COOLING HEERLEN

Bsc Thesis by Lianne Klein Lankhorst

Student: Lianne Klein Lankhorst

Student Number: 941027-440-080

Topic: ‘Really cooling water bodies’ in Dutch cities

Project: Cooling Heerlen

Supervisor: Dr. Dipl.Ing. MA (AA) Sanda Lenzholzer

Coordinator: Dr. Dipl.Ing. Sven Stremke MA

Date: 28/10/2016

Source cover photo: (NLwandel 2016)

Contents

List of Figures

List of Tables

1. Introduction

1.1 The Urban Heat Island

“Possible third regional heat wave in Limburg this year”(NU.nl 2016b)

“Heat waves will more often occur due to warming climate” (NOS 2015a)

“Warmest 7th September in over a hundred years” (NU.nl 2016a)

“2015, warmest year ever measured” (NOS 2015b)

These are all headlines which are more often occurring in the Dutch news over the last few years. The warming of the earth, and the rising of temperatures in cities is happening now. There will be more heat waves, more extreme precipitation, more periods of drought and an increased Urban Heat Island (UHI) effect.

The Urban Heat Island effect arises when the green areas and natural lands are replaced by hard, impervious surfaces (Sun and Chen 2012). When there is little vegetation and surface water in the cities, the evapotranspiration rate is relatively low (Steeneveld et al 2014), which has a negative influence on the cooling of the city. The increasing temperature in cities is primarily caused by the sun. The sun’s energy gets absorbed by the high amount of materialized surface in the city centre during the day. At night the warmth is emitted again, this causes the air in the city at night to warm up. The same process happens with the water (Lenzholzer 2013). For some time the assumption was made that water bodies in cities would help the city cool down. However, this turned out to be false. The open water bodies in the cities actually contribute to the warming climate. Results from research done by Steeneveld et al (2014) show that the Urban Heat Island is significantly related to the Open Water Fraction. Compared to their surroundings, water bodies have a relatively large heat capacity. In the end of summer and autumn these water bodies have reached relatively high temperatures. The water stores the warmth during the day, and during the night the warmth is slowly emitted, contributing to the Urban Heat Island effect (Theeuwes et al 2013).

The heating of the city influences all its inhabitants. Sun and Chen (2012) mention in their article the negative influences of the UHI:

“The negative impacts of UHI are well known such as increasing energy consumption, compromising human health and comfort, and intensifying carbon dioxide emissions”.

To keep the city inhabitable it is important to cool down the city climate. if the process of warming water bodies, and thus warming cities, can be reversed, liveability in cities could potentially improve. Therefore it is important to design cooling waterbodies. Since most of these waterbodies are in the residential areas, they also need to be pleasing to the eye. There is the opportunity to create something beautiful which fits in the urban context and where citizens can go to cool down during heat waves. Designs made in this project can function as example for other cities and landscape architects to create cooler city climates.

1.2 REALCOOL

The REALCOOL project, a research project from the Wageningen University, the University of Applied Sciences Amsterdam, Alterra and AMS, has the goal to develop urban water bodies to keep dry feet in the city and keep the city from overheating. These water bodies should have a cooling effect on their surroundings and should fit their surroundings functionally as well as aesthetically.

The aim of this Bachelor Thesis is to inspire and inform the REALCOOL project by conducting research through design on cooling water bodies in the city of Heerlen

1.3 Heerlen

Heerlen is a city in the south of the Netherlands (see figure 1), it is located on a loamy soil, it is important to know that water infiltrates easily in these soils. Causing there to be almost no natural water bodies in the city. The goal of this research is to cool down the city, using water. In order to do so we need to implement new cooling water bodies in Heerlen.

This design will be developed by research through design on a ‘testbed’ area in the city of Heerlen in the south of the Netherlands. Heerlen is a relatively young city with an open spatial structure, greenery finds its way deep into the city. Areas around the city edges are opening up due to centralization of functions and facilities (Gemeente Heerlen 2015). This could provide a good opportunity for the placement of design interventions to counteract the Urban Heat Island effect.

Figure 1 City of Heerlen Location

1.4 Research Objective

The objective of this research is to design cooling water bodies to lower the temperature in urban heat islands.

1.5 Design & Knowledge Questions

1.5.1 Design Question

How can a design intervention with water decrease the water nuisance and counteract the effects of the Urban Heat Island in the city of Heerlen?

1.5.2 Knowledge Questions

Where are the Urban Heat Islands located in the city of Heerlen?

Where are areas with water nuisance in the UHI locations in the city of Heerlen?

What design interventions can be used to cool down the city?

What design interventions can be used to decrease water nuisance in the city?

1.6 Methods & Materials

The first phase of this research is analytical. I will be looking for answers on my knowledge questions by collecting and reviewing literature and other data. This information can be used to come up with design hypotheses, which will be tested in my Research Through Design phase. I will also collect information to assemble a design toolbox and design criteria, with which to create and test designs (see table 1).

In Research Through Design the designing functions as a research method (Lenzholzer et al 2013). A post-positivist approach on research through design will be used, I will be looking for clear cause-effect relationships and will be make hypotheses which are tested in designs (Lenzholzer and Brown 2016). A design is created using the beforehand assembled information. This design will be tested, using a checklist with Design Criteria. The design will be altered and retested until a final, optimal design arises, following the idea of the TOTE-model mentioned by de Jong and van der Voordt (2002 p.455) (see figure 2).

Figure 2 TOTE-model

Table 1 Methods and Materials

Research Questions	**Materials**	**Where to find information**	**What information to find**	**For what use**
Knowledge Questions				
Where are the Urban Heat Islands located in the city of Heerlen?	Urban heat maps City maps	Municipality of Heerlen Climate Effect Atlas GIS maps	Climate maps City maps Demographic maps	To locate UHI in combination with residential areas. To create design concepts To locate water bodies To locate potential testbed area
Where are areas with water nuisance in the UHI locations in the city of Heerlen?	City maps Elevation maps	GIS maps Municipality of Heerlen AHN map	Elevation map Water Flow Direction Water Accumulation Areas Vegetation in area	To locate potential testbed area To create design concepts To locate the water flow To locate water accumulation areas To Analyse testbed area
What design interventions can be used to cool down the city?	Literature on cooling cities Literature on urban climate Information on city climate Information on testbed use	Scientific articles on cooling city design Master Theses KNMI Observation location Municipality website	Multiple solutions to cool down urban en-vironments Effects of interventions in urban areas Wind Direction Shading patterns Functionality and people flow patterns on square Vegetation in area	To create design concepts To test design concepts To frame Design Criteria To assemble Design Toolbox To Analyse testbed area
What design interventions can be used to decrease water nuisance in the city?	Literature on flooding prevention Information on testbed use	Scientific articles Master theses Observation location	Multiple solutions to prevent flooding in the urban area	To create design concepts To test design concepts To frame Design Criteria To assemble Design Toolbox To Analyse testbed area
Design Question				
How can a design intervention with water decrease the water nuisance and counteract the effects of the Urban Heat Island in the city of Heerlen?	UHI location map Location Residential areas Location Testbed area Water Flow map Water Accumulation areas Design Toolbox Design Criteria Functional use map Accessibility map Design Concepts	Information assembled through Knowledge Questions	An optimal design for the testbed	To cool the UHI and prevent flooding

2. Theoretical Framework

2.1 Literature

A lot of research has already been done on the cooling of urban areas, with many possible solutions. One element which keeps returning in these articles is the use of green spaces, planting and evapotranspiration. “Evaporative cooling is arguably one of the most efficient ways of passive cooling for buildings and urban spaces in hot regions” (Robitu et al 2006. p.436). Planting provides shading and cooling via evapotranspiration, but green spaces also provide an improvement of the surface porosity. This in turn provides an increasing capacity for water storage and available water for evaporative cooling (Hathway and Sharples 2012). Because of the increase of capacity, these green areas can regulate the climate in the city (Robitu et al 2006). Trees and water ponds are elements which cannot be missed out on when designing these green spaces, because they have an important function in the improvement of microclimatic conditions outdoors (Robitu et al 2006). With this we have to take in mind that not all water bodies are cooling, a requirement of these ponds is that they do have a cooling function, and do not contribute to the Urban Heat Island. When all these elements are added to the city it has the potential to reduce the Urban Heat Islands (Hathway and Sharples 2012). But vegetation can also have a negative effect on the cooling of the UHI, it can reduce the wind speed in the city and the natural ventilation of urban spaces and building surfaces (Robitu et al 2006). Trees have also been found to block cool air flows from parks to surrounding urban areas (Sun and Chen 2012). Some other possible solutions for the UHI are shading, replacing hard riverbanks for vegetated riverbanks (Hathway and Sharples 2012), Placing water facilities in narrow city spaces, like waterfalls and spray-type water features (Nishimura et al 1998) or orientating streets on prevailing winds that occur in hot summer weather (Yokohari et al 2001).

2.2 Key Concepts

Table 2 Key Concepts

Concept	**Explanation**
Urban Heat Island	City or Urban area where the average temperature is higher than its rural surroundings, due to human interventions.
Water Bodies	Accumulation of water in an area, can be still or flowing (for example: lakes, ponds, wetlands, streams, rivers, canals)
Heat Capacity	Amount of energy absorbed by a substance, which increases the temperature of the substance.
Evapotranspiration	The movement of water from the earth to the atmosphere by evaporation of water and transpiration of plants.

2.3 Design Toolbox

Based on the literature I assembled a Design Toolbox (see table 3), with which the most suitable design solution will be determined for the testbed area. The Design Toolbox consists of design interventions which can be used to prevent flooding and cool down the Urban Heat Island.
I will use some of these interventions in my final design.

Table 3 Design Toolbox

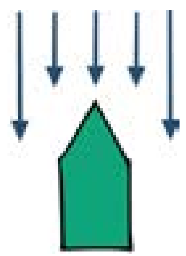
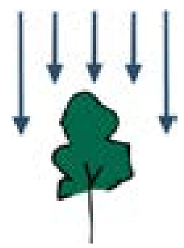
Flooding Prevention		
Storm Water Interception	Interception of rainwater slows down the surface run off, reducing the chance of flooding. Rainwater can be intercepted by the placement of green interventions such as green façades or street trees (Chang and Ji 2012).	
Green Façade		Rain water is intercepted by planted facades, slowing down the water runoff and decreasing the pressure on the sewer system (Chang and Ji 2012).
Street Trees		Rain water is intercepted by trees, slowing down the water runoff and decreasing the pressure on the sewer system (Chang and Ji 2012).

Table 3 Design Toolbox (continuation)

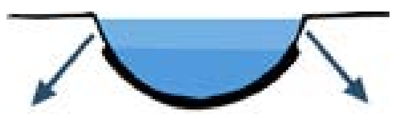
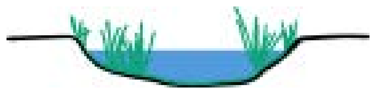
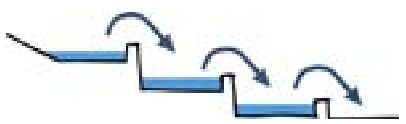
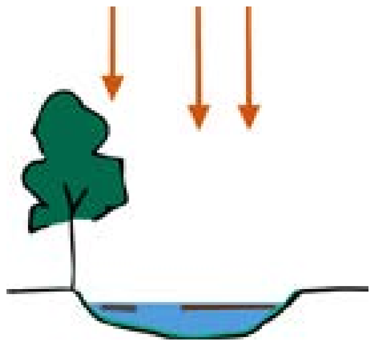
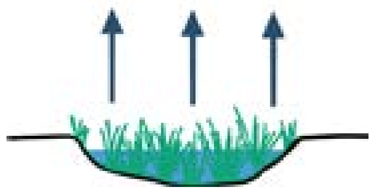
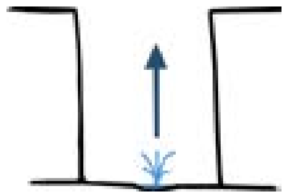
Flooding Prevention		
Storm Water Detention	Storm Water Detention relieves the pressure on the sewer system, by detaining the storm water in the area where it hits the surface, above the ground. Different interventions to detain the rain water are partly sealed basins, swales, rain gardens, green gutters, filter strips, weirs and terraced basins (Chang and Ji 2012).	
Partly Sealed Basin		In a Partly Sealed Detention Basin the basin is partly covered by an impermeable material. The sealed area remains filled with water, while excess storm water can overflow and infiltrate in the soil (Chang and Ji 2012).
Swale	 *(adapted figure from (shen 2015a))*	A swale collects the first flush of rainwater (Shen 2015).
Rain Garden	 *(adapted figure from (shen 2015b))*	Rain gardens can function as overflow basins during heavy rainfall (Shen 2015).
Green Gutter	 *(adapted figure from (shen 2015c))*	A Green Gutter collects the first flush of rainwater (Shen 2015).
Filter Strip	 *(adapted figure from (shen 2015d))*	The vegetated filter strip can trap sediments taken from paved surfaces by the water. The storm water can also infiltrate in the soil in this strip (Shen 2015).
Weir	 *(adapted figure from (shen 2015e))*	Weirs can be applied on steep slopes to slow down the surface run off (Shen 2015).
Terraced Basin	 *(adapted figure from (shen 2015f))*	Terraced basins can be created on steep slopes (Shen 2015).

Table 3 Design Toolbox (continuation)

Cooling UHI		
Shading		Planting can provide shading, so the water receives less short wave radiation (Hathway and Sharples 2012).
Evapotranspiration		Planting can evaporate water and cool the air with evapotranspiration (Robitu et al 2006).
Evaporation		Evaporating water features can cool down the air (Nishimura et al 1998).
Wind		Wind can move cooled air in an open space (Hathway and Sharples 2012).

3. Analyses

3.1 Heerlen

To locate a testbed area in the city of Heerlen it is important to locate the residential area with the largest Urban Heat Island problem. In order to do so I used a map from the climate effect atlas.
It indicates the number of nights when it is over 20 degrees Celsius. This provides a general overview of where the problem area roughly is located.

As you can see on the map from figure 3 the entire city centre is a UHI location, the next step is to analyse the city centre and locate a testbed area.

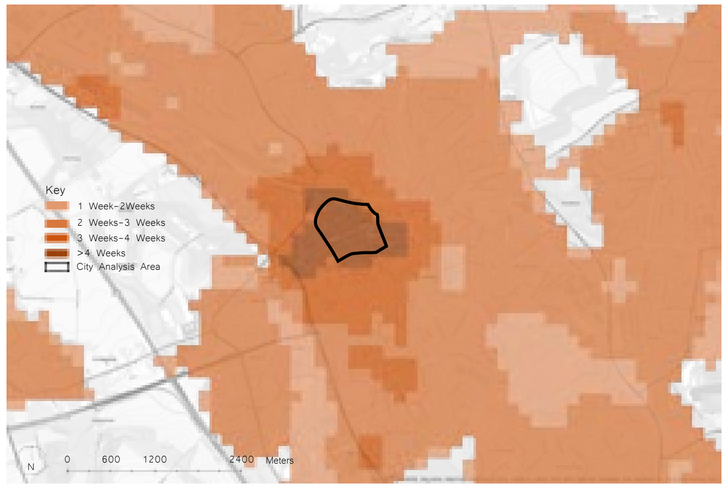


Figure 3 Urban Heat Island location Heerlen (adapted map from (Kennisportaal Ruimtelijke Adaptie 2016) and ArcGIS Topographic base map)

3.2 City Centre

The map below shows zoom in of the city centre where, according to the map in figure 3, the UHI is the highest. I assumed that the UHI would be strongest in the area with the highest building density. This is also in the city centre. The edges of the city are relatively green and so I reasoned that the UHI would be less there. The area of my analysis is now narrowed down to the area shown on the map in figure 4

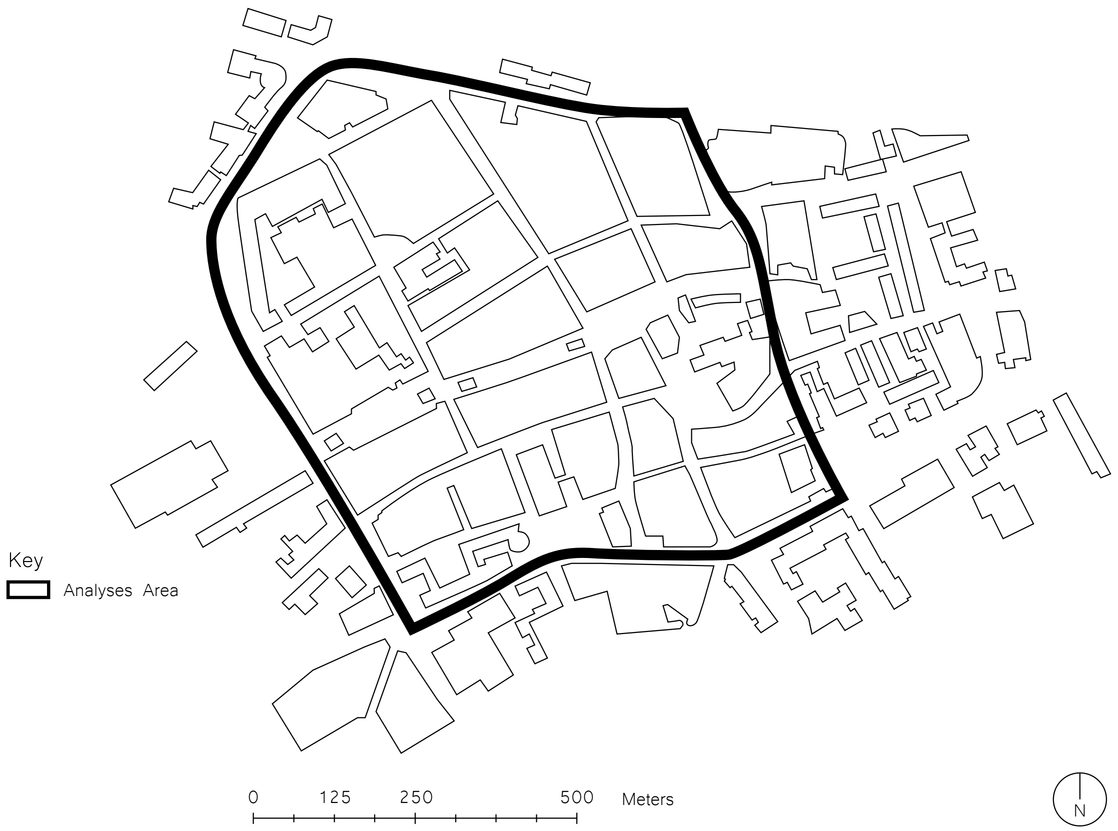


Figure 4 Analysis Area

In the city centre of Heerlen there are no existing water bodies. But there are problems with flooding after heavy rainfall in multiple areas in the city according to information from Ruud Weijers (Sep 2016) from the municipality of Heerlen. The areas where the storm water accumulates need to be located so interventions can be added to keep the water longer in the area and prevent flooding elsewhere in the city.

On my field trip to Heerlen I took note of the use of the buildings, whether they were residential or non-residential (see figure 5). I also looked at the vegetation present in the city and noted all the street trees and green patches (see figure 6). In the city centre there is a high amount of impermeable surface, and a small amount of drainage systems. Most streets were paved from building to building, leaving no space for the rainwater to infiltrate in the soil. There is certainly the necessity for improvement.

Figure 5 Analysis Building Use

Figure 6 Vegetation Analysis

Based on the height map/elevation map from AHN, I made assumptions about the flow direction of the rainwater and about the accumulation of rainwater. Most of the water flows to the North-West part of the city centre. The city centre is located on a ridge, with on both sides old brook valleys.

With the rainwater flowing through the city, it ought to accumulate in some places. On the map in figure 7 I showed the possible locations for the rainwater to accumulate. These are also the areas where a design intervention can be implemented to solve this problem.

There are two areas where the water can accumulate, with high human activity. These are the Bongerd and the Pancratiusplein (see figure 8) These squares are highly used during the day. Along the Bongerd there are a lot of shops and the weekly market is also located on this square. The Pancratiusplein is surrounded by restaurants and cafés. The Pancratiusplein also has a night time use, because there are also living quarters above the aforementioned facilities. Due to this day and night time use, the Pancratiusplein be-comes the perfect location for a cooling design intervention. Taking into mind that the goal of the cooling water bodies is to provide a cooler city and a more habitable environment, it is important to design an intervention in a location where residential areas profit from the cooling.

Figure 7 Storm Water Analysis

Figure 8 Potential Design Locations

3.3 Pancratiusplein

Before a design can be made for the square, an analysis needs to be made, which consists of vegetation, shading, elevation, wind flow, water flow, accessibility and functional use.

The amount and type of vegetation has an influence of water runoff and water infiltration. Permeable green areas can let rainwater infiltrate, reducing the surface runoff. Trees and shrubs can reduce the runoff by intercepting the rainwater. For the design it is important to know whether or not these elements are already present in the testbed area so this can be taken into account when designing.

The amount of shading, and with that the amount of sunshine on the square influences the surface temperature of the square and also the potential warming (or cooling) of implemented water bodies. Table 4 shows the shading in summer and winter on different times during the day.

The elevation influences the water runoff. It is important to know in which direction the water flows and accumulates in order to intercept, detain or infiltrate it. Figure 9 shows a model from the Pancratiusplein and in which direction the main water flows run.

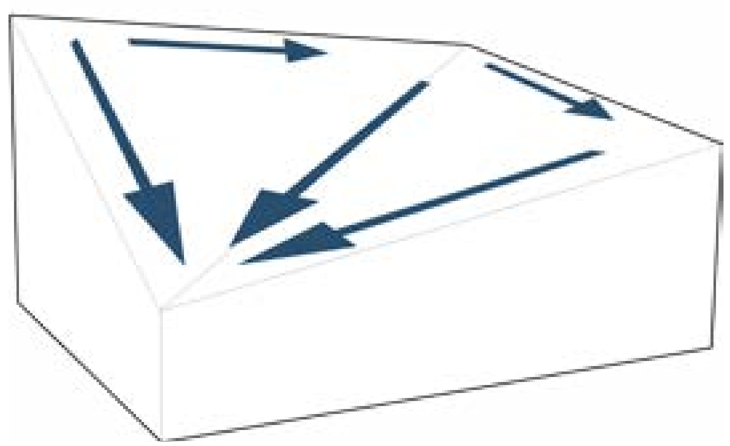


Figure 9 Conceptual Height Model and Main Water Flow Pancratiusplein

Table 4 Shading Analysis

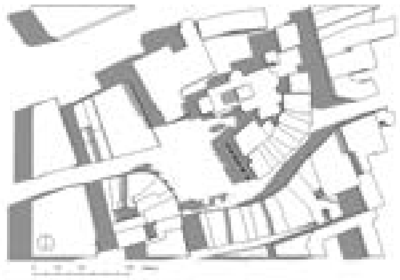
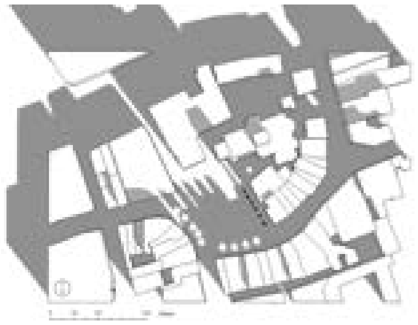
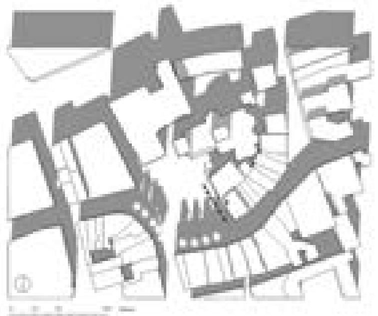
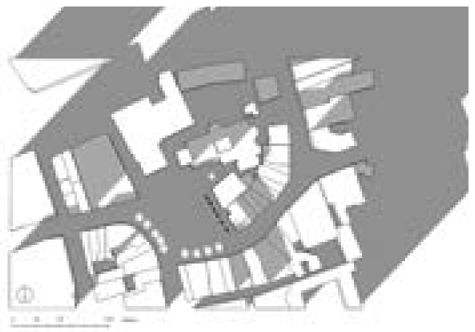
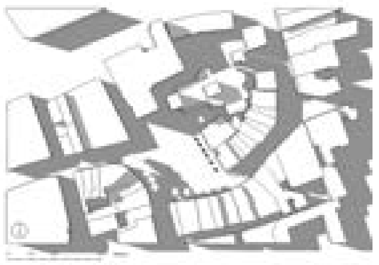
Time	Summer	Winter
8:00		
11:00		
14:00		
17:00		
20:00		

Table 5 Wind Direction on Warm Summer Days (KNMI 2016)

Date	Measured Temperature (Degrees Celsius)	Average Temperature (Degrees Celcius)	Measured Wind Direction	Average Wind Direction
05/06/2016	26.4	20.5	W	ZW
06/06/2016	26.1	20.5	NNO	ZW
07/06/2016	26.6	20.5	NNO	ZW
10/07/2016	29.8	22.8	ZW	ZW
18/07/2016	28.9	23.2	ZZW	ZW
19/07/2016	30.8	23.2	O	ZW
20/07/2016	33.9	23.2	Z	ZW
21/07/2016	27.9	23.9	W	ZW
22/07/2016	26.6	23.9	NNO	ZW
23/07/2016	25.8	23.9	NNW	ZW
24/07/2016	26.5	23.9	W	ZW
25/07/2016	25.2	23.9	WZW	ZW
17/08/2016	25.6	23.4	ONO	ZW
23/08/2016	28.7	21.5	ZZO	ZW
24/08/2016	32.1	21.5	OZO	ZW
25/08/2016	33.3	21.5	ZZO	ZW
26/08/2016	31.0	21.5	NNW	ZW
27/08/2016	32.3	21.5	ONO	ZW
28/08/2016	27.1	21.5	WZW	ZW
30/08/2016	25.7	21.5	WZW	ZW
07/09/2016	26.6	20.2	O	ZW
08/09/2016	27.6	20.2	ZW	ZW
10/09/2016	26.1	20.2	NNW	ZW
11/09/2016	25.8	20.2	Z	ZW
12/09/2016	29.5	19.0	ZO	ZW
13/09/2016	32.7	19.0	ZO	ZW
14/09/2016	32.2	19.0	O	ZW
15/09/2016	28.5	19.0	Z	ZW

Wind flow can be used to cool down the square, but in order to do so we need to know how the wind flows over the square, in which direction and if the wind flow reaches the surface of the square. Table 5 shows the measured wind direction on hot days (over 25 degrees Celsius) and the average wind direction from the weather station in Maastricht. Figures 10, 11 and 12 show how the wind flows over the square, and where it reaches the surface.

Figure 10 Location Wind Sections

On the analysis map in figure 13 you can see that there is little vegetation on the square. There are no vegetated permeable surfaces where the water can infiltrate. There are trees along the square, which can intercept rainwater and provide shading for the terraces.

The shading analysis show that most of the daytime use areas (the terraces) are shaded during the warm summer days, either by buildings or by the trees. There is however one terrace, on the north side of the square, where it is always sunny. The rainwater also flows to this corner where it will accumulate. The combination of wettest and sunniest area is an interesting puzzle to solve. Because when a waterbody is implemented here, it is also important to keep the water from warming up due to the constant radiation from the sun on summer days.

The information from the KNMI shows that on warm days (over 25 degrees Celsius) the wind flows most of the time from the North-West (instead of the usual South-West). This wind, in combination with a cooling design intervention, can be used to cool the terraces and the residential areas on the south and west side of the square.
In order to cool the Northern terrace, solve the flooding problem and cool the residential areas on the north-west corner an intervention should be located in the north-west corner. To cool the terraces and the residential areas on the south side using the wind flow over the square, an intervention should be implemented in the south-west corner.

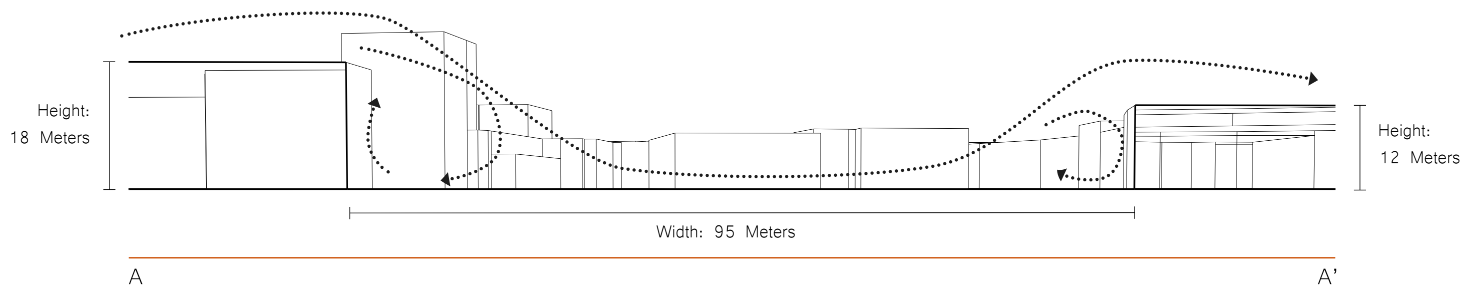


Figure 11 Wind Section A-A'

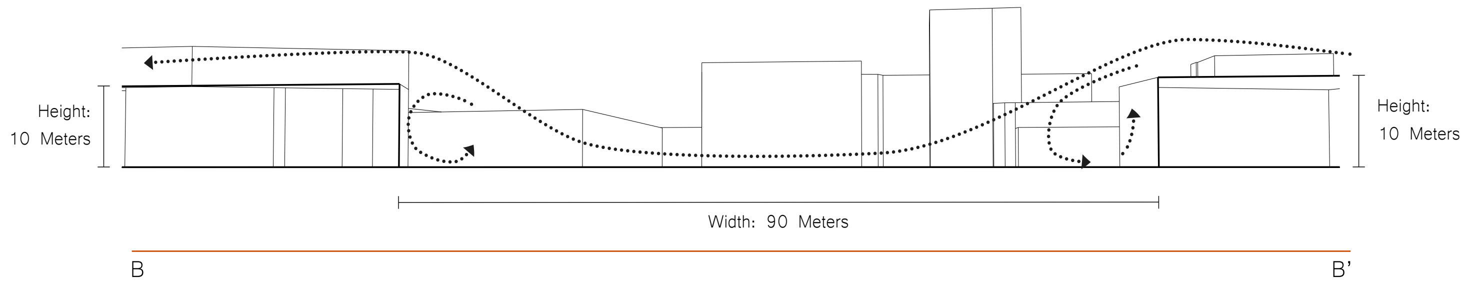


Figure 12 Wind Section B-B'

Figure 13 Analysis Map Pancratiusplein

The accessibility and functional use are also important elements to take into account. The new design should have a minimal impact on both elements, as not to limit the current accessibility and functional use of the space. Figure 14 shows the flow of people over the square. The city centre is car-free. The most intensely used route is the north-south route on the west side of the square. The access from the north-east corner is barely used.

Throughout the year there are multiple events located on the Pancratiusplein. There are book fairs, carnival and festivals among the activities. The map in figure 15 shows the location of these different events, the entire square gets used.

Figure 14 Analysis People Flow

Figure 15 Analysis Event Locations

4. Research Through Design

4.1 Testing Designs

Based on the analyses I started designing interventions for the square. I tested the designs with a checklist with design criteria. With each new design new criteria were added to the list to eventually come up with the best design

The designs are conceptual and on a 1:1000 scale (on A3), the final design will be explained in more detail in the next sub-chapter. The first 3 designs are tested with Cooling and Flooding Prevention Design Criteria. To look for combinations of design tools from the Design Toolbox and see how they could fit in the square and provide the best cooling and flooding prevention. The designs 4-8 all scored the same on the cooling and flooding design criteria.
I tested these last 5 designs also on accessibility and functionality. The impact of the design should be minimal on these last two factors, as not to limit the current use of the square.

4.1.1 Design Concept 1

Design 1 (see figure 16) consists of one main large vegetated infiltration area, with trees for rainwater interception. There are two main water detention basins which come together in one basin in the north-west corner. The rainwater on the square either infiltrates in the permeable vegetated area or gets collected in the basins. The vegetated area provides cooling via evapotranspiration.

Table 6 shows which design criteria are incorporated in this design.

Table 6 Design Criteria Concept 1

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	-
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-

Figure 16 Design Concept 1

4.1.2 Design Concept 2

Design 2 (see figure 17) is created on a grid, some of the blocks are water bodies, the water flows from block to block all around the square, from the highest point to the lowest. This long water way functions as rainwater runoff route, during dry days there is no water in these blocks. The short route for the water is always filled with water, at the bottom all the water gets collected in a detention basin. There are trees along the short route here which shade the water, to prevent it from warming up. Some blocks consist of vegetation where water can infiltrate and cooling via evapotranspiration takes place and trees intercept rainwater to slow down the runoff. Excess storm water, which overflows from the water blocks can also infiltrate in the vegetated blocks.

Table 7 shows which design criteria are incorporated in this design.

Table 7 Design Criteria Concept 2

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-

Figure 17 Design Concept 2

4.1.3 Design Concept 3

Design 3 (see figure 18) has a main element on the north side, which is a cascade intervened with strips of permeable, vegetated infiltration areas. Each basin of the cascade functions as a detention basin, excess water can overflow in the infiltration strip or in the next basin. The overflowing of the cascade provides evaporating of water, and with this cooling of the air. The Water which flows to the basin is collected in three main gutters which run over the square and are connected to the cascade. The cascade is shaded with trees to prevent the water from warming up and to intercept rainwater to slow down the rainwater runoff.

Table 8 shows which design criteria are incorporated in this design.

Table 8 Design Criteria Concept 3

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	+
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-

Figure 18 Design Concept 3

4.1.4 Design Concept 4

Design 4 (see figure 19) consists of a cascade going all around the square. The rainwater is collected directly into the detention basins of the cascade. Between the basins there are infiltration strips, which are vegetated and which also provide evapotranspiration. On the north-east side at the top of the cascade there is a fountain, evaporating water and providing water to keep the cascade flowing. The cascade itself also provides evaporation. At the end of the cascade there is another detention basin with a fountain, this fountain cools the nearby terrace by evaporation. The trees provide shading to keep the water cool. The centre of the square is left open so the wind can cool the area using the cooled air.

Design 4 consists of all the cooling and flooding prevention design criteria (see table 9). Now we need to analyse what the effect of the design will be on the functional use of the square. Figure 20 shows that design 4 hinder most of the events on the square. Only the use of the screen is still possible, but there is little space for people to gather on the square to make use of the screen so its usability is questionable. Figure 21 shows the effect of the design on the accessibility and people flow on the square. Most routes get blocked by the cascade, hindering people in their use of the square.

Table 9 Design Criteria Concept 4

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-
Functional	
High used Routes	-
Medium used Routes	-
Low used Routes	-
Stage	-
Market Stalls	-
Bars	-
Tent	-
Screen	+

Figure 19 Design Concept 4

Figure 20 Design 4 Event Analysis

Figure 21 Design 4 People Flow Analysis

4.1.5 Design Concept 5

The main element of Design 5 (see figure 22) is the detention basin in the north-west corner. Here all the water gets collected. Three small cascades are connected to the basin. At the top of each cascade a fountain is placed, which cool the air by evaporation. Around the basin and along the cascades there are green infiltration strips which also provide cooling via evapotranspiration. The rainwater gets collected in the cascades, which function as overflow basins for excess storm water. Three trees provide shading for the main water basin to prevent it from warming up, the trees also intercept rainwater to slowdown the runoff. The centre of the square is left open to let the wind cool the area, using evaporated water from the fountains.

Table 10 shows which design criteria are incorporated in this design.

Design 5 still blocks most of the event functions of the square. Like design 4, this design only had space left over for the screen. But also on this design there is no space for people to gather to make use of this facility. There is more room for fair stalls, but the use is still limited (see figure 23). The accessibility of the square has improved, as there is now again a highly used people flow route available. The crossing of the square however is still limited (see figure 24).

Table 10 Design Criteria Design 5

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-
Functional	
High used Routes	+
Medium used Routes	-
Low used Routes	-
Stage	-
Market Stalls	-
Bars	-
Tent	-
Screen	+

Figure 22 Design Concept 5

Figure 23 Design 5 Event Analysis

Figure 24 Design 5 People Flow Analysis

4.1.6 Design Concept 6

Design 6 (see figure 25) consists of two water basins which are connected by a cascade. The element is surrounded by a vegetated infiltration strip which provides evapotranspiration cooling. In both basins there is an evaporative fountain, cooling the terrace in the north-west corner and those in the south-west corner. All the rainwater runoff flows into the water element, not via gutters but over the surface. Trees provide shading for the water basin which is located in the sunny area. The trees also intercept rainwater, slowing down the runoff. The centre of the square is left open to let the wind flow cool the terraces on the south side of the square.

Table 11 shows which design criteria are incorporated in this design.

Figure 26 shows the effect of design 6 on the functionality of the square. This design provides more space for events, while still cooling and preventing flooding. But there is still no space for larger events, like the book fair. Over a third of the square is still occupied by the design, limiting its current use. The map in figure 27 shows which routes are still blocked by the design. There is now a good connection between north and south, but crossing the square in other directions is still a challenge.

Table 11 Design Criteria Concept 6

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-
Functional	
High used Routes	+
Medium used Routes	-
Low used Routes	-
Stage	+
Market Stalls	+
Bars	-
Tent	+
Screen	-

Figure 25 Design Concept 6

Figure 26 Design 6 Event Analysis

Figure 27 Design 6 People Flow Analysis

4.1.7 Design Concept 7

Design concept 7 (see figure 28) has two interventions. The intervention in the south consists of a detention basin with evaporative fountains. The basin is surrounded by a vegetated filter strip which also provides evapotranspiration. The water which flows in this direction over the square is collected in this basin. The intervention in the south is similar to the one in the north. This basin is larger, it is locate on the lowest point of the square and more water will flow into this basin. The basin is shaded by some trees, which also intercept rainwater. The fountains in the south cool the terraces and residential buildings in the south using the wind flow. The terrace in the north and the residential building in the north-west are cooled by the fountains in the northern intervention.

Table 12 shows which design criteria are incorporated in this design.

Opening up the square, as done in design 7, provides more space for the functional use of the square. On the map in figure 29 you can see that almost all events can occur on the square, there is only still limited space for bars and the screen. Figure 30 shows that the routes are still not all accessible, but with little adjustments the square could almost be fully accessible. Especially the routes in the south of the square could also go around the element without changing the flow to much.

Table 12 Design Criteria Concept 7

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-
Functional	
High used Routes	+
Medium used Routes	+
Low used Routes	-
Stage	+
Market Stalls	+
Bars	-
Tent	+
Screen	-

Figure 28 Design Concept 7

Figure 29 Design 7 Event Analysis

Figure 30 Design 7 People Flow Analysis

4.1.8 Design Concept 8

Design 8 (see figure 31) consists of two elements. There is a row of fountains on the south side, which cool the terraces and residential buildings there using the wind flow over the square. On the north side there is a detention basin, a green infiltration strip provides cooling via evapotranspiration. The rainwater which flows over the square to this area will infiltrate here and in case of excess storm water, it will overflow into the basin. In the basin there are fountains to cool the terrace and residential building on the north side of the square. Trees provide shading for the water basin and intercept rainwater to slow down the runoff. All the rain water flows naturally to the north-west corner of the square, because of this there is no need for an infiltration area on the south side of the square.

Table 13 shows which design criteria are incorporated in this design.

Figure 32 shows that all the functions, except for the screen, can still occur on the square. The fountains are in a location where there are also stalls and bars, but the fountains can be turned off. The screen is a small event location, which can be moved to another location since it is not used in combination with for example the stage. When the fountains are off there is more space for the events on the square. Figure 33 shows that all the people flow routes are still possible with design 8, only one route in the north is blocked, but with a small adjustment this problem can be solved, and the natural flow can continue.

Design 8 consists of all requirements, making it the final design for the Pancratiusplein. In the next chapter I will explain the design in further detail.

Table 13 Design Criteria Concept 8

Design Criteria	**Incorporated in Design (+/-)**
Flooding Prevention/Cooling UHI	
Water Collection	+
Water Detention	+
Evaporative Water Feature	-
Shading of Water Body	+
Cooling Wind Flow	-
Evapotranspiration (planting)	+
Rainwater Interception	+
Excess Storm Water Infiltration	+
Cool Terraces	-
Cool Residential Buildings	-
Functional	
High used Routes	+
Medium used Routes	+
Low used Routes	+
Stage	+
Market Stalls	+
Bars	+
Tent	+
Screen	-

Figure 31 Design Concept 8

Figure 32 Design 8 Event Analysis

Figure 33 Design 8 People Flow Analysis

4.2 Final Design

The map in figure 34 shows how the design is fitted into the square. The intervention in the north, the Cooling Island, has as one of its functions cooling the terrace on the north side of the square. The cooling island is situated closely to the terrace and the steps in front of it, but leaving space in between to improve accessibility of both the terrace and the square.

The intervention in the south, the Cooling Curtain, is implemented in the drainage system which is already present on the square. The fountains will be fitted into this system, the water can be easily collected into the gutter and reused.

Figure 34 Final Design

4.2.1 Cooling Island

The Cooling Island (see figure 35) consists of two main elements. One is the water basin with the evaporative fountains, the other is the infiltration area with the shading trees. The water basin is terraced to emphasize the elevation of the square on the north side the basin has a high edge, where people can sit (see figures 36, 37 and 38). The design provides in this way a new meeting space for people. On the south side it has a low edge, on the same level as the infiltration area, so excess storm water can overflow from the infiltration area into the basin. The basin itself can store the extra water, when the storage level is exceeded, the water will infiltrate through the permeable edge of the partly sealed detention basin (see figures 39 and 40).

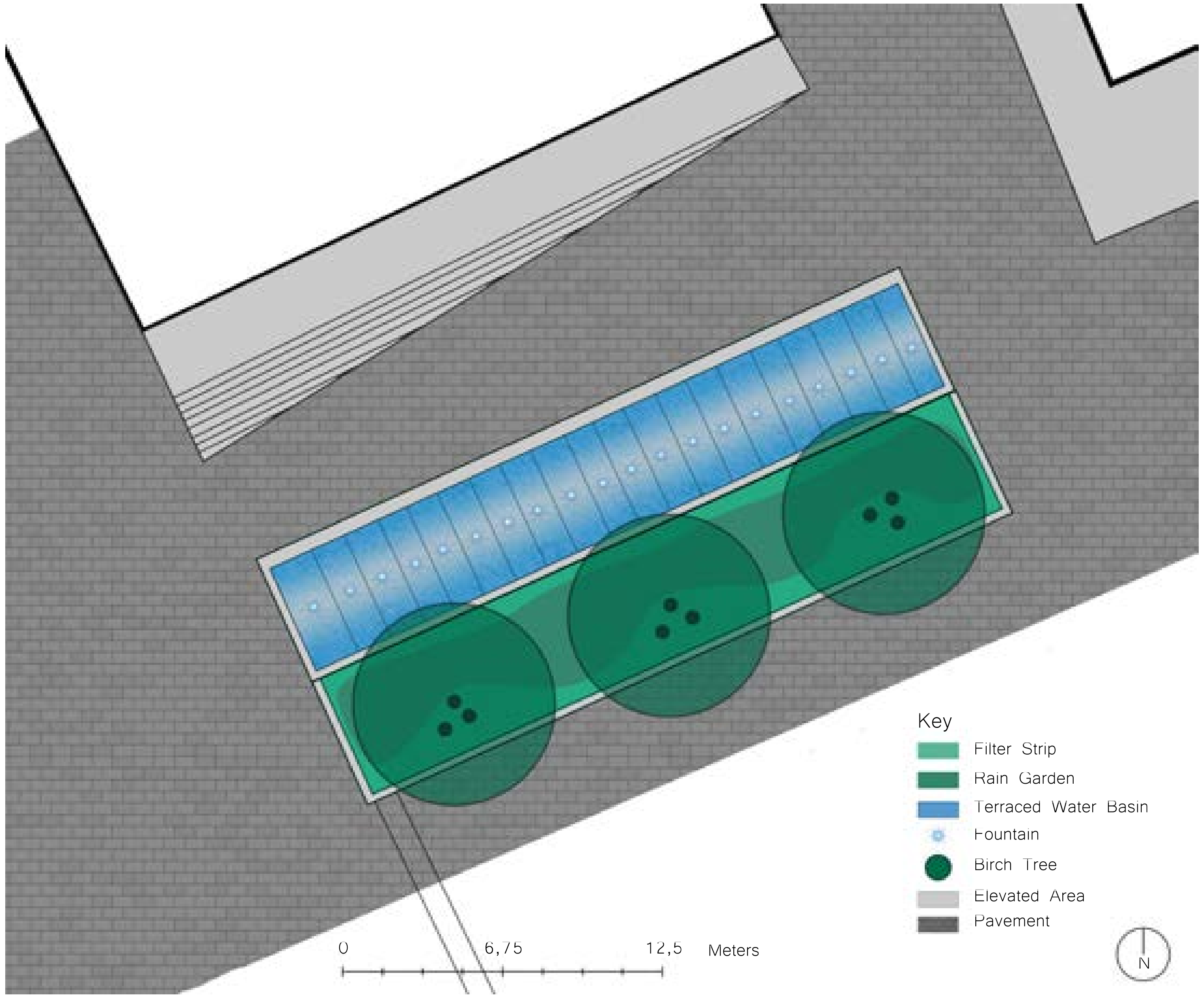


Figure 35 Detailed Design Cooling Island

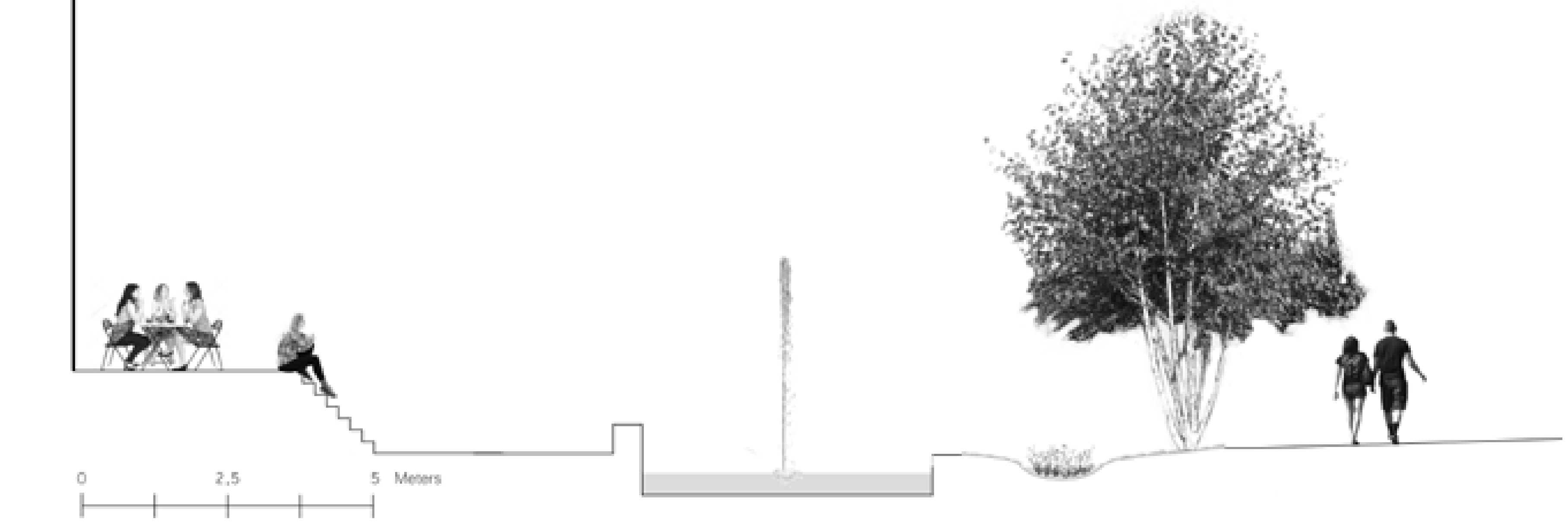


Figure 37 Cooling Island: Section

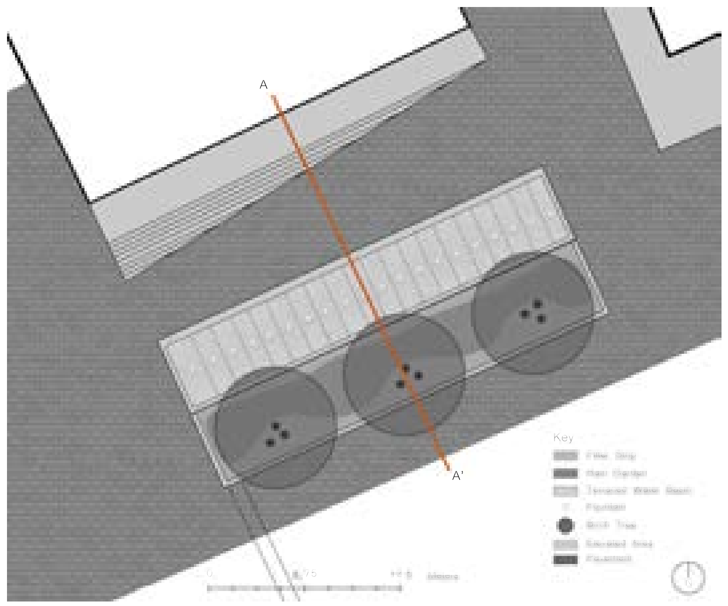


Figure 36 Cooling Island: Section Location

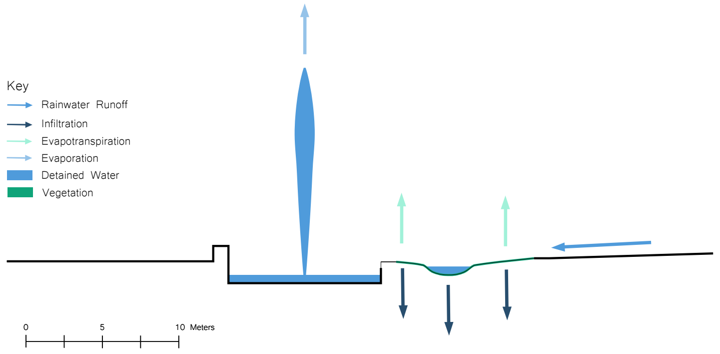


Figure 39 Cooling Island Water System Basic Situation

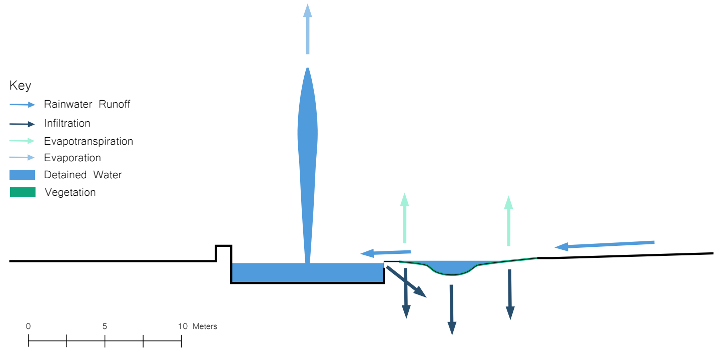


Figure 40 Cooling Island Water System Excess Water Situation

The infiltration area has three main elements, a raingarden, a buffer zone and shading trees. The rainwater is stored in the raingarden, where it will infiltrate in the soil. The raingarden will be planted with native, white flowering species for a fresh and light vibe. The trees will be multi-stem birch trees. These multi-stem trees have a larger canopy mass than single-stem trees, providing more shading (Van den Berk 2016b). The white ornamental bark contributes to the fresh and light vibe from the plants in the raingarden. In table 14 there is an overview of the species used in the Cooling Island design.

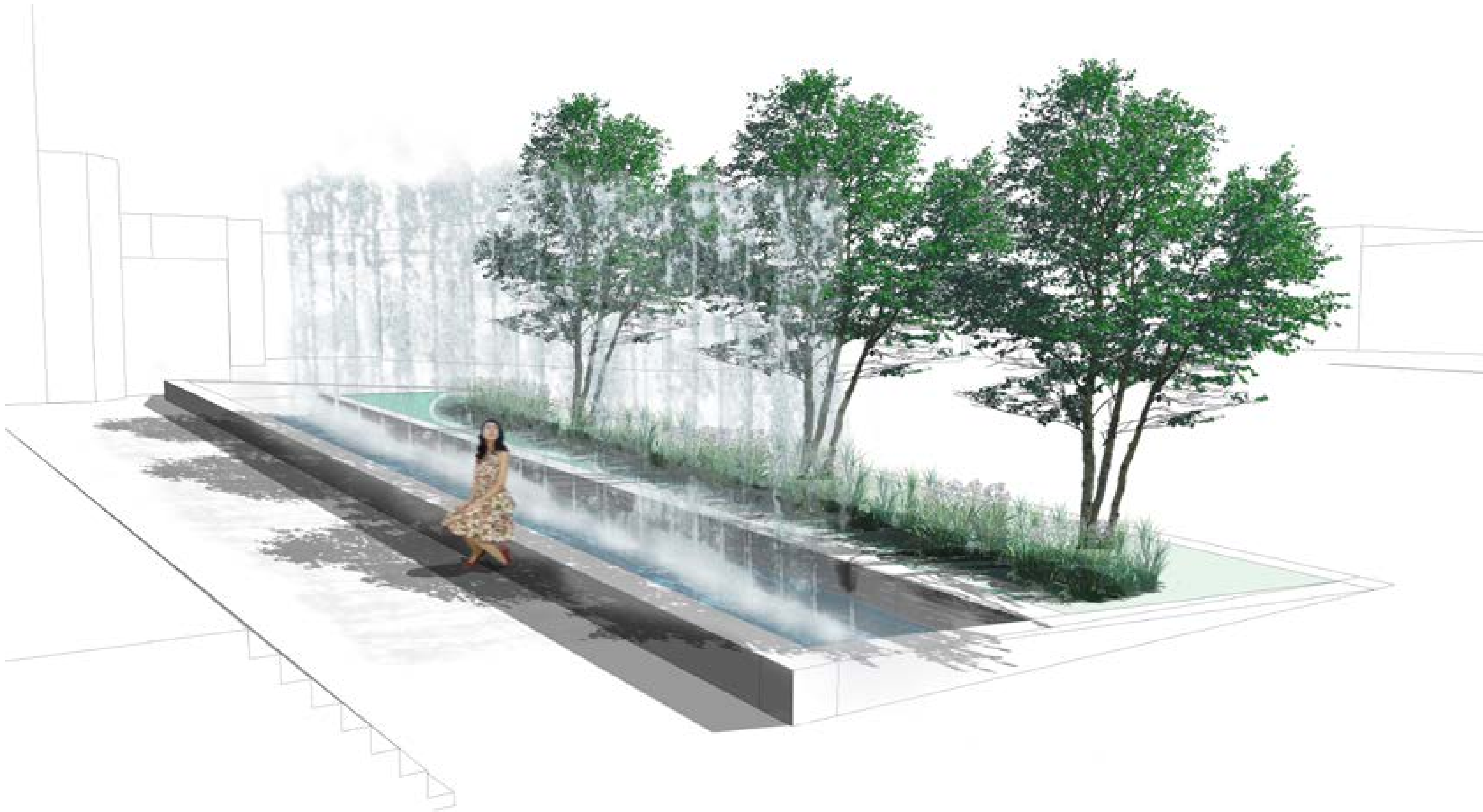
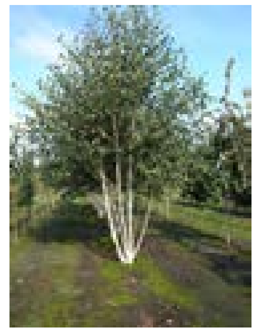


Figure 38 Cooling Island: Visual

Table 14 Species Cooling Island

Species Cooling Island	
Herbaceous	
Eleocharis palustris	 *(Kwekerij Schiffelers 2016a)*
Eriophorum angustifolium	 *(Kwekerij Schiffelers 2016b)*
Hippuris vulgaris	 *(Kwekerij Schiffelers 2016c)*
Sagittaria sagittifolia	 *(Kwekerij Schiffelers 2016d)*
Trees	
Betula utilis ' Doorenbos'	 *(Van den Berk 2016a)*

4.2.2 Cooling Curtain

The Cooling Curtain has a simple design (see figure 41). It is a row of fountains, in an angle, placed in a gutter where all the water gets collected (see figures 42 and 43). Depending on the wind direction the fountains can be turned on or off, to waste as little water and energy as possible. When there are events the fountains can also be turned off, to provide enough space. The fountains evaporate water, which the wind can blow to the terraces, in this way the Cooling Curtain provides cooling for the terraces and residential buildings on the south and south-west side of the square. An additional function of the element is recreational. When the weather is nice it can function as play element, for children (or adults) to cool down (see figure 44).

Figure 44 Cooling Curtain: Visual (adapted photo from (Plangroep Heggen B.V. 2016))

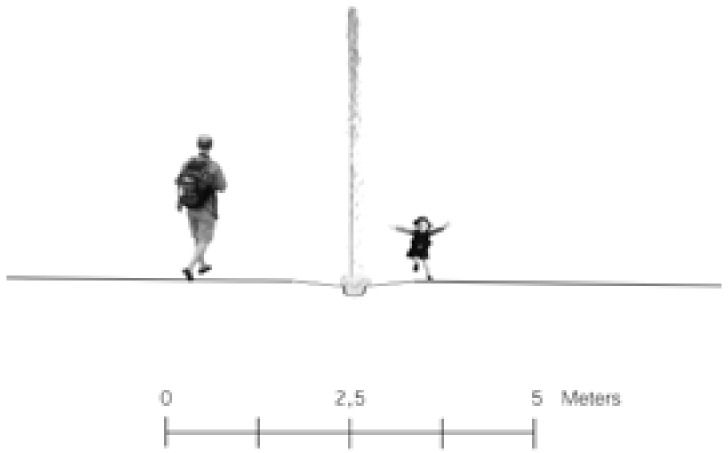


Figure 43 Cooling Curtain: Section

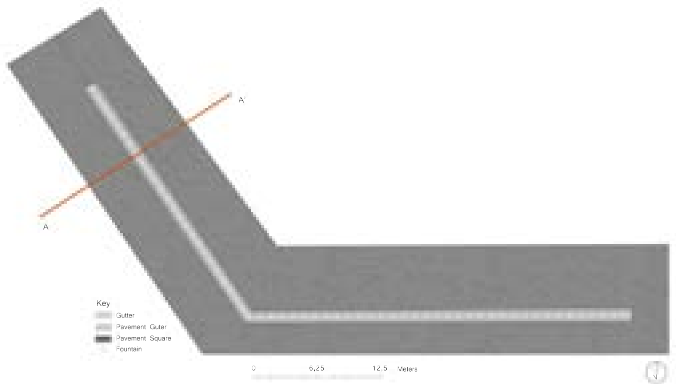


Figure 42 Cooling Curtain: Section Location

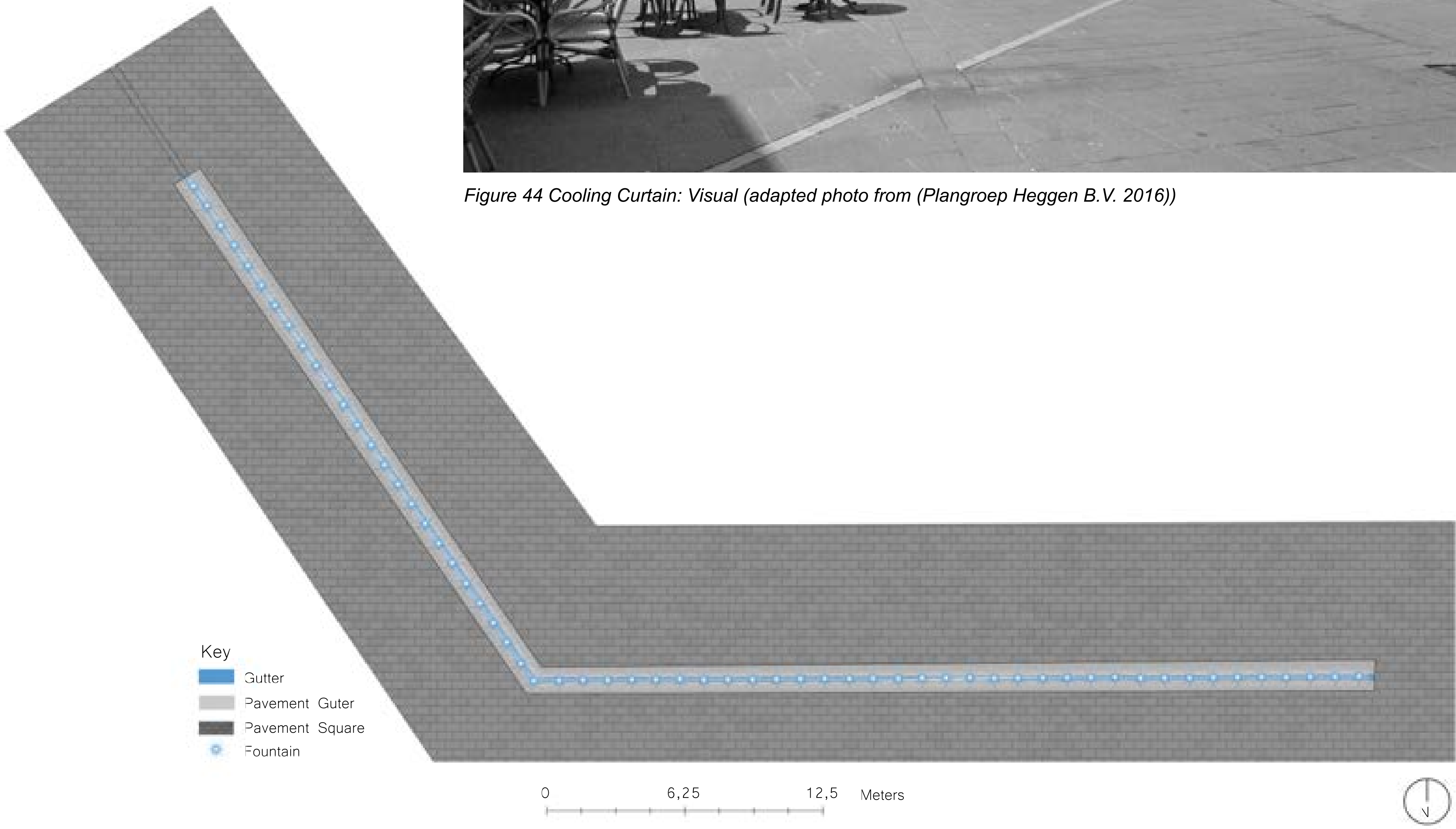


Figure 41 Detailed Design Cooling Curtain

4.2.3 Water System

To waste as little water as possible I designed a semi-closed water system (see figure 45). The water from the Cooling Curtain is collected in the open gutter. The rainwater which runs over the surface will partially also be collected in the fountain gutter and partially in the raingarden. This water flows under the street to the water basin from the Cooling Island. The water from the fountains of the Cooling Island is also collected in the water basin, as is the overflow of the raingarden. This water partially infiltrates in the soil (due to the partially sealed detention basin), the rest of the water can be reused for the fountains in both the Cooling Island and the Cooling Curtain. The system is partially closed because in case of drought, new water has to be added to the system. In case of severe rainfall the water basin of the Cooling Island will overflow into the sewer system to prevent the flooding of the basin.

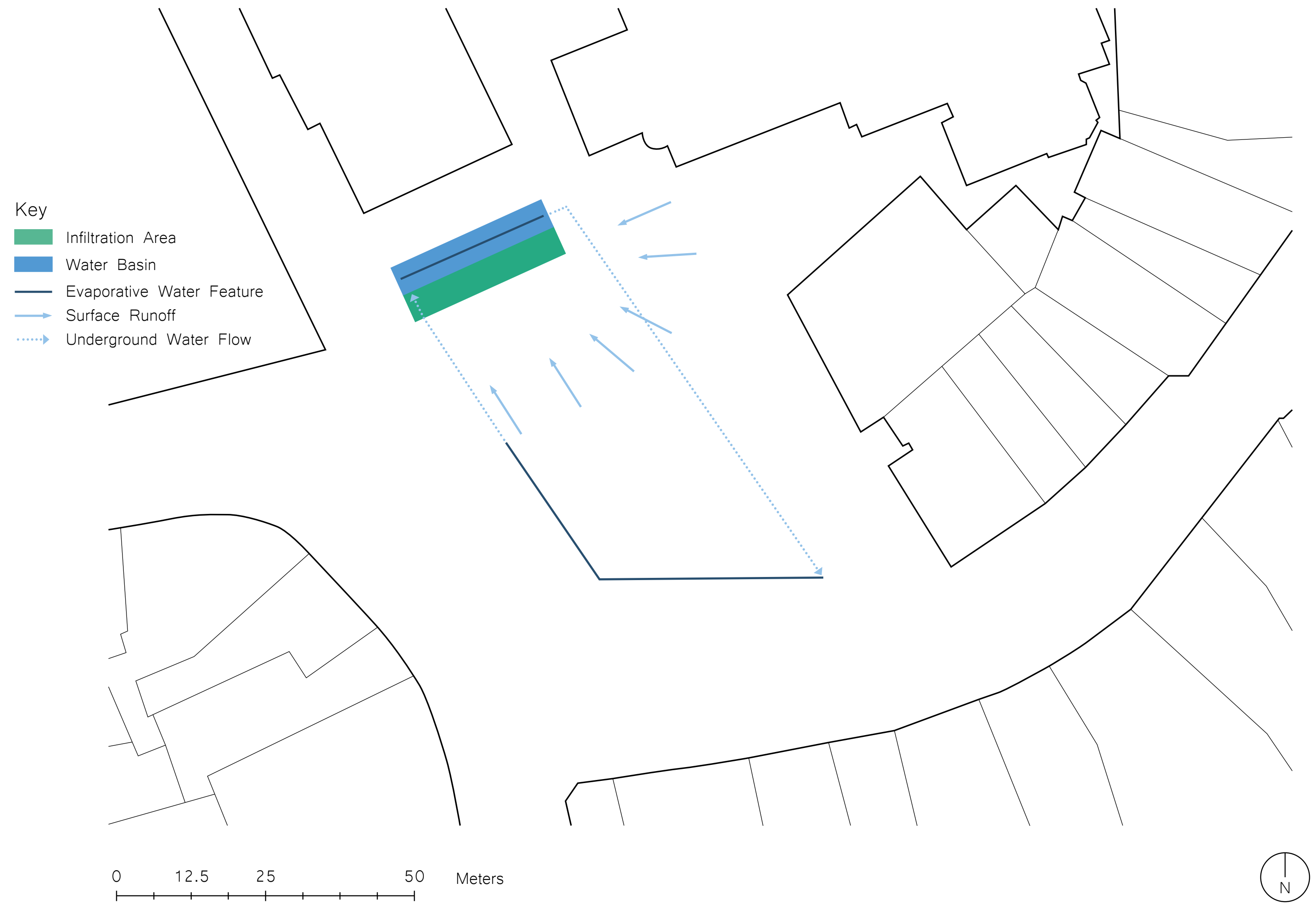


Figure 45 Water System

4.2.4 Cooling Effect

The map of figure 46 shows the effect of the design on the Pancratiusplein. The Cooling Island provides cooling via evaporation, evapotranspiration and shading. The Cooling Curtain provides evapotranspiration, the wind cools the nearby terraces with this cooled air (see figure 47).

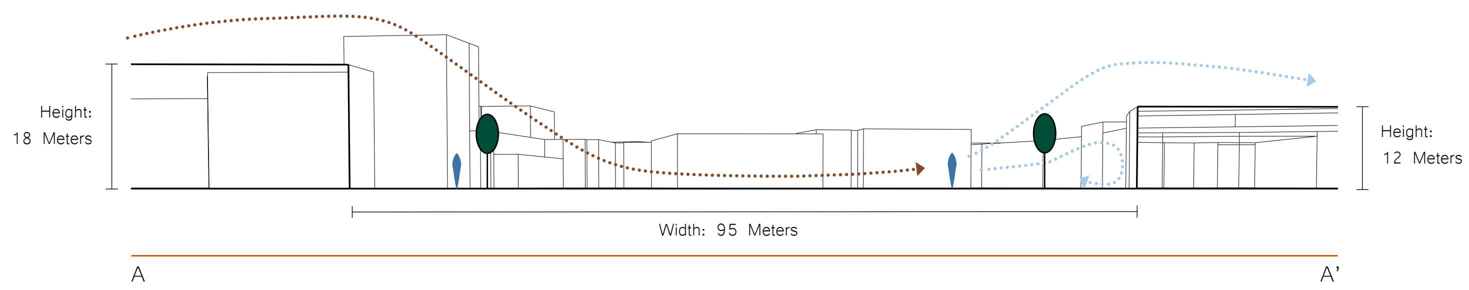


Figure 47 Cooling Effect: Section

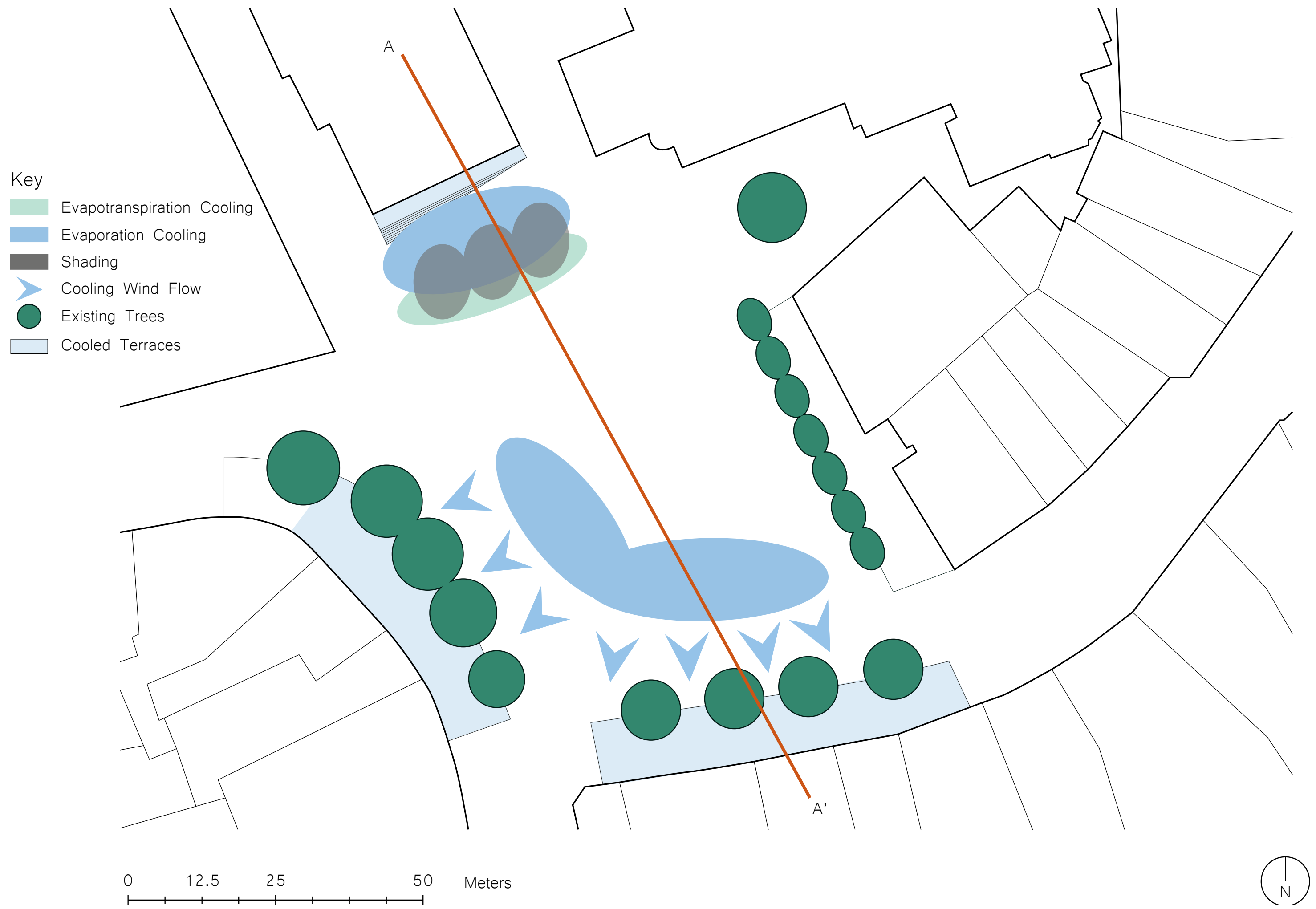


Figure 46 Cooling Effect

5. Discussion & Conclusion

5.1 Discussion

For the research of the city of Heerlen there was very little information available. With the assembled information I was able to make logical assumptions, analyses and connections which led to a final design. With the limitation of resources there is a wider range for misconceptions. The map which I used to locate the UHI was very general. There is the possibility that the UHI effect was higher in a different part of the city. Other areas of the city were much more open and contained more vegetation than the city centre. The city centre also had a very high amount of impermeable surface which made it more probable for the problem to be the largest in the city centre.

Solving the flooding problem and water nuisance in Heerlen might not necessarily need to be located on the Pancratiusplein, or in the city centre at al. According to information from the municipality there was no flooding in the city centre. This could be possible because of the elevated location of the city centre. The city is located on a ridge, with old brook valleys on both sides. The water which causes the problem elsewhere in the city might have flooded from the city centre into this area, but it might also have not. It is important to take in mind that the main goal of this research is not to solve water nuisance but to cool the city, and tackle the UHI. Therefore I went looking for possible problems and solutions for the water nuisance in the UHI location. The solution for the water nuisance might not be necessary now, but in the future, with warming climates and more extreme precipitation, it might become indispensable.

The location for the water accumulation in the city centre is now estimated, it could be that not all the locations where the water theoretically accumulates have water nuisance. There could be very proper drainage systems in the area. Or if you look at it the other way around, there could be more areas with water accumulation and water nuisance due to the lack of properly working drainage systems.

Al these ‘what ifs’ and possible flaws in assumptions made could mean that there is another location in the city where the problem of the UHI should be tackled. But the toolbox which I assembled is applicable in multiple situations. It is the combination of elements which can be changed and adjusted to fit in other areas. So the solution might be the same, but the final design will be different.

The final design which I made is not generalizable, it cannot per se be applied to squares all over Limburg or the Netherlands, but the method of analyses and research through design can be generalized and the toolbox can be applied to more areas then only Heerlen. It is in this way that the RealCool Heerlen project can be an example for other designers and can be an inspiration to the REALCOOL project.

5.2 Conclusion

I started my research with five questions, which led to my final design.

(Knowledge) Question 1:
Where are the Urban Heat Islands located in the city of Heerlen?

The first quest was to find the location of the Urban Heat Island in Heerlen.
In order to do so I used maps from the climate effect atlas. The analyses of these maps showed that there was one main area with a high amount of warm nights, indicating the UHI, which was covering the city centre of Heerlen.

(Knowledge) Question 2:
Where are areas with water nuisance in the UHI locations in the city of Heerlen?

The second quest was to locate the water nuisance areas within the Urban Heat Island of Heerlen. To locate these I first needed to know how the water flows through the city centre (as this was the location of the UHI). Based on the elevation map I determined the flow direction on the rainwater. To indicate this I placed arrows in a map of the area. In areas where many arrows came together, or where the direction of a flow was blocked by a building, I reasoned that the rainwater would accumulate here, and could provide water nuisance (see figure 48).

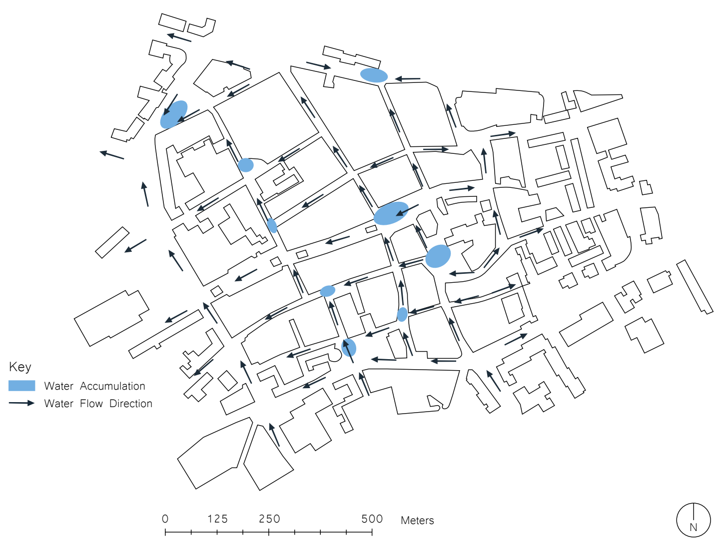


Figure 48 Water Nuisance Location

(Knowledge) Question 3:
What design interventions can be used to cool down the city?

In order to counteract the events of the UHI I need to know what interventions can be used to do so. Information from scientific articles and master theses provided me with a wide range of tools to reach this goal. The main interventions are:

- Shading from planting
- Evapotranspiration from planting
- Replacing hard materials for vegetation
- Using evaporative water features
- Using wind to spread cooled air

(Knowledge) Question 4:
What design interventions can be used to decrease water nuisance in the city?

Flooding, and water nuisance can be prevented by intercepting and detaining rainwater to slow down the runoff and relieve the pressure from the sewer system. Two ways of intercepting rainwater are by green facades or by street trees. For the detention of rainwater there are multiple interventions. The soil in Heerlen has a high infiltration rate (when the surface is permeable), but to cool down the city with water, there needs to be water in the city. So it is also important to not let all the water infiltrate in the soil.
Therefore a partly sealed detention basin is a possible intervention. Water can be stored in the area, and excess storm water can infiltrate in the soil. This detention basin can have many shapes. It can be a swale, a raingarden or a green gutter. On steep slopes water can be detained by adding weirs or terraced basins. Infiltration of water can also take place in vegetated filter strips, to reduce the surface runoff.

(Design) Question 5:
How can a design intervention with water decrease the water nuisance and counteract the effects of the Urban Heat Island in the city of Heerlen?

With this last question all the information comes together. My final design has shown how both the water nuisance and the UHI can be tackled in one design. I combined certain aspects of the flooding prevention and cooling of the city. There is a vegetated infiltration area, to reduce the surface runoff, but the combination of planting and water also provides cooling via evapotranspiration. Trees are used to shade the main water body from the sun and prevent the water from warming up. Evaporative water features are combined with wind flow to spread the cool air. And the water basin, which’s water is used for the fountains has a second function as detention area and partly sealed basin for the excess storm water. The combination of multiple tools is the key to solve the puzzle of the UHI and water nuisance in the city of Heerlen.

6. Reflection

6.1 Research Approach and RTD Process

During my time as a Bachelor student at the Wageningen Univeristy I followed multiple design studios. In these courses we already learn to work with the facts, to analyse our research area and make logical cause-effect relationships. But to do a Bachelor Thesis is something else. There was the search to do something new, to come up with interventions which no one had thought of yet. The research approach of design has an exciting element to it. You acquire new knowledge which can be applied to your designs. And making designs based on research helps support and strengthen your designs which helps you in creating a story about the landscape you are wor-king with.

Designing based on information from research also helps building confidence, you know what you are designing could work, that you are right. If then it appears it is not such a good idea after all you either didn't think properly about it or your graphical skills or imagination is just not as good as you expected.

Designing also helps in the research process, through designing you come up with new ideas which can be tested, altered, changed, optimized. You learn new things about the object you are working with and you can come up with new hypotheses.

Working with design criteria and a design toolbox guide you through the process of Research Through Design. Your gut is telling you something is not right, but the criteria are telling you what it is. Not only your design is changing but also your criteria. At each new stage in you RTD process adjustments need to be made and new ideas occur. The more you design the more you learn about what it should become and what it should look like. Each stage you dive deeper into your design and eventually every detail will be clear to you and a final design will be created.

6.2 Experiencing the Bachelor Thesis

My expectations of the course was that it would be similar to a design studio, but we would also have to write a report. At the first meeting with the supervisors, coordinators and fellow students, we were told that the bachelor thesis would be very different from a design studio. The tutoring would be limited to 5 hours per student, which made the process of this research more independent than a studio. The limited supervision also provided more freedom to plan my work, which made the process less stressful. The tutoring each week and the intermediate deadlines for presentations and the report kept me on track but did not hinder my workflow.

In the past 8 weeks I made steady progress in my research, the tutoring helped me each time move into the next phase of designing and the presentations opened my eyes for other possibilities to approach the designing.

During this thesis I learned to be more confident about my work, and not stress out at each bump in the road. The analytical approach to the research helped me understand how to create a design with a convincing story.

6.3 Personal Learning Objectives

When I started my thesis I wrote down four personal learning objectives.

The first learning objective was to efficiently write a report. Before I wrote this report I had the tendency to assemble as much information as I could find, then try to fit it into a report-shape and at the same time get lost in the amount of information which I had assembled. Luckily for me, this time things changed. Of course I had thought about it before hand, by writing down that I did not want it to become a maze this time, and it did not. This time I thought beforehand what I wanted to tell, which information I needed and then I assembled this information. Though another problem might be that there is too little information in this report, but I will find out when I get my grade. I also actually enjoyed writing this report, that is also a first. I used to want to do everything perfectly, but I let that go and just rewrote parts which didn't make sense after I wrote it down the first time. This made the process of writing a report much more relaxing and more fun.

The second learning objective was to work on paper and digitally simultaneously. Up to now I first drew everything by hand and worked it out digitally at the end of the term. Now however I started digitalizing each drawing after I knew it was finished and I would add it to my report. Especially digitalizing my detailed designs was useful, as it helped me by making design decisions, which eventually improved the design.

The third objective was to improve my graphical skills. As mentioned before I did not use digitalization unless required, which also limited my skills in creating graphically pleasing products. During this thesis I did improve my skills, but there is still a lot to learn. My new goal is to make more use of examples from other landscape architects and designs to practice my skills.

The last goal was also the most important one and a very personal one. The goal was to finish my thesis within the 8 weeks given and with a sufficient grade. In 2014 I got a burn out and was limited in my study progress. The last two and a half years have been very hard for me, but I also got to learn more about myself. During this time I continued studying, but on a part time basis. Up until now I have not been able to finish a course within the time given. The fact that it is probably happening now makes me very happy. I made it, I reached the finish line with only one breakdown. I managed my own time, made sure I didn't overload myself with work, and my confidence was boosted by the positive feedback I got from my tutors. The only thing now is to actually finish the report and the poster and hope my pc does not crash. If I make it to Friday it will be awesome and I will be back on track!

(The sufficient grade part is up to my supervisors and coordinators, I will leave it in their capable hands).

7. References

7.1 Literature

Chang, Y.P., Ji, Y. (2012) *Urban Green-Waterscape on street level,* unpublished thesis (MSc), Wageningen University

Gemeente Heerlen, (2015) 'Structuurvisie Heerlen 2035', 7 July, available: http://www.ruimtelijkeplannen.nl/documents/NL.IMRO.0917.SV000001-0401/d_NL.IMRO.0917.SV000001-0401.pdf [accessed 8 September 2016]

Hathway, E. A., Sharples, S. (2012) 'The interaction of rivers and urban form in mitigating the Urban Heat Island effect: A UK case study'. *Building and Environment*, Volume 58, 14-22

de Jong, T. M., van der Voordt, D. J. M., eds. (2002) *Ways to study and research urban, architectural and technical design*, Delft: Delft University Press

Lenzholzer, S. (2013) *Het weer in de stad*, Rotterdam, nai010.

Lenzholzer, S., Brown, R. D. (2016) 'Post-positivist microclimatic urban design research: A review'. *Landscape and Urban Planning*, Volume 153, 111-121

Lenzholzer, S., Duchhart, I., Koh, J. (2013), ''Research through designing' in landscape architecture'. *Landscape and Urban Planning*, Volume 113, 120-127

Nishimura, N., Nomura, T., Iyota, H., Kimoto, S. (1998) 'Novel water facilities for creation of comfortable urban micrometeorology'. *Solar Energy*, Volume 64, 197-207

NOS, (2015a) Vaker hittegolf door warmer klimaat, 3 July, available: http://nos.nl/artikel/2044901-vaker-hittegolf-door-warmer-klimaat.html [accessed 10 September 2016]

NOS, (2015b) VN: 2015 is het warmste jaar ooit gemeten, 25 November, available: http://nos.nl/artikel/2071300-vn-2015-is-het-warmste-jaar-ooit-gemeten.html [accessed 10 September 2016]

NU.nl, (2016a) Warmste 7 september in meer dan honderd jaar, 7 September, available: http://www.nu.nl/binnenland/4318280/warmste-7-september-in-meer-dan-honderd-jaar.html [accessed 10 September 2016]

NU.nl, (2016b) Kans op derde regionale hittegolf van het jaar in Limburg, 10 September, available: http://www.nu.nl/binnenland/4319479/kans-derde-regionale-hittegolf-van-jaar-in-limburg.html [accessed 10 September 2016]

Robitu, M., Musy, M., Inard, C., Groleau, D. (2006) 'Modelling the influence of vegetation and water pond on urban microclimate'. *Solar Energy*, Volume 80, 435-447

Shen, G. (2015) *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China,* unpublished thesis (MSc), Wageningen University

Steeneveld, G.J., Koopmans, S., Heusinkveld, B. G., Theeuwes, N. E. (2014) 'Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect'. *Landscape and Urban Planning*, Volume 121, 92-96

Sun, R., Chen, L. (2012) 'How can urban water bodies be designed for climate adaptation?'. *Landscape and Urban Planning,* Volume 105, 27-33

Theeuwes, N. E., Solcerová, A., Steeneveld, G. J. (2013) 'Modelling the influence of open water surfaces on the summertime temperature and thermal comfort in the city', *Journal of Geophysical Research*, Volume 118, 8881-8896

Van den Berk (2016b) *Meer mogelijk met meerstammige bomen* [online], available: http://www.vdberk.nl/meerstammige-bomen [accessed 25 October 2016].

Yokohari, M., Brown, R. D., Kato, Y., Moriyama, H. (1997) 'Effects of paddy fields on summertime air and surface temperatures in urban fringe areas of Tokyo, Japan', *Landscape and Urban Planning*, Volume 38, 1-11

Yokohari, M., Brown, R. D., Kato, Y., Yamamoto, S., (2001) 'The cooling effect of paddy fields on summertime air temperature in residential Tokyo, Japan', *Landscape and Urban Planning*, Volume 53, 17-27

7.2 Figures and Tables

Cover Photo:
NLwandel (2016) 31 Pancratiusplein [image online], available: http://www.nlwandel.nl/Album/GW-Heerlen-488/slides/31%20Pancratiusplein.html [accessed 26 October 2016]

Figure 3:
Kennisportaal Ruimtelijke Adaptie (2016) Klimaateffectatlas [online], available: http://www.ruimtelijkeadaptatie.nl/nl/klimaateffectatlas [accessed 14 September 2016].

Figure 44:
Plangroep Heggen B.V. (2016) 01-150x150 [image online], available: http://plangroepheggen.nl/portfolio-view/pleinenplan-heerlen/ [accessed: 20 October 2016]

Table 3:
Swale
Shen, G. (2015a) ‘Swale’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 69, illus.

Rain garden
Shen, G. (2015b) ‘Rain garden’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 68, illus.

Green gutter
Shen, G. (2015c) ‘Green gutter’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 90, illus.

Filter strip
Shen, G. (2015d) ‘Vegetated filter strip’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 73, illus.

Weir
Shen, G. (2015e) ‘Weir’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 69, illus.

Terraced basin
Shen, G. (2015f) ‘Terraced basin’, *Designing the Shangbu Watershed: An Examplary Landscape Design for Stormwater Management in Hangzhou, China*, unpublished thesis (MSc), Wageningen University, 73, illus.

Table 5:
KNMI (Koninklijk Nederlands Meteorologisch Instituut) (2016) *Klimatologie, Daggegevens van het weer in Nederland* [online], available: http://projects.knmi.nl/klimatologie/daggegevens/index.cgi [accessed 7 October 2016].

Table 14:
Photo Eleocharis palustris
Kwekerij Schiffelers (2016a) Eleocharis palustris [image online], available: http://www.kwekerijschiffelers.nl/wordpress/product-categorie/water-en-moeras-planten/ [accessed: 25 October 2016].

Photo Eriophorum angustifolium
Kwekerij Schiffelers (2016b) Eriophorum angustifolium [image online], available: http://www.kwekerijschiffelers.nl/wordpress/product-categorie/water-en-moeras-planten/ [accessed: 25 October 2016].

Photo Hippuris vulgaris
Kwekerij Schiffelers (2016c) Hippuris vulgaris [image online], available: http://www.kwekerijschiffelers.nl/wordpress/product-categorie/water-en-moeras-planten/ [accessed: 25 October 2016].

Photo Sagittaris agittifolia
Kwekerij Schiffelers (2016d) Sagittaris agittifolia [image online], available: http://www.kwekerijschiffelers.nl/wordpress/product-categorie/water-en-moeras-planten/page/3/ [accessed: 25 October 2016].

Photo Betula utilis ‘Doorenbos’
Van den Berk (2016a) Betula utilis ‘Doorenbos’ [image online], available: http://www.vdberk.nl/boom/betula-utilis-doorenbos [accessed: 25 October 2016].

All other figures and tables are made by the author

Figures 4-8, 10, 13-36, 41, 42, 45, 46, 48 are based on ArcGis Topographic Basemap