Eindhoven University of Technology

MASTER

The influences of urban morphology on the average temperature of Rotterdam city

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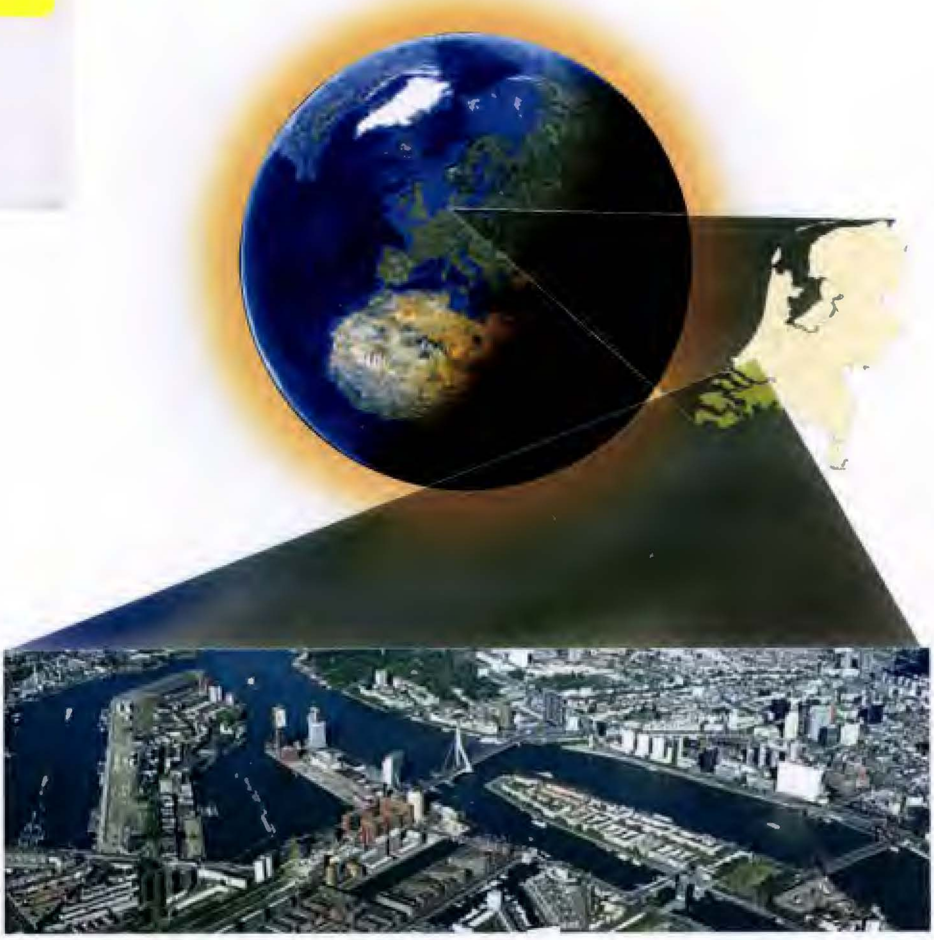

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Construction Management and Engineering

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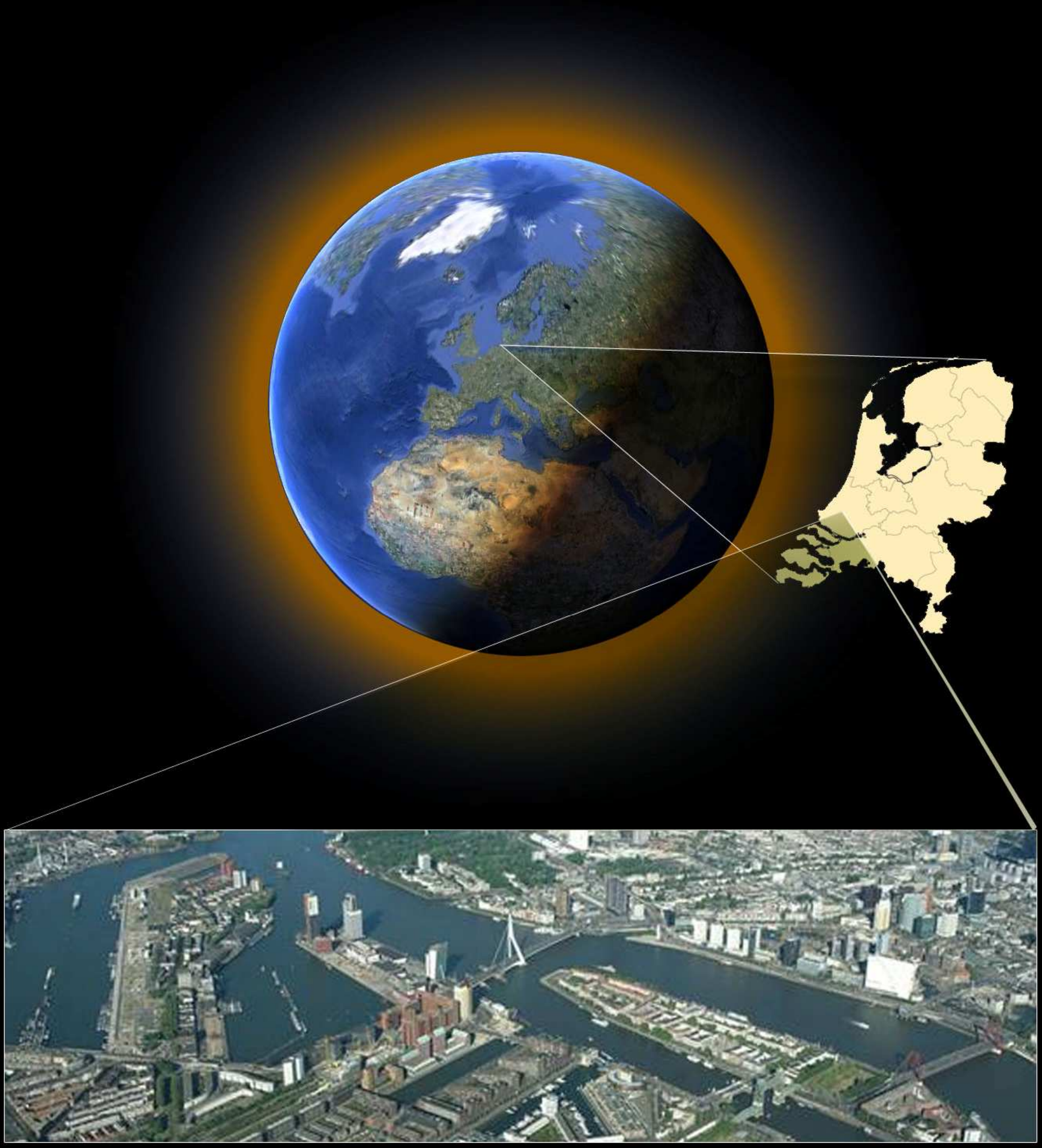


The influences of urban morphology on the average temperature of Rotterdam city.

What are the effects of urban morphology?

With summers becoming warmer, we need more energy to keep the cities liveable. Isn’t it more wisely to understand the effects of our current city environment, so we can protect ourselves against the unbearable city climate we have created?

Stijn J. Janssen

Summary:

Urban heat island (UHI) is the temperature difference between urban and rural areas. Studies on the relation between these two areas exist for decades. In the Netherlands UHI has been an understanding used by scientists for several years, but society thought that UHI was an understanding which was overestimated by these scientists. In the summer of 2003 the Dutch population was caught by the heat. From that moment on we realised that our climate was changing. A research from the KNMI (2008) showed that the temperature will rise to 0,9-2,8°C in 2050 and 2-4°C in 2100 and as an effect of urbanization the temperature will rise even further. Following Oke (1997), cities with a population of 1 million or more the UHI can climb to 1-3°C and on clear calm nights this difference can be as much as 12°C. Brandsma (2010) showed that there was a maximum UHI of 4°C for cities with a population of 100.00 and a maximum UHI of 7°C for a population of 200.000 and more. KNMI (2011) showed that the average UHI for Dutch cities lays between 0,5-1,0°C. A research done by Berdahl & Bretz (1997) showed that when the sky is clear and there is less wind, the temperature gets stocked in the city and the temperature will reach its maximum. The rising surface temperatures could even climb to 27-50°C. Effects from this rising temperature were indicated in a study from CBS (2007) who said that the increase of the average temperature by one degree Celsius leads to an extra mortality rate of 31 persons per week and our productivity drops by 2% for each degree above 25°C (Kleerekoper, 2009). Also the environment showed the influences of the growing heat, an increase of 1,0°C leads to an 6,6% extra electricity demand (Hiroaki & Yukihiro, 2003) using more energy, energy plants need more cooling water which causes a rise of the water temperature and as a result the quality drops. Heated materials will also effect the water. When the rainwater flows along heated materials, this water heats up as well. A study from EPA (2003) showed a temperature increase of surface water as high as 4°C in 40 minutes after a heavy summer shower.

The effects of the UHI can be reduced by smart planning and the use of materials that have a cooling effect. Comte, Le & Warren (1981) showed that vegetation has a cooling effect of 1-4,7°C that spreads 100m to 1km into urban areas. A study done by Upmanis, Elisasson & Lindqvist (1998) in Göteborg showed a maximum temperature difference of 5,9°C between a city park of 156 ha and the city centre. Kravcik (2007) showed that a street

tree can have a cooling effect through evaporation of 20-30 kW, which stands for more than 10 air-conditioners. Water can also be helpful in reducing urban temperature. Water has an average cooling effect of 1-3°C to an extent of 30-35 meters, and can be felt even further when we have to deal with large surfaces of water. Water doesn’t heat as quickly and as a result it is able to transport the heat out of the city.

Research on the UHI was done by oke (1973) to investigate the relation between population and the UHI. Oke showed that there was a linear connection between the population and the temperature for European and for North American cities. KNMI (2011) also examined the relation between rural KNMI weather stations and urban amateur stations for 4 different cities. In this research they showed the relation between wind direction, wind speed, time of the day and the temperature. One of the main causes of the UHI was the wind speed, the UHI is the lowest when the wind speed is the highest. A third research was described by Brandsma (2010) who rode a 14 km track trough Utrecht while measuring the temperature, the wind direction and the percentage of clouds. Brandsma (2010) concluded that for a wind speed of 1 m/s or less the UHI is the biggest and especially with wind coming from the south or the east.

In foregoing research, the relations between different influences on the UCI were not combined. Therefore, the research question for current research was derived, proposing a solution to this limitation:

> *What are the influences of urban morphology on the average temperature of Rotterdam city?*

To analyze these influences, measurements from 4 tramlines (received from B. Heusinkveld and B. Van Hove from WUR-Alterra) were used that drove through the Rotterdam city centre in July and August of 2010. These tram lines measured the temperature every 20 seconds (dependent variable) on a tracked route each day. These temperatures were linked to the topographic map of Rotterdam where each part of the map has a function of the urban morphology (independent variables). These independent variables where categorized in 6 classes: dwellings, industry, paved open space, unpaved open space, vegetation and water. For each class the percentage for one single research area (cell) which was part of the tramline, was calculated. The track of the 4 tramlines was divided in 50 equal cells (research areas) of 600 meters with a width of 200 metre to both sides. The relation between the independent and dependent variables were analyzed on quantitative (multiple regression) and qualitative descriptions and calculations for 3 periods: morning, afternoon and evening during July and August.

It was difficult to draw conclusions from the quantitative research because the output was not one sided. 8 out of 14 tests where significant, indicating a relation between urban morphology and the temperature. This meant that for the 8 significant tests only 2 had 2 or more significant independent individual variables. For the morning (hour 05) period of July, industry (*p*= 0,000, *B*= -0,149) and vegetation (*p*= 0,049, *B*= -0,022.) indicated a significant effect on average temperature. In other words: Industry effects the average temperature. An increase of industry by 1%, the average temperature drops with 0,149 degree. Vegetation also effects the average temperature. An increase of vegetation by 1%, the average temperature drops 0,022.

The second significant test with independent individual variables was the evening period (hour 19) of August with the independent individual variables unpaved open space (*p*=0,004 and *B*= -0,124) and vegetation (*p*=0,001 and *B*=0,092). Concluded from the analysis it was well founded to say that there is a relation between the (in) dependent variables. It was not possible to deduct mutual relations from the output.

Within the qualitative analysis it was even harder to analyze and to formulate a relation between the (in)dependent variables. The percentage of each of the 6 independent variables was compared with the 10 hottest and coolest cells. The 10 hottest and coolest cells and the urban morphology of the cell were also analyzed taking possible influences from (outside) the cell into count. The output from the analysis was so diverse that a connection between these (in)dependent variables and the average temperature was multilateral. Therefore a clear relation between the hours from the same period and a relation between the same period for July and August was not possible. Nevertheless, we could see a tendency of the warmer and cooler spots. Cool cells situated in the south and north, change position and move to the centre during the day. In contrast, the hottest cells start in the centre and spread to the north and south during the day. A reason for this tendency could be the wind, which came mostly from the south-west (KNMI, 2011) carried cool air and cooled the south side of Rotterdam. These winds also provide the centre with cool air when it flows across the Meuse and gets mixed with the cool air from the river causing the complete temperature waves to move during the day. Warm air from the south moves to the south side of the Meuse. Cool air from the south side of the Meuse (which cools down during the night) flows past the Meuse to the centre and cools the centre. And the warm air from the centre flows with the southern wind to the north and warms the north side.

Analyzing the differences between the average urban heat obtained from this research, and the average rural heat from the KNMI weather stations (Zestienhoven), it can be concluded that the UHI is following the guideline from Oke (1973). Oke said that the average temperature for a city with the population size of Rotterdam (+/- 600.000) should be 8°C. From the data used for this research the UHI for July morning was 0,93-5,78°C, 2,41-9,79°C in the afternoon, and 0,57-7,47°C in the evening. For the August period the UHI for the morning was 0,14-5,61°C, 1,25-10,43°C in the afternoon, and 0-7,54°C in the evening. These results overrule the research from Brandsma (2010) who said that cities with a population of 200.00 more can have a maximum UHI of 7°C. The average UHI in current research is also higher than Brandsma (2010) indicated in his research (0,5-1°C). The average UHI for July morning was 2,81-3,27°C, 4,84-5,20°C in the afternoon and 2,89-3,59°C in the evening. For August morning 1,87-2,10°C, 3,18-3,32°C in the afternoon and an average UHI of 2,25-2,48°C in the evening

1 Introduction

The ice ages in the distant past prove that the climate can change by itself, and radically. Adding to that is the belief that human activity can change the climate. In 1896, Swedish scientists published a new theory called the “greenhouse effect”. It argued that, as humanity burned fossil fuels that released carbon dioxide (CO2) into the atmosphere, the planet’s average temperature would rise. This is because the CO2 absorbs heat radiated from the sun, trapping it in the Earth’s atmosphere. Despite accepting the theory, the greater scientific community believed that major climate change would take tens of thousands of years to materialise (Shell, 2007).

By the 1930s, people realised that the United States and North Atlantic region had warmed significantly during the previous half century. Scientists believed this was just a phase of some mild natural cycle, with unknown causes. Only one lone voice, G.S. Callendar (1930), insisted that greenhouse warming was on it´s way.

In the 1950s, Callendar’s claims provoked new studies that showed that carbon dioxide could indeed build up in the atmosphere and lead to global warming. Painstaking measurements drove home the point in 1961, by showing that the level of CO2 was in fact increasing year by year. A 1967 calculation suggested that average temperatures might rise a few degrees within the next century.

Over the following decade, curiosity about climate turned into anxious concern. Study panels began to warn that future climate change might pose a severe threat and research activity accelerated. Programmes were organised on international scale and the world governments created the Intergovernmental Panel on Climate Change in 1988 (ICPP). By 2001, ICPP managed to establish a consensus, announcing that it was likely that our civilisation faced severe global warming. Since 2001, the abundance of data has strengthened the conclusion that human emissions are very likely causing serious climate change.

Depending on what steps people take to restrict emissions, the planet’s average temperature might rise between 1.4-6°C by the end of the century. Although, only a small fraction of this warming has happened so far, predicted effects are already becoming visible – more deadly heat waves, rising sea levels, more frequent severe floods and droughts, the spread of tropical diseases and the decline of species sensitive to temperature changes (Kleerekoper, 2009). The Dutch meteorology institution (KNMI) (2008) also calculated the temperature and came up with four scenarios in 2006 that predicted the average summer temperature for the Netherlands. The average summer temperature is approximately 17°C and will be between 18-19°C in 2050 and 19-23°C in 2100.

A number of key characteristics of climate change in the Netherlands and surrounding areas are common across all scenarios: temperature will continue to rise. Mild winters and hot summers will become more common; on average, winters will become wetter and extreme precipitation amounts will increase; the intensity of extreme rain showers in summer will increase, however the number of rainy days in summer will decrease (KNMI, 2008). Another effect why the world, and especially cities are becoming hotter is the use of computers, television, fast cars, air-conditioning, and far holidays going by air: we will not or cannot live without it. This caused an enormous growth of energy consumption in the past decade and an increase of greenhouse gas like CO2 in the atmosphere. So on one hand we have the rise of temperature and on the other hand we have the exploding growth of energy using and other things that cause an extra heat (Shell, 2007). On international level countries made appointments about the reduction of discharge of greenhouse gas. The Netherlands is one of them and translated the international ambitions into national ambitions. The national climate objective can only be reached if the federal government, companies, provinces, municipality welfare organizations and citizens all work together (Roorda, 2008).

In the summer of 2003 and 2006 we had an extreme summer period with extreme measured temperatures. During these summers the average death increased even more as usually. The Dutch central bureau for statistics (CBS) (2007) calculated that an increase of 1°C degree on average during the summer will lead to an extra mortality rate of 31 people each week.

The focus in this report will be on the hotter summers, because during summers cities will become ovens. Buildings and roads will absorb heat and high rise buildings block the wind. Because the heat can’t easily blow away this heat will be trapped in the city, as a result, urban areas are becoming much warmer compared to rural areas (Wilby, 2007). The difference between urban and rural temperature is called the urban heat island (UHI). In this survey the UHI for the Rotterdam city will be analyzed by comparing the urban morphology and the temperature to indicate that a specific morphology influences the temperature and enlarges or decreases the UHI.

1.1 Climate change:

That the human race is changing the climate is a brought carried idea, but what the specific effects will be is still hard to predict. On some places it will be hotter, on other places it just becomes colder or wetter. The most important consequences of climate change are:

- Sea level rising: Under the present rising of the sea level the forecast will be that the number of victims of flooding will grow from 13 to 94 million. During the future hundred years the sea level will climb between the five and ten centimetres. The most heavily impact will be felt in third world countries, especially low-lying and dry tropical areas.
- Harmful effect of the ecosystem: Climate change goes hand in hand with displacement of the climate zone. Some plants and animals cannot adjust to new environments and will be threatened with extinction. In some places climate change will lead to more aridity, with more forest fires and desertification as a possible result.
- A shortage of fresh water: The greatest part of the world population lives in countries with a shortage of clean freshwater. The bigger the world population gets, the bigger the problem will be. Climate change will increase the water scarcity in some regions, like the middle-East, the Sahel and Australia.
- Decline of the arable farming productivity: Especially in areas like the middle-East and India where dryness caused by the climate change will increase.

Climate change asks for climate policy, but also because of the decreasing amount of fossil energy stocks (oil, gas, coals), action is very hard needed. Prognosis is diverse, but one thing we know for sure: energy stocks are running out. That’s why the development of new sustainable energy sources is of crucial interest: use of sun boilers, PV-cells, heat-pumps and windmills are developments that not only should be developed because of their climate neutral character, but also because we simply cannot do without them in the future (Municipality-Houten, 2008).

1.2 The Dutch Government:

The Dutch government has a good prognosis towards meeting its Kyoto target of 6% reduction of greenhouse gas emissions by 2012. However, the Kyoto targets will not be sufficient enough to prevent dangerous global climate change and to be prevented for the urbanization (in 2008 at least 50% of the world population lives in cities, in 2050 this would be probably 80%). Therefore the Dutch government has formulated ambitious new climate and energy targets for 2020 in order to become one of the cleanest and most energy efficient countries in the world (VROM, 2006). These targets are:

- To cut emissions of greenhouse gas by 30% in 2020 compared to 1990 levels;
- To double the rate of yearly energy efficiency improvement from 1-2% in the upcoming years;
- To reach a share of renewable energy of 20 % by 2020.

The most cities developed their own target to become energy neutral as best as possible (EnergySquare). These targets are:

- Dronten is energy neutral since 2007;
- Groningen wants to be energy neutral in 2025;
- Maastricht and Utrecht want to be energy neutral in 2030;
- Nijmegen wants to be energy neutral in 2032;
- Eindhoven wants to be energy neutral in 2033;
- Den-Haag and ‘s-Hertogenbosch want to be energy neutral in 2050;
- Rotterdam wants to save 50% on their current energy consumption;
- Amsterdam wants to save 40% on their current energy consumption.

1.3 Definition of energy neutral:

Now we know the targets from the cities it is important to know what the expected result will be or where they will be striving for. A city is energy neutral if on annual base no net import of fossil or nuclear fuel from outside the system borders is used to construct-, maintain and demolish a building. It means that the energy consumption is internally equal to the amount of sustainable energy which is produced internally or which can be added based on external measures (Adviseurs, 2009). Trias Energetica, discussed in the next paragraph, is a well-known method, to obtain the targets of these cities.

1.4 Definition of Trias-Energetica:

Trias-Energetica is a way of dealing with energy. It is a concept that helps cities to achieve energy savings, reducing our dependence on fossil fuels to save the environment (Trias Energetica). The three elements of the Trias-Energetica:

1. Reduce the demand for energy by implementing energy-saving measures;
2. Use renewable sources of energy instead of finite fossil fuels;
3. Produce- and use energy with the most efficient techniques available.

The first step is to reduce the need on energy use. Architects of buildings can easily help with that, for example with good isolation. Users are able to save fossil fuels, for example by lowering the heating temperature, by more energy efficient lights or by using tools that provides real time information about your energy consumption.

The second step is to make more use of sustainable energy sources. Sustainable energy sources are energy sources which are inexhaustible and lower the environmental impact. For example: PV-solar cells, windmills or heat pumps.

The third step is to use energy more efficient. In this step the main goal is to use the energy produced by finite recourses as efficient as possible. Finite recourses are commodities for energy production which are finite. Examples are: Natural gas and coal which are used for the generation of energy. These sources are limited and aggravating for the environment (CO2-emision). These sources should be used as efficiently as possible (MAQ and ESS-CC-WUR, 2010).

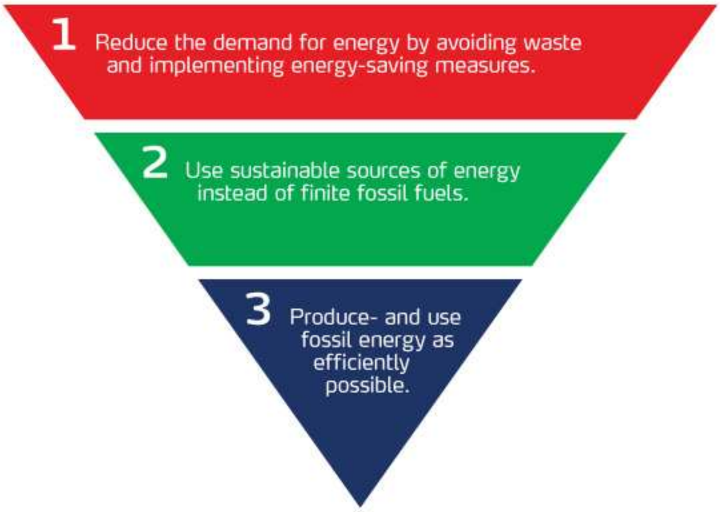


Illustration 1.4: Trias-Energetica model. The most sustainable energy is saved energy.

This research will contribute to current theories regarding to the reduction of energy used for cooling in the summer, by lowering the temperature in a city. These reductions could be realised by a better insight of the effects of dwellings, paved or unpaved open spaces, all kinds of vegetation, water and industry on the temperature in Rotterdam city.

The idea exists that due to rising temperatures and the growing size of the cities and populations (Oke, 1973) the temperature will climb to an unbearable wind chill factor (European Environment Agency, 2009). An effect of the unbearable wind chill factor is that people will need more electricity for cooling. According to the targets from the different municipalities together and the Trias Energetica model, it seems to be important to prevent cities to become ovens.

In this survey, research will be done to the influences of the way we build our cities (urban morphology) and temperatures for the city of Rotterdam. 50 areas (later on referred to as cells) with their urban morphology will be analyzed with measured temperature. The expectation of this survey is that certain types of morphology are causing warmer or cooler spots in the city. The temperature that is used in this survey was measured by 4 tram lines that drove through Rotterdam city and created series of thousands of points. Each point has his own X-coordinate, Y-coordinate, date, time of measurement and temperature. These information points will be linked to the morphology of the 50 unique cells to find a pattern between the morphology and the temperature for the morning, afternoon and evening.

During this report you will be guided through multiple steps towards answering the research question. To answer the question there is some background information needed about the UHI. This background information is described in the second chapter: Theoretical groundwork for the urban heat island and in the third chapter: Previous research on the urban heat island. In the second chapter the definition of UHI is described what kind of tools there are to measure the UHI and what the positive and negative effects of UHI are. The third chapter is a chapter where research on the UHI, and especially based on Dutch cities is described. Also, the relation between population and the UHI, and between measurements from fixed and mobile measurement stations was indicated. Finally, research to global warming for the period 2050 and 2100 and it’s effects the Netherlands were described. In chapter 4 the research question will be introduced and the different approaches that were used to analyze the UHI of Rotterdam. The quantitative and qualitative analyses were analyzed and the results are presented. The results from both analysis and the theoretical chapters found the final chapter seven, where the conclusions, discussion and the recommendations relating to the effects of the urban morphology for Rotterdam city are made.

2 Theoretical groundwork for the urban heat island

2.1 Definition of UHI

As urban areas develop, changes occur in the landscape. Buildings, roads, and other infrastructure replaces open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry. This change in landscape may differ in regions such as desserts, where moisture may increase in urban areas if development introduces grass lawns and other irrigated vegetation. This development leads to the formation of UHI.

2.2 What is UHI?

Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings. This difference in temperature is what constitutes an UHI. This sub chapter focuses on surface and atmospheric UHIs. These two heat island types differ in the ways they are formed, the techniques used to identify and measure them, their impacts, and to some degree, the methods available to mitigate them. Table 2.2 summarizes the basic characteristics of each type of heat island. These features are described in the following sub chapter.

Basic characteristics of surface and atmospheric urban heat islands (UHIs)		
Feature	**Surface UHI**	**Atmospheric UHI**
Temporal development	Present at all times of the day and night Most intense during the day in the summer	May be small or non-existent during the day Most intense at night or predawn and in the winter
Peak intensity (most intense UHI conditions)	More spatial and temporal variation: Day: 10 to 15 °C Night: 5 to 10 °C	Less variation: Day: -1 to 3 °C Night: 7 to 12 °C
Typical identification method	Indirect measurements: Remote sensing	Direct measurement: Fixed weather stations Mobile traverses

Typical depiction	Thermal image	Isotherm map Temperature graph
Table: 2.2		

2.2.1 *Surface UHI*

On a hot, sunny summer day, the sun can heat and drying exposed urban surfaces, like roofs and pavement to temperatures 27-50°C hotter than the air (Berdahl & Bretz, 1997). While shaded or moist surfaces, often in more rural surroundings, remain close to air temperatures. Surface UHIs are typically present during day and night, but tend to be strongest during the day when the sun is shining.

On average, the difference in daytime surface temperatures between developed and rural areas is 10-15°C; the difference at night-time surface temperatures is typically smaller: 5-10°C (Voogt & Oke, 2003). The magnitude of surface UHI varies with seasons, due to changes in the suns intensity as well as ground cover and weather. As a result of such variation, surface UHIs are typically largest in the summer (Oke, 1982). To identify UHI, scientists use direct and indirect methods, numerical modelling, and estimates based on empirical models. Researchers often use remote sensing, an indirect measurement technique, to estimate surface temperatures. They use the data collected to produce thermal images, such as that shown in illustration 2.2.1.

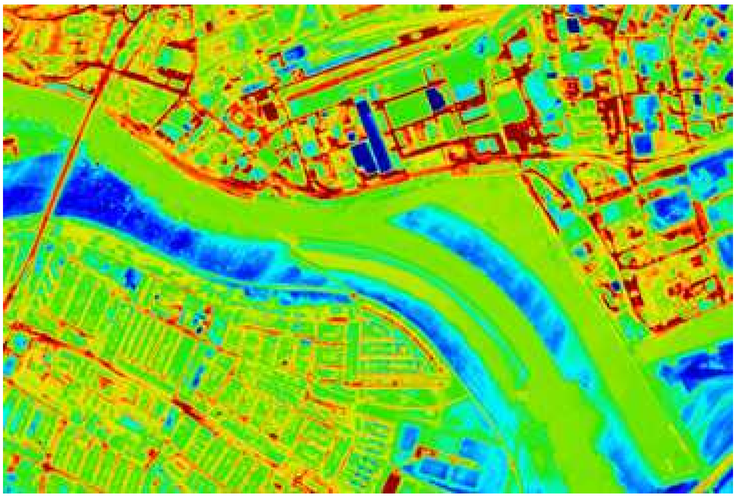


Illustration 2.2.1: Heat scan from Arnhem, the Netherlands.

2.2.2 *Atmospheric heat*

Warmer air in urban areas compared to cooler air in nearby rural surroundings defines atmospheric UHI. Experts often divide these heat islands into two different types:

- Canopy layer UHI, exist in the layer of air where people live, from the ground to the tops of trees and roofs, illustration 2.2.2.A.
- Boundary layer UHI, starts from rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere. This region typically extends no more than one mile (1.5 km) from the surface (Oke, 1982) illustration 2.2.2.B.

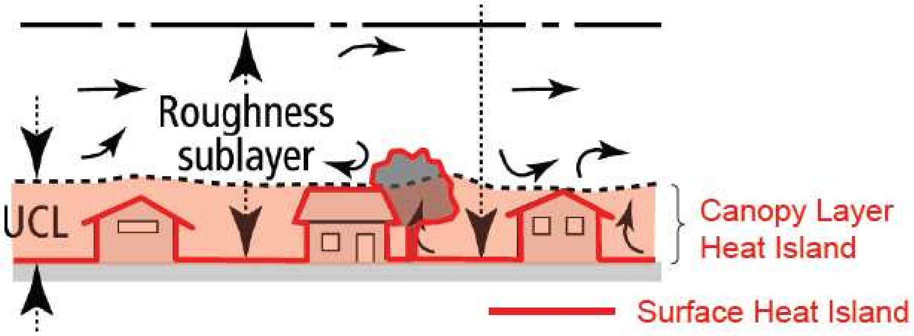


Illustration 2.2.2.A: Atmospheric canopy layer and surface heat island (Oke, 1997).

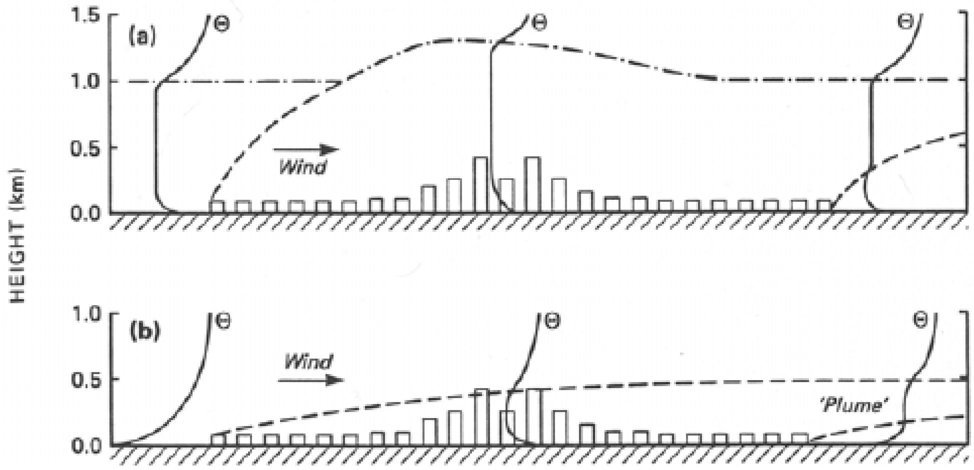


Illustration 2.2.2.B: Boundary layer UHI. A) during the day, B) during the night (Oke, 1982).

Atmospheric UHIs are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure. The timing of this peak, however, depends on the properties of urban and rural surfaces, the season, and prevailing weather conditions.

Researchers typically measure air temperatures through a dense network of sampling points from fixed stations or mobile traverses, the one also used at the trams. Illustration 2.2.2.C illustrates a conceptual isotherm map that depicts an atmospheric UHI. The centre of the figure, which is the hottest area, is the urban core. A simple graph of temperature differences, as shown in illustration 2.2.2.D, is another way to show the results (Partnership Division Climate Protection).

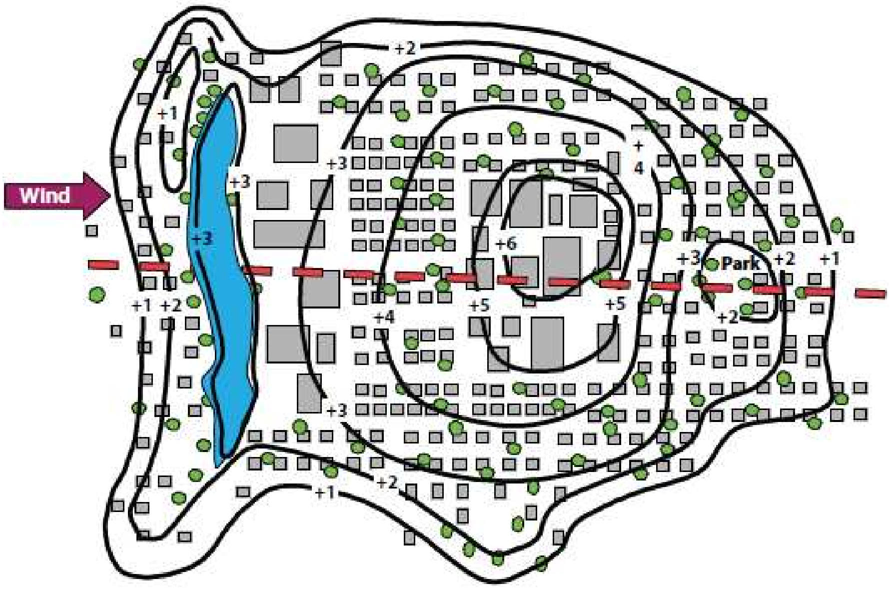


Illustration 2.2.2.C: Isotherm map depicting an atmospheric night time UHI (Voogt J. , 2002).

Illustration 2.2.3.C shows a conceptual map with overlaid isotherms (lines of equal air temperature) exhibits a fully developed night time atmospheric UHI. The dotted red line indicates a traverse along which measurements are taken.

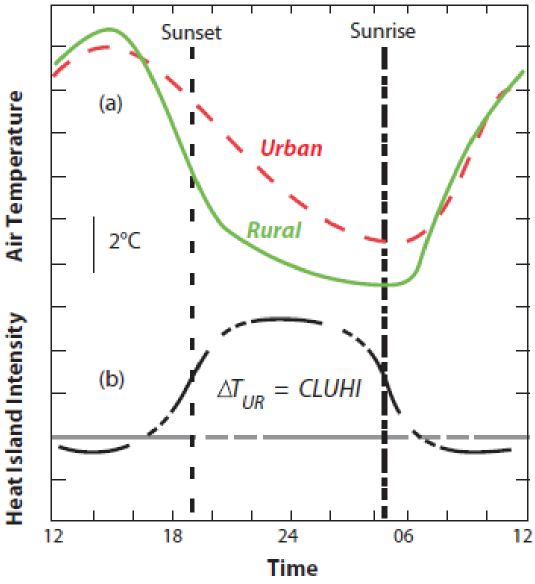


Illustration 2.2.2.D: Conceptual drawing of the diurnal evolution of the UHI during calm and clear conditions (Oke, 1982; Runnall & Oke, 2000).

Illustration 2.2.2.D primarily shows atmospheric UHIs result from different cooling rates between urban areas and their surrounding rural or non-urban surroundings. The differential cooling rates are most pronounced on clear and calm nights and days when rural areas can cool more quickly than urban areas. The heat island intensity typically grows from mid-to-late afternoon to a maximum a few hours after sunset. In some cases, a heat island might not reach peak intensity until after sunrise.

2.2.3 Surface and air temperatures: How are they related?

Surface temperatures have an indirect, but significant, influence on air temperatures, especially in the canopy layer, which is closest to the surface. For example, parks and vegetated areas, which typically have cooler surface temperatures, contribute to cooler air temperatures. Dense, built-up areas, on the other hand, typically lead to warmer air temperatures. Because air mixes within the atmosphere, though, the relationship between surface and air temperatures is not constant, and air temperatures typically vary less than surface temperatures across an area (see illustration 2.2.3).

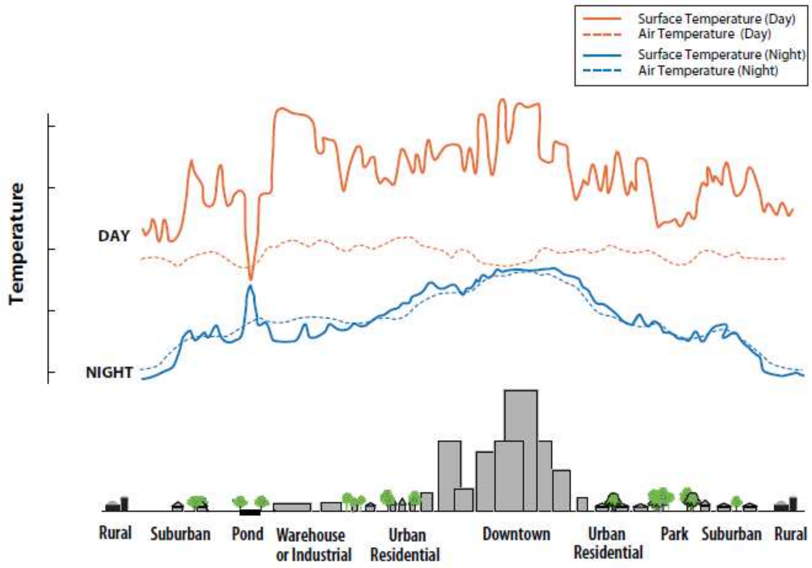


Illustration 2.2.3: Variations of surface and atmospheric temperatures (Voogt J. , 2002).

Surface and atmospheric temperatures vary over different land areas. Surface temperatures vary more than air temperatures during the day, but they both are fairly similar at night. The dip and spike in surface temperatures over pond show how water maintains a fairly constant temperature during day and night, due to its high heat capacity.

2.3 How can UHI arise in our environment?

By changing our environment the influences of the UHI becoming bigger and bigger. In this chapter the influences of the reduction of vegetation, properties of materials we use to build, anthropogenic heat, the weather, geographic location and the influences of population on UHI.

There are different causes for the existence of the UHI. The main cause is the geometry of the city, normally called: sky-view-factor (SVF) or the relation between the height of the buildings (H) and the width (W) of the streets. SVF is the visible area of the sky from a given point on a surface. For example, an open parking lot or field that has few obstructions would have a large SVF value (closer to 1). Conversely, an urban canyon in a downtown area that is surrounded by closely spaced, tall buildings, would have a low SVF value (closer to zero), as there would only be a small visible area of the sky, illustration 2.3. Because of multiple reflection a small SVF (large H/W relation), compared with a large SVF, causes a strong absorption of incoming radiation and blocks the outgoing infrared radiation. A small SVF in cities is the cause of a decline in the transportation of turmoil (larger shelter).

The large percentage of paved surface in cities and the fast draining of rainwater is one of the reasons why more energy is needed for evaporation compared to rural areas. Instead, this energy is stored in materials and constructions and can slowly be released. For example: parks with water are beneficial because they evaporate more compared with the surrounded area, becoming a cool spot for the city. The other cause for the existence of the UHI is the air pollution which causes absorption and reflection of infrared radiation and lowering of incoming radiation (especially at night when it keep the heat in the city like a blanket). An overview of the factors that contribute to the UHI is illustrated in table 2.3.

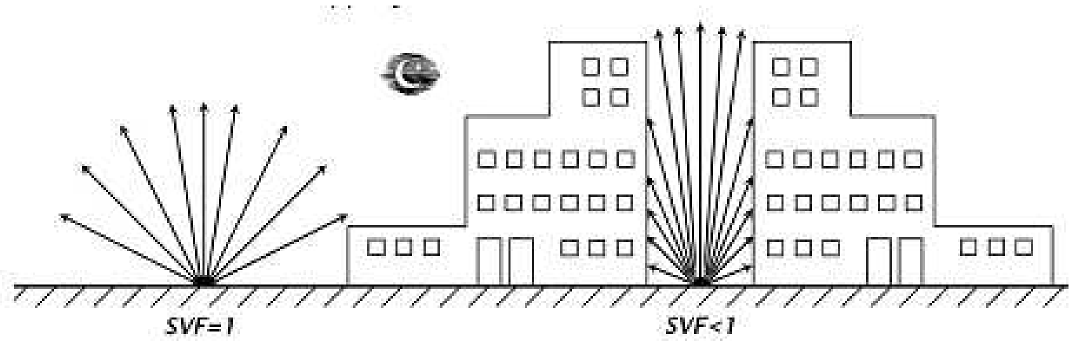


Illustration 2.3: Nocturnal radiation at a high SVF (open spaces) and a low SVF (high density built area) (KNMI, 2009).

Factors that create urban heat islands	
Factors communities are focussing on	Reduced vegetation in urban regions: reduces the natural cooling effect from shade and evapotranspiration.
	Properties of urban materials: contribute to absorption of solar energy, causing surfaces, and the air above them, to be warmer in urban areas than those in rural surroundings.
Future factors to consider	Urban geometry: the height and spacing of buildings affects the amount of radiation received and emitted by urban infrastructure.
	Anthropogenic heat emissions: contribute additional warmth to the air.*
Additional factors	Weather: certain conditions, such as clear skies and calm winds, can foster urban heat island formation.
	Geographic location: proximity to large water bodies and mountainous terrain can influence local wind patterns and urban heat island formation.
Table: 2.3	

2.3.1 *Reduced vegetation in urban areas*

In rural areas, vegetation and open land typically dominate the landscape. Trees and vegetation provide shade, which helps lower surface temperatures. They also help reduce air temperatures through a process called evaporation, in which plants release water to the surrounding air, dissipating ambient heat. In contrast, urban areas are characterized by dry, impervious surfaces, such as conventional roofs, sidewalks, roads, and parking lots. As cities develop, more vegetation is lost, and more surfaces are paved or covered with buildings. The change in ground covering results in less shade and moisture to keep urban areas cool. Built up areas evaporate less water (illustration 2.3.1), which contributes to elevated surface and air temperatures.

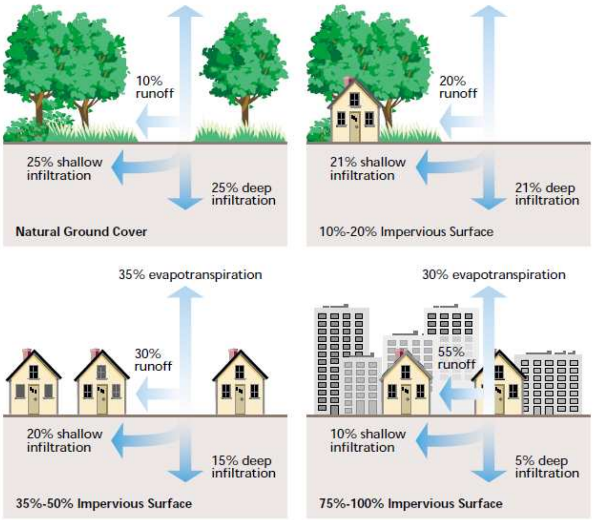


Illustration 2.3.1: Impervious surfaces and reduced evaporation (Partnership Division Climate Protection).

Illustration 2.3.1 shows a highly developed urban area (under), which is characterized by 75%-100% impervious surfaces, has less surface moisture available for evaporation than natural ground cover (above), which has less than 10% impervious cover. This characteristic contributes to higher surface and air temperatures in urban areas.

2.3.2 *Properties of urban materials*

Properties of urban materials, in particular solar reflectance, thermal emissivity, and heat capacity also influence UHI development as they determine how the sun's energy is reflected, emitted, and absorbed. Solar energy is composed of ultraviolet (UV) rays, visible light, and infrared energy, each reaching the earth in different percentages: 5% of solar energy is in the UV spectrum, including the type of rays responsible for sunburn; 43% of solar energy is visible light, in colours ranging from violet to red; and the remaining 52% of solar energy is infrared, felt as heat. Energy in all of these wavelengths contribute to UHI formation. Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface. Much of the suns' energy is found in the visible wavelengths, illustration 2.3.2. Thus, solar reflectance is correlated with the colour of a material. Darker surfaces tend to have lower solar reflectance values than lighter surfaces. Researchers are studying and developing colours that can cool materials. These products can be dark in colour but have a solar reflectance close to that of a white or light-coloured material.

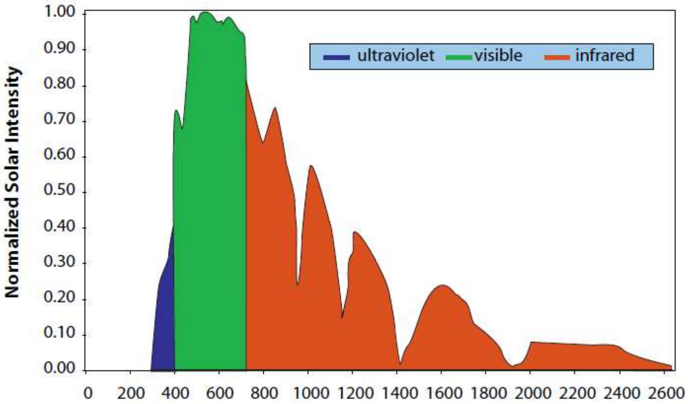


Illustration 2.3.2: Solar energy versus wavelength reaching earth's surface (Partnership Division Climate Protection).

Urban areas typically have surface materials, such as roofing and paving, which have a lower albedo than those in rural settings. As a result, built up communities generally reflect less and absorb more of the suns energy. This absorbed heat increases surface temperatures and contributes to the formation of surface and atmospheric UHIs.

Although solar reflectance is the main determinant of a materials surface temperature, thermal emittance, or emissivity, also plays a role. Thermal emittance is a measure of a surfaces ability to shed heat, or emit long-wave (infrared) radiation. All things equal, surfaces with high emittance values will stay cooler, because they will release heat more readily. Most construction materials, with the exception of metal, have high thermal emittance values. Thus, this property is mainly of interest to those installing cool roofs, which can be metallic.

Another important property that influences heat island development is a material's heat capacity, which refers to its ability to store heat. Many building materials, such as steel and stone, have higher heat capacities than rural materials, such as dry soil and sand. As a result, cities are typically more effective at storing the suns energy as heat within their infrastructure. Downtown metropolitan areas can absorb and store twice the amount of heat compared to their rural surroundings during the daytime (Christen & Vogt, 2004).

2.3.3 Urban geometry

An additional factor that influences UHI development, particularly at night, is urban geometry, which refers to the dimensions and spacing of buildings within a city. Urban geometry influences wind flow, energy absorption, and a given surface's ability to emit long-wave radiation back to space. In developed areas, surfaces and structures are often at least partially obstructed by objects, such as neighbouring buildings, and become large thermal masses that cannot release their heat very readily because of these obstructions. Especially at night, the air above urban centres is typically warmer than air over rural areas. Night time atmospheric heat islands can have serious health implications for urban residents during heat waves (see textbox in Section 2.5.2 Health: heat stress).

Researchers often focus on an aspect of urban geometry called urban canyons, which can be illustrated by a relatively narrow street lined by tall buildings. During the day, urban canyons can have competing effects. On the one hand, tall buildings can create shade, reducing surface and air temperatures. On the other, when sunlight reaches surfaces in the canyon, the suns energy is reflected and absorbed by building walls, which further lowers the cities overall albedo (the net reflectance from surface albedo plus urban geometry) and can increase temperatures (Sailor & Fan, 2002). At night, urban canyons generally impede cooling, as buildings and structures can obstruct the heat that is being released from urban infrastructure.

2.3.4 Anthropogenic heat

The heat that is produced because of human activities is anthropogenic heat. This can be the heat production of air conditioners, cars, buildings, humans themselves, etc. Reducing the heat production by reducing the activities can in some cases be achieved by smart planning. For instance, good public transportation and safe bicycle routes to avoid car use. An increase of 1.0°C of the outdoor temperature leads to an average of 6.6% extra electric energy demand (Hiroaki & Yukihiro, 2003). Given this knowledge the mechanism of air-conditioning system is rather odd. While using a lot of energy for cooling an indoor space an air conditioner blows more heat into the outdoors than it cools the indoors. This is an accumulating problem since the ongoing growth of cities and wealth lead to an increase in energy consumption for air conditioners. Anthropogenic heat typically is a concern in urban areas which can significantly contribute to heat island formation.

In cities of the USA, the urban warming increases the peak electric energy demand by 3-6% with 1.0°C temperature rise (Hiroaki & Yukihiro, 2003). A study in Germany focused on the anthropogenic heat release from the highly industrialized and populated Ruhr region. The study shows a permanent warming ranging from 0.15°C over land up to 0.5°C over the Ruhr (Block, Keuler, & Schaller, 2004). When there is no possibility to reduce heat there are possibilities to benefit from it. During the last decade, buildings in the Netherlands have started to manage their internal heat distribution by storing heat underground in summer and using this in the winter. This reduces energy consumption by 40-80% (Ruimtexmilieu). This measure may at first seem to be a building component and not part of an urban design, but it can be much more effective and feasible when applied on a larger scale. Besides anthropogenic heat from buildings, the heat production from traffic, green houses and all other kinds of human activity could be used in the same way.

2.3.5 Additional factors

Weather and location strongly influence UHI formation. While communities have little control over these factors, residents can benefit from understanding the role they play.

- Weather**:** two primary weather characteristics affect UHI development: wind and cloud cover. In general, UHIs form during periods of calm winds and clear skies, because these conditions maximize the amount of solar energy reaching urban surfaces and minimize the amount of heat that can be convected away. Strong winds increase atmospheric mixing, and so lowering the UHI (Partnership Division Climate Protection).
- Geographic location: climate and topography, which are in part determined by a city’s geographic location, influence UHI formation. For example, large bodies of water moderate temperatures and can generate winds that convect heat away from cities. Nearby mountain ranges can either block wind from reaching a city, or create wind patterns that pass through a city. Local terrain has a greater significance for heat island formation when larger-scale effects, such as prevailing wind patterns, are relatively weak.

- The annual mean air temperature of a city with one million or more people can be 1-3 °C warmer than its surroundings (Oke, 1997), and on a clear, calm night, this temperature difference can be as much as 12°C (Oke, 1987). Even smaller cities and towns will produce heat islands, though the effect often decreases as city size decreases (Oke, 1982).

2.4 How can we prevent ourselves against the growing UHI?

By diminishing the accumulation of heat and applying cooling techniques, cities can
Mitigate their UHI effect. This chapter describes design principles for Dutch cities in four categories: vegetation, water, built form and material.

2.4.1 Vegetation

Vegetation cools the environment actively by evaporation and transpiration (evaporation), and passively by shading surfaces like soil, pavement and
façades. There are four different types of application of vegetation in urban areas: urban forests (park), street trees, greens and green roofs or façades. Vegetation has an average cooling effect of 1-4.7°C (Comte, LE, & Warren, 1981) that spreads 100 to 1000 meters into an urban area, but is highly dependent on the amount of water the plant or tree has available. A good example is the tree in illustration 2.4.1.A.

A test by the Institute of Physics shows the great importance of the availability of water for a green cooling effect. The plants of the green façade of the Berlin-Adlershof evaporate considerably more when they have a surplus of water available compared to the evaporation values when they are lacking water (Schmidt, 2006).

An urban forest or a park is a green area within an urbanized environment. These areas have a lower air and surface temperature and thus form a PCI (Park Cool Island). The characteristics of the green area that lead to cooling are evaporation of plants and trees, shade, evaporation of surface water or moist in the soil. During the night the high SVF of open fields causes these areas to cool down very fast.

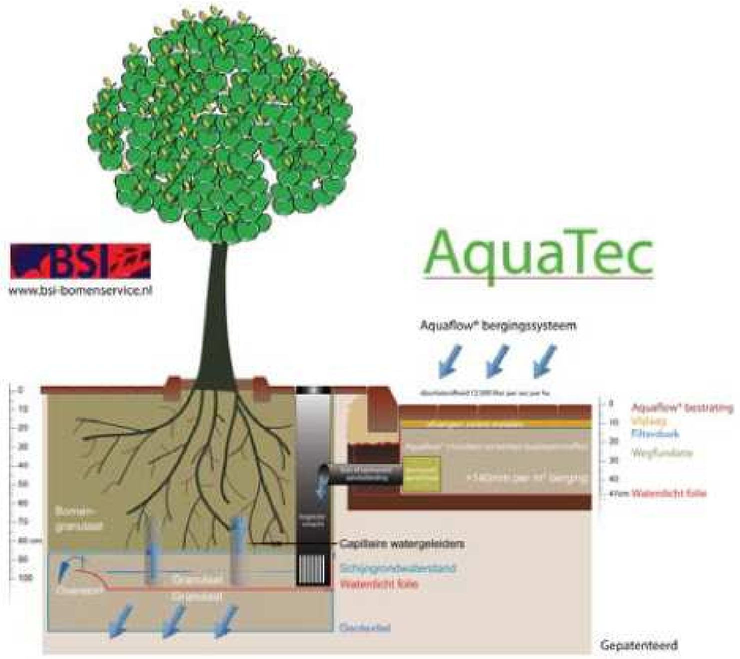


Illustration: 2.4.1.A: Aqua flow water storage system that supplies trees with water (Kleerekoper, 2009).

In numerous studies, vegetated areas result in PCI. A green area doesn’t have to be particularly large in order to generate a cooling effect. According to a study in Tel Aviv a park of only 0.15 ha had an average cooling effect of 1,5 °C and at noon reached 3°C difference (Sashua-Bar & Hoffman, 2000). A study in Göteborg from Upmanis, Eliasson & Lindqvist (1998) shows that a large green area does generate a big cooling effect. A maximum difference of 5.9°C in summer in a green area of 156 ha was measured here.

When using PCI for cooling, the effect on the periphery is very important. The effect is variable, depending on airflow and other climatological circumstances. The studies mentioned above show an effect at 100 meters distance from the PCI in Tel Aviv and an effect at 1100 meters distance from Göteborg’s PCI.

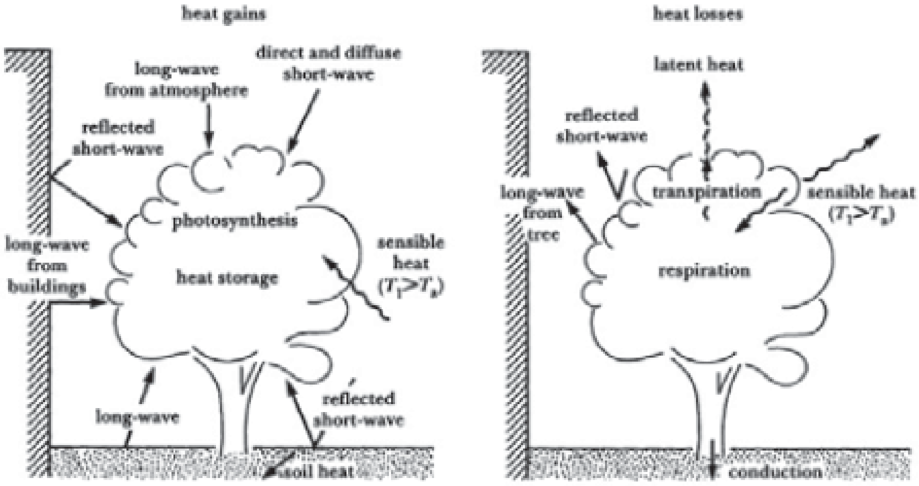


Illustration: 2.4.1.B: Scheme of the daytime energy exchanges between an isolated tree and its street canyon environment (Kleerekoper, 2009).

Street trees might seem to have a low impact on the temperature within the city because they are so dispersed, but since there are so many they actually have a big impact. The characteristics of a tree that lead to cooling are: evaporation, shading and reflecting sunlight illustration 2.4.1.B. On a sunny day the evaporation alone cools with a power equal to 20-30 kW, a power comparable to that of more than 10 air-conditioning units (Kravcik, Pokorny, Kohuitiar, & Kovac, 2007). Their position in a paved area makes them soft and vulnerable elements, and this adds another dimension to the hard surfaces of the street and buildings.

During the day, open fields with a natural grass surface do not cool the city as much as the same space when filled with trees would. Though, at night, an open grass field does cool more effectively than a forested area. At daytime an open field catches a lot of sun that causes the soil to evaporate quickly, followed by warming up. During the night this reverses as the accumulated heat can radiate fast into the atmosphere since there are no obstacles to reflect or retain the heat (Upmanis, Eliasson, & Lindqvist, 1998).

Covering roof or façade with vegetation has a cooling effect on the urban environment and the building itself. In a review of studies done by Yukihiro Kikegawa, and others, the effect of green facades was measured for the outdoor temperature and the effect on air-conditioner savings. The greening leads to an average decrease of 0.2–1.2°C in the near-ground temperature and results in a cooling energy saving of 4-40% (Yukihiro, Genchi, Kondo, & Hanaki, 2006).

Other suggestions to improve the application of vegetation (Mcpherson, 1994):

- Shading of windows and west-facing walls provides the most savings in cooling energy.
- Trees selected for shade, crown shape can be more important than crown density.
- Energy and water rates determine the extent to which it is economical to substitute cooling for electric air conditioning.
- Effects of tree shade on winter heating demand can be substantial with non-deciduas trees.

2.4.2 Water

Water can reduce temperatures by evaporation, by transporting it out of the city and as a buffer that slowly absorbs heat. This is already happening in Dutch cities due to existing water applications. Water has an average cooling effect of 1-3°C to an extent of about 30-35 meters. Water applications in general are more effective when they have a large surface, when it is flowing water or dispersed water, like from a fountain. The effect of cooling by water evaporation depends on the air flow that replaces the cooled air through the city. In urban areas, water can cool by evaporation or by absorbing heat when there is a large water mass (buffer) or when the water is moving, as in rivers (heat transport out of the city). In the Netherlands, warm weather usually comes with high relative humidity. Therefore it could be assumed that cooling with water is not effective, however this is a misunderstanding, according to Dr. T. Schuetze (2007). Cooling with water, as with PCI, is dependent on weather circumstances. A study executed by Robitu et al (2004) in Bucharest shows the cooling effect of a pond of 4.4 m wide. The cooling was about 1°C at a height of 1 m, measured at 30 meters distance. While flowing water has a larger cooling effect than stagnant water, dispersed water like from a fountain has the biggest cooling effect. A study from Nishimura et al. (1998) in Japan shows air temperature measurements on the leeward side of a fountain with a reduction of approximately 3°C. The effect of the water system can be felt (from 14.00 to 15.00) up to 35 m distance.

2.4.3 Built form

Building density, and built form are composition variables that combine parameters like the area of exposed external surfaces, the thermal capacities and surface reflectance of built elements, and the view of SVF of surfaces. The lower the SVF, the less heat will radiate back at night or reflect back during the day. The higher the SVF, the more façades warm up by solar radiation during the day. When a building is shaded by another building to reduce heating in summer, the building will be even more shadowed in the winter in the Dutch situation. Overheating by solar radiation in summer can be reduced with high H/W ratios (Futcher, 2008), see also chapter 2.3. However this also implies less air flow, multiple solar reflections and a lower SVF which traps heat. These last negative effects may do more harm than the positive effects of the measure itself. Even if the measure would help in summer, in winter even more buildings will overshadow other buildings. A better alternative to shade buildings are trees and green walls, which are green in summer and transparent in winter. Also, canvas or other kinds of materials can be used to shade buildings and can be easily removed in winter. Built form also influences air flows and speed. In many warm countries wind is an important cooling factor. In the Netherlands, wind is a dangerous measure for cooling. Stimulating wind for ventilation in summer means a very unpleasant situation in winter. The main wind direction in summer is from the South-West, but in winter we have the coolest wind from the North-East (KNMI, 2011). When streets are oriented on this wind direction, some protection is needed from North-East winds. Another way to improve ventilation is to generate a mix of the air in the canopy layer (the air space in a street profile) with the air from the boundary layer (the layer of air above the roughness elements of a surface). One way to obtain this mix is to adjust the canopy layout. The best ventilation is acquired at a H/W ratio of around 0.5. At a H/W of more than 2 there is almost no mix of the canopy and boundary layer (Esch, Bruin-Hordijk, & Duijvestein, 2007). The mix of the two layers also takes place with slanted roofs. These generate effective natural wind ventilation at the ‘mouth’ openings of urban street canyons. This is a much more effective means for improving natural ventilation than increasing building spacing (Rafailidis, 1997).

2.4.4 Material

In cities the soil is covered with artificial pavement, in rural areas mostly with natural greenery or agricultural crops. There is a big difference in the temperature flux between these materials. The hard materials in cities do not absorb water and therefore do not cool by evaporation. The other missing cooling mechanism is the evaporation of plants. Instead of cooling, the hard materials accumulate heat. The heat is absorbed not only at the surface as in areas of the city can be increased. Results of increasing albedo were computed in a simulation model for Sacramento, California, illustration 2.4.4. By increasing a city-wide albedo from 25-40% a temperature drop of 1-4°C can be achieved. Increasing the building albedo from 9-70% can reduce the annual cooling demand with 19%. Simulations showed a reduction of 62% in cooling energy demand when both the city-wide albedo and building albedo are increased (Taha, Rosenfeld, Akbari, & Huang, 1988).

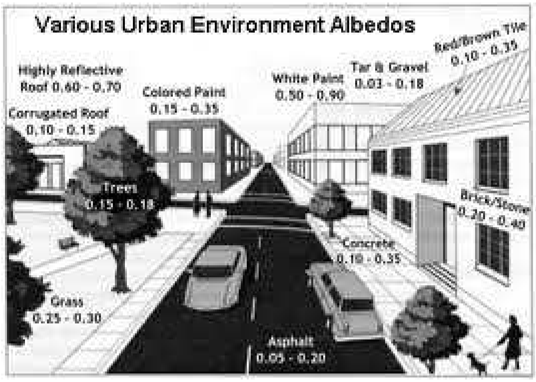


Illustration 2.4.4: albedo values for various urban surfaces (Goodman, 1999).

Another aspect is the time in which a material cools down. Materials like brick have a long time lag, which results in radiating heat into the air during night time until sunrise. Hollow block concrete cools down much faster. The temperature difference between materials can go up to 19°C. During heat waves the temperature in cities can be cumulative day by day when there is no cooling wind or enough green to compensate. A research done by Wong Nyuk (2007)project in Singapore focused on the difference in temperature on building facades due to d ark or light colours. A maximum temperature difference of 8-10°C on the external wall was measured during 13.00 and 16.00. Also the façade material in relation to the cooling time-lag was studied in Singapore. Three types were tested: a brick, a concrete and a hollow block wall. The brick wall had the longest time lag, followed by the concrete wall and the hollow block wall cooled at the fastest rate.

2.5 Consequences of the UHI effect

2.5.1 Climate

Thermal comfort is the state of mind that expresses the sense of satisfaction with the surrounding environment. Thermal comfort is usually measured according to 4 physical variables: temperature, humidity, air speed and thermal radiation. The experience of thermal comfort depends on individual characteristics such as; clothing, sex, age, activity level and previously experienced temperatures (Ashrae, 2004).

A comfortable air temperature depends on the kind of activity one is performing. When exercising or doing physical labour comfortable temperatures are lower than when one is having a stroll through the park. Enjoying the weather on a terrace or sunbathing requires even higher temperatures.

When people are able to adjust their activities during warm weather there will be less discomfort. For office employees this is usually not an option, which means that the temperature in the working space needs to be adjusted. The building stock in the Netherlands is not very well equipped for warm weather and offices are often too warm and unable to get rid of this heat. The productivity decreases when the temperature exceeds 25°C. Above this temperature every degree extra leads to 2% productivity loss in an office environment (Kleerekoper, 2009).

In general wind has a large negative influence on thermal comfort in winter, extensive described in chapter 3.2: KNMI UHI research. This implies an important constraint when designing to use wind to cool cities in summer. The Dutch standard for wind comfort is a maximum acceptable wind speed of 5 m/s, more than 3 Beaufort, and danger for wind speed 15 m/s, more than 7 Beaufort (NEN 8100, 2006). Like temperature, wind comfort is also highly dependent on the kind of activity (see Table 2.5.1).

Comfort criteria according to Devonport for an air temperature above 10 °C

Activity	Applicable for	Relative comfort at wind speeds according to Beaufort			
		Pleasant	admissible	unpleasant	dangerous
Walking fast	Walkway	5	6	7	8
Strolling, skating	Parking, building entrances	4	5	6	8
sanding still or sitting down for a short period of ti	Parking, squares, shopping malls	3	4	5	8
Standing still or sitting down for a long period of tim	Open air theatre, terraces, stadiums, recreation areas	2	3	4	8

Table: 2.5.1 Bouwfysisch tabellarium, 1987

2.5.2 Health

Heat stress: In the Netherlands 25°C can be taken as a starting point for heat stress. Increased daytime surface temperatures, reduced night time cooling, and higher air pollution levels associated with UHIs can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality. In 2006 the month July was extremely warm which led to many more heat-related deaths than usual people (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006; Kalkstein, 1991). This heat wave was rated as the world's fifth worst natural disaster in terms of actual deaths in 2006 (Table 2.5.2.A).

Natural disasters in 2006			
	Type of natural disaster	**Land**	**Number of deaths**
1	Earthquake (Yogyakarta)	Indonesia	5.778
2	Storm (typhoon Durian)	Philippines	1.399
3	Extreme temperature (heat waves)	France	1.388
4	Mud streams (earth movements)	Philippines	1.126
5	Extreme temperature (heat waves)	Netherlands	1.000
6	Extreme temperature (heat waves)	Belgium	940
7	Storm (typhoon Billes	China	820
8	Flood waves (tsunami)	Indonesia	802
9	Extreme temperature (frost period)	Ukraine	801
10	Flood	Ethiopia	498
Table: 4.3.1.B			

Based on the data from the warm summer in 2006, the CBS (2007) calculated that the increase of the average temperature by one degree Celsius leads to an extra mortality of about 31 persons per week, in Illustration 2.5.2. In 1995, a mid-July heat wave in the Midwest caused more than 1,000 deaths (Taha, Kalkstein, Sheridan, & Wong, 2004). The Centres for Disease Control estimated that from 1979 to 1999, excessive heat exposure contributed to more than 8,000 premature deaths in the United States (CDC, 2004). Table 2.5.2.B ranks the Netherlands as second in premature deaths due to particulate matter in European countries per year.

Source: CBS

Illustration: 2.5.2: The number of deaths (light blue) in relation to the maximum average of temperature (dark blue) during week 20 to 32 of 2006.

EU premature deaths due to particulate matter		
		% of total inhabitants
Hungary	11.067	0.111%
Netherlands	13.123	0.080%
Germany	65.088	0.079%
Czech Republic	7.996	0.077%
Poland	27.934	0.073%
Italy	39.436	0.066%
Belgium	10.669	0.064%
France	36.868	0.057%
Austria	4.634	0.056%
UK	32.652	0.053%
Spain	13.939	0.030%

Table: 2.5.2.B (EU Member states, 2000)

According to the KNMI (2008) a heat wave occurs when during five consecutive days temperatures are 25°C or more, including three consecutive days of 30°C or above. The optimal outdoor temperature related to health is 16.5°C (Huynen, Martens, Schram, & Weijenberg, 2001).

2.5.3 Energy Consumption

The building stock in the Netherlands is mainly prepared for cold periods. High isolation values prevent loss of heat, large windows let in sunlight and generate a comfortable climate during cold periods. But the large amount of window surface causes overheating of buildings in warmer periods. Office buildings need to switch on their air conditioning system when the outdoor temperature rises above 12-15°C. Also households tend to obtain air conditioning systems. Currently only 1% of the households is equipped with air conditioning, but this percentage is expected to increase to 3% in the next years.

Elevated summertime temperatures in cities increase energy demand for cooling and add pressure to the electricity grid during peak periods of demand. Offices are running cooling systems (generally) on hot summer weekday, illustration 2.5.3.A. This peak in urban electric demand increases 1.5-2% for every 0.6°C increase in summertime temperature. Steadily increasing downtown temperatures over the last several decades mean that 5-10% of community-wide demand for electricity is used to compensate for the heat island effect.

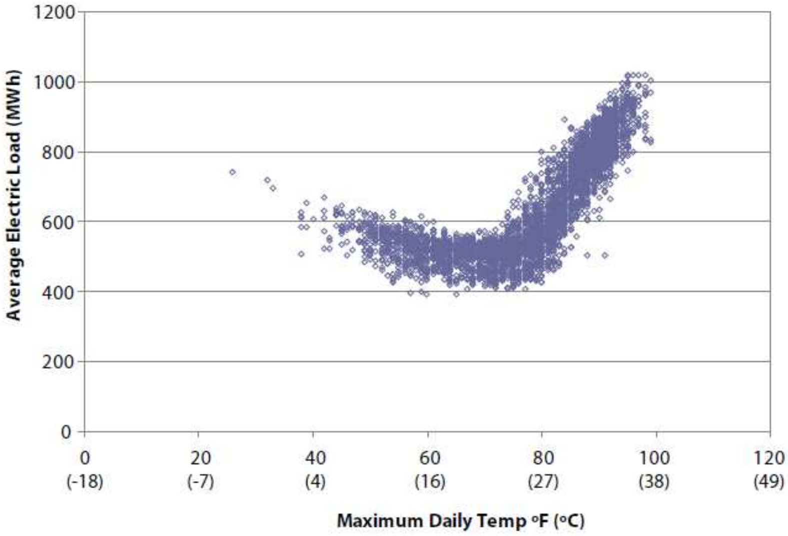


Illustration 2.5.3: Increasing power loads with temperature increases (Sailor, 2002)

Another problem occurring when electricity plants need to produce at their maximum during warm periods, is the lack of cooling water. Regulations in the Netherlands set limits to the water temperature that is discharged to surface water to protect nature and the landscape. This cannot exceed temperatures around 30°C. The higher the water temperature, the more water is needed to cool 1°C, illustration 2.5.3.B (Kleerekoper, 2009).

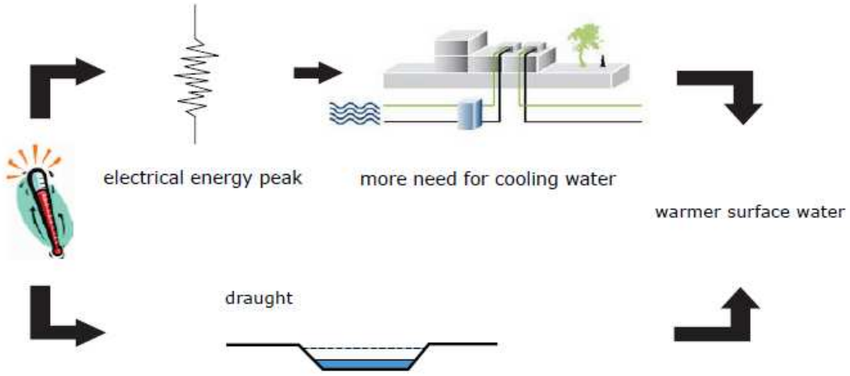


Illustration 2.5.3.B: Energy plants will not be able to deliver enough at peak demands due to the lack of cooling water.

2.5.4 Organic life

Changes in flora and fauna as a result of the milder climate:

- Insects occur earlier in the year and in greater numbers;
- Species can migrate and cause a nuisance;
- Non–indigenous species may survive in urban areas due to the UHI effect;
- Abundant vegetation may cause an increase in allergies;

Water temperature affects all aspects of aquatic life, especially the metabolism and reproduction of many aquatic species. Rapid temperature changes in aquatic ecosystems resulting from warm stormy water runoff can be particularly stressful. Fishes experience thermal stress and shock when the water temperature changes more than 1-2°C in 24 hours (EPA, 2003). But also arising of the blue algue is not uncommon, illustration 2.5.4. The way these rapid temperature changes in aquatic ecosystems can occur is as followed: pavement and rooftop surfaces that reach temperatures 27-50°C higher than air temperatures transfer excess heat to stormy water. Field measurements from a study from Roa-Espinosa, Wilson, Norman, & Jones (2003) showed that runoff from urban areas was about 11-17°C hotter than runoff from a nearby rural area on summer days when pavement temperatures at midday were 11-19°C above air temperature, illustration 2.3.1. When the rain came before the pavement had a chance to heat up, runoff temperatures from the rural and urban areas differed by less than 2°C Roa-Espinoza, et al. (2003). This heated stormy water generally drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes. A study from EPA (2003) recorded temperature increases in surface waters as high as 4 °C in 40 minutes after heavy summer rains.

Illustration: 2.5.4: Growth of blue-algue in warm periods.

3 Theoretical research

In the last a couple of years studies have been done to investigate the influence of the number of habitants in a city and the UHI. Most of these studies are based on a study executed by Oke in 1973. In this study Oke (1973) proved that the population influenced the UHI for Europe and for north-America cities. KNMI (2009) studies the relation between amateur weather stations situated in urban areas with rural KNMI weather station for 4 Dutch cities. Brandsma (2010) studied the same research for Utrecht. Instead of using fixed weather station he drove 14 km by bike on a fixed route. KNMI (2009) researched the global warming and made a forecast for 4 different scenarios for the average and maximum temperature in 2050 and 2100. These three researches: population, Dutch UHI and scenarios are described in this chapter.

3.1 Population vs. UHI

In the last decade there has been a large number of research done regarding the relation between the city population and UHI. Especially after2003 and 2006, as described in chapter 2.5.2: Health, when we had extreme heat waves in the Netherlands. In 1973 Oke published a report about the city size and the UHI. In this survey the relation between the population of North American and European cities and the UHI was analyzed.

Oke (1973) explained two different illustrations and one table. In table 3.1 he showed the population, the measured maximum Δu-r (difference between urban and rural temperature) and for North American cities he even predicted the maximum Δu-r. In the first illustration 3.1.A, he shows the correlation between the North American population (P on the horizontal axis) and the maximum Δu-r (vertical axis) in degrees. In the second illustration 3.1.B, he shows the same correlation for European cities.

Maximum heat island (Δυ–ρ (max)) of North American and European settlements			
Settlement	**Population (x 10^3)**	**Δυ–ρ(max) observed (°C)**	**Predicted (°C)**
North America			
Montreal, P.Q.	2.000	12,0	10,3
Vancouver, B.C.	1.000	12,2	9,7
San Francisco, Calif.	784	11,1	9,5
Winnipeg, Manitoba	534	11,6	9,2
Edmond, Atla.	401	11,5	9,0
Hamilton, Ont.	300	9,5	8,7
San Jose, Calif.	101	7,7	7,8
Palo Alto, Calif.	33	6,9	6,9
Corvallis, Ore.	21	6,1	6,5
Europe			
London, U.K.	8.500	10,0	
Berlin, Germany	4.200	10,0	
Vienna, Austria	1.870	8,0	
Munich, Germany	822	7,0	
Sheffield, U.K.	500	8,0	
Utrecht, Netherlands	278	6,0	
Malmo, Sweden	275	7,4	
Karlsruhe, Germany	160	7,0	

Reading, U.K.	120	4,4	
Uppsala, Sweden	63	6,5	
Lund, Sweden	50	5,8	

Table: 3.1 (Oke, 1973)

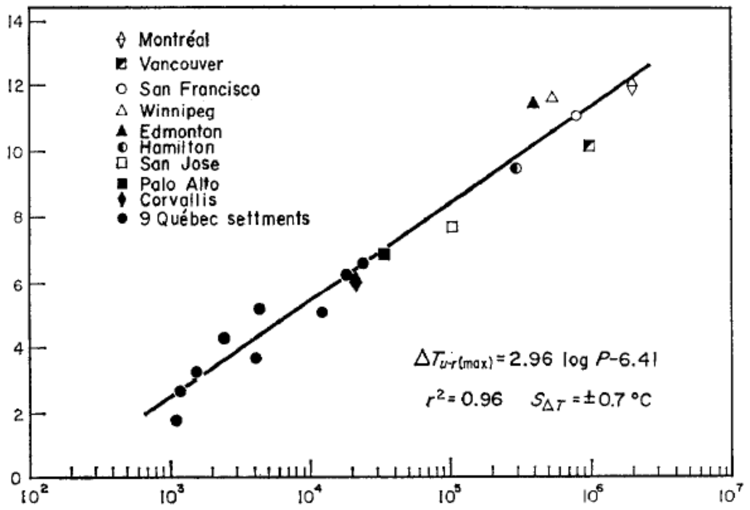


Illustration 3.1.A: Relation between Δu-r (max) and log P for North American settlements (Oke, 1973).

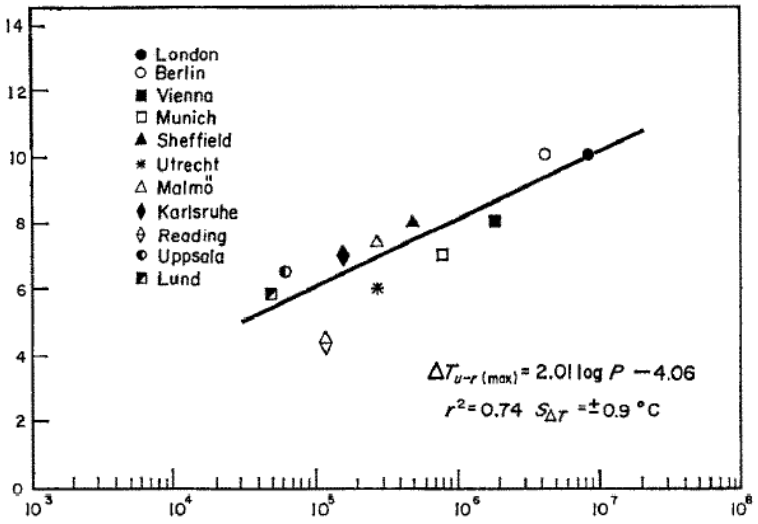


Illustration 3.1.B: Relation between Δu-r (max) and log P (population) for European settlements (Oke, 1973).

As seen in the two illustrations above there is a difference between North American cities and European cities. It seems that for a given city population the UHI for European cities will be smaller. This might appear a little surprising since European cities have greater population densities, and might therefore be expected to show more concentrated modification of temperature field. The explanation for this might be lower artificial energy flux densities, lower heat capacity of the urban fabric, or greater evaporation in European cities.

Brandsma showed in 2010 that the UHI can be 4°C for cities with a population of 100.000 and even 7°C for cities with a population of 200.000. These differences are the biggest and appear only when the sky is clear and there is no wind during the night. Put into practice, these big differences between urban and rural heat don't show that often, on average the difference is almost 1/10 smaller compared with the maximum (Brandsma, 2010).

The KNMI (2011) published a research on the correlation between the population and the UHI based on Dutch amateur weather stations. For all stations the population density for the relevant station was compared with the measured temperature for the summer of 2010. The results are shown in illustration 3.1.C. The vertical axis shows the difference between the urban and rural average summer temperature (UHI in degrees) based on the amateur station (urban) and the nearest KNMI station (rural). The horizontal axis shows the population (in thousands per square meter) and the crosses are the amateur weather stations.

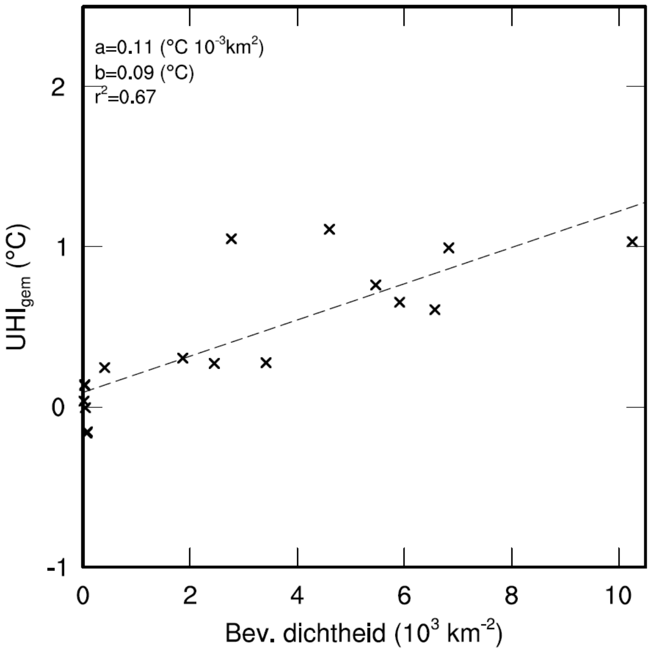


Illustration 3.1.C: Scatter plot of the average UHI for the summer of 2010, the dotted line is the linear trend (KNMI, 2009).

What can be derived from the illustrations above is that at a growing population the difference between urban and rural also grows and the UHI becomes stronger. In the last illustration there are some stations situated at country sides and small villages where the population is very small, close to 0, and so is also the UHI. The average UHI is between 0,5-

1,0°C for bigger cities the Netherlands. This is much lower compared to illustration 3.1.B because the maximum UHI is shown and in the illustration above the average UHI. With the average UHI and the maximum UHI we can predict the UHI for a random chosen city. For this survey, the average and the maximum UHI for Rotterdam city was based on previous research.

3.2 KNMI UHI research

3.2.1 KNMI research with amateur weather stations compared with KNMI weather stations

KNMI did research on the UHI to compare data from amateur weather stations with the closest KNMI weather station. KNMI compared hourly data to create 4 different variables: different wind directions, different wind speed, different temperatures and different periods during the day. With these 4 variables it is possible to say something about properties and the cause of the differences between the measurements. The measured data is based on September 2009. The four cities that were compared are:

- Region of Rotterdam: Capelle a/d Ijssel;
- Region of the Hague: Voorburg;
- Enschede;
- Amsterdam.

Region of Rotterdam:

For the region of Rotterdam, KNMI focussed on amateur weather stations of Capelle a/d Ijssel and KNMI station Rotterdam airport Zestienhoven, illustration 3.2.1.A.

Wind direction: The amateur station showed an increase of 0.6°C for the month September 2009 compared with the KNMI station. In the illustration (3.2.1.A) a scatter plot is illustrated. The left upper row shows that the most wind came from the direction 0-45 (north-east) degrees and 200-300 (south-west to west-north-west) degrees. Unfortunately there is no link between the wind direction and the temperature measured at the amateur and KNMI stations. The red line (difference in average temperature for the different wind directions) is almost horizontal.

Wind speed: The wind speed had a significant influence on the difference between the temperature measured at the amateur and KNMI stations. In the second scatter plot, right one in the upper row, it is shown that less wind effects the temperature. When there is less wind the difference between the two stations is much bigger compared with much wind. When the wind speed is 10 m/s or more the red line is almost zero and horizontal, which means that there is almost no difference between the urban and rural stations.

Temperature: A clear link is visible in the temperature scatter plot, third scatter plot left under. The lower the temperature the bigger the UHI. It is a proof that the UHI during (cool) nights is the biggest. The fact that the UHI is the biggest when there is less wind speed is also proven: when there is a strong wind the temperature is the lowest during the night.

Time of day: the difference in temperature during the day is clearly shown in the fourth scatter plot (bottom right). The difference in temperature is the biggest during the night (after 18.00 UTC = 20.00 local time), to an average of 1°C, and decreases heavily during the morning at sunrise.

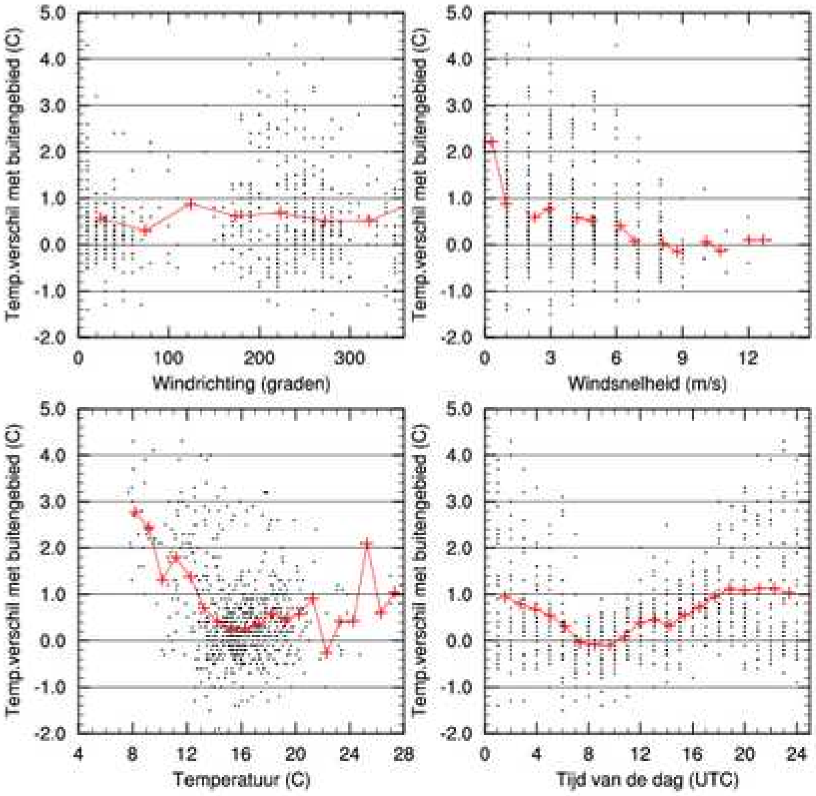


Illustration 3.2.1.A: Temperature differences between the urban and rural area vs. wind direction (upper left), wind speed (upper right), temperature (left bottom) and different times during the day (right bottom) for the station Capelle a/d Ijssel (120) compared with KNMI-station Rotterdam airport Zestienhoven, hourly measurements for September 2009. The red plus signs are the average values (KNMI, 2009).

The Hague region:

For The Hague region the Voorburg residential with low block of flats is compared with the Valkenburg KNMI station, illustration 3.2.1.B. The amateur weather stations show an almost 1°C degree warmer average compared with the surrounding KNMI stations. As shown in the Rotterdam analysis above, there is also no connection between the wind direction and the temperature. In spite of this, the relation between the wind speed and the temperature seems very clear. When there is less wind, the average temperature is almost 2°C warmer compared to the KNMI station. When there is a lot of wind, the average is close to zero. The connection with the temperature seems also clear. Like was shown in Rotterdam, the UHI is bigger at a lower temperature, and the day analysis is also comparable with Rotterdam. The difference is the biggest during the night, and the smallest in the morning.

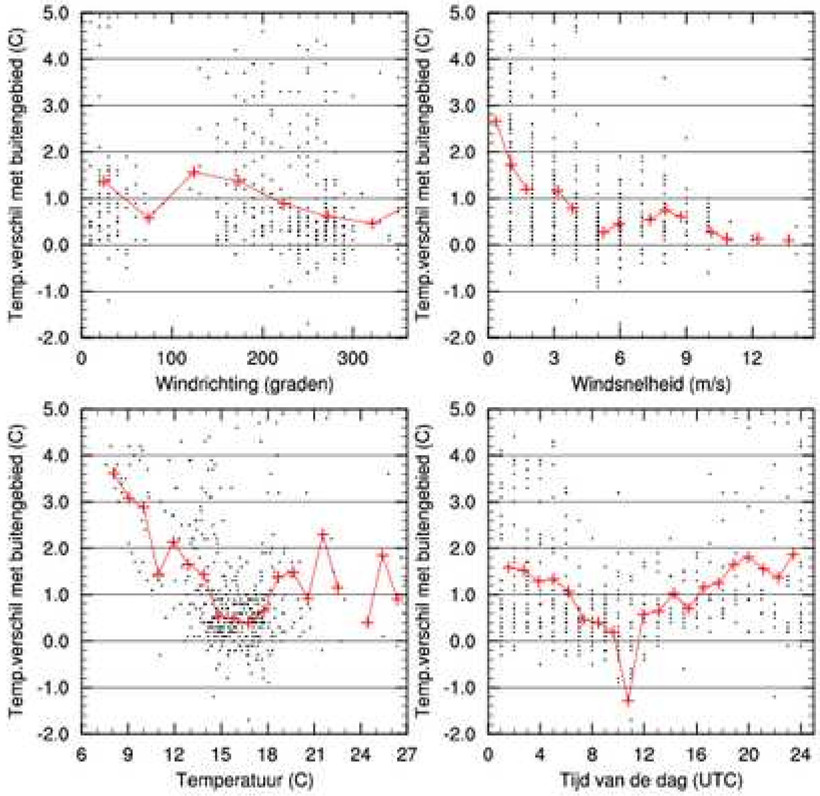


Illustration 3.2.1.B: Temperature differences between the urban and rural area vs. wind direction (upper left), wind speed (upper right), temperature (bottom left) and different times during the day (bottom right) for the station Voorburg (158) compared with KNMI-station Valkenburg, hourly measurements for September 2009. The red plus signs are the average values (KNMI, 2009)

Enschede:

The amateur weather station was situated in a residential outside the city centre and is compared with the KNMI weather station in Twente (see illustration 3.2.1.C). In September 2009, the average temperature at the amateur stations was 0.7°C warmer compared to the

KNMI station. The second scatter plot shows the influences of the wind speed which is clearly visible and the scatter plot of the 24hour period is comparable with the two cities above.

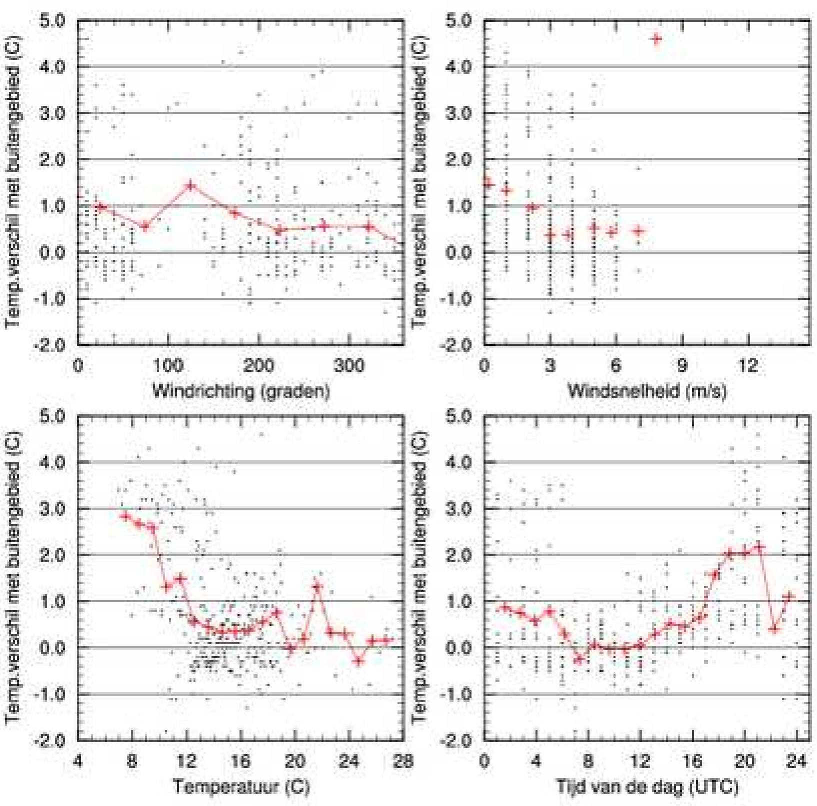


Illustration 3.2.1.C: Temperature differences between the urban and rural area vs. wind direction (upper left), wind speed (upper right), temperature (left bottom) and different times during the day (right bottom) for the station Enschede (258) compared with KNMI-station Twente, hourly measurements for September 2009. The red plus signs are the average values (KNMI, 2009).

Amsterdam:

When looking at the amateur weather stations (see illustration 3.2.1.D) that there is no clear link between the UHI and the wind speed. The average difference between the urban (Amsterdam) and rural (Schiphol KNMI weather station) area (0.57°C 2009) is almost equally divided over the different wind speeds in September. The same applies for the temperature: on both weather stations it is not visible that when the temperature drops, the UHI becomes stronger, like we saw on the stations above. The difference in temperature is comparable with the stations above: the biggest difference between urban and rural (UHI) in the evening and the lowest in the morning around sunset. The weather stations show only the temperature from morning till evening, so the night is missing. This could be an explanation why there was no link between the wind speed and the temperature. The night is missing, and so is the cool night with less wind. Especially at this type of night the UHI is the strongest.

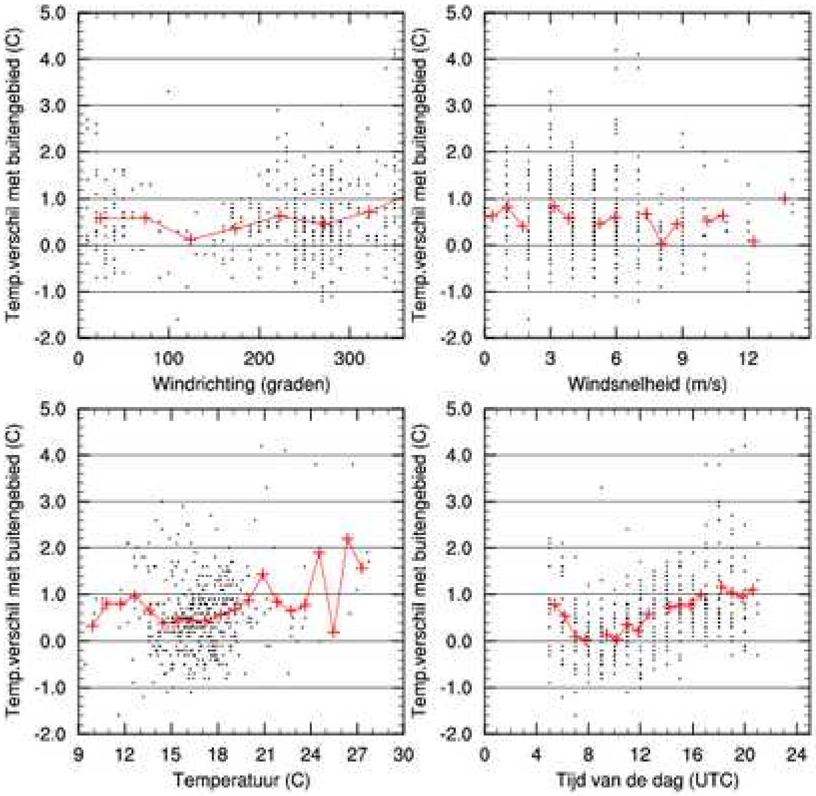


Illustration 3.2.1.D: Temperature differences between the urban and rural area vs. wind direction (upper left), wind speed (upper right), temperature (left bottom) and different times during the day (right bottom) for the station Amsterdam (64) compared with KNMI-station Schiphol, hourly measurements for September 2009. The red plus signs are the average values (KNMI, 2009).

Summarizing the outcome of the four region research, the weather stations above show comparable effects. On all stations, except from Amsterdam, the weather stations show the biggest difference between urban and rural areas when the wind speed is the lowest. The fluctuation of the temperature is almost the same for all stations: the strongest UHI in the evening and at night, and the weakest UHI in the morning. Also the strongest UHI appears when the temperature is the lowest.

3.2.2 UHI of Utrecht

In 2010 Brandsma published an article about the UHI in Utrecht. In the period from March 2006 till January 2009 he rode a track of 14 kilometres through the urban and rural environment of Utrecht on a bicycle, with special tools to measure the temperature, humidity and the SVF. The results can be seen as an addition to the research of (Conrads, 1975).The research of Brandsma (2010) and the one of Conrad, the UHI was analyzed for a morning (before sunset) and an afternoon time period. The UHI in the morning is 7-1,5°C and 0,6°C during the day and the biggest UHI appeared around kilometre 9, see illustration 3.2.2.A.

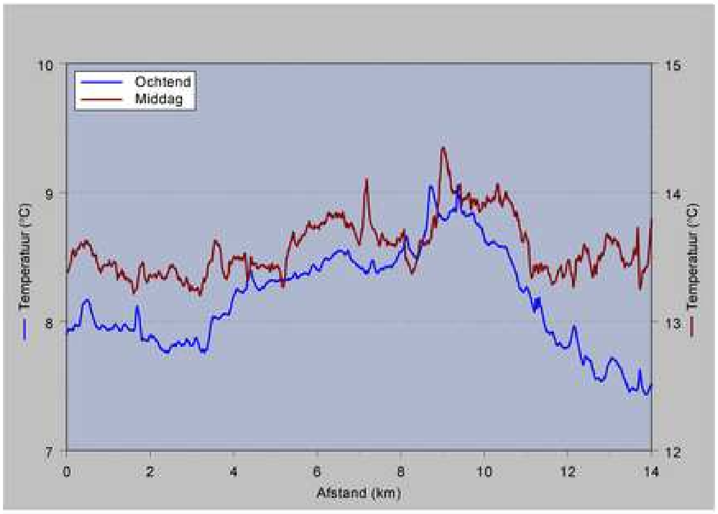


Illustration 3.2.2.A: the average profile for the morning measurements clearly shows a difference between the Utrecht centre (between kilometre 6 and 11), surrounding area and the difference between the morning and the afternoon.

Next illustration shows the three days with the biggest UHI. What we can see is the UHI of 7°C on 13 March 2007 which is not even a summer month. Normally the summer months are the hottest.

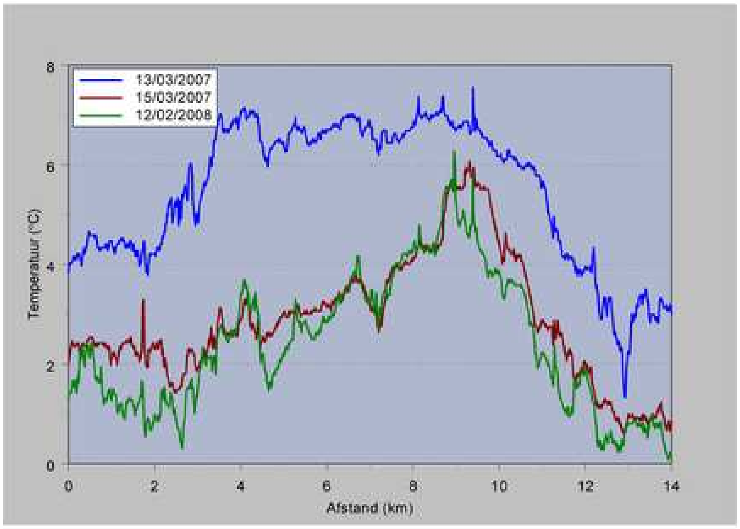


Illustration 3.2.2.B: The three days with the biggest UHI maximum.

In this research from Brandsma (2010) the effect of the wind direction on the temperature profiles is also shown. To analyze the effect of the wind direction, the morning measurements is subdivided into 4 directions: north, east, south and west. In the illustration 3.2.2.C the wind directions and the differences between the overall average and the wind direction average are shown. The profiles for the wind direction west and south and the profiles for east and north are similar.

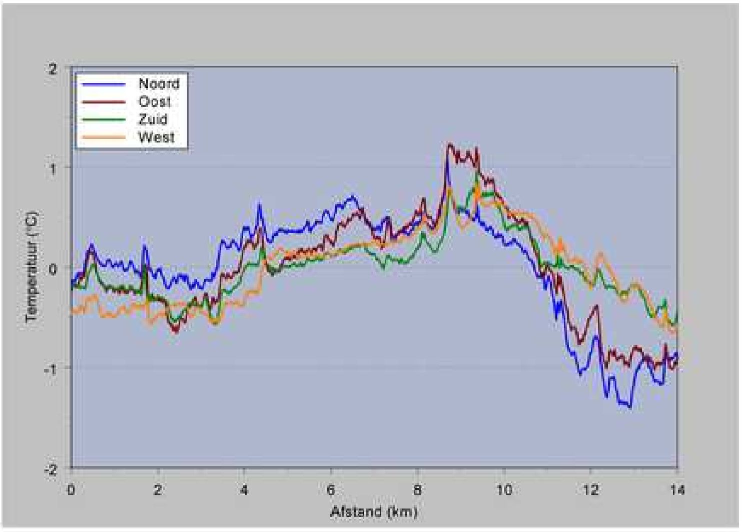


Illustration 3.2.2.C: The profiles for the average temperature for each wind directions (each profile shows the deviation of his average).

Finally also the effects of the wind speed and cloudiness on the UHI maximum were shown. Brandsma divided the cloudiness into two categories: <4/8 and 4/8>. In illustration 3.2.2.D the correlation between UHI maximum and the wind speed for two cloudiness types is shown. In the illustration is visible that when the wind speed is 1 m/s or less and especially when there are less clouds, the UHI is the biggest and reaches it’s maximum.

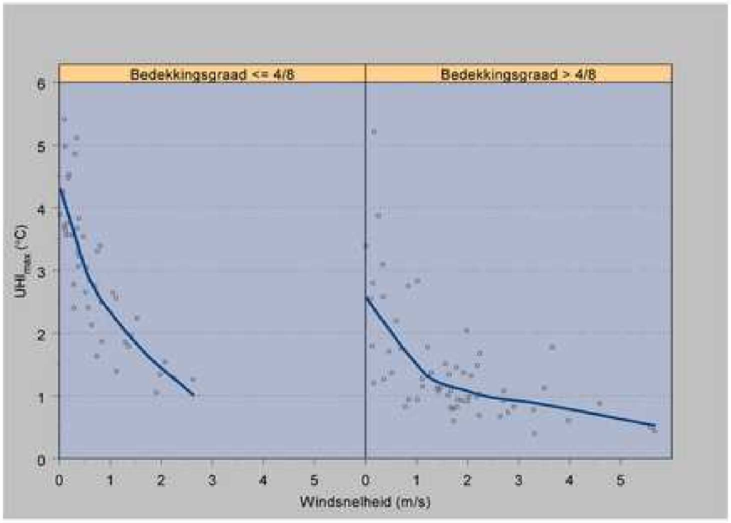
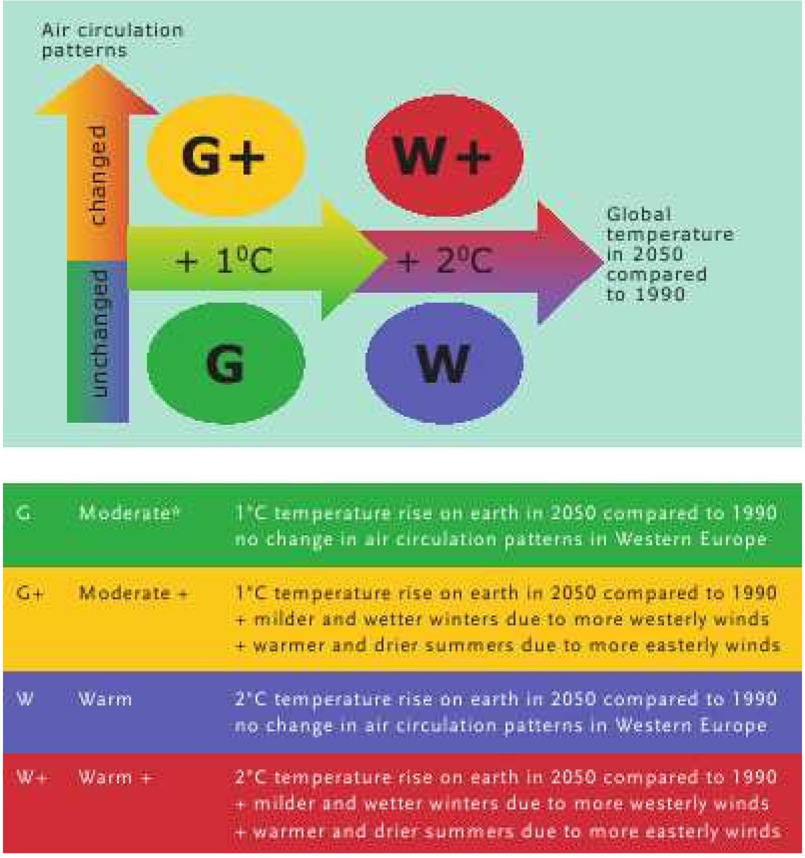


Illustration 3.2.2.D: The correlation between the maximum UHI and the wind speed for two cloudiness categories.

The conclusions from Brandsma (2010) show the biggest differences in temperature at night, 5°C. Also the influence of the wind speed, wind direction and the percentage of clouds seems not to be under the estimate. Especially when it is less cloudy, the wind speed is low and the wind comes from south or east. Then the differences in temperature and the differences between centre and rural area seem to be the biggest.

3.3 *KNMI scenarios*

KNMI (2006) has developed four climate scenarios for the Netherlands; indicated by G, G+, W and W+. A schematic overview of these KNMI'06 climate scenarios are shown in illustration 3.3. In Table 3.3 the climate change in the year 2050 and 2100 is expressed in average temperature and hottest/coolest day for each year and each scenario.



G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

Illustration 3.3: Schematic overview of the four KNMI'06 scenarios. 'G' is derived from 'gematigd' = Dutch for 'Moderate' (KNMI, 2008).

Climate change in the Netherlands around 2050 and 2100					
2050		**G**	**G+**	**W**	**W+**
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		No	yes	No	Yes

Summer	Average temperature	+0,9°C	+1,4°C	+1,7°C	+2,8°C
	Warmest summer day per year	+1°C	+1,9°C	+2,1°C	+3,8°C
Winter	Average temperature	+0,9°C	+1,1°C	+1,8°C	+2,3°C
	Coldest winter day per year	+1°C	+1,5°C	+2,1°C	+2,9°C
2100		**G**	**G+**	**W**	**W+**
Global temperature rise		+2°C	+2°C	+4°C	+4°C
Change in air circulation patterns		No	yes	No	Yes
Summer	Average temperature	+1,7°C	+2,8°C	+3,4°C	+5,6°C
	Warmest summer day per year	+2,1°C	+3,8°C	+4,2°C	+7,6°C
Winter	Average temperature	+1,8°C	+2,3°C	+3,6°C	+4,6°C
	Coldest winter day per year	+2,1°C	+2,9°C	+4,2°C	+5,8°C

Table: 3.3 (KNMI, 2008)

Note: table 3.3: Climate change in the Netherlands around 2050 and 2100 compared to the baseline year 1990, according to the four KNMI'06 climate scenarios. The climate in the baseline year 1990 is described with data from the period 1976 to 2005. The seasons are defined as followed: 'winter' stands for December, January and February, and 'summer' stands for June, July and August.

The KNMI'06 climate scenarios present changes in temperature for a climatological period of 30 years. The scenarios for 2050 are, therefore, representative for the climate around 2050 (between 2036 and 2065). Likewise, the climate in the baseline year 1990 is described with data from 1976 to 2005. The numbers per KNMI'06 climate scenario do not include information on year-to-year variability and longer-term natural fluctuations, which also occurred in the past (KNMI, 2008).

Current KNMI'06 scenarios for temperature:

Climate models calculate a global mean temperature increase of 1-6°C for the year 2100, compared to 1990. In Europe the average temperature will probably increase slightly faster than the world average. In the Scandinavian countries especially winter temperatures will increase more rapidly than the global average, and in southern Europe summer temperatures will increase more rapidly.

In the KNMI'06 climate scenarios the temperature increase in the Netherlands does not equal global temperature rise. The Netherlands is located at the edge of a continent, which warms faster than the global average. At the same time, it is located close to the north-eastern part of the Atlantic Ocean, for which most climate models calculate a relatively slow temperature increase. The scenarios with changes in air circulation show a faster warming than the scenarios that do not include such changes.

The four scenarios show a warming by 2050 of 0.9-2.8°C in summer and 0.9-2.3°C in winter (illustration 0 A and B). The observed temperature rising between 1990 and 2005 is comparatively high: on average more than 0.5°C. This does not mean necessarily that the lowest scenarios for 2050 are too conservative. Also, natural fluctuations clearly affect the observed temperature increase. Since these fluctuations will also continue in the future, it is possible that in the coming decades we will temporarily experience a period with relatively colder weather (KNMI, 2008).

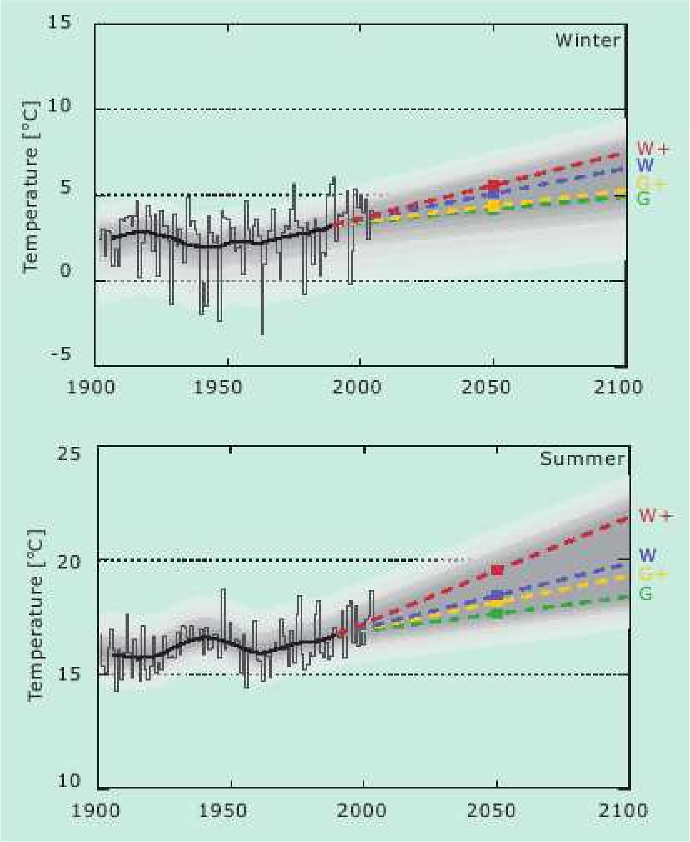


Illustration 0.A: Temperature in de Bilt between 1900 and 2005 and the four climate scenarios for 2050 (coloured points). The thick black line presents the 30-year moving average of the observations. The thick coloured and dashed lined connected each climate scenario with the baseline year 1990. The grey band represents the year to year variation, derived from the observations (KNMI, 2008).

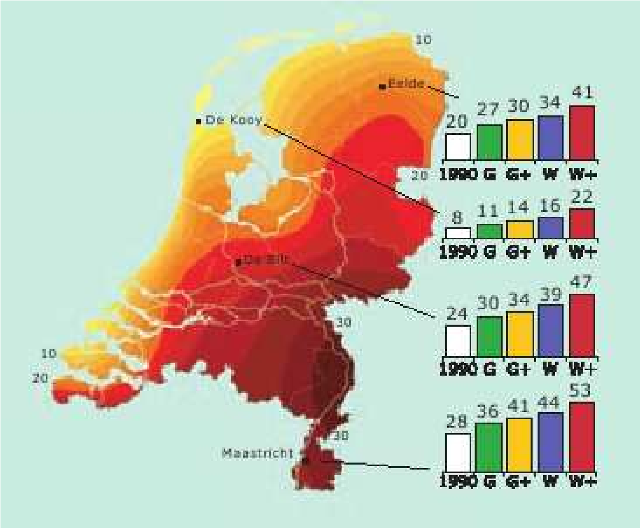


Illustration 0.B: map with the observed numbers of summer days (maximum temperature > = 25 °C) per year for 1971 – 2000, and four locations in the Netherlands the climate scenarios for 2050. The differences in summer days between the four locations are due to the differences in the current climate (KNMI, 2008).

4 Case description

4.1 Research question

In the chapters 2 and 3 the theoretical part was described. Explaining the term UHI, the existence of the UHI, the effects of the UHI, previous theoretical researches and the design principles. It was described that there are different forms of UHI and that surface and temperature are related. A research done by Oke (1997) shows that for a city with a population of 1 million or more the difference between urban and rural can climb to 1-3°C and on clear calm nights this difference can be as much as 12°C. Berdahl & Bretz (1997) show that when the sky is clear and there is less wind the temperature gets stocked in the city and the temperature will reach it maximum. The difference between the air temperature and the surface temperature can even climb to 27-50°C (in the advantage of the surface). Another type of UHI is the atmospheric UHI which is divided in canopy and boundary layer, illustration 2.2.2. The atmospheric canopy layer is formed by the air temperature that was measured between the ground and the top of the trees/buildings. The second layer, boundary, is measured from above the tree/building tops and doesn't extend to no more than 1,5km from the surface. The reason why we have to deal with temperature differences between the urban and rural area is also explained in this chapter, it said that one of the reasons is the reduction of the green in urban areas. When the environment gets urbanized the percentage of temperature that can be absorbed by the ground is less. The sun reflects and will be absorbed by some material, the degree of absorption is influenced by the type of material. Following Christen & Vogt (2004) the absorbed heat can be twice as much compared to rural surroundings. The urban geometry influences the difference as well and especially at night. The geometry is dependent of windflow so that the heat that is absorbed during the day can be released and emit long-wave radiation back to space. Not only the urban morphology influences the UHI but also our population, which uses more instruments that produce heat as well. Finally, the weather and the geographic location influence the UHI but are not impressionable.

The inconvenience and effects of the UHI are different for everyone. Elderly people and sick people have more inconvenience of the UHI (a rise of deaths during extreme summers like 2003 and 2006) but our productivity also drops by 2% for each degree above the 25°C (Kleerekoper, 2009). To compare this productivity and to keep our inside climate comfortable we are using more energy to cool. The side effect of using more energy is that the energy plants need more cooling water which causes a rise of water temperature and so the quality of this water drops. Also the heated materials will effect the water (indirectly). When the rainwater flows along the heated materials, they heat up as well. A study from EPA (2003) showed a temperature increase in surface water as high as 4°C in 40 minutes after heavy summer showers. Water is not the only organic life that gets influenced by the UHI: also insects, species, etc.

Now we know what UHI is and that the human behaviour (also) influences the difference in temperature, we discuss the different types of research that is done in the past. The first research that was described is the relation between population and the UHI. It shows that there is a linear connection between the population and the temperature for European and for North American cities (Oke, 1973). Brandsma (2010) shows that there is a maximum UHI of 4°C for cities with a population of 100.00 and even an maximum UHI of 7°C for a population of 200.000 and more. KNMI shows that the average UHI for Dutch cities between 0,5-1,0°C lays. KNMI (2011) did a research between rural KNMI weather stations and urban amateur stations for 4 different cities. In this research they showed the relation between wind direction, wind speed, time of the day and the temperature. One of the main causes of the UHI was the wind speed, the UHI is the lowest when the wind speed is the highest. A final research was described (Brandsma, 2010) for the city of Utrecht. Brandsma (2010) concluded that for a wind speed of 1 m/s or less the UHI is the biggest and especially with wind from the south or east.

Humanity is the main cause for the UHI, and knowing that the UHI is the biggest with less wind, less clouds, wind from the south-east and with cities with rising population density, the UHI will become an even bigger problem in the future. An effect what makes this problem even bigger is the prognosis from ICPP (2001) which shows and also predicts global warming. KNMI (2008) predicts a rise of the average temperature between 0,9-2,8°C in 2050 and 2-4°C in 2100 for the Netherlands.

Knowing what an UHI is, what causes the UHI, the way we build our cities and the effects of urbanizing and global warming, we also need to know how we can fight the rising UHI. Comte, Le & Warren (1981) showed that vegetation has a cooling effect of 1-4,7°C that spreads 100m to 1km into urban areas. A study done by Upmanis, Elisasson & Lindqvist (1998) in Göteborg shows a maximum temperature difference of 5,9°C between a city park of 156 ha and the city centre. A study done by Kravcik (2007) shows that a street tree can have a cooling effect through evaporation of 20-30 kW, which stands for more than 10 air-conditioners. Another positive effect of trees in the summer is that they provide shade and in winter, when the trees have no leaves they let the sun through which is positive because shade is not desirable in winter. Water can also be helpful in reducing urban temperature. Water has an average cooling effect of 1-3°C to an extent of 30-35 meters, and can be felt even further when we have to deal with large surfaces of water. Another benefit of water is that it doesn’t heat as quickly, and as a result is able to transport the heat out of the city. For that reason we find the coolest spots in city centres along river banks during the summer.

The density and the form of the buildings are important for the amount of sun that reaches the ground and reflects on or will be absorbed by the ground and the walls. The density and the form of the buildings also influences shade and ventilation. The best mix for the canopy surface is a H/W ratio of 0,5. If the H/W ratio is 2 or more, there is no mix of air at all (Esch, Bruin-Hordijk, & Duijvestein, 2007). Not only the density and the shape of the building, the materials that are used are also important. By increasing a city-wide albedo from 25-40%, a temperature drop of 1-4°C can be achieved. Increasing it to 70%, could reduce energy demands with 19% (Taha, Rosenfeld, Akbari, & Huang, 1988). The amount of absorption of materials is also important. At one hand some materials, like brick, absorb heat slowly, what means that they take quite some time before heating up and feel relatively cool during the morning and the beginning of the afternoon. On the other hand it also takes quite some time before it cools down which causes a heating effect during the evening and at night. The difference between air temperature and material temperature can go up to 19°C. The last tool to prevent cities for large UHI is the amount of products we use that produce heat as well, anthropogenic heat. An increase of 1,0°C leads to a 6,6% extra electricity demand and extra anthropogenic heat (Hiroaki & Yukihiro, 2003).

Summary: the world gets more urbanized every day and the temperature will increase by human influences and due to global warming. We know why these UHI exist and how we can prevent cities from the increasing difference between urban and rural areas. Studies show the relation between the population and the UHI. Knowing that cities are getting more urbanized, the difference between urban and rural will only grow even further. In research done in the past we saw the effects of water, vegetation, materials, and the relation between height of the buildings and width of the streets. What was never indicated up till now, is how all different theories and research can be used together. Therefore, current research combines, the influences of water, vegetation but also dwellings, industry, paved and unpaved open space. All these variables together are called the urban morphology and are independent variables in current research. Stated is that the urban morphology influences the temperature, the dependent variable in this research.

Where in previous studies the width of the streets is mentioned, the scope in this research will not be street width, but will be broader, 200 meters to each site. For this research, the influences of urban morphology were measured and will be related to the temperature for 50 different areas in the urban area of Rotterdam.

In this survey, the relation between each independent and dependent variables will be quantitative and qualitative analyzed to answer the research question:

> *What are the influences of urban morphology on the average temperature of Rotterdam city?*

4.2 Current Research:

The basic idea behind this research, is to link the percentage of 6 different functions (dwellings, industry, paved open space, unpaved open space, vegetation and water) to measured temperature data and to analyze the influences of each (combined and separate) on the average temperature. Thanks to the Wageningen University and Alterra (WUR-Alterra) I was able to get hands on temperature data measured from July 2010 till January

2011. WUR-Alterra installed temperature tools on 4 tramlines that drove through urban and rural areas across Rotterdam. Rotterdam is the second largest city of the Netherlands with a surface of 319,35 km^2 existing of 205,90 km^2 land, 113,45 km^2 water, and a population of 611.000. During this measuring period, the four tramlines drove, roughly, the fixed route, (illustration 4.2.A), and passed the districts shown in table 4.2.A. On this track the trams each measured the temperature, the time and the X and Y-coordinates for 20 seconds. As a result, WUR-Alterra collected an enormous dataset with temperatures. To relate the independent variables with the dependent variable, the track was cut into 50 equal pieces (cells) of approximately 600 meters. A buffer of 200 meters was created around the tramline piece, illustration 4.2.B and C. The benefit of cutting the track in pieces was the option to compare them. Without cutting, the dataset could only be compared to individual research like the ones described in chapter 2 and 3. The surplus value of this research is the combination between the different types of research executed in the past, the dataset from WUR-Alterra and the percentage of each independent variable. The percentage of each independent variable was calculated in ArcGIS, an ESRI software. In ArcGIS, a 2D map of Rotterdam was uploaded, thanks to the municipality of Rotterdam. In this 2D map every space had a function and it was possible to indicate the square metres for every cell of the independent variables. After that, the complete dataset (illustration 4.2.D) from the trams was uploaded and related to the temperature measurements of related cells.

The measurements were divided into different time periods. As showed in the chapters before, there were 3 interesting time periods. The first period is during the early morning, from 05:00 till 06:59. During this two hour period there should be no UHI. If there is still a difference after a night (cool down period), the rest heat will be taken with for this day. The second period is from 13:00 till 14:59. This two hour period is interesting because the difference between urban and rural temperature will start growing, the difference between the growing urban temperature and the rural temperature is visible, and during these two hours we can also see the maximum day temperature. The final period is from 17:00 till 19:59. This three hour period is probably (following the theoretical part) the most interesting period because UHI reaches it’s maximum.

Districts							
District number	**District name**	**National number**	**Total m^2**	**Land m^2**	**Water m**	**Population**	**Population density**

01	Stadscentrum	1.528	557	438	119	30.070	6.866
03	Delfshaven	1.534	579	503	76	70.270	13.964
05	Noord	1.500	537	515	22	49.850	9.682
06	Hilligersberg-Schiedar	1.439	1.328	1.177	151	40.880	3.473
10	Feyenoord	1.546	789	638	151	70.810	11.092
12	Ijselmond	1.561	1.312	1.183	129	58.780	4.970
15	Charlois	1.565	1.209	1.144	65	64.570	5.646
19	Nieuw-Mathenesse	1.550	218	134	84	58.780	13
Tabel: 4.2							

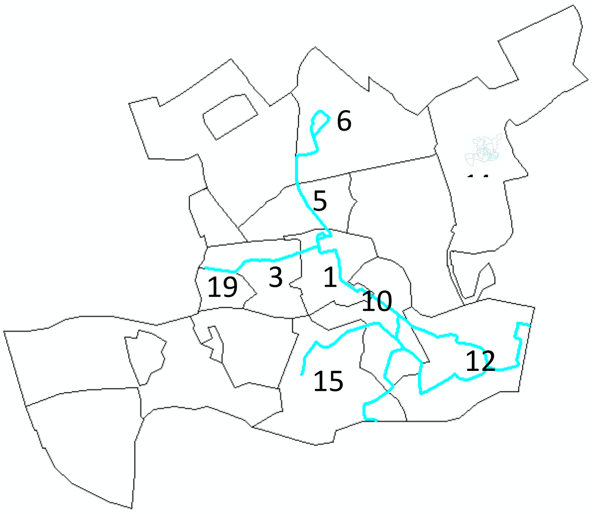


Illustration 4.2.A: The turquoise line is the tram route through the urban and rural areas of Rotterdam.

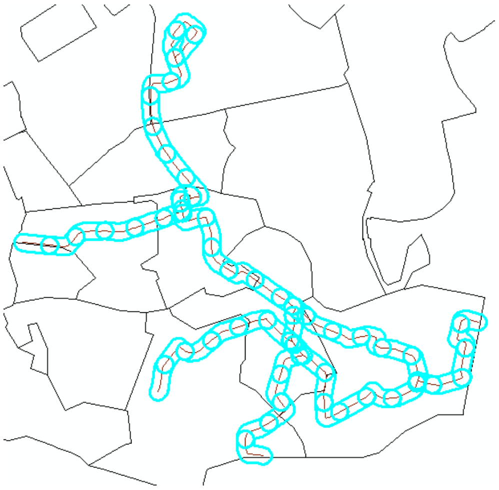


Illustration 4.2.B: the total research area consists of 50 cells.

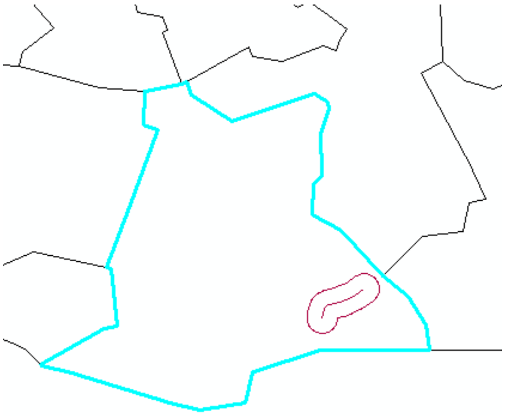


Illustration 4.2.C: Each cell consists of a (purple) piece of the line and a (purple) buffer around the line of 200 meter.

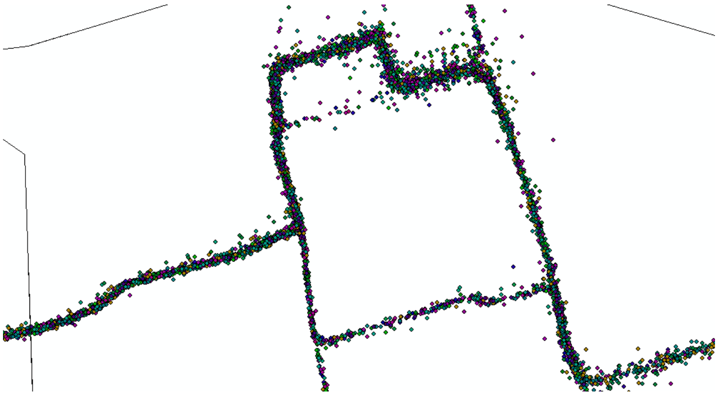


Illustration 4.2.D: A small part of the tram measurements with the x and y coordinates, time stamp and the temperature.

4.3 Output

The output from the 2D map in ArcGIS and the temperature measurements is an excel table where the following information is provided for 50 cells:

1. The cell number;
2. Total square metres;
3. The square metres for the following independent variables also known as the urban morphology, illustration ;
    a. Dwellings, which consists of all houses, offices or other built areas (exclusive industry). Dwellings have the colour red in ArcGIS.
    b. Industry has the colour purple and includes all light and heavy industry. I chose to put them together because the amount of heavy industry is so small that it is negligible.
    c. Paved open space is painted orange and so are roads, squares, cultural ground, paved industry area and airports.

    d. Unpaved open space is sand dune, beaches, sport park and allotment gardens, and is painted yellow.
    e. Vegetation is coloured green and includes all trees, grass, parks and other vegetation.
    f. Water, which has the colour blue, consists of al rivers, fountains or other water related objects.
    g. Finally there is some space left which has the colour white. White will be separate mentioned but hereafter is included with paved open space. The white parts are small streets and other paved spaces which are usually very small areas but together they form a large area.
4. From the square metres of each variable the percentage of the whole is calculated. Note: the yellow and white areas are combined and are part of the paved open space (yellow).
5. The temperature of two months will be used: July and August. We use the dataset for these two months because during this period the UHI seems to be the biggest (result from the theoretical research). Normally the data from June will be used as well, but the measuring tools where not installed yet. For July we have the following days: 1-13, for August we have the complete month. Together we have +/- 40 usable days from the summer period which is quite a number and enough to underpin our conclusions.
6. Each month is divided into three time periods with 7 hours (05, 06, 13, 14, 17, 18 and 19).
7. Each hour is divided in:
    a. Average temperature: which is the average for that cell in the specific month during the specific hour. These averages will be used to compare the average urban and rural temperatures and so formulate for each hour the difference and the UHI.
    b. The hottest single cell and the 10 hottest cells will be highlighted. For each hour the hottest cell will be painted a dark shade of red and the top 10 hottest cells will be painted red. With these cells we can analyze the problem areas, assuming that these cells are the problem areas.

    c. Same as the single hottest cell and the 10 hottest cells the coolest single cell and the 10 coolest cells will analyzed as well. The coolest single cell will be painted dark blue and the top 10 coolest cells will be painted blue. As the (top 10) warmest cell(s) are problem areas, the (top 10) coolest area(s) are also areas where we can learn from.

8. What was done for the average of each hour for the complete month in the excel table, the minimum, maximum and average was also calculated for all the cells for each day in the period of July and August.

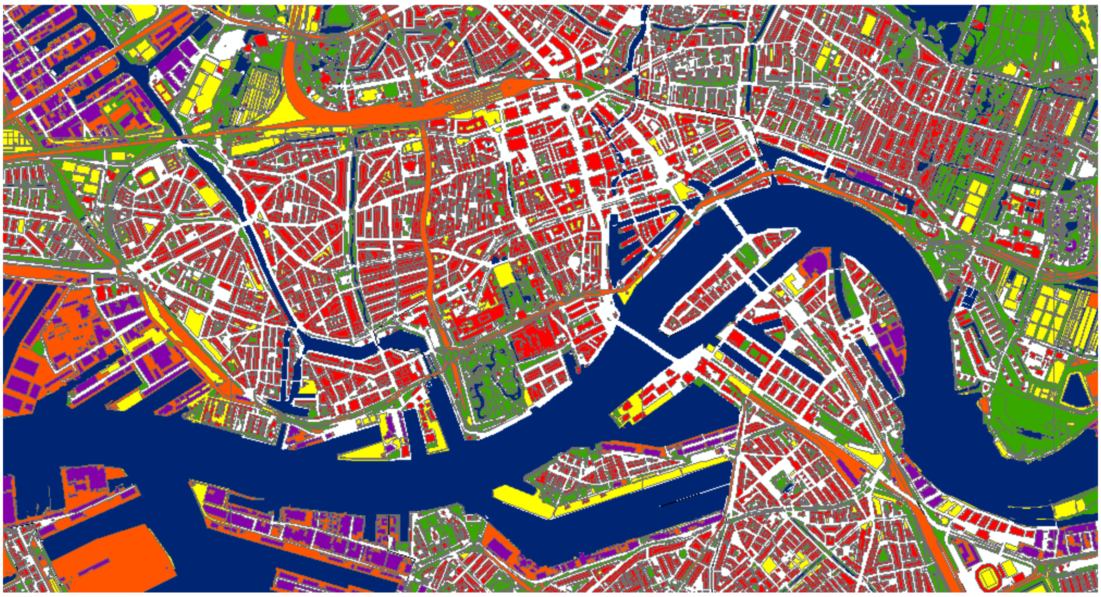


Illustration 4.3 Fout! Verwijzingsbron niet gevonden.**: Rotterdam city centre divided in the 6 colours.**

4.4 Cell analysis

How can the data in the Excel table be used to analyze the relation between the urban morphology and the temperature? This relation will be analyzed with two methods. The first method is the quantitative analysis, which is the analysis done by SPSS. In SPSS a (linear) multiple regression analysis was executed for both months for each hour. If there was an effect of the independent variables on the dependent variable, this would be provable with quantitative outcome. This quantitative analysis will be shown in chapter 5. The second analysis is the qualitative analysis, the (10) hottest cell(s) and the (10) coolest cell(s) were analysed. This analysis is based on the percentage of each independent variable in the cell but also in the area just outside the cell. If for example a cell just lays next to a river and suddenly the temperature is very low, it is not possible to relate water with the lower temperature outcome with only the data analysis. For that reason the focus will be on percentages in the cell regarding the area just outside the cell in the qualitative analysis. The qualitative analysis is shown in chapter 6.

5 Quantitative analysis

In this chapter for each hour the data from the excel table that was described in chapter 4.3, is quantitative analyzed. After analyzing, the result that can be formulated from the analysis are described in results.

The quantitative data analysis is based on the output of SPSS 19. For each period for both months, the relations between the dependent (temperature) and the independent values (percentage paved, unpaved etc.) were tested on their level of significance and percentage of explained variance. The test that was used to analyze the data is the (linear) multiple regression analysis.

For this analysis, two hypotheses were formulated:

HO= No effect of 6 independent variables on variances in dependent variable temperature.
($R^2=0$, $B=0$).
H1= an effect of 6 independent variables on variances in dependent variable temperature
($R^2 \neq 0$, $B \neq 0$).

In statistics, regression analysis includes techniques for modelling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. Regression analysis helps to understand how the type value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed (Wikipedia, 2011). Linear regression analysis is defined in terms of a number of unknown parameters that are estimated from the data and are useful even when the assumptions are moderately violated (Cook & Weisberg, 1982).

For each hour the estimation and test of the regression parameter in a model with 6 predictors was executed. For each analysis the following tables are important:

1) Descriptive statistics: where means for all (in) dependent are shown, and N which indicates the number of useful cells with an average temperature and percentage of each urban morphology. 2) Model summary: where R square indicates the percentage of total variance explained for all 6 independent variables together in relation to the variance in temperature. When R square is 0,10 (10% or less) the effect is small, when R square is

bigger than 0,10 and smaller as 0,30 (between the 10-30%) the effect is medium and when the R square is bigger than 0,3 (more as 30%) the effect is large (Voeten & van den Bercken, 2003). 3) ANOVA table: the ANOVA table indicates two important numbers. The first one is F which indicates the strength for rejecting or adopting the null hypothesis, where model variance is equal to residual variance. The second important number is the level of significance, which also indicates whether or not the null hypothesis needs to be rejected. The null hypothesis needs to be rejected when sig. is smaller than 0.05 (Voeten & van den Bercken, 2003)*. 4) The table: Coefficients shows two important columns. The first: B shows the values for the regression equation for predicting the dependent variable from the independent variable. The regression equation is presented in 2 different ways, B1: 0,38 => for every unit increase in percentage, a 0,38 unit increase in average temperature is expected, holding all other variables constant. B2:-3,66 => for every unit increase in percentage, a 3,66 unit decrease in average temperature is expected, holding all other variables constant. The second: Sig. (P) is used in testing whether a given coefficient is significantly different from zero. Using an alpha of 0,05. For example: The coefficient for B1 (0,39) indicates a change in value of the dependent value different from 0 because of its P-value is 0,00, which is smaller than 0,05. And therefore the null hypotheses need to be rejected. Or, the coefficient for B2 (-3,66) is not significant and therefore doesn't indicate a change in value of the dependent value different from 0 because its P-value is 0,083, which is larger than 0,05. Therefore the null hypotheses cannot be rejected. If 2 independent variables (or more) have a P of 0,05 or lower, they can be tested pair wise what mean that not 6 independent variables are tested but just 2. 5) The table excluded variables shows if some independent variables are excluded, which indicates that this variable has such a low impact that it is not even appreciable and has no influence on the other independent variables.

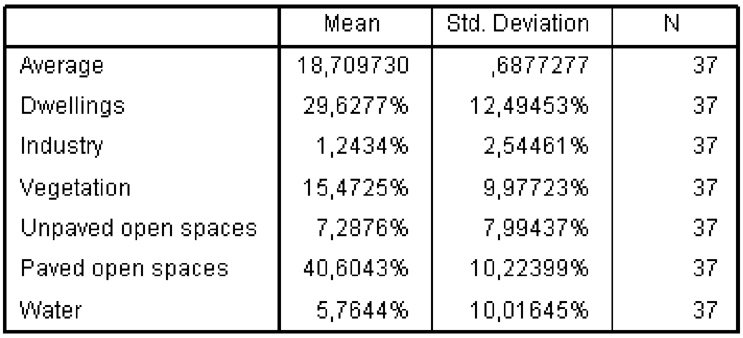
When adopting the null hypothesis, F needs to be < 1. The null hypothesis is rejected for bigger values of F.

*Note: if the hypothesis is rejected it will not be discussed any further. The outcome will be showed in the appendix 10.1.

5.1 July analysis

5.1.1 July - hour05

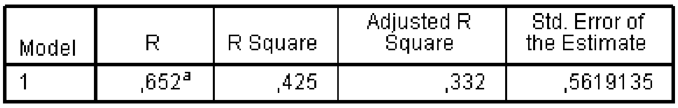
table 5.1.1.A shows the Descriptive statistics. In this table the average temperature (*Mean1*=18,7097) from now on the first *Mean* is *Mean1* and the second *Mean* is *Mean2* and so on) and percentage (*Mean2*=29,6277%; *Mean3*=1,2434%; *Mean4*=15,4725%; *Mean5*=7,2876%; *Mean6*=40,6043%; *Mean7*=5,7644%) of all usable cells. For example: if one of the (in)dependent variables has no number (no number does not mean 0% or 0°C) the complete row will be left out for further analysis (listwise deletion). The number of usable cells (*N*=37) is shown in the last column and is always equal (for each hour).



	Mean	Std. Deviation	N
Average	18,709730	,6877277	37
Dwellings	29,6277%	12,49453%	37
Industry	1,2434%	2,54461%	37
Vegetation	15,4725%	9,97723%	37
Unpaved open spaces	7,2876%	7,99437%	37
Paved open spaces	40,6043%	10,22399%	37
Water	5,7644%	10,01645%	37

Table: 5.1.1.A

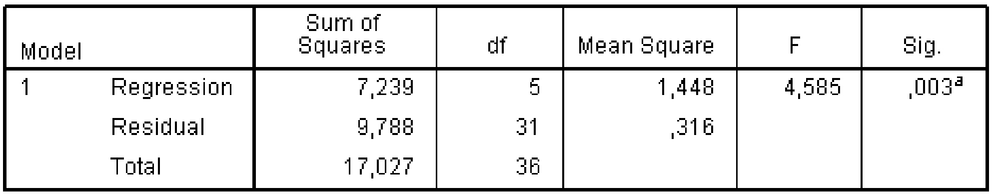
Model summary (Table 5.1.1.B) shows the R square for this model (*R Square* =0,425 or *R Square*=42,25%) indicating that the 6 independent variables together have a large effect of 42% (R^2>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,652^a	,425	,332	,5619135

Table: 5.1.1.B

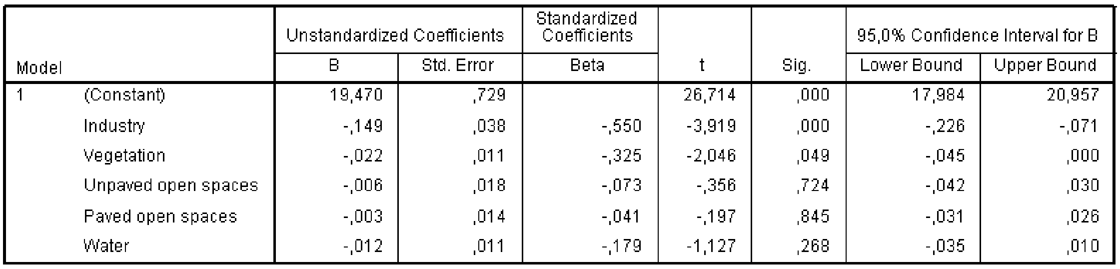
Table 5.1.1.C, the ANOVA table which shows the values of F (*F*=4,585) and P (*P*=0,003). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, the average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7,239	5	1,448	4,585	,003^a
	Residual	9,788	31	,316		
	Total	17,027	36			

Table: 5.1.1.C

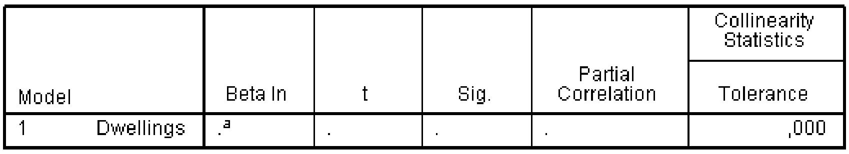
Table 5.1.1.D shows the Coefficients *(B1*=-0,149; *B2=-0,022 B3*=-0,006; *B4=-0,003; B5*=-0,012). It also shows that the independent variables: Industry (*B1*) and Vegetation (*B2*) are significant (*p*=0.00 , *p*=0.049) and therefore interesting to submit to further examination. This will be done in the next sub paragraph 5.1.2.



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	19,470	,729		26,714	,000	17,984	20,957
	Industry	-,149	,038	-,550	-3,919	,000	-,226	-,071
	Vegetation	-,022	,011	-,325	-2,046	,049	-,045	,000
	Unpaved open spaces	-,006	,018	-,073	-,356	,724	-,042	,030
	Paved open spaces	-,003	,014	-,041	-,197	,845	-,031	,026
	Water	-,012	,011	-,179	-1,127	,268	-,035	,010

Table: 5.1.1.D

The final interesting Table: 5.1.1.E shows the excluded Variables or in this case the excluded variable. The excluded variable is ‘dwellings’ which means that dwellings have such a low impact for hour05 on the dependent variable that it is disregarded.



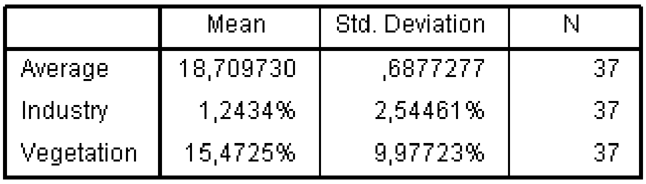
Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

Table: 5.1.1.E

a. Predictors: (constant), water, unpaved open space, Industry, Vegetation, Paved open spaces.
b. Dependent variables: Average

5.1.2 July - hour 05 a further examination of industry and vegetation

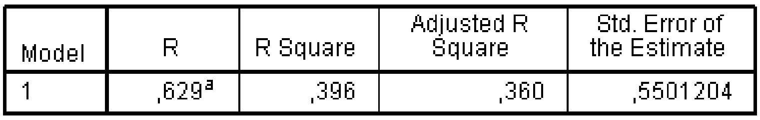
Table 5.1.2.A shows the average temperature for *Mean1*=18,709730 and average percentages for *Mean2*=1,2434% and Mean3=15,4725% of all usable cells. The number of usable cells is (*N*=37).



	Mean	Std. Deviation	N
Average	18,709730	,6877277	37
Industry	1,2434%	2,54461%	37
Vegetation	15,4725%	9,97723%	37

Table: 5.1.2.A

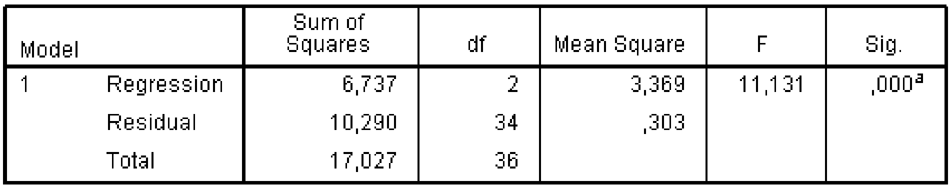
Table 5.1.2.B shows the (*R Square* =0,396) indicating that the 2 independent variables together have a large effect (>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,629^a	,396	,360	,5501204

Table: 5.1.2.B

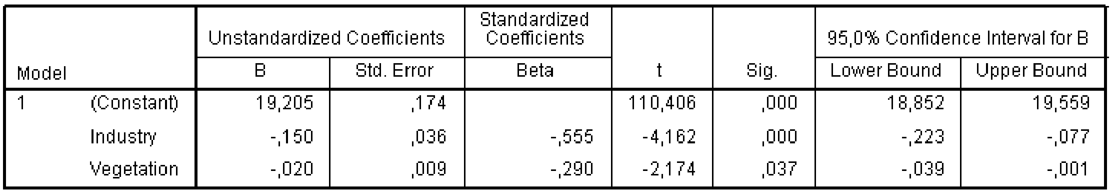
Table 5.1.2.C, the ANOVA table which shows the values of F (*F*=11,131) and P (*P*=0,000). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6,737	2	3,369	11,131	,000^a
	Residual	10,290	34	,303		
	Total	17,027	36			

Table: 5.1.2.C

Table 5.1.D shows the Coefficients *(B1= -0150 B2*= -0,020). It also shows the signification level of the independent variables (*p1*= 0.000; *p2*= 0.037).

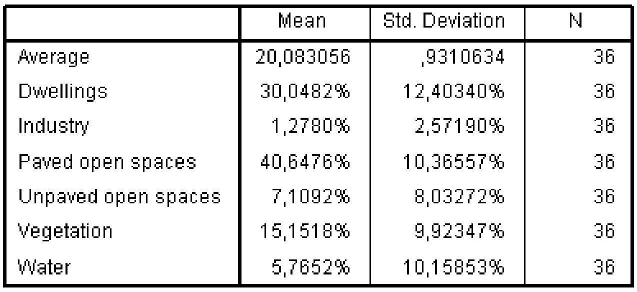


Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	19,205	,174		110,406	,000	18,852	19,559
	Industry	-,150	,036	-,555	-4,162	,000	-,223	-,077
	Vegetation	-,020	,009	-,290	-2,174	,037	-,039	-,001

Table: 5.1.D

5.1.3 July - hour06

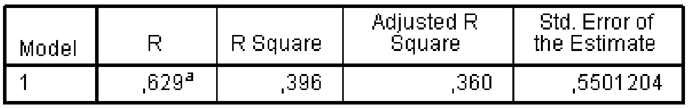
Table 5.1.3.A shows the average temperature for *Mean1*= 20,083056 and average percentages for *Mean2*= 30,0482%; *Mean3*= 1,2780%; *Mean4*= 40,6476%; *Mean5*= 7,1092%; *Mean6*= 15,1518% and *Mean7*= 5,7652 of all usable cells. The number of usable cells is (*N*=36).



	Mean	Std. Deviation	N
Average	20,083056	,9310634	36
Dwellings	30,0482%	12,40340%	36
Industry	1,2780%	2,57190%	36
Paved open spaces	40,6476%	10,36557%	36
Unpaved open spaces	7,1092%	8,03272%	36
Vegetation	15,1518%	9,92347%	36
Water	5,7652%	10,15853%	36

Table: 5.1.3.A

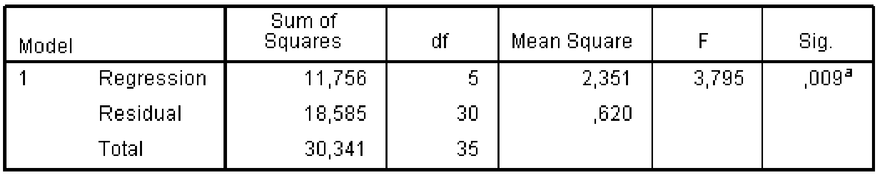
Table 5.1.1.B shows the (*R Square* =0,629) indicating that the 2 independent variables together have a large effect (>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,629^{a}	,396	,360	,5501204

Table: 5.1.3.B

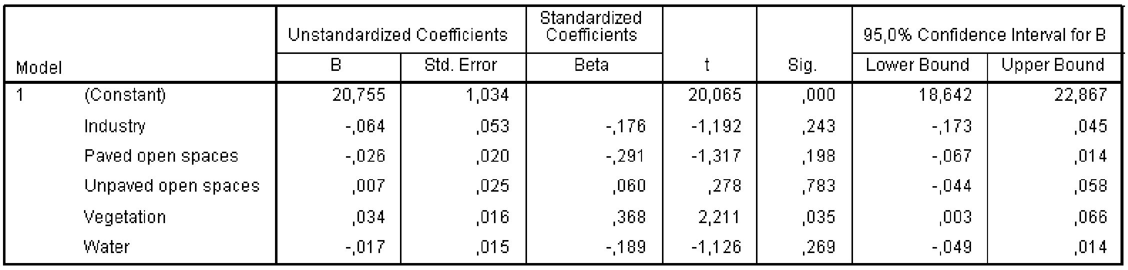
Table 5.1.3.C, the ANOVA table which shows the values of F (*F*=3,795) and P (*P*=0,009). H0 needs to be rejected what indicate that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11,756	5	2,351	3,795	,009^{a}
	Residual	18,585	30	,620		
	Total	30,341	35			

Table: 5.1.3.C

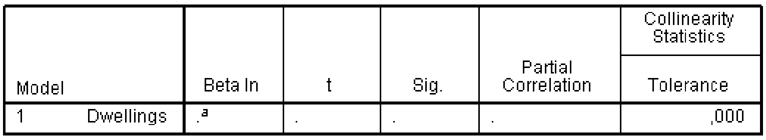
Table 5.1.3.D shows the Coefficients *(B1= -0064; B2=* -0,026; *B3= -0,007; B4*= -0,034 and *B5= -0,017*). It also shows the signification level of the independent variables (*p1*= 0.243; *p2*= 0.198; *p3*= 0 .783; *p4*= 0.035 and *p5*= 0.269).



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	20,755	1,034		20,065	,000	18,642	22,867
	Industry	-,064	,053	-,176	-1,192	,243	-,173	,045
	Paved open spaces	-,026	,020	-,291	-1,317	,198	-,067	,014
	Unpaved open spaces	,007	,025	,060	,278	,783	-,044	,058
	Vegetation	,034	,016	,368	2,211	,035	,003	,066
	Water	-,017	,015	-,189	-1,126	,269	-,049	,014

Table: 5.1.3.D

Table: 5.1.3.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings. It also shows that the independent variable: Vegetation (*B4*) is significant (*p*=0 .035).

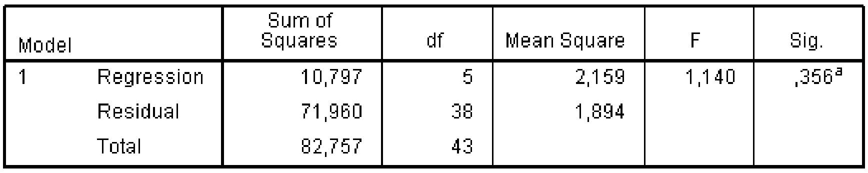


Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.^{a}	.	.	.	,000

Table: 5.1.3.E

5.1.4 July - hour13

Table 5.1.45.1.1.A, the ANOVA table shows the values of F (*F*= 1,140) and P (*P*= 0,356). H0 cannot be rejected what indicates that all 6 predictors together doesn’t influence the independent variable, average temperature. The output of July - hour13 will be shown in appendix 10.1.1.

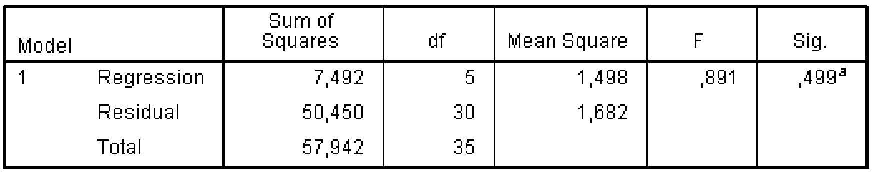


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10,797	5	2,159	1,140	,356[a]
	Residual	71,960	38	1,894		
	Total	82,757	43			

Table: 5.1.4

5.1.5 July - hour14

Table 5.1.5.A, the ANOVA table shows the values of F (*F*= 0,891) and P (*P*= 0,499). H0 cannot be rejected what indicates that all 6 predictors together doesn’t influence the independent variable, average temperature. The output of July - hour14 will be shown in appendix 10.1.2.

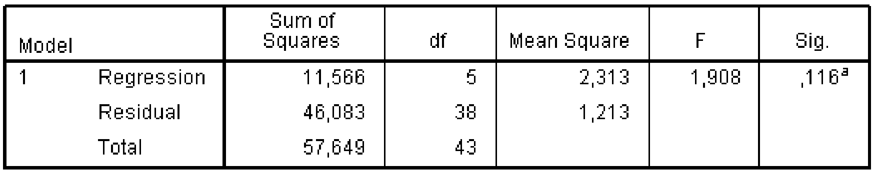


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7,492	5	1,498	,891	,499[a]
	Residual	50,450	30	1,682		
	Total	57,942	35			

Table: 5.1.5

5.1.6 July - Hour17

Table 5.1.6.A, the ANOVA table shows the values of F (*F*= 1,908) and P (*P*= 0,116). H0 cannot be rejected what indicates that all 6 predictors together doesn’t influence the independent variable, average temperature. The output of July - hour17 will be shown in appendix 10.1.3

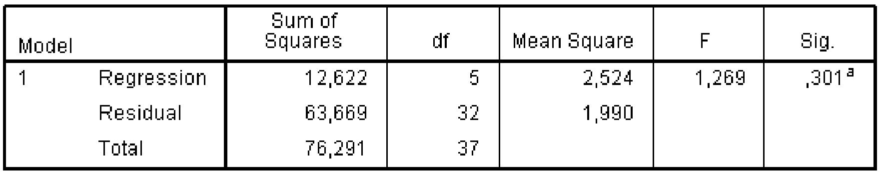


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11,566	5	2,313	1,908	,116[a]
	Residual	46,083	38	1,213		
	Total	57,649	43			

Table: 5.1.6

5.1.7 July - Hour18

Table 5.1.1.A, the ANOVA table shows the values of F (*F*= 1,269) and P (*P*= 0,301). H0 cannot be rejected what indicates that all 6 predictors together doesn't influence the independent variable, average temperature. The output of July - hour18 will be shown in appendix 10.1.4

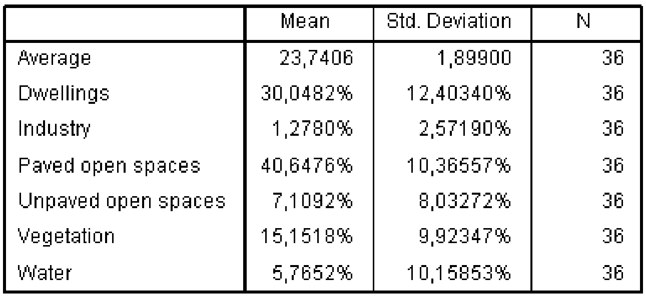


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12,622	5	2,524	1,269	,301[a]
	Residual	63,669	32	1,990		
	Total	76,291	37			

Table: 5.1.1

5.1.8 July – hour19

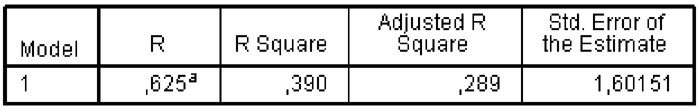
Table 5.1.8.A shows the average temperature for *Mean1*= 23,7406 and average percentages for *Mean2*= 30,0482%; *Mean3*= 1,2780%; *Mean4*= 40,6476%; *Mean5*= 7,1092%; *Mean6*= 15,1518% and *Mean7*= 5,7652% of all usable cells. The number of usable cells is (*N*=36).



	Mean	Std. Deviation	N
Average	23,7406	1,89900	36
Dwellings	30,0482%	12,40340%	36
Industry	1,2780%	2,57190%	36
Paved open spaces	40,6476%	10,36557%	36
Unpaved open spaces	7,1092%	8,03272%	36
Vegetation	15,1518%	9,92347%	36
Water	5,7652%	10,15853%	36

Table: 5.1.8.A

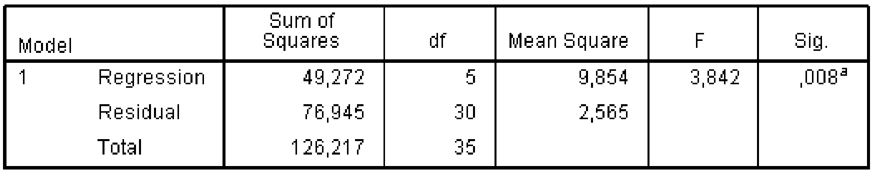
Table 5.1.8.B shows the (*R Square* =0,289) indicating that the 2 independent variables together have a medium effect (>.10 and <.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,625[a]	,390	,289	1,60151

Table: 5.1.8.B

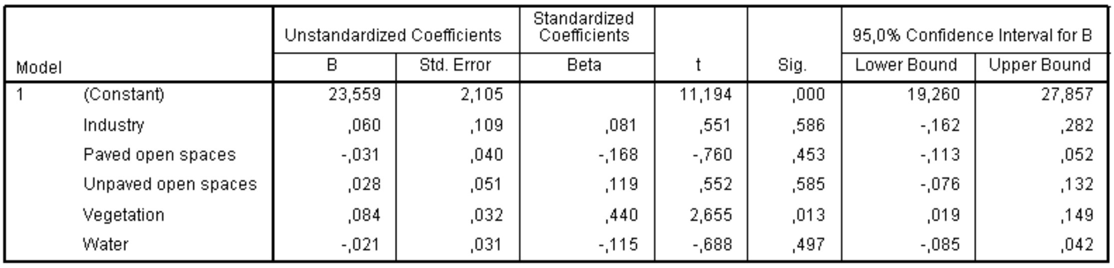
Table 5.1.8.C, the ANOVA table which shows the values of F (*F*=3,842) and P (*P*=0,008). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	49,272	5	9,854	3,842	,008^a
	Residual	76,945	30	2,565		
	Total	126,217	35			

Table: 5.1.8.C

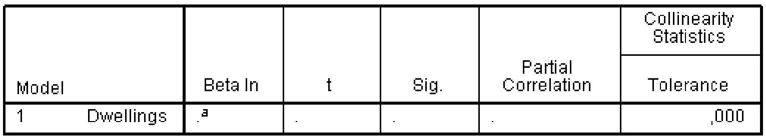
Table 5.1.8.D shows the Coefficients *(B1= 0,060; B2*= -0,031; *B3= 0,028; B4*= 0,084 and *B5*= -*0,021*). It also shows the level of significance for the independent variables (*p1*= 0.586; *p2*= 0.453; *p3*= 0 .585; *p4*= 0.013 and *p5*= 0.497).



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	23,559	2,105		11,194	,000	19,260	27,857
	Industry	,060	,109	,081	,551	,586	-,162	,282
	Paved open spaces	-,031	,040	-,168	-,760	,453	-,113	,052
	Unpaved open spaces	,028	,051	,119	,552	,585	-,076	,132
	Vegetation	,084	,032	,440	2,655	,013	,019	,149
	Water	-,021	,031	-,115	-,688	,497	-,085	,042

Table: 5.1.8.D

Table: 5.1.8.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings. It also shows that the independent variable: Vegetation (*B5*) is significant (*p*=0 .013).



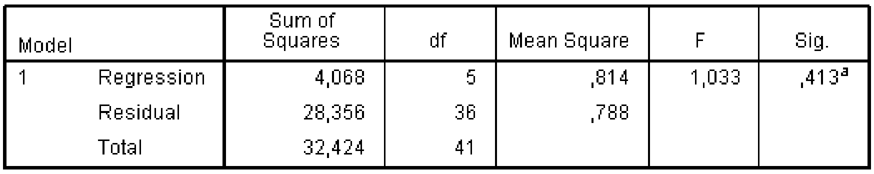
Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.^{a}	.	.	.	,000

Table: 5.1.8.E

5.2 August analysis

5.2.1 August – Hour05

Table 5.2.1, the ANOVA table shows the values of F (*F*= 1,033) and P (*P*= 0,413). H0 cannot be rejected what indicates that all 6 predictors together doesn't influence the independent variable, average temperature. The output of August - hour05 will be shown in appendix 10.1.5.

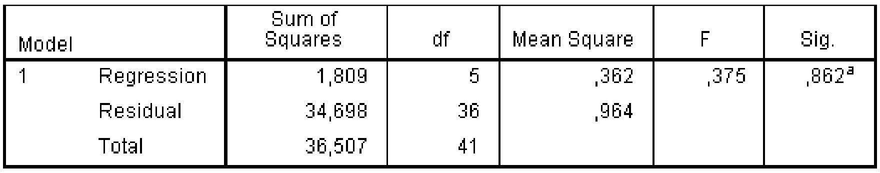


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4,068	5	,814	1,033	,413^a
	Residual	28,356	36	,788		
	Total	32,424	41			

Table: 5.2.1

5.2.2 *August – Hour06*

Table 5.2.2, the ANOVA table shows the values of F (*F*= 1,033) and P (*P*= 0,413). H0 cannot be rejected what indicates that all 6 predictors together doesn't influence the independent variable, average temperature. The output of August - hour06 will be shown in appendix 10.1.6.

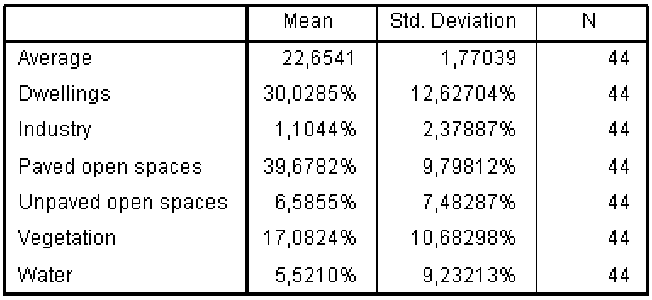


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,809	5	,362	,375	,862^a
	Residual	34,698	36	,964		
	Total	36,507	41			

Table: 5.2.2

5.2.3 *August – hour13*

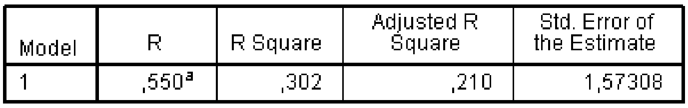
Table 5.2.3.A shows the average temperature for *Mean1*= 22,6541 and average percentages for *Mean2*= ,0285%; *Mean3*= 1,1044%; *Mean4*= 39,6782%; *Mean5*= 6,5855%; *Mean6*= 17,0824% and *Mean7*= 5,5210% of all usable cells. The number of usable cells is (*N*=44).



	Mean	Std. Deviation	N
Average	22,6541	1,77039	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Table: 5.2.3.A

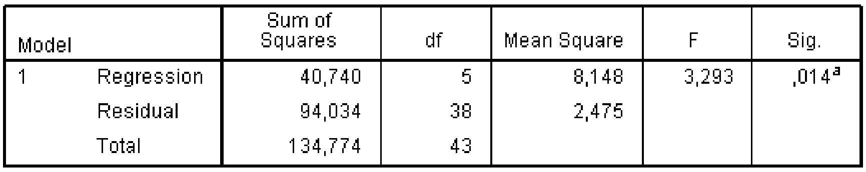
Table 5.2.3.B shows the (*R Square* =0,302) indicating that the 2 independent variables together have a high effect (>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,550^a	,302	,210	1,57308

Table: 5.2.3.B

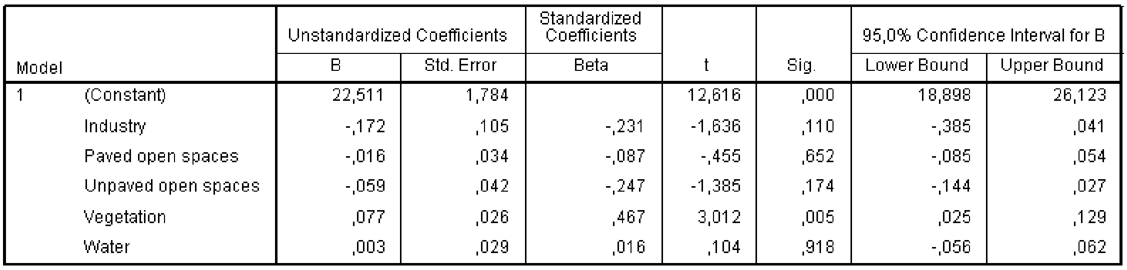
Table 5.2.3.C, the ANOVA table which shows the values of F (*F*=3,293) and P (*P*=0,014). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40,740	5	8,148	3,293	,014^a
	Residual	94,034	38	2,475		
	Total	134,774	43			

Table: 5.2.3.C

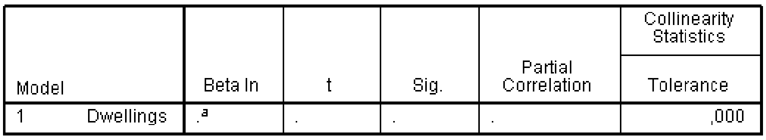
Table 5.2.3.D shows the Coefficients *(B1= -0,172; B2=* -0,016; *B3= -0,059; B4=* 0,077 and *B5= 0,003*). It also shows the signification level of the independent variables (*p1*= 0.110; *p2*= 0.652; *p3*= 0 .174; *p4*= 0.005 and *p5*= 0.918). It also shows that the independent variable: Vegetation (*B4*) is significant (*p*=0 .005)



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	22,511	1,784		12,616	,000	18,898	26,123
	Industry	-,172	,105	-,231	-1,636	,110	-,385	,041
	Paved open spaces	-,016	,034	-,087	-,455	,652	-,085	,054
	Unpaved open spaces	-,059	,042	-,247	-1,385	,174	-,144	,027
	Vegetation	,077	,026	,467	3,012	,005	,025	,129
	Water	,003	,029	,016	,104	,918	-,056	,062

Table: 5.2.3.D

Table: 5.2.3.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings.

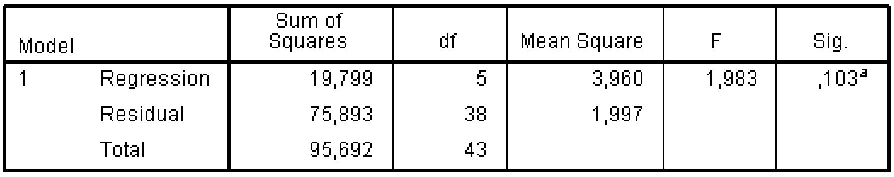


Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.^{a}	.	.	.	,000

Table: 5.2.3.E

5.2.4 August – Hour14

Table 5.2.45.2.3.A, the ANOVA table shows the values of F (*F*= 1,983) and P (*P*= 0,103). H0 cannot be rejected what indicates that all 6 predictors together doesn't influence the independent variable, average temperature. The output of August – hour14 will be shown in appendix 10.1.7.

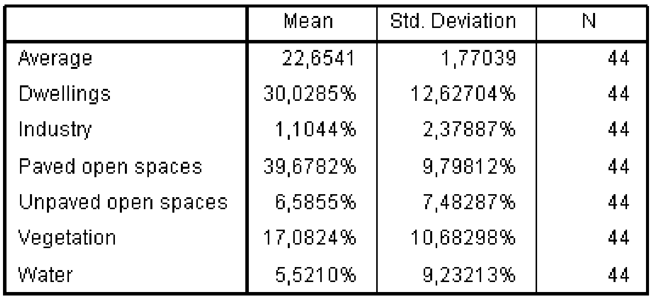


Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19,799	5	3,960	1,983	,103^a
	Residual	75,893	38	1,997		
	Total	95,692	43			

Table: 5.2.4

5.2.5 August – hour17

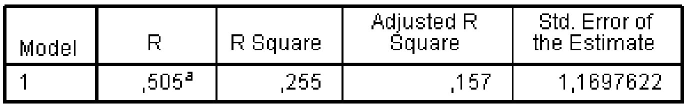
Table 5.2.5.A shows the average temperature for *Mean1*= 22,6541 and average percentages for *Mean2*= 30,0285%; *Mean3*= 1,1044%; *Mean4*= 39,6782%; *Mean5*= 6,5855%; *Mean6*= 17,0824% and *Mean7*= 5,5210% of all usable cells. The number of usable cells is (*N*=44).



	Mean	Std. Deviation	N
Average	22,6541	1,77039	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Table: 5.2.5.A

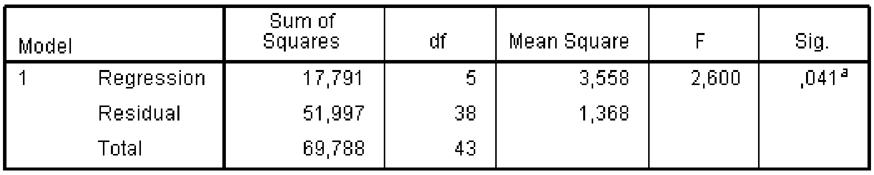
Table 5.2.5.B shows the (*R Square* =0,255) indicating that the 2 independent variables together have a medium effect (>.10 and <.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,505^{a}	,255	,157	1,1697622

Table: 5.2.5.B

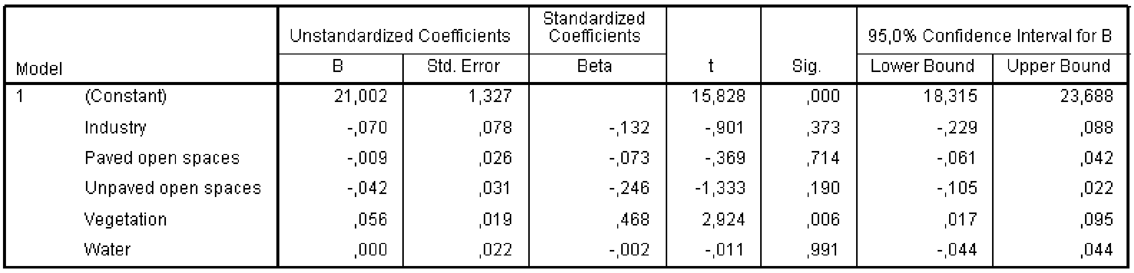
Table 5.2.5.C, the ANOVA table which shows the values of F (*F*=2,600) and P (*P*=0,041). H0 needs to be rejected what indicate that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	17,791	5	3,558	2,600	,041^{a}
	Residual	51,997	38	1,368		
	Total	69,788	43			

Table: 5.2.5.C

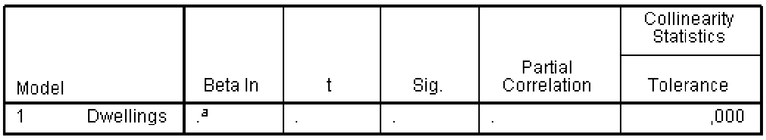
Table 5.2.5.D shows the Coefficients *(B1= -0,070; B2*= -0,009; *B3= -0,042; B4*= 0,056 and *B5= 0,000*). It also shows the signification level of the independent variables (*p1*= 0.373; *p2*= 0.714; *p3*= 0 .190; *p4*= 0.006 and *p5*= 0.991). It also shows that the independent variable: Vegetation (*B4*) is significant (*p*=0 .006).



Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95,0% Confidence Interval for B Lower Bound	95,0% Confidence Interval for B Upper Bound
1	(Constant)	21,002	1,327		15,828	,000	18,315	23,688
	Industry	-,070	,078	-,132	-,901	,373	-,229	,088
	Paved open spaces	-,009	,026	-,073	-,369	,714	-,061	,042
	Unpaved open spaces	-,042	,031	-,246	-1,333	,190	-,105	,022
	Vegetation	,056	,019	,468	2,924	,006	,017	,095
	Water	,000	,022	-,002	-,011	,991	-,044	,044

Table: 5.2.5.D

Table: 5.2.5.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings.

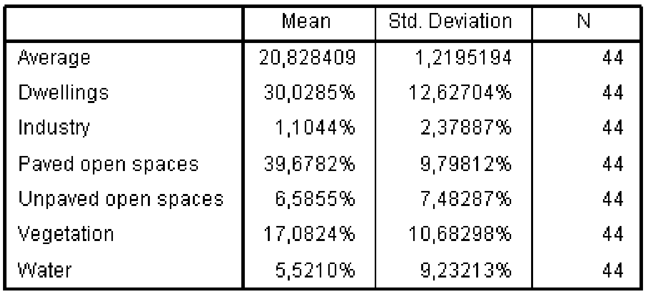


Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Dwellings	.[a]	.	.	.	,000

Table: 5.2.5.E

5.2.6 August – hour18

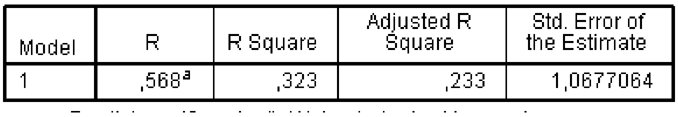
Table 5.2.6.A shows the average temperature for *Mean1*= 20,82409 and average percentages for *Mean2*= 30,0285%; *Mean3*= 1,1044%; *Mean4*= 39,6782%; *Mean5*= 6,5855%; *Mean6*= 17,0824% and *Mean7*= 5,5210% of all usable cells. The number of usable cells is (*N*=44).



	Mean	Std. Deviation	N
Average	20,828409	1,2195194	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Table: 5.2.6.A

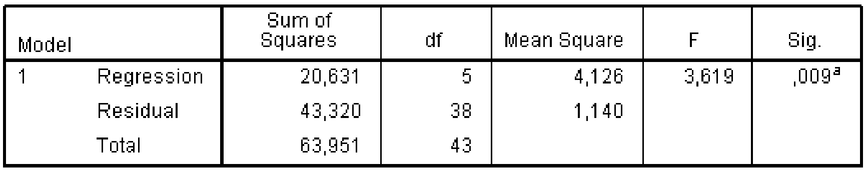
Table 5.2.65.1.1.B shows the (*R Square* =0,323) indicating that the 2 independent variables together have a medium effect (>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,568[a]	,323	,233	1,0677064

Table: 5.2.6.B

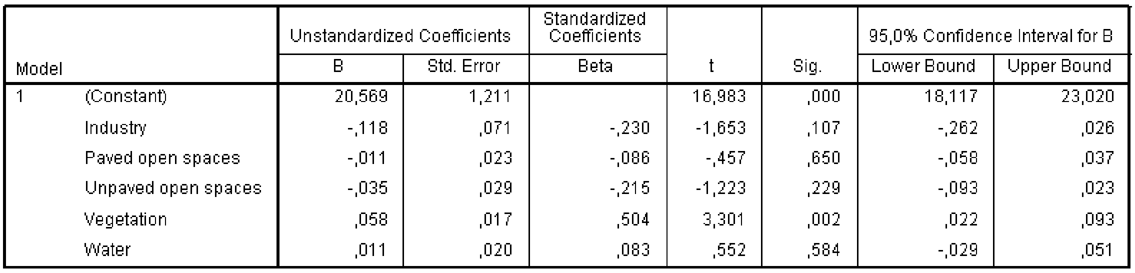
Table 5.2.65.1.1.C, the ANOVA table which shows the values of F (*F*=3,619) and P (*P*=0,009). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20,631	5	4,126	3,619	,009^a
	Residual	43,320	38	1,140		
	Total	63,951	43			

Table: 5.2.6.C

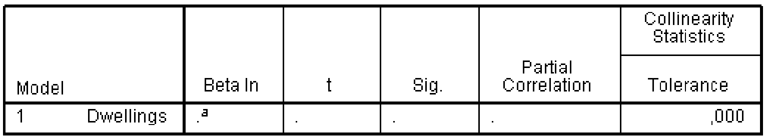
Table 5.2.6.D shows the Coefficients *(B1= -0,188; B2=* -0,011; *B3= -0,035; B4=* 0,058 and *B5= 0,011*). It also shows the signification level of the independent variables (*p1*= 0.107; *p2*= 0.650; *p3*= 0 .229; *p4*= 0.002 and *p5*= 0.584). It also shows that the independent variable: Vegetation (*B4*) is significant (*p*=0 .002).



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	20,569	1,211		16,983	,000	18,117	23,020
	Industry	-,118	,071	-,230	-1,653	,107	-,262	,026
	Paved open spaces	-,011	,023	-,086	-,457	,650	-,058	,037
	Unpaved open spaces	-,035	,029	-,215	-1,223	,229	-,093	,023
	Vegetation	,058	,017	,504	3,301	,002	,022	,093
	Water	,011	,020	,083	,552	,584	-,029	,051

Table: 5.2.6.D

Table: 5.2.6.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings.

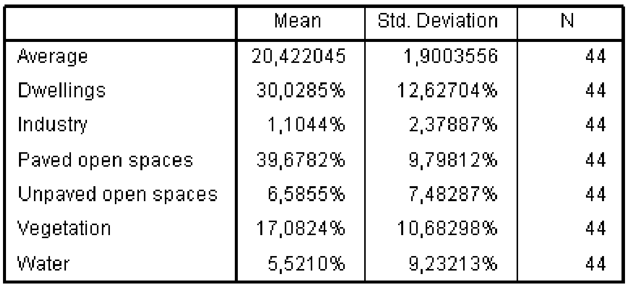


Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.^{a}	.	.	.	,000

Table: 5.2.6.E

5.2.7 August – hour19

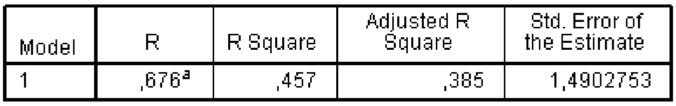
Table 5.2.7.A shows the average temperature for *Mean1*= 20,422045 and average percentages for *Mean2*= 30,0285%; *Mean3*= 1,1044%; *Mean4*= 39,6782%; *Mean5*= 6,5855%; *Mean6*= 17,0824% and *Mean7*= 5,5210% of all usable cells. The number of usable cells is (*N*=44).



	Mean	Std. Deviation	N
Average	20,422045	1,9003556	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Table: 5.2.7.A

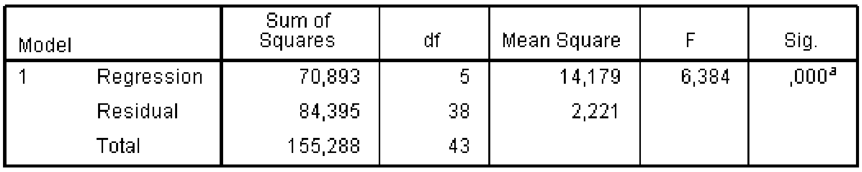
Table 5.2.7.B shows the (*R Square* =0,457) indicating that the 2 independent variables together have a medium effect (>.30) on the variances in temperature.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,676[a]	,457	,385	1,4902753

Table: 5.2.7.B

Table 5.2.7.C, the ANOVA table which shows the values of F (*F*=6,384) and P (*P*=0,000). H0 needs to be rejected what indicate that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	70,893	5	14,179	6,384	,000[a]
	Residual	84,395	38	2,221		
	Total	155,288	43			

Table: 5.2.7.C

Table 5.2.7.D shows the Coefficients *(B1= -0,166; B2*= -0,046; *B3= -0,124; B4*= 0,092 and *B5= 0,005*). It also shows the signification level of the independent variables (*p1*= 0.105; *p2*= 0.165; *p3*= 0 .004; *p4*= 0.001 and *p5*= 0.669). It also shows that the independent variable: Unpaved open space (B3) and Vegetation (*B4*) are significant (p= 0,004; *p*=0 .001) and therefore interesting to submit to further examination. This will be done in the next sub paragraph: August - hour19 a further examination of unpaved open space and vegetation.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	21,707	1,690		12,841	,000	18,284	25,129
	Industry	-,166	,100	-,207	-1,663	,105	-,367	,036
	Paved open spaces	-,046	,033	-,237	-1,412	,166	-,112	,020
	Unpaved open spaces	-,124	,040	-,489	-3,105	,004	-,205	-,043
	Vegetation	,092	,024	,515	3,764	,001	,042	,141
	Water	-,005	,028	-,022	-,166	,869	-,061	,051

Table: 5.2.75.1.1.D

Table: 5.2.7.E shows the excluded Variables or in this case the excluded variable. The excluded variable is dwellings.

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

Table: 5.2.7.E

5.2.8 August - hour19 a further examination of unpaved open space and vegetation

Table 5.2.8.A shows the average temperature for *Mean1*= 20,422045 and average percentages for *Mean2*= 6,5855% and *Mean3*=17,0824% of all usable cells. The number of usable cells is (*N*=44).

	Mean	Std. Deviation	N
Average	20,422045	1,9003556	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44

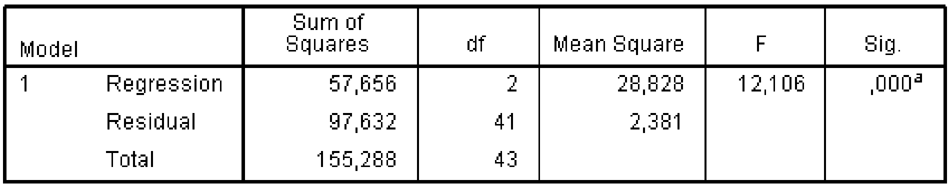
Table: 5.2.8.A

Table 5.2.8.B shows the (*R Square* =0,371) indicating that the 2 independent variables together have a large effect (>.30) on the variances in temperature.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,609[a]	,371	,341	1,5431347

Table: 5.2.8.B

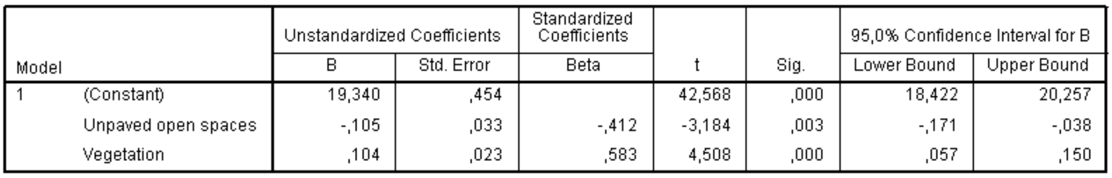
Table 5.2.8.C, the ANOVA table which shows the values of F (*F*=12,106) and P (*P*=0,000). H0 needs to be rejected what indicates that all 6 predictors together influence the independent variable, average temperature.



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	57,656	2	28,828	12,106	,000^a
	Residual	97,632	41	2,381		
	Total	155,288	43			

Table: 5.2.8.C

Table 5.2.8.D shows the Coefficients *(B1= -0105 and B2=* -0,104). It also shows the signification level of the independent variables (*p1*= 0.003 and *p2*= 0.000).



Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	19,340	,454		42,568	,000	18,422	20,257
	Unpaved open spaces	-,105	,033	-,412	-3,184	,003	-,171	-,038
	Vegetation	,104	,023	,583	4,508	,000	,057	,150

Table: 5.2.8.D

5.3 Results

The outcome from the analysis was that from the 14 tested models, 8 had a significant level of 0,05 or under (<0,05) which means that the 6 independent variables together influenced the variance in average temperature for that particular hour. Looking at each hour for both months only hour19 has a significant level of 0,05 or under for both months. Looking at the coefficients table from significant tests: once industry and vegetation are significant, once time unpaved open space and vegetation were significant. 6 times vegetation was the only significant independent variable and only once, industry was the significant independent variable. A remarkable fact is that the vegetation B values for the significant tests are, except from July-hour05, positive (-0,022; 0,034; 0,084; 0,036; 0,077; 0,058; 0,092) what means that for each percentage extra vegetation the temperature will rise. What we saw in the literature was that vegetation can provide a cool wind and that the temperature in parks and around trees is cooler compared to other spots in the city centre. The B value from the variable Industry, which belongs to the category heat producing functions, was negative the first time (July hour05) what means that each percentage extra of industry cools the average temperature (-0,149). For July hour17 each percentage industry warms the average temperature (0,084). Finally the unpaved open space for August hour19 showed a negative B value (-0,124) and so helps the city to lower the average temperature in August for hour19.

Looking at the further examination for July hour05, which has significant variables: industry and vegetation , the B value for Industry (-0,150) and for vegetation (-0,020). What means that the 2 independent variables together still help to cool down the average temperature for this period. Looking at August hour19 the B value changes. Unpaved open space still helps, for each extra percentage, to lower the average temperature (-0,105) and vegetation (0,104) to warm the average temperature.

Some of the tests (models) that were executed had an independent variable within the model that had a high significant level indicating a value <0.05. For July hour17 this variable was industry (0,013) and for August hour05 and 14 this was vegetation (0,036; 0,020). These tests (models) were not significant, but independent variables within the model were independently significant excluding the other independent variables .

Conclusions that can be drawn from this analysis is that for above average periods the combination of the 6 independent variables had an significant influence in variations of average temperature for that particular hour. For the test that were significant, there were only 2 that were suitable for further examination. Also, the independent variables that should rise according to diverse theories discussed in chapter 2 should lead to rising or lowering average temperature (the B values) were switched. Vegetation which seems to lower the temperature (according to the theory), helps the temperature to rise and industry, lowers the temperature where it should, according to the theory, provide extra heat. The unpaved open space helps, in line with theoretical research, to lower the temperature (ability for the wind to blow and less absorption materials that hold heat).

6 Qualitative analysis

In this chapter the data is analyzed in a qualitative way. What means that the relation between the independent variables and the dependent variables will be described according to diverse research. This will be done by analyzing the percentage of each cell with the average temperature for that cell. In the second part are the results from the analysis described.

6.1 Analysis

For the qualitative analysis only the cell number and the 10 hottest and coolest cells are shown, the complete overview of each cell is shown in appendix 10.2 (square metres per cell for each independent variable) and appendix 10.3 (percentage per cell for each independent variable). If in the analyse the cell has been mentioned or the area around the cell. This will not be showed in the analysis. The complete list of cells are visualized in appendix 10.4 in their function/colour. The colours are described in chapter 4.3: output.

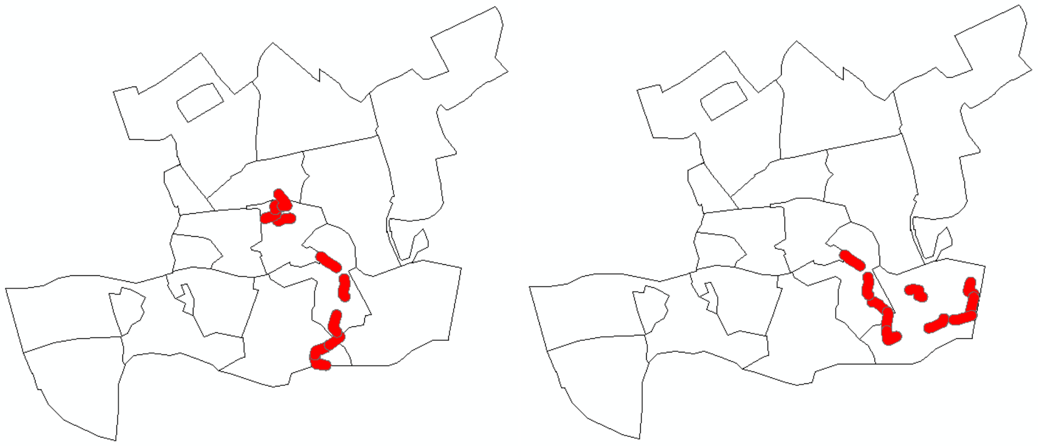
6.1.1 July – morning

In table 6.1.1 the hottest cell, the 10 hottest cells, the 10 coolest cells and the coolest cell are presented. The first thing that can be noticed is that the highlighted hottest cells only emerge twice and for the coolest cells this is just once. It may be even more remarkable that 9 cells belong to the hottest cells one hour, and to the coolest cells the other hour (or or vice versa). Looking at the percentage for the coolest cell for both hours, paved open space is very high (53-55%) what can indicate that the paved open spaces absorb cool air, and when the sun rises (for the month July 2010 this was between 05:24 and 06:00) the paved open space acted as a cooling element the first hours. Just outside the cell, the river the Meuse is situated. What we saw in the theoretical research was a cooling effect of 1-3°C. Looking at the percentage of the hottest cell and the 10 hottest cells, there is no real relation between . The main independent variables are dwellings and paved open space for hour05 and unpaved open space and vegetation for hour06. Cell 28 goes through a green zone which should have a cooling effect of 1-4°C following the theory but in this cell has a heating effect instead.

							July 2010 morning									
							Hour 05					Hour 06				
Cell number:	Dwellings	Industry	Paved open spaces	Unpaved open spaces	Vegetation	Water	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest 10 cells	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest cell
1	14%	0%	40%	9%	31%	6%	19,48		19,48			19,60				
2	14%	0%	39%	14%	27%	6%	19,40		19,40							
3	15%	0%	39%	14%	27%	6%	19,21		19,21			19,97				
4	43%	0%	33%	2%	20%	2%	19,09		19,09			20,16				
6	41%	1%	44%	0%	12%	2%	18,79					20,82		20,82		
7	25%	6%	44%	3%	21%	1%	18,74					21,12		21,12		
8	23%	0%	42%	3%	31%	2%	18,74					20,52		20,52		
11	25%	0%	35%	6%	31%	3%	18,43			18,43		20,71		20,71		

13	31%	0%	53%	0%	14%	2%	18,72					18,66			18,66	18,66
14	47%	2%	43%	1%	7%	0%	18,76					18,70			18,70	
15	30%	8%	7%	30%	7%	18%	18,86					18,70			18,70	
16	29%	4%	46%	0%	10%	12%	18,78					18,96			18,96	
18	21%	0%	49%	11%	18%	0%	18,33			18,33		19,89				
19	23%	0%	32%	10%	33%	3%	18,00			18,00		20,17				
20	14%	4%	36%	10%	32%	4%	17,29			17,29		20,83		20,83		
21	17%	9%	46%	10%	17%	2%	16,92			16,92		19,91				
22	12%	8%	55%	9%	15%	0%	16,83			16,83	16,83	19,63				
24	41%	1%	43%	4%	9%	1%	19,81	19,81	19,81			20,73		20,73		
26	39%	0%	38%	4%	14%	5%	18,31			18,31		22,01		22,01		
27	33%	0%	16%	27%	19%	6%	17,96			17,96		22,34		22,34		
28	13%	0%	21%	28%	33%	4%	18,27			18,27		22,59	22,59	22,59		
30	24%	0%	50%	3%	18%	4%	19,71		19,71			20,49		20,49		
31	15%	0%	37%	4%	6%	38%	18,36			18,36		19,47			19,47	
33	32%	0%	48%	2%	2%	15%	18,99					19,26			19,26	
34	47%	0%	44%	2%	7%	1%	19,49		19,49			19,24			19,24	
40	45%	0%	45%	7%	3%	1%	19,29		19,29			19,41			19,41	
41	32%	0%	56%	9%	2%	0%	19,45		19,45			19,37			19,37	
42	39%	0%	55%	1%	5%	1%	19,66		19,66			19,31			19,31	
Average U							**18,71**	**19,81**	**19,46**	**17,87**	**16,83**	**20,08**	**22,59**	**21,22**	**19,11**	**18,66**
Average R							**15,90**	**15,90**	**15,90**	**15,90**	**15,90**	**16,81**	**16,81**	**16,81**	**16,81**	**16,81**
UHI (U-R)							**2,81**	**3,91**	**3,56**	**1,97**	**0,93**	**3,27**	**5,78**	**4,41**	**2,30**	**1,85**

Table 6.1.1: Remarkable cells for the morning July morning period. The average U is the average temperature for the urban morning period. The average R is the average temperature for the rural, airport Zestienhoven, morning period. UHI (U-R) is the difference between the urban and rural average temperature for the morning period.



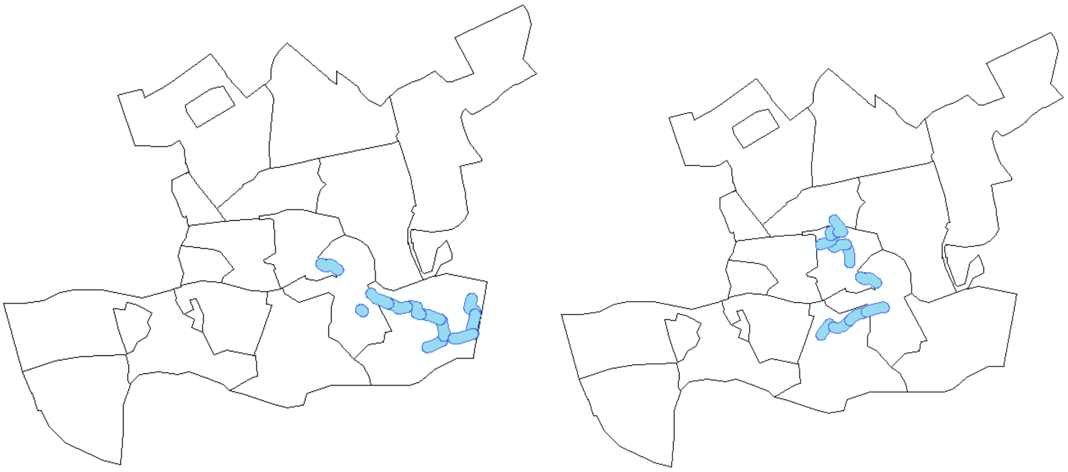


Illustration 6.1.1: The ten hottest (red) and coolest (blue) cells for the July morning period. From top left to the right bottom hour05, hour06, hour05 and hour06.

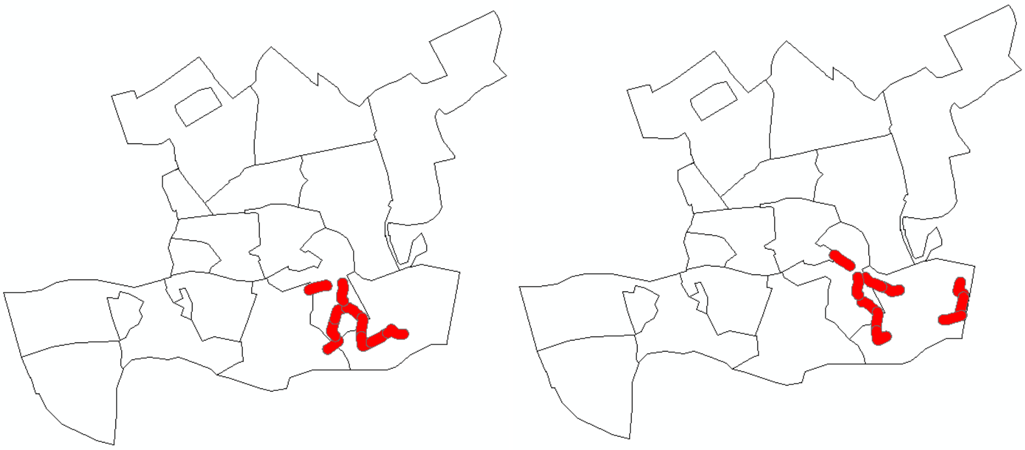
6.1.2 July – afternoon

The first noticeable thing is that for the 10 coolest cells, 6 are the same and also the hottest cell is the same for both hours. The 2 hottest cells are the same as the hottest cell for hour05 what can indicate that the dwellings (41%) and the paved open space (43%) influence the temperature. Reason for that can be the dense area with the narrow streets what, following the theory, causes a difficult mix of air and so the temperature will rise. The coolest cell from hour14 can be explained by the high percentage of vegetation (32%) and the high percentage of open space (46%) what encourages the airflow and therefore the mix of cool and warm air. For the coolest cell from hour13 it is hard to say why they are the coolest. Looking at the cell, it shows 50% dwellings and 40% paved open spaces. All together there are a lot of materials that absorb the heat and for that reason it would be expected that cell 39 belongs to the hottest cells instead of coolest.

							July 2010 afternoon									
							Hour 13					Hour 14				
Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**
1	14%	0%	40%	9%	31%	6%	28,33					27,45			27,45	
3	15%	0%	39%	14%	27%	6%	28,55		28,55			27,07			27,22	
4	43%	0%	33%	2%	20%	2%	28,59		28,59			27,08			27,08	

5	48%	0%	38%	0%	13%	2%	28,92		28,92			27,84				
6	41%	1%	44%	0%	12%	2%	29,49		29,49			28,68		28,68		
7	25%	6%	44%	3%	21%	1%	29,62		29,62			28,86		28,86		
8	23%	0%	42%	3%	31%	2%	29,76		29,76			28,67		28,67		
9	16%	0%	39%	21%	22%	2%	29,77		29,77			28,55				
10	29%	0%	35%	12%	23%	1%	29,47		29,47			28,67				
16	29%	4%	46%	0%	10%	12%	28,60		28,60			28,66				
19	23%	0%	32%	10%	33%	3%	26,56					27,13			27,13	
20	14%	4%	36%	10%	32%	4%	26,28			26,28		25,93			25,93	25,93
21	17%	9%	46%	10%	17%	2%	26,04			26,04		29,55		29,55		
22	12%	8%	55%	9%	15%	0%	26,24			26,24		30,65		30,65		
24	41%	1%	43%	4%	9%	1%	32,70	32,70	32,70			32,61	32,61	32,61		
26	39%	0%	38%	4%	14%	5%	27,75					29,71		29,71		
27	33%	0%	16%	27%	19%	6%	27,69					30,21		30,21		
28	13%	0%	21%	28%	33%	4%	27,84					30,13		30,13		
30	24%	0%	50%	3%	18%	4%	26,52			26,52		28,89		28,89		
32	12%	0%	34%	2%	2%	49%	26,35			26,35		27,73				
33	32%	0%	48%	2%	2%	15%	26,33			26,33		27,56				
36	24%	3%	54%	1%	17%	0%	25,94			25,94		26,85			26,85	
37	42%	0%	42%	4%	6%	5%	25,94			25,94		27,18			27,18	
38	48%	0%	41%	1%	5%	6%	26,15			26,15		27,22			27,22	
39	52%	0%	39%	2%	4%	2%	25,32			25,32	25,32	27,01			27,01	
42	39%	0%	55%	1%	5%	1%	26,50			26,50		26,79			26,79	
Average U							**27,75**	**32,70**	**29,55**	**26,15**	**25,32**	**28,27**	**32,61**	**29,80**	**26,99**	**25,93**
Average R							**22,91**	**22,91**	**22,91**	**22,91**	**22,91**	**23,07**	**23,07**	**23,07**	**23,07**	**23,07**
UHI (U-R)							**4,84**	**9,79**	**6,64**	**3,24**	**2,41**	**5,20**	**9,54**	**6,73**	**3,92**	**2,86**

Table 6.1.2: Remarkable cells for the afternoon July period. The average U is the average temperature for the urban afternoon period. The average R is the average temperature for the rural, airport Zestienhoven, afternoon period. UHI (U-R) is the difference between the urban and rural average temperature for the afternoon period.



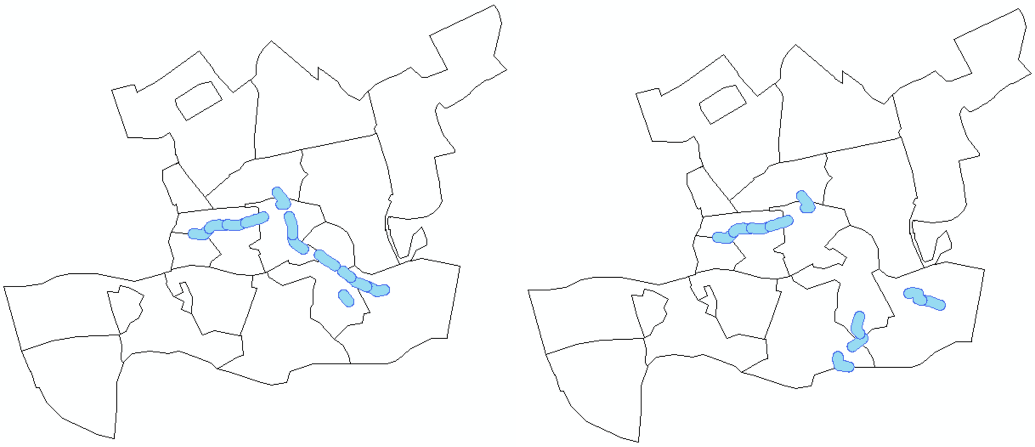


Illustration 6.2.2: The ten hottest (red) and coolest (blue) cells for the July period. From top left to the right bottom hour13, hour14, hour13 and hour14.

6.1.3 July – evening

What was noticed immediately when analyzing the cells, was that the coolest cells go from cell 13-22 to 32-42. This indicates that the coolest cells go from south-east (the first cells) to north-west (the last cells). The hottest cells are situated in the middle, especially 24,26-28, which are the cells on the south side of the Meuse. Cell 31 which belongs to the hottest cells for hour18 is a cell that crosses the Meuse, what provides cool air instead of warm air. And for that reason it is a remarkable cell. But also the cells 32, 33 and 34 which are situated in the city centre and belong to the coolest spot during the evening. The cells 38-42 which are situated in the city centre and around central the station are remarkable. According to the theory, the city centres should be the hottest spots, from this data the opposite can be reflected. The cells 13-17 belong to the coolest spots which is in line with the theory because these cells lay next to the Meuse.

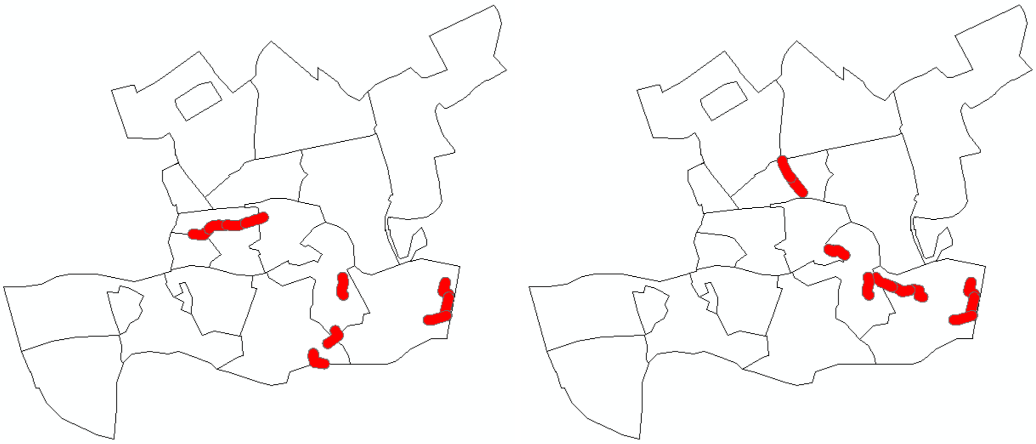
							July 2010 evening									
							Hour 17					Hour 18				
Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**
1	14%	0%	40%	9%	31%	6%	26,21		26,21			25,23				
3	15%	0%	39%	14%	27%	6%	26,04		26,04			24,94				
13	31%	0%	53%	0%	14%	2%	23,92			23,92		23,33			23,33	

14	47%	2%	43%	1%	7%	0%	23,75			23,75		23,39			23,39	
15	30%	8%	7%	30%	7%	18%	23,49			23,49		23,14			23,14	23,14
16	29%	4%	46%	0%	10%	12%	23,24			23,24		23,24			23,24	
17	43%	0%	43%	2%	9%	3%	23,77			23,77		23,88			23,88	
18	21%	0%	49%	11%	18%	0%	23,94			23,94		24,31				
19	23%	0%	32%	10%	33%	3%	23,08			23,08	23,08	25,36				
20	14%	4%	36%	10%	32%	4%	23,95			23,95		27,92		27,92		
21	17%	9%	46%	10%	17%	2%	24,00			24,00		28,11	28,11	28,11		
22	12%	8%	55%	9%	15%	0%	23,61			23,61		27,57		27,57		
24	41%	1%	43%	4%	9%	1%	28,87	28,87	28,87			27,42		27,42		
26	39%	0%	38%	4%	14%	5%	26,69		26,69			26,94		26,94		
27	33%	0%	16%	27%	19%	6%	26,11		26,11			27,69		27,69		
28	13%	0%	21%	28%	33%	4%	25,89		25,89			28,05		28,05		
31	15%	0%	37%	4%	6%	38%	24,45					25,80		25,80		
32	12%	0%	34%	2%	2%	49%	24,31					25,76				
33	32%	0%	48%	2%	2%	15%	24,36					25,74				
34	47%	0%	44%	2%	7%	1%	24,50					24,60				
36	24%	3%	54%	1%	17%	0%	26,84		26,84			23,79			23,79	
37	42%	0%	42%	4%	6%	5%	26,85		26,85			24,24				
38	48%	0%	41%	1%	5%	6%	26,70		26,70			24,35			24,24	
39	52%	0%	39%	2%	4%	2%	26,68		26,68			23,96			23,96	
40	45%	0%	45%	7%	3%	1%	25,48					23,79			23,79	
41	32%	0%	56%	9%	2%	0%	25,33					24,21			24,21	
42	39%	0%	55%	1%	5%	1%	25,51					24,70				
43	50%	0%	40%	3%	6%	1%	25,38					26,45		26,45		
44	32%	0%	42%	4%	18%	4%	25,46					26,37		26,37		
Average U							**25,06**	**28,87**	**26,69**	**23,68**	**23,08**	**25,25**	**28,11**	**27,23**	**23,70**	**23,14**
Average R							**22,19**	**22,19**	**22,19**	**22,19**	**22,19**	**21,66**	**21,66**	**21,66**	**21,66**	**21,66**
UHI (U-R)							**2,87**	**6,68**	**4,50**	**1,49**	**0,89**	**3,59**	**6,45**	**5,57**	**2,04**	**1,48**

							July 2010 evening				
							Hour 19				
Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**
1	14%	0%	40%	9%	31%	6%	25,45		25,45		
3	15%	0%	39%	14%	27%	6%	25,49		25,49		
13	31%	0%	53%	0%	14%	2%	22,24			22,24	
14	47%	2%	43%	1%	7%	0%	22,48				
15	30%	8%	7%	30%	7%	18%	22,40			22,40	

16	29%	4%	46%	0%	10%	12%	22,72				
17	43%	0%	43%	2%	9%	3%	22,85				
18	21%	0%	49%	11%	18%	0%	23,67				
19	23%	0%	32%	10%	33%	3%	25,15		25,15		
20	14%	4%	36%	10%	32%	4%	25,33		25,33		
21	17%	9%	46%	10%	17%	2%	26,05		26,05		
22	12%	8%	55%	9%	15%	0%	24,96				
24	41%	1%	43%	4%	9%	1%	26,15		26,15		
26	39%	0%	38%	4%	14%	5%	28,29	28,29	28,29		
27	33%	0%	16%	27%	19%	6%	27,61		27,61		
28	13%	0%	21%	28%	33%	4%	27,11		27,11		
31	15%	0%	37%	4%	6%	38%	22,50				
32	12%	0%	34%	2%	2%	49%	21,77			21,77	
33	32%	0%	48%	2%	2%	15%	21,60			21,60	
34	47%	0%	44%	2%	7%	1%	21,39			21,39	21,39
36	24%	3%	54%	1%	17%	0%	23,89				
37	42%	0%	42%	4%	6%	5%	26,21		26,21		
38	48%	0%	41%	1%	5%	6%	21,57			21,57	
39	52%	0%	39%	2%	4%	2%	21,57			21,57	
40	45%	0%	45%	7%	3%	1%	21,47			21,47	
41	32%	0%	56%	9%	2%	0%	21,44			21,44	
42	39%	0%	55%	1%	5%	1%	21,43			21,43	
43	50%	0%	40%	3%	6%	1%					
44	32%	0%	42%	4%	18%	4%					
Average U							**23,74**	**28,29**	**26,28**	**21,69**	**21,39**
Average R							**20,82**	**20,82**	**20,82**	**20,82**	**20,82**
UHI (U-R)							**2,92**	**7,47**	**5,46**	**0,87**	**0,57**

Table 6.1.3: Remarkable cells for the evening July period. The average U is the average temperature for the urban evening period. The average R is the average temperature for the rural, airport Zestienhoven, evening period. UHI (U-R) is the difference between the urban and rural average temperature for the evening period.



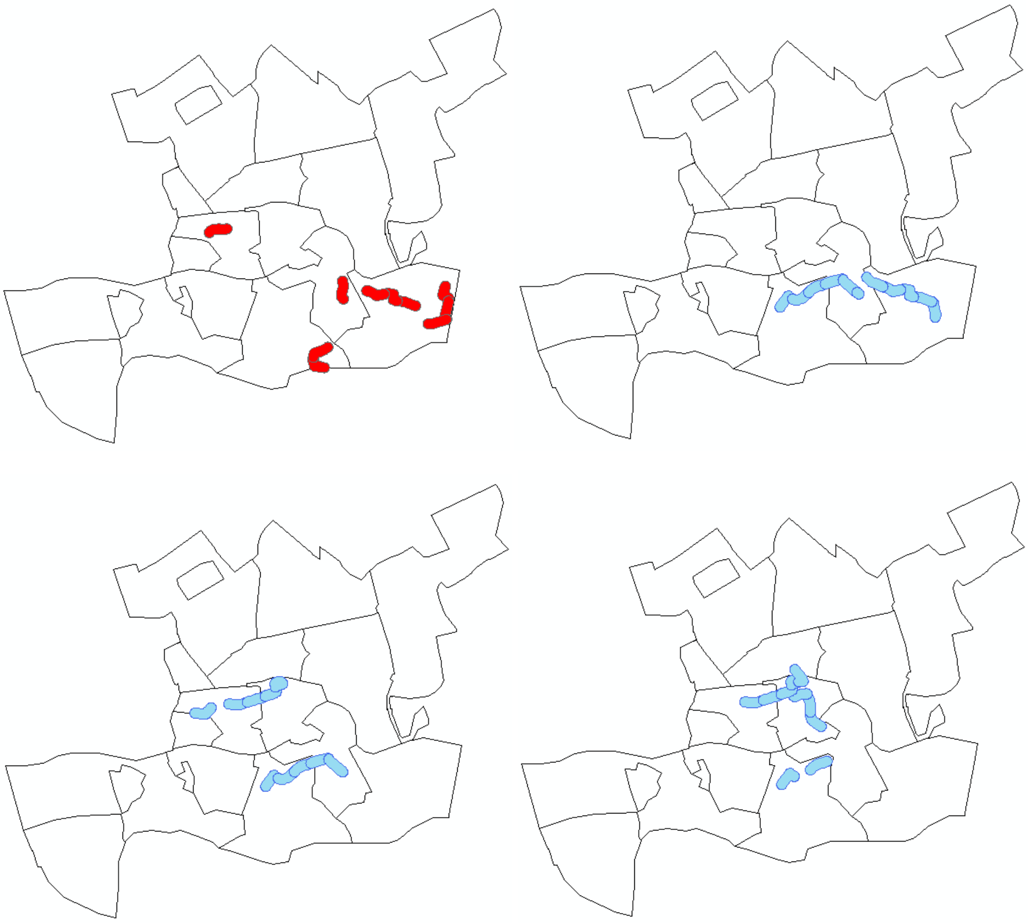


Illustration 6.3.3: The ten hottest (red) and coolest (blue) cells for the July morning period. From top left to the right bottom hour17, hour18, hour19, hour17, hour18 and hour19.

6.1.4 August – morning

For the morning period 8 out of 10 cells are the coolest for both hours, what means that they have something in common. The cells 3-7 belong for both hours to the coolest spots in the city and are all situated in or next to an (un)paved open space and al lot of vegetation. From the theory it can be indicated that the wind have enough open space to blow and to mix the hot and cold air. 30-32 are logical according to theory because they lay next to the Meuse, what provides cool air. Only cell 24 is a bit strange because for the month July it belongs to the hottest cells and now to the coolest. For the morning period of July it was already mentioned that cell 24 should belong to the coolest cells because it lays next to a river (same as the cells 30-32) what should have a cooling effect. The hottest cells are rare because they are very scattered and the percentage for the hottest cell for both morning hours are meaningless. They don't have a main independent variable that provides heat like dwellings (when families and offices start a new day, they use a lot of heat generating devices) or heat producing industry. So based on these cells there is nothing to say about a relation between the heat and the urban morphology for the August morning period.

							August 2010 morning									
							Hour 05					Hour 06				
Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest 10 cells**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**
1	14%	0%	40%	9%	31%	6%	19,48	19,48	19,48			19,60		19,60		
3	15%	0%	39%	14%	27%	6%	15,85			15,85		16,36			16,36	
4	43%	0%	33%	2%	20%	2%	15,08			15,08		16,37			16,37	
5	48%	0%	38%	0%	13%	2%	15,53			15,53		16,34			16,34	
6	41%	1%	44%	0%	12%	2%	15,20			15,20		16,02			16,02	
7	25%	6%	44%	3%	21%	1%	14,97			14,97		15,59			15,59	
8	23%	0%	42%	3%	31%	2%	18,74		18,74			20,52	20,52	20,52		
9	16%	0%	39%	21%	22%	2%	14,76			14,76	14,76	15,34			15,34	15,34
10	29%	0%	35%	12%	23%	1%	14,97			14,97		15,54			15,54	
11	25%	0%	35%	6%	31%	3%	16,31					17,07				
15	30%	8%	7%	30%	7%	18%	16,21					19,02		19,02		
16	29%	4%	46%	0%	10%	12%	16,34					18,63		18,63		
17	43%	0%	43%	2%	9%	3%	15,90			15,90		17,13		17,13		
19	23%	0%	32%	10%	33%	3%	17,25		17,25			17,02				
20	14%	4%	36%	10%	32%	4%	17,12		17,12			16,85				
21	17%	9%	46%	10%	17%	2%	16,98		16,98			16,93				
22	12%	8%	55%	9%	15%	0%	17,08		17,08			16,81				
24	41%	1%	43%	4%	9%	1%	15,72			15,72		16,67				
26	39%	0%	38%	4%	14%	5%	16,78					17,58		17,58		
27	33%	0%	16%	27%	19%	6%	16,67					17,32		17,32		
28	13%	0%	21%	28%	33%	4%	16,62					17,13		17,13		
30	24%	0%	50%	3%	18%	4%	15,94					16,48			16,48	
31	15%	0%	37%	4%	6%	38%	16,03			16,03		16,62			16,62	
32	12%	0%	34%	2%	2%	49%	16,15					16,54			16,54	
43	50%	0%	40%	3%	6%	1%	16,42					17,19		17,19		
44	32%	0%	42%	4%	18%	4%	16,45					17,15		17,15		
47	19%	0%	37%	6%	32%	7%	17,13		17,13			16,84				
48	37%	0%	26%	2%	31%	4%	17,19		17,19			16,99				
49	46%	0%	32%	0%	20%	2%	17,22		17,22			17,13		17,13		
50	31%	0%	33%	1%	31%	3%	17,26		17,26			17,02				
Average U							**16,49**	**19,48**	**17,55**	**15,40**	**14,76**	**17,01**	**20,52**	**18,13**	**16,12**	**15,34**
Average R							**14,62**	**14,62**	**14,62**	**14,62**	**14,62**	**14,91**	**14,91**	**14,91**	**14,91**	**14,91**

UHI (U-R)	**1,87**	**4,86**	**2,93**	**0,78**	**0,14**	**2,10**	**5,61**	**3,22**	**1,21**	**0,43**

Table 6.1.4: Remarkable cells for the morning August morning period. The average U is the average temperature for the urban morning period. The average R is the average temperature for the rural, airport Zestienhoven, morning period. UHI (U-R) is the difference between the urban and rural average temperature for the morning period.

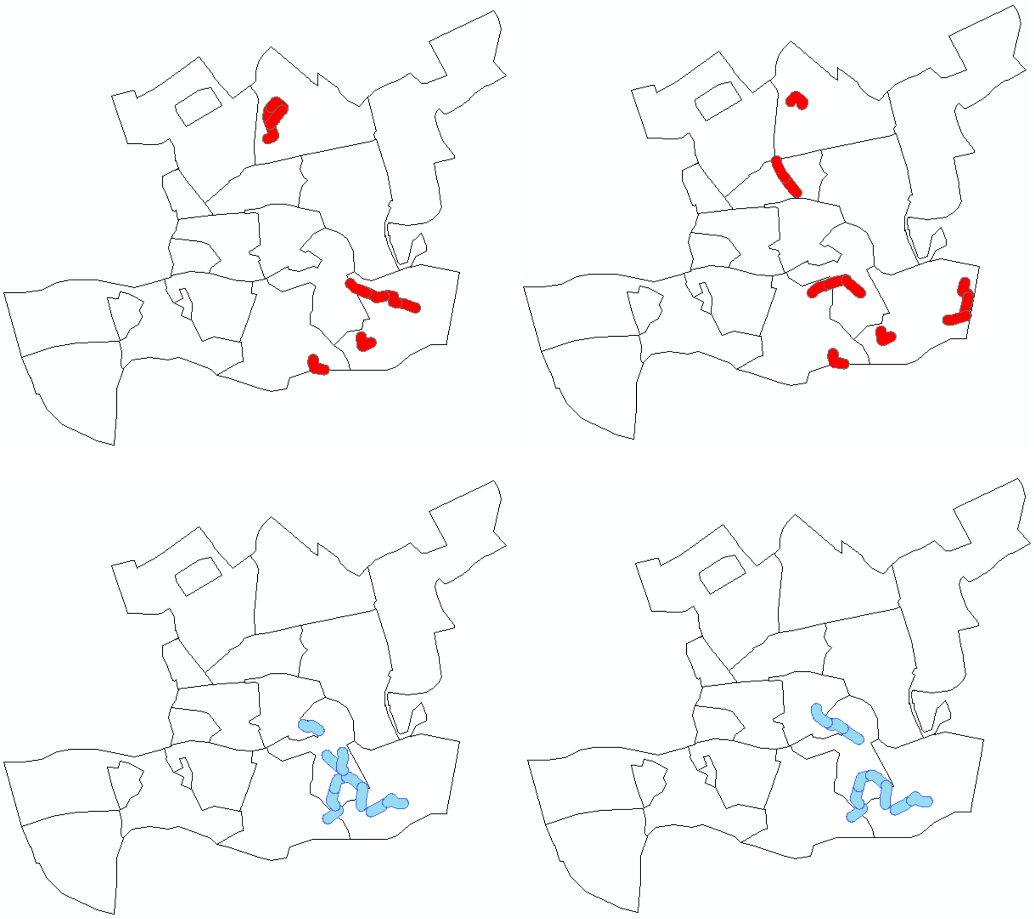


Illustration 6.4.4: The ten hottest (red) and coolest (blue) cells for the August morning period. From top left to the right bottom hour05, hour06, hour05 and hour06.

6.1.5 August – afternoon

Like the evening period from July, the cells change from district. The coolest cells change from south-east to centre-west and the hottest cells change from north to south. The hottest cell is the same as in the period before and for this period it is also hard to relate the urban morphology to the reason why it is hotter compared to other cells. For the coolest cells it is easier in spite of the different cells. Both cells are situated on the branch of the Meuse but on different spots. Because the cells for the hottest and the coolest are situated for both hours differently it is not possible to relate the temperature to the urban morphology.

							August 2010 afternoon									
							Hour 13					Hour 14				
Cell number:	Dwellings	Industry	Paved open spaces	Unpaved open spaces	Vegetation	Water	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest cell	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest cell
1	14%	0%	40%	9%	31%	6%	28,33		28,33			27,45		27,45		
3	15%	0%	39%	14%	27%	6%	22,57					24,31		24,31		
4	43%	0%	33%	2%	20%	2%	22,49					24,19		24,19		
5	48%	0%	38%	0%	13%	2%	22,55					23,94				
6	41%	1%	44%	0%	12%	2%	22,49					23,97		23,97		
7	25%	6%	44%	3%	21%	1%	22,38					24,13		24,13		
8	23%	0%	42%	3%	31%	2%	29,76	29,76	29,76			28,67	28,67	28,67		
9	16%	0%	39%	21%	22%	2%	22,04					24,27		24,27		
10	29%	0%	35%	12%	23%	1%	21,87					25,35		25,35		
11	25%	0%	35%	6%	31%	3%	22,13			22,13		24,00		24,00		
13	31%	0%	53%	0%	14%	2%	20,72			20,72		21,57			21,57	
14	47%	2%	43%	1%	7%	0%	20,92			20,93		21,49			21,49	21,49
15	30%	8%	7%	30%	7%	18%	21,83			21,83		21,73			21,73	
16	29%	4%	46%	0%	10%	12%	20,58			20,58	20,58	22,80				
17	43%	0%	43%	2%	9%	3%	22,20					24,00		24,00		
19	23%	0%	32%	10%	33%	3%	21,13			21,13		22,63				
20	14%	4%	36%	10%	32%	4%	20,74			20,74		22,41				
21	17%	9%	46%	10%	17%	2%	21,03			21,03		22,24				
22	12%	8%	55%	9%	15%	0%	20,89			20,89		22,22				
30	24%	0%	50%	3%	18%	4%	21,79			21,79		22,25				
31	15%	0%	37%	4%	6%	38%	21,99					21,89			21,89	
32	12%	0%	34%	2%	2%	49%	21,86					21,68			21,68	
33	32%	0%	48%	2%	2%	15%	22,09					21,92			21,92	
34	47%	0%	44%	2%	7%	1%	22,09					21,92			21,92	
36	24%	3%	54%	1%	17%	0%	22,41					21,58			21,58	
37	42%	0%	42%	4%	6%	5%	22,33					21,70			21,70	
38	48%	0%	41%	1%	5%	6%	22,01					21,86			21,86	
43	50%	0%	40%	3%	6%	1%	24,01		24,01			22,01				
44	32%	0%	42%	4%	18%	4%	24,23		24,23			21,98				
45	11%	0%	34%	12%	35%	8%	24,28		24,28			21,98				
46	14%	3%	38%	6%	33%	7%	24,34		24,34			22,14				
47	19%	0%	37%	6%	32%	7%	24,40		24,40			22,30				
48	37%	0%	26%	2%	31%	4%	24,39		24,39			22,29				
49	46%	0%	32%	0%	20%	2%	24,34		24,34			22,33				
50	31%	0%	33%	1%	31%	3%	24,30		24,30			22,41				

Average U	**22,65**	**29,76**	**25,24**	**21,18**	**20,58**	**22,92**	**28,67**	**25,03**	**21,73**	**21,49**
Average R	**19,33**	**19,33**	**19,33**	**19,33**	**19,33**	**19,74**	**19,74**	**19,74**	**19,74**	**19,74**
UHI (U-R)	**3,32**	**10,43**	**5,91**	**1,85**	**1,25**	**3,18**	**8,93**	**5,29**	**1,99**	**1,75**

Table 6.1.5: Remarkable cells for the afternoon August period. The average U is the average temperature for the urban afternoon period. The average R is the average temperature for the rural, airport Zestienhoven, afternoon period. UHI (U-R) is the difference between the urban and rural average temperature for the afternoon period.

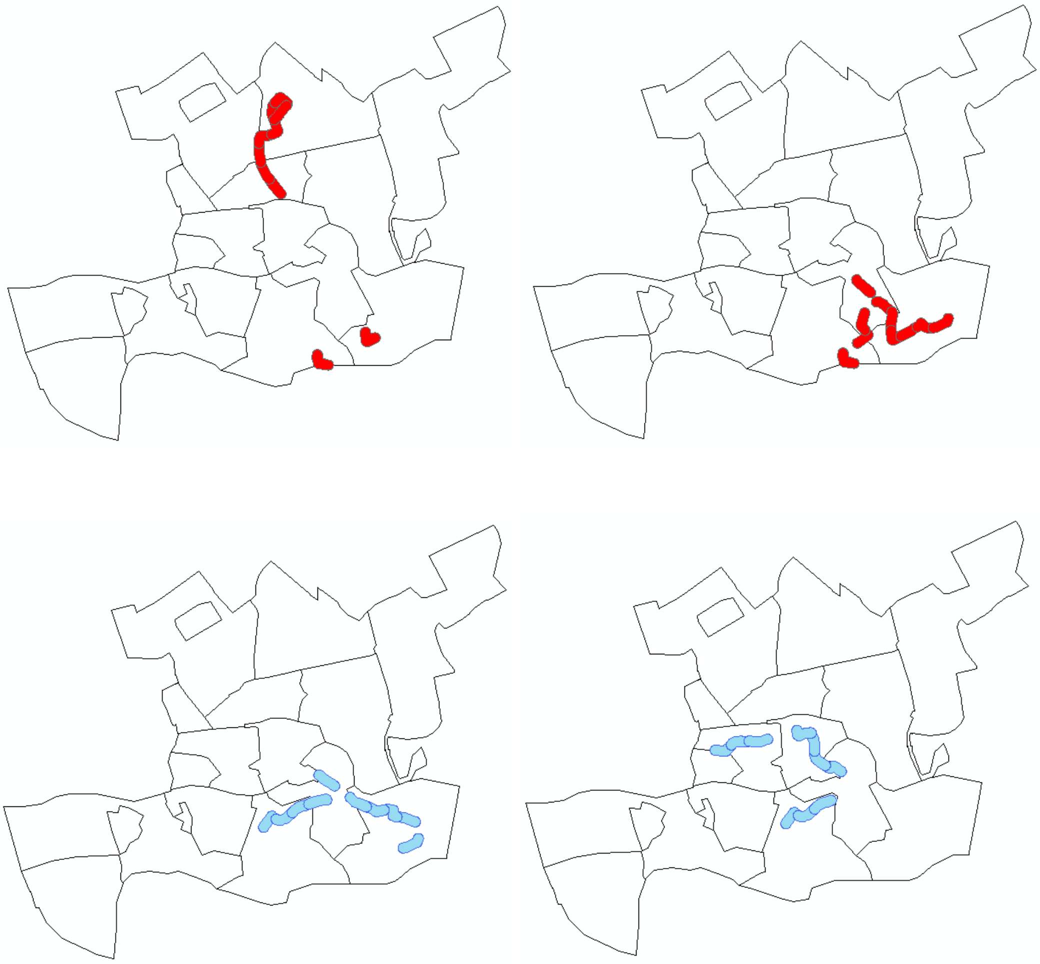


Illustration 6.5.5: The ten hottest (red) and coolest (blue) cells for the August afternoon period. From top left to the right bottom hour13, hour14, hour13 and hour14.

6.1.6 *August – evening*

Once again the hottest cells are situated in the south and the north-west of Rotterdam, the coolest cells are situated around the south side of the Meuse and around the city centre, but south from central station. The hottest cell for all hours is cell 1 which is situated in the south and has a high percentage of paved open space and 30% vegetation what should indicate a cooler cell. Also the coolest cells are rare because they are situated on the west side of the centre with 42-52% dwellings and 42-39% paved open space. Both absorb heat during day and give off heat during the evening and night when the rest is already cooling.

Following literature, these cells should be the hottest instead of the coolest. The hottest 6 or 8 cells are situated in the north of Rotterdam which are, except from the cell 43 and 44, cells with a high percentage vegetation and water and therefore should indicate a cooler cell.

							August 2010 evening									
							Hour 17					Hour 18				
Cell number:	Dwellings	Industry	Paved open spaces	Unpaved open spaces	Vegetation	Water	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest cell	Average	Hottest cell	Hottest 10 cells	Coolest 10 cells	Coolest cell
1	14%	0%	40%	9%	31%	6%	26,21	26,21	26,21			25,23	25,23	25,23		
3	15%	0%	39%	14%	27%	6%	20,96					22,24		22,24		
4	43%	0%	33%	2%	20%	2%	20,75					22,25		22,25		
6	41%	1%	44%	0%	12%	2%	20,43			20,43		20,96				
7	25%	6%	44%	3%	21%	1%	20,37			20,37		20,58				
8	23%	0%	42%	3%	31%	2%	24,26		24,26			24,73		24,73		
9	16%	0%	39%	21%	22%	2%	20,43			20,43		20,57				
15	30%	8%	7%	30%	7%	18%	21,02					20,42				
16	29%	4%	46%	0%	10%	12%	20,58					19,86			19,86	
17	43%	0%	43%	2%	9%	3%	20,27			20,27		20,47				
19	23%	0%	32%	10%	33%	3%	20,36			20,36		19,66			19,66	
20	14%	4%	36%	10%	32%	4%	20,41			20,41		19,61			19,61	
21	17%	9%	46%	10%	17%	2%	20,71					19,58			19,58	
22	12%	8%	55%	9%	15%	0%	20,26			20,26		19,60			19,60	
27	33%	0%	16%	27%	19%	6%	20,63					20,53				
28	13%	0%	21%	28%	33%	4%	20,61					20,42				
31	15%	0%	37%	4%	6%	38%	20,28			20,28		20,59				
32	12%	0%	34%	2%	2%	49%	20,18			20,18		20,66				
36	24%	3%	54%	1%	17%	0%	20,79					19,69			19,69	
37	42%	0%	42%	4%	6%	5%	19,68			19,68	19,68	18,58			18,58	18,58
38	48%	0%	41%	1%	5%	6%	20,81					19,60			19,60	
39	52%	0%	39%	2%	4%	2%	20,70					19,45			19,45	
40	45%	0%	45%	7%	3%	1%	20,54					20,10			20,10	
43	50%	0%	40%	3%	6%	1%	23,32		23,32			21,56				
44	32%	0%	42%	4%	18%	4%	23,23		23,23			21,62		21,62		
45	11%	0%	34%	12%	35%	8%	23,50		23,50			21,78		21,78		
46	14%	3%	38%	6%	33%	7%	22,36		22,36			21,70		21,70		
47	19%	0%	37%	6%	32%	7%	22,22		22,22			21,53				
48	37%	0%	26%	2%	31%	4%	22,30		22,30			21,62		21,62		
49	46%	0%	32%	0%	20%	2%	22,23		22,23			21,65		21,65		

50	31%	0%	33%	1%	31%	3%	22,49		22,49			21,63		21,63		
Average U							**21,23**	**26,21**	**23,21**	**20,27**	**19,68**	**20,83**	**25,23**	**22,45**	**19,57**	**18,58**
Average R							**18,92**	**18,92**	**18,92**	**18,92**	**18,92**	**18,58**	**18,58**	**18,58**	**18,58**	**18,58**
UHI (U-R)							**2,31**	**7,29**	**4,29**	**1,35**	**0,76**	**2,25**	**6,65**	**3,87**	**0,99**	**0,00**

							August 2010 evening				
							Hour 19				
Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**	**Average**	**Hottest cell**	**Hottest 10 cells**	**Coolest 10 cells**	**Coolest cell**
1	14%	0%	40%	9%	31%	6%	25,45	25,45	25,45		
3	15%	0%	39%	14%	27%	6%	21,74				
4	43%	0%	33%	2%	20%	2%	21,84				
6	41%	1%	44%	0%	12%	2%	20,55				
7	25%	6%	44%	3%	21%	1%	20,07				
8	23%	0%	42%	3%	31%	2%	23,25		23,25		
9	16%	0%	39%	21%	22%	2%	19,86				
15	30%	8%	7%	30%	7%	18%	18,63			18,63	
16	29%	4%	46%	0%	10%	12%	19,00				
17	43%	0%	43%	2%	9%	3%	20,12				
19	23%	0%	32%	10%	33%	3%	18,90			18,90	
20	14%	4%	36%	10%	32%	4%	18,63			18,63	
21	17%	9%	46%	10%	17%	2%	18,55			18,55	
22	12%	8%	55%	9%	15%	0%	18,34			18,34	
27	33%	0%	16%	27%	19%	6%	18,84			18,84	
28	13%	0%	21%	28%	33%	4%	18,49			18,49	
31	15%	0%	37%	4%	6%	38%	19,31				
32	12%	0%	34%	2%	2%	49%	19,61				
36	24%	3%	54%	1%	17%	0%	18,71			18,71	
37	42%	0%	42%	4%	6%	5%	19,67				
38	48%	0%	41%	1%	5%	6%	18,42			18,42	
39	52%	0%	39%	2%	4%	2%	18,31			18,31	18,31
40	45%	0%	45%	7%	3%	1%	19,15				
43	50%	0%	40%	3%	6%	1%	22,65		22,65		
44	32%	0%	42%	4%	18%	4%	22,62		22,62		
45	11%	0%	34%	12%	35%	8%	22,64		22,64		
46	14%	3%	38%	6%	33%	7%	22,96		22,96		
47	19%	0%	37%	6%	32%	7%	23,43		23,43		
48	37%	0%	26%	2%	31%	4%	23,85		23,85		
49	46%	0%	32%	0%	20%	2%	24,07		24,07		

50	31%	0%	33%	1%	31%	3%	23,98		23,98		
Average U							**20,42**	**25,45**	**23,49**	**18,58**	**18,31**
Average R							**17,94**	**17,94**	**17,94**	**17,94**	**17,94**
UHI (U-R)							**2,48**	**7,51**	**5,55**	**0,64**	**0,37**

Table 6.1.6: Remarkable cells for the evening August period. The average U is the average temperature for the urban evening period. The average R is the average temperature for the rural, airport Zestienhoven, evening period. UHI (U-R) is the difference between the urban and rural average temperature for the evening period.

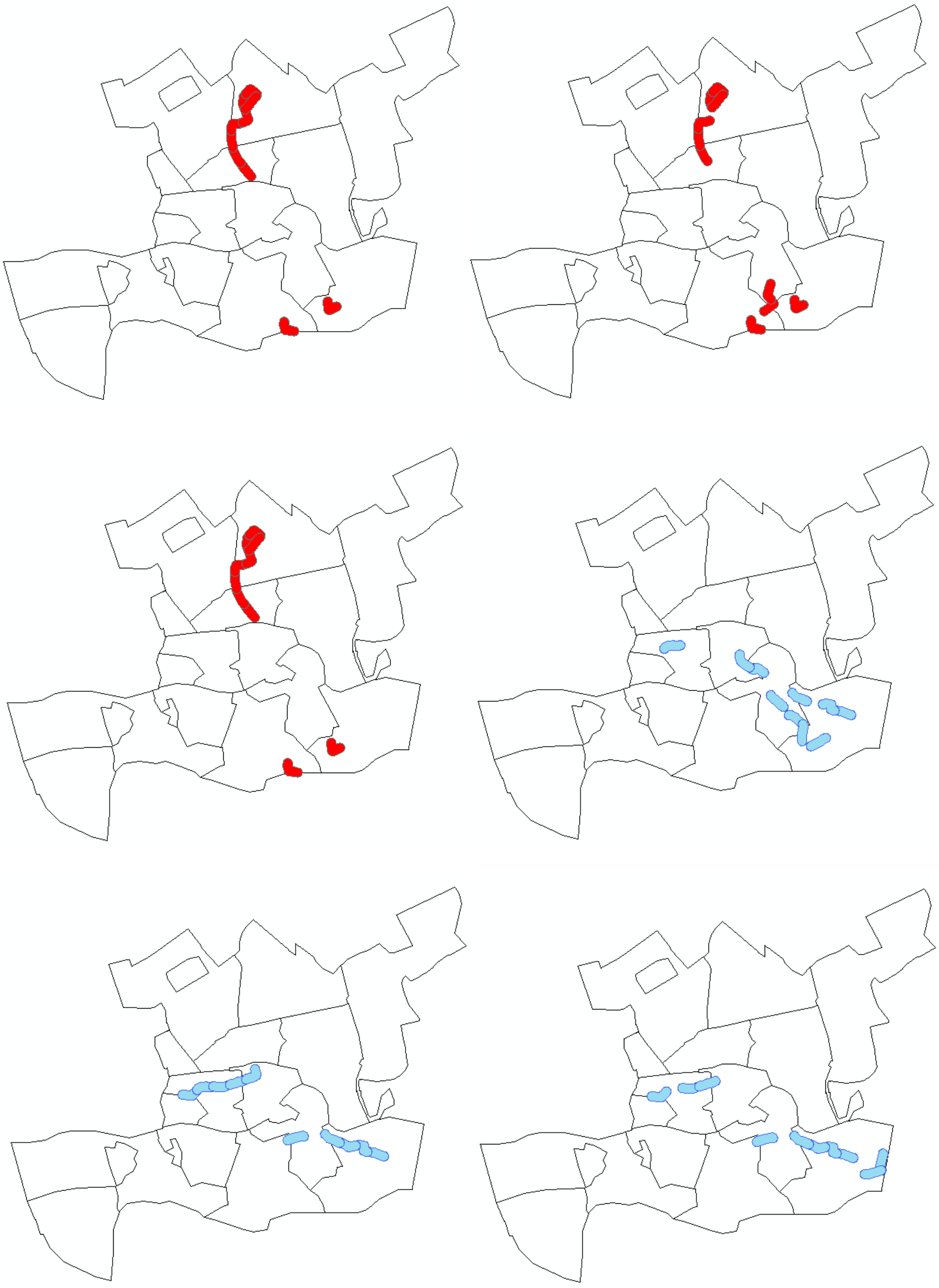


Illustration 6.6.6: The ten hottest (red) and coolest (blue) cells for the August evening period. From top left to the right bottom hour17, hour18, hour19, hour17, hour18 and hour19.

6.2 Results

The results are hard to define because of the wide range of cell numbers belonging to the hottest or coolest. A cell that belongs to the coolest for a specific hour could belong to the hottest the next hour. Another example is a trend for the evening can be different for July and August. For that reason it was hard to formulate an univocal result after the qualitative analysis. One of the main remarkable notices was that theory in the theoretical research doesn't have to match with this research. For example, a cell which was crossing the Meuse and therefore, following the theory, should have a cooling effect, belongs to the top 10 hottest cells (morning and evening period from July). Also a high percentage vegetation what, following the theory, should have a cooling effect, can belong to the hottest cells. Cells 26, 27, and especially 28 have a high percentage vegetation or are situated next to a large green zone, but nevertheless still belong to the hottest cells 5 or 6 times in current research

Analysing the position of the hottest and coolest cells on the geographic map, the July morning and afternoon have most of their coolest cells in and around the south side of the Meuse and (west side of) the city centre. The coolest and hottest cells for the morning and afternoon period for August were very diverse and aren't situated on specific locations. The tendency for the July evening period is mirrored for the August period. In July the most of the top 10 coolest cells are situated in the south of Rotterdam and the hottest cells in the middle. During the evening the cool zone changed from the south to the north-west and the hottest cells changed from centre and the south side of the Meuse to the south of Rotterdam. In August these top 10 coolest cells changed direction from the south side of the Meuse to the city centre and the hottest cells changed from centre to the north and south side.

Looking at the percentage for each cell with a remarkable average temperature there is not an univocal answer. Analysing these remarkable cells by looking at the colours (functions), the influences from just outside the cell can be taken into count. For some cells around cell number 30, the percentage water is low, based on the percentage it would be strange if these cells belong to the coolest but in current research, influences from just outside the cell can be of great effect. These cells are situated near the Meuse and therefore it would be logical that these cells are relatively cooler because the theory said: water can have a cooling effect up to 30 metres (Robitu et al., 2004) and for rivers like the Meuse this effect can be felt even further.

7 Conclusions

In the theoretical research there are a lot of influences of the independent variables on the dependent variable. A disadvantage is the standalone where only one topic has been researched. This research tried to prove a relation between the urban morphology and the average temperature based on research from the past, a quantitative analysis and a qualitative analysis.

In the theoretical analysis the (dis)advantage of each of the 6 independent variables was described. Following Robitu et al. (2004) water can have a cooling effect of up to 3°C and vegetation can have a cooling effect of 1-5,9°C (Comte et al, (1981) and Upmanis et al. (1998). When analyzing the difference between the average urban heat from this research and the average rural heat from the KNMI we can conclude that the UHI for Rotterdam is equal compared to the research from Oke (1973). Following the results in his research the average UHI for a city with the population size of Rotterdam (+/- 600.000) should be 8°C. From the data used for this research the UHI for Rotterdam city in July was 0,93-5,78°C for the July morning, 2,41-9,79°C in the afternoon and 0,57-7,47°C in the evening. For the August period the UHI was 0,14-5,61°C in the morning, 1,25-10,43°C in the afternoon and 0-7,54°C in the evening compared to research from Brandsma (2010), who said that cities with a population of 200.000 or more can have a maximum UHI of 7°C. This statement was overruled for the months July and August 2010 in current research. Finally the average UHI should be between 0,5-1°C following Brandsma (2010). In excel table chapter 6.1, we saw values of 2,81-3,27°C for the July morning, 4,84-5,20°C for the afternoon, and 2,89-3,59°C for the evening. For August values were as followed: 1,87-2,10°C in the morning, 3,18-3,32°C in the afternoon, and 2,25-2,48°C in the evening. The average temperature is also higher than the average temperature indicated by Brandsma (2010).

For Rotterdam, a city with the river the Meuse flowing through, water can be a powerful tool to provide the city from cool air. On the south side of Rotterdam there are many pastures and greenhouses what can positively influence the airflow. On the west side of Rotterdam there is the harbour and the North sea which provide enough open space for the wind as well and the sea can even provide cool sea winds to the city. The warm air can be convected from the north where the Randstad is situated which is the part of Holland with the highest population density. In the period of July and August 2010 the most wind came from the south, south-west and south-east (KNMI, 2011) direction which should help to provide the city from cool air.

Looking at the theoretical part, it can be stated that vegetation and water provide Rotterdam from cool air and helps cooling down in the evening. Unpaved and paved open spaces help to cool down because wind can blow and mix the hot air with the cool air. The paved open space will be less effective because the paved spaces absorb heat during the day which should be released before they are able to contribute to the cooling down process of the city. Dwellings and industry (which is uncommon in the city) absorb the heat the same as paved open space, but it also blocks the wind what causes a stagnation in the mixing of cool and hot air. Especially in the centre of Rotterdam where many high rise buildings are situated.

The outcome from the analysis was looking at each hour for both months only hour19 has a significant level of 0,05 or under for both months.

The quantitative analysis showed that from the 14 tested models, 8 were significant which means that all 6 independent variables together influenced the variance in average temperature for that particular hour. The effect of each significant independent variable within these significant models with all 6 independent variables, was only possible twice what makes it difficult to form a statement about the individual effect of a independent variable on temperature changes regarding the other 5 independent variables.

The qualitative analysis was even harder to analyze because there was no clear answer. Like described in the chapter before, there was no consistency between any of the 6 independent variables on the dependent variables. Cells that following the theory should belong to the coolest cells belonged to the coolest cells in one particular hour but appear later on as one of the hottest cells in the same variable . A tendency that can be derived is the location of the coolest and hottest cells for different periods and hours. Where the cool cells are situated in the south and north, and during the day change position and move to the centre. The hottest cells are start in the centre and during the day they spread to the north and south. A reason for that can be the wind which coming mostly from the south (KNMI, 2011) and like described before, provides cool air which cools the south side of Rotterdam. It also provides the centre with cool air when it flows across the Meuse and gets mixed with the cool air from the river. So the complete temperature wave moves during the day. The warm air from the south moves to the south side of the Meuse. The cool air from the south side of the Meuse (which cools down during the night) flows past the Meuse to the centre and therefore cools the centre. The warm air from the centre flows with the southern wind to the north and so warms the north side.

The overall tendency of theoretical, qualitative and quantitative results from current research could be considered twofold. First, all research shown in the theoretical part is one sided, combining just one independent variable with the temperature, therefore the relation between variables is not made. And second, the quantitative and qualitative part where a relation between all these independent variables as pointed out in the theoretical part were combined. But looking at the overall results of the qualitative analysis, it could also be considered standing somewhere in-between because clear relations between this analysis and knowledge from the theoretical part were not found. Therefore it wasn’t possible to prove relations between separate independent variables on the temperature.

A reason why it’s possible that results were not significant could be the amount of data that was used. With more data a more specific average for each cell could be calculated and adding to that, outliers are of less influence when working with a large amount of data. Also the average wind for a July and August was used to help understand the results from the qualitative analysis. For future research it would be recommended to relate average temperature to the daily wind and so relate wind to the influence on the urban morphology. Also a third dimension (3D) could be added to relate the influence of the high rise buildings on the temperature, which can be added to the urban morphology. Finally the average temperature for each district could also be related to the population, in order to formulate the influence of the population density on the temperature. This can be a supplementation to the study from Brandsma (2010).

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10 Appendix

10.1 Not significant SPSS models

10.1.1 Not significant regression analysis July 2010 hour13

Descriptive Statistics

	Mean	Std. Deviation	N
Average	27,747727	1,3872926	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,361[a]	,130	,016	1,3761150

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10,797	5	2,159	1,140	,356[a]
	Residual	71,960	38	1,894		
	Total	82,757	43			

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	28,993	1,561
	Industry	-,051	,092
	Paved open spaces	-,032	,030
	Unpaved open spaces	-,016	,037
	Vegetation	,022	,022
	Water	-,032	,026

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		18,575	,000
	Industry	-,088	-,559	,579
	Paved open spaces	-,227	-1,071	,291
	Unpaved open spaces	-,084	-,421	,676
	Vegetation	,166	,957	,345
	Water	-,214	-1,258	,216

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	25,834	32,153
	Industry	-,238	,135
	Paved open spaces	-,093	,029
	Unpaved open spaces	-,090	,059
	Vegetation	-,024	,067
	Water	-,084	,020

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.2 Not significant regression analysis July 2010 hour14

Descriptive Statistics

	Mean	Std. Deviation	N
Average	28,2708	1,28666	36
Dwellings	30,0482%	12,40340%	36
Industry	1,2780%	2,57190%	36
Paved open spaces	40,6476%	10,36557%	36
Unpaved open spaces	7,1092%	8,03272%	36

Vegetation	15,1518%	9,92347%	36
Water	5,7652%	10,15853%	36

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,360[a]	,129	-,016	1,29679

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7,492	5	1,498	,891	,499[a]
	Residual	50,450	30	1,682		
	Total	57,942	35			

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	27,476	1,704
	Industry	,081	,088
	Paved open spaces	,013	,033
	Unpaved open spaces	,058	,041
	Vegetation	-,013	,026
	Water	-,008	,025

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		16,122	,000
	Industry	,162	,922	,364
	Paved open spaces	,104	,394	,697
	Unpaved open spaces	,361	1,400	,172
	Vegetation	-,101	-,509	,615
	Water	-,061	-,306	,762

Coefficients[a]

Model	95,0% Confidence Interval for B	
	Lower Bound	Upper Bound

1	(Constant)	23,996	30,956
	Industry	-,099	,261
	Paved open spaces	-,054	,080
	Unpaved open spaces	-,027	,142
	Vegetation	-,066	,039
	Water	-,059	,044

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.3 Not significant regression analysis July 2010 hour17

Descriptive Statistics

	Mean	Std. Deviation	N
Average	25,0566	1,15788	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44
Water	5,5210%	9,23213%	44

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,448[a]	,201	,095	1,10123

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11,566	5	2,313	1,908	,116[a]
	Residual	46,083	38	1,213		
	Total	57,649	43			

Coefficients

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	25,914	1,249
	Industry	-,192	,074
	Paved open spaces	-,006	,024
	Unpaved open spaces	,018	,030
	Vegetation	-,020	,018
	Water	-,032	,020

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		20,745	,000
	Industry	-,394	-2,607	,013
	Paved open spaces	-,052	-,257	,798
	Unpaved open spaces	,119	,625	,536
	Vegetation	-,187	-1,127	,267
	Water	-,252	-1,549	,130

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	23,385	28,442
	Industry	-,341	-,043
	Paved open spaces	-,055	,042
	Unpaved open spaces	-,041	,078
	Vegetation	-,057	,016
	Water	-,073	,010

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.4 Not significant regression analysis July 2010 hour18

Descriptive Statistics

	Mean	Std. Deviation	N
Average	25,2489	1,43594	38
Dwellings	30,6241%	12,49430%	38
Industry	1,2107%	2,51808%	38
Paved open spaces	40,6786%	10,08456%	38
Unpaved open spaces	6,9130%	7,86051%	38
Vegetation	14,9876%	9,76743%	38
Water	5,5860%	9,91747%	38

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,407[a]	,165	,035	1,41055

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12,622	5	2,524	1,269	,301[a]
	Residual	63,669	32	1,990		
	Total	76,291	37			

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	24,399	1,807
	Industry	,105	,096
	Paved open spaces	-,004	,035
	Unpaved open spaces	,014	,045
	Vegetation	,046	,027
	Water	,018	,027

Coefficients[a]

Model		Standardized Coefficients	t	Sig.

		Beta		
1	(Constant)		13,503	,000
	Industry	,184	1,097	,281
	Paved open spaces	-,027	-,108	,914
	Unpaved open spaces	,075	,308	,760
	Vegetation	,311	1,665	,106
	Water	,121	,648	,522

Coefficients[a]

Model		95,0% Confidence Interval for B Lower Bound	95,0% Confidence Interval for B Upper Bound
1	(Constant)	20,718	28,080
	Industry	-,090	,299
	Paved open spaces	-,075	,068
	Unpaved open spaces	-,077	,104
	Vegetation	-,010	,102
	Water	-,038	,073

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.5 Not significant regression analysis August 2010 hour05

Descriptive Statistics

	Mean	Std. Deviation	N
Average	16,488333	,8892801	42
Dwellings	29,5977%	12,64817%	42
Industry	1,1111%	2,42666%	42
Paved open spaces	39,2859%	9,79109%	42
Unpaved open spaces	6,8693%	7,54359%	42
Vegetation	17,3968%	10,81605%	42
Water	5,7391%	9,39626%	42

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,354[a]	,125	,004	,8875024

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4,068	5	,814	1,033	,413[a]
	Residual	28,356	36	,788		
	Total	32,424	41			

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	15,793	1,030
	Industry	,011	,060
	Paved open spaces	,005	,020
	Unpaved open spaces	-,016	,024
	Vegetation	,032	,015
	Water	,007	,017

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		15,329	,000
	Industry	,030	,181	,857
	Paved open spaces	,055	,252	,802
	Unpaved open spaces	-,135	-,660	,514
	Vegetation	,389	2,175	,036
	Water	,074	,418	,678

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	13,703	17,882
	Industry	-,110	,132
	Paved open spaces	-,035	,045

	Unpaved open spaces	-,065	,033
	Vegetation	,002	,062
	Water	-,027	,041

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.6 Not significant regression analysis August 2010 hour06

Descriptive Statistics

	Mean	Std. Deviation	N
Average	17,013810	,9436151	42
Dwellings	29,5977%	12,64817%	42
Industry	1,1111%	2,42666%	42
Paved open spaces	39,2859%	9,79109%	42
Unpaved open spaces	6,8693%	7,54359%	42
Vegetation	17,3968%	10,81605%	42
Water	5,7391%	9,39626%	42

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,223[a]	,050	-,082	,9817478

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,809	5	,362	,375	,862[a]
	Residual	34,698	36	,964		
	Total	36,507	41			

Coefficients[a]

Model	Unstandardized Coefficients	
	B	Std. Error

1	(Constant)	17,643	1,140
	Industry	,042	,066
	Paved open spaces	-,019	,022
	Unpaved open spaces	-,012	,027
	Vegetation	,008	,016
	Water	,004	,018

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		15,481	,000
	Industry	,108	,636	,529
	Paved open spaces	-,198	-,870	,390
	Unpaved open spaces	-,092	-,433	,667
	Vegetation	,087	,466	,644
	Water	,036	,195	,846

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	15,332	19,954
	Industry	-,092	,176
	Paved open spaces	-,064	,025
	Unpaved open spaces	-,066	,042
	Vegetation	-,025	,041
	Water	-,034	,041

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dwellings	.[a]	.	.	.	,000

10.1.7 Not significant regression analysis August 2010 hour14

Descriptive Statistics

	Mean	Std. Deviation	N
Average	22,9211	1,49178	44
Dwellings	30,0285%	12,62704%	44
Industry	1,1044%	2,37887%	44
Paved open spaces	39,6782%	9,79812%	44
Unpaved open spaces	6,5855%	7,48287%	44
Vegetation	17,0824%	10,68298%	44

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,455[a]	,207	,103	1,41322

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19,799	5	3,960	1,983	,103[a]
	Residual	75,893	38	1,997		
	Total	95,692	43			

Coefficients[a]

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	20,145	2,308
	Dwellings	,015	,026
	Industry	-,093	,098
	Paved open spaces	,026	,032
	Unpaved open spaces	,033	,043
	Vegetation	,069	,028

Coefficients[a]

Model		Standardized Coefficients	t	Sig.
		Beta		
1	(Constant)		8,728	,000
	Dwellings	,127	,570	,572
	Industry	-,148	-,943	,352
	Paved open spaces	,172	,821	,417

	Unpaved open spaces	,166	,768	,447
	Vegetation	,491	2,433	,020

Coefficients^{a}

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	15,472	24,817
	Dwellings	-,038	,068
	Industry	-,292	,106
	Paved open spaces	-,038	,091
	Unpaved open spaces	-,054	,120
	Vegetation	,012	,126

a. Predictors in the Model: (Constant), Water, Unpaved open spaces, Industry, Vegetation, Paved open spaces

b. Dependent Variable: Average

10.2 Research cells with their square metre

Cell number:	**Cell area m²**	**Dwellings m²**	**Industry m²**	**Paved open spaces m²**	**Unpaved open spaces m²**	**Vegetation m²**	**Water m²**	**Rest are Streets and are part of paved open spaces m²**
1	416.436,6	59.403,4		3.843,6	35.616,2	128.960,7	23.807,4	164.805,3
2	417.969,7	60.563,2			57.305,6	112.925,1	23.977,7	163.198,0
3	414.270,3	60.563,2			57.305,6	112.925,1	23.977,8	159.498,6
4	417.711,5	178.188,2			9.257,3	81.856,0	9.401,6	139.008,4
5	417.790,9	199.474,3		22.129,3	73,2	52.441,6	8.556,6	135.115,9
6	418.162,9	170.279,0	4.882,9	40.085,8	60,5	51.821,2	8.011,8	143.021,7
7	418.603,4	103.657,4	24.118,4	49.277,4	13.867,3	89.060,2	3.596,3	135.026,4
8	407.651,1	93.023,2		27.082,4	10.202,8	124.656,1	7.601,3	145.085,3
9	418.801,1	66.094,8	250,8	57.663,3	89.528,3	90.274,0	8.484,0	106.506,0
10	410.253,8	119.292,7		35.925,1	48.823,2	92.927,7	5.571,3	107.713,8
11	418.361,4	103.605,7		24.041,2	26.313,1	127.724,1	14.581,7	122.095,7
13	412.011,5	128.357,4		4.333,3	1.488,7	56.063,9	6.985,8	214.782,4
14	418.548,9	196.705,1	8.075,6	24.860,7	3.719,1	30.760,3	773,5	153.654,6

15	418.759,5	126.560,2	31.863,7	23.690,5	123.686,0	31.020,9	76.127,0	5.811,2
16	417.152,9	120.442,4	15.263,9	12.886,7	912,2	40.044,1	50.162,9	177.440,8
17	418.784,0	178.545,1			10.244,8	36.293,7	12.444,4	181.256,0
18	543.849,8	115.916,6		19.881,0	60.121,1	100.137,5	1.244,5	246.549,1
19	418.728,1	96.181,2		24.712,6	41.646,7	136.193,7	10.587,1	109.406,7
20	408.678,8	56.500,3	16.527,9	25.706,3	42.539,6	132.095,4	14.879,6	120.429,9
21	418.056,2	69.298,6	38.743,3	31.523,4	41.506,5	70.201,3	6.978,1	159.805,1
22	418.764,9	48.598,6	34.597,8	57.689,5	38.084,2	64.478,8	1.070,8	174.245,1
24	418.148,4	170.647,4	4.099,7	9.792,2	18.182,0	39.417,5	4.829,6	171.180,0
26	410.202,7	158.906,0	41,7	17.587,3	16.955,9	59.219,2	18.935,6	138.557,1
27	417.533,4	137.734,3		6.525,1	113.423,3	77.911,9	23.231,6	58.707,2
28	418.396,0	53.734,3		42.184,3	118.296,8	140.037,7	18.106,6	46.036,4
30	418.814,0	100.980,1	913,3	51.009,2	12.613,5	75.844,2	17.052,4	160.401,4
31	414.747,8	62.111,2		7.281,4	14.849,4	25.612,5	157.191,1	147.702,1
32	418.707,7	51.990,1		12.015,5	9.096,7	8.362,0	204.848,4	132.395,1
33	418.788,8	135.615,6		10.335,6	9.723,9	9.647,2	61.795,5	191.671,0
34	410.492,4	191.680,1			6.809,3	27.200,4	5.045,3	179.757,4
36	417.652,5	101.744,1	12.685,2	57.292,6	6.057,7	70.764,6	1.840,5	167.267,9
37	418.589,0	176.240,2			17.835,3	26.790,5	20.671,0	177.052,0
38	418.736,6	200.043,3			3.773,7	19.364,0	23.327,3	172.228,2
39	418.788,4	219.531,1		17.097,9	9.234,4	18.231,9	6.993,7	147.699,4
40	415.583,2	185.893,5		17.597,7	28.829,1	13.431,3	2.341,0	167.490,6
41	322.397,8	104.277,3		40.804,5	28.898,8	6.924,8	1.099,2	140.393,3
42	399.082,1	154.274,0		21.817,2	2.584,3	20.426,3	3.146,2	196.834,2
43	418.814,2	209.663,7		3.738,1	10.617,1	26.550,7	3.027,8	165.216,9
44	418.781,4	133.672,9		21.761,5	17.692,8	74.234,6	16.741,0	154.678,5
45	418.810,9	45.079,0		36.092,0	49.090,1	148.379,4	32.647,0	107.523,6
46	416.178,5	58.232,1	10.773,2	41.384,0	23.433,2	139.267,2	27.830,2	115.258,7
47	416.113,5	78.073,7		1.871,5	26.247,8	131.332,8	27.417,7	151.170,0
48	415.548,3	155.163,2			7.270,5	127.739,1	17.039,9	108.335,6
49	410.282,0	189.045,4			1.344,5	80.208,7	9.175,3	130.508,1
50	417.186,6	127.670,2			5.561,1	130.791,7	13.548,9	139.614,7

10.3 Research cells with their percentage

Cell number:	**Dwellings**	**Industry**	**Paved open spaces**	**Unpaved open spaces**	**Vegetation**	**Water**
1	14%	0%	40%	9%	31%	6%
2	14%	0%	39%	14%	27%	6%
3	15%	0%	39%	14%	27%	6%

4	43%	0%	33%	2%	20%	2%
5	48%	0%	38%	0%	13%	2%
6	41%	1%	44%	0%	12%	2%
7	25%	6%	44%	3%	21%	1%
8	23%	0%	42%	3%	31%	2%
9	16%	0%	39%	21%	22%	2%
10	29%	0%	35%	12%	23%	1%
11	25%	0%	35%	6%	31%	3%
13	31%	0%	53%	0%	14%	2%
14	47%	2%	43%	1%	7%	0%
15	30%	8%	7%	30%	7%	18%
16	29%	4%	46%	0%	10%	12%
17	43%	0%	43%	2%	9%	3%
18	21%	0%	49%	11%	18%	0%
19	23%	0%	32%	10%	33%	3%
20	14%	4%	36%	10%	32%	4%
21	17%	9%	46%	10%	17%	2%
22	12%	8%	55%	9%	15%	0%
24	41%	1%	43%	4%	9%	1%
26	39%	0%	38%	4%	14%	5%
27	33%	0%	16%	27%	19%	6%
28	13%	0%	21%	28%	33%	4%
30	24%	0%	50%	3%	18%	4%
31	15%	0%	37%	4%	6%	38%
32	12%	0%	34%	2%	2%	49%
33	32%	0%	48%	2%	2%	15%
34	47%	0%	44%	2%	7%	1%
36	24%	3%	54%	1%	17%	0%
37	42%	0%	42%	4%	6%	5%
38	48%	0%	41%	1%	5%	6%
39	52%	0%	39%	2%	4%	2%
40	45%	0%	45%	7%	3%	1%
41	32%	0%	56%	9%	2%	0%
42	39%	0%	55%	1%	5%	1%
43	50%	0%	40%	3%	6%	1%
44	32%	0%	42%	4%	18%	4%
45	11%	0%	34%	12%	35%	8%
46	14%	3%	38%	6%	33%	7%
47	19%	0%	37%	6%	32%	7%
48	37%	0%	26%	2%	31%	4%
49	46%	0%	32%	0%	20%	2%
50	31%	0%	33%	1%	31%	3%

10.4 All cells with the function and colours

Cell 1:

Cell 2:

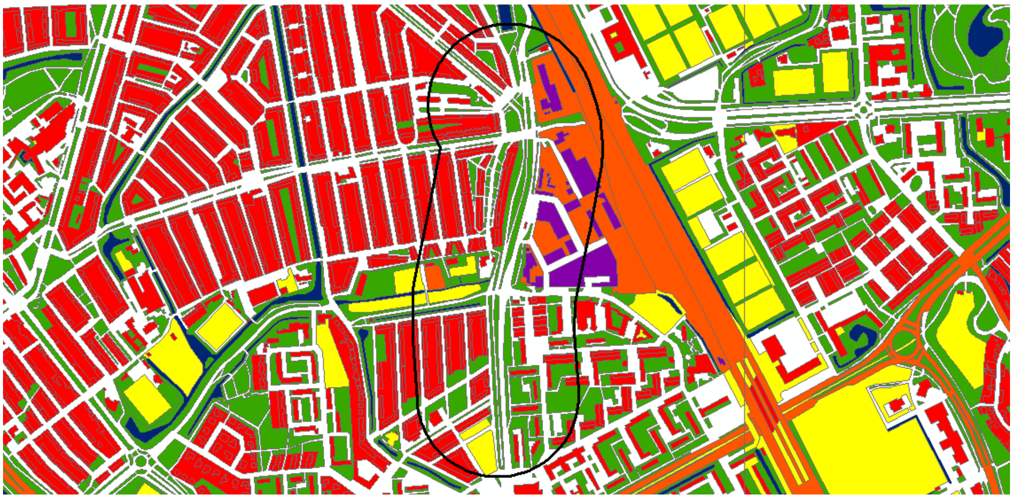
Cell 3:

Cell 4:

Cell 5:

Cell 6:

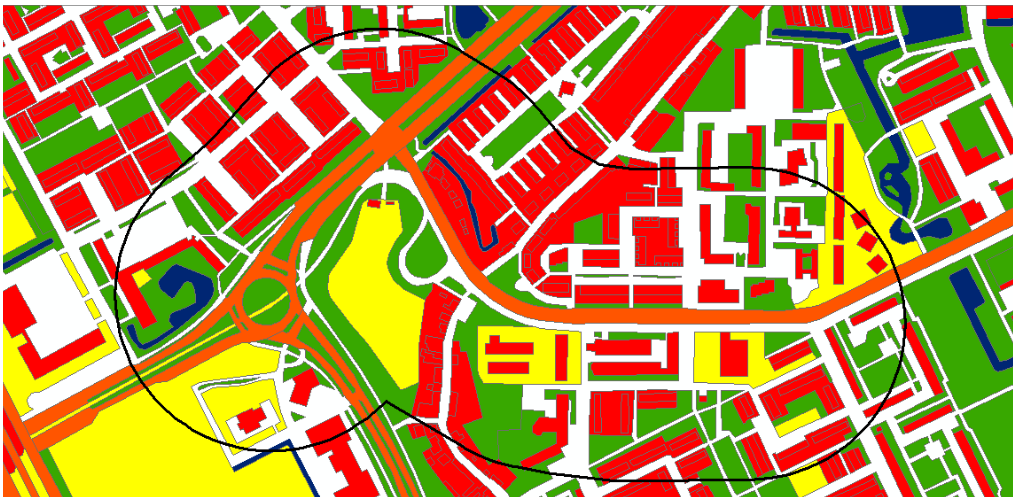
Cell 7:



Cell 8:

Cell 9:

Cell 10:



Cell 11:

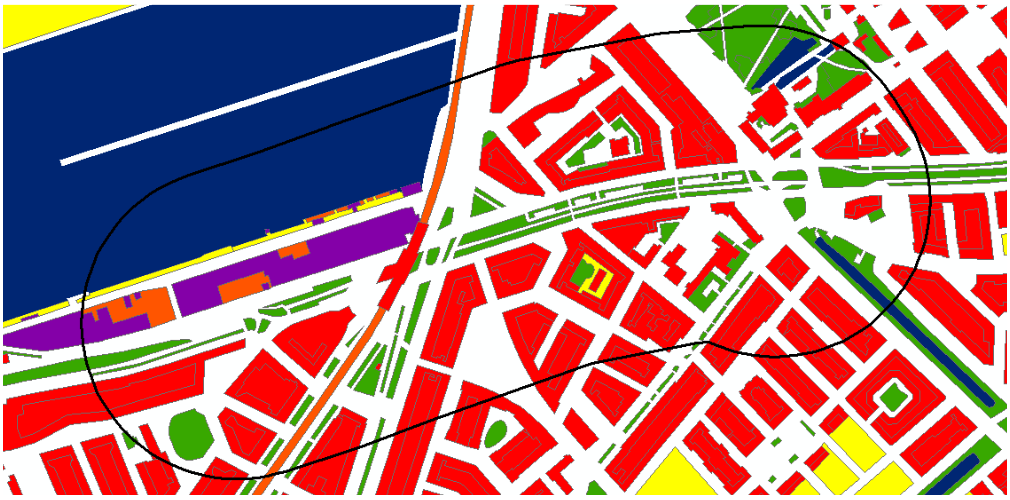
Cell 12:

Cell 13:

Cell 14:

Cell 15:

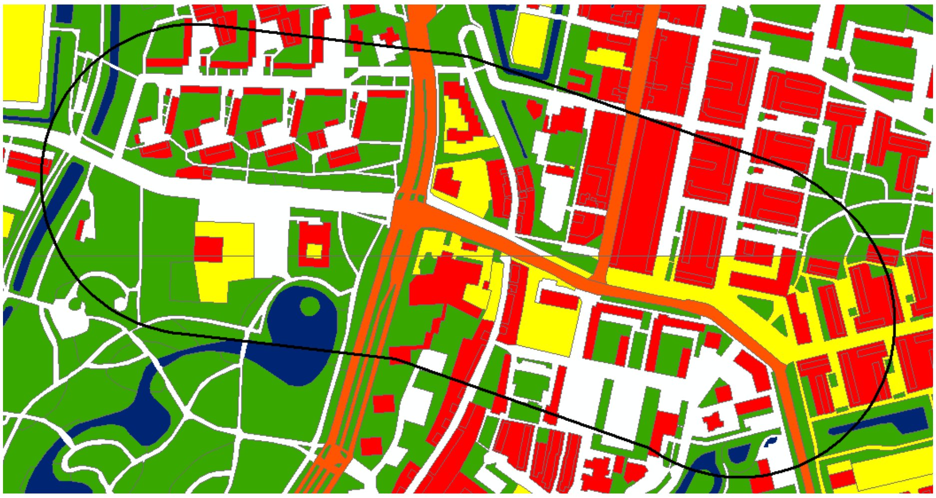
Cell 16:



Cell 17:

Cell 18:

Cell 19:



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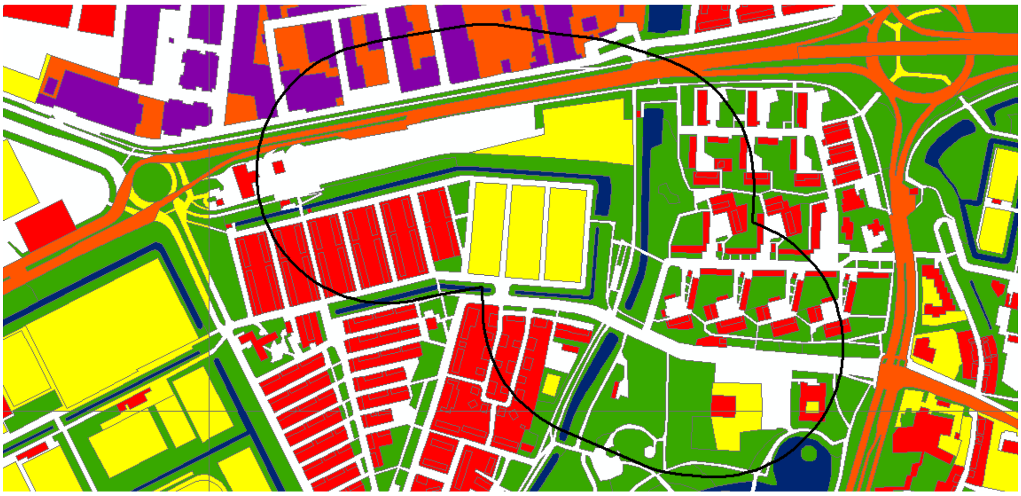

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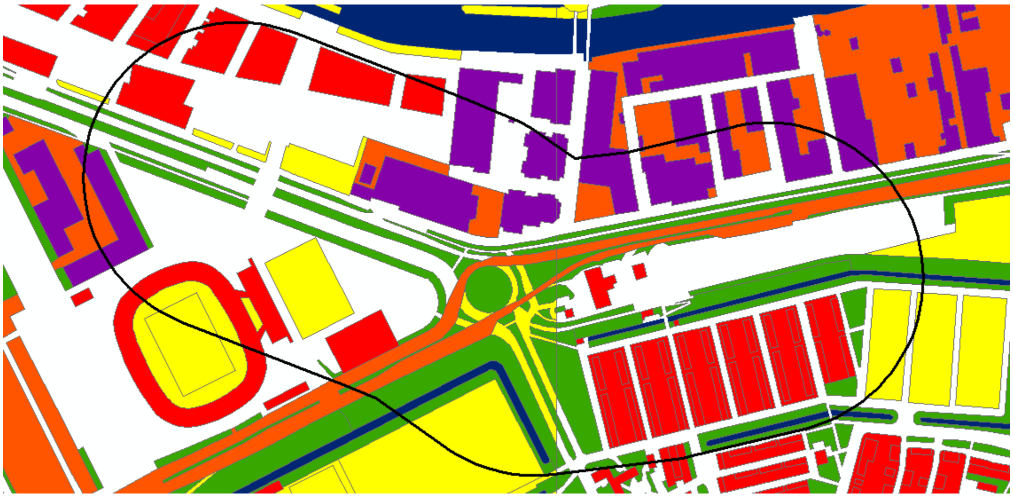

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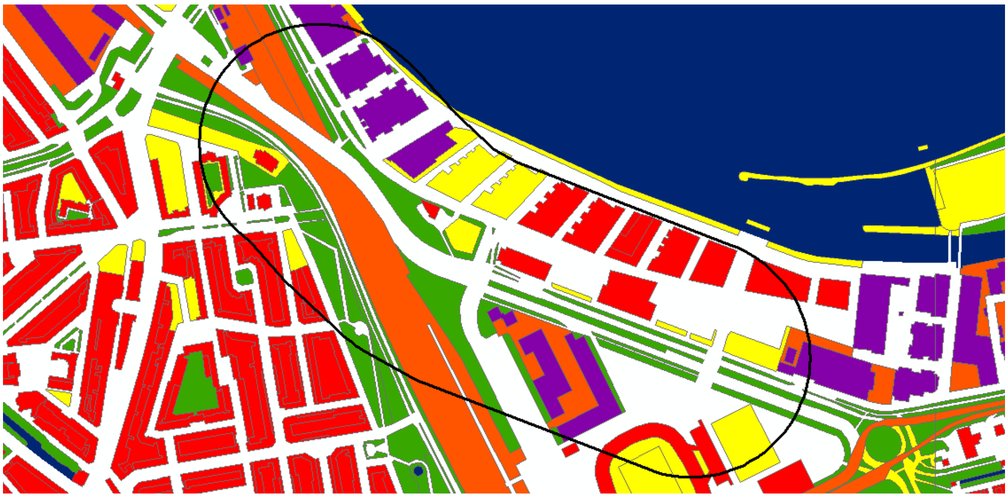
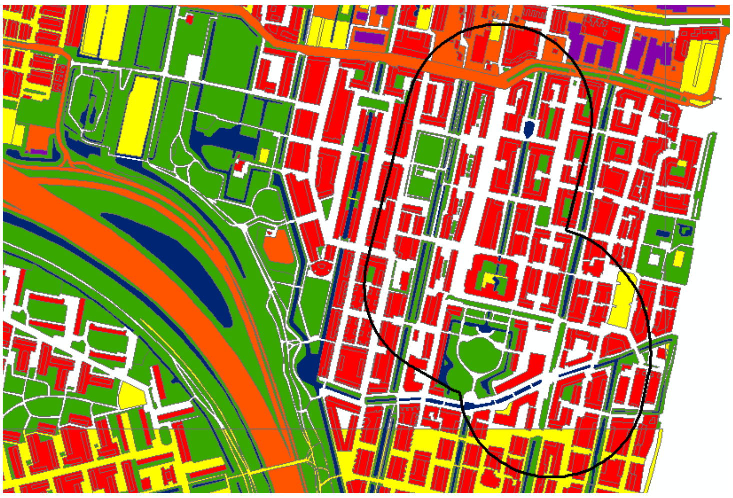


Cell 23:

Cell 24:

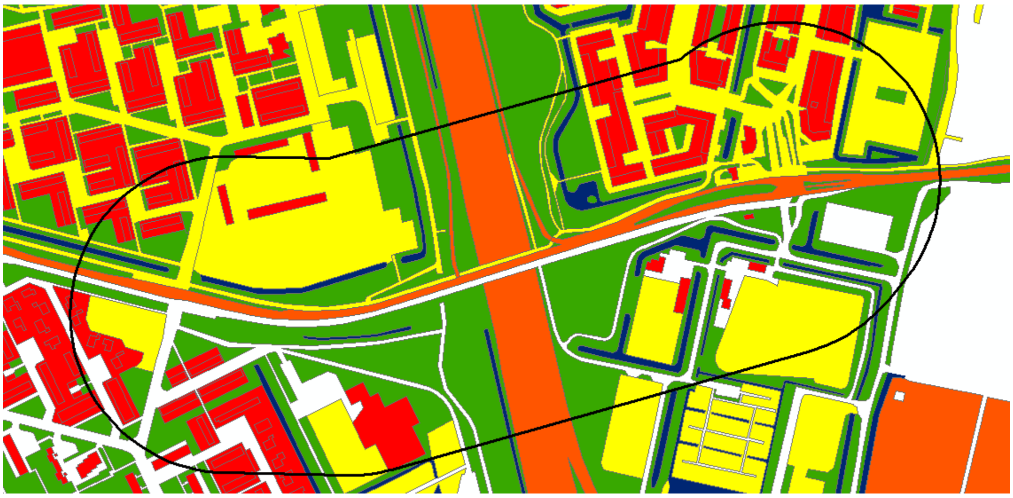
Cell 25:

Cell 26:



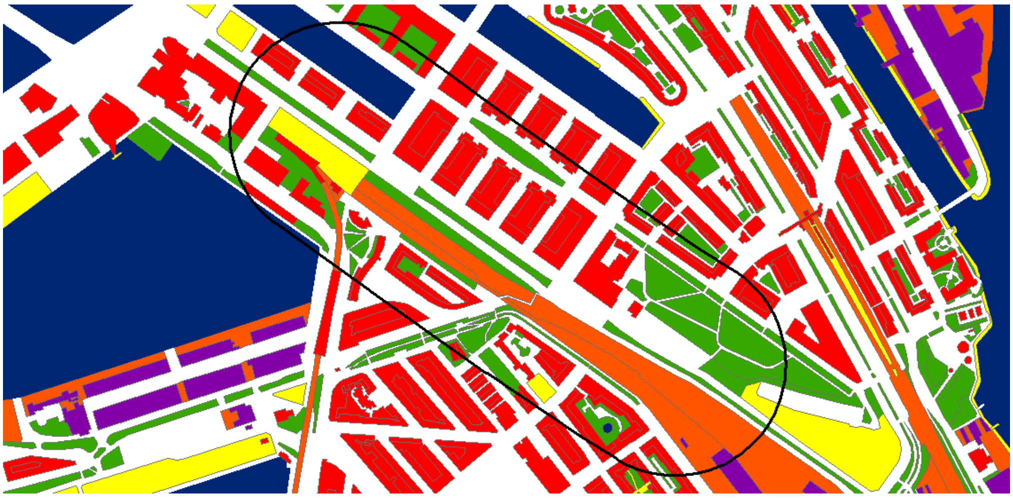
Cell 27:

Cell 28:



Cell 29:

Cell 30:



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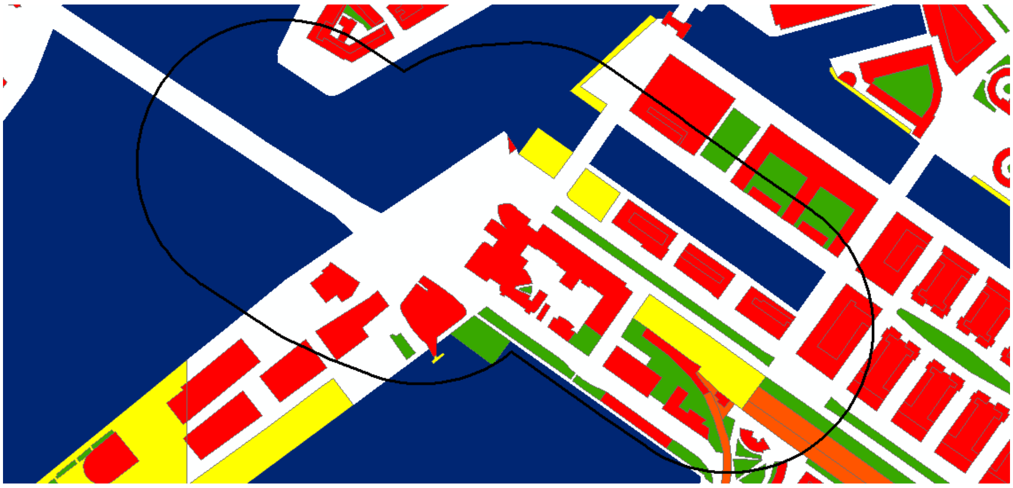

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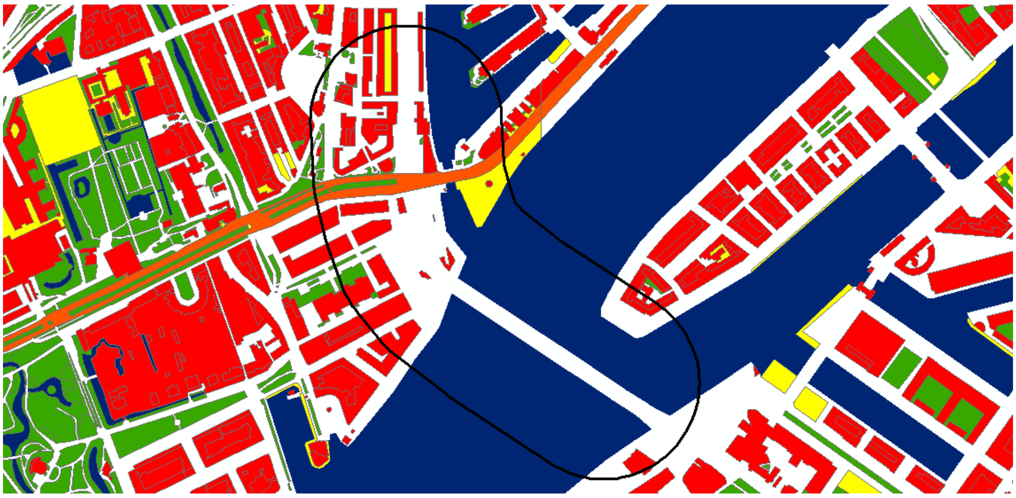
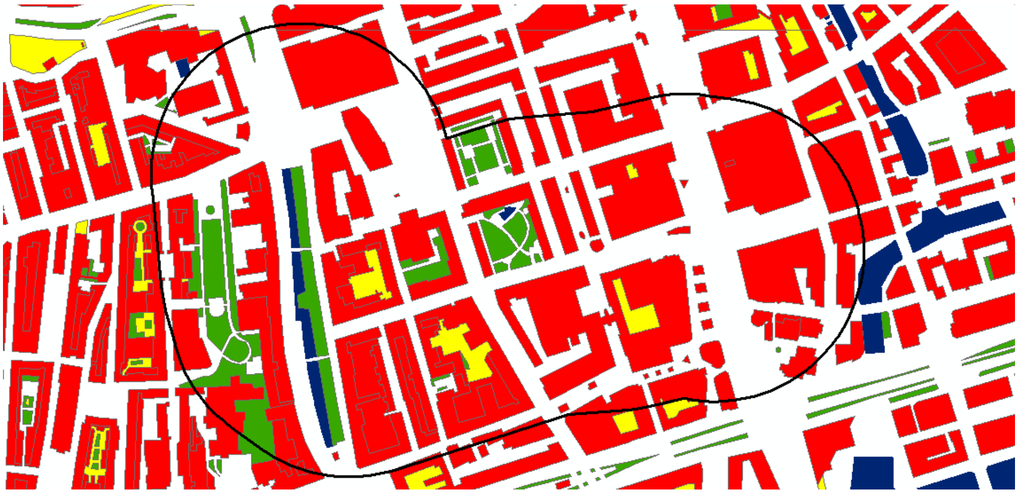


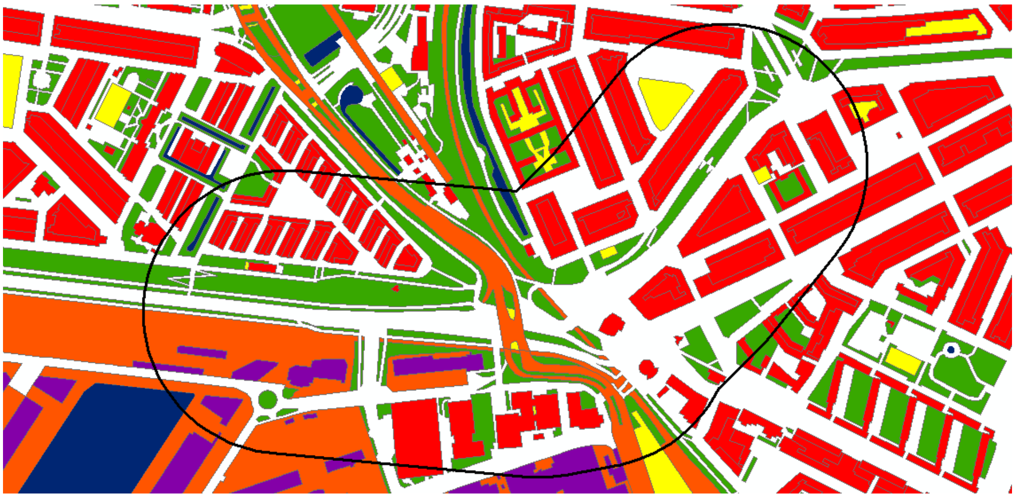
Cell 33:

Cell 34:



Cell 35:

Cell 36:



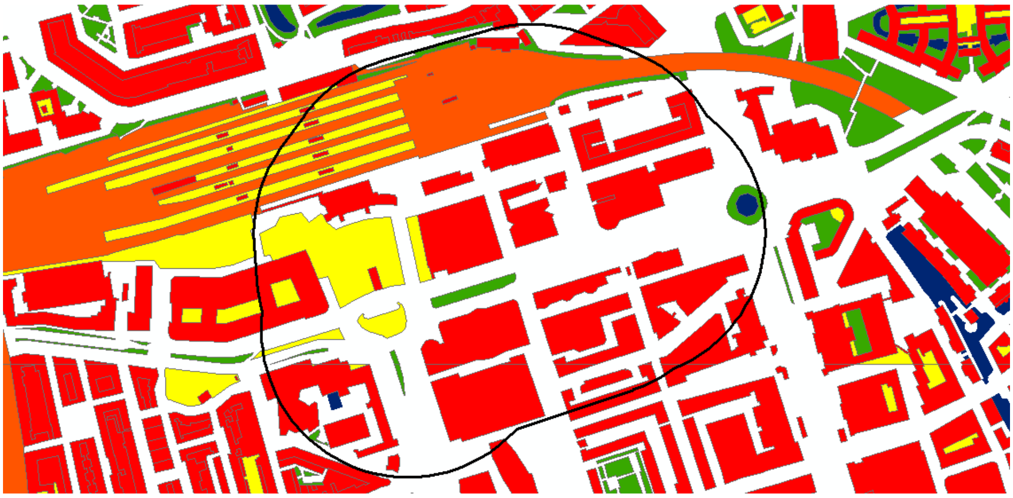
Cell 37:

Cell 38:

Cell 39:

Cell 40:

Cell 41:



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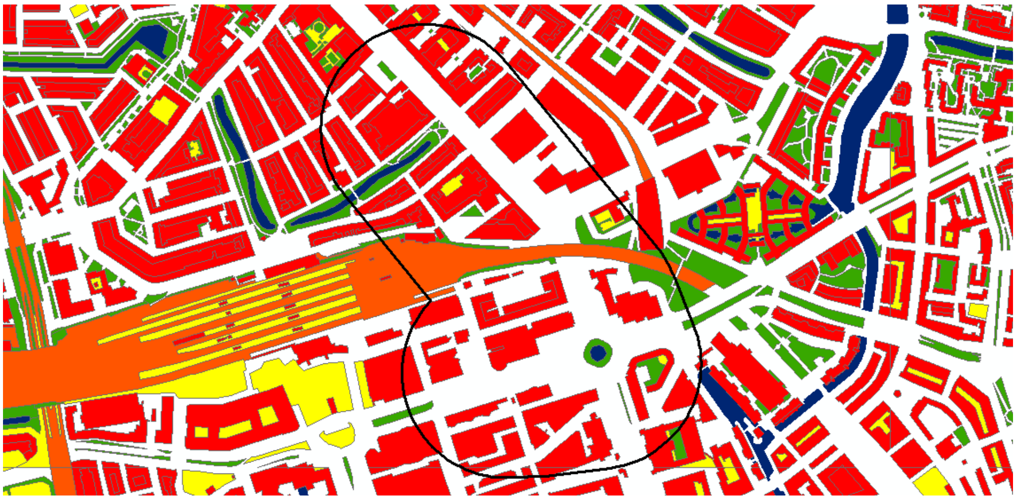
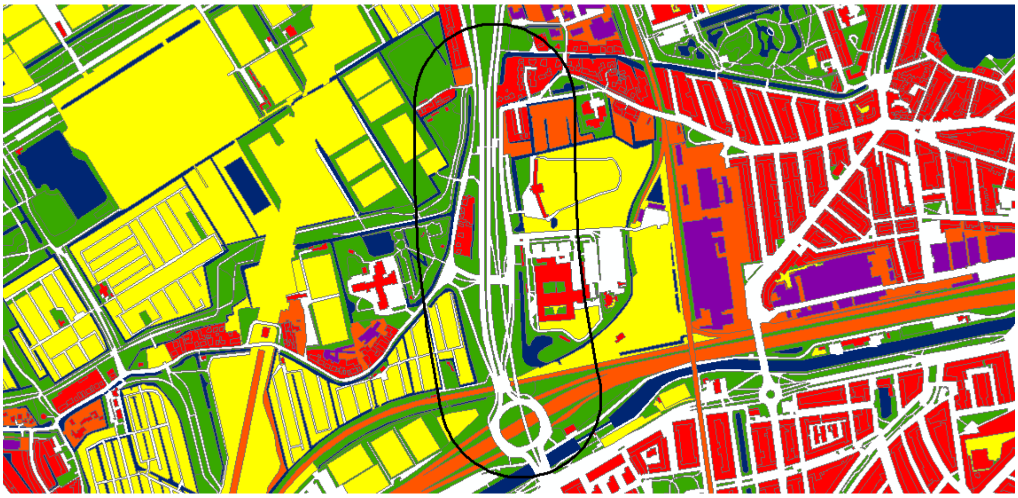


Cell 43:

Cell 44:

Cell 45:



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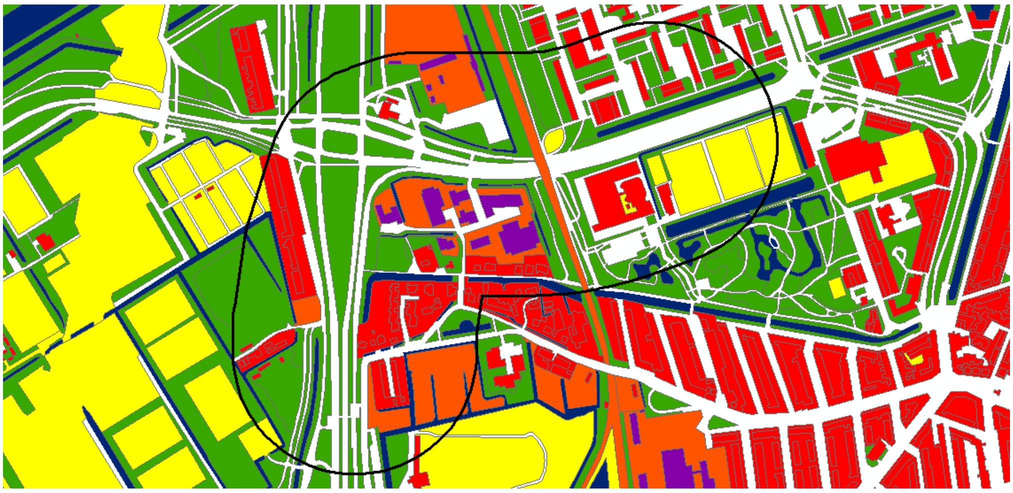

Cell 47:

Cell 48:

Cell 49:

Cell 50:

Overall: