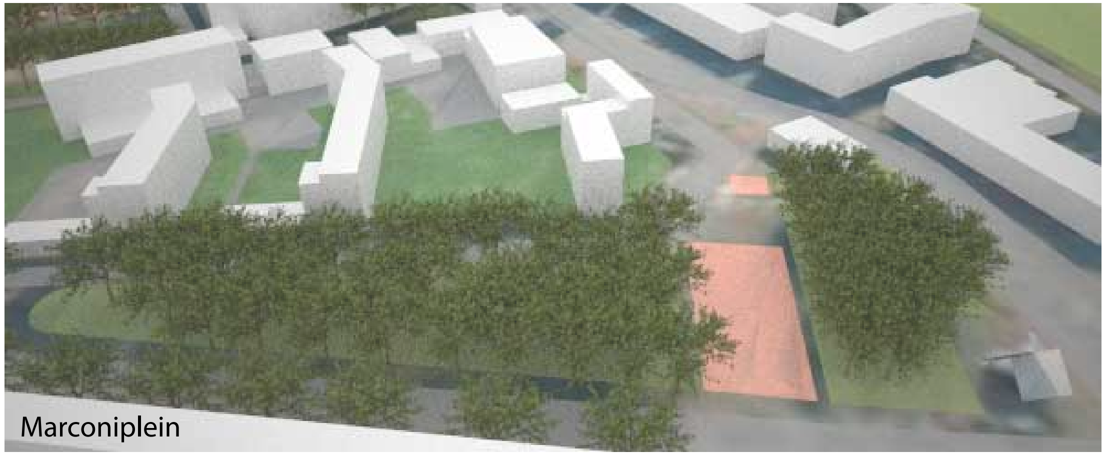


Figure 59.
Image by author.

- adjacent shops along the Schiedamseweg are part of the development
- houses have good quality outdoor space, like a garden or roof terrace
- addition of a new residential environment, like elderly housing, owner-occupied housing, and family housing
- green space nearby and parking solutions
- elderly housing can be combined with elderly care


Marconiplein


Lijnbaan

Recommendation for improvement:
By choosing another pavement, the park can get a higher albedo, and it can be a pervious surface as well. If a podium is made with a light coloured canopy, the shadow and albedo can be improved. When the flat buildings are replaced by new buildings, they can be made with more vegetation.

Marconiplein

Goals (Deelgemeente Delfshaven et al. 2009)
- lively and recognisable entrance
- straightening the Schiedamseweg
- connection with Dakpark and harbour

Recommendation for improvement:
The Marconiplein can be improved by looking at the albedo and the impervious part of the area. This can be done by changing the surface, which has a higher albedo and perviousness.

Lijnbaan

Goals (Gemeente Rotterdam Stadsontwikkeling 2013)
- greening public spaces, rooftops and supply streets, against heat stress and for water storage
- green roofs are used by penthouses, or otherwise for public or semi-public use
- inner courtyards are made attractive by creating active ground floors, additional programme and closable fences
- Joost Banckertplaats combines green, water and a playground
- Jan Evertsenplaats combines, drinking, reading and flowers

Recommendation for improvement:
Since the sky-view factor cannot be improved, the focus should be on other elements. The albedo of the streets can be strongly improved. Furthermore, vegetation can be added. The large amount of roofs can be used for adding vegetation or to increase the albedo.

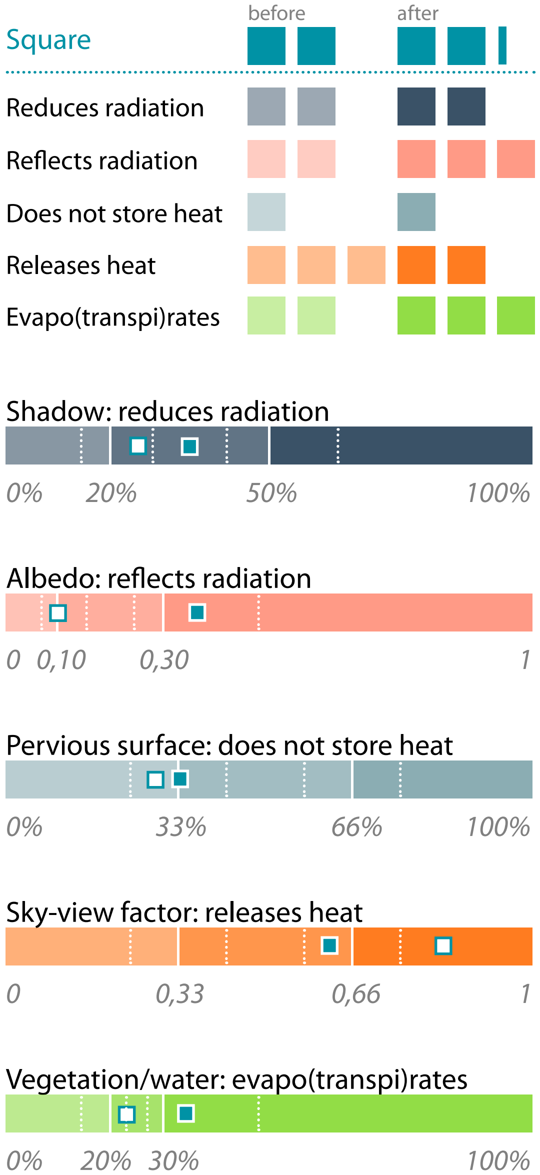
Visserijplein - Variant 1

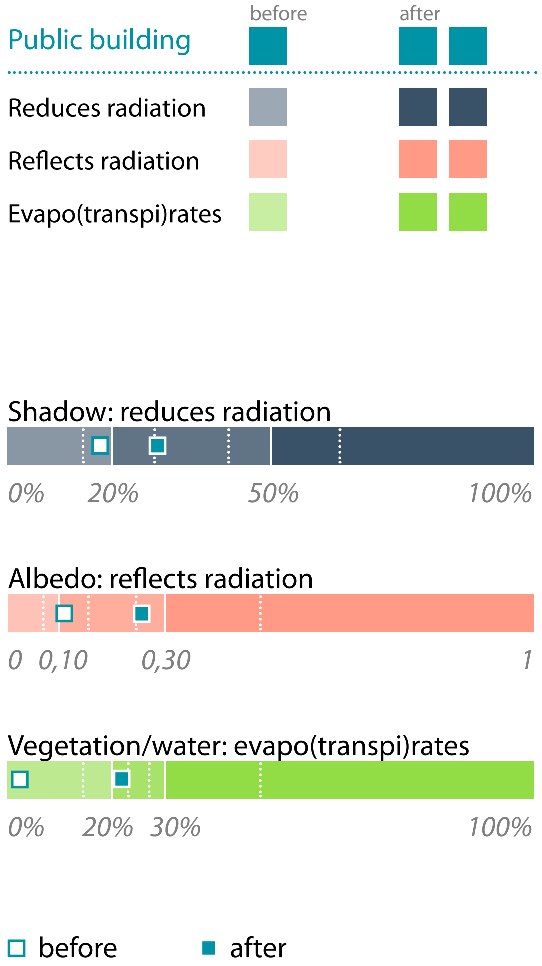
Figure 60.
Image by author.

This variant is mainly based on the initial goals, as mentioned by Deelgemeente Delfshaven. This means that patterns are still used in the design, but the focus is not on the improvement of the heat related characteristics.

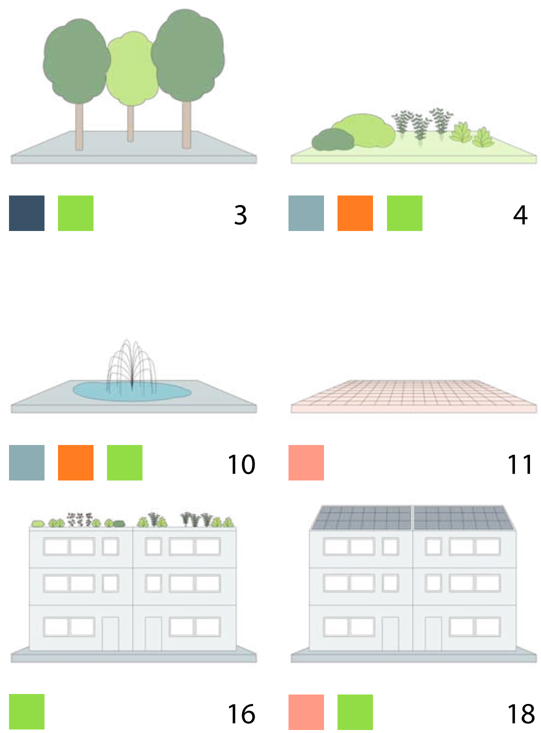
The community building is relocated, and has become larger because of the demand for various functions. The roof exists of solar panels and has some plant boxes around the viewpoint. When you enter the square from the Schiedamseweg, you walk underneath the community building. The square has beds of flowers and plants, and is surrounded by trees. The fountain, which is close to the middle, is also visible from the straight Grote Visserijstraat. The open spots on the square can be used for the market twice a week. The ground is covered with a high albedo pavement.

Heat characteristics





Patterns



Visserijplein - Variant 2

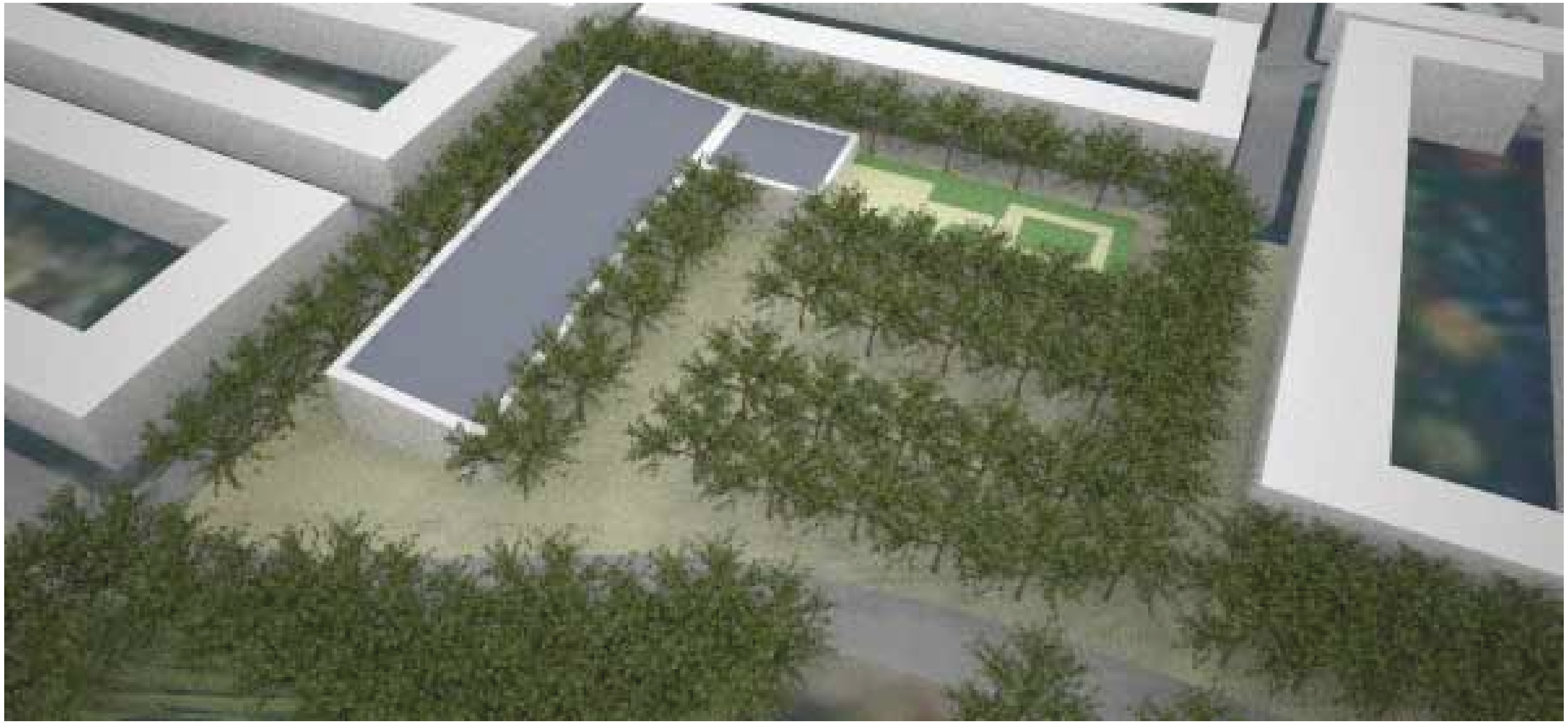


Figure 61.
Image by author.

Figure 62.
Image by author.

This variant mainly focuses on improving the heat characteristics, while the goals of Delfshaven are taken into account.

A new community building is placed at the same location, with a large extension. The roof is covered with solar panels and a roof garden. The square is filled with a combination of old and new trees, which leads to a green and shaded square. The market stalls are placed underneath the trees, so people can walk in the shadow. The square is covered in gravel, which makes it a pervious surface.

Figure 63.
Image by author.

Square	before	after
	■■	■■▌
Reduces radiation	■	■■■
Reflects radiation	■■	■■
Does not store heat	■	■■■
Releases heat	■■■	■
Evapo(transpi)rates	■■	■■■

Public building	before	after
	■	■■▌
Reduces radiation	■	■■■
Reflects radiation	■	■■
Evapo(transpi)rates	■	■■■

Municipality of Rotterdam

- Redevelopment and maintenance of the square itself

Deelgemeente Delfshaven

- Construction and maintenance of the community building
- Renting out the different spaces inside the community building

Design principles

Empty square now becomes a square with trees, which is more in proportion.

Roof becomes part of the public space.

Heat characteristics

Shadow: reduces radiation

Open space

Buildings

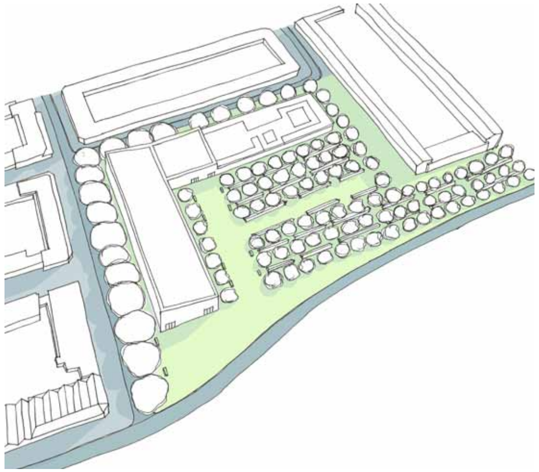
Sky-view factor: releases heat

Albedo: reflects radiation

Open space

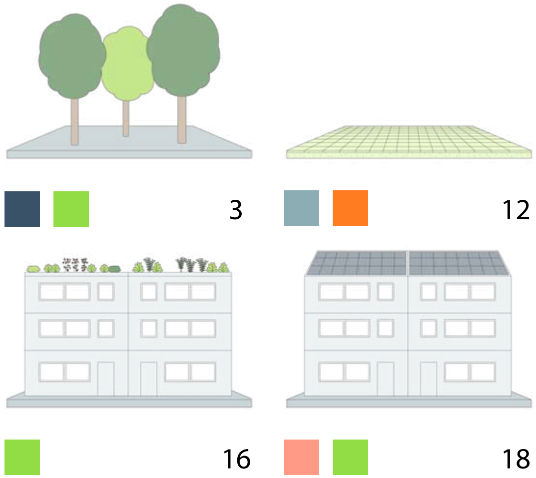
Buildings

□ before ■ after

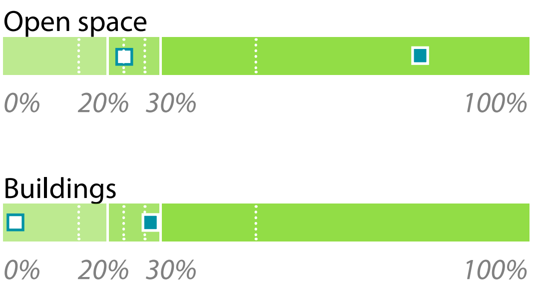


Pervious surface: does not store heat

Patterns



Vegetation/water: evapo(transpi)rates



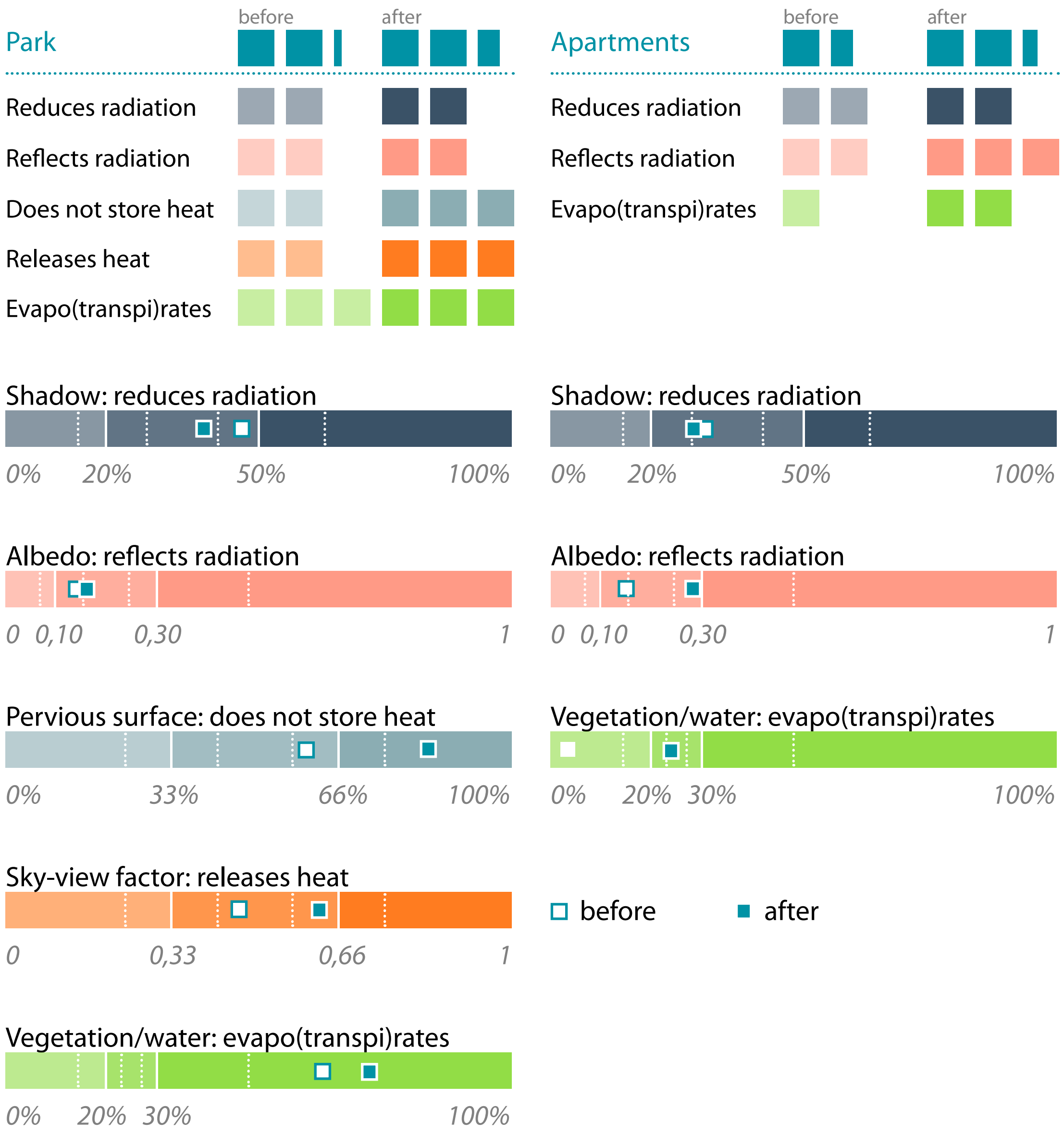
Park 1943 - Variant 1

Figure 64.
Image by author.

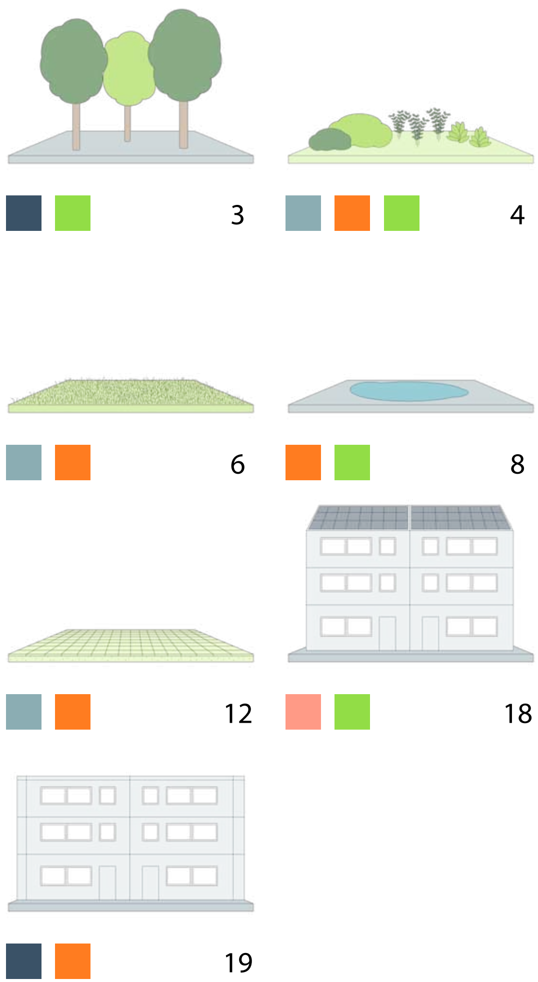
This variant is mainly based on the initial goals, as mentioned by Deelgemeente Delfshaven. This means that patterns are still used in the design, but the focus is not on the improvement of the heat related characteristics.

The new buildings that replace the Gijsingflats have ground floor access, and have different target groups. As shown in the section, the buildings along the Schiedamseweg are shops, the dwellings in the middle are meant for elderly, and the dwellings along the park are for families. The dwellings have solar panels, a garden at the south side, and parking lots with pervious surfaces are placed across the street. The park itself is partly a nature playground, and partly a place for walking and sitting. When you enter the park from the square, you look at the 1943 monument, and walking towards the water body.

Heat characteristics



Patterns



Park 1943 - Variant 2

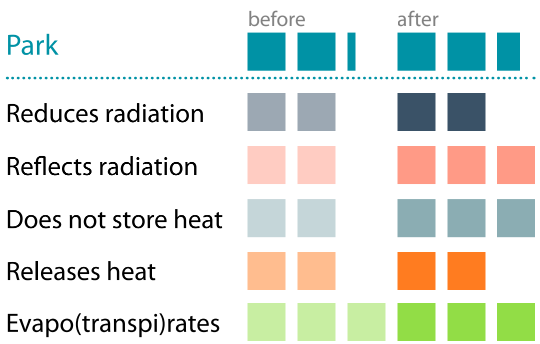
Figure 65.
Image by author.

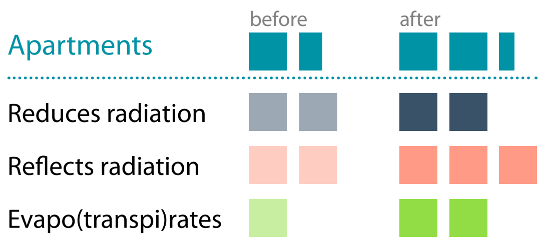
This variant mainly focuses on improving the heat characteristics, while the goals of Delfshaven are taken into account.

The Gijsingflats are replaced by two building blocks and two streets. The buildings have four layers, divided in two apartments. The dwellings on ground level can use the communal garden or they have a private garden, while the dwellings on top have a roof garden. Along the Schiedamseweg the ground floor is used for shops.

The gardens of the two streets are located directly along the park. The park design is to a large extent built around the existing trees, and is a mix of water, green, a wadi, walking paths, benches and play elements. The open space can be used for playing sports, and for the local festival. This makes it a multifunctional park, where the inhabitants of the neighbourhood can come together.

Figure 66.
Image by author.





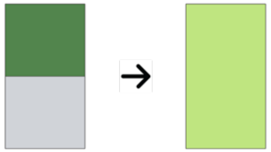
Municipality of Rotterdam

- Redevelopment and maintenance of the park itself
- Construction of the new dwellings and the surrounding street layout

Inhabitants

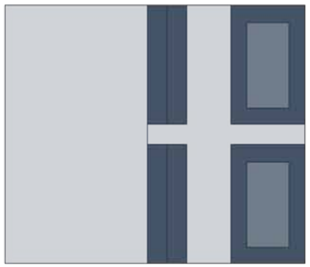
- Maintenance of the dwellings (owner-occupied housing)
- Layout and maintenance of the communal garden, private garden or roof garden..

Design principles



Two separate parts are merged together.

From monofunctional to multifunctional.



Different accessibility for green and open space: the darker the more private.

Every dwelling has a (private, roof or communal) garden.

Heat characteristics

Shadow: reduces radiation

Open space

Buildings

Sky-view factor: releases heat

Albedo: reflects radiation

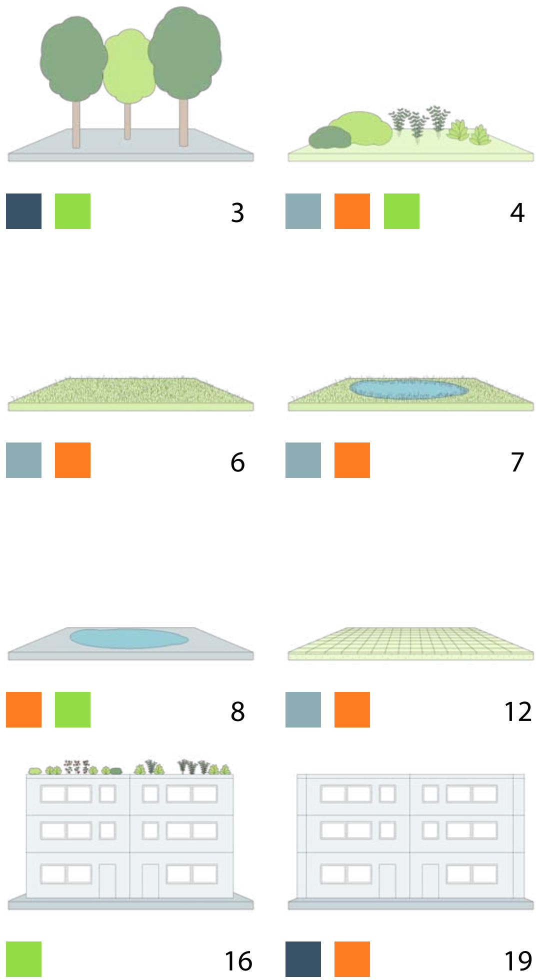
Open space

Buildings

□ before ■ after

Patterns

Pervious surface: does not store heat



Vegetation/water: evapo(transpi)rates

Open space

Buildings

Marconiplein - Variant 1

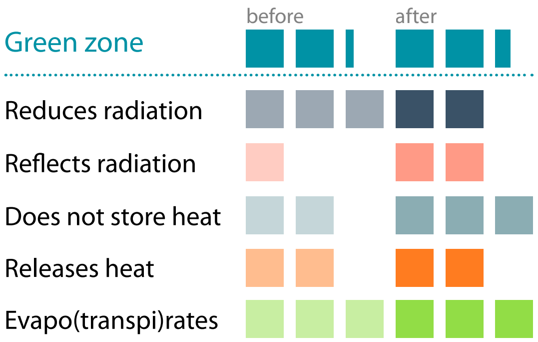
Figure 67.
Image by author.

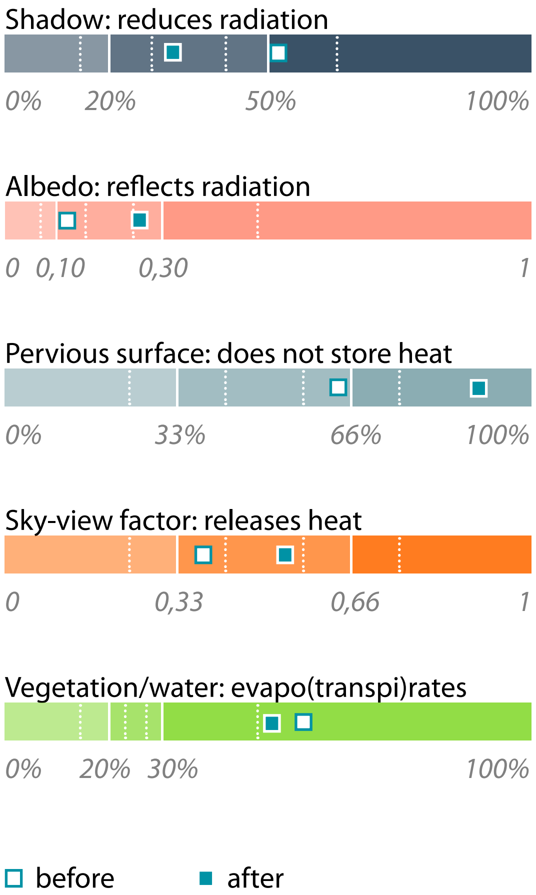
This variant is made from the perspective of the initial goals. Patterns are applied as well, but the approach was not to focus on improving specific heat characteristics.

In the design, the developed part of the Marconiplein exists of two different zones. At the eastern side, many mature trees can be found which will be preserved. Only a walking path is added between the grass, which creates the possibility to walk in the shadow of the trees. The western side of the area is very open and offers the inhabitants various activities. It is a combination of urban agriculture, places to sit, a playground, and a fountain to mark the entrance of the neighbourhood. It is expected that these different elements attract people, which makes it a lively area. By adding a crossing for pedestrians, the Marconiplein can easily be connected to the Dakpark and harbour, because the square is accessible from many directions.

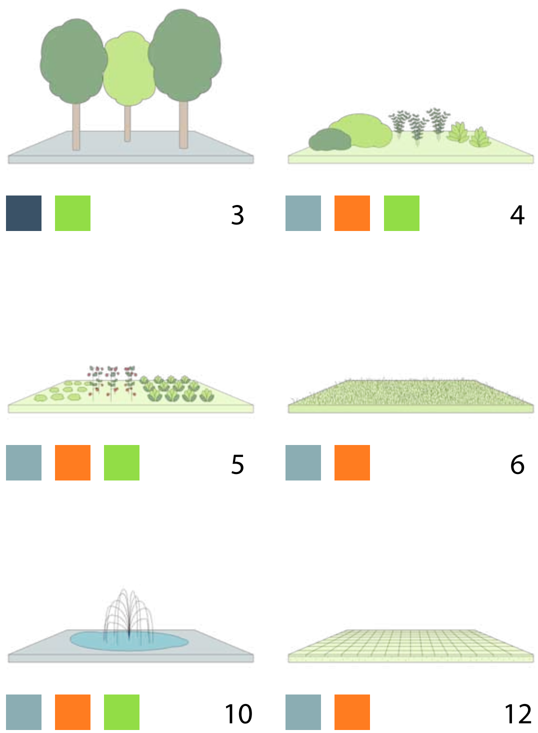
Also, there is an increased permeability of the neighbourhood: the paths between the buildings lead you to Park 1943, where you are immediately in the center of the neighbourhood.

Heat characteristics





Patterns



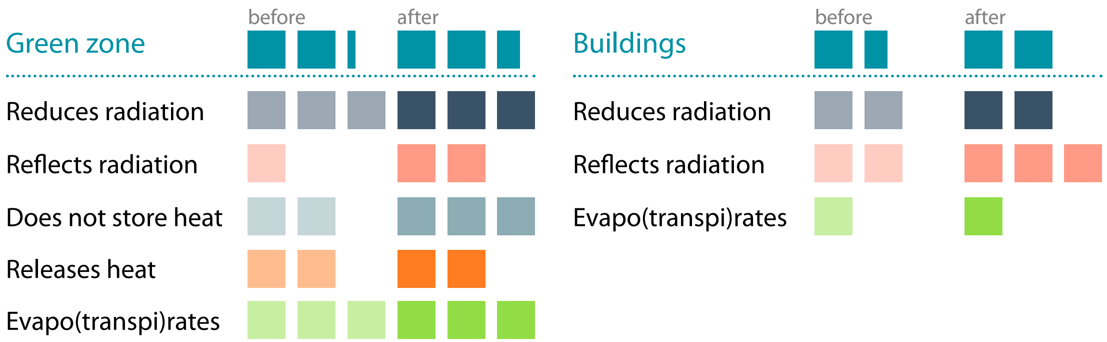
Marconiplein - Variant 2

Figure 68.
Image by author.

For this variant the focus was on improving the combination of heat characteristics, while also considering the goals from Delfshaven.

The existing trees are part of the design, because there are many mature trees which give a lot of shade. Only a few trees are taken away, in order to create a path from the metro station to the neighbourhood. This path is covered with a long pergola, overgrown by climbing plants. Along both sides of the pergola, flowers are growing between the grass. All the walking paths are made in such a way that the neighbourhood is well connected with the surroundings for pedestrians. In order to improve the permiability of the neighbourhood, paths are created between the buildings. This makes it possible to walk from the green zone of the Marconiplein to Park 1943 and other parts of the neighbourhood. Along the paths, some trees are planted to create shadow. The higher roofs of the buildings in this area are high albedo roofs. All the paths are made from a permeable surface with shells. In the middle of the area, an open zone is created, which is marked by the surrounding vegetation. In this zone, boxes are placed for urban agriculture, and benches for people to sit on. In this way, a zone is created which is both suitable for passing by and meeting people from the neighbourhood.

Figure 69.
Image by author.



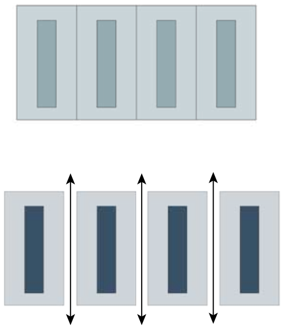
Municipality of Rotterdam

- Redevelopment and maintenance of the green zone

Inhabitants / school children

- Planting and maintenance of the boxes for urban agriculture

Design principles

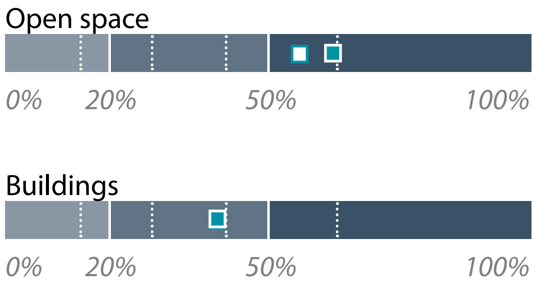


Increased permeability towards the neighbourhood.

Retain existing trees in new design.

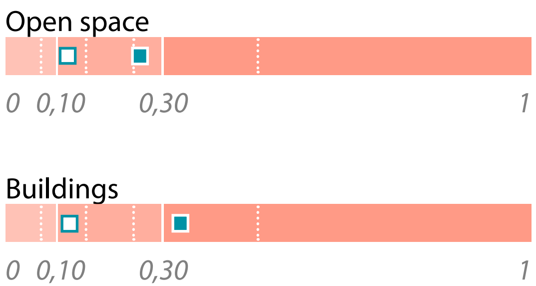
Heat characteristics

Shadow: reduces radiation



Sky-view factor: releases heat

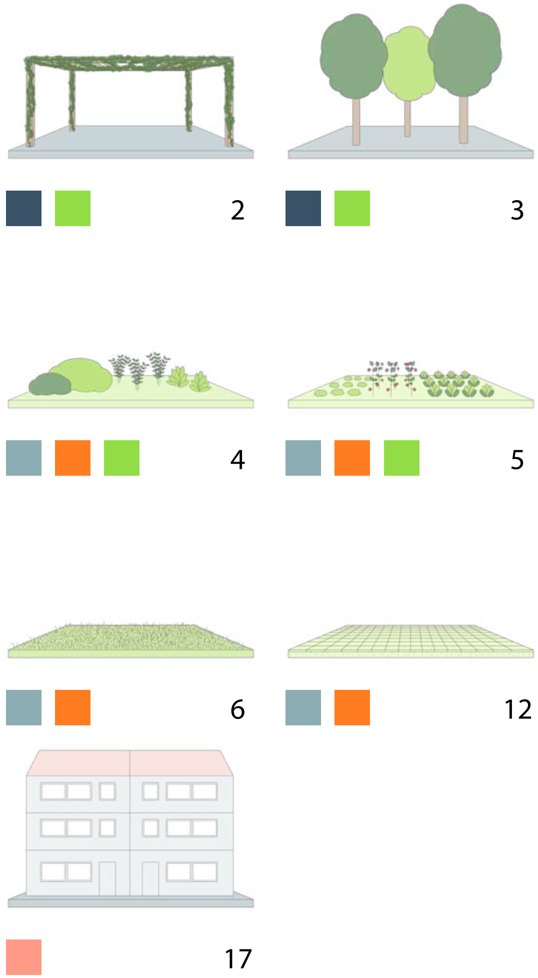
Albedo: reflects radiation



□ before ■ after

Patterns

Pervious surface: does not store heat



Vegetation/water: evapo(transpi)rates

Open space

Buildings

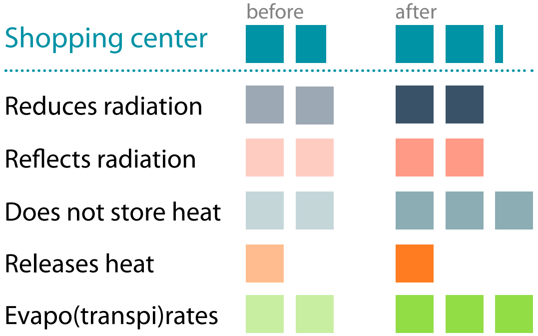
Lijnbaan - Variant 1

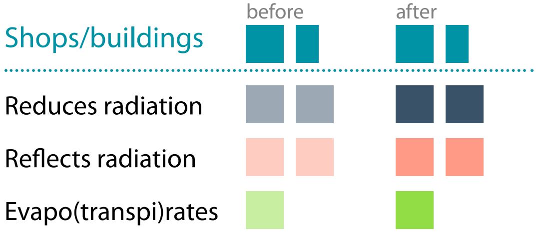
Figure 70.
Image by author.

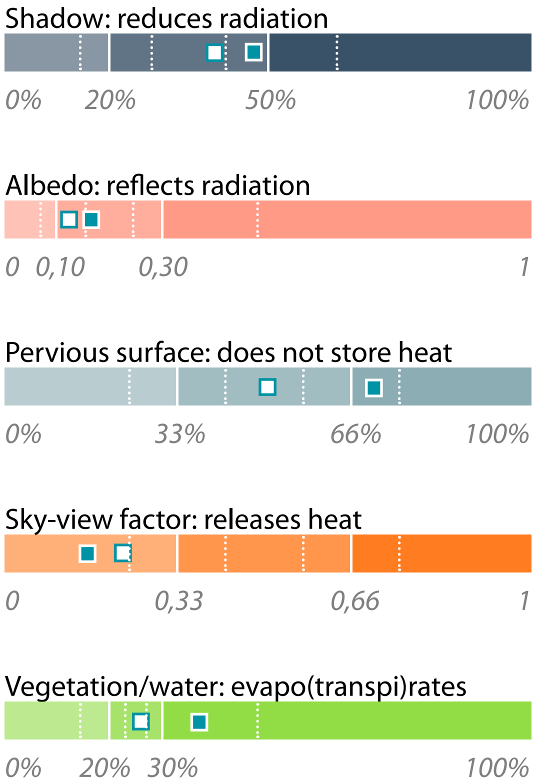
This design variant is mainly based on the goals of the municipality, but gives some attention to patterns to improve the heat characteristics as well.

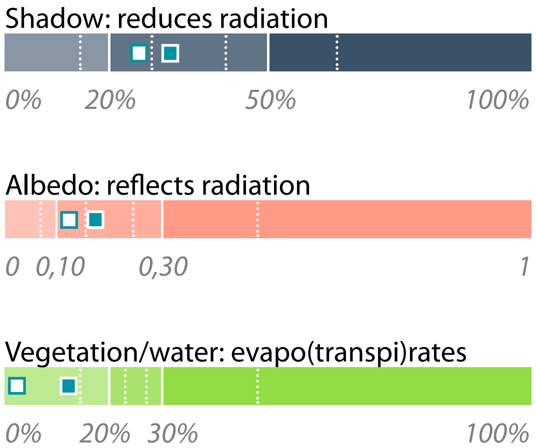
Since the inner courtyards are already green, and there is not much room for greening the shopping streets, green is added to the lower roofs and supply streets. This is done by making public roof gardens above the main shopping street, and by making pergolas above parts of the shopping and supply streets. The inner courtyards both have a different use, according to the goals of the municipality. The northern courtyard can be used as a playground, in which much green and water can be found. This creates mainly possibilities for playing. Terraces can be placed along the sides where restaurans or pubs are located. The southern courtyard exists of vegetation, like trees and flowers, and has many places to sit. The fences around the inner courtyards, create the possibility to close the areas in the evening and night. The existing pavement in the shopping streets is replaced by permeable tiles.

Heat characteristics



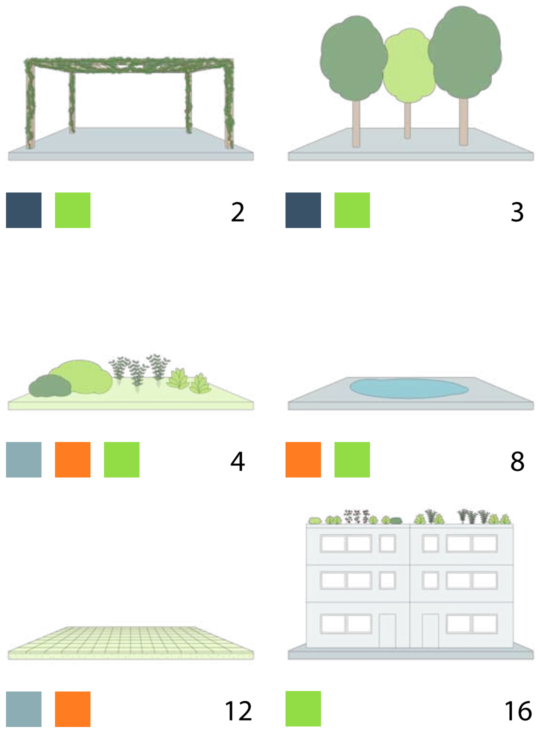






□ before ■ after

Patterns



Lijnbaan - Variant 2

Figure 71.
Image by author.

In this variant, the focus is on implementing useful patterns to improve the heat characteristics. At the same time, the goals of the municipality are taken into account to a large extent.

The roofs of the buildings are developed into accessible areas. They are green to a large extent, and have different degrees of publicness. The building blocks around the inner courtyards have private gardens for the two lowest apartment buildings, while the higher ones have penthouses on the roof. Four of the high rise buildings are connected to roofs in the shopping streets, in order to create communal roof gardens. The other roofs in the shopping street are accessible from inside restaurants or pubs, and are open to the public. Here they can have a view on the shopping street, but also on the old city hall. In the shopping streets, a water stream is created, including some fountains. This area is paved with permeable stone. The back sides of the shops, where the supplies take place, have green facades. The northern inner courtyard has terraces, a pond, and a playground, surrounded by vegetation. The southern inner courtyard exists of many flowers in the grass, and places to sit in between trees. A fence is built around the courtyards, so they can be closed for public when desired. All the trees from the existing situation are still present in this design variant.

Figure 72.
Image by author.

Shopping center — before / after

Reduces radiation

Reflects radiation

Does not store heat

Releases heat

Evapo(transpi)rates

Shops/buildings — before / after

Reduces radiation

Reflects radiation

Evapo(transpi)rates

Shop (restaurant/pub) owners

- Development and maintenance of the roof gardens and pergolas

Inhabitants / owners dwellings

- Development and maintenance of the inner courtyards, communal roof gardens and private gardens

Design principles

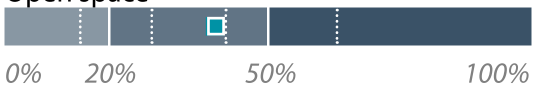
Roof gardens on the buildings,
water stream in shopping street

Different accessibility for public:
the darker the more private

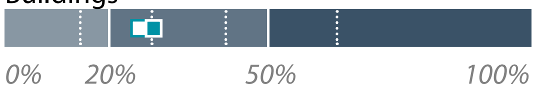
Heat characteristics

Shadow: reduces radiation

Open space



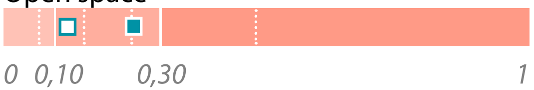
Buildings



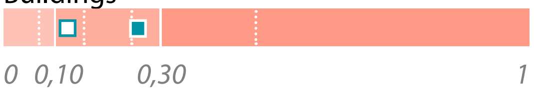
Sky-view factor: releases heat

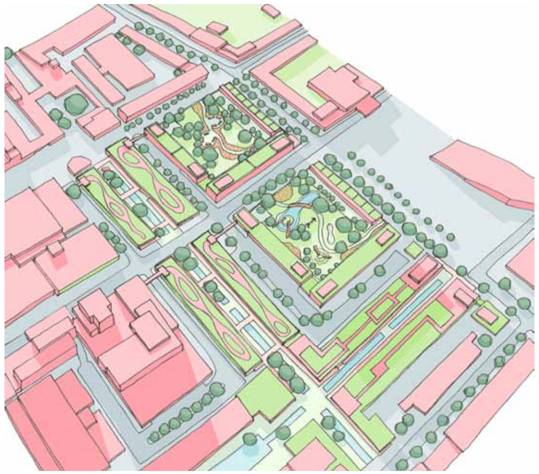
Albedo: reflects radiation

Open space

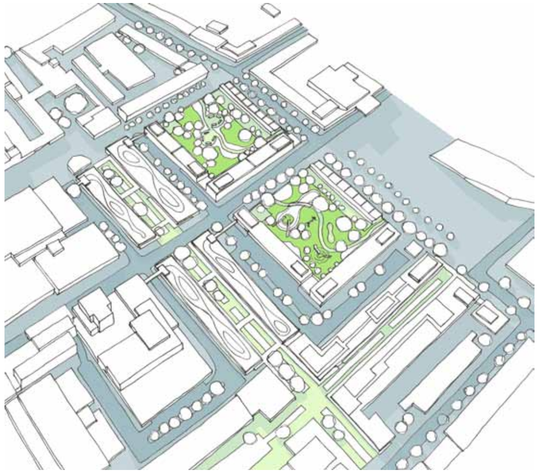


Buildings

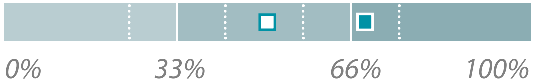




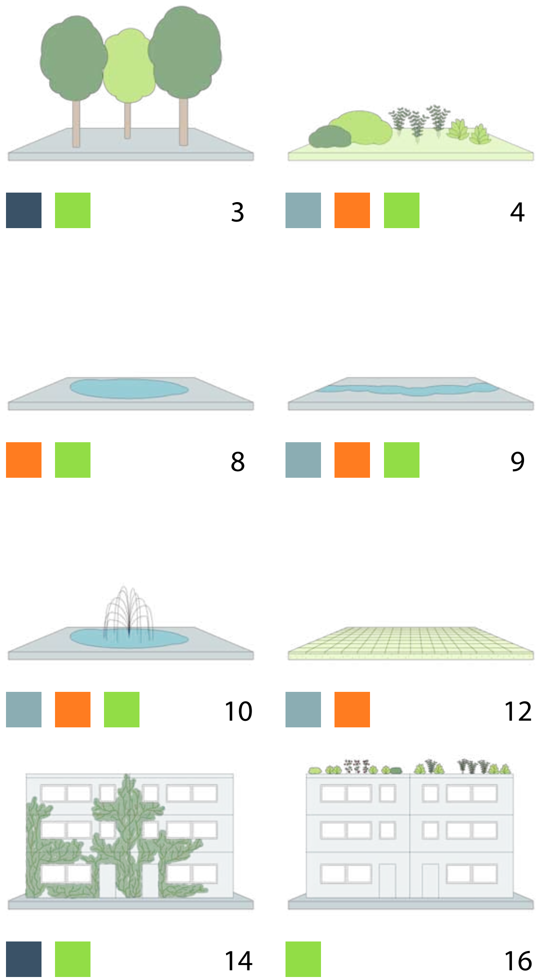
□ before ■ after

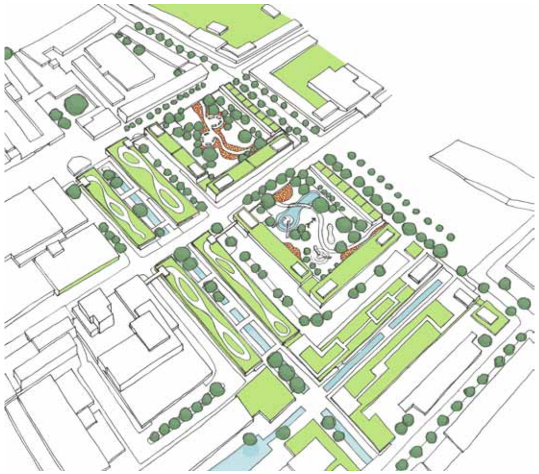


Pervious surface: does not store heat



Patterns





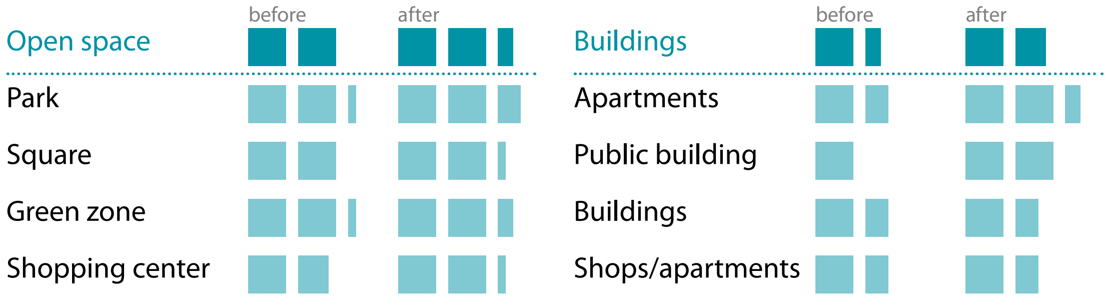
Vegetation/water: evapo(transpi)rates

Open space

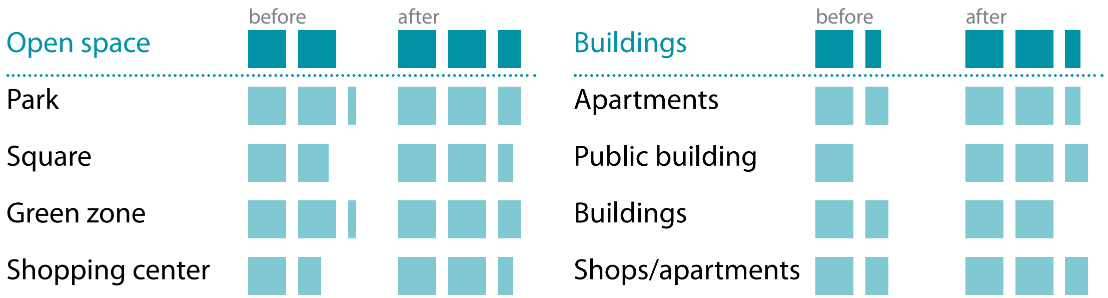
Buildings

Effectivity of the urban designs

Variant 1: focus on policies



Variant 2: focus on heat characteristics



When the results of measuring the heat characteristics are compared, the following conclusions can be drawn about the urban design examples:
- All the urban designs lead to an improved situation in terms of heat characteristics.
- There is a difference in the effectivity of variant 1 and 2 for the open space, but this is only a slight difference.
- In the case of the buildings, it can be concluded that there is a clear difference in variant 1 and 2. As a result, the focus on heat characteristics leads to a more effective approach than the focus on policies.

Part 6: Conclusion

Photo © Ossip van Duivenbode / Rotterdam Image Bank

Ethical considerations

During the project some research methods are used in which ethical considerations need to be done. Therefore a brief explanation is given in which it is made clear how these ethical considerations are approached.

Anonymity and the use of data

Data is needed for this project to determine vulnerable neighbourhoods. Information is needed on i.e. the age, ethnicity, and income of the inhabitants. Although names, addresses, and so on, are not mentioned, there is a problem with anonymity in this. According to Sweeney (2002) it is often possible to link the "anonymous" data to personal information about the concerning people. This phenomenon is called 're-identification'. In the article a method is described to keep the used data anonymous, called 'the k-anonymity protection model'. Basically, what the model does is make the information less detailed, but still adequate for the research. This is a way to deal with the re-identification problem.

In the project information should be approached with caution when it comes to data related to locations. When data is linked to a map, it is easier to identify the person attached to the information. This is something that especially should be taken into account during the research.

Research conclusions

From the literature review it has become clear that there is a demand for investigating how effective adaptation strategies to heat are. Also, knowledge is missing about how these adaptation strategies can be integrated in urban design. Therefore, the main research question for this graduation project is:

How can adaptation strategies to the Urban Heat Island effect be integrated in urban design, and how can this be done in two exemplary neighbourhoods in Rotterdam?

By means of the research outcomes of the sub research questions, an answer to the main question is described in this section.

1. What is the Urban Heat Island effect, and what are the causes and consequences of it?

The Urban Heat Island effect can be described as a temperature difference between the city and its surroundings, in which the city is warmer because of its use and structure. It can be concluded from literature that urban heat is mainly caused by the following elements:
1. Materials with a low albedo.
2. Mechanical cooling systems.
3. Lack of vegetation and soil.
4. Lack of water structures (close to vegetation and soil).
5. Production of heat by buildings, vehicles and people.
6. High roughness structure of the buildings.

As a result of these higher temperatures, the well-being of people is at risk. Heat stress can lead to disease, but also to significant amounts of extra deaths. This is especially the case for vulnerable people like elderly, and people who live in poor neighbourhoods. Next to the well-being of people, heat can have a negative influence on the well-being of the city in terms of the economy and environment.

2. What are the possible adaptation strategies to the Urban Heat Island effect, and how effective are they?

Many adaptation strategies and measures are possible, but what they have in common, is that they focus on increasing at least one of the following characteristics of the city structure:
- amount of shadow
- amount of reflection
- perviousness of surfaces
- possible heat release
- possible evapo(transpi)ration

Since these heat related characteristics can be measured, it is possible to determine whether these characteristics have a weak, moderate or strong position in terms of heat. This indicates how effective a certain strategy can be. A method for measurement is developed during this research, in which the characteristics are connected to their effect on heat in the city. The following characteristics are part of the measurements:
- Shadow: reduces radiation
- Albedo: reflects radiation
- Pervious surface: does not store heat
- Sky-view factor: releases heat
- Vegetation and water: evapo(transpi)rates

In the case comparison, these characteristics are used to show what the impact of a development can be on heat. From this case comparison, it can be concluded that the scale of development does not have an influence on if there is a local impact on heat. It should be noticed that this still can have an influence on the temperature for the larger scale. Furthermore, the case comparison demonstrated that even in situations where a new district was built, the designs had a good influence on reducing heat. This was not expected, since often these areas were developed from a non-urban part of the city. This demonstrates that making a conscious urban design, for a better environment, can contribute to heat adaptation.

3. How can adaptation strategies be integrated in urban design?

For the integration of adaptation strategies to heat into urban design, the key is again in the heat related characteristics. A pattern language is developed, that contains generic design elements. This pattern language has a focus on reducing urban heat, because adaptation measures are used as base for the design element (patterns). Next to the general descriptions of the patterns, information is given on how it can help to decrease the temperature. By linking the heat characteristics to the patterns, the patterns can be compared with the measurements that are done for the five characteristics. In this way, design elements are applied which are at the same time adaptation measures.

4. How can adaptation strategies be integrated in two exemplary neighbourhoods in Rotterdam?

The heat vulnerability analysis of Rotterdam has shown that the central, western and southern part of Rotterdam are the hottest parts of the city. In these areas, the neighbourhoods Bospolder-Tussendijken and Cool can be found. These neighbourhoods are exemplary for the heat problem, because they show different vulnerabilities and have different characters. Bospolder-Tussendijken is a neighbourhood with a weak social cohesion and many children. Cool is a neighbourhood in the city center, with many working people. The integration of adaptation strategies into these neighbourhoods is done by means of combining goals from policies with patterns in urban designs.

From the example designs for these neighbourhoods in Rotterdam, it has become clear that the effectivity of adaptation measures is not related to the amount of different patterns that are applied. However, the effectivity is related to the fraction of application in the area of development. The larger, the better. This is also shown in the case when the same adaptation strategies are applied in the same area, but at other places and in other amounts. Furthermore, it is useful to look at which characteristics have a weak (or moderate) position in the current situation, because improving specific characteristics can have more effect than improving the characteristics in general.

In general it can be said, that the pattern language makes it possible to integrate adaptation strategies into urban design. In this way, people are able to cool down when it is hot, and the city as well.

Recommendations for further research

As continuation of this research, further research can be done in the field of the Urban Heat Island effect or climate issues. Three approaches are discussed:
- Measuring heat characteristics to quantify the influence on the temperature
- Expand the scope of patterns to other kinds of climate adaptation measures
- Investigate the role of buildings for the UHI effect.

Measure quantitative effects of changing heat characteristics

This research has shown that certain characteristics of a city are related to heat. It is expected that changing these characteristics will have influence on the temperature in a city. This is based on what we know about these characteristics. However, it is not clear how large the effect of this will be exactly.

When further research is done on the Urban Heat Island effect, it can be investigated what the quantitative effects of implementing adaptation strategies are:
- This can be done by comparing temperatures for two situations that are quite similar, except for one heat characteristic.
- It is possible to look at temperature data for one location, before and after a development. The developed pattern language can be used to do this.

By doing quantitative research on the heat related characteristics, we can gain insight in the difference in how effective changing a certain characteristic can be. In this way, a hierarchy can be created in the effectivity of the five heat related characteristics. Next to the quantification, it is recommended to consider the value of the effects the measures have. During the project, the question raised: When is it enough? Once we know more about the actual effect of a measure, it can also be considered how far you should go in improving the heat characteristics. This can be part of the further research on quantitative effects.

Relate pattern language to other climate issues

The developed pattern language focuses on adaptation strategies to heat in the city. For other climate adaptation strategies, patterns can be developed as well. This can lead to an expanded pattern language, which relates the existing patterns to the other climate issues. It is expected that new patterns are needed as well, in order to integrate measures which address the new issues. Climate issues can i.e. be water nuisance or energy use. Similar to the present research, the effectivity of the measures for the other climate issues can be investigated.

Another master thesis which can be useful to use for this research is from Josephine van Lohuizen (2014). She made a toolbox with climate adaptive solutions.

The role of buildings for urban heat

From measuring the heat characteristics, it has become clear that changing existing buildings can really help to improve the situation. Especially roofs can have additional value for heat protection, and at the same time have another function. Since buildings only had little attention in this thesis, it is useful to investigate the role of buildings on heat islands. When buildings are researched for this topic, it is important to consider the effects for high and low outdoor temperatures. In the Netherlands there are often long colder periods, so dwellings should be able to stay warm in winter, and release or keep out heat in summer. Probably the insulation plays a significant role in regulating the indoor temperature. It can be a research similar to the present research, but then with the focus on buildings instead of outdoor spaces.

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Appendix

Photo © 500Watt / Rotterdam Image Bank

a. Before transformation of the theater square.

b. After transformation of the theater square in 2009.

c. After planting of different vegetation in 2012.

Theater square, Antwerp

The square in front of the city theater was badly used and out of proportion, before the transformation in 2009. A canopy roof and a garden were added to the square during the transformation. Because of the time-consuming maintenance of the vegetation, the city decided to make a prairie garden instead of the initial garden.

Initial goals (Stad Antwerpen 2012)
- Attract people to the square
- Create clear proportions
- Bring colour to the square (vegetation)

d. New situation of theater square, Antwerp.

Adaptation measures
The transformation of the square is not specifically part of the UHI adaptation, but it addresses the city's ambition for greening the city. This is indirectly one of the adaptation methods, as mentioned by Lauwaet et al. (2013). The following adaptation measure can be identified:

More green / water in public space

Shadow gathering place

Impact on the UHI effect

Explanation (see Figure 73):
Because of the canopy and planted trees, shadow is added to the square. Also, the vegetation provides the possibility for evaporation.

Recommendation for improvement:
Because of the weekly market en the canopy, enhancing the square in terms of evapotransporation and perviousness is difficult. Therefore the recommendation is to increase the albedo further.

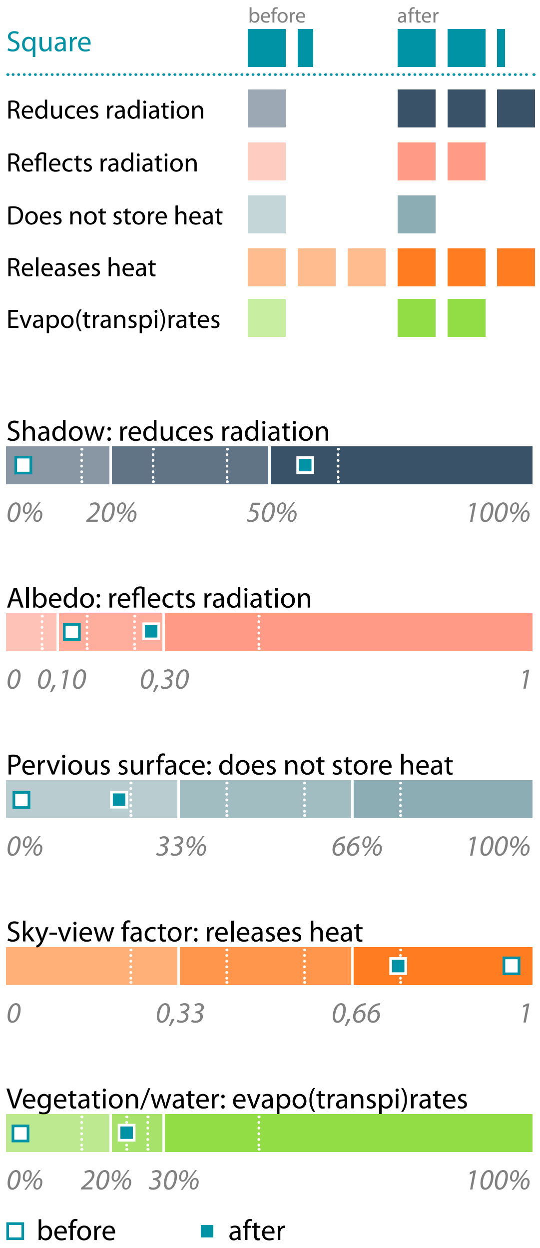
Impact on social and economic conditions
- The possibility to stay at the square attracts more people to this public space.

Figure 73.

a and b:
Bravo Bordas, D., 2010. Theater square Antwerpen (Belgium), 2009. CCCB. Available at: http://www.publicspace.org/en/works/f116-theater-square [Accessed November 13, 2014].

c:
Perreijn, K., 2013. 2013 Vlaanderen. Stichting het Panorama. Available at: http://hetpanorama.nl/excursies/activiteiten/2013-belgie/ [Accessed November 13, 2014].

d:
Google Maps.



Olympic Park, London

The Stratford area in London East End, has been transformed into the hosting area of the Olympic Games in 2012. The transformation after the Games was taken into account on beforehand, which has led to the design of the Queen Elizabeth Olympic Park.

Initial goals (London Legacy Development Corporation 2012a)
- Creating London's new district for business, leisure and life
- Creating a local destination with parks, waterways and visitor attractions
- Linking to the greater London region and beyond
- Building neighbourhoods inspired by London's heritage
- Connecting to East London's vribrant communities
- Securing a lasting sports legacy
- Creating jobs, skills and enterprise
- Ensuring sustainability (environmental responsibility, economic viability, social welfare and efficient resource utilisation)

Adaptation measures
Although the Olympic Park is mentioned by the Mayor of London (2013) as one of the enhancement projects of green space, this is not mentioned in the masterplan. Adapting to the UHI effect can be seen as one of the underlying aspects of the

Left:
Stratford as a wasteland in 2001, before the area is transformed for the purpose of the Olympic Games.

Right:
The Olympic Legacy Masterplan, in construction since the Olympic Games in 2012, planned to be finished in 2030.

a. Impression of the Olympic Park, adjacent to the stadium.

b. Impression of one type of dwellings in the Olympic Park.

'environmental responsibility', which is part of the goal to ensure sustainability. Remarkably, all the adaptation measures mentioned by the London authorities, are used in the project (London Legacy Development Corporation 2012b):

- Green roof
- Street trees
- Good quality green space
- Greenery
- Cool roof technology
- Low-carbon, energy-efficient cooling
- Improve building insulation
- Adapted building (less cooling)
- Decentralised energy

Impact on the UHI effect

Explanation (see Figure 74 and 75):
Because there was no significant amount of buildings in the initial situation, it is not possible to compare the situation before and after the intervention. The height of the dwellings and street trees determine the amount of shadow on the building surfaces, and it decreases the sky-view factor. Also, the albedo is moderate, because some buildings are quite light

Figure 74.

Left:
Oliver, A., 2012. Changing face of the Olympic Park: Incredible pictures show how London 2012 site went from wasteland to multimillion pound sporting hub in ten years. The Mail on Sunday. Available at: http://www.dailymail.co.uk/news/article-2130363/London-2012-Olympics-How-Olympic-Park-went-wasteland-multimillion-pound-sporting-hub.html [Accessed November 19, 2014].

Right:
London Legacy Development Corporation, 2012a. A Walk Around Queen Elizabeth Olympic Park, London.

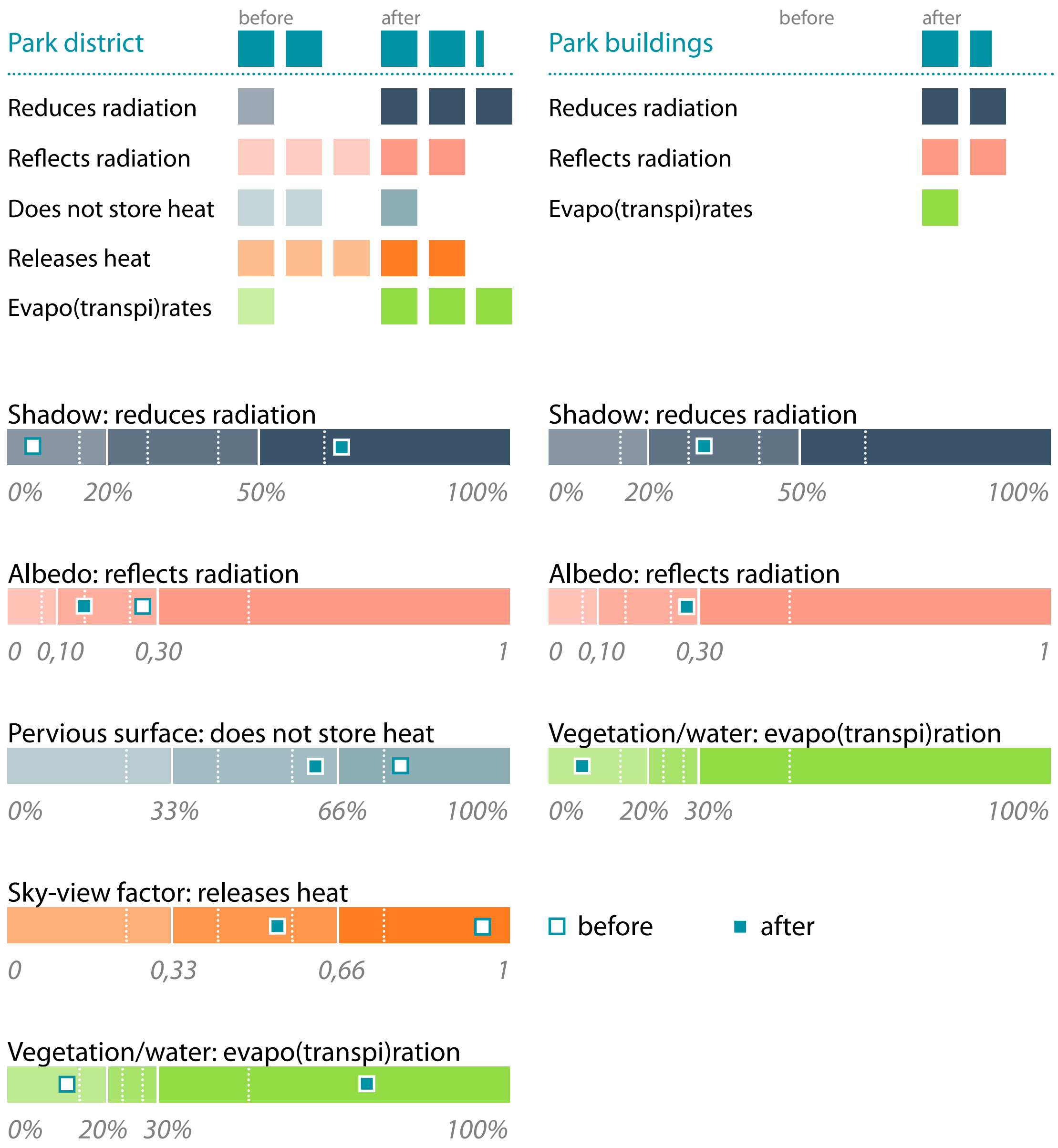
Figure 75.
London Legacy Development Corporation, 2012a. A Walk Around Queen Elizabeth Olympic Park, London.

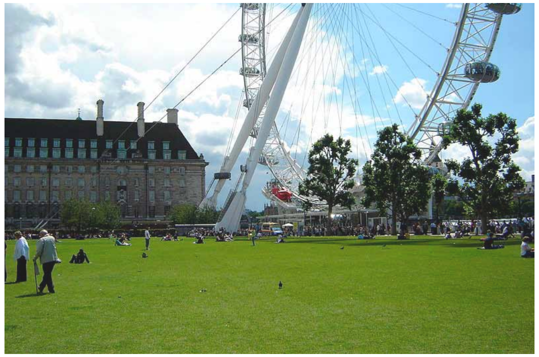
coloured. The park site is strongly improved in terms of evapotranspiration and shadow. This is mainly because of the large amount of vegetation and the additional waterway. Remarkably, the perviousness and albedo decreased. This can be contributed to the fact that buildings are added, while there was only bare soil in the previous situation.

Recommendation for improvement:
Since the perviousness and albedo cannot be changed without removing green or buildings, the park cannot be improved much further. Therefore, the focus could be on green facades, or an even higher albedo, for the buildings.

Impact on social and economic conditions
- Good living conditions for sustainable and conscious people.
- Fresh start for building a new community.
- Wasteland is turned into vibrant parkland.
- New functions and sports activities can give an impuls to the economy.
- Many new jobs are provided.

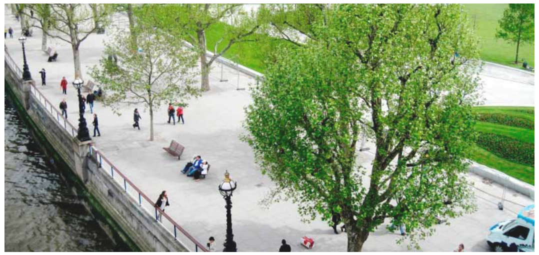
(Note: these social and economic impacts are for a large part yet to be proven.)





a. Jubilee Gardens before the transformation in 2012.

b. Playground in the former appearance of Jubilee Gardens.



Jubilee Gardens after the transformation in 2012.

Jubilee Gardens, London

The Jubilee Gardens were transformed for the occasion of Queen Elizabeth's diamond jubilee in 2012. The park, designed by West 8, is located along the river Thames and next to the London Eye.

Initial goals (West 8 2012)
- Creating a destination, instead of a thoroughfare.
- Transform the grassed garden in a world-class park.
- Access routes connect the surrounding hotspots.

Adaptation measures
The focus of this project is mainly on its local function. Also, the environmental impact is not mentioned in the project description at all. The Mayor of London (2013) has pointed the Jubilee Gardens out as one of the green space enhancement project. The following measure is used:

Good quality green space

Impact on the UHI effect

Explanation (see Figure 76-78):
Besides the improved appearance of the park, the trees are of important value for the Jubilee Gardens. Trees provide shadow

Figure 76.

a:
Wikimedia Commons, 2007. File: London Eye from Jubilee gardens.JPG. Wikimedia Commons. Available at: http://commons.wikimedia.org/wiki/File:London_Eye_from_Jubilee_gardens.JPG?uselang=nl [Accessed November 19, 2014].

b:
Clarke, L., 2010. File: London, Lambeth - Jubilee Gardens Playground - geograph.org.uk - 1780216.jpg. Wikimedia Commons. Available at: http://commons.wikimedia.org/wiki/File:London_,_Lambeth_-_Jubilee_Gardens_Playground_-_geograph.org.uk_-_1780216.jpg [Accessed November 19, 2014].

Figure 77.
West 8, 2012. Jubilee Gardens. Available at: http://www.west8.com/projects/jubilee_gardens/ [Accessed November 19, 2014].

for the visitors, and the evaporation will increase. Vegetation is also useful for evaporation.

Recommendation for improvement:
The addition of water elements would fit very well in this park. By the use of water, evaporation would still be possible in dry periods. In this case, it could be used as play element for the children, and as refreshing element for the other visitors.

Impact on social and economic conditions
- The park is intensively used, because there are many places to sit.

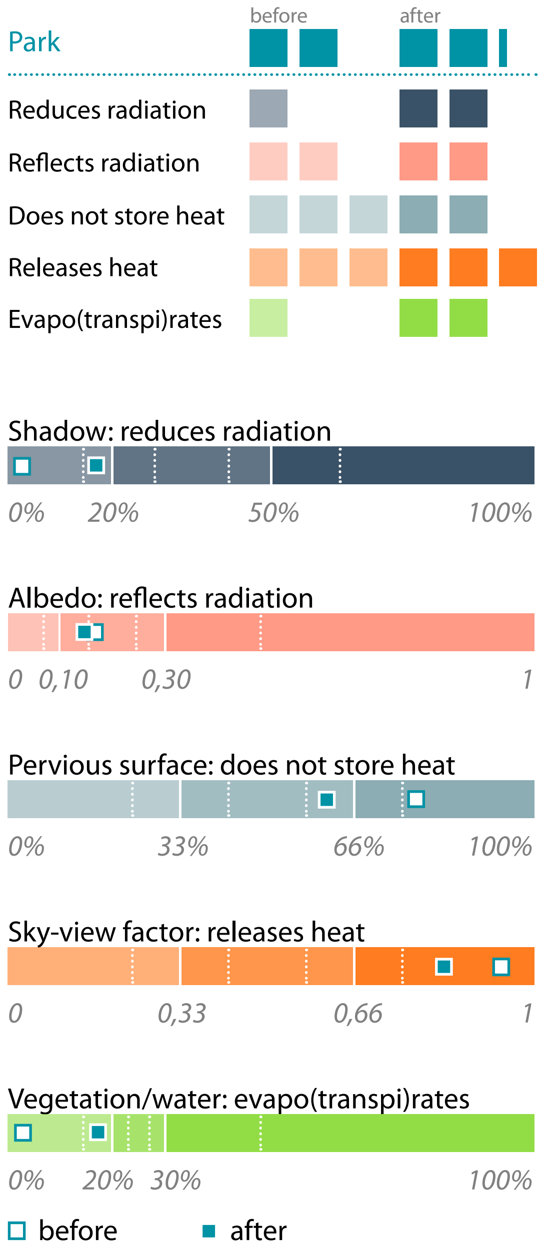
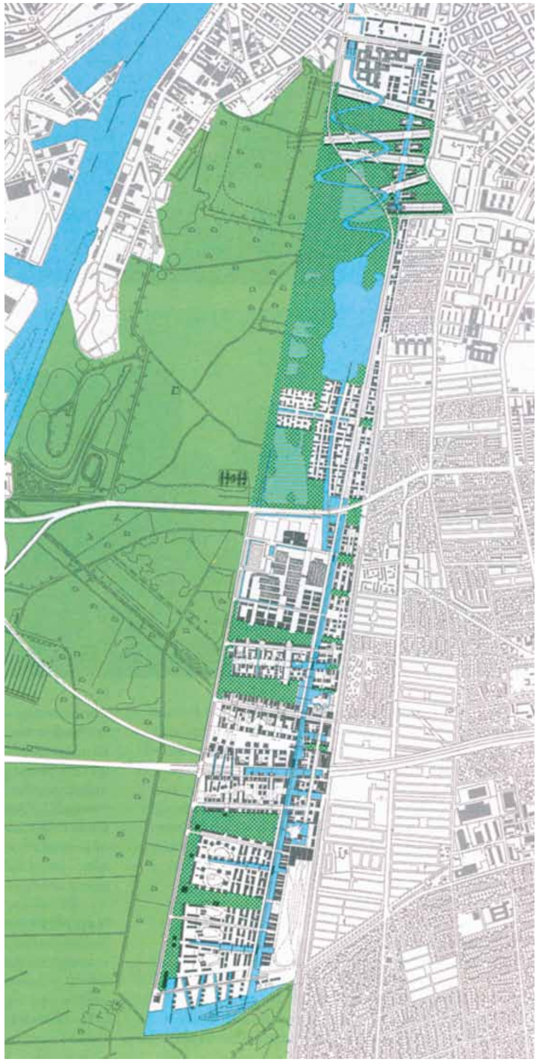


Figure 78.
Google Maps.

New situation of Jubilee gardens, London.

Ørestaden, Copenhagen



Masterplan design of the Ørestad development area in Copenhagen.

A complete new urban quarter has been developed in Copenhagen, which combines the work, study and living environment. An important requirement was the metro connection to the central part of the city, because the quarter has to be attractive for people to live there. In the design, the neighbourhoods are densely built, in order to leave as much space as possible for nature.

Initial goals (CPH City and Port Development 2011)

- Creating a dense and modern city
- High density neighbourhoods surrounded by nature
- Canals form a recreative line

Adaptation measures

Although nature plays an important role in the development of Ørestaden, and rain water reservoirs are provided, nothing is mentioned about the UHI effect or something related to that. In the natural environment, the following adaptation measures are integrated (CPH City and Port Development 2011):

Green network

Trees

Storm water basin

Impact on the UHI effect

Explanation (see Figure 79 and 80):
Before the transformation, the site only existed of meadows. Because this was beneficial for heat prevention, the new situation does not seem very profitable in this respect. In the open spaces, shadow and evapotranspiration increased. Especially the large amount of water in the meadows stimulates evapotranspiration in this area. The addition of grand buildings, has resulted in a decrease of perviousness. For the built areas, shadow and albedo increased in very low numbers, but the natural environment is in general very beneficial to prevent the UHI effect.

Recommendation for improvement:
As mentioned before, the natural environment has a positive influence on heat prevention. Nevertheless, the buildings can be improved much further, by giving attention to more green or reflective facades and roofs.

Impact on social and economic conditions

- For the people that live in this new district, all necessary functions are nearby.
- The metro facilitates a fast connection to the central city.
- The natural environment can be used for recreational purposes.

Figure 79.
Detail, 2002. Reports: A Critique of Copenhagen's Ørestad Development. Available at: http://www.detail-online.com/inspiration/reports-a-critique-of-copenhagens-orestad-development-106621.html [Accessed December 2, 2014].

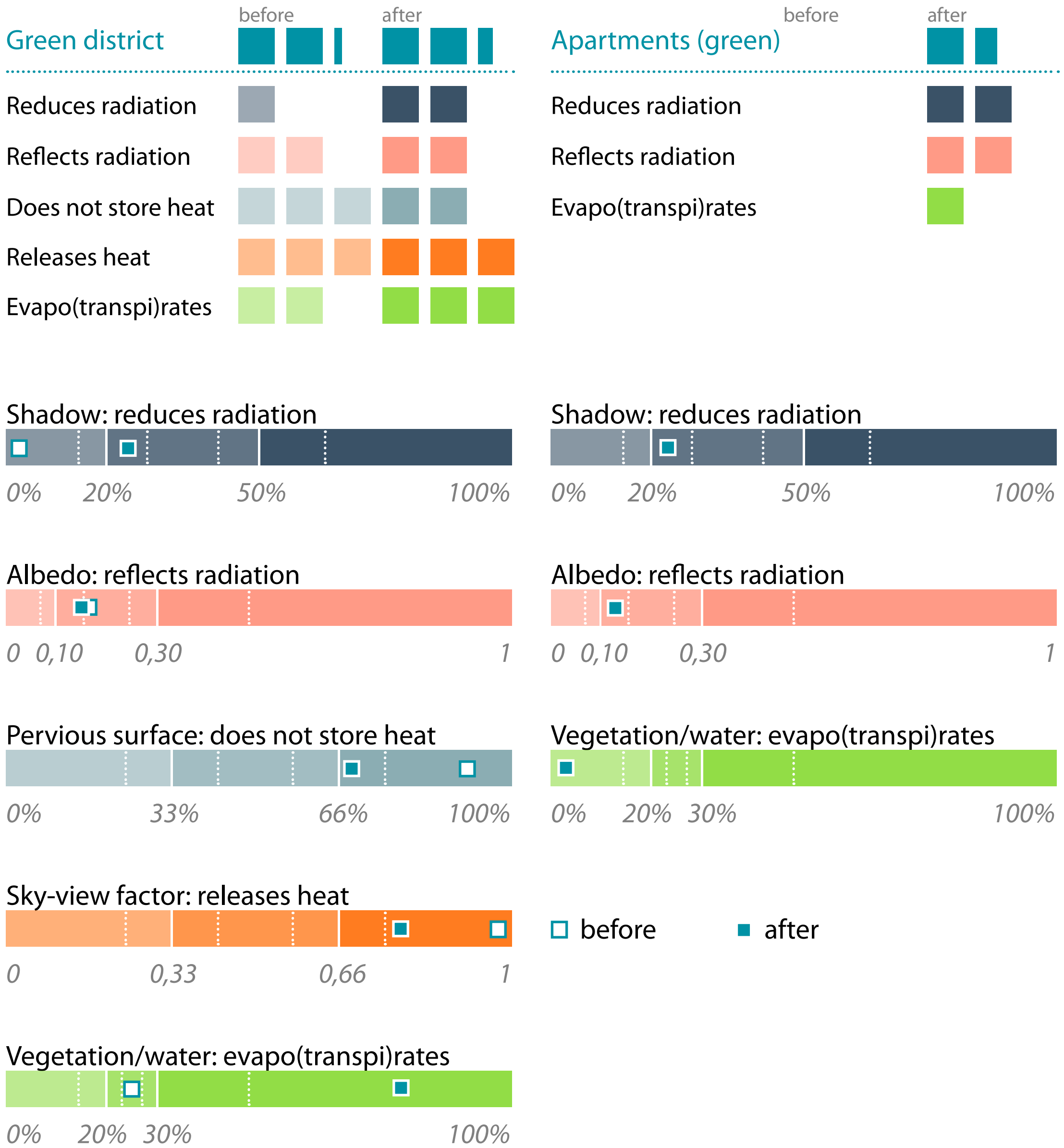


Figure 80.
CPH City and Port Development, 2011. Copenhagen Growing: The Story of Orestad, Copenhagen.

Ørestaden after the transformation.

Nordhavnen, Copenhagen

The district exists of islets, divided by water, which form stand alone areas. It provides accommodation for residential and commercial purposes. Green and water is combined with compact built areas, including highrise buildings. It is a sustainable plan in which the district is integrated with the rest of the city.

Initial goals (CPH City and Port Development 2012)
Become the sustainable city of the future by creating:
- an eco-friendly city
- a city by the water
- a city for everyone
- a dynamic city
- a city of sustainable mobility
- a vibrant city

Adaptation measures
There is much room for green and water in this urban plan. Also, attention is paid to energy savings, which is also visible in the use of water for district cooling. All the named adaptation measures for Copenhagen are visible in Nordhavnen (CPH City and Port Development 2012):

Green network

Trees

Green wall

a. Situation before development in Nordhavnen, 1948.

b. Impression of the new environment in Nordhavnen.

c. Design drawings of Nordhavnen. On the left the urban structure is visible, and on the right the green structure.

Figure 81.
CPH City and Port Development, 2012. Nordhavnen from idea to project, Copenhagen.

Rain garden

Storm water basin

Pond

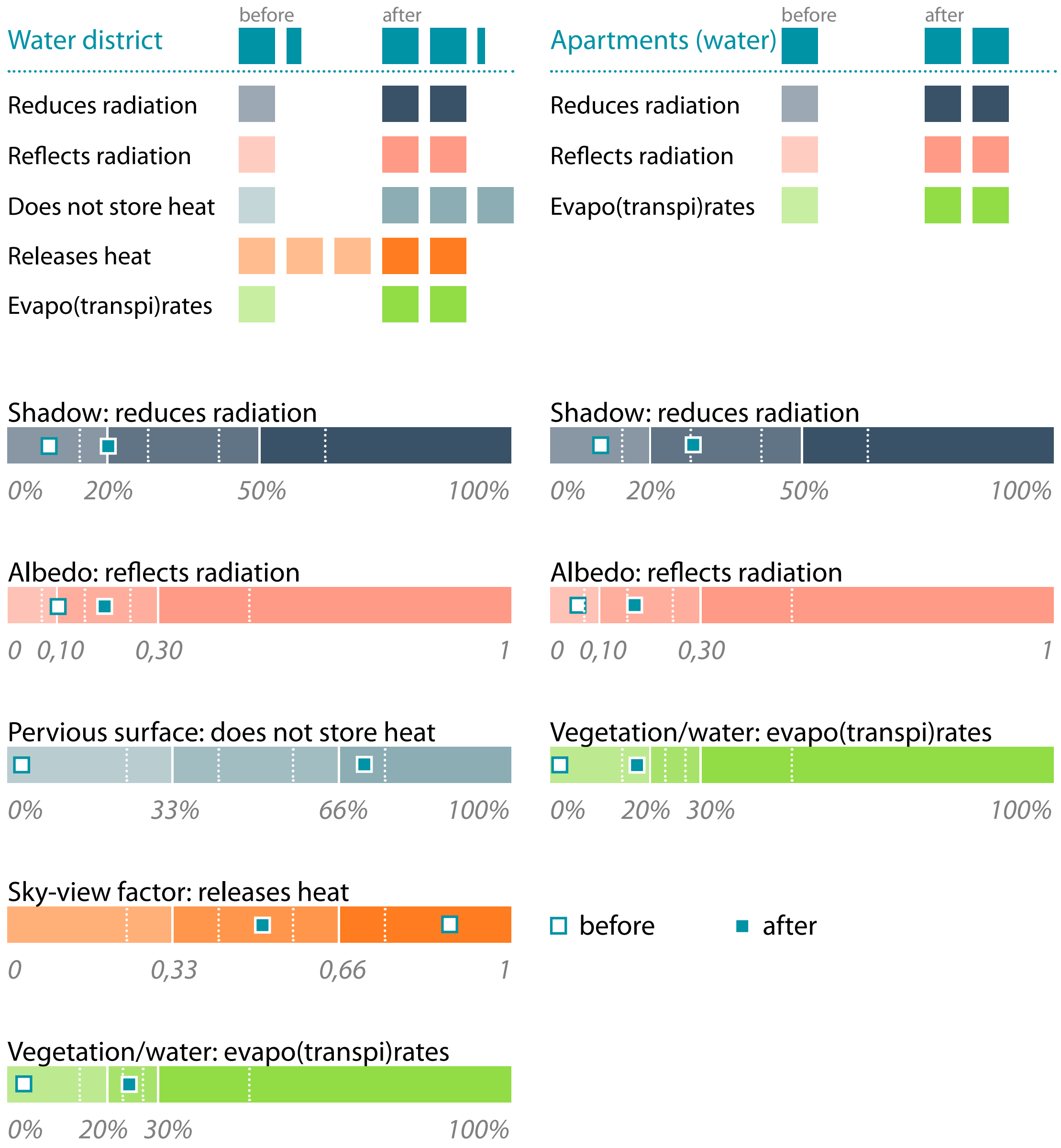
District cooling of buildings

Impact on the UHI effect

Explanation (see Figure 81):
All the different aspects are improved, except for the sky-view factor. This is the effect of the relatively high buildings in the district. Because the harbour was filled with industrial buildings, and is replaced by other pavements, buildings and more green, it has become a strongly improved environment.

Recommendation for improvement:
There are not many things which can be improved. The sky-view factor fits the compact district, and cannot be changed for that reason. A point of improvement could be to add more shaded spaces.

Impact on social and economic conditions
- Sustainable living conditions.
- The district is close to the inner city of Copenhagen.
- Short distances between facilities stimulate to walk and cycle.
- Urban (green) spaces provide room for social interaction.



Vision Bospolder-Tussendijken

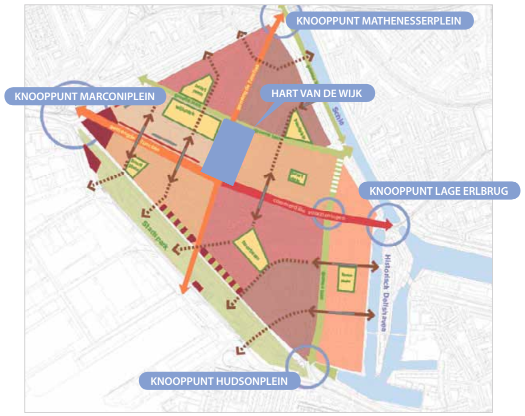
Gebiedsplan Delfshaven 2014-2018
(Gebiedscommissie Delfshaven 2014)

Objectives:
- empowerment and participation of inhabitants by means of enhancing their capacities and skills
- inhabitants feel safe and have enough public facilities in the neighbourhood
- the neighbourhood is an attractive place to live and to stay

Gebiedsvisie Bospolder-Tussendijken 2020
(Deelgemeente Delfshaven et al. 2009)

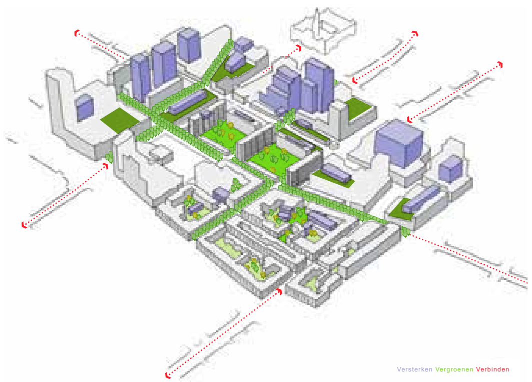
Key strategies (see Figure 82):
- enhance safety and liveability
- empowerment for youth and women
- investing in current housing stock
- reinforce identity and recognisability
- enlarge the varity of dwellings and residential environments
- give an impuls to economic structure
- reinforcement of social facilities
- enhance Visserijplein and its surroundings
- enhance public space and green structure
- enhance infrastructure

Areas of development: Visserijplein, Park 1943, Schiedamseweg, Marconiplein, Kleine Visserijstraat, Haringpakkerstraat



Spatial programmatic vision on Bospolder-Tussendijken.

Figure 82.
Deelgemeente Delfshaven, Com wonen & Proper-stok, 2009. Gebiedsvisie Bospolder-Tussendijken 2020, Rotterdam.



Connection, reinforcement and greening Lijnbaankwartier.

Figure 83.
Gemeente Rotterdam Stadsontwikkeling, 2013. Ontwikkelingsvisie Lijnbaankwartier, Rotterdam.

Vision Cool

Gebiedsplan Rotterdam Centrum
(Horeman & Kion 2014)

Focus of Cool Noord / Lijnbaankwartier: shops, catering industry, culture, dwellings, employment

Focus of Cool Zuid: culture, art, dwellings, entrepeneurship

Ontwikkelingsvisie Lijnbaankwartier
(Gemeente Rotterdam Stadsontwikkeling 2013)

The development focuses on connection, reinforcement and greening (see Figure 83)

Ambitions:
- reinforce and connect the central shopping area with distinctive surrounding shopping areas
- enhance the quality to stay in public space with focus on Rotterdamse Stijl, greening and good infrastructural network
- mixed public programme for shopping, culture and nightlife
- reinforce the residential environment for the different areas
Mauritskwartier: lively, urban and historical residential area
Lijnbaanensemble: highly urbanised residential area with a green environment
Boulevardzone: metropolitan, residential
- greening for an attractive environement
Mauritskwartier: green inner courtyards
Lijnbaanensemble: green roofs and inner courtyards
Boulevardzone: green roofs and facades
- collaborative approach to prevent cluttering in the city center
- cluster office buildings at Weena and Westblaak

Spatial analysis

City road
Main road
Car road

scale 1:25.000

Train
Metro
Tram
Bus
Train station
Metro station
Tram stop
Bus stop

Figure 84.
Image by author.

The neighbourhoods are both close to a city road, which are connected with the main roads that cross the neighbourhoods. Therefore, the neighbourhoods are divided in two parts by the roads. The smaller car roads create accessibility for the inhabitants of the neighbourhood. Many of these car roads are one-way traffic.

Because the Cool area is part of the city center, it is wel connected with public transport. The central train station is close to the northern part of the area, and the other connections are linked to this station. The metro, tram and bus have stops mainly around the neighbourhood. Bospolder-Tussendijken has metro and tram stops along the Schiedamseweg, which divides the neighbourhood in two parts.

It is remarkable that there are a lot of schools and playgrounds in Bospolder-Tussendijken. This shows that a lot of children live in this neighbourhood. Next to the park and the square, which can be seen as the core of the neighbourhood, the only cultural building can be found. This is a community center with a library. Also the most southern part of Cool has several schools and playgrounds. There are many cultural services in this neighbourhood, like i.e. a theater and cinema. For Cool it is remarkable that it almost completely exists of retail and commercial buildings.

Both the neighbourhoods exist mostly of (almost) closed building blocks. The front doors of dwellings are located directly at the street, and inside the building blocks there are many private gardens. In the case of Bospolder-Tussendijken, these inner courtyards are often green. In Cool this is only the case for some of the private inner courtyards, which are in the south-western part of the neighbourhood.

Figure 85.
Image by author.

SWOT analysis

Figure 86.
Image by author, based on Bing Maps.

Schiedamseweg

Strengths:
- Lively street with many shops
- Good accessibility by public transport (metro and tram) and by car

Weaknesses:
- Because of the high amount of stone and pavement this street looks quite grey, and absorbs a lot of heat

Opportunities:
- Addition of more shops and community facilities

Threats:
- Unsafe crossings
- Cluttered streetscape outside the shops

Figure 87.
Image by author, based on Google Maps.

Kleine Visserijstraat & Haringpakkerstraat

Strengths:
- Located close to public functions (community center, market, park, schools, playgrounds)
- Quiet streets which are at the same time good accessible
- Green inner courtyards

Weaknesses:
- Cars and pavement dominate the streetscape

Opportunities:
- Open spaces beside the schools can be used as playgrounds for the schools and children who live in the neighbourhood

Threats:
- The straight streets can look monotonous

Figure 88.
Image by author, based on Google Maps.

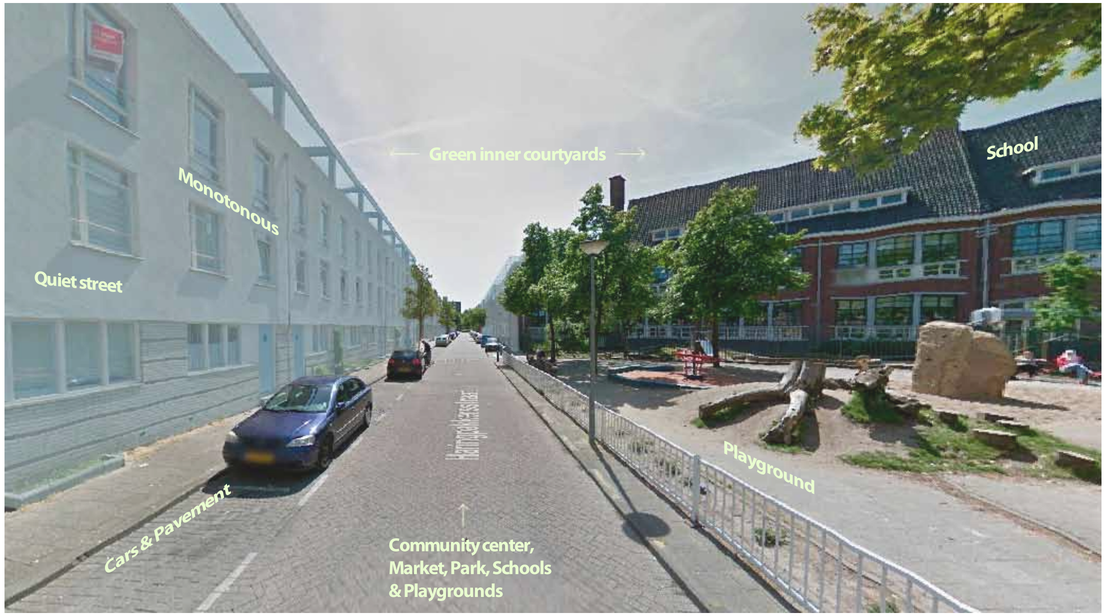


Figure 89.
Left:
Image by author, based on Bing Maps.

Right:
Image by author, based on Google Maps.

Jacobusstraat & Mauritsstraat

Strengths:
- Close to shopping area
- Quiet streets in between intensively used public space
- Green inner courtyards

Weaknesses:
- The streets are very narrow
- Cars dominate the streetscape

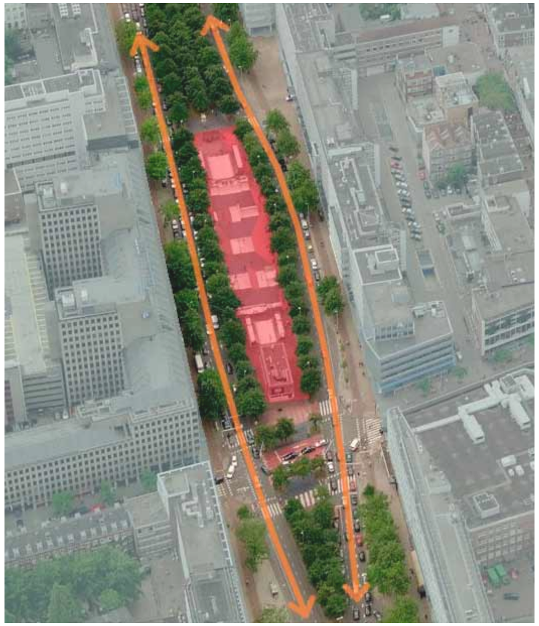
Opportunities:
- The wider parts of the streets can have something extra to create variation in the streetscape

Threats:
- Some dwellings can have the impression of bad maintenance

Figure 90.
Image by author, based on Google Maps.

Figure 91.
Left:
Image by author, based on Bing Maps.

Right:
Image by author, based on Google Maps.



Westblaak

Strengths:
- There are many grown trees, which gives a pleasant feeling to the broad street

Weaknesses:
- There is a lot of traffic

Opportunities:
- The skatepark can be made underground instead of the loose elements on the ground

Threats:
- Because of the very broad street and the skatepark it can be a barrier to cross

Figure 92.
Image by author, based on Bing Maps.

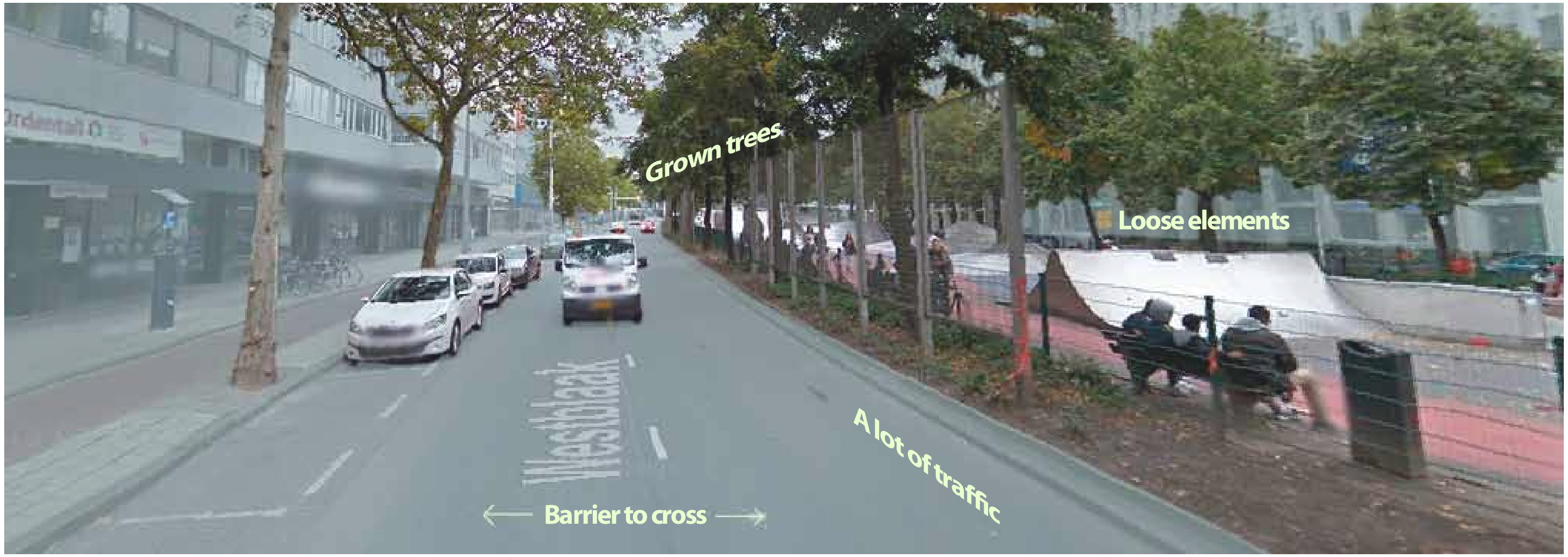


Figure 93.
Image by author, based on Google Maps.

Figure 94.
Image by author, based on Google Maps.

Eendrachtsplein

Strenghts:
- Good accessibility by public transport (metro, tram, bus) and car
- The old buildings and singels give character to the location
- The weekly biological market is a good example of functions which can be added

Weaknesses:
- The large open space is paved to a large extent, and absorbs a lot of heat

Opportunities:
- The square can help to clarify connections between important locations of the city center
- Bring back the water structure which has been taken away between the singels

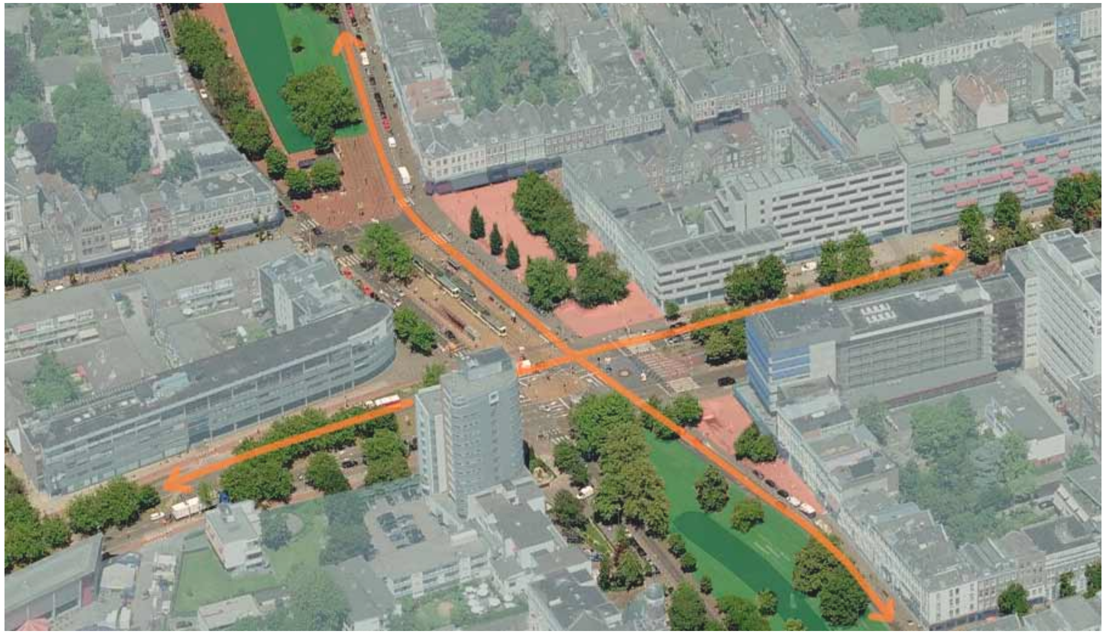


Figure 95.
Image by author, based on Bing Maps.

Threats:
- The square becomes monofunctional

Downtown

Strengths:
- Terraces give an attractive atmosphere to the streets
- There is not much traffic in the concerning streets

Weaknesses:
- The various streets are quite far from each other in terms of walking distance

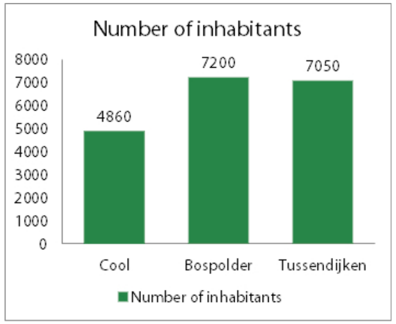
Opportunities:
- The streets can refer to each other by making a recognisable look

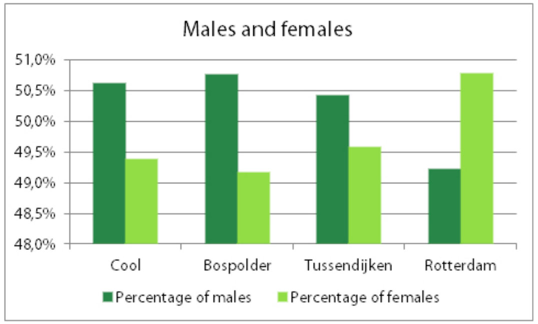
Threats:
- Downtown can be in the shadows of the Lijnbaan and other shopping streets

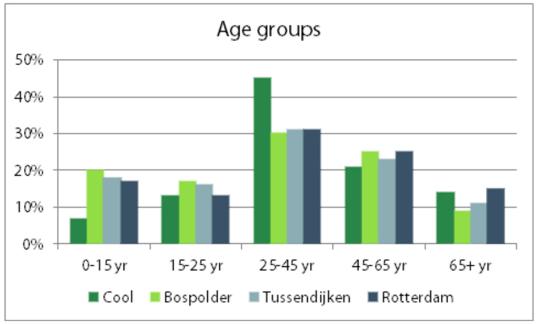
Figure 96.
Image by author, based on Bing Maps.

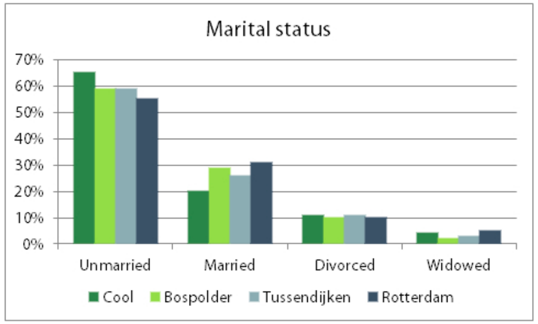
Figure 97.
Image by author, based on Google Maps.

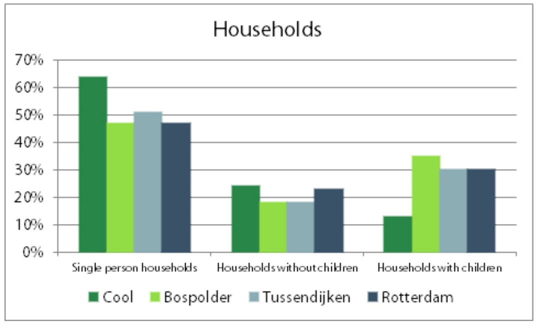
Demographic numbers

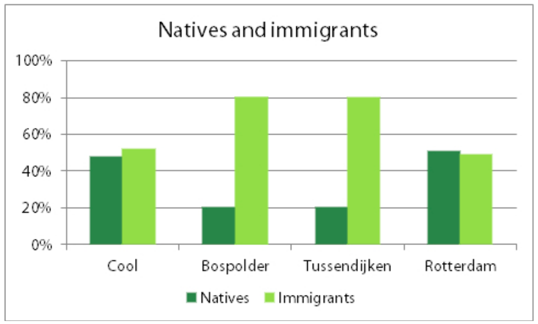












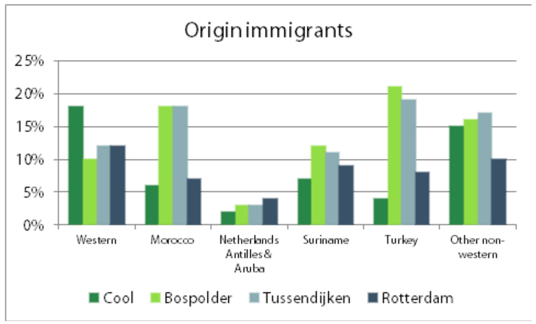


Figure 98.
Image by author, based on: CBS, 2014. Kerncijfers wijken en buurten 2014. Available at: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82931ned&D1=0,3-21,26-31,84-92&D2=8030-8031,8034,8040-8041,8137,8432&VW=T [Accessed January 5, 2015].

Ages and number of people

For 5 minutes it is counted how many people were present in the different areas (see Figure 99). It is also taken into account to which age group they belong: 0-15, 15-25, 25-45, 45-65 or 65+ years old.

Bospolder-Tussendijken

It is remarkable that there are many children in this neighbourhood, who play outside in playgrounds or in the park. The Schiedamseweg is the most crowded place, followed by the Visserijplein and Park 1943. These are also the places where a lot of activities took place. This was also the case for the Marconiplein, although there were not many people. Traffic was specifically passing by at the Schiedamseweg and Marconiplein. In general, people were under the age of 45 to a large extent.

Cool

This neighbourhood includes other activities than Bospolder-Tussendijken. Clearly, people went outside for a break from work, in which they eat and drink, smoke, or call someone. Other people came here to go shopping, or meet people at a terrace. Traffic was intensively passing by at the Eendrachtsplein and Westblaak, while the Lijnbaan and Oude Binnenweg were (almost) car free. Only a few children passed by in Cool, and people are generally older than 25.

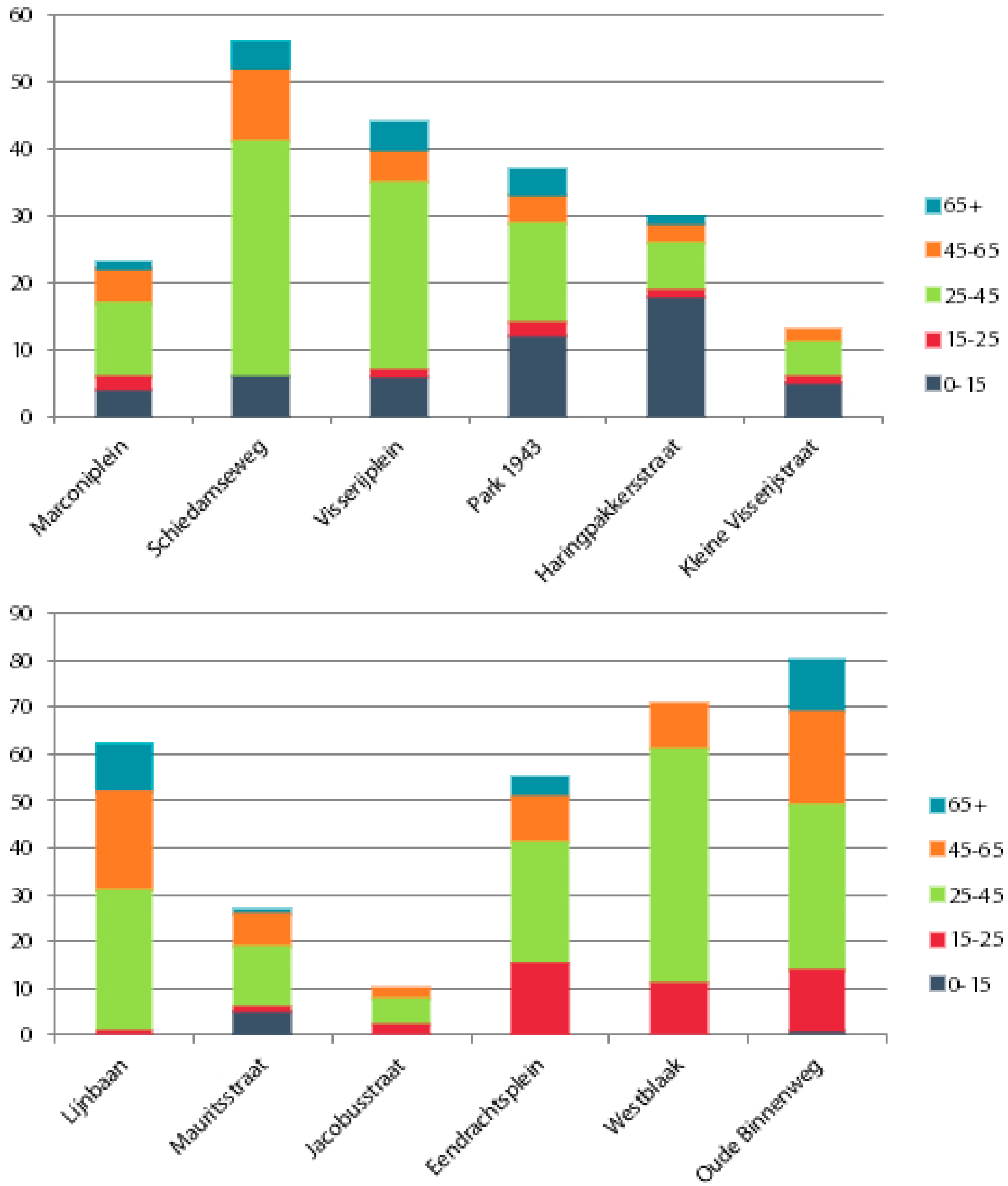


Figure 99.
Image by author.

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