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Mental maps describing thermal comfort in the urban environment

A GIS methodology to analyse (spatial-) variables defining a place of thermal comfort

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Abstract

In the urban environment temperatures rise to higher levels during warm summer periods in comparison with its surrounding rural area, also known as the Urban Heat Island effect (Oke, 1982). Predicted global warming and ongoing urbanization urges urban designers to examine whether the city is climate proof for its inhabitants in the future. In Rotterdam, Utrecht and Arnhem respectively 192, 179 and 182 questionnaires and mental maps have been collected which inquired the perception of the citizen towards the urban environment during warm summer periods (Phd research “Green infrastructure for climate-proof cities”, Klemm. W., Wageningen UR).

The mental maps give personal information about *where* within the urban environment comfort is experienced in terms of temperature, and for *what reasons*. This information was communicated by drawings and textual information on a base map (ground plan) of the respective city.

The research objective of this thesis is to explore a methodology of digitalisation, visualisation and analysis within Geo-information sciences, that is able to deduce, from the drawn mental maps of the citizens, a generic idea which (spatial-) variables define a place of thermal comfort. In doing so, three main research steps have been defined: 1) definition “place of thermal comfort” 2) quantification of (spatial-) variables, and 3) relating spatial variables with “places of thermal comfort”.

In the methodological approach the qualitative information of the mental map has been preserved; e.g. satellite imagery helped to define the spatial boundary of the places of thermal comfort, and the chosen spatial variables measured in a GIS referred to words mentioned frequently in the questionnaire, like “Sun”, “Shadow”, “Water”, “Green” and “Trees”.

The following results and conclusions were found: *Step 1)* for each of the three cites, a composite of all mental maps presented the level of agreement among respondent for specific places of thermal comfort. *Step 2)* The measured and visualization of the spatial variables 1) land cover (water, trees, open), and view angle towards the sky have presented variation in numerical value. This variation in numerical value indicate that the top places of thermal comfort differ in their spatial environment. Distance calculations show that the median distance of a group visitors differs for the separate places of thermal comfort. *Step 3)* Before conducting statistical validation of how multiple (spatial-) variables determine a place of thermal comfort, (e.g. by means of mixed logit regression), the personal character and place specific information of the mental map should be revisited. Both on the side of the respondent (age, home situation) and the urban environment (selection of more places and independent variables), more interesting discrete- and continuous independent variables can be found.

Acknowledgements

The citizens of Rotterdam, Utrecht and Arnhem communicated many visions for the course of my thesis. By reading their mental maps I've been introduced to the summer experience of the three cities. I thank my supervisors Wiebke Klemm and Ron van Lammeren for their attendance, and supervision which enabled me to take adequate steps, in finding a route of comfort. The msc-thesis has a great process to have experienced.

I thank the scientific community for sharing their interesting knowledge. The world of mental maps is rich in their perspectives. Furthermore I thank the GIS community, active on world-wide fora, for sharing their experience with Geo-information systems.

In the process of the thesis my family and friends were of great support. I thank my parents, brother and sister, French house mates, and friends in Wageningen and beyond for the good times and pleasant conversations which enriched the spirit.

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Chapter 1. Introduction

The urban environment is home to half of the world's population these days. Especially in the 20th century a rapid incline of city area has been prevalent (UN World Population prospects 2012). The city facilitates in a diversity of jobs, education and social facilities in the close vicinity.

Understanding the rate of comfort a citizen describes within a geographical space like the urban environment is challenging. Every citizen is affected by the urban space surrounding him in his/her own way, and to maintain a comfortable state – if wanted – he or she would naturally look for those elements that pleases him/her. Those elements can be of any nature; whether it is the social contact with friends, the aesthetics of surrounding objects, or the presence of music.

Spatio-temporal changes within the city could influence the rate of comfort experienced by a person. It is given that within the urban environment climate conditions show increased alterations across space and time. The presence of stone, altered convection (wind), and the heat production of buildings, cars and the people itself, make that temperatures are above average, during all seasons, especially in the night: also known as the Urban Heat Island effect (Oke, 1982). "Green elements" within the city, are physically cooler, due to the higher portion of evapotranspiration of water by the plants (Chen et al., 2012; Kleerekoper et al., 2011; Su et al., 2012). Although there is variation in climate conditions within the city, it is the personal experience of the inhabitants which defines the rate of comfort with these climate conditions – the thermal comfort.

The urban population continues to grow. In the year 2050, with a continued rate of urbanization, 65% of the world's population is expected to live in cities (Argueso et al., 2013). As global temperatures are expected to rise further (IPCC, 2007), attention to the thermal comfort within the urban environment is not superfluous. As stated in Potchter and Ben-Shalom: *"Alcoforado and Andrade (2008) concluded that the impact of global warming including its effect on human well-being and health may be exacerbated in urban areas" (p. 113).*

Different fields of research are focussed on the social and technological phenomena of the city, and moreover how these two interact with each other. One group is Urban designers. Urban designers define and give shape to the physical properties of the city and in this way can influence microclimatic conditions within cities, e.g. by implementing green elements, such as green rooftops, trees and parks. A better understanding of the experienced thermal comfort of the citizens within spatial configurations of the urban environment helps to develop effective design guidelines (Lenzholzer, 2008).

During hot summer periods the UHI effect is even more pronounced, which could influence the experienced thermal comfort by the citizen. Within the Phd research "Green infrastructure for climate-proof cities" at the Landscape Architecture Group, Wageningen UR, done by Klemm,W, some mayor cities in the Netherlands (Rotterdam, Utrecht and Arnhem), were chosen "*to examine and define climate-responsive design principles for urban green at various scale levels in order to improve thermal comfort during warm summer periods.* As part of this study the perception of the citizen towards the urban environment during warm summer periods was recorded by means of interviews and mental maps.

Mental mapping is a method that helps to clarify the link between the people's character and their interactions with the environment. According to Tuan (1975) "*a mental map is a cognitive representation of place".* Within the case of the Phd-research, the mental map consisted of a ground plan (base map) on which respondents indicated (draw) places within the city they found comfortable in terms of temperature, which we call from now on "places of thermal comfort". Furthermore, they gave information why they found these places comfortable.

This report will explore methodologies of integration, visualization and analysis of the drawn mental maps within Geo-Information sciences to understand which variables define a place of thermal comfort within the urban environment during warm summer periods, according citizens.

Figure 1 Thermal comfort in the urban environment

1.1 Problem background

The city is a heterogeneous environment, both in terms of socio-demographic characteristics and individual preferences, as in the spatial distribution of spatial characteristics (buildings, parks, water, etc.). A mental map intents to visualize the emotional relationships individuals have with each other and the environment (Ellis et al., 2012; Findlay & Thagard, 2011; Wolfe, 2012). Literature shows that these maps are constructed in distinctive ways across groups and between individuals (Bentley et al, 2010; Brennan-Horley et al., 2010; Lenzholzer, 2008; Raman & Dempsey, 2012).
The field survey in Rotterdam, Arnhem, and Utrecht has demonstrated the distinctive construction of mental maps. A wide variation of drawing and textual information has been recorded. The places of thermal comfort are indicated by circles, points, expression marks and/or only names on a ground plan. The reasons why these places were comfortable ranged from single words to sentences.
With the development of GIS in the last decade, the study of mental maps have been given a resurgence. Though, In recent studies the 1) acquisition - 2) digitalization and visualization in a GIS – and 3) analysis of the mental maps do not present a common methodological framework, which depends, among others, on the research at hand (Boschmann & Cubbon, 2013; Brennan-Horley et al., 2010; Campbell et al., 2009; Ceccato & Snickars, 2000; Coulton et al., 2001; Curtis et al., 2013; Dennis, 2004; Doran & Lees, 2008; Kwan & Ding, 2008; Matei et al, 2001; Spilsbury et al., 2009; Veitch et al, 2008; Wridt, 2010).
The utilization of mental maps to uncover the perception of citizens during hot summer periods is again a unique study. A (GIS-) methodological framework to deduce from this collection of qualitative data a generic idea which variables define a place to be comfortable in terms of temperature is a challenge.

1.2 Research objective

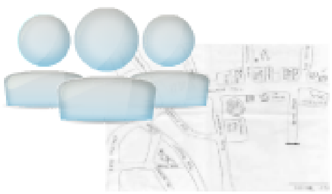
The research objective is to explore a methodology of digitalisation, visualisation and analysis within Geo-information sciences, that is able to deduce, from the drawn mental maps of the citizens, a generic idea which variables determine places of thermal comfort within the urban environment during warm summer periods.

1.3 Research Question

1.3.1 General research question

How can a Geo-information science complement to estimate which variables determine places of thermal comfort in the hot urban environment, when using Mental Maps as source of information?

1.3.2 Specific research questions

Places of thermal comfort	
	*How can the mental map be digitalized?* • *How is the location of the home addresses digitalized?* • *How are the places of thermal comfort digitalized?*
Spatial variables	
	*Which spatial variables are suitable and can be measured on city level by a Geo-Information system?*
Relation Spatial variables and Places of thermal comfort	
	*How can we statistically validate which variables determine a place of thermal comfort?*

Chapter 2. Literature Mental maps

This chapter gives an explanation of what a mental map is, and why it is used in several studies. A first encounter with the words mental map would say that we are dealing with a map that is stored within the mind; a map which appears to us when information is needed. The interpretation of a geo-scientist could be: *"a geographical map in the mind that informs the individual where to go in a specific situation".*

The inquiry of the words mental map in literature does not make the definition of mental map more clear in the first place. There are many definitions (cognitive maps, concept maps, sketch maps, fuzzy cognitive maps, mental models and symbol maps) that pass by interchangeably. The interpretation of these definitions, and the relation with regard to each other differs between authors and area of study. A discussion of the fuzzy character of the "mental-map-like" words can be found as initial part of several articles (Boschmann & Cubbon, 2013; Brennan-Horley et al.; 2010, Hannes et al., 2012). As in our study we focus on the relation between the citizen and the urban environment during warm summer periods, we ease the confusion about the mental map and confine ourselves to the domain of environmental sciences. For example, mental mapping in the field of psychology, computer-, and social science could direct the scope of research towards social relations, policy-making and psychological processes as memory, and change of emotions during negotiations (Archambault & Purchase, 2012; Furrer et al., 2011; Gonzalez et al., 2012).

Let us first talk about the *map*, a we know it in its physical form. "*Production of maps is always preceded by mental interpretation of the world, by mapping*" (Soini, 2001, p. 225). In this sense, a map which is created and laid in front of us can be regarded as a personal abstract of the real world. Map-making calls for decisions to redesign the three-dimensional world in a two-dimensional format. As Halseth (2000) states: "*Maps can contain only so much information. They therefore have biases and perspectives built in. Similarly, maps can only show detail about information with which the map maker is interested or familiar*" (p. 566).
As I would summarize, a (geographical-) map is a representation of the real world, which is influenced by how the author sees the world, and what he wants to communicate.

Many definitions of the words mental maps have passed over time. According to Tuan (1975), "*the mental map is the cognitive representation of place".* The position of the mental map, internally – within the mind -, or externally – a map as we know it on paper, differs;

"The mental map is human's spatial knowledge base, incomplete and biased, regularly updated by travel experiences and foundation of various travel decisions at the same time" (Weston and Handy 2004, in Hannes et al, 2012, p.145).

"This brings us to the second notion of the mental map stemming from decision theory and human reasoning: it conveys the mental representation of a decision problem; a temporarily generated mental model in someone's thought process including relevant choice factors and decision rules" (Johnson-Laird 2004, in Hannes et al, 2012, p. 145).

"Although our cognitive maps may not satisfy the rules of cartographic construction, they serve the same purpose of storing and communicating information. Whether inherently `map-like' or not, our cognitive maps contain and represent our impressions and understandings of places" (Halseth et al, 2000, p. 568).

"In this sense, mental maps are externalisations of the mind onto paper in a complete and observable form" (Soini, 2001, p. 229).

The gradual passage of the mental map being a map in the mind or on the paper parallels the action of what the act of mental mapping is: transferring knowledge related to a place onto paper. As stated in chapter 1, within the case of the Phd-research, our mental map is a base map on which respondents indicated 1) which places they found comfortable in terms of temperature 2) and based on what reasons.

Mental maps – "*cognitive representations of a place*" (Tuan, 1975) - are unique for every person. There are many factors which influence how an individual perceives information of the environment, and creates knowledge. A statement of Gould and White (1986) could articulate the personal aspect of the formation of knowledge: "*views of the world and about people and places in it, are formed from a highly filtered set of impressions, and our images are strongly affected by the information we receive through our filters'.(...) Sensory input from touch, smell, feeling, and moving, is combined with and filtered by our memories, experiences, values, and beliefs*" (Halseth, et al, 2000, p. 568).
Spatial behaviour is related to cognitive representations. "*Spatial cognition is based on the assumption that certain environments have unique characteristics that make their cognitive representations especially interesting, and that some types of spatial behaviour are uniquely tied to certain characteristics of the environment through these cognitive representation" (Soini, 2001, p 227).*

A resemblance of our study with this statement would be: citizens have a life experience of places where they felt comfortable in terms of temperature. They have attached this feeling to certain characteristics in those places. A next time, in need of thermal comfort, the person would recall those characteristics that has made him/her feel comfortable, and look for a place where these characteristics can be found.
The mental maps have tried to visualize this process by asking the spatial knowledge of where in the cities of Rotterdam, Utrecht and Arnhem places of thermal comfort can be found, and for what reasons they are comfortable.

Returning to the concepts fuzzy cognitive map, symbol maps and sketch maps, mentioned earlier; these are practical mental-mapping techniques frequently used within the domain of environmental sciences:

- Fuzzy cognitive mapping emphasises the relation between textual information that describes a certain phenomenon. Concepts are displayed as a kind of mental cloud. In between these concepts there are connections. These connections have weights and directions. With the direction and weights an idea is given about the causal relationship between concepts. After determining these weights and directions based on e.a. interviews, a simulation can be conducted to verify how the construction of this mental model would be influenced by an adjustment (Reckien et al., 2013).

- Symbol mapping is a mental mapping technique with which a person is asked to indicate on a base map what places are beautiful, ugly, save, busy.
- A sketch map refers to free drawings. Dependent on the research in question, participants are asked to draw street plans, features, with or without textual information on a blank page. There are several aspects of the drawings that can be analysed as to abstract meaning, like the order in which features are drawn, or the detail, size and shape. Sketch maps could also make use of a base map, which is a simple ground plan of a study area, on which the drawings are made. (Soini, 2001)

Regarding this information our mental maps could be regarded as both a symbol map and sketch maps. The mental maps which are gathered in Rotterdam, Utrecht and Arnhem have not only locations of thermal comfort – symbol map -, but also drawings and extra textual information. So, I prefer to define our mental maps as sketch maps. There are aspects about the practical drawing and use of mental maps which authors discuss positively:

"Drawing is another way of expressing the world, and while challenging for some, it also aided in overcoming the inherent English-language proficiency bias of the interview mode" (Brennan-Horley et al., 2010, p. 96).

"In addition to increasing their comfort, many participants were excited by the maps and became eager to discuss and show their experiences in the context of a familiar map. The base maps stimulated informants' memories, furthering the interview conversation and enriching the quality and quantity of spatially specific data acquired" (Boschmann & Cubbon, 2013, p. 5).

Mental mapping is an in-depth data collection method, which uncovers extensive local knowledge, and is useful to develop adequate environmental policy like "*improving thermal comfort in the urban environment"*. The experience of *where* and *why* places are comfortable in terms of temperature, makes the citizens a walking database of detailed spatial information (Boschmann & Cubbon, 2013; Cinderby, 1999; Gray 2012; Jordan, 2013; Soini, 2013).

There are also some drawbacks discussed by authors about the reliability of the drawings. As stated by Curtis (2013): " *For example, Pocock (1976), Evans (1980), and Blades (1990) have all found that variables such as individual characteristics, and instructions and materials may influence the resulting map. In addition, these representations are temporally dynamic based on events and interactions with the environment (Mathews 1980; Kitchin1994) and as such may be based on structural or social features or on past events"* (p. 6).
Since the configurations of the drawings and the textual content of mental maps are unique for every person, it needs more than one mental map per city to verify which places are comfortable, and for what reasons. In the next chapter it will be presented that a sampling scheme has been set up to cover this wide variation in mental maps. Since the spatial configurations and people are different within every city, separate surveys are required to deduce which (spatial-) variables determine comfort in terms of temperature in the urban environment.

Chapter 3. Materials

This chapter will discuss the materials which will be used for the thesis.
Section 3.1 presents the data collection method, and the content of the questionnaires.
Section 3.2 gives a preliminary analysis of the materials that will help to find a methodological approach.

3.1 “Green infrastructure for climate proof cities”, Klemm, W*

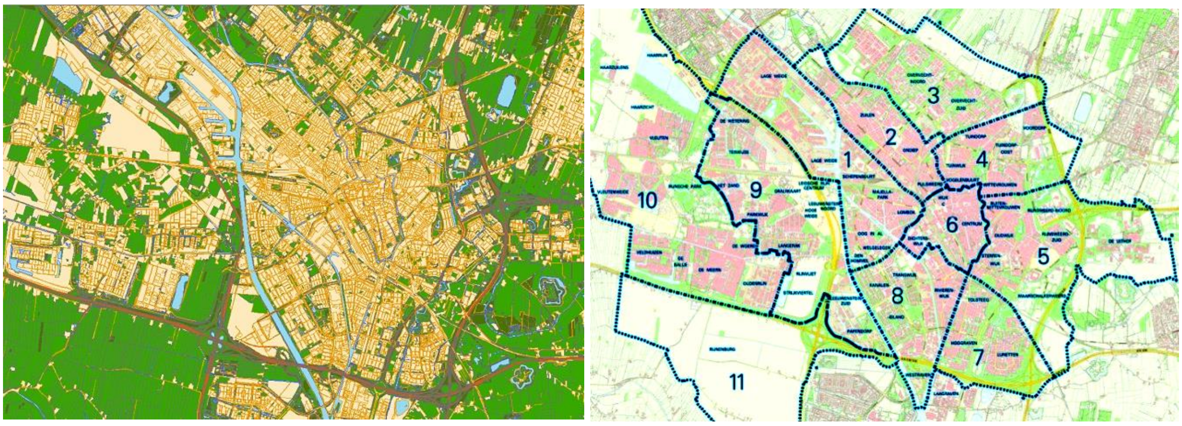


Figure 2 Example sampling scheme: Utrecht city

3.1.1 Data collection

In the summers of 2011 and 2012 the citizens of Rotterdam, Utrecht and Arnhem were questioned on the street for participation of the PhD-research “Green infrastructure for climate proof cities” lead by Klemm, W.
The perception of the citizen towards the urban environment during warm summer periods was questioned, and as a mean of data collection questionnaires were filled in by the respondents. The questionnaires were accompanied with a ground plan of the respective city on paper. The specific six questions will be discussed in this chapter. All the surveys were done during warm summer periods.
For the sake of demographic representation the surveys covered distinctive neighbourhoods within the city (Figure 2). Both genders, and people from all ages were approached in the survey.

3.1.2 Questionnaires

The questionnaires consisted of four closed questions, and two open questions. The answers to the closed questions (Question 1 – 4) will be discussed in this chapter. The open questions, 5 & 6, referred to the ground plan of the respective city on which the participants had to draw. The drawings – answers to question 5 & 6 – are the mental maps, and are used as material for this thesis. An example of a questionnaire can be found in Appendix A.

* http://www.wageningenur.nl/en/show/PhD-Green-infrastructure-for-climateproof-cities.htm

3.2 Preprocessing

3.2.1 Digitalizing questionnaires

As part of the MSc-thesis the answers of the questionnaires were inserted manually from Hardcopy into Excel. A distribution of all age classes that were covered by the study can be found in the Appendix B.

	Non-Response	Response	Male	Female	Age
Rotterdam	519	192	80 (=41%)	112 (=59%)	10-88
Utrecht	418	179	89 (=49%)	90 (=51%)	16-83
Arnhem	276	182	81 (=45%)	101 (=55%)	9-82

Table 1 Socio-demographic data of field survey

3.2.2 Preliminary analysis

Closed Questions

Question 1

Could you indicate for the following public spaces how comfortable you would feel on hot summer days?

- Options: Shopping street, garden, swimming pool, square, outside city, beach, forest, parking lot, pond, park, terrace, canal
- Answers: very uncomfortable – uncomfortable – neutral – comfortable - very uncomfortable

The twelve options are types of public open spaces. These types of public open spaces have been defined based on dominant spatial components. These dominant spatial components are Green, Water, and Stone. The types of public opens spaces have been ordered randomly in the questionnaire, based on these dominant spatial components. Question 1 of the questionnaire gives an idea about the rate of thermal comfort within a type of public open space. The answers can be found in Appendix C.

In Table 2 the percentage finding a type of public open space comfortable or very comfortable is averaged over the three cities. Taking this percentage as a reference, a ranking of the types of public open places in and around the city is presented, The top type of public open spaces Park, Lake, Outer Area, Beach, present preference among the citizens. The dominant spatial component in these public open spaces are Green and Water. It is rough to conclude that the most important spatial characteristics are Green and Water, because the average percentage is in a close range. Though, Table 2 gives an indication that green environments are perceived more comfortable in stead of environments which are dominated by stone.

Type of Public open space	Dominant spatial component	Average percentage finding the public open place “comfortable” or “very comfortable”
Park	Green	84.0%
Lake	Water	83.4%
Outer Area	Green	79.8%
Beach	Water	78.6%
Garden	Green	78.8%
Forest	Green	76.9%
Terrace	Stone	69.2%
Swimming pool	Water	64.0%
Canal	Water	54.4%
Square	Stone	37.4%
Shopping street	Stone	25.7%
Parking lot	Stone	5.3%

Table 2 Thermal comfort within type of public open space, percentage averaged over three cities

Question 2

To which extent do you agree with the following statements? A green environment on a hot summer day I find:

- ...pleasant (fijn), ...important, ...essential, ...pleasant (aangenaam)
- Answers: really don’t agree – don’t agree – neutral – agree – really agree

With this question the participants have been approached more directly about the role of Urban Green during hot summer days. The answers of the separate cities can be found in Appendix D. The percentage in Table 3 stands for the average over the three cities which answered “agree” or “really agree” to the statement. Nearly half (44.9%) of the respondents found a green environment essential during warm summer periods.

An urban environment I find...

	Average percentage
Essential	44.9%
Important	70.3%
Fijn	90.3%
Aangenaam	91.1%

Table 3 Opinion about a green environment on a hot summer day, averaged over three cities

Question 3

Where do you go to on a hot summer day within a time frame of: <2 hours, half a day, one day, one weekend? Which kind of transport do you use?

- Options: home, garden/balcony, street, own neighbourhood, within city, outside city
- Options: bike, scooter, car, public transport

Question 3 gives an idea what is the mental horizon of the citizen within a certain time frame in finding a places of thermal comfort. The answers could present to what extent the city facilitates in places of thermal comfort. In the Figures Figure 3 - Figure 5 (page 12 and 13) the answers are presented.

Figure 3– Destination during warm summer periods – subdivided city

Constrained to the six options, in a time frame of;

- 2 hours, most people stay home(garden/terrace), (average three cities = 69%)
- half a day, most people go into the city (neighbourhood/street) (average three cities = 49%)
- a day, most people go out of the city (average three cities = 48%)
- a weekend, most people go out of the city. (average three cities = 65%)

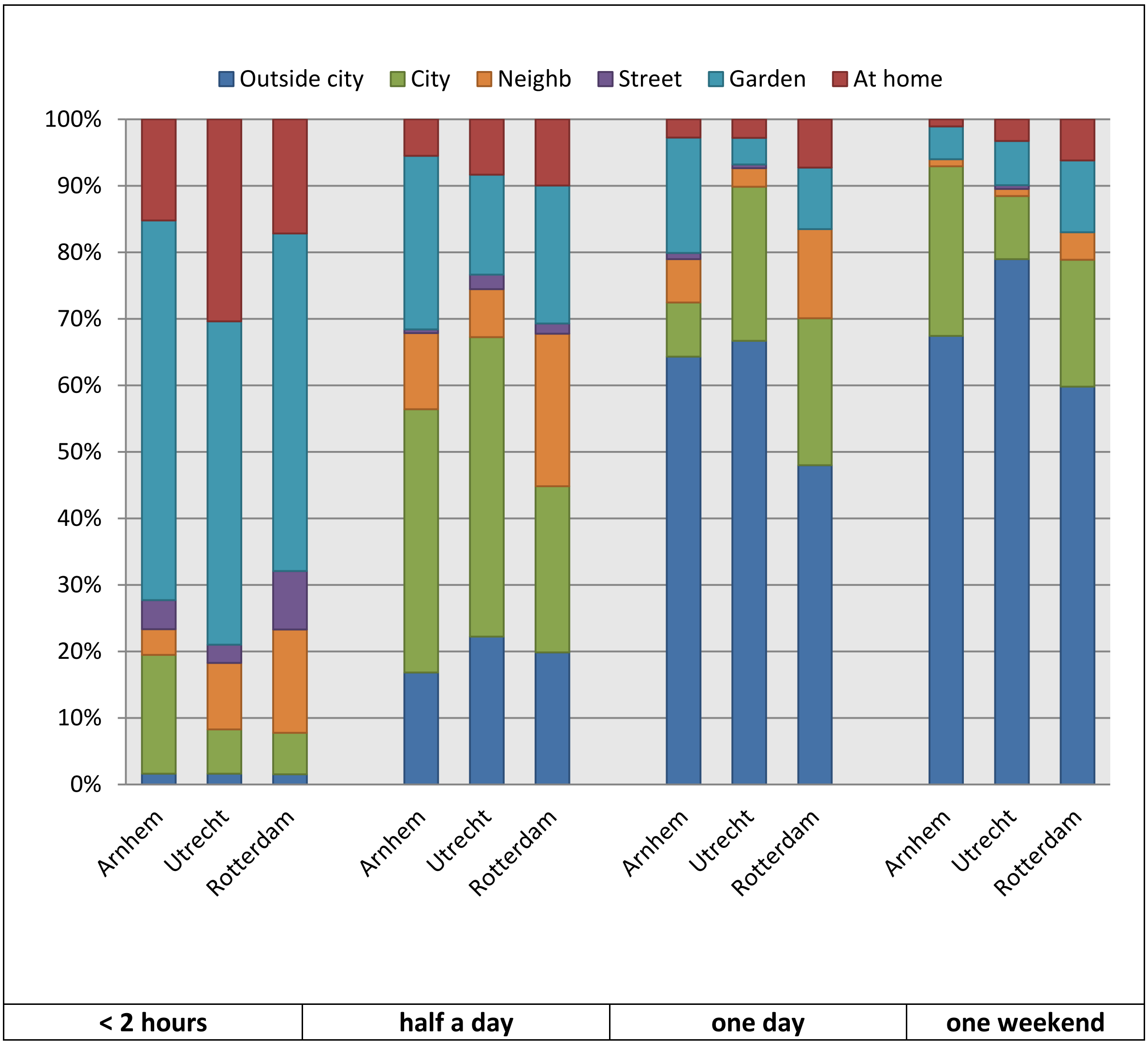


Figure 3 Destination during warm summer periods, per time frame – subdivided per city

Figures Figure 4 and Figure 5 (page 13) – Destination during warm summer periods – subdivided by age and home situation.

A classification of the respondents into groups by age and home situation (None/terrace/garden) presents whether socio-demographic characteristics influence the mental horizon of the citizen in finding a place of thermal comfort.

Figure 4 presents a trend that older people stay closer to home in every time frame.

Figure 5 presents a trend that within a time frame of 2 hours, people without any balcony, terrace or garden, go outdoors significantly more than people with a balcony, terrace or garden.

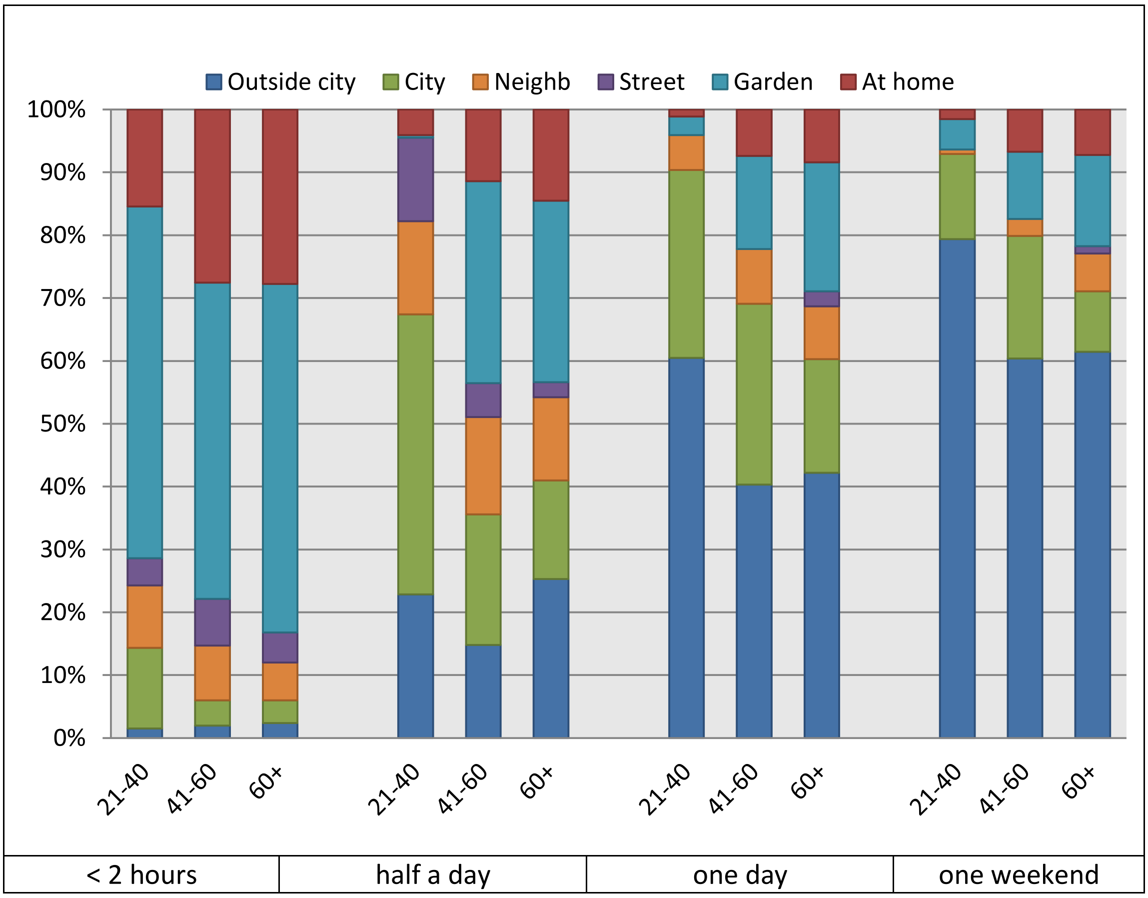


Figure 4 Destination during warm summer periods, per time frame – subdivided by age class

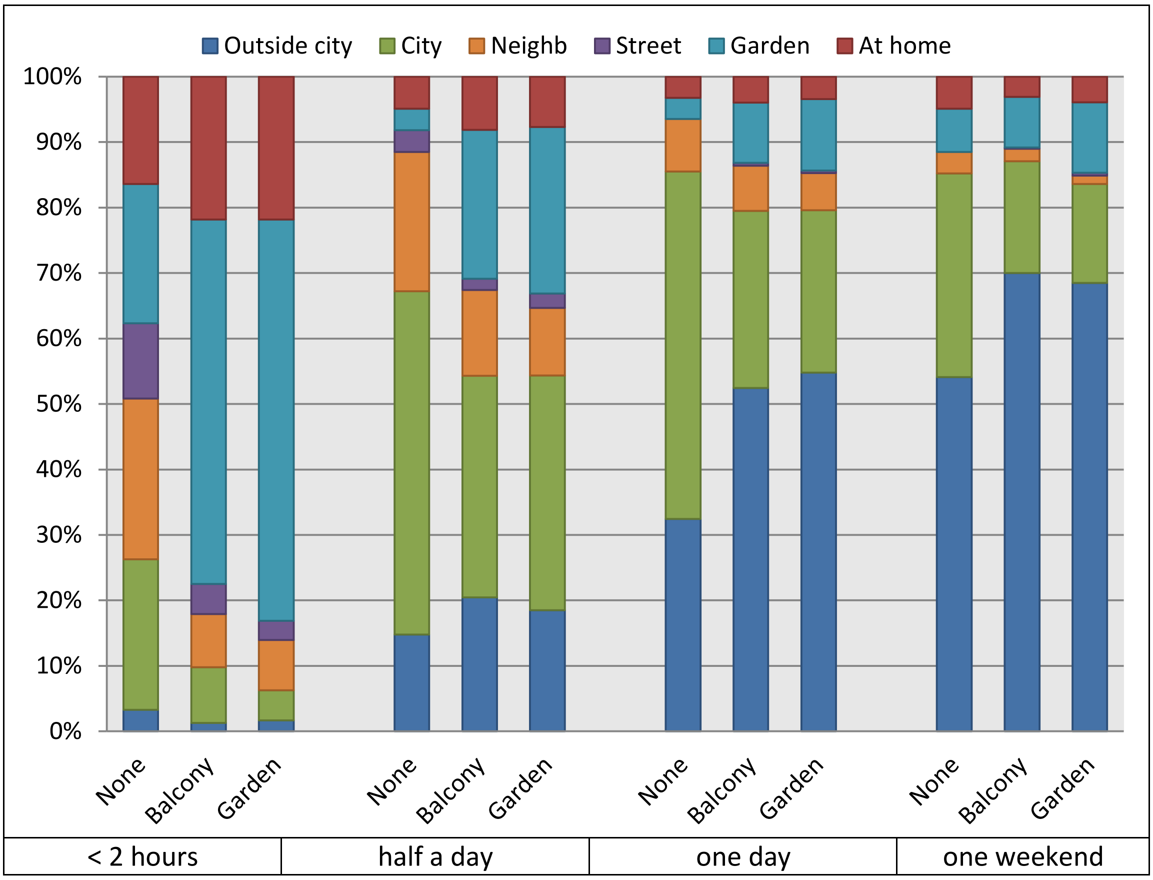


Figure 5 Destination during warm summer periods, per time frame – subdivided by home situation

Open questions: Mental map

Question 5

> *Which places within the city you find most comfortable in terms of temperature on hot summer days?*

The citizens of Rotterdam, Utrecht and Arnhem indicated several places on the base map of their respective city. An example of every base map can be found in Appendix E.

In the handwritten material there are specific places within the three cities which appear more recurrent than the other. The manner of drawing the places of thermal comfort on the mental map is presented in distinctive ways by the respondents, and causes a wide variation of drawings and textual information. Several cases can give an example of the variation of the representation of the places of thermal comfort on the base map (see examples, Figure 6)

- **Case 1** The places of thermal comfort have a collections of indicators: points, lines, circles, and expression marks.
  - *Example: the "Wilhelminapark" is indicated with an expression mark.*
- **Case 2** The same name can cover different areas, or has a misplaced drawing.
  - *Example: The "Singel" is a channel around the city centre of Utrecht. Circles have been drawn around distinctive areas.*
  - *Example: The area indicated on the map is not "Neude", but "Janskerkhof"*
- **Case 3** The same place can be indicated with several names
  - *Example: the centre of Utrecht has been named as "Centre" and "Inner city"*
- **Case 4** The place of thermal comfort is only indicated by a name.
  - *Example: The "Voortveldsepolder"* is present on the base maps, but not indicated by a drawing.
- **Case 5** The place of thermal comfort is outside the base map.
  - *Example: the "Maarsseveense plassen" is situated just outside the border of the base map*
- **Case 6** Specific places of thermal comfort are situated within another place of thermal comfort
  - *Example: the "Neude" is a situated within the "Centre" of Utrecht. Both names are indicated as places of thermal comfort.*

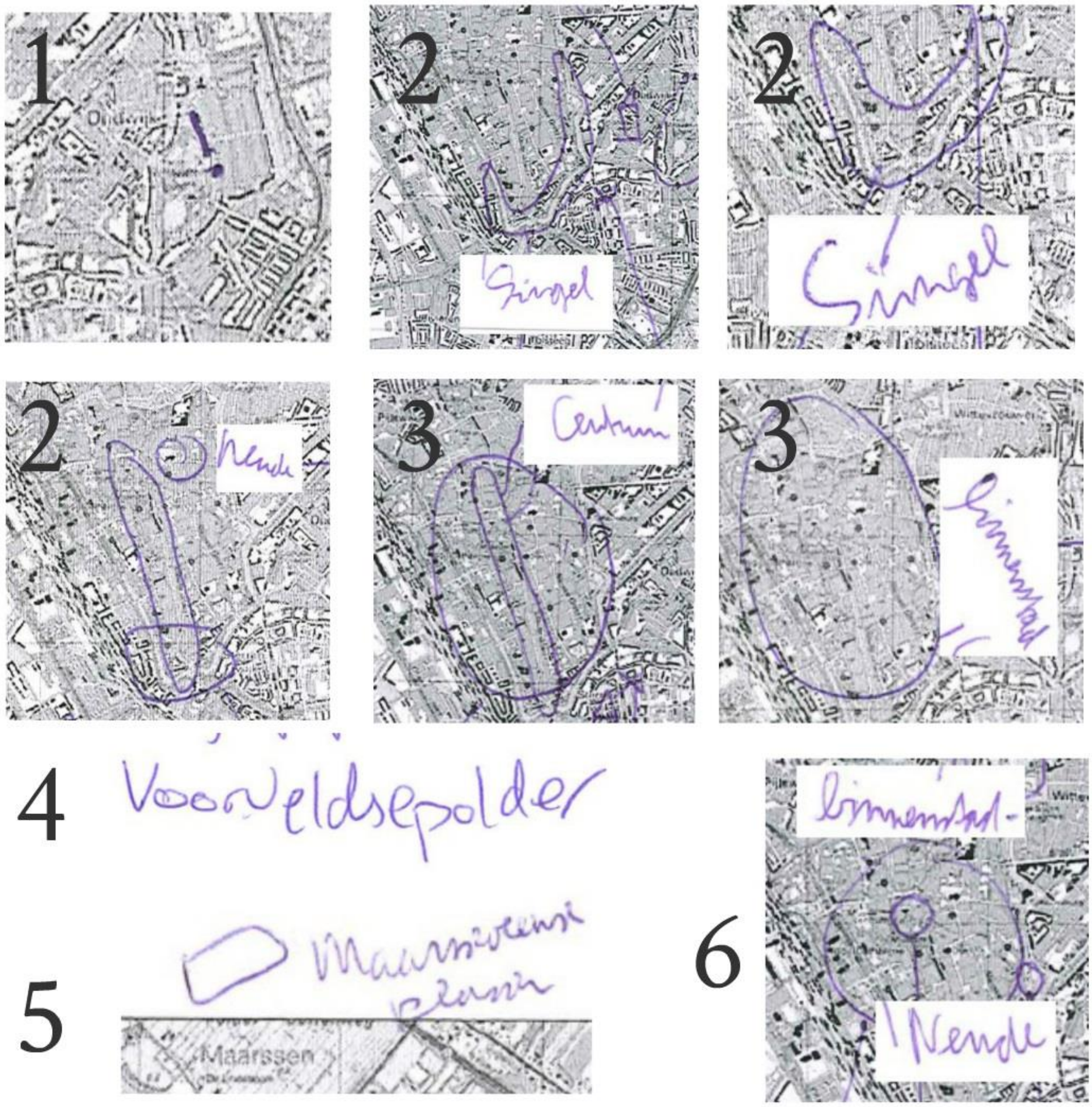


Figure 6 Drawings of respondents

Question 6

The particants of the three cities pointed out which place they found comfortable in terms of temperature during warm summer periods (Question 5). Questions 6 continued on this information by asking the participants what were the reasons these places were comfortable. The arguments ranged from just one word, like “shadow”, to several sentences per argument.

Table 4 shows an initial query on the arguments of the respondents; a list of the common words found in the respondents’ answer sheets. Based on this table, within all cities together (column; summation) a top five arguments for a place to be comfortable in terms of temperature is “Shadow”, “Sun”, “Water”, “Green, “Trees”.

		Rotterdam	Utrecht	Arnhem	Summation
Shadow	Schaduw	87	106	68	261
Sun	Zon	63	51	57	171
Water	Water	21	66	53	140
Green	Groen	24	43	36	103
Trees	Bomen	23	20	34	77
Wind	Wind	18	45	14	77
Nature	Natuur	13	31	32	76
Beautiful...	Mooi...	21	14	27	62
Tranquility	Rust	16	12	33	61
Close	Dichtbij	19	20	21	60
Swim	zwemmen	10	14	26	50
Space	Ruimte	11	18	17	46
Terrace	Terras	30	0	9	39
Open	Open	3	31	2	36
Gras	Gras	6	17	4	27

Table 4 A Query on words related to places of thermal comfort

What Table 4 communicates, moreover, is the spatial variation of cognitive information, i.e. the difference in amount of words encountered in the three cities. Words like “Terrace”, “Open”, “Wind” and “Water” present difference in amount. This could represent the unique character of each of the three cities and/or the difference in perception of it’s inhabitants.

- The word “Terrace” is significantly mentioned more in Rotterdam (30) in comparison with the other two cities (Arnhem; 9, Utrecht; 0). Does this mean that there are more terraces in Rotterdam? Or are there plenty terrace in Arnhem and Utrecht, which causes that only the scarce spatial features are mentioned, and terraces are “not that special”?

- The word “Open” is mentioned 31 times in Utrecht, and just few times in the other cities. A visual scan of the ground plan of the three cities gives an idea that Utrecht is more compacted than the other two cities, Arnhem and Rotterdam. An hypothesis could be that citizens in Utrecht feel a lack of open spaces within the city environment, and when a question is posed to indicate a place of thermal comfort he or she would immediately recall place which are more open.

- The word "Water" is mentioned less in Rotterdam, in comparison with the other cities. You wouldn't say when knowing Rotterdam has some large water bodies to encounter, like the Maas and the Kralingse plas. Probably the abundance of water in Rotterdam, does not make it a feature worth mentioning.

Furthermore, the words on itself which are related to the places of thermal comfort in the city - i.e. the cognitive representations related to the places of thermal comfort - are of a wider scope than solely the spatial configurations of the urban environment. The definition of a place of thermal comfort seems to be dependent too on its practical position ("close"), general comfort ("tranquillity") or aesthetic value ("Beautiful").

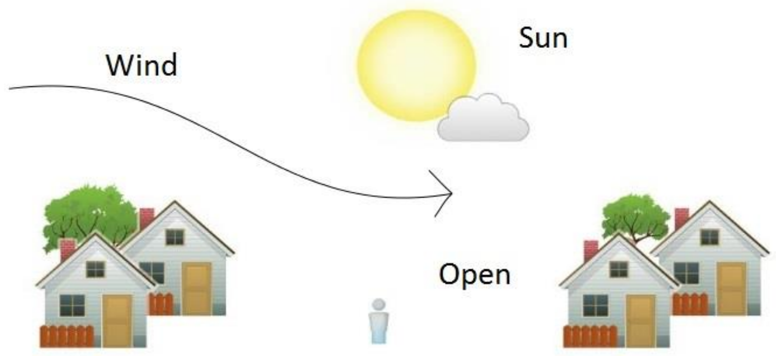


Figure 7 Spatial relation between Words related to places of thermal comfort

An addition has to be made about the spatial- and/or relation between of the words encountered. "Gras", "Green", "Trees", and "Nature" are related to each other. "Gras" and "Trees" could be denominated as "Nature", and are generally "Green". Also "Shadow" and "Trees" are closely related to each other. A shadow can be found under a tree. A shadow is also formed by any other object that obstructs the sun, as a high building or a sunshade on a terrace. The words "Sun", "Wind" and "Open" show have overlapping features. If the building height is comparable over the city, and we define the word "Open" as the size of perimeter accessible without any obstruction for a pedestrian, than, as the "Openness" increases, more sun could reach the ground, and convection (i.e. "Wind") has clear ground (Figure 7).

The representativity of the written information should be mentioned. Not all information obtained from the respondents has been written down by the respondents themselves. Several interviewers wrote down their information.
Furthermore, the answers to Question 6 are either related to specific places within the urban environment, or to several places. In a case where one respondent indicated four places, and answered by one phrase that he or she likes "Trees", that word would have been counted one time, according to the initial query of Table 4. In case the arguments have been noted down seperately with regard to each place of thermal comfort, the word "Trees" would have been counted four times.

Overview preliminary analysis

The pre-processing on the closed- and open questions introduced us to the spatial knowledge and behaviour of the citizens of Rotterdam, Utrecht and Arnhem in the warm urban environment. This helps us to find a position towards the material and an adequate methodological approach.

The result of the closed question gave a rough idea that green environments are perceived more comfortable instead of environments which are dominated by stone. From all cities together, 91% finds green environments *pleasant*, and 45% even *essential* during warm summer periods. Socio-demographic characteristics like age, and home situation (possession of balcony, terrace, garden or no outer space at all) seem to influence the behaviour of the citizen; aged people stay closer to home, and people without a garden or terrace could be found out doors more frequently.

The results of the open questions give more specific information about where, by whom, and why thermal comfort is experienced within the three cities, all indicated on a base map. A preliminary analysis of the mental maps uncovers 1) a variation in spatial distribution of the places of thermal comfort within the city, and 2) a variation in (spatial-) variables and conditions citizens relate to a place of thermal comfort.

With the formulation of the specific research questions (paragraph 1.3.2) three main research steps have been defined: 1) definition “place of thermal comfort” 2) quantifying (spatial-) variables, and 3) relating spatial variables with “places of thermal comfort”.

Places of thermal comfort (Question 5)

The “places of thermal comfort”, indicated by circles, names, points and expression marks on a base map, cover a range of places within the three cities. A decision has to be made for the representation of the drawn “places of thermal comfort” and home adresses in a GIS.

Spatial variables (Question 6)

The words Shadow”, “Sun”, “Water”, “Green”, and “Trees” are frequently related to places of thermal comfort. These words are related to each other. A comparison of the places of thermal comfort could be done, by measuring variables related to these words, which are spatially exclusive, within within Geo-information systems like ArcGIS.

Relation spatial variables and places of thermal comfort

The relative contribution of (spatial-) variables, like urban green, to thermal comfort in a place, is person specific. To validate the relation between the (spatial-) variables and a the definition of a place to be comfortable, a statistical model should consider the variation of interests of the citizens.

Chapter 4. Methods

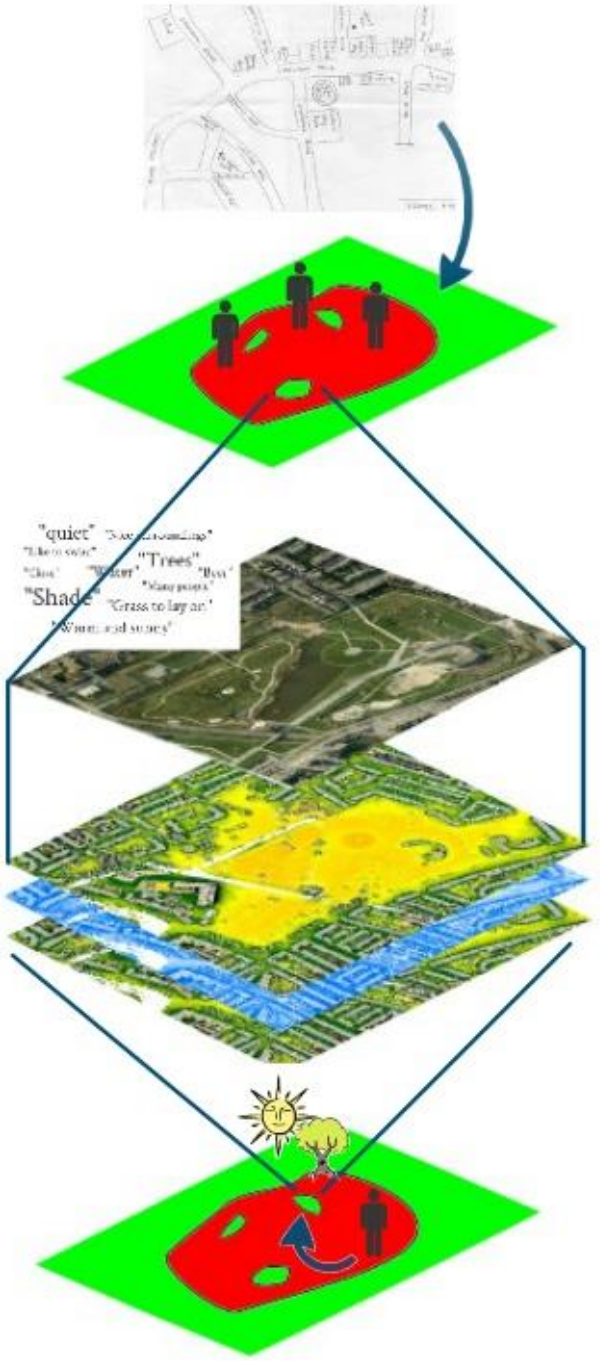
There is only a handful of studies that have experience with the integration-, and analysis of sketch maps. Mostly, the sketch map is part of several data-acquisition practices within a study, alongside interviews (Spilsbury et al., 2009, Wridt, 2009). Hereby, the sketch maps gives more detailed information related to place. With the help of Geo-Information Systems more data interpretability is given to the sketch maps: *"GIS can integrate multiple forms of data, facilitating information analysis and allowing visual representation of complex socio-spatial processes embedded in everyday life experiences of individuals (Kwan and Knigge 2006; Jones & Evans, 2012, in Boschmann & Cubbon, 2013, p. 3)*

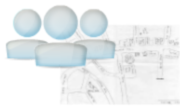
Referred to literature, the integration of data is given shape by assigning demographic attributes to the sketch maps. Subsequently, the analyses focus on relations between several aspects of the sketch maps, and demographic and spatial data, like inconsistencies with subjective and real neighbourhood boundaries (Campbell et al., 2009), spatial distribution of the feeling of fear in the city (Curtis et al., 2013), and the distance children of several ages move from home (Veitsch et al., 2008).

One example of how GIS enhance the interpretability of sketch maps in a visual manner is overlay- or composite mapping. The sketch map drawings are digitized and laid on top of each other. An overlay of sketch maps can "*visualize the areas of agreement or disagreement among study participants*" (Weiner and Harris, 2003 in Boschmann & Cubbon, 2013, p. 4). Within our study such an overlay could present which areas in the three cities are experienced relatively more comfortable in terms of temperature.

The preliminary analysis of the questionnaires has shown that the perception of the urban environment – presented by the mental maps - during warm summer periods is both personal and location-specific; distinctive types of public open spaces are regarded comfortable, demographic subgroups prefer different destinations during warm summer periods, and specific words related to thermal comfort are more pronounced within one city than the other.

The methodologies that will be chosen with regard to the three research steps; 1) definition "place of thermal comfort" 2) quantifying (spatial-) variables, and 3) relating (spatial-) variables with "places of thermal comfort", will have to consider the qualitative nature of the data, and take adequate methodological approaches within the GIS domain which illuminate the place- and person specific feeling of thermal comfort. Digitalization decisions of sketch maps, overrepresentation, and ecological fallacy can devaluate the complex relation between the citizen and his/ her environment (Boschmann & Cubbon, 2013; Brennan-Horley et al., 2010; Ceccato & Snickars, 2000; Coulton et al., 2001; Curtis et al., 2013; Dennis, 2006). Within the quantifiable epistemology of GIS, the qualitative nature of sketch map should not be overlooked. *As Jordan et al. (2013) state about Huntington: "Huntington (1998) argues that for biological and ecological researchers who wish to fairly combine two knowledge systems in data collection, one means to determine these context-specific best practices is to use techniques based in the social sciences to inform the biological science aspects of the project" (p 160).*





4.1

Digitalization and visualization of the home addresses and places of thermal comfort

4.2

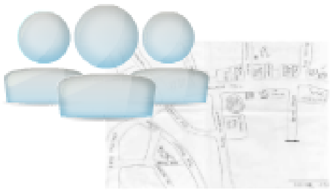
Quantifying (spatial) variables within the "places of thermal comfort".

Discussion

Definition of place of thermal comfort based on spatial variables.

Figure 8 Methodological framework

4.1 Mental map – Places of thermal comfort



How can the mental map be digitalized?

- *How is the location of the home addresses digitalized?*
- *How are the places of thermal comfort digitalized?*

In paragraph 4.1.1 a methodology is defined to digitalize the home addresses of the respondent on three maps of the cities. The questionnaires include handwritten home addresses. The location of the home address is pointed on a map by the respondents.

In paragraph 4.1.2 a methodology is defined to digitalize the places of thermal comfort, which practically means that the drawings of the places of thermal comfort are represented by a polygon within ArcGIS. The most comfortable places are based on the answers to Question 5 of the questionnaire, namely: Which places within the city you find most comfortable in terms of temperature on hot summer days?

In paragraph 4.1.3 a methodology is defined how to visualize the home addresses and places of thermal comfort.

4.1.1 Digitalization of home addresses citizens

The respondents named in which streets they lived, and indicated on the map the location of their house. The database of map.google.com helps to validate the location of the home addresses of the respondents (see Figure 9, page 23). The handwritten home addresses are inserted in *maps.google.com*. The home addresses are correctly localized when the location visualized by *maps.google.com* coincided with the home address location drawn on the mental map. In case the address on the base map can not be localized, or presents geographical difference with the pointer of maps.google.com, a street is chosen which geographically coincides with the location on the mental map.

All addresses which have been verified in *maps.google.com*, are stored in a table in Excel, accompanied with the answers to all the questions of the questionnaire. Also the initial found addresses are stored in a separate column in the table.

A web-application *mapalist.com* exports the table with addresses to a KML file. Among the respondents there are also duplicates – several respondents living in one street. For these respondents the KML files were copied and coded to guarantee unique records. ArcGIS exports the KML files to Layer files which will be used for further analysis in the research.

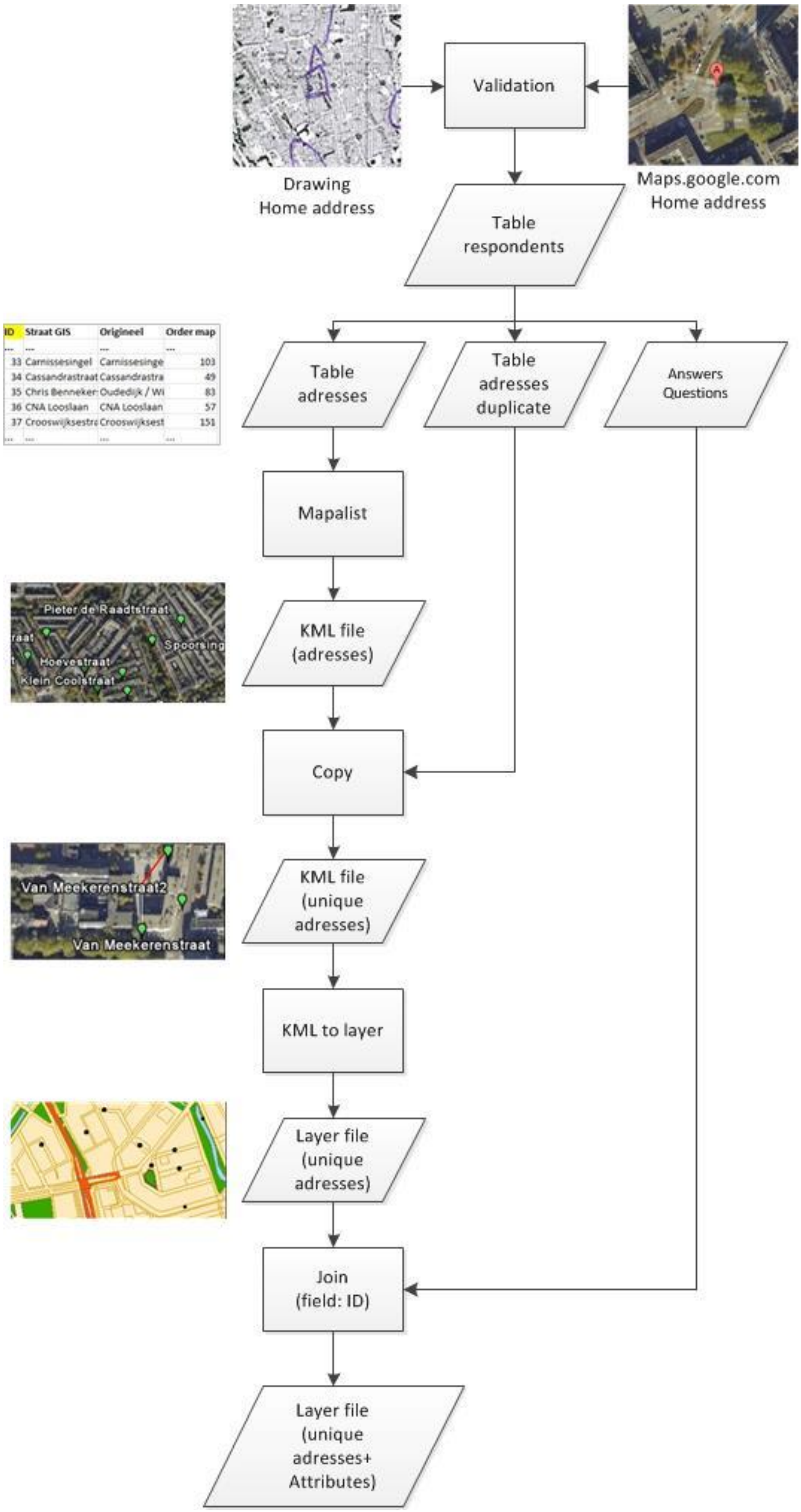


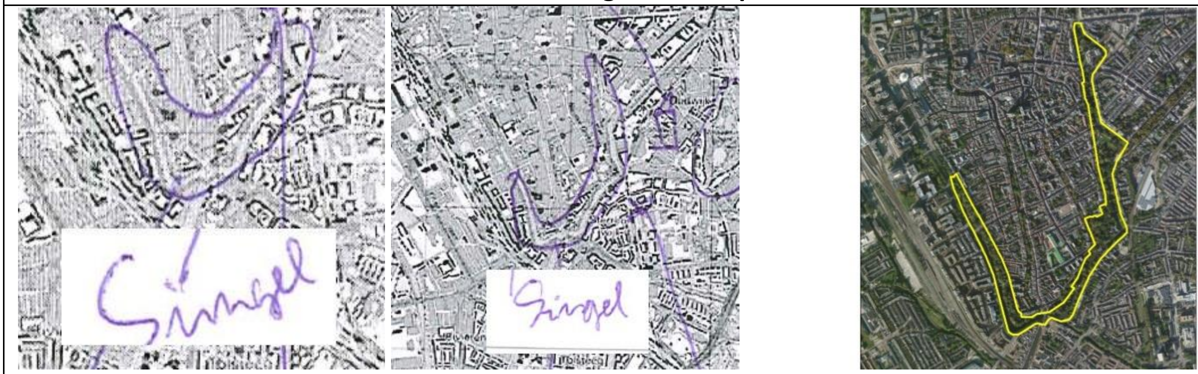
Figure 9 Digitalization of home addresses

4.1.2 Digitalization of places of thermal comfort

With the digitalization of the places of thermal comfort the intention is to stand as close as possible with the citizen in what he or she defines as a place of thermal comfort. At the same time, the representations of the places in the real world onto the base map could create a biased view of the spatial boundary of that place; as discussed in paragraph 3.2.2, the base maps have a wide variation of drawing and textual information. To compare (spatial-) variables within or with respect to the places of thermal comfort in a further stage, the digitalization of the place thermal comfort needs a consistent definition of the spatial boundary, which is defined as followed:

- *The drawing (circles, point, expression marks) and/or names of the places of thermal comfort will inform about the location and geographical extent of the place of thermal comfort. The location is validated with help of the database in maps.google.com.*
- *The specific spatial boundary is determined by roads or other physical barriers surrounding the place of thermal comfort. A satellite image – Base map "Imagery" – is used to find physical barriers on ground level. The places of thermal comfort are drawn in Editor, ArcGIS.*
- *In case the placement of the spatial boundaries is left undecided, the initial drawing of the mental map is maintained.*
- *According to paragraph 3.2.2, these steps will cover the cases 1,4 and 5:*
    - **Case 1** The places of thermal comfort have a collections of indicators: points, lines, circles, and expression marks.
    - **Case 4** The place of thermal comfort is only indicated by a name.
    - **Case 5** The place of thermal comfort is outside the base map.
- This leaves the cases 2,3 and 6:
    - **Case 2** The same name can cover different areas, or has a misplaced drawing.
    - **Case 3** The same place can be indicated with several names
    - **Case 6** Specific places of thermal comfort are situated within another place of thermal comfort
- *When cases 2,3 and 6 occur the following steps will be taken (see Figure 10, page 25)*

***Case 2* – Areas with the same name will be merged to one place of thermal comfort**



***Case 3* – Names referring to the same area are considered the same place of thermal comfort**

Case 6 – A specific place of thermal comfort is maintained, if situated within another place of thermal comfort

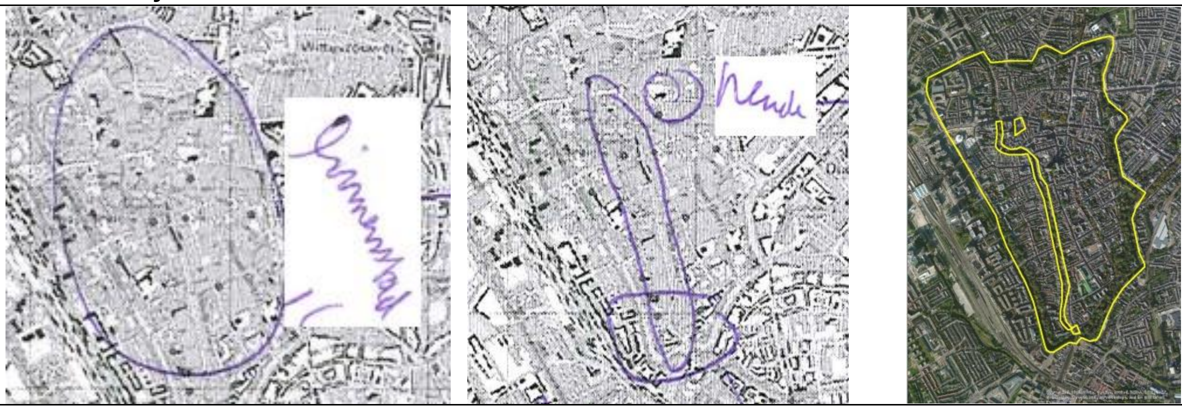


Figure 10 Digitalization of places of thermal comfort, case 2,3 and 6

4.1.3 Visualization of survey data

Representation of districts

Section 3.1.1 discussed that the survey in the three cities used a sampling scheme. Each of the three cities has been divided in districts, and per district the citizens were approached to participate in the study. The sampling scheme (map with districts) will be digitalized in Editor, ArcGIS, and with a spatial join the number of home addresses per district will be counted and visualized. The spatial distribution of the home addresses will clarify which districts in the cities are represented by the survey.

Spatial relation home addresses and places of thermal comfort

A visualization of the places of thermal comfort with an indication of its frequency, like a composite map, tells us about which areas in the three cities have agreement among the respondents in experiencing thermal comfort. The places of thermal comfort will be presented next to the home addresses. To emphasize the spatial information of the survey data the following data-processing steps will be conducted:

- As explained in paragraph 4.1.1, the home addresses will be represented as point features. A *buffer* of 500 meter around the point features will emphasize which region within the city has been covered by the survey.
- The *kernel density* function will take the point features as input data to present in which places the respondents' home addresses are relatively concentrated.
- The land cover classes buildings, trees, grass, and water will be visualized with help of the feature data set *Top10NL* (Basisvlakkentop10NL).
- As explained in paragraph 4.1.2, the places of thermal comfort will be represented as polygons. A *frequency* function will count how many times a specific place of thermal comfort is called. In case when four or more people consider a place comfortable in terms of temperature, the spatial boundary of this place is presented on the map, with a symbol that indicates its frequency.

4.2 Mental map – Spatial variables

	*Which spatial variables are suitable and can be measured on city level by a Geo-Information system?*

This section will present a methodology to quantify (spatial-) variables, found within the places of thermal comfort. The variation of the values of the measured (spatial-) variables within the places of thermal comfort could give more statistical underground to explain why certain places are preferred above the other in a further stage. With the variation we mean how much the values of measured spatial variable are spread out. The spatial variables will be measured with help of ArcGIS, and are related to words mentioned frequently by the respondents in Table 4 (page 16), like "*Shadow*", "*Sun*", "*Water*", "*Green* ", and "*Trees*".

Geo-information systems enables to measures spatial variables for large scale areas in a time-efficient manner. The spatial scale of our study covers three cities. Datasets that cover a regional area, and have a fine spatial resolution will enable to accurately measure the spatial variables within the places of thermal comfort.

In this study we will use the datasets top10NL and AHN as source data to quantify the area (m2) of the land cover classes trees, water, and open area. Furthermore a proposition is made to calculate a view angle towards the sky for every 2.50m*2.50m raster cell within the city environment. The calculation of these spatial variables will be done for the places of thermal comfort which found agreement with four or more respondents. The distance between the home addresses and the top two places of thermal comfort for each city will be calculated too. As to explain the methodology the illustrations and naming take the city of Utrecht as an example.

Materials

AHN - The AHN (Actueel Hoogtebestand Nederland) is a digital elevation model that covers the Netherlands. The latest version, AHN-2, has a spatial resolution of 0,50m. For every 0,50 by 0,50 meter there is a height determined with an accuracy of 5 centimetres. To reduce calculation time, the spatial resolution has been reduced from 0,50m*0,50m to 2.50*2.50m.

- *Top10NL* (Basisvlakkentop10NL) – this is topographic map which covers the Netherlands, and gives information about the land use for every unique polygon. Three clip features have been used to cut out the three study areas Rotterdam, Utrecht, and Arnhem.

- *"Utrecht_Parks"* – This feature dataset represents the places of thermal comfort which will be defined according to the methodology presented paragraph 4.1.2.

4.2.1 Landcover

Water

The respondents mentioned "Water" to be important for thermal comfort in the Urban environment. The area covered by water (m2) per specific places of thermal comfort will be measured.

The Top10NL data set has the attribute TDN-code which enables to distinguish the water from the rest of the area. The TDN-codes representing water are the codes beginning with 06. Within ArcGIS the following steps will be made:

- Two datasets will be created which represent the areas under Water and Buildings; *"Utracht_Water"* and *"Utrecht_Building"*
- With the data set "*Utrecht_Parks*" as input features, and the data set "*Utrecht_Water" and "Utrecht_Building"* as Erase features, the area under water and buildings will be removed from the places of thermal comfort with the *Erase* function, with "*Utrecht_Parks_Dryland*" as output data set.
  The dataset "*Utrecht_Parks_Dryland*" represents the accessible land outside doors for the citizen, within the spatial boundary of the places of thermal comfort. This dataset will be used in a further stage to measure the area under tree canopy.
- With the data set "*Utrecht_Parks*" as input features, and the data sets *"Utrecht_Parks_Dryland*" and "*Utrecht_Building*" as Erase features, the output data set "*Utrecht_Parks_Water*" is created.
- The function *Calculate Areas* will export a table with areas under water per specific place of thermal comfort, with "*Utrecht_Parks_Water*" as input data set.

Figure 11 "Utrecht_Parks_Water"

Open area and Trees

The respondents mentioned “Shadow”, “Sun” and “Open” to be important for thermal comfort in the Urban environment. The presence of sun and shadow within the city varies in time and space. The time of the day, the presence of clouds, and the orientation and height of the physical surrounding determines whether sunlight would reach the citizen. The respondents also mentioned “Green” and “Trees” to be important for thermal comfort in the Urban environment, which also influence the presence of “Sun” and “Shadow”.

Taking the words “Shadow”, “Sun”, “Open”, “Green”, and “Trees” as a reference, the area (m2) covered by tree-canopy per specific places of thermal comfort will be measured. Areas which are not classified as tree-canopy, or water, are quantified as a third land cover class “Open Area”. The three land cover classes Water, Trees and Open area will represent the spatial environment of the places of thermal comfort (see Figure 12)

On city level the area under trees could be calculated, based on spectral information. Indices like NDVI can quantify vegetation cover within the urban environment based on the reflectance values of the infra-red part of the light spectrum (Dadvand et al., 2012; Pearsall & Christman, 2012; Senanayake et al., 2013). Spectral images are not included within the materials of this study. In this study the digital elevation model AHN will be used to distinguish trees from surrounding areas. The advantage of the AHN is the high spatial resolution of 0,50m*0,50m.
The high resolution of the DEM enables to find trees based on the irregular height of tree canopy, which is in contrast with the “smooth” ground floor. By visual interpretation the model will be validated.

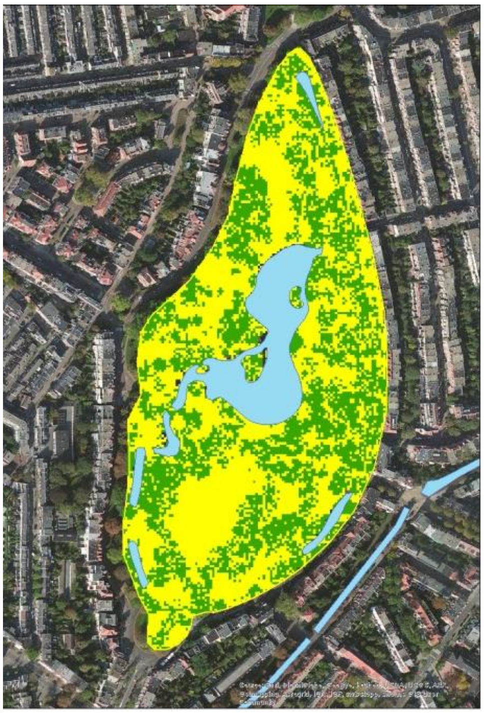


Figure 12 Land cover classes Water, Trees and Open Area

From the Top10NL_basisvlakken the streets are selected. The TDN-codes corresponding to the streets begin with 03. The dataset "*Utrecht_Parks_Dryland"* and the selected streets are merged to a new dataset called "*Utrecht_streets_parks*". (See Figure 13) "*Utrecht_streets_parks*" will represent the walkable area outside for the citizen. Within this spatial boundary the distinction between "open area" – area not covered by canopy –, and "trees" – area covered by trees - will be made.

With <u>*Extract to mask*</u> the AHN is retrieved within the spatial boundary of "*Utrecht_street_parks*", which creates "*Utrecht_street_raster*"

To retrieve the open area from "*Utrecht_street_raster*" three steps will be taken as presented in table..:

- <u>Condition1 – irregular height of tree canopy</u>.
  From "*Utrecht_street_raster*" the "smoothness" is calculated
  - *Slope* –For every cell the maximum angle in degrees with the surrounding pixels is calculated.
  - *Focal statistics* – for every cell the standard deviation in maximum angle is calculated based on the eight surrounding cells.

  Output: "*Utrecht_slope_standard_deviation"*
- <u>Condition2: Difference between AHN (orignal data set) and Ground level</u>
  From *"Utrecht_street_raster"* the ground level is retrieved.
  - *Focal statistics* – For every raster cell, in a radius of 25 meters, the lowest height is searched and assigned to the raster cell, as a first step to find the ground level
  - *Filter* – A low pass filter levels the irregular pattern of the created raster, and determines the walking area of the pedestrian.
  - *Extract by Mask* – The created raster with the ground level is extracted by the polygon *"Utrecht_streets_and_parks".*

  Output: *"Utrecht_ground_outside"*

- <u>Conditional statement: finding open area based on condition 1 an 2.</u>
  The *Raster calculator* does a conditional statement based on the output datasets "*Utrecht_street_raster*", and the output data sets "*Utrecht_slope_standard_deviation"* and *"Utrecht_ground_outside"* to retrieve the area outside not covered by tree canopy: "*Utrecht_Open_Area*" The conditional statement is constructed in a step-wise approach, and the outcome validated by visual interpretation:
  - **Condition1:** To find the open areas, the raster cells of *"Utrecht_street_raster"* that have a standard deviation of the maximum slope angle smaller than 7 (stored in "*Utrecht_slope_standard_deviation")* come out as true value, and are considered ground level. The raster cells that are left – areas with raster cells that show an irregular height pattern - continue to the second conditional statement.
  - **Condition2**: With raster cells in the vicinity of buildings and trees, the calculation of the slope (and standard deviation of the slope) would show relatively high values and would be considered area under tree-canopy based on condition1.
    In reality these raster cells represent ground level. A second conditional statement considers the raster cells of *"Utrecht_street_raster"* ground floor if the difference with the ground floor - *"Utrecht_ground_outside"* – is less than 3 meter.

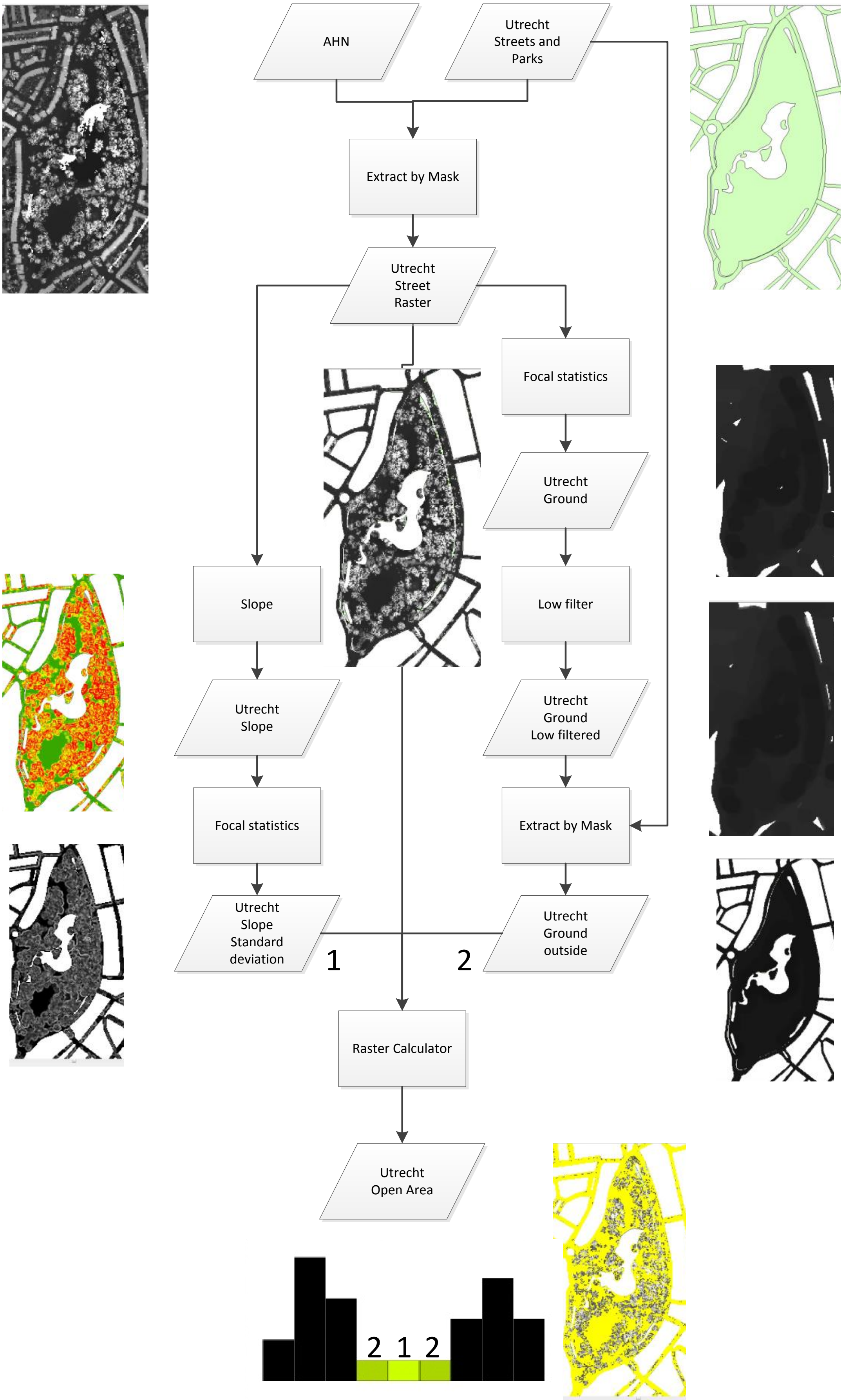


Figure 13 Model to quantify land cover classes Trees and Open area

4.2.2 View angle towards sky

As an approximation of the characteristics "Sun", "Shadow", and "Wind" we look for a metric which informs us about the openness of the urban environment. Literature reveals several metrics, calculated in GIS, which try to approximate the human experience of space on ground level, like isovists, viewsheds, field of view, and visual exposure (Bartie et al., Chamberlain & Meitner, 2013; Domingo-Santos et al., 2011; Weitkamp et al., 2011). These metrics are oriented to the surface area which is visible to the observer. Hereby, an observation point has to be defined on a Digital elevation model (raster dataset) to calculate these metrics.
In this thesis we would like to know the openness for multiple points within a places of thermal comfort, preferably for each raster cell which can be found within its spatial boundary. Furthermore, with respect to the words "*Sun*", "*Shadow*", and "*Wind*" , the openness should be oriented more towards the sky (see Figure 14).

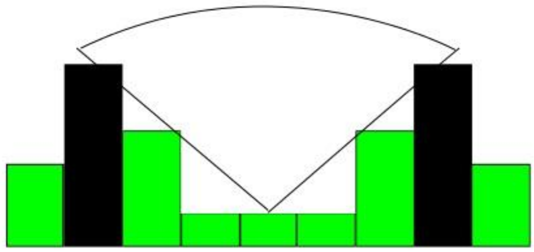


Figure 14 View angle towards the sky

The height of an object and the distance between the object and the citizen determines at what angle above the horizontal plane the sky is visible for the citizen. To approach the view angle towards the sky for every raster pixel, the complete raster data set is used. In this example "*Utrecht_Raster_all*". The calculation is explained on the next page, and illustrated in Figure 15.

- *Focal statistics* – with an annulus of different radii, the average height surrounding a pixel will be calculated, and separate raster data sets are created (See Figure 15). The raster cells have a dimension of 2.50*2.50m. For instance, to find the average height at a distance of four cells, within the focal statistics function the *inner*- and *outer radius* are set to 4 cells, and the *statistics type* to mean. The radii of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 75 and 100 meter are chosen.
- *Raster calculator* – the raster calculator determines the angle towards the sky in degrees. As an example the view angle with respect to a distance of 4 four cells (10 meter) is calculated as followed; **180 - 2 * ((ATan(("%Utr_ras_mean4 (2)%" - "%Utrecht_raster_all%") / 10))*57.3)**
  The number 57.3 converts radians into degrees. The rest of the formula is in accordance with the formula of Pythagoras.
- *Cell statistics* – the cell statistics finds the minimum view angle from all the input rasters and assigns this value to the raster cell.

With *Extract to Mask* the view angle towards the sky is stored for the open area within the three cities. The open area is determined as explained in paragraph 4.2.1. *Zonal statistics as Table* will store statistics about the view angle for every top places of thermal comfort of the three cities.

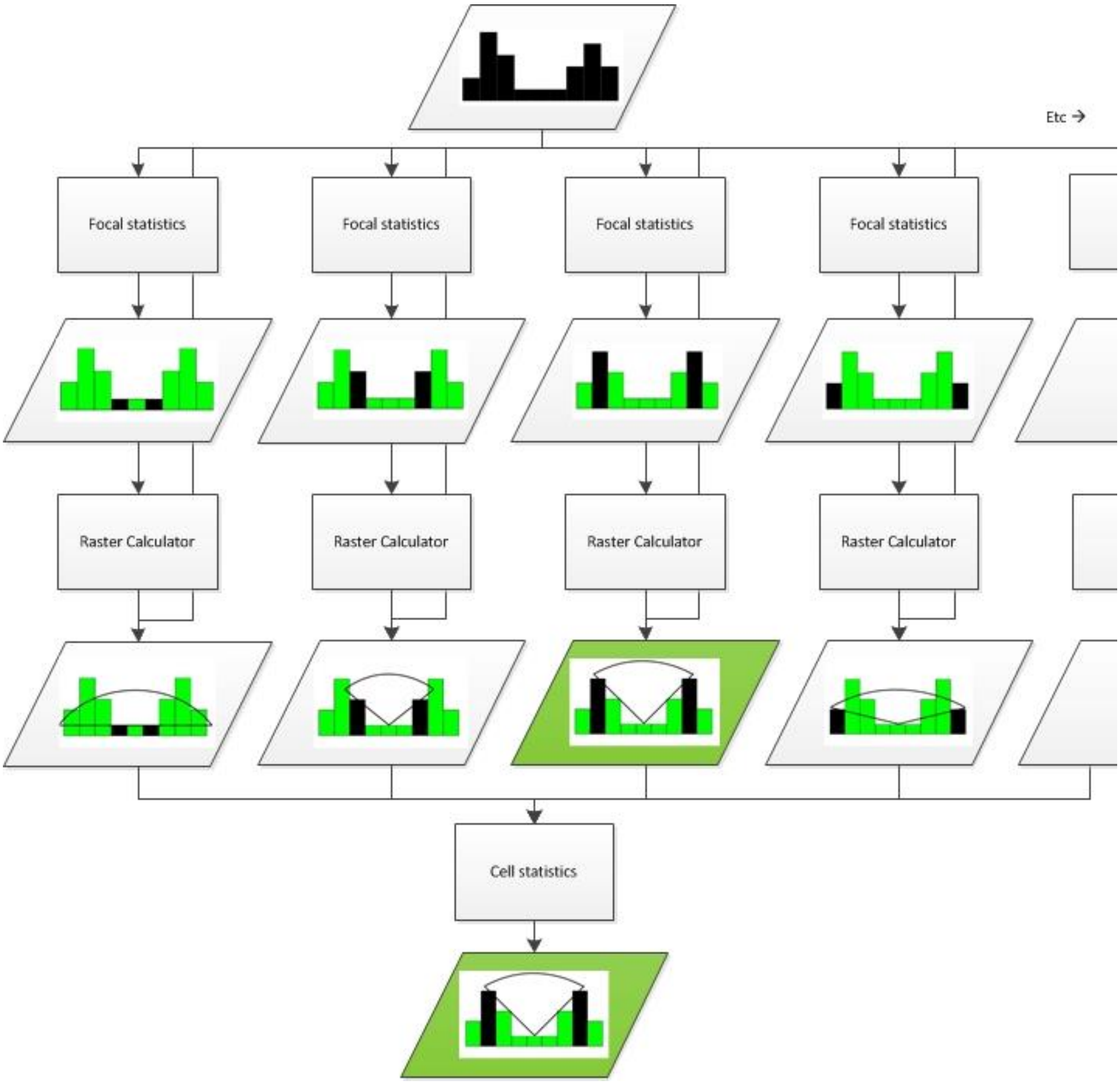


Figure 15 Model to calculate the view angle towards the sky

4.2.3 Distance – between home address and place of thermal comfort

In paragraph 3.2.2 (Question 3) it is discussed that citizens move further from their home if more time is given. The network analyst tool in ArcGIS is a way to approximate the distance one person has to overcome to reach a certain point. Within each of the three cities, the distances will be calculated from the respondent of the top two places of thermal comfort. As demonstrated in the Figure 16, the places of thermal comfort (named "Parks" in the figure) are converted to a point feature. Between the home addresses and the point feature the shortest path is calculated over the edges and junctions (derived from a polyline feature dataset representing the road network: TOP10_weglijnen).

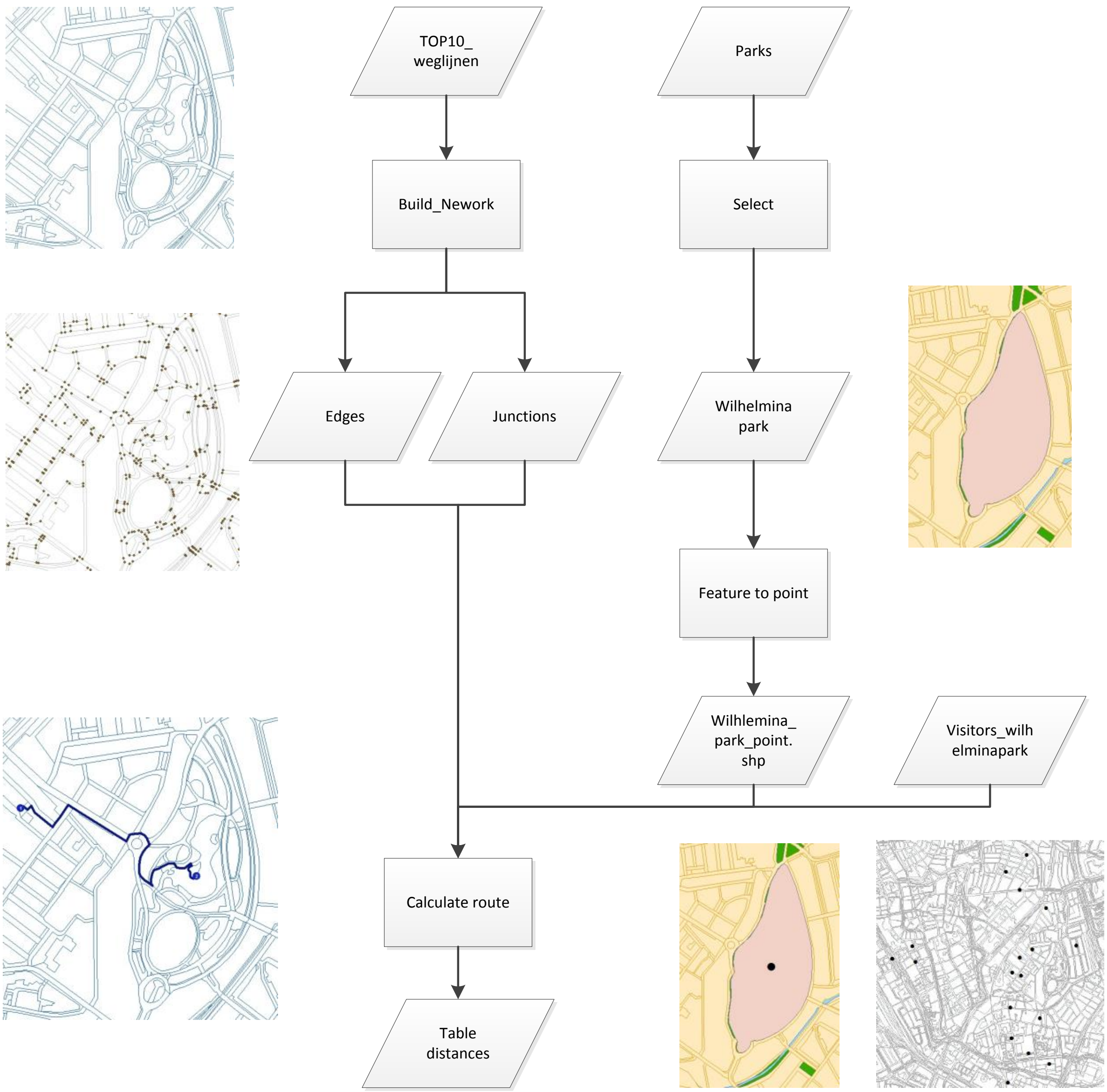


Figure 16 Model to calculate the Distance between a home address and a places of thermal comfort

Chapter 5. Results

In this chapter the results will be presented. Section 5.1 will present the digitalized home addresses and places of thermal comfort. Section 5.2 will present the spatial variables total area, land cover and view angle towards sky measured for each places of thermal comfort, and the distance towards the places of thermal comfort.

5.1 Mental map – Places of thermal comfort

5.1.1 Representation districts survey

In Figures Figure 17 - Figure 19 the districts used by the survey are presented by the red borders. The black points indicate the home addresses of the respondents. The colored maps in the right corner of the figures represent the amount of home addresses localized within each district.

In Figure 17 it can be seen that the districts in the north of Rotterdam are represented by more respondents. In some districts none of the respondents have their home address, indicated by a zero. Outside of the borders of the districts more home addresses can be found, especially in the most northern part of the city.

In Figure 18, Utrecht, it appears that more home addresses have been found in the eastern districts of the city. The district in the city centre has a relatively high number of home addresses (26) with respect to its area.

In Figure 19 the districts of Arnhem are situated south and north of the river Rhine. The districts in north of the river represent 117 respondents, and the districts in south of the river represent 56 respondents. So, constrained to the 12 districts in Arnhem, it is demonstrated that most respondents are from the north of Arnhem.

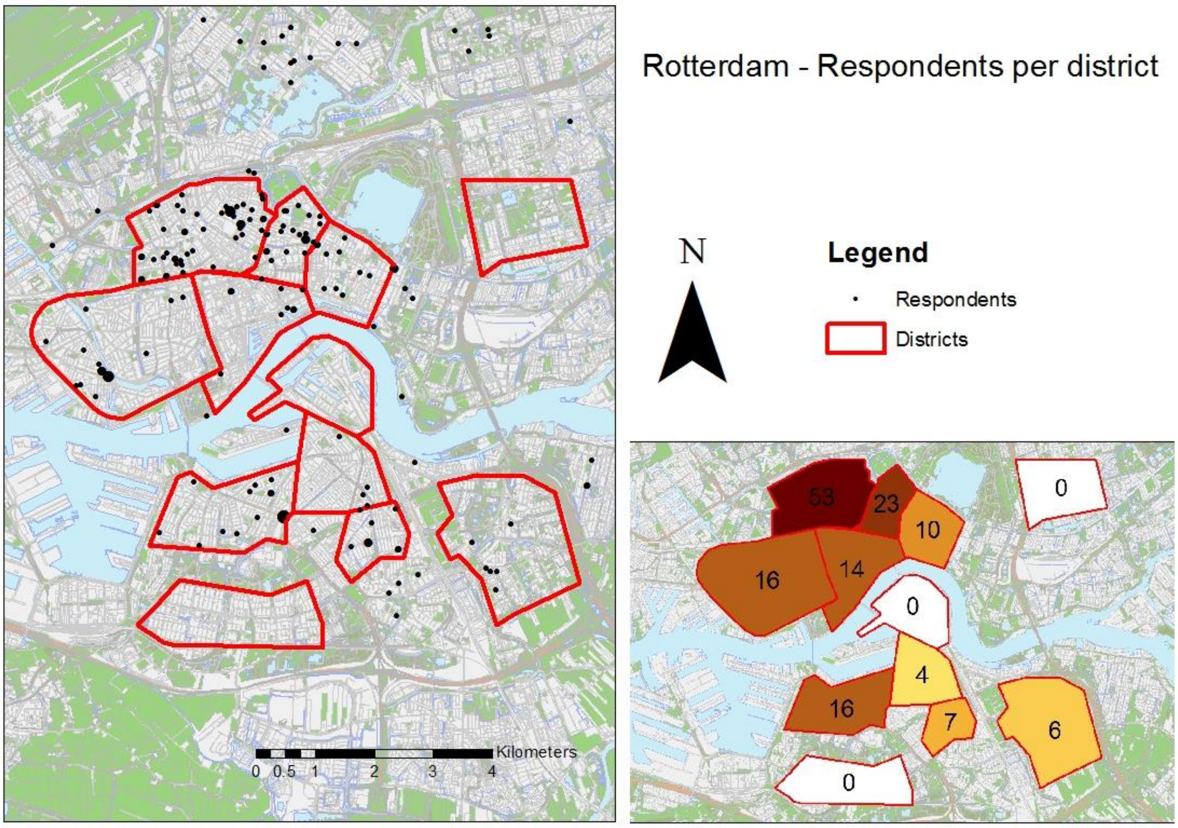


Figure 17 Rotterdam - Respondents per district

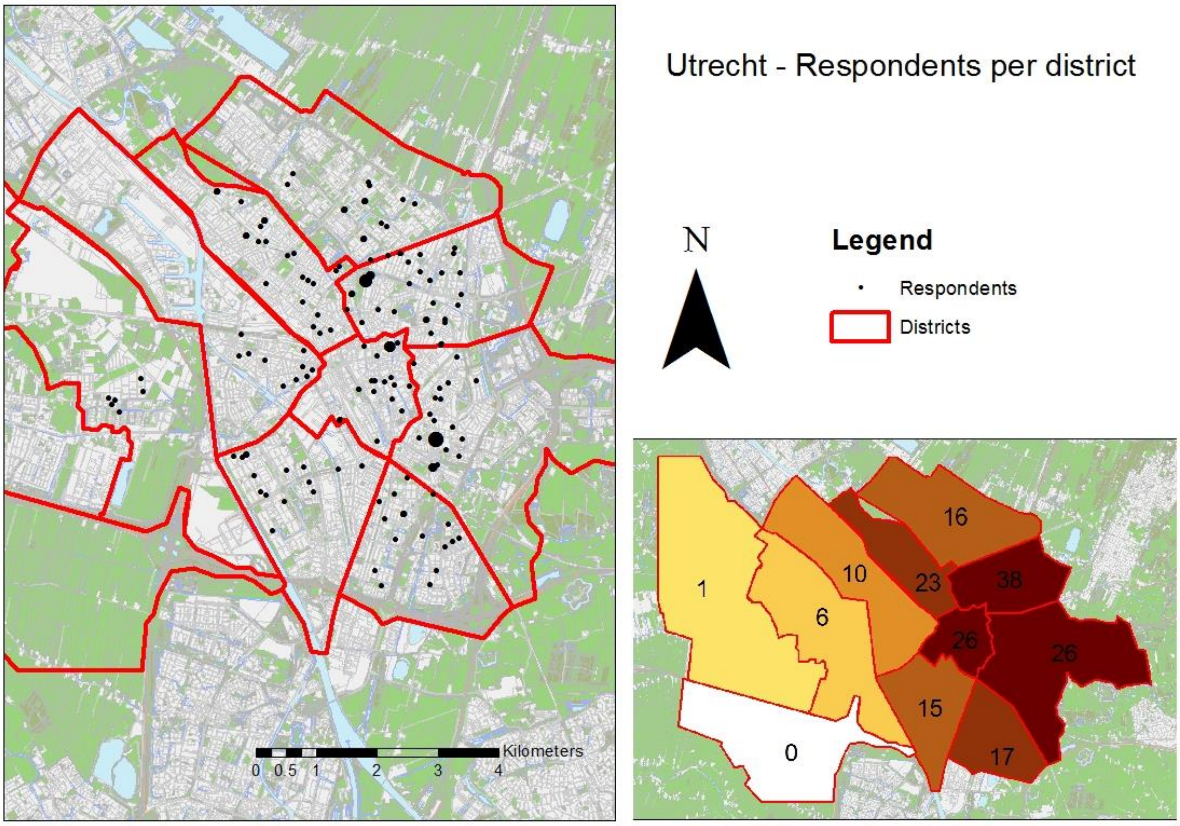


Figure 18 Utrecht - Respondents per district

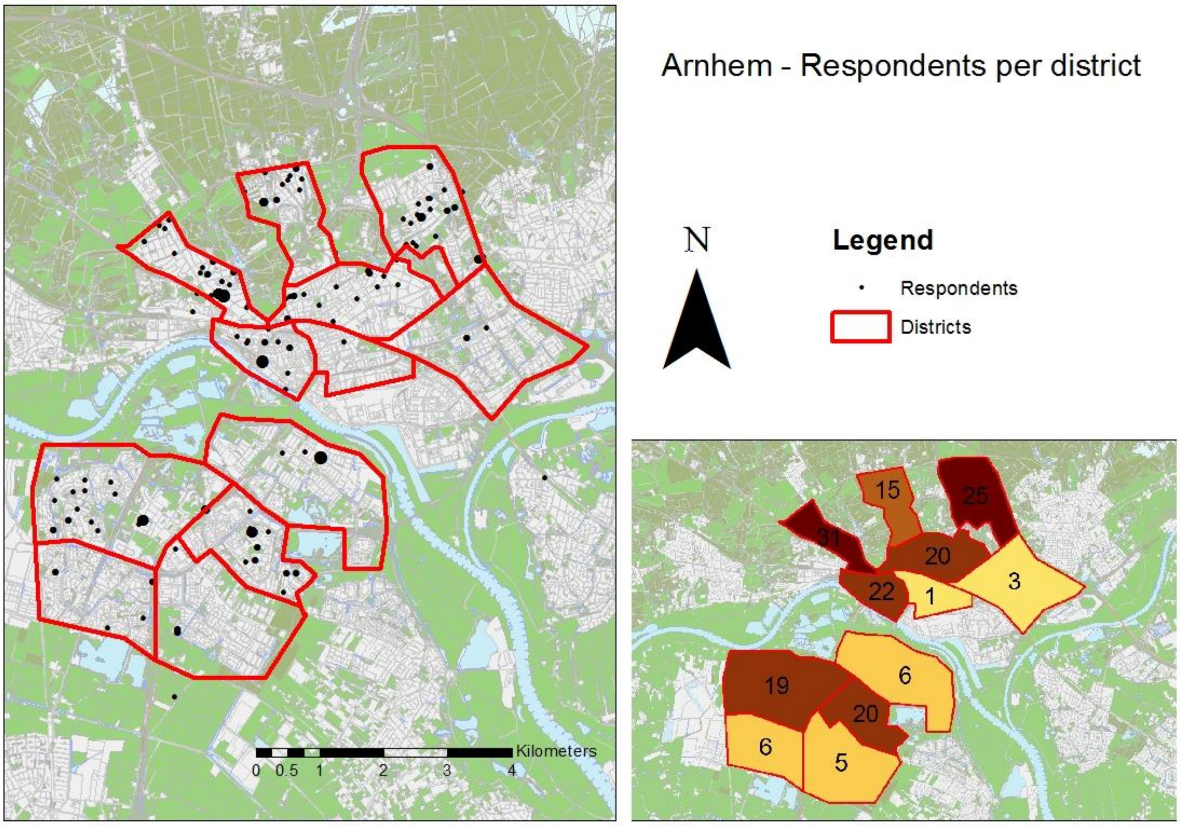


Figure 19 Arnhem - Respondents per district

5.1.2 Visualization Home addresses and Places of thermal comfort

Table 5 presents how many streets are represented by the survey, and the amount of respondents sharing one street. As an example, (see Table 5); in Arnhem there are 29 streets where in each of the streets two home address can be found; in Utrecht there is 1 street where seven home addresses can be found.
Within Rotterdam, Utrecht an Arnhem, respectively 160, 148 and 129 unique streets have been located. In Arnhem least streets have been represented by the survey.

	Streets containing:														Number of respondents
	1 person	subtotal	2 persons	subtotal	3 persons	subtotal	4 persons	subtotal	5 persons	subtotal	6 persons	subtotal	7 persons	subtotal	
Rotterdam	137	137	17	34	4	12	1	4	1	5	0	0	0	0	192
Utrecht	129	129	14	28	2	6	1	4	1	5	0	0	1	7	179
Arnhem	91	91	29	58	4	12	3	12	2	10	0	0	0	0	183

Table 5 Amount of streets having multiple home addresses of respondents

The spatial distribution of the origin of the respondents can be seen in Figures Figure 20 - Figure 22 (page 39 - 41). The points indicate the home addresses of the respondents. The size of the point is in accordance with the number of respondents living in that street. The kernel density (red glow), and the buffer of 500m (black) line emphasize the density of the respondents' home addresses, respectively region covered by the survey.

The respondents could indicate multiple places they found comfortable in terms of temperature within the city. In total, in Rotterdam, Utrecht and Arnhem respectively 287, 337, and 302 not unique places were indicated within the city. In Figures Figure 20 - Figure 22 (page 39 - 41) the places of thermal comfort which found agreement with four or more respondents are visualized together with the home addresses. The blue bars are in accordance with the amount of respondents going to these places of thermal comfort (see legend: Frequency). In Rotterdam, Utrecht, and Arnhem these places cover respectively 74.9%, 75.9%, and 76.5% of the total amount of places that have been called by the respondents.
In Rotterdam, Utrecht and Arnhem, respectively 13, 20 and 15 places of thermal comfort have been visualized. The exact amount of respondents who indicated to go to these "top places of thermal comfort" can be found in Appendix F.

There have been places of thermal comfort mentioned by the respondents which lay within the spatial boundaries of other places of thermal comfort visualized in the figures, like "*Koopgoot*" (a street) lays within the center ("*Centrum*") of Rotterdam, or "*Korenmarkt*" lays within the center of Arnhem. These specific places within the center do not represent the center in total, and thus are not classified as center. Especially in Utrecht there are specific places within the spatial boundary of the center of Utrecht which stand out in their number of agreement; *"Dom"(9) "Ledig Erf" (20),* and *"Neude" (22).* Since these places found agreement among more than four respondents, they have been visualized separately. In the three cities together, the spatial boundary of 39 out of the 48 visualized places of thermal comfort were within a reach of 500 meter from a home address. More remarks about the separate cities can be found under the Figures Figure 20 - Figure 22 (page 39 - 41).

Rotterdam

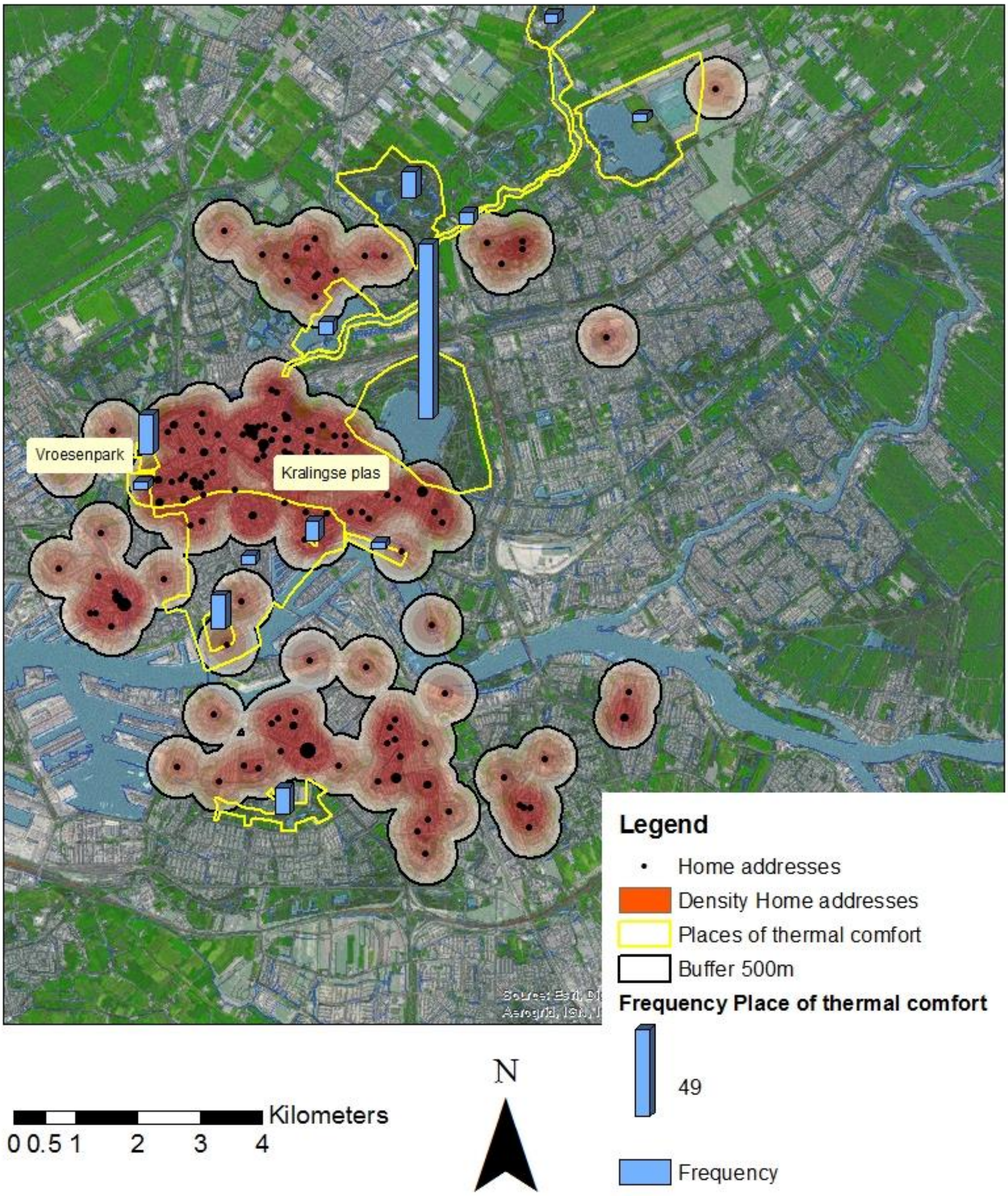


Figure 20 Rotterdam - Home addresses and Places of thermal comfort

The municipality of Rotterdam has a population of 616 260 inhabitants and covers an area of 319,35 km^2. The population density is 2986 pop. per km^2. The top two places of thermal comfort are "*de Kralingse plas*" (97 respondents) and "*Vroesenpark*" (22 respondents). Considering all visualized places of thermal comfort, the *Kralingse plas* attracts significantly more respondents than the rest of the places which are in the same vicinity of the majority of the respondents.

Utrecht

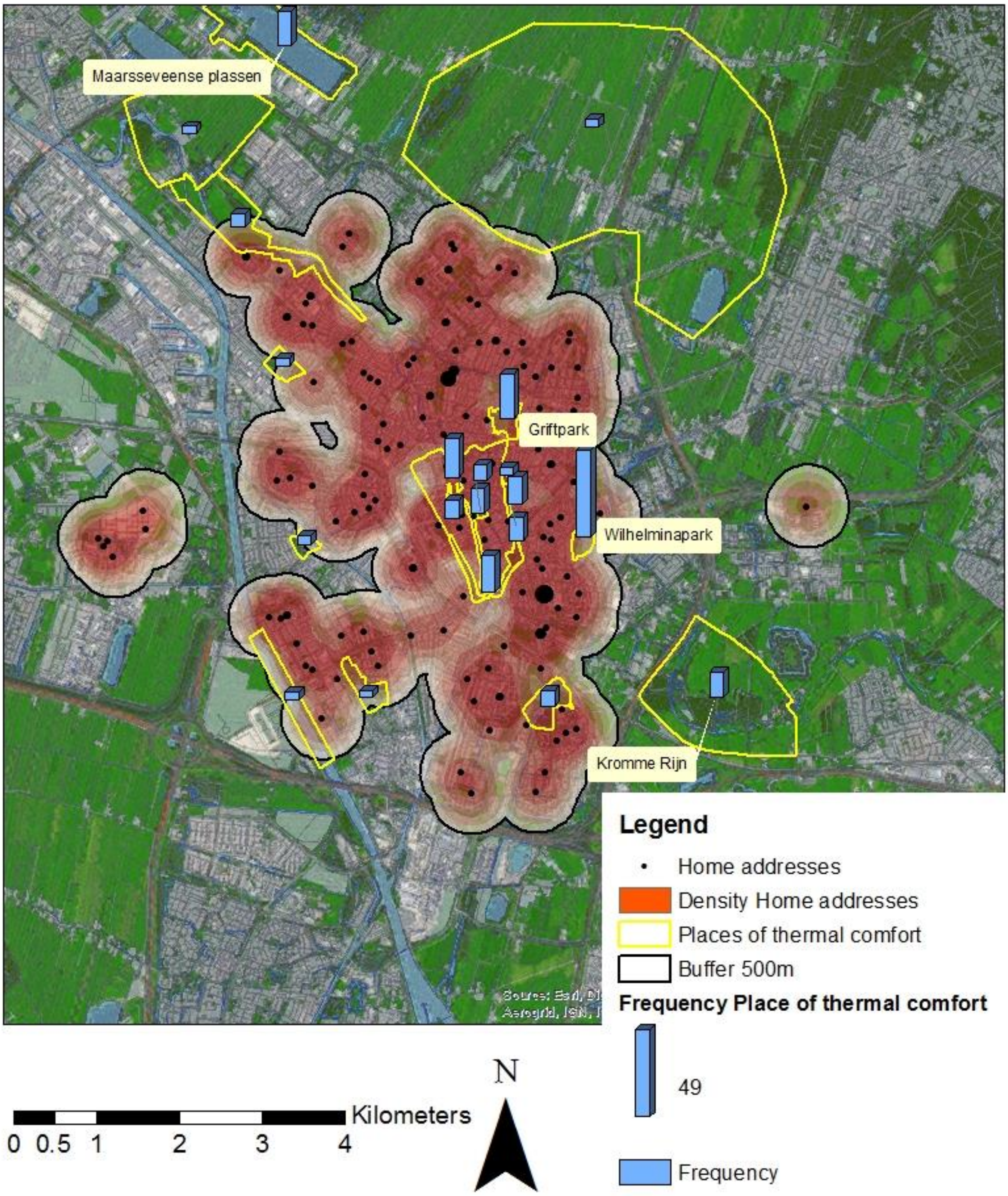


Figure 21 Utrecht - Home addresses and Places of thermal comfort

The municipality of Utrecht has a population of 321 916 inhabitants and covers an area of 99,21 km^2. Out of the three cities it is the most densely populated area (3442 pop. per km^2). The top two places of thermal comfort are "*Wilhelminapark*" (48 respondents) and "*Griftpark*" (25 respondents). In the figure it is clear that the level of agreement (Frequency) about places of thermal comfort increases towards the center of Utrecht. Towards the edges of the survey area, the level of agreement per places of thermal comfort is lower. "*Wilhelminapark", "Kromme Rijn"* and "*Maarsseveense plassen"* seem to be exceptions; these three places have a relatively high level of agreement among the respondents, although they are around – or outside the edge of the survey area.

Arnhem

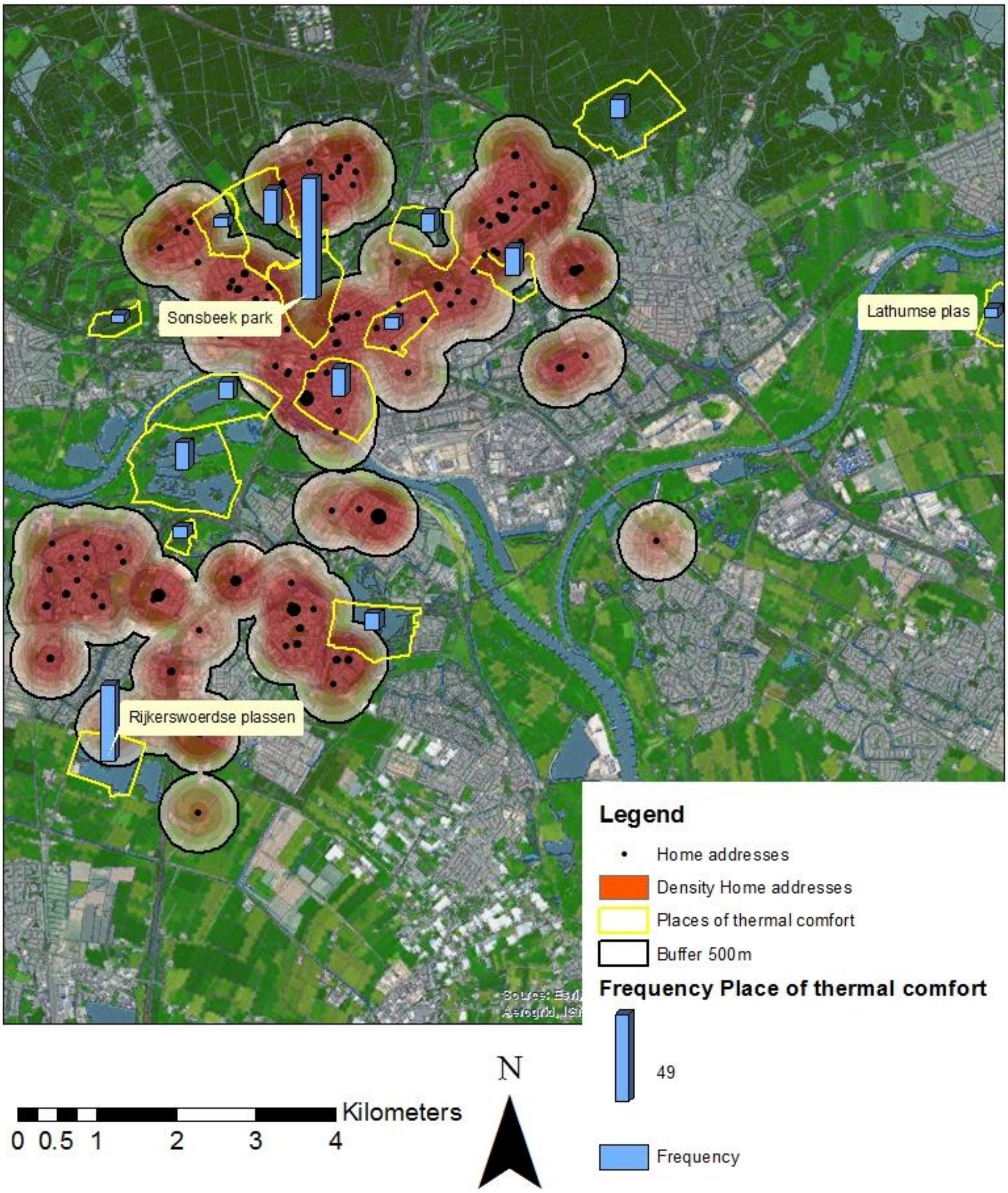


Figure 22 Arnhem - Home addresses and Places of thermal comfort

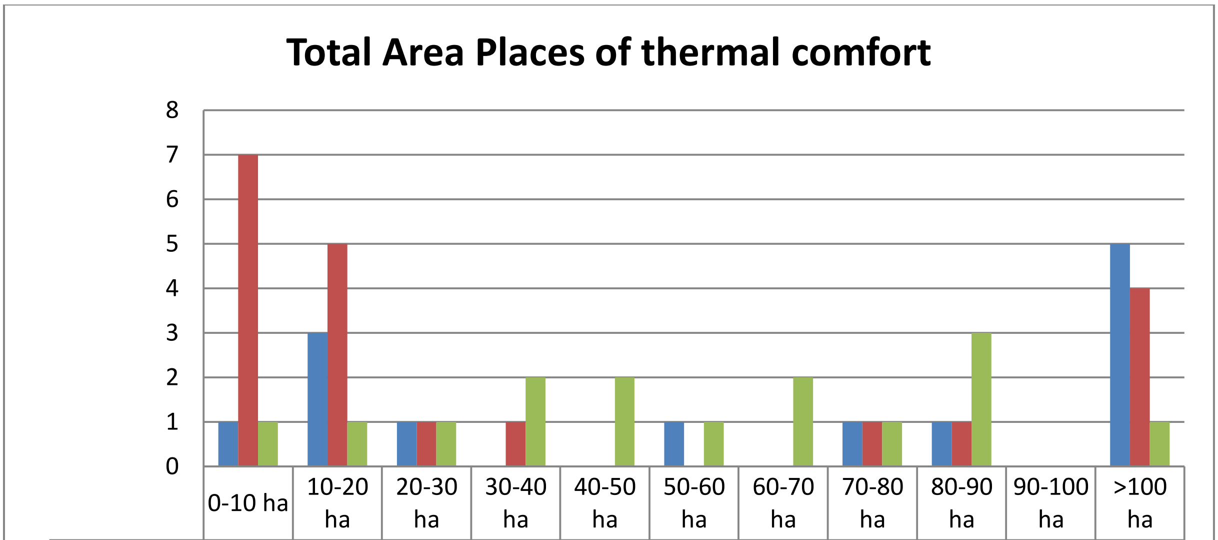
The municipality of Arnhem has a population has a population of 149 271 inhabitants and covers an area of 101,54 km^2. From the three cities, Arnhem has the lowest population density (1534 inw/km^2). The top two places of thermal comfort are "*Sonsbeekpark*" (67 respondents) and "*Rijkerswoerdse plassen*" (42 respondents). Focusing on the nine places indicated north of the river "Rhine", *Sonsbeekpark* stand out from the rest in number of respondents going there. The *Rijkerswoerdse plassen* is on the edge of the survey area but still shows a relatively high level of agreement among the respondents. From the three cities, the "Lathumse plas" - on the eastside of Arnhem – has the biggest distance with respect to the survey area.

5.2 Mental map – Spatial variables

This section presents the (spatial-) variables which have been measured within the places of thermal comfort which found agreement among four or more respondents. The variation of the measured (spatial-) variables, both in their numerical value and spatial distribution is presented.

5.2.1 Total area

In Figure 23 the frequency distribution of the total area of the places of thermal comfort is presented. It can be seen, that in Utrecht the total area of 7 out of the 20 places of thermal comfort are smaller than 10 hectares. In Utrecht these places are: "*Ledig Erf*" (0,2 ha), "*Neude*" (0,5 ha), "*Dom*" (1.0 ha), "*Lucasbolwerk*" (1,1 ha), "*Lepelenburg*" (2,9 ha), "*Oude Gracht*" (5,5 ha) and "Oog in Al" (6,7 ha). In Appendix G the total area of all places of thermal comfort can be found.



	0-10 ha	10-20 ha	20-30 ha	30-40 ha	40-50 ha	50-60 ha	60-70 ha	70-80 ha	80-90 ha	90-100 ha	>100 ha
Rotterdam	1	3	1			1		1	1		5
Utrecht	7	5	1	1				1	1		4
Arnhem	1	1	1	2	2	1	2	1	3		1

Figure 23 Frequency distribution Total Area Places of thermal comfort

5.2.2 Land cover

The calculated land cover classes water, trees and open area are represented by the pie-diagrams in Figures Figure 25 - Figure 28 (page 45 - 48) with the respective colours blue, green and yellow. In Appendix G the exact area of the land cover classes per specific place of thermal comfort is presented.

In Appendix G the order (left to right) of the places of thermal comfort is based on the ratio *Area Trees : Area Open.* In other words, the area covered by trees in relation to the area covered by open area, within the spatial boundaries of the places of thermal comfort. From now on we will call this relative tree cover the *"Tree ratio".* The range and median value of the *Tree ratio*, constrained to the places of thermal comfort of Figures Figure 25 - Figure 28 is presented in Table 6. The table tells us that Rotterdam has the smallest, and Utrecht the biggest variation of the *Trees ratio* found within the places of thermal comfort.

	Tree ratio (range)	Tree ratio - median
Rotterdam	0,12 – 0,47	0,32
Utrecht	0,06 – 1,00	0,33
Arnhem	0,06 – 0,71	0,47

Table 6 Values tree ratio within places of thermal comfort

In Rotterdam all places of thermal comfort (total 13) have presence of water, in Utrecht 17 out of 20, in Arnhem 12 out of 15. The pie-diagrams visualize the percentage in area of each land cover class, per place of thermal comfort. The median value of these percentages per city creates an image of the spatial environment of the top places of thermal comfort (see Figure 24).

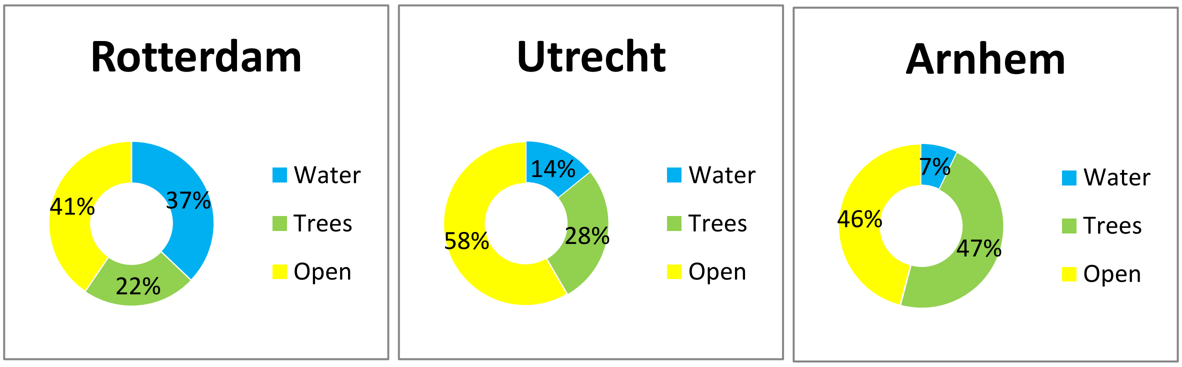


Figure 24 Land cover classes found within the Places of thermal comfort, per city

Rotterdam

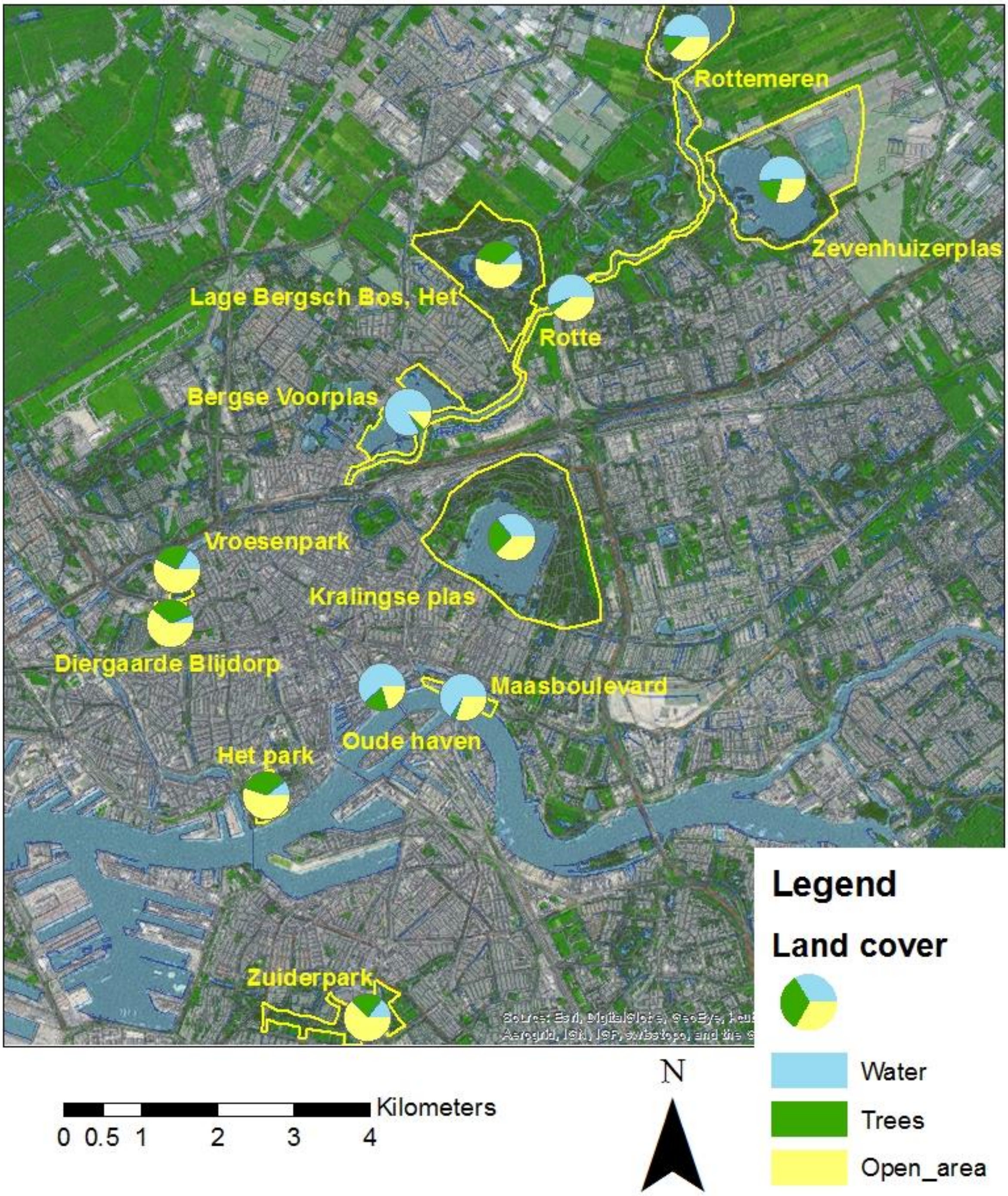


Figure 25 Rotterdam - Land cover classes

Based on the Tree ratio "*Oude haven*" (0,47) , "*Kralingse Plas*" (0,45) and "*Zevenhuizerplas*" (0,43) are the places of thermal comfort with highest cover of trees on dry land. Though, the tree ratio is not significantly different for the other places of thermal comfort (see Appendix G). The "*Rotte*" (0,12), "*Maasboulevard"* (0,13) and "*Bergse Voorplas*" (0,25) could be named the three most open places. "*Diergaarde blijdorp*", "*Vroesenpark*", and "*Het park*" (west-side), and "*Zuiderpark*" (South-side) appear comparable in their division of land cover classes. The "*Kralingse plas*" is with 340, 8 hectares the biggest defined place of thermal comfort. The total amount of area under trees within this place is 94,8 hectares.

Utrecht

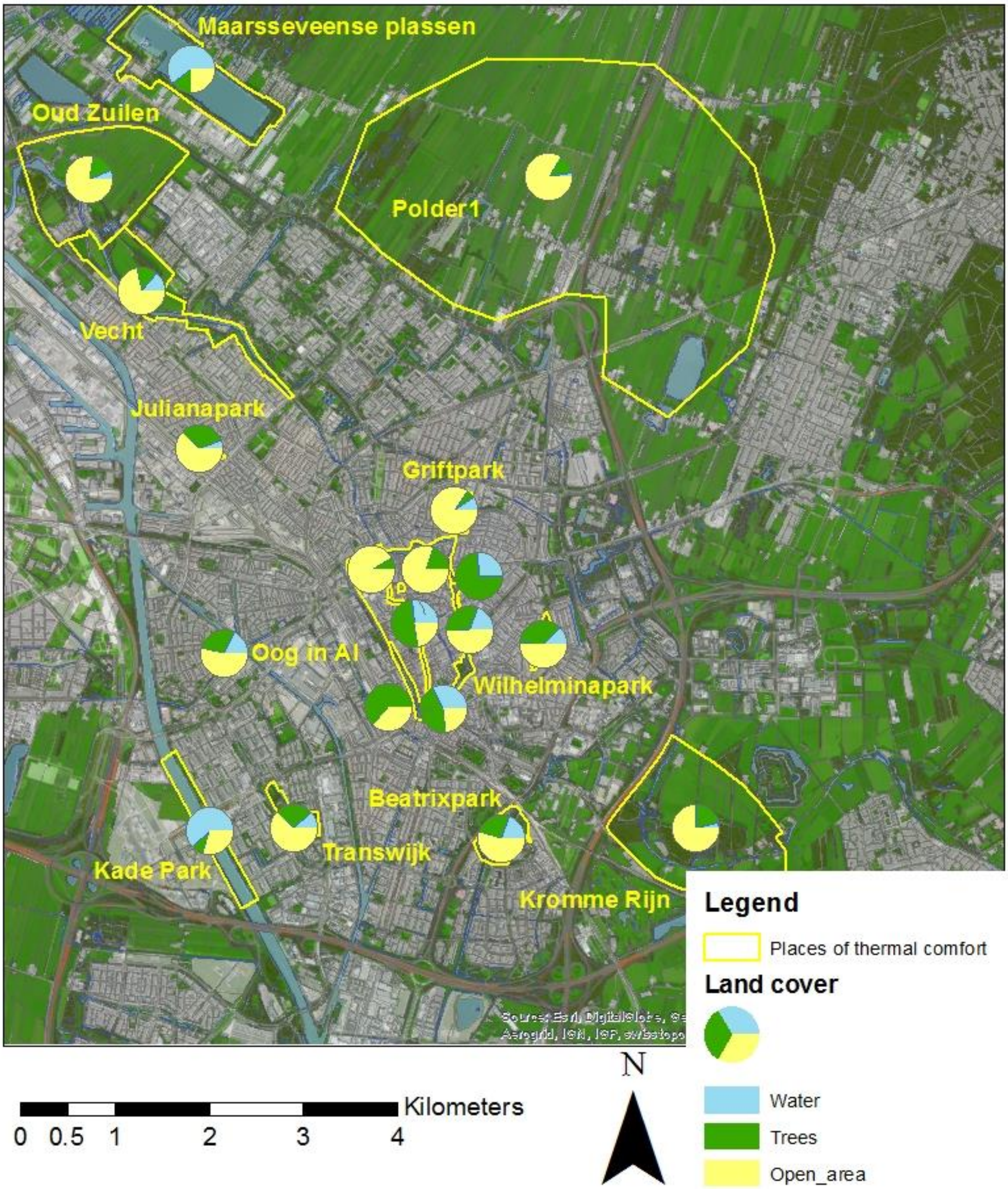


Figure 26 Utrecht - Land cover classes

Based on the Tree ratio "*Lucasbolwerk*" (1,00) , "*Oude Gracht*" (0,68) and "*Singel*" (0,66) are the places of thermal comfort with highest cover of trees on dry land. All these places are situated within the city center, see Figure 27 (next page). The "*Griftpark*" (0,06), "*Neude"* (0,13) and "*Polder"* (0,14) could be named the three most open places. With respect to the total area of a place of thermal comfort, the "*Kade Park*" (62,1%), "*Maarsseveense plassen*" (60,2%), and "*Singel"* (31,4%) are the top three places of thermal comfort with presence of water.

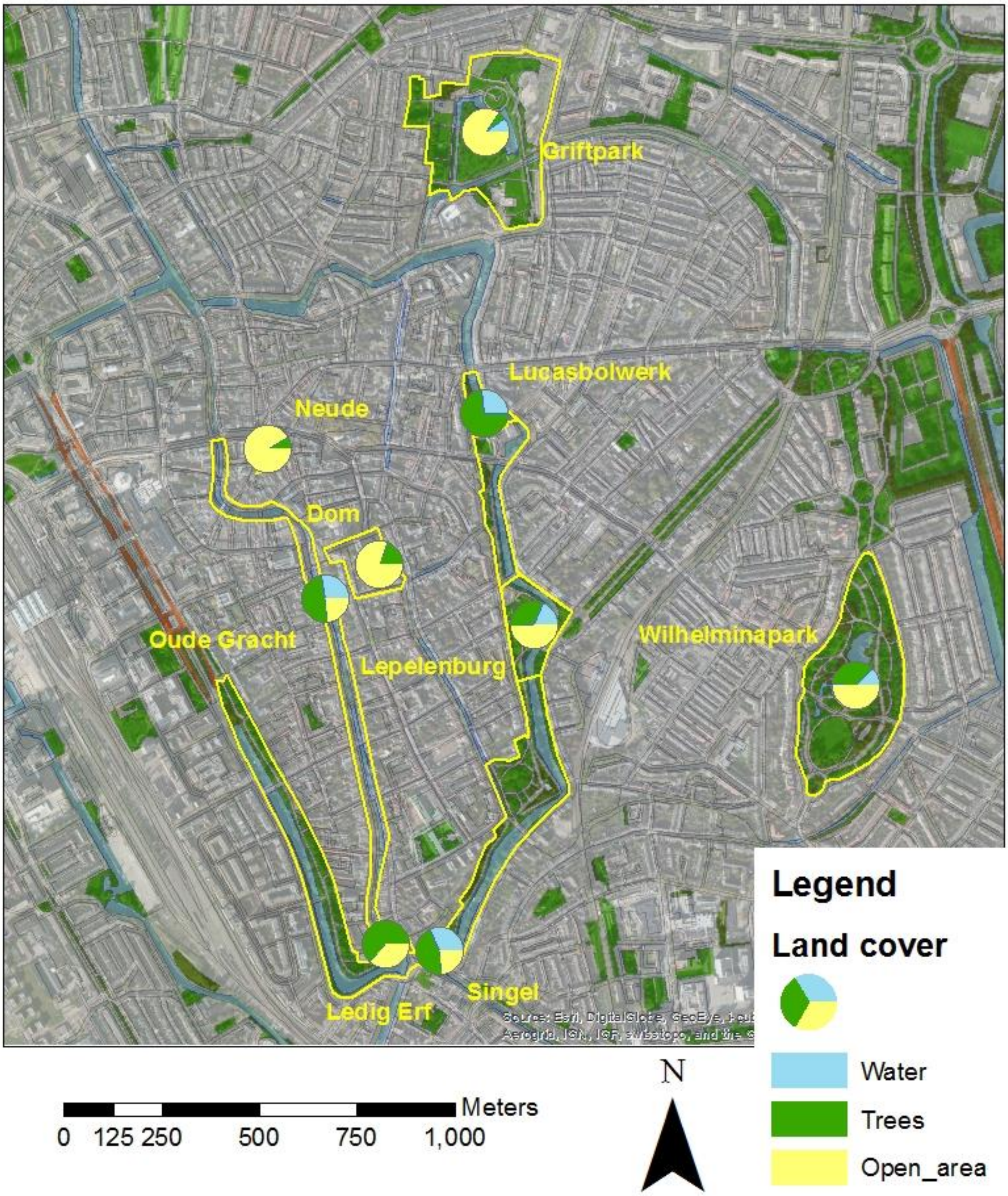


Figure 27 City centre Utrecht - Land cover classes

The figure above zooms in on the city-centre of Utrecht. The U-shape around the city centre is the "*Singel*". Within this place of thermal comfort, the "*Lepelenburg*" is relatively more open, and "*Lucasbolwerk*" relatively more closed with tree cover. In the city centre, the order of Tree ratio is as followed:

"*Griftpark*" (0,06), "*Neude*" (0,09), "*Dom*" (0,19), "*Lepelenburg*" (0,38), "*Wilhelminapark*" (0,42), "*Ledig Erf*" (0,64), "*Singel*" (0,66), "*Oude Gracht*" (0,68) and "*Lucasbolwerk*" (1,00).

The "*Ledig Erf*", "*Neude*" and "*Dom*" cover respectively 0.2, 0.5 and 1 hectare. This implies that the area covered under trees in this three places of thermal comfort could be caused by a handful of trees.

Arnhem

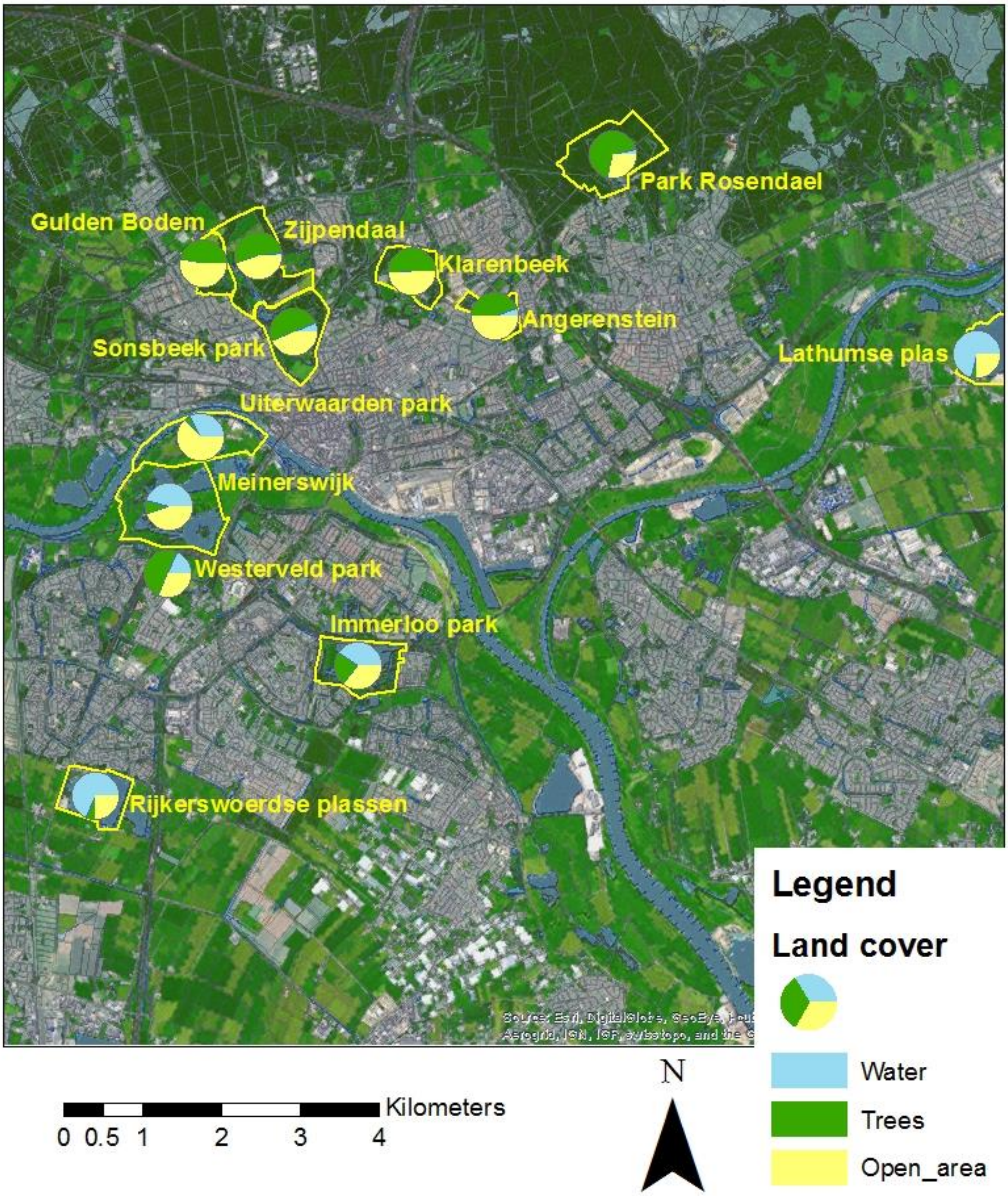


Figure 28 Arnhem - Land cover classes

Based on the Tree ratio “*Park Rosendael*” (0,71) , “*Westerveld Park*” (0,62) and “*Zijpendaal*” (0,54) are the places of thermal comfort with highest cover of trees on dry land. The “*Uiterwaarden park*” (0,06), “*Lathumse plas”* (0,10) and “*Meinerwijk*” (0,18) could be named the three most open places. With respect to the total area of a place of thermal comfort, the “*Lathumse plas*” (71,6%), “*Rijkerswoerdse plassen*” (68,2%), and “*Meinerswijk*” (45,8%) are the top three places of thermal comfort with presence of water. In Arnhem there is a general division in the places of thermal comfort north and south of the Rhine/IJsel, regarding the dominant land cover class present; in the north the presence of trees is more pronounced, in the south the presence of water is more pronounced.

5.2.3 View angle towards sky

The view angle in degrees towards the sky has been measured for each raster cell in the open area in the three cities. Taking the places of thermal comfort separately, the function *zonal statistics as table* has stored the frequency distribution of the values found. These frequency distributions are visualized in Appendix G by means of box-plots. Among the places of thermal comfort there is variation in the median- and interquartile range of the view angle, as presented in Table 7.

	Median View angle *(range of values)*	**Interquartile range view angle** *(range of values)*
Rotterdam	141,8 – 170,7	32,9 – 79,8
Utrecht	122,4 – 173,0	19,1 – 55,6
Arnhem	133,8 – 175,18	16,1 – 93,3

Table 7 Values Median and interquartile range of the View angle towards the sky within places of thermal comfort

A general trend is visible in the relation between the variables *Tree ratio*, the median- and interquartile range of the view angle, as demonstrated in Figure 29 (figures belonging to Arnhem, in Appendix G the graphs for Rotterdam and Utrecht are presented). The figures show that:

- with increasing amount of trees, the interquartile range of the view angle increases.
- with increasing amount of trees, the median of the view angle decreases.
- with increasing median of the view angle, the interquartile range of the view angle decreases.

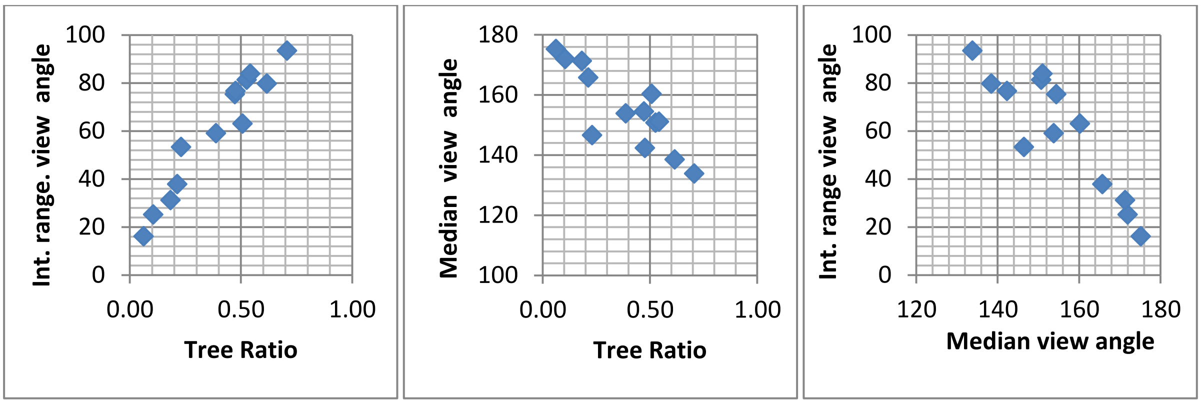


Figure 29 Relation between spatial variables Tree ratio, Median View angle, and Interquartile range of View angle

In Figures Figure 30 - Figure 33 (page 50 - 53) the value of the median view angle within a place of thermal comfort is represented by yellow circles. Based on the trends found, it should be kept in mind that a low median view angle within a place of thermal comfort is at the same time accompanied with a higher variation (interquartile range) in value of the view angle; so, in these places there are still spots with a high view angle. Some places of thermal comfort could be regarded as ‘outliers’, taking the three trends in the graphs (Figure 29) as a reference. These outliers are mentioned under the Figures Figure 30 - Figure 33.

Rotterdam

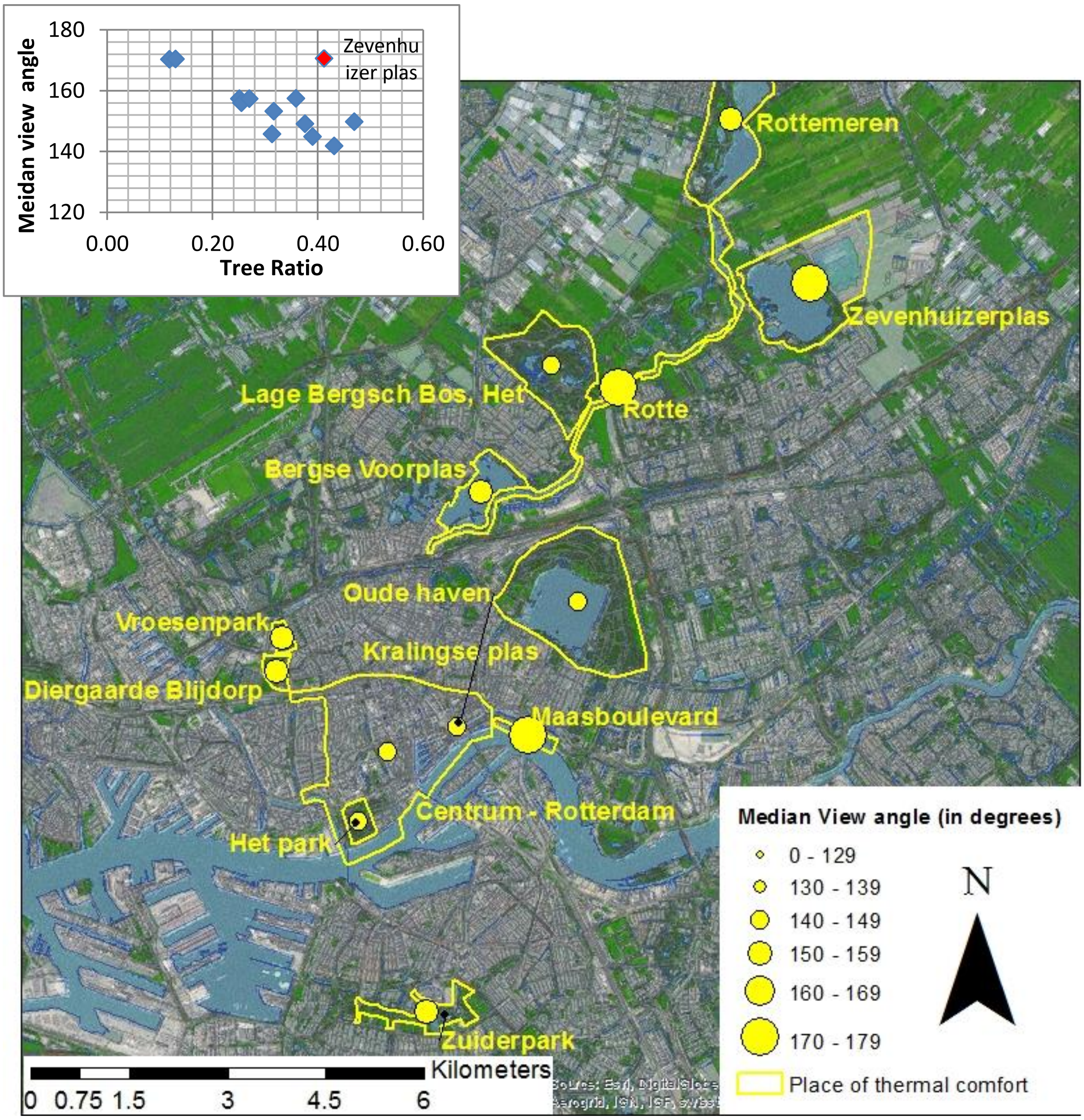


Figure 30 Rotterdam - Median View angle towards the sky

Median View angle	Place of thermal comfort
0^o - 139^o	-
130^o - 139^o	-
140^o - 149^o	"Kralingse plas" *(141,8^o)*, "Lage Bergsche Bos" *(144,9^o)*, "Centrum" *(145,8^o)*, "Het Park" *(149,1^o)*, "Oude haven" *(149,1^o)*
150^o - 159^o	"Vroesenpark" *(153,2^o)*, "Zuiderpark" *(156,0^o)*, "Bergse Voorplas" *(157,4^o)*, "Rottemeren" *(157,4^o)*, "Diergaarde Blijdorp" *(157,4^o)*
160^o - 169^o	-
170^o - 179^o	"Rotte" *(170,3^o)*, "Maasboulevard" *(170,4^o)*, and "Zevenhuizerplas" *(170,7^o)*

Table 8 Rotterdam - Values Median View angle towards the sky

The "*Kralingse plas*" has the lowest -, and the "*Zevenhuizerplas*" the highest median view angle. The "*Zevenhuizerplas*" stand out from the other places of thermal comfort with a relatively high median view angle with respect to the tree ratio (0,41), see Figure 30.

Utrecht

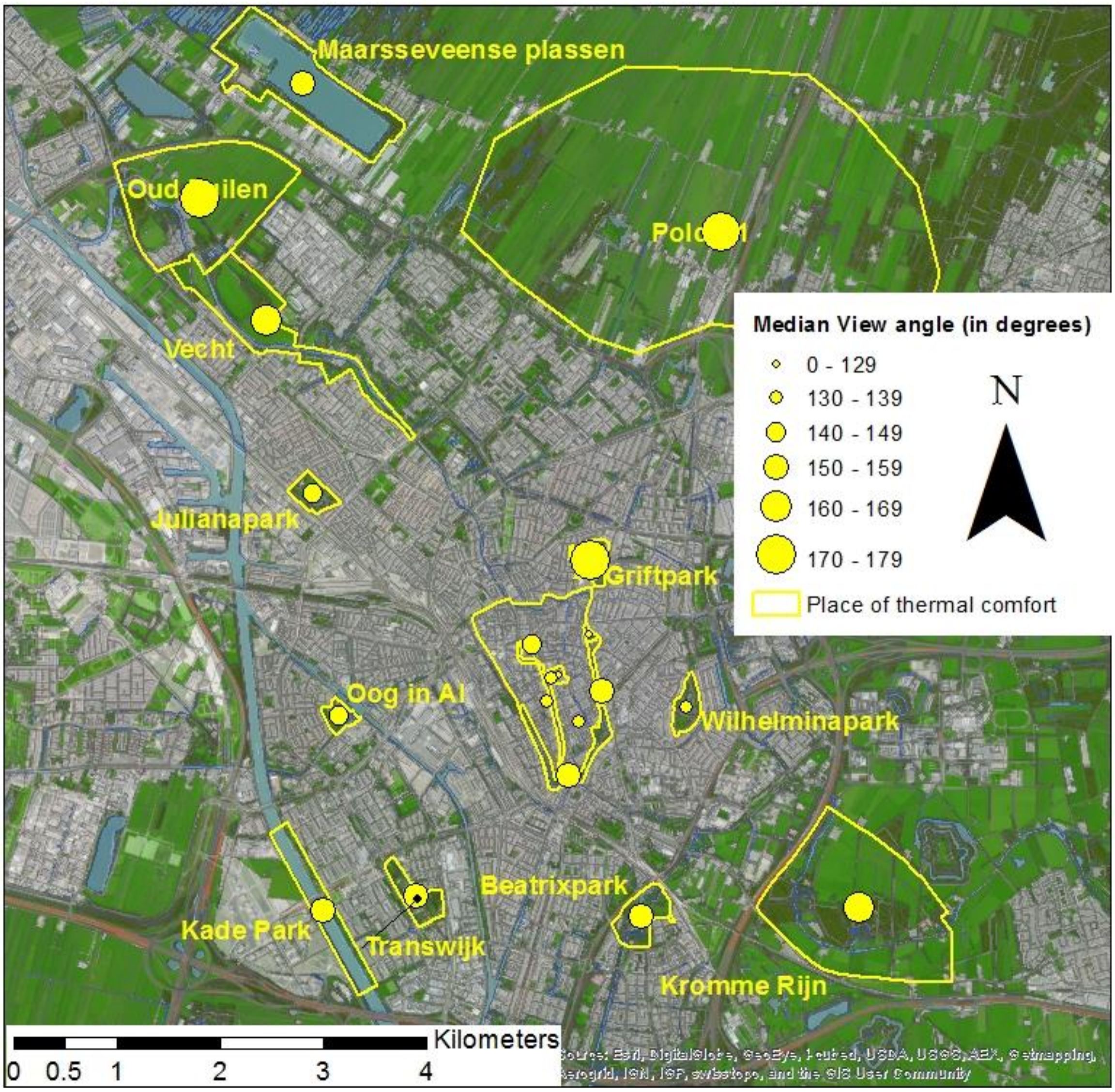


Figure 31 Utrecht - Median View angle towards the sky

Median View angle	Place of thermal Comfort
0^o - 129^o	"*Dom*" (122,4^o)
130^o - 139^o	"*Oude Gracht*" (132,3^o), "*Centrum*" (135,5^o), "*Wilhelminapark*" (138,5^o), "*Singel*" (139,3^o)
140^o - 149^o	"*Neude*" (145,0^o)
150^o - 159^o	"*Julianapark*" (150,0^o), "*Oog in Al*" (150,0^o), "*Maarsseveense plassen*" (151,3^o), "*Ledig Erf*" (152,6^o), "*Lepelenburg*" (154,9^o), "*Transwijk*" (157,3^o), "*Beatrixpark*" (159,2^o), "*Kade Park*" (159,9^o)
160^o - 169^o	"*Kromme Rijn*" (163,5^o), "*Vecht*" (166,2^o)
170^o - 179^o	"*Oud Zuilen*" (170,8^o), "*Polder*" (172,4^o), "*Griftpark*" (173,0^o)

Table 9 Utrecht - Values Median View angle towards the sky

The "*Dom*" has the lowest -, and the "*Griftpark*" the highest median view angle. The underscored names are situated within the city centre. Generally speaking, the places of thermal comfort within the centre show lower median view angles, and places of thermal comfort outside the city show higher median view angles. The median view angle of the places of thermal comfort in the city center are visualized on the next page, Figure 32.

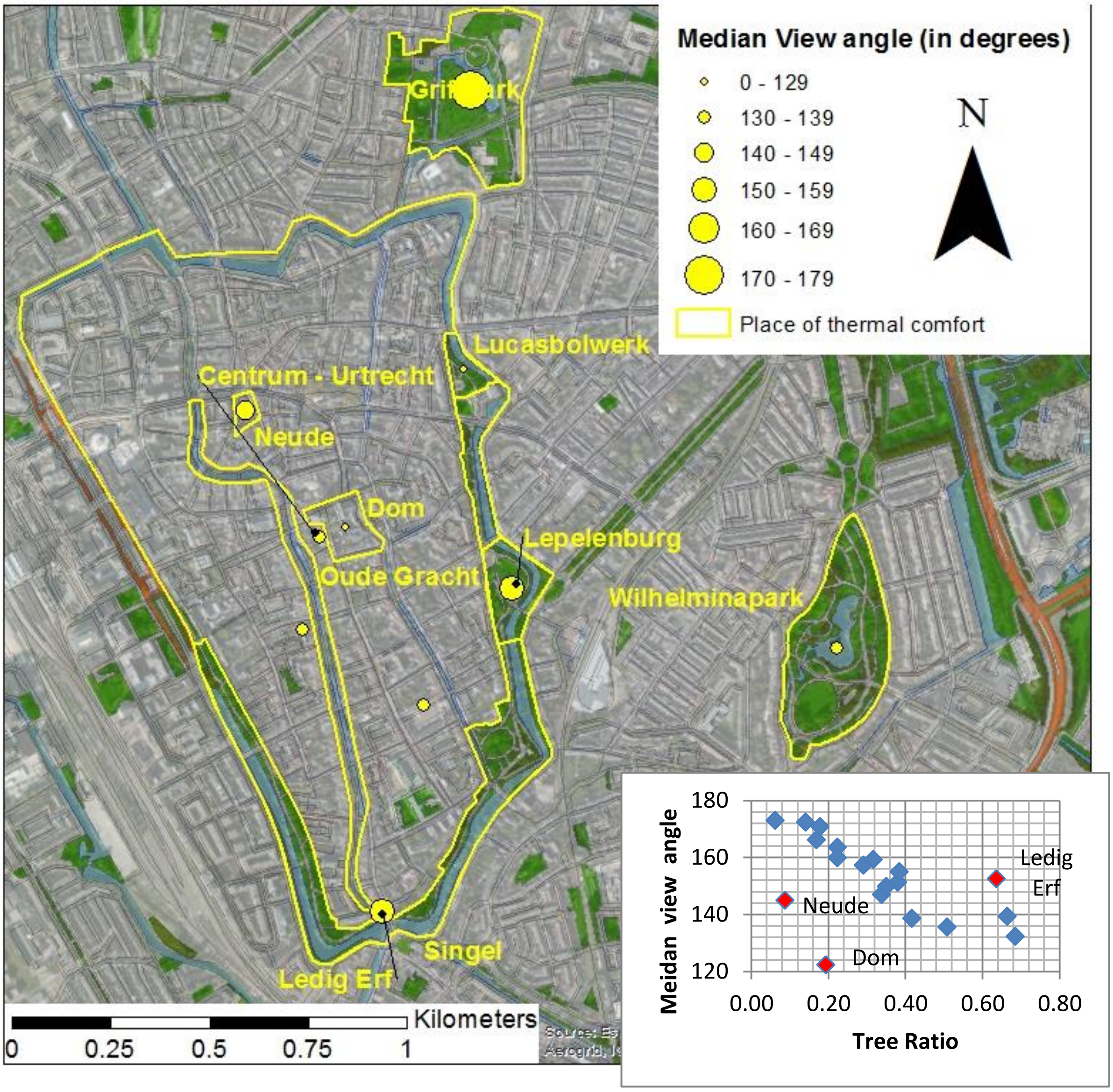


Figure 32 City centre Utrecht - Median View angle towards the sky

The two parks "*Griftpark*" and "*Wilhelminapark*", situated in the vicinity of the city centre, show distinctive characters with regard to median view angle. Based on the median view angle, the "*Griftpark*" could be interpreted open and sunny, and the "*Wilhelminapark*" more closed and shadowed. For complete interpretation of the two parks the interquartile range of the view angle of the "*Griftpark*" and "*Wilhelminapark*" , respectively 19.1^{o} and 65.1^{o} has to be considered too. This statistic tells that within "*Wilhelminapark*" there is high variation of view angle present, from closed/shadowed places to open and sunny places. In appendix J there a visualization of the view angle for the Centre of Utrech can be found.

The "*Neude*" and "*Dom*", with a tree ratio of 0,09 respectively 0,19, stand out from the other places of thermal comfort with a relatively low median view angle. The two places of thermal comfort are situated in the middle of the centre. The "*Ledig Erf*", with a tree ratio of 0,64, stand out with a relatively high median view angle.

Arnhem

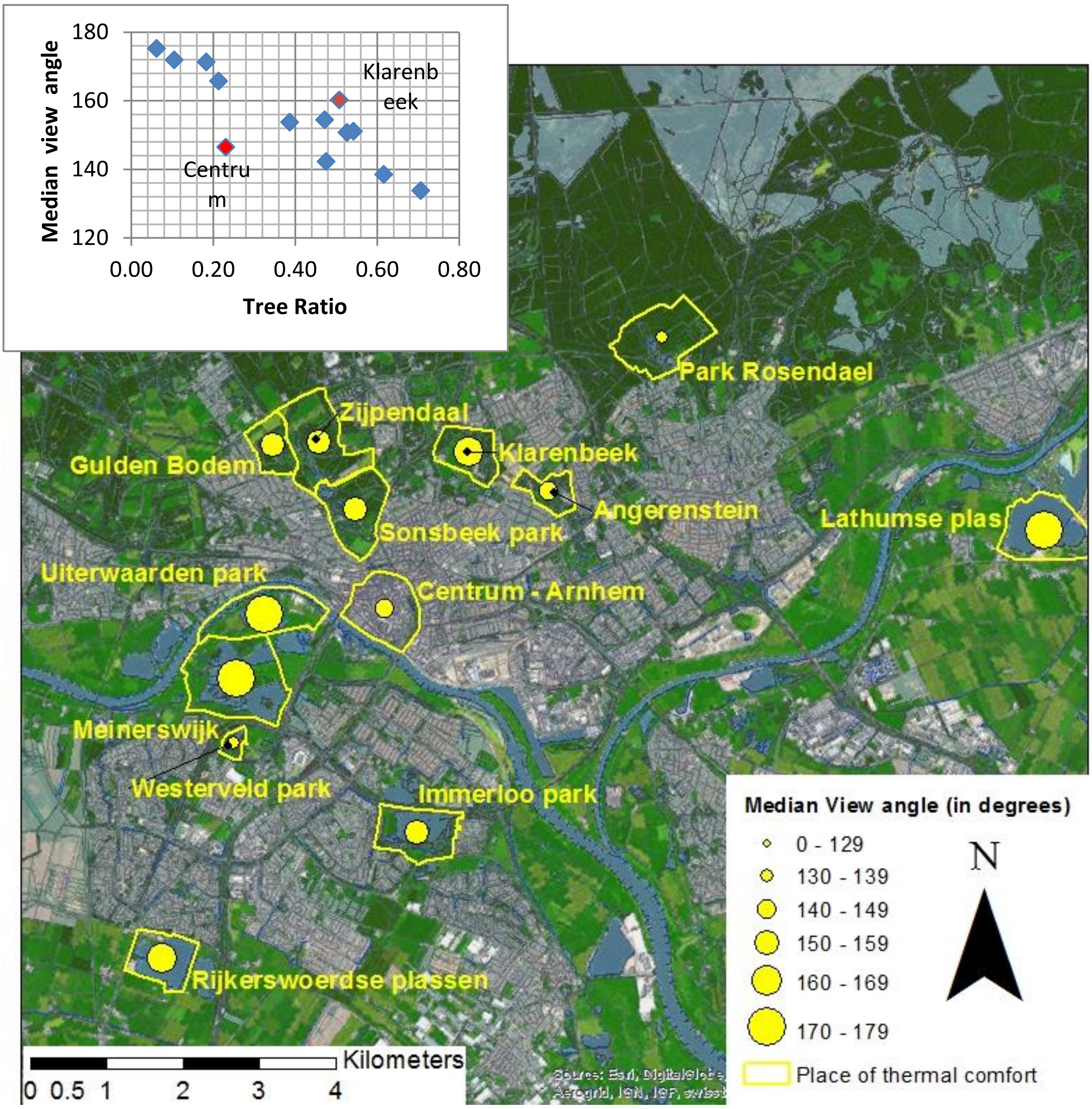


Figure 33 Arnhem - Median View angle towards the sky

Median View angle	Place of thermal Comfort
0° - 129°	
130° - 139°	"Park Rosendael" *(133,8°)*, "Westerveld Park"*(138,5°)*
140° - 149°	"Angerenstein" *(142,3°)*, "Centrum" *(146,5°)*
150° - 159°	"Sonsbeekpark" *(150,7°)*, "Zijpendaal" *(151,0°)*, "Immerloo park" *(153,7°)*, "Gulden Bodem" *(154,4°)*
160° - 169°	"Klarenbeek" *(160,3°)*, "Rijkerswoerdse plassen" *(165,7°)*
170° - 179°	"Meinerswijk" *(171,3°)*, "Lathumse plas" *(171,9°)*, "Uiterwaarden park" *(175,2°)*

Table 10 Arnhem - Values Median View angle towards the sky

The "Park Rosendael" has the lowest -, and the "*Uiterwaarden park*" the highest median view angle. The "*Centrum*" stands out from the other places of thermal comfort with a relatively low median view angle with respect to the tree ratio (0,31), see Figure 33. The park "*Klarenbeek*" stands out from the other places of thermal comfort with a relatively high median view angle with respect to the tree ratio (0,51).

5.2.4 Distance

In Figures Figure 35 - Figure 40 (page 55 - 57) give a visualization from which part of city the visitors of the top places of thermal comfort originate. The additional graphs present the distance all respondents have to overcome to reach a the selected place of thermal comfort, divided per classes of 1 kilometre (x-axes). The red bars indicate which amount of all respondents fall within each distance class. The blue bars indicate which amount of those respondents indicated to go to that place during warm summer periods. As an example, Figure 36 shows that 47 respondents of all 192 respondents in Rotterdam live in a distance between 3 to 4 kilometres of the "*Vroesenpark*". From those 47 respondents, 5 indicated to go to the "*Vroesenpark*" during warm summer periods.

There is a trend that with increasing distance from the place of thermal comfort, a smaller portion of the respondents per distance class has indicated to go to the respective place (Figure 34, example "*Vroesenpark*"). The probability distribution – based on the distance class of one kilometre – to go to a place of thermal comfort appears to be not symmetrical. To compare both groups - all respondents and visitors – the median distance of these two groups has been calculated.

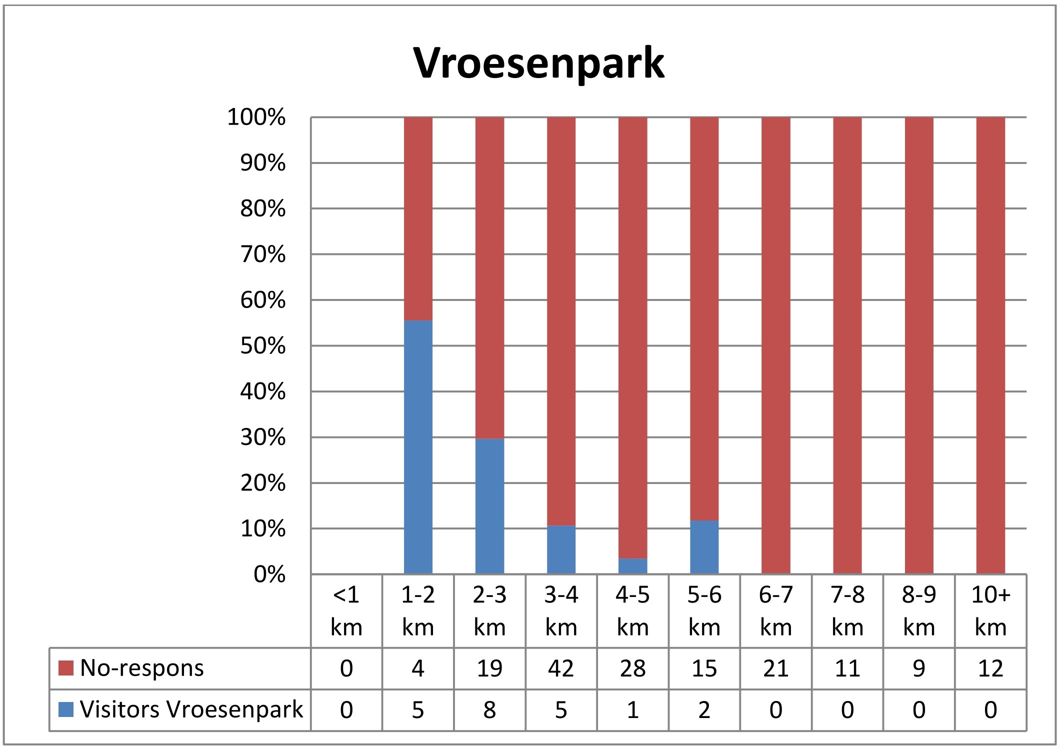
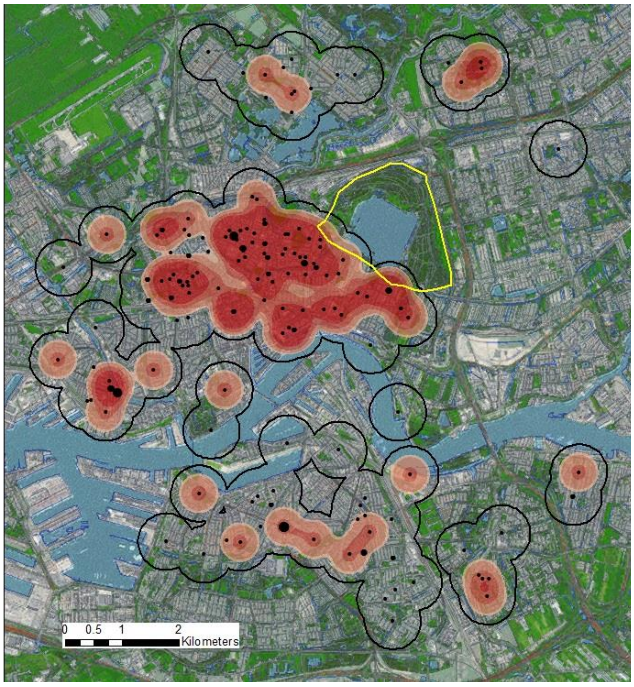


Figure 34 Percentage which indicate to go to Vroesenpark, per distance class

Rotterdam

The “*Kralingse Plas*” and “*Vroesenpark*” are both situated in the north of Rotterdam. With a median distance of 4,43 kilometre, “*Vroesenpark*” is closer in reach of all respondents than the “*Kralingse plas*” (5,19 km). Though, the “*Kralingse plas*” appears to attract more citizens in Rotterdam. Respondents up to 10 kilometres distance indicated to visit the “*Kralingse plas*”. It is noticeable that citizens in the direct vicinity of the “*Vroesenpark*” indicate to go to the “*Kralingse plas*”. This appears to be less prominent the other way around.



Respondents total:	192
Respondents Kralingse plas:	97
Median distance total:	5,19 km
Median distance Kralingse plas	4,09 km

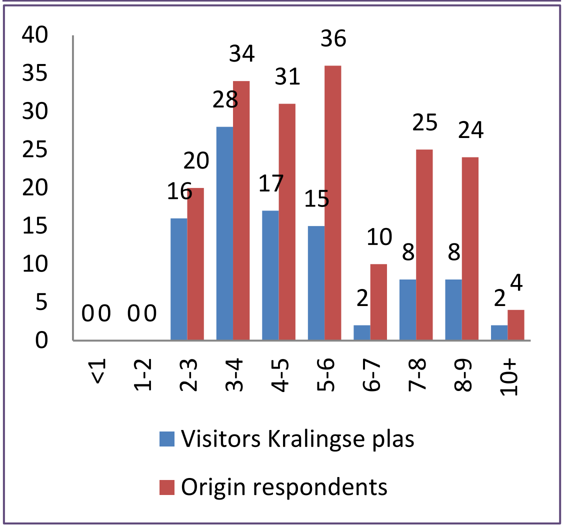
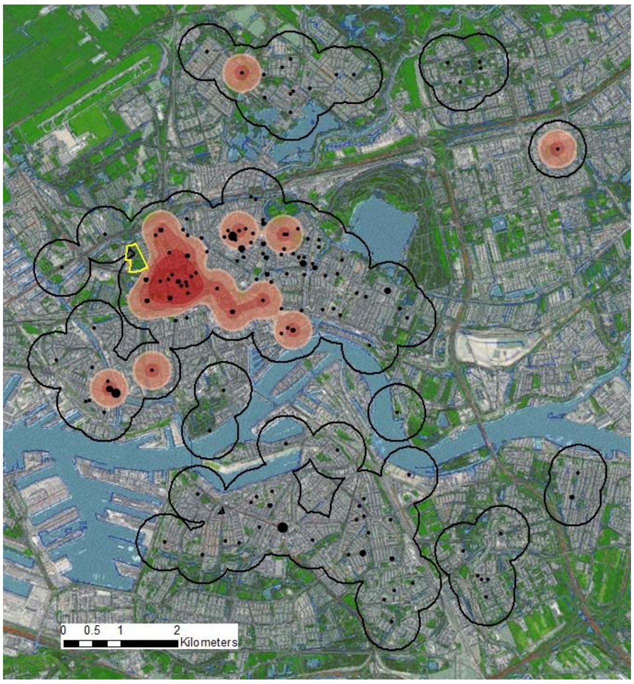


Figure 35 Rotterdam - Visitors Kralingse Plas



Respondents total:	194
Respondents Vroesenpark:	22
Median distance total:	4,43km
Median distance Vroesenpark:	2,36 km

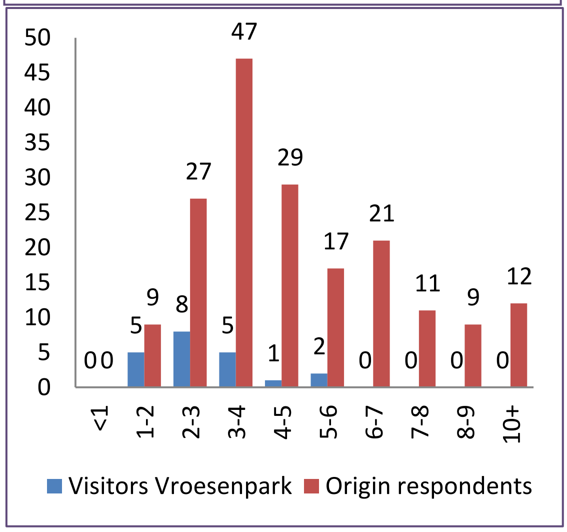


Figure 36 Rotterdam - Visitors Vroesenpark

Utrecht

The “*Wilhelminapark*” and “*Griftpark*” are situated on the east –, respectively north-east side of the city. With a median distance of 2,94 km, “*Griftpark*” is slightly closer in reach of all respondents than the “*Wilhelminapark*” (3,26 km). Though, in total more respondents have indicated to go to the “*Wilhelminapark*”. The median distance of the visitors (2,87 km) of the “*Wilhelminapark*” is even close to that of the median distance of all respondents to the “*Wilhelminapark*”. As we can see on the map, the visitors from the “*Wilhelminapark”* are coming from all parts of Utrecht.

Respondents total:	179
Respondents Wilhelminapark:	48
Median distance total:	3,26 km
Median dist. Wilhelminapark:	2.87 km

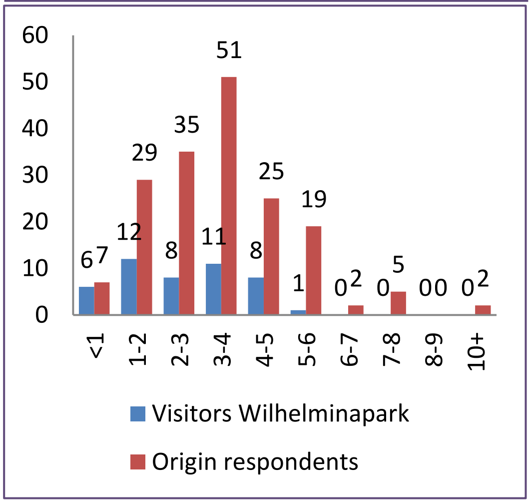


Figure 37 Utrecht - Visitors Wilhelminapark

Respondents total:	179
Respondents Griftpark:	25
Median distance total:	2,93 km
Median distance Griftpark:	1.94 km

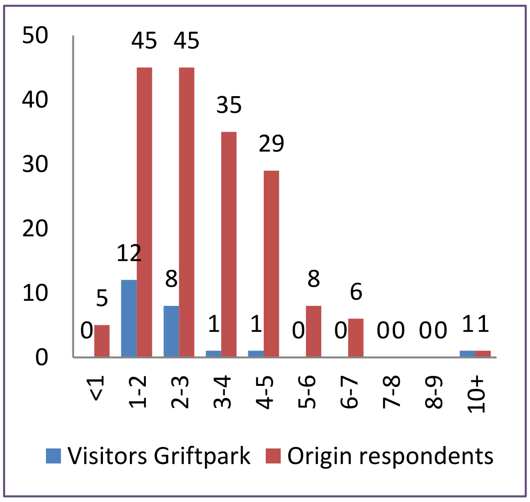
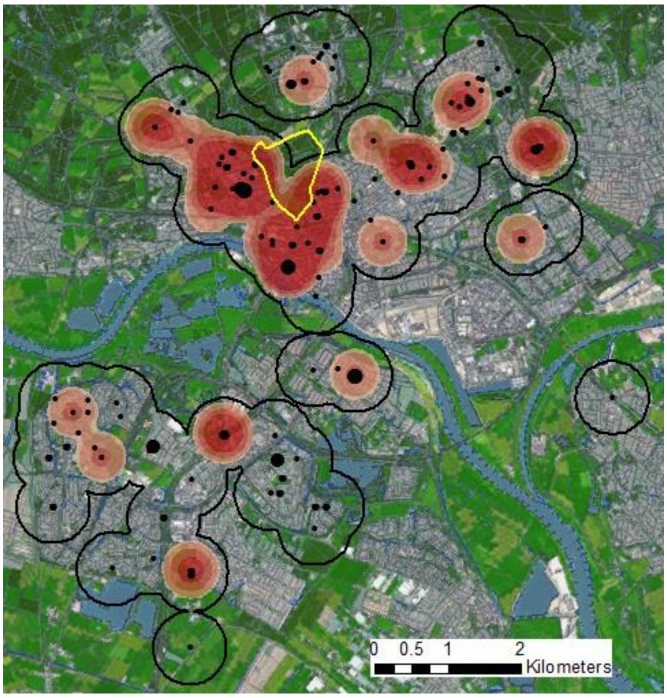


Figure 38 Utrecht - Visitors Griftpark

Arnhem

The “*Sonsbeekpark*” is situated in the north of Arnhem. The median distance of all respondents to “*Sonsbeekpark*” is 2,67 km. The visitors of “*Sonsbeekpark*” appear to come from a closer range (median distance 1,88 km), which is visible on the map. The “*Rijkerswoerdse plassen*” is situated in the very south of Arnhem, and the median distance of all respondents to this place is 7,55 km. The visitors from the “*Rijkerswoerdse plassen*” appear to come from all parts of Arnhem.



Respondents total:	182
Respondents Sonsbeekpark:	65
Median distance total:	2,67 km
Median distance Sonsbeekpark:	1.88 km

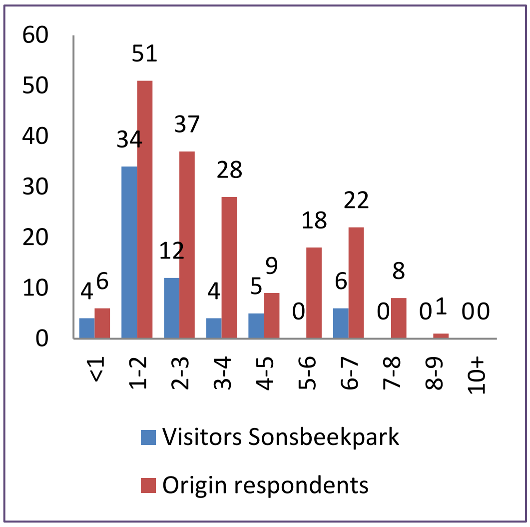
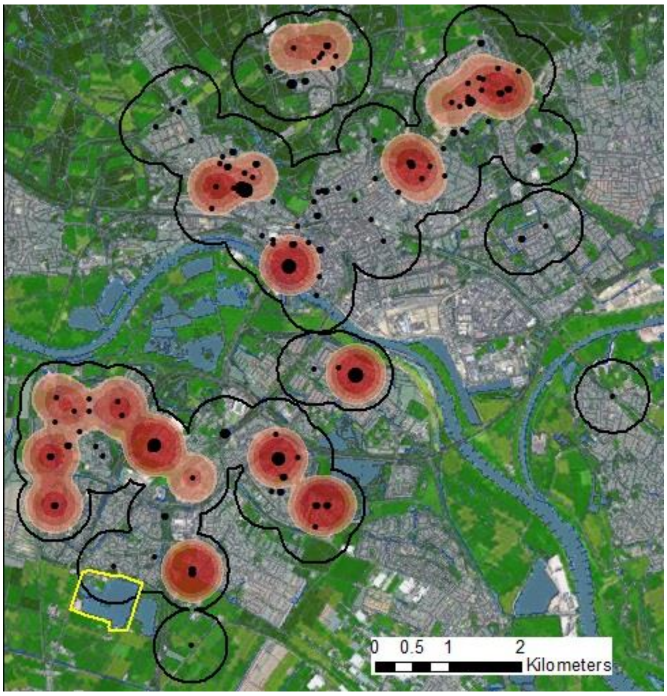


Figure 39 Arnhem - Visitors Sonsbeekpark



Respondents total:	182
Respondents Rijkersw plas.:	42
Median distance total:	7,55 km
Median distance Rijkersw plas.:	4.56 km

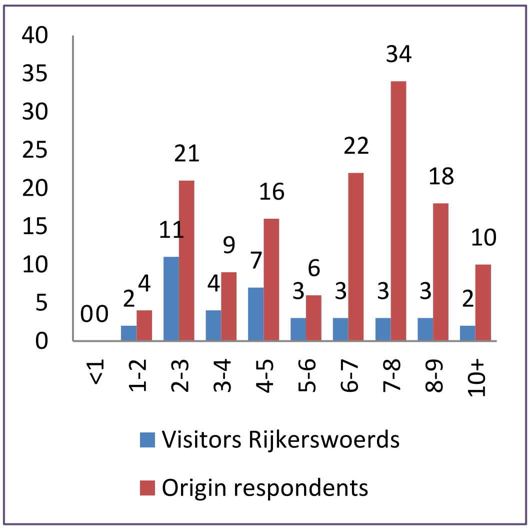


Figure 40 Arnhem - Visitors Rijkerswoerdse plassen

Chapter 6. Discussion

The mental maps of the citizens in Rotterdam, Utrecht and Arnhem have been digitalized and visualized. The resulting figures and tables (page 36 - 57) show on city level which places are preferred during warms summer periods in terms of temperature, and how the spatial environment of these places of thermal comfort compare to each other in land cover and view angle towards the sky. The Network analyst tool has approximated the distance from the respondents to the places of thermal comfort. There are several points with respect to the methodological approach and results which will be discussed in this chapter.

Places of thermal comfort

The samplings scheme of the survey intends to represent citizens from different parts of the respective city to give a reliable image which specific places are considered comfortable in terms of temperature. The geo-graphical representation of the home addresses in the three cities has been demonstrated per district (Figures Figure 17 -Figure 19, pages 36 - 37) and per street (Table 5, page 38).

The visualizations of the mental maps (Figures Figure 20 - Figure 22, pages 39 - 41) show that the places of thermal comfort which found agreement among four or more respondents, are in the vicinity of the home addresses. In the three cities together, the spatial boundary of 39 out of the 48 visualized places of thermal comfort were within a reach of 500 meter from a home address. In further distance of the home addresses there is less agreement among the respondents in what the group considers a place of thermal comfort.

A high level of agreement for a specific place to be comfortable in terms of temperature could be related to the density of home addresses surrounding the respective place. As an example; the "*Wilhelminapark*" counts the highest level of agreement among the respondents in Utrecht. At the same time it is located in- and next to districts, which represent the majority of the respondents in Utrecht. The district of the "*Wilhelminapark*" together with the three neighboring districts represent 109 out of the 179 respondents.

As noted by Curtis et al. (2013), "*though a sketch map may begin as a simple sheet of paper, it is anything but a simplistic approach to accessing people's feelings about their environment." When integrating the sketch map with GIS, these complexities are further propagated by the constraints of the software and the decisions made by the researcher*." (p. 21)

The methodology for digitalization - the localization of the home addresses and categorization-, and definition of the spatial boundaries of the places of thermal comfort - have intended to preserve the mental map as close as possible.

This was not without challenge. As Ceccato (200) has stated: "*When a bottom-up approach is used and information is gathered by means of questionnaires, there is a risk of overrepresentation of certain groups in detriment of others" (p. 925).* Moreover, restating Curtis (2013): "*... Pocock (1976), Evans (1980), and Blades (1990) have all found that variables such as individual characteristics, and instructions and materials may influence the resulting map" (p. 6).*

In this study, the configuration of the drawings itself (circles, points, expression marks) could give more weight to a certain place, which causes that the information of one respondent is more

stressed than the information given by another respondent. In this case, more input of the researcher is asked in retrieving what is meant by the respondent.
In Rotterdam, Utrecht and Arnhem with respectively 12, 15 and 11 of the home addresses there were difficulties with the localization for several reasons; a first problem was that the inserted addresses within maps.google.com database indicated another street than the location drawn by the respondent. As a solution another street which is geometrically closer to the location drawn by the respondent is used.
A second problem is the missing of an address in the database of maps.google.com. As a solution the location drawn by the respondents was compared to the map of maps.google.com, and a street was chosen that coincided with that drawn location.
Also the definition of spatial boundaries of the places thermal is sometimes completely left over to the researcher: the "*Rottemeren*" (Rotterdam), "*Maarsseveens plassen*" (Utrecht) are situated outside the extent of the base map.

In the visualization, Figures Figure 20 - Figure 22, not all indicated places of thermal comfort are included; only the places of thermal comfort which found agreement among four or more respondents. As mentioned in the results, in Rotterdam, Utrecht and Arnhem this would leave respectively 25,1%, 24,1%, and 23,5% of the indicated places of thermal comfort not visualized. These places are falling outside the categorization- and visualization decisions; the places stand for a specific street or cafe, or are outside of the city.

According to the defined methodology (paragraph 4.1.2), within the geographical extent of the drawings, physical barriers define the spatial boundary of the polygon. By "*visiting*" the places of thermal comfort with a satellite image, in some situations it is doubted whether physical barriers would also represent the experience of the respondent on the ground, visually speaking. Especially in places of thermal comfort that were outside of the building environment, and visual sightlines could reach further than the defined physical boundaries, like the dike next to the "*Rotte*" (river in Rotterdam), "*Maasboulevard*" (Rotterdam) or "*Meinerswijk*" (Arnhem). The visual experience could also be smaller than the defined spatial boundaries; within the place of thermal comfort "*Vecht*", outside of Utrecht, there are biking lanes surrounded by hedges.

Spatial variables

The quantification and visualization of the land cover classes (water, trees, open), and view angle towards the sky have presented variation in numerical value. This variation in numerical value indicate that the places of thermal comfort differ in their spatial environment. As an example; the median view angle in "*Griftpark*" and "*Wilhelminapark*" (Utrecht) have a value of 173,0° and 138,5°, which could present that the "*Griftpark*" has a more open and sunny spatial environment.
Furthermore, the Figures Figure 25 - Figure 33 show that a dominant land cover class or the value of the median view angle can be clustered within a certain region of the city, taking the places of thermal comfort as a reference. As an example; in Arnhem the land cover class Trees appears to be more dominant in the north of the city, and the land cover class water appears to be more dominant in the south of the city; in Utrecht the places of thermal comfort with a low median view angle are more concentrated in center of Utrecht.

The visualization of the pie-diagrams of Figures Figure 25 - Figure 28 can be misleading in "what is out there". The definition of 1) the spatial boundary of the place of thermal comfort, and 2) the land cover classes could create a biased view of the spatial environment of the place of thermal comfort:

Total area

- The "*Oude haven*" has the biggest tree ratio of all places of thermal comfort in Rotterdam. Since it is a small area (1.6 ha), this tree ratio could be based on just a few trees. Same counts for "*Dom"*, "*Neude"*, and "*Ledig Erf"* in Utrecht, which cover an hectare or less.
- The "*Kralingse Plas*" has a total defined area of 340.8 ha. The land cover classes Trees and Open are cover respectively an area of 94.5 ha and 124.6 ha. It is imaginable that within this place of thermal comfort there are relatively large areas covered with only trees or, or relatively large areas which are completely open.

Shape

- The place of thermal comfort "*Rotte*" has a relatively oblong shape. In a close perimeter around a location within "Rotte" there are other spatial variables which could be part of the experience of a respondent.

Land cover classes

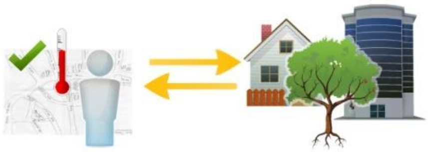
- Sometimes spatial variables are not spatially exclusive, like water and trees in "*Oude Gracht*". The water within this places of thermal comfort can be found under the trees.

Despite the validity of the measurements in ArcGIS, the quantification of the spatial variables - on city level - give more interpretation of how these spatial variables relate to each other. The scatterplots of the relation between the Tree ratio, and median- and the interquartile range of the view angle (see Appendix G) could represent the influence of tree canopy on the openness of the environment. With increasing amount of trees, the median of the view angle within a place of thermal comfort decreases.
Furthermore, the scatterplots gave a notion that not only the total area under trees, but also the spatial planning of the trees or surrounding buildings influence the median view angle within the place of thermal comfort:
"*Neude*" and "*Dom*" (Utrecht), and "*Centrum Arnhem*" have a relatively low median view angle in comparison with the tree ratio, which could be caused by surrounding buildings.
"*Zevenhuizerplas*" (Rotterdam) and "*Klarenbeek*" (Arnhem) have a relatively high mean view angle in comparison with the tree ratio, which could be related to the clear division between open area and trees.
The results of the distance calculations (Figures Figure 35 - Figure 40) have presented that respondents visiting a specific place of thermal are mainly from closer neighborhoods. The median distance of the visitors of a certain place of thermal comfort is smaller than the median distance of all respondents in the respective city. In some cases, this median distance of the visitors reaches relatively more remote areas ("*Rijkerswoerdse plassen*", Arnhem, 4.56 km), or even approximates the median distance of all respondents in the city ("*Wilhelminapark*", Utrecht, see Figure 37).
The influence of distance on whether a respondents would indicate place of thermal comfort, returns us to the visualized places of thermal comfort of Figures Figure 20 - Figure 22. As an example, Figure 21 (Utrecht) makes it questionable whether higher levels of agreements are found in the center

because they are relatively close to all respondents. Eight out of the 20 visualized places of thermal comfort are situated within the center of Utrecht.

The accuracy of the measured spatial variables is discussed. If a digital elevation model like AHN is used to distinguish vegetation from surrounding buildings, a higher resolution (0.50*0.50m in stead of 2.50*2.50m) would give more accurate results. Hyper spectral data could give more accurate information about the spatial distribution of trees, and even tree species. Within this thesis the distance has been calculated to a point of gravity which represents the place of thermal comfort. In a case when the shape is rather stretched, the distance towards a place of thermal comfort like "*Rotte*" could be overestimated.

Relation spatial variables and places of thermal comfort

	*How can we statistically validate which variables determine a place of thermal comfort?*

In this section a methodological approach will be discussed to determine which (spatial-) variables determine a place of thermal comfort. As a start I will reflect on the research steps taken so far:
Going back to the literature review on mental maps (Chapter 2), and the preliminary analysis of the mental maps of the citizens of Rotterdam, Utrecht and Arnhem (Section3.2), I recall that the mental map gives personal and place specific information. The personal character of the mental maps comes forward through its content (where and why thermal comfort is experienced), and the way it is communicated (the manner of drawing and argumentation).
In the methodological framework of this thesis the intention was to preserve the mental maps as close as possible with the digitalisation of the home addresses and places of thermal comfort, as described in Methods section 4.1.1 and 4.1.2.
Furthermore, the respondents informed us which (spatial-) variables would be important in a place of thermal comfort (referred to words like “Sun”, “Shadow”, “Water”, “Green” and “Trees”). Spatial variables have been defined (land cover, view angle towards the sky, and distance) which approximated these words, and were spatially exclusive and quantifiable in Geo-Information systems like ArcGIS.

So far, the application of the methodology has digitalized the home addresses and places of thermal comfort, and quantified the chosen (spatial-) variables. The resulted collection of figures and tables (see Chapter 5) enables the researcher to do analysis on city level, and see:

- which places have agreement among the respondents to be comfortable in terms of temperature.
- which districts are represented by the survey, referring to the home addresses of the respondents.
- how the numerical value of the measured spatial variables varies between the visualized places of thermal comfort (,-and how spatial variables relate to each other, like the Tree ratio and view angle)
- which distance respondents have to overcome to reach a place of thermal comfort.

This is not new information. But what I would like to stress is that at this stage we merely see attributes (frequencies, land cover, view angle, etc) with their values, related to a place. As an example, referring to the “*Wilhelminapark*”, the visualizations answer questions like: how many people go there and where do they come from? How much area is covered by trees? Are there possibilities to move from the sun into the shade during the day?
But, how can we statistically validate the relationship between this information, i.e. which (spatial-) variable explains that more respondents in Utrecht indicated to go to the “*Wilhelminapark*”? Does the presence of trees attract citizens to the park? Or is the level of agreement higher in this park because more respondent originate from the surrounding districts? The definition of a place of thermal comfort most probably does not rely on just one of these variable. That leaves the question what is the relative contribution of these variables? How do the respondent value these variables?

The research objective was to obtain a generic idea which (spatial-) variables determine places of thermal comfort within the urban environment during warm summer periods. During the course of this thesis, we "*lifted off*" from the city ground (see Figure 41), after being informed by the respondents in the pre-processing phase (section 3.2). We saw variation in level of agreement for the places of thermal comfort, and variation in the numerical value of the measured (spatial-) variables.
The variation of the values of the independent variables (spatial variables), could give more statistical underground to explain why certain places are preferred above the other.

Though, to achieve the research objective we will have to return to the information embedded in the questionnaires and mental maps. Until now, the analysis of the chosen spatial variables and visualized places of thermal comfort leaves much personal an place specific information of the mental maps unnoticed. In the end, the person defines what value he or she attaches to certain spatial variables, which would make up a place to be comfortable in temperature or not. The closed questions of the questionnaire already indicated that the difference in home situation or age class influence the chosen destination within the urban environment during warm summer periods.
Referring to the place specific information: in this thesis, the analysis of the spatial variables is constrained to the most preferred places of thermal comfort, defined by the respondents. With the visualized pie-diagrams it is questionable what the urban environment would look like outside these places of thermal comfort; whether, for instance, the visualized places of thermal comfort find more agreement because all other places within the cities do not have trees at all.
Furthermore, by revisiting the arguments of the respondents (see Appendix H) we see that certain characteristics related to thermal comfort are solely found in a certain place and are discrete in nature, like the presence of a terrace or the opportunity to swim.

In a multivariate statistical model like mixed logit regression, discrete- (opportunity to swim) and continuous variables (Tree ratio/View angle/etc.) could validate the discrete definition of a place to be comfortable. Such a statistical model allows that the value for a certain spatial variable is not fixed (do students prefer beer on a terrace above other minority groups?), and places of thermal comfort as being a group give a higher probability to be defined as comfortable (because "*Dom*", "*Lepelenburg*" and "*Oude Gracht*" are in each vicinity). (Termansen et al., 2008)

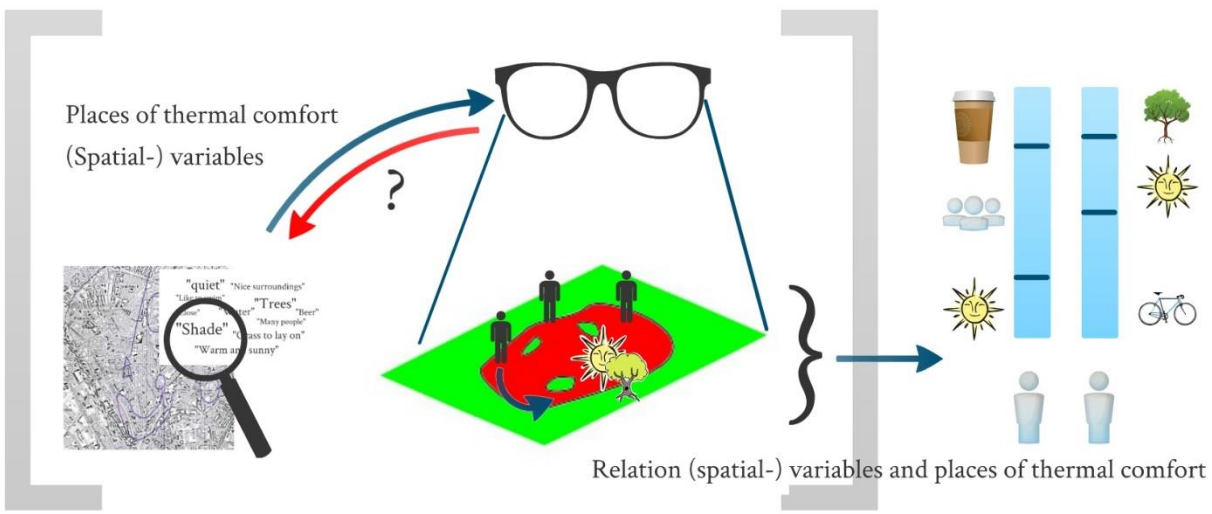


Figure 41 Methodological approach to define relation between (spatial-) variables and places of thermal comfort

Chapter 7. Conclusion

In Rotterdam, Utrecht and Arnhem respectively 192, 179 and 182 questionnaires and mental maps have been collected which inquired the perception of the citizen towards the urban environment during warm summer periods. The sampling scheme of the surveys was based on districts.

The mental maps give personal information about *where* within the urban environment comfort is experienced in terms of temperature, and for *what reasons*. This information is communicated by drawings and textual information on a base map (ground plan) of the respective city.

In this thesis, a methodology of digitalisation, visualisation and analysis within Geo-information sciences has been explored, that is able to deduce, from these drawn mental maps of the citizens, a generic idea which (spatial-) variables determine a places of thermal comfort.

In doing so, three main research steps have been defined: 1) definition "place of thermal comfort" 2) quantification of (spatial-) variables, and 3) relating spatial variables with "places of thermal comfort".

In research step one, the mental maps have been digitalized. In the digitalisation process, decisions have been formulated for the localization and categorization of the places of thermal comfort, and definition of its spatial boundaries. The freedom given to the respondents to answer, brought forward a variation (points/circles/expression marks/names) of how the places of thermal comfort are indicated. In some case this leaves the researcher in question how to represent the information of the respondent, not in disadvantage of others. The names given by the respondents, database maps.google.com and satellite image "*Basemap Imagery*" enabled the validation of location-, and spatial boundary of the places of thermal comfort.

The home addresses indicated on the mental maps have been digitalized and visualized. A spatial join with the districts of the sampling scheme showed that several districts were represented by relatively more respondents.

Per city, a composite of all mental maps presented which specific places found agreement among the respondents in finding thermal comfort. Places of thermal comfort which found agreement among four or more respondents have been visualized (i.e. top places of thermal comfort). It has been discussed that the level of agreement for a place of thermal comfort could be influenced by the density of home addresses surrounding the respective place, referring to the amount of home addresses per district.

In research step two, several spatial variables have been quantified within the spatial boundaries of the top places of thermal comfort. The questionnaires informed us that words like "Sun", "Shadow", "Water", "Green" and "Trees" were mentioned frequently in relation to a place of thermal comfort.

Spatial variables have been defined which approximated these words, and were spatially exclusive and quantifiable in Geo-Information systems like ArcGIS. These spatial variables were 1) the land cover classes water, trees, and open area, 2) view angle towards the sky.

The calculation of the land cover classes and view angle, and visualization of the obtained numerical value have shown that the places of thermal comfort differ in their spatial environment, even constrained to the top places of thermal comfort (13 in Rotterdam, 20 in Utrecht, 15 in Arnhem). Furthermore, the visualizations have demonstrated that places of thermal comfort with a similar spatial environment can be clustered in one region of the city (forest area in the north of Arnhem).

Scatter plots have demonstrated that tree cover (Tree ratio) measured within a place of thermal comfort diminishes the experienced openness (view angle towards the sky) of that place. Exeptions to this relationship (outliers) have demonstrated that also spatial position of trees or surrounding buildings can influence the experienced openness.
The results of the questionnaire showed that distance is a restriction for the respondents in finding a place of thermal comfort. In accordance, a thirds spatial variables had been chosen. Distance calculations between the home addresses of the respondents and the places of thermal comfort have presented that respondents visiting a specific place of thermal are mainly from closer neighborhoods.

The two research steps conducted so far have defined the places of thermal comfort in the three cities, and quantified spatial variables. The variation of the values of the independent variables (spatial variables), could give statistical underground to explain why certain places are preferred above the other in finding thermal comfort. Though, before trying to construct a model that could statistically validate how several independent variables are relatively valued by a person, the mental map should be revisited.
More information given by the respondents can be integrated. Both on the side of the respondent (age, home situation) and the urban environment (selection of more places) more variety in independent variables can be measured. The mental maps have presented that some characteristics can only be found within certain places in the urban environment, like the presence of a terrace, opportunity to lay down in the grass or swim in a lake.
The personal and place specific information in the mental map should function as a guide to verify how (spatial-) variables are valued, and define whether a place in the urban environment is regarded comfortable in terms of temperature.

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Appendices

Appendix A - Questionnaire Example

English translation

Closed questions

Question 1

Could you indicate for the following public spaces how comfortable you would feel on hot summer days?

- Options: Shopping street, garden, swimming pool, square, outside city, beach, forest, parking lot, pond, park, terrace, canal
- Answers: very uncomfortable – uncomfortable – neutral – comfortable - very uncomfortable

Question 2

To which extent do you agree with the following statements? A green environment on a hot summer day I find:

- ...pleasant (fijn), ...important, ...essential, ...pleasant (aangenaam)
- Answers: really don't agree – don't agree – neutral – agree – really agree

Question 3/4

Where do you go to on a hot summer day within a time frame of: <2 hours, half a day, one day, one weekend? Which kind of transport do you use?

- Options: garden/balcony, street, own neighbourhood, within city, outside city
- Options: bike, scooter, car, public transport

Open questions: Mental map

Question 5

Which places within the city you find most comfortable in terms of temperature on hot summer days?

Question 6

What are the reasons you find these places comfortable?

Other information:

- home address (also indicated on the ground plan)
- age, gender
- home situation: garden/balcony/terrace.

Original questionnaire (dutch)

Intro: Wij doen onderzoek naar thermisch comfort in de stad en welke stedelijke buitenruimtes mensen op warme zomerse dagen aangenaam vinden. Woont u in deze stad en mag ik u een paar vragen hierover stellen?

De vragen in dit interview hebben betrekking op warme en hete zomerse dagen (boven de 25 graden).

Plaats	Sub-plaats:	Datum:	Weekdag:	Tijd:	Signatuur:

1. **Kunt u voor elk van de twaalf onderstaande buitenruimtes aangeven hoe thermisch comfortabel u zich voelt op hete zomerse dagen?**

	Heel oncomfortabel	Oncomfortabel	Neutraal	Comfortabel	Heel comfortabel
Winkelstraat					
Tuin					
Zwembad					
Plein					
Buitengebied					
Strand					
Bos					
Parkeerplaats					
Meertje					
Park					
Terras					
Gracht/ kanaal					

2. **In hoeverre bent u het eens met de volgende stellingen?**
" Een groene omgeving op hete zomerse dagen is voor mijn thermisch comfort... ."

	Zeer oneens	Oneens	Nog eens/ nog oneens	Eens	Zeer eens
... fijn.					
... belangrijk.					
... essentieel.					
... aangenaam.					

3. **Waar bevinden zich de buitenruimtes waar u zich het meest comfortabel voelt qua temperatuurbeleving op hete zomerse dagen?**

Bij een tijdvak van...	Mijn tuin/ balkon	Mijn straat	Mijn wijk	Mijn stad	Buiten mijn stad	Nergens, Ik blijf binnen	**Vervoersmiddel** L=lopend, F=fiets, B=brommer, A=auto OV=openbaar vervoer
< dan 2 uur							
Één dagdeel							
Één dag							
Één weekend							

4. **Welk vervoersmiddel gebruikt u (zie laatste column vraag 5.)?**

5. **Waar in deze stad vindt u thermisch comfortabele buitenruimte op warme zomerse dagen (zie bijgevoegde kaart)?**

6. **Wat zijn de redenen waarom u deze plek comfortabel vindt (zon, wind, schaduw, bescherming etc.)**

7. **Algemeen**

Geslacht a) man b) vrouw

Hoe oud bent u? ……………………………………………………………………

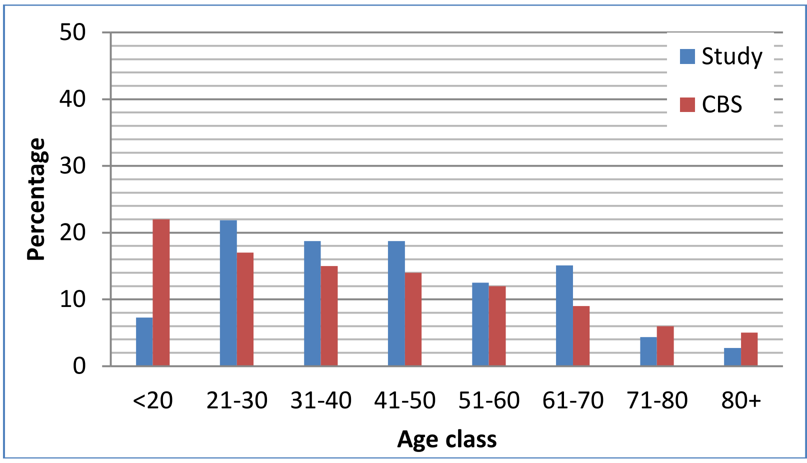
Waar woont u? …………………………………………………………………...

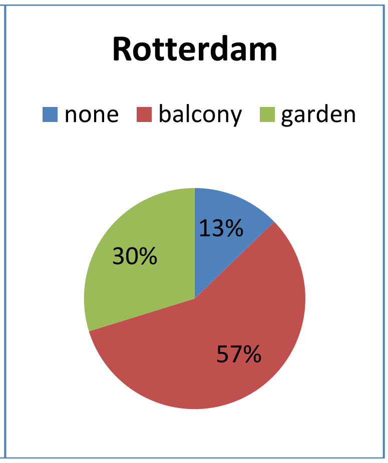
(straatnaam / plek op kaart markeren)

Beschikt u woonruimte over privé buitenruimte? a) nee b) balkon/terras c) tuin

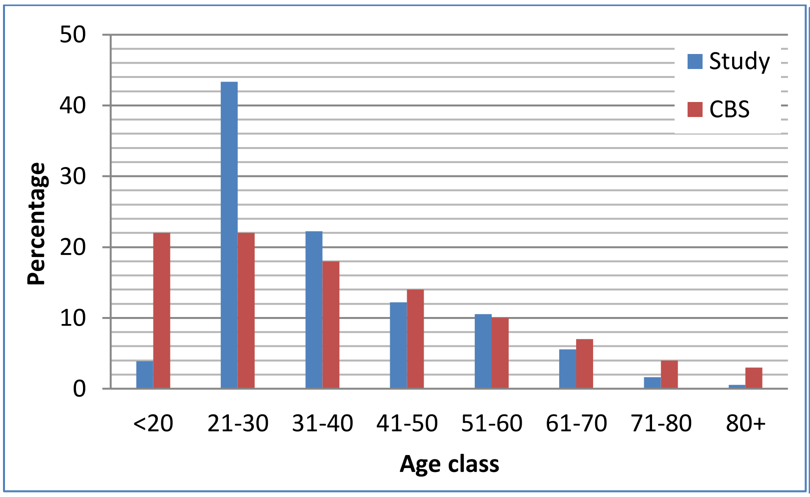
Appendix B - Questionnaire Socio-demographic characteristics

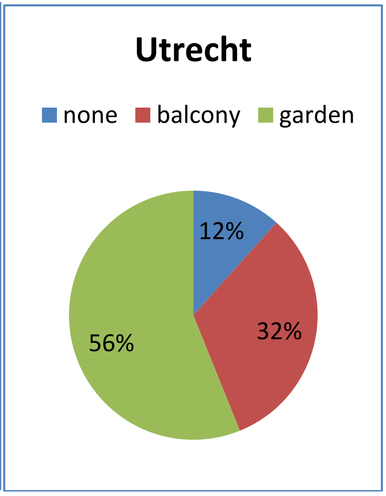
Rotterdam



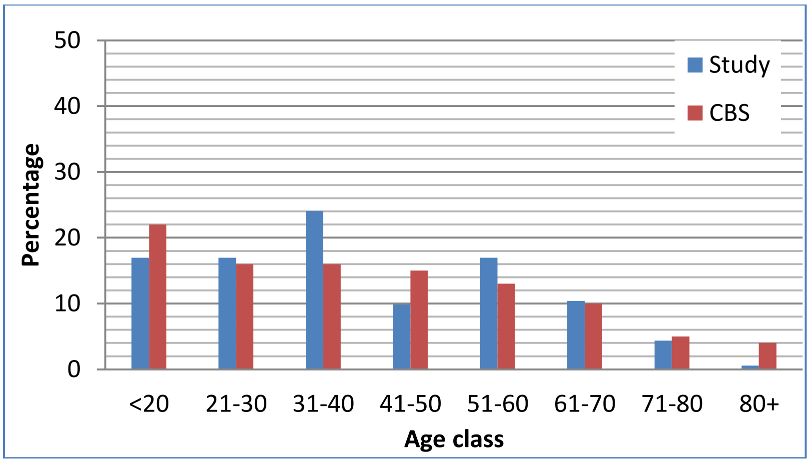


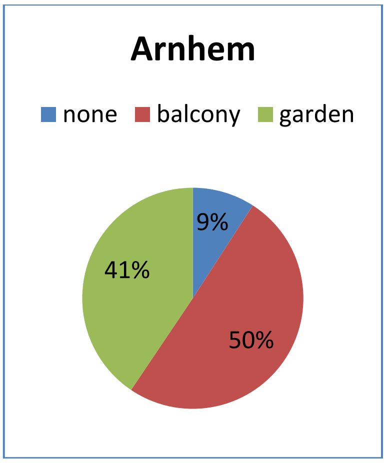
Utrecht





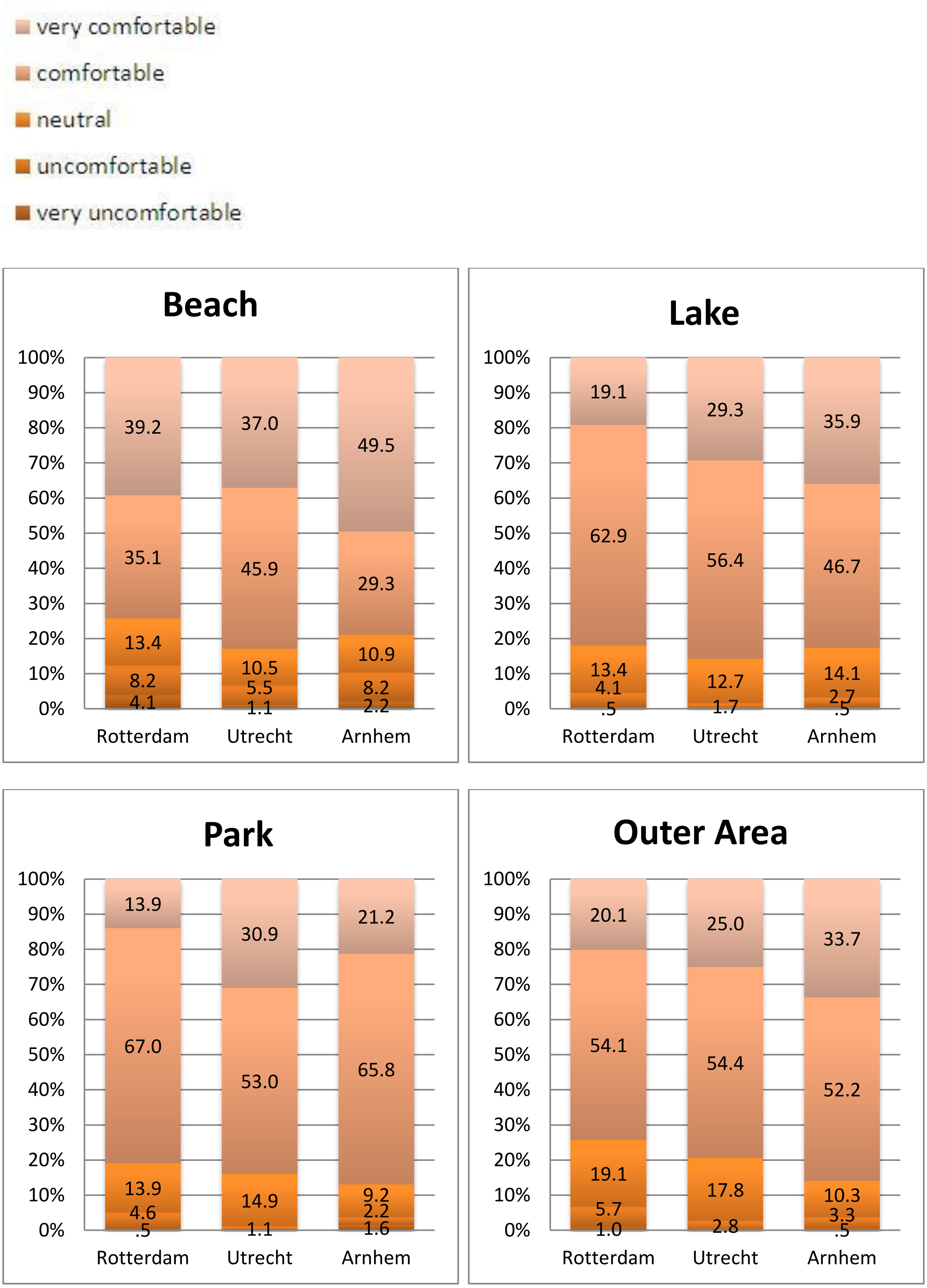
Arnhem



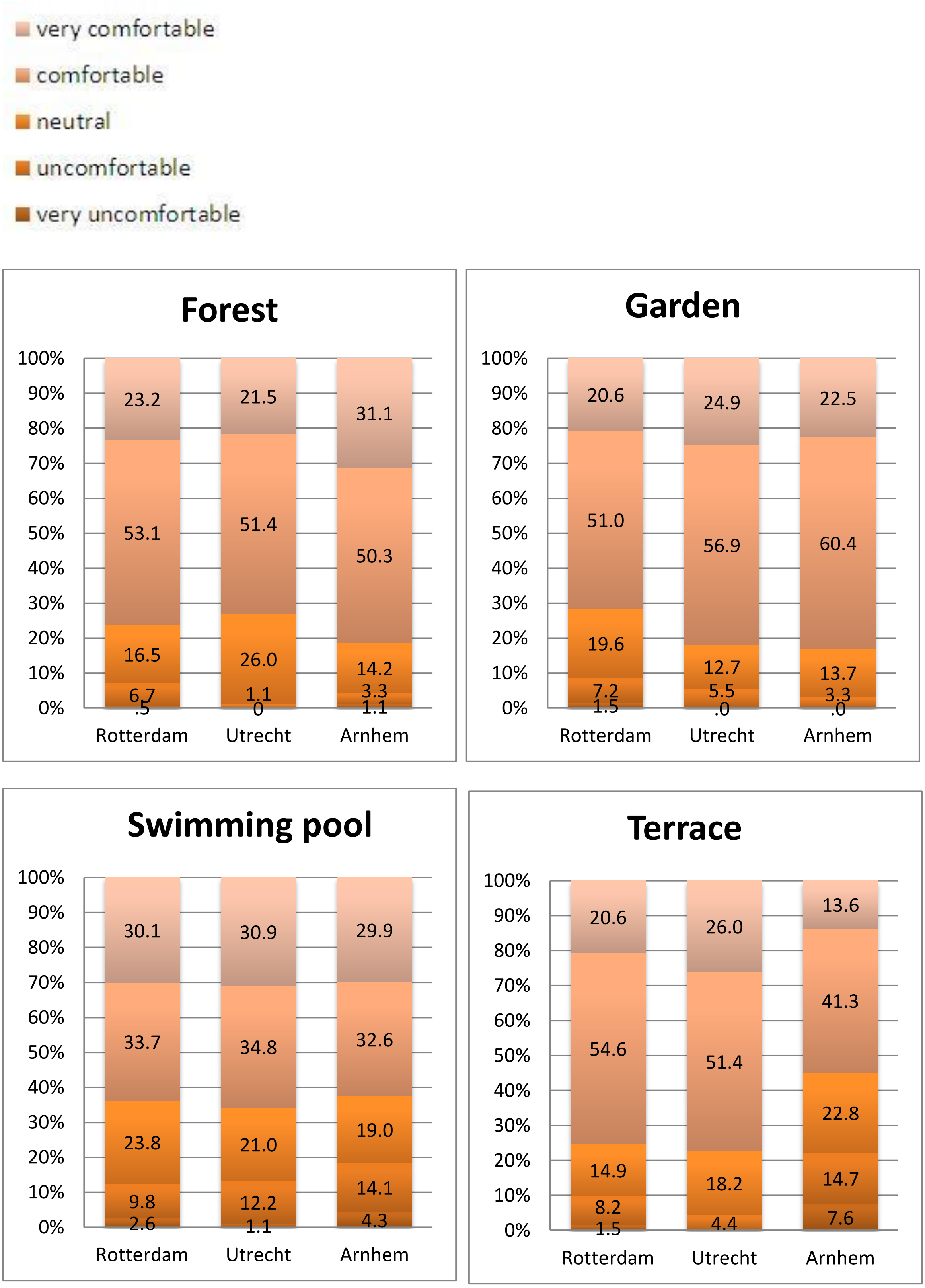


Appendix C - Questionnaire Question 1

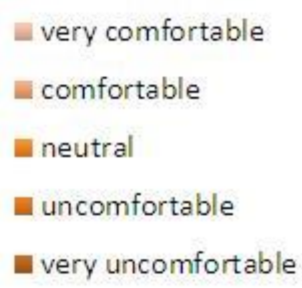
Could you indicate for the following public spaces how comfortable you would feel on hot summer days?

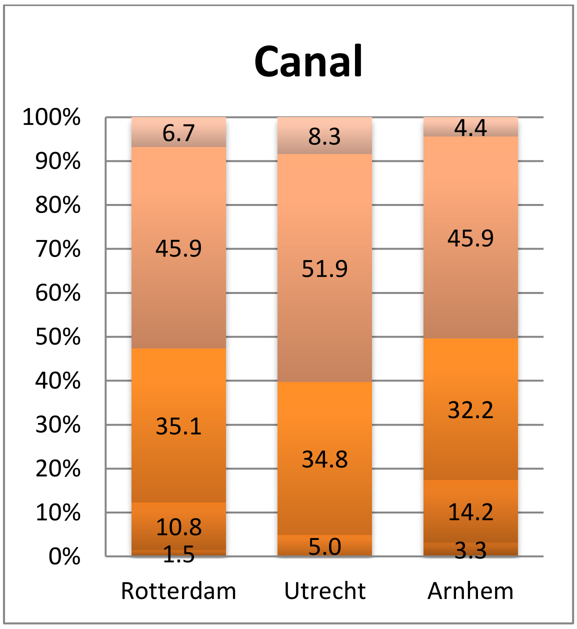


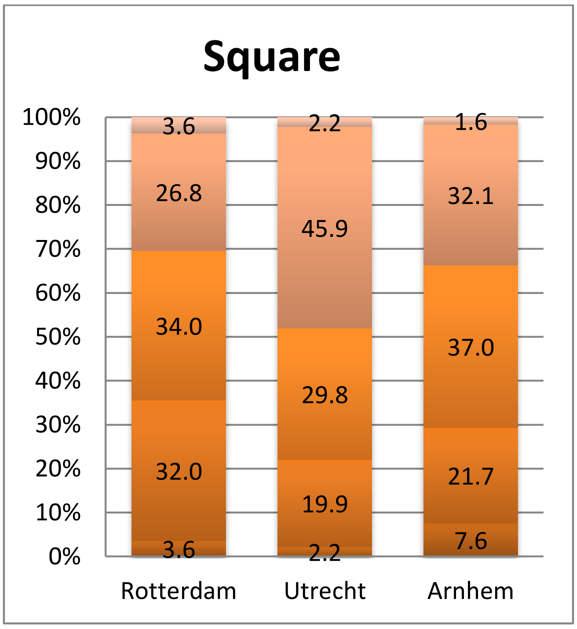
(Could you indicate for the following public spaces how comfortable you would feel on hot summer days?)

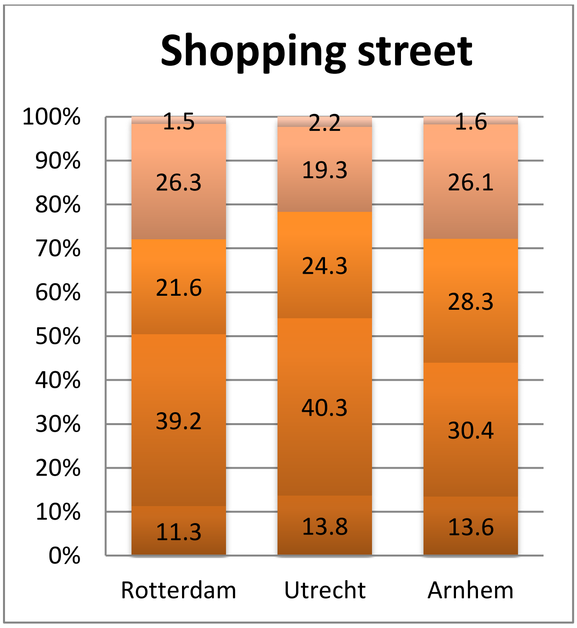


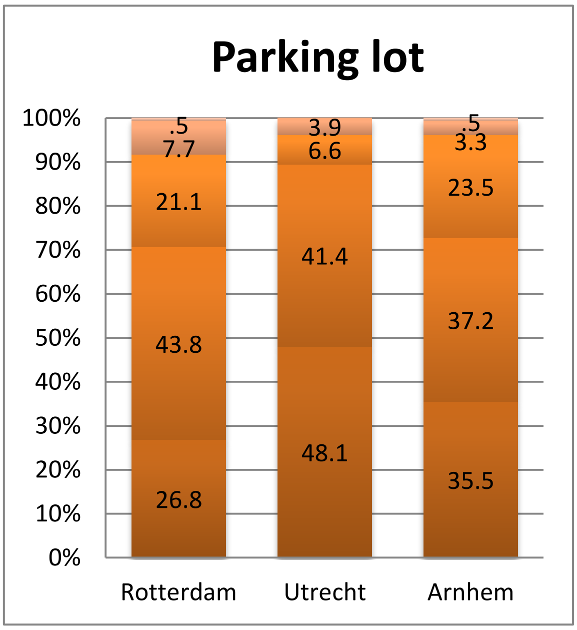
(Could you indicate for the following public spaces how comfortable you would feel on hot summer days?)



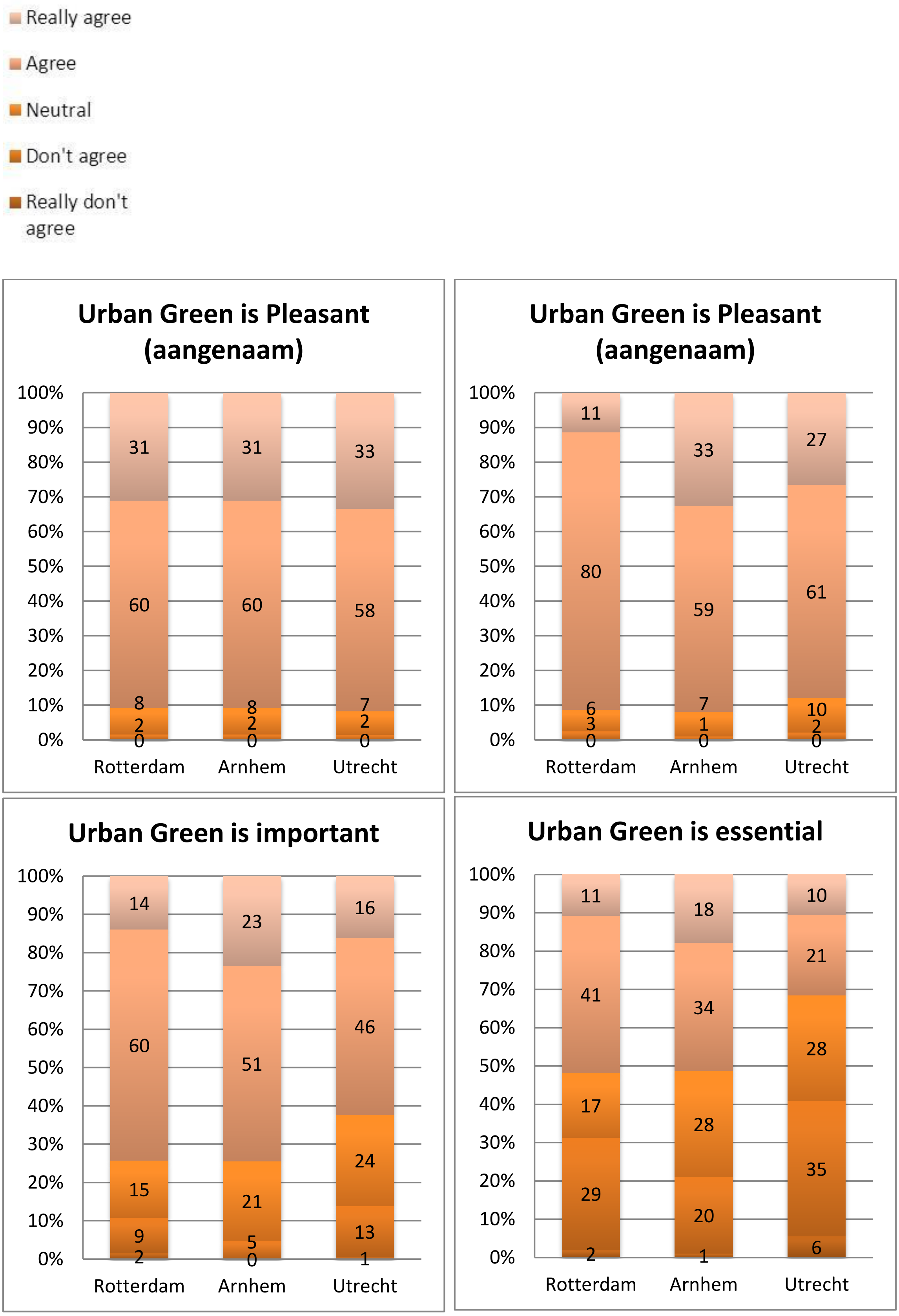








Appendix D - Questionnaire Question 2



Appendix E - Base maps questionnaire

Rotterdam


N
ROTTERDAM
NIEUWE MAAS
ROTTERDAM
ROTTERDAM
ROTTERDAM
Heijplaat
Waalhaven
Eemhaven
Gemeente Rotterdam

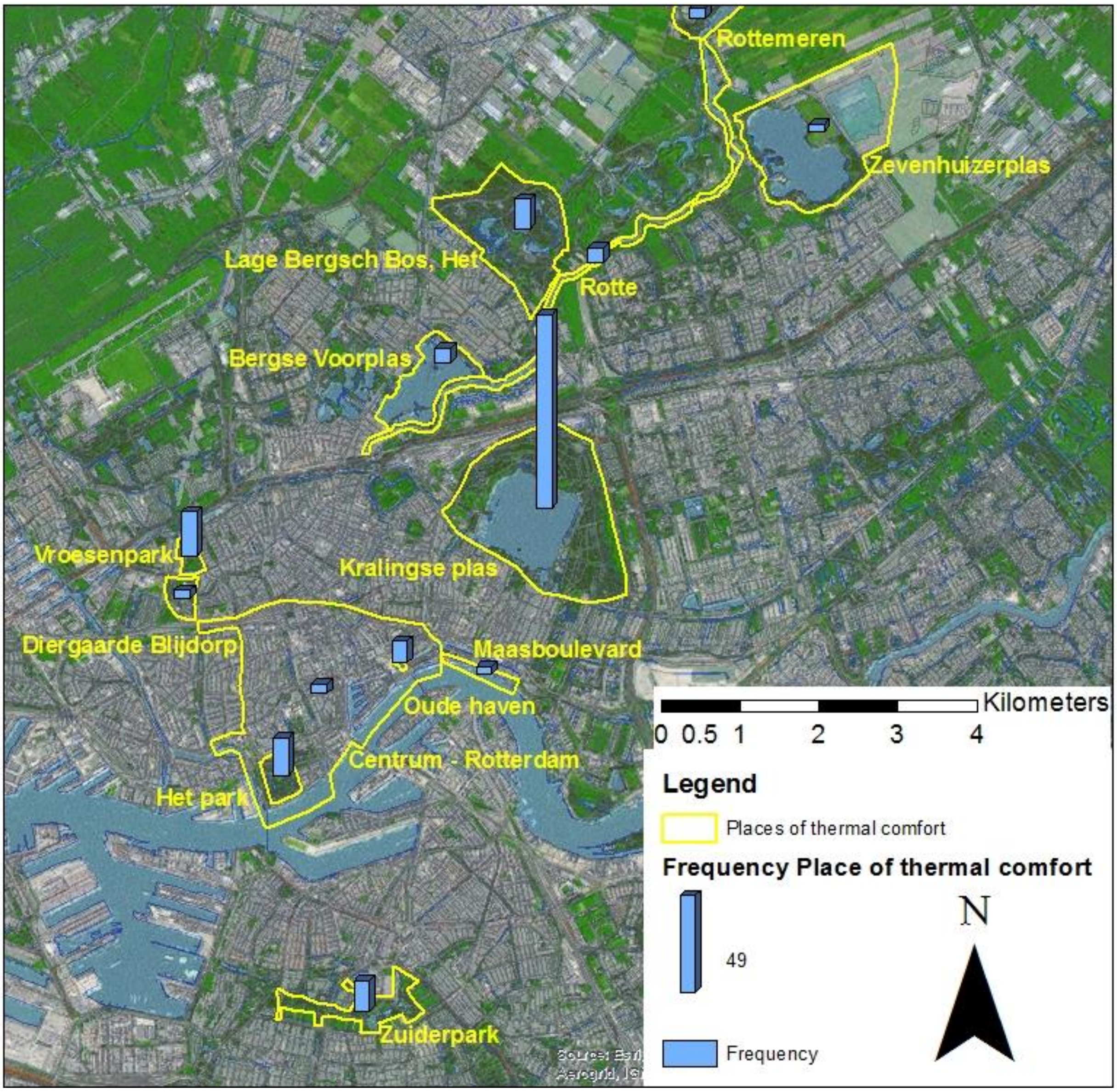
Utrecht

Arnhem


N
Velp
Rozendaal
Westervoort
Huissen
ARNHEM
Elden
Oosterbeek

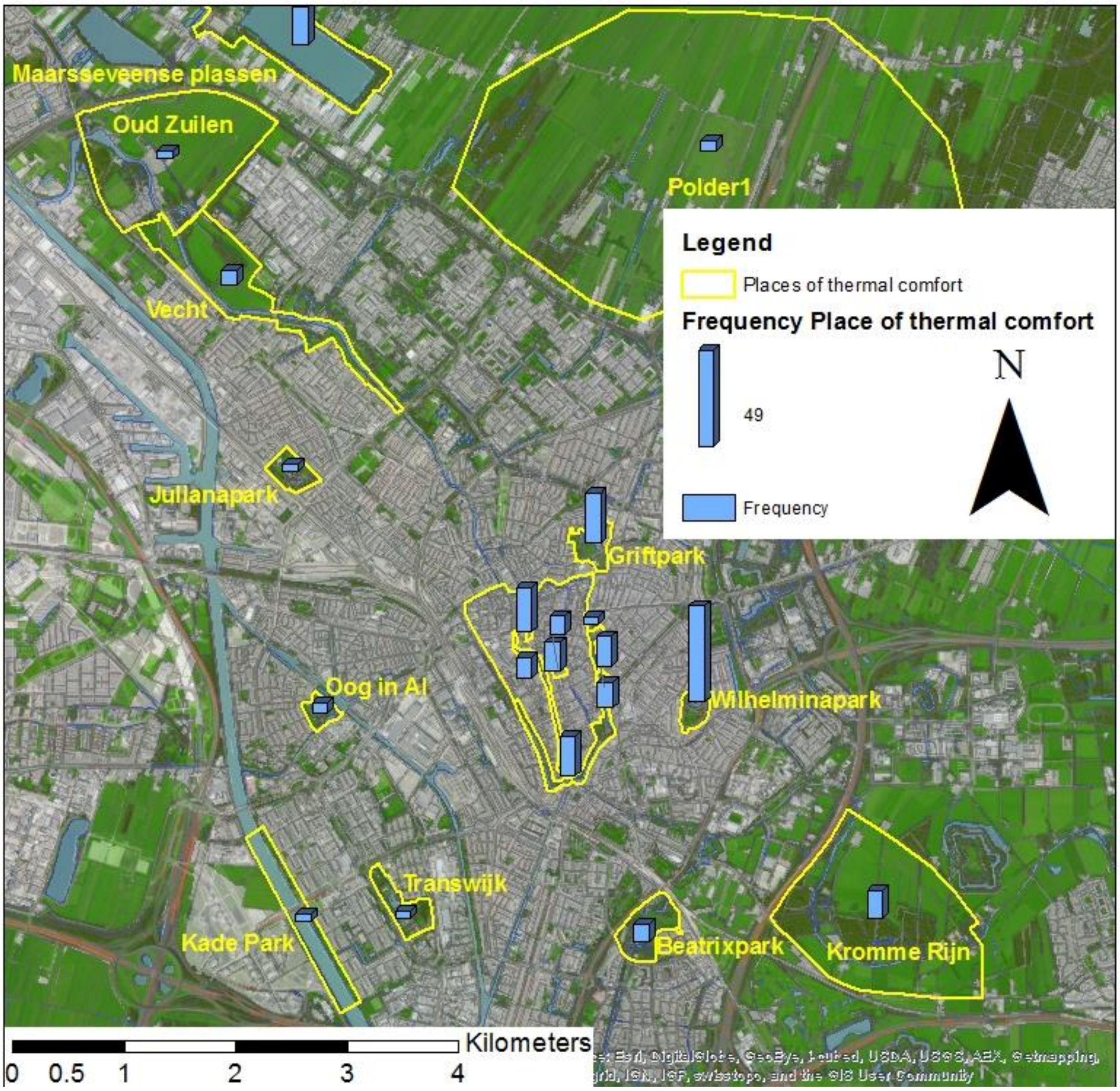
Appendix F - Places of thermal comfort

Rotterdam



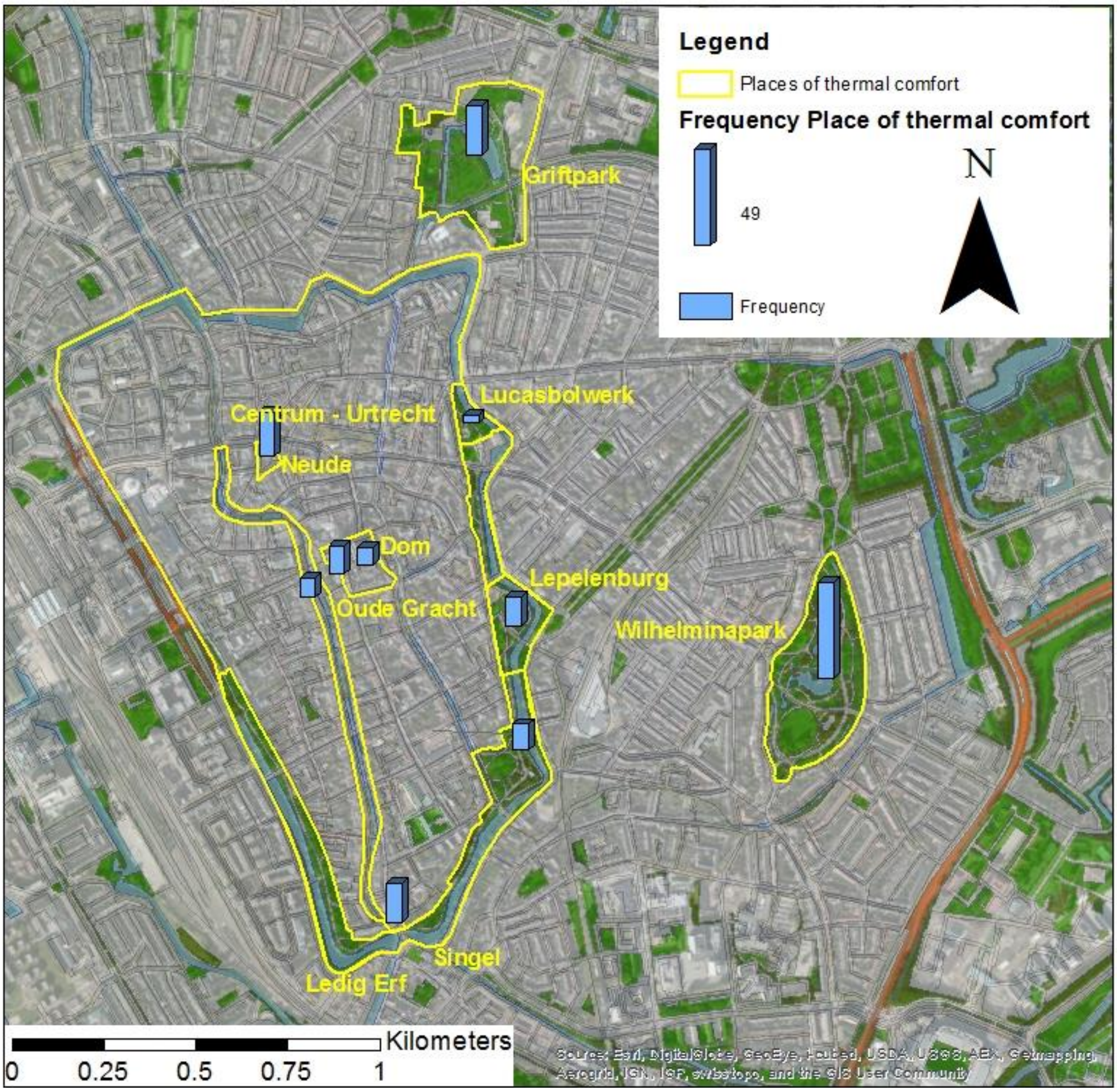
	Frequency		Frequency
Kralingse plas	*97*	Bergse Voorplas	*7*
Vroesenpark	*22*	Centrum - Rotterdam	*5*
Het park	*19*	Rottemeren	*5*
Zuiderpark	*15*	Diergaarde Blijdorp	*4*
Lage Bergsch Bos, Het	*15*	Maasboulevard	*4*
Oude haven	*11*	Zevenhuizerplas	*4*
Rotte	*7*		

Utrecht



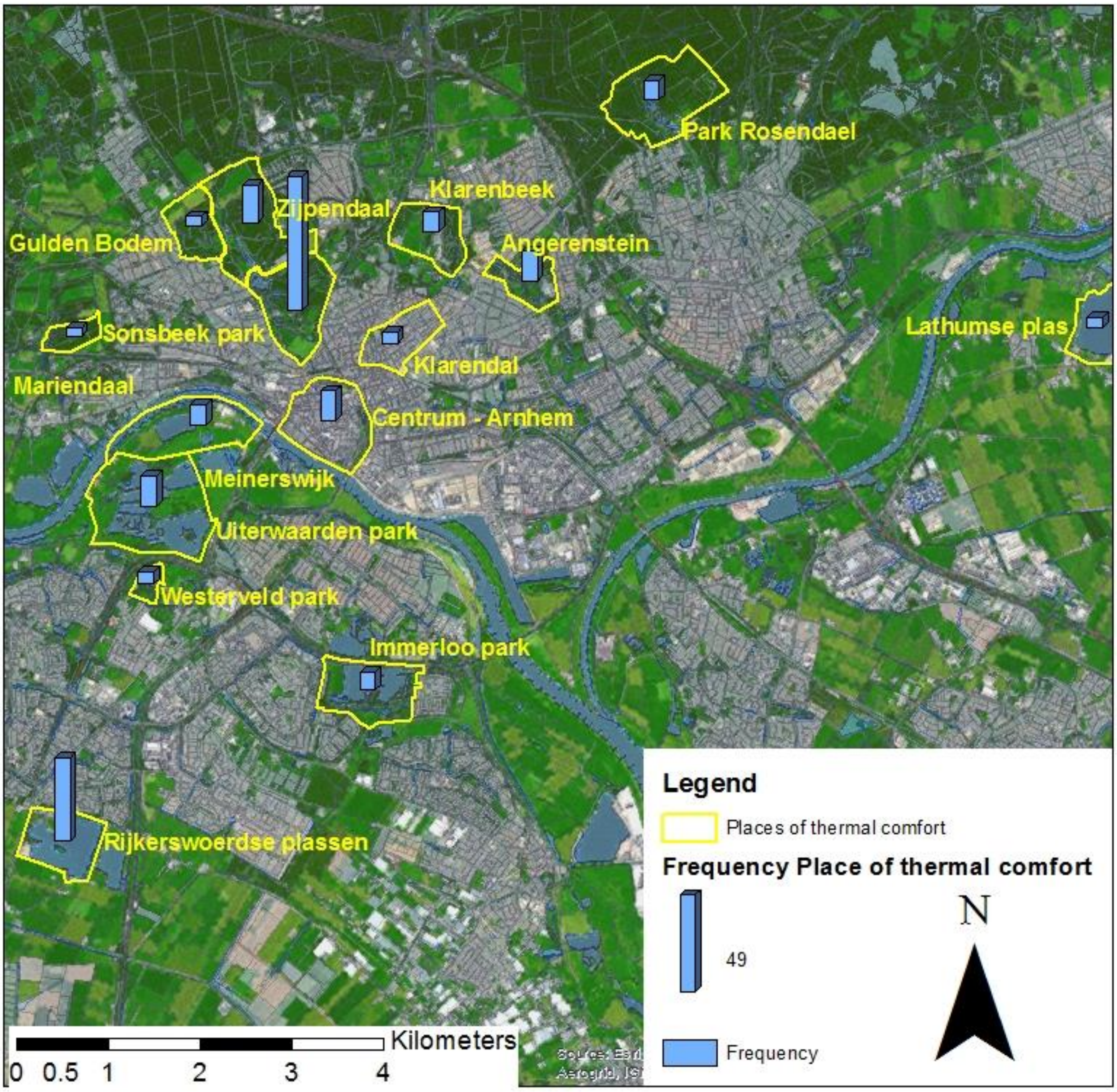
	Frequency		Frequency
Wilhelminapark	*48*	**Beatrixpark**	*9*
Griftpark	*25*	**Dom** (centre)	*9*
Neude (centre)	*22*	**Vecht**	*7*
Ledig Erf (centre)	*20*	**Polder1**	*5*
Maarsseveense plassen	*19*	**Oog in Al**	*5*
Lepelenburg (centre)	*15*	**Julianapark**	*4*
Kromme Rijn	*14*	**Transwijk**	*4*
Centrum - Urtrecht	*14*	**Oud Zuilen**	*4*
Singel (centre)	*13*	**Kade Park**	*4*
Oude Gracht (centre)	*10*	**Lucasbolwerk** (centre)	*4*

Utrecht centre



	Frequency		Frequency
Wilhelminapark	***48***	Beatrixpark	*9*
Griftpark	***25***	**Dom (centre)**	***9***
Neude (centre)	***22***	Vecht	*7*
Ledig Erf (centre)	***20***	Polder1	*5*
Maarsseveense plassen	*19*	Oog in Al	*5*
Lepelenburg (centre)	***15***	Julianapark	*4*
Kromme Rijn	*14*	Transwijk	*4*
Centrum - Urtrecht	***14***	Oud Zuilen	*4*
Singel (centre)	*13*	Kade Park	*4*
Oude Gracht (centre)	***10***	**Lucasbolwerk (centre)**	***4***

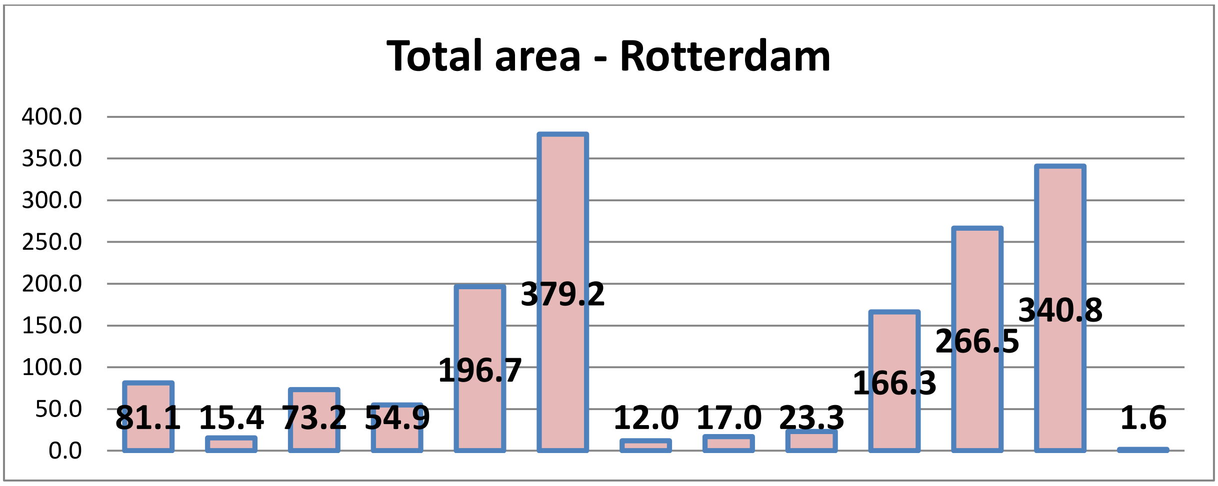
Arnhem

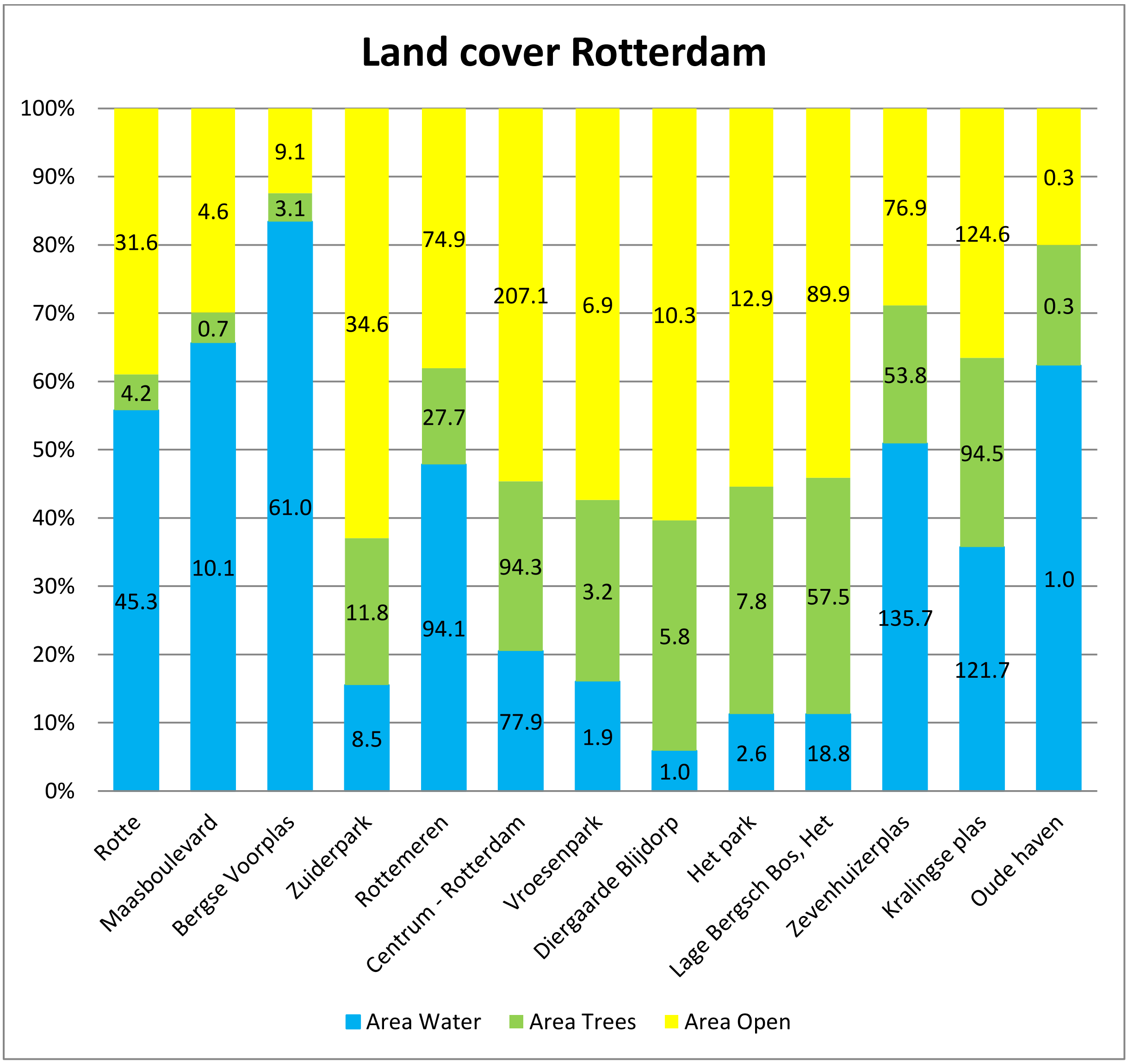


	Frequency		Frequency
Sonsbeek park	***67***	**Park Rosendael**	***10***
Rijkerswoerdse plassen	***42***	**Immerloo park**	***9***
Zijpendaal	***19***	**Westerveld park**	***6***
Centrum - Arnhem	***15***	**Klarendal**	***6***
Meinerswijk	***15***	**Gulden Bodem**	***5***
Angerenstein	***15***	**Lathumse plas**	***5***
Uiterwaarden park	***10***	**Mariendaal**	***4***
Klarenbeek	***10***		

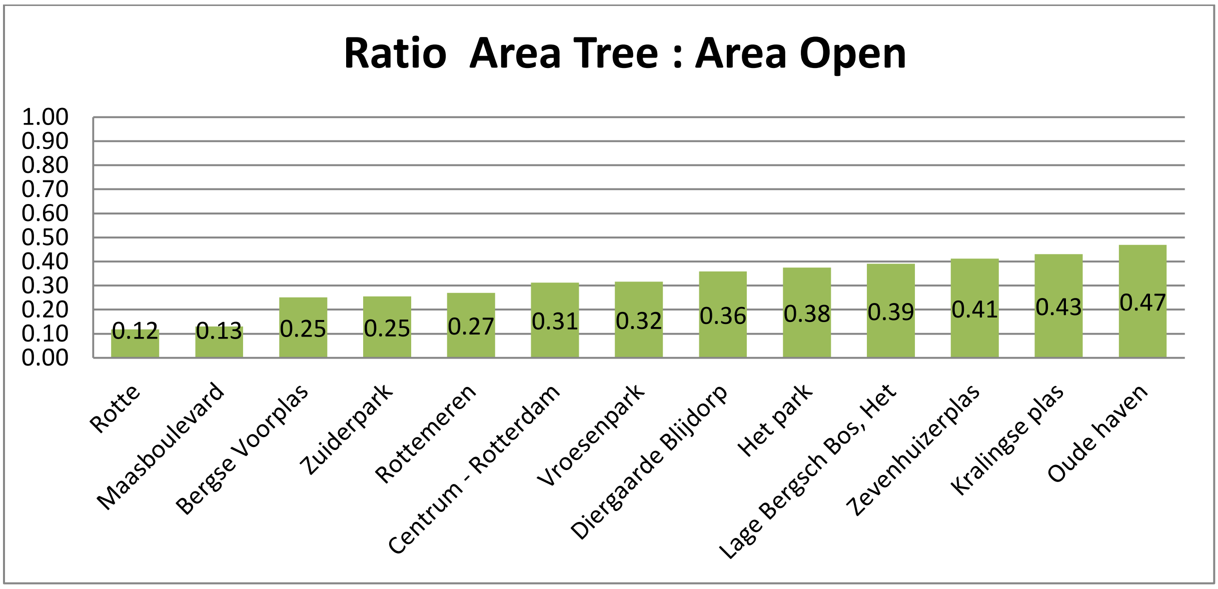
Appendix G – Spatial variables measured in GIS

Rotterdam





Land cover Utrecht – label is the area in hectares


Ratio Area Tree : Area Open
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
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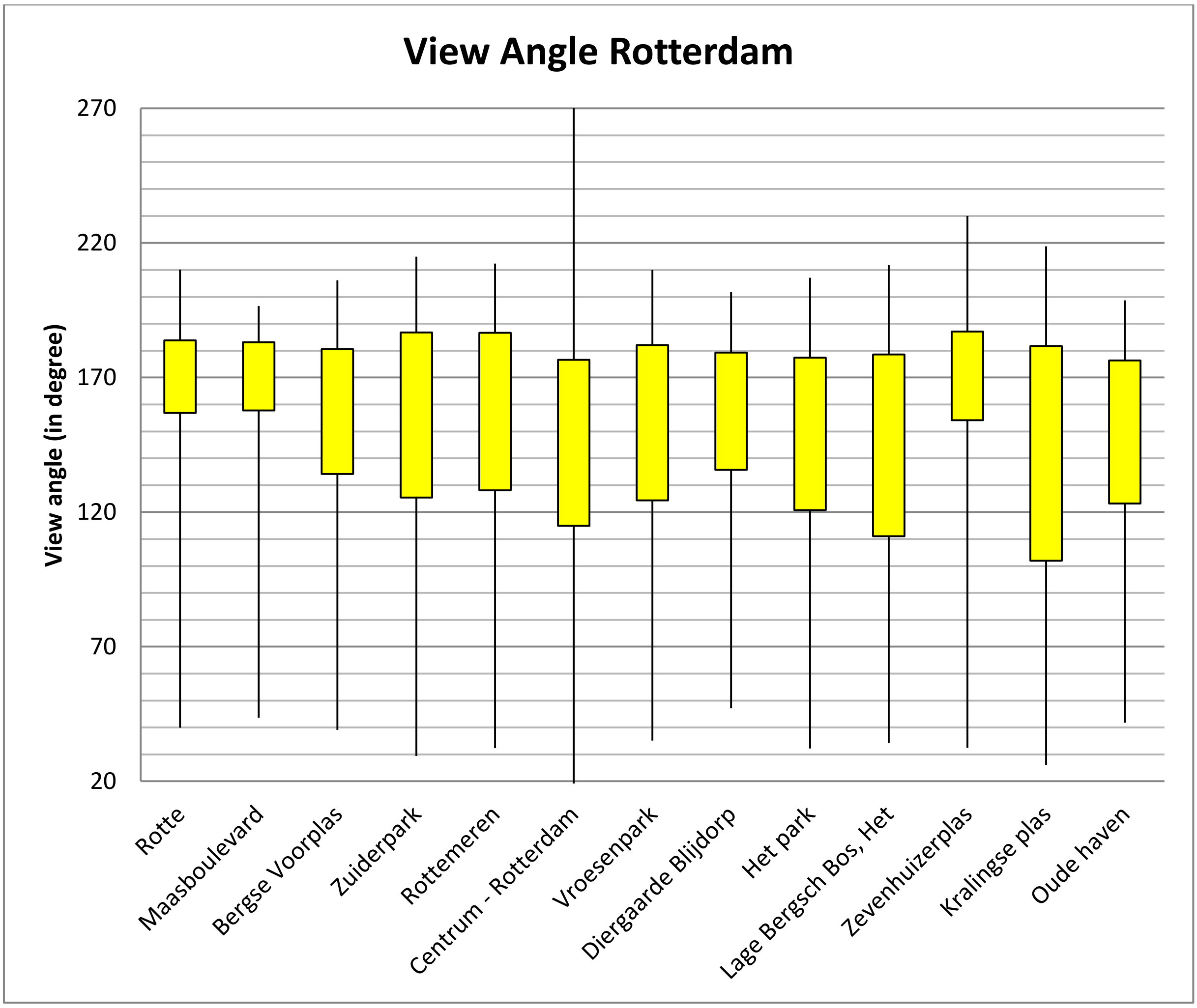
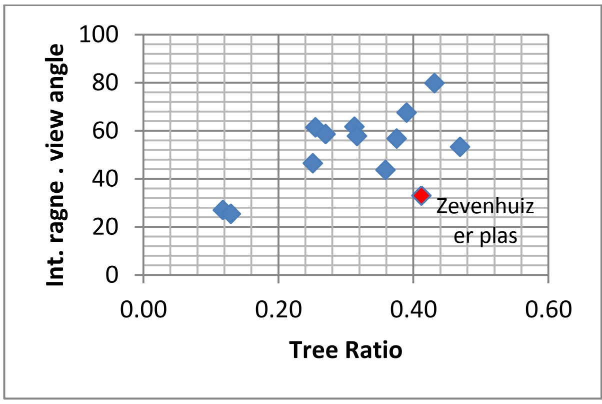
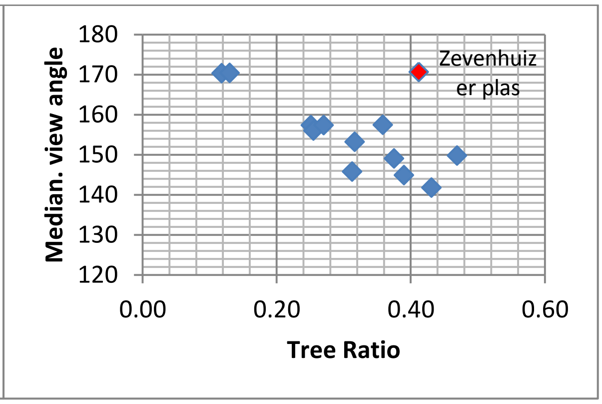
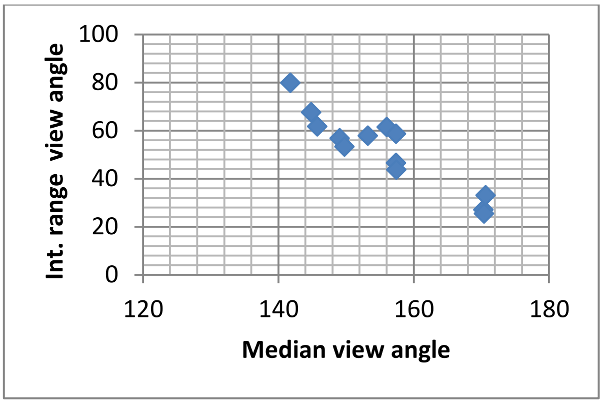
0.00
0.12
0.13
0.25
0.25
0.27
0.31
0.32
0.36
0.38
0.39
0.41
0.43
0.47
Rotte
Maasboulevard
Bergse Voorplas
Zuiderpark
Rottemeren
Centrum - Rotterdam
Vroesenpark
Diergaarde Blijdorp
Het park
Lage Bergsch Bos, Het
Zevenhuizerplas
Kralingse plas
Oude haven


View Angle Rotterdam
View angle (in degree)
270
220
170
120
70
20
Rotte
Maasboulevard
Bergse Voorplas
Zuiderpark
Rottemeren
Centrum - Rotterdam
Vroesenpark
Diergaarde Blijdorp
Het park
Lage Bergsch Bos, Het
Zevenhuizerplas
Kralingse plas
Oude haven

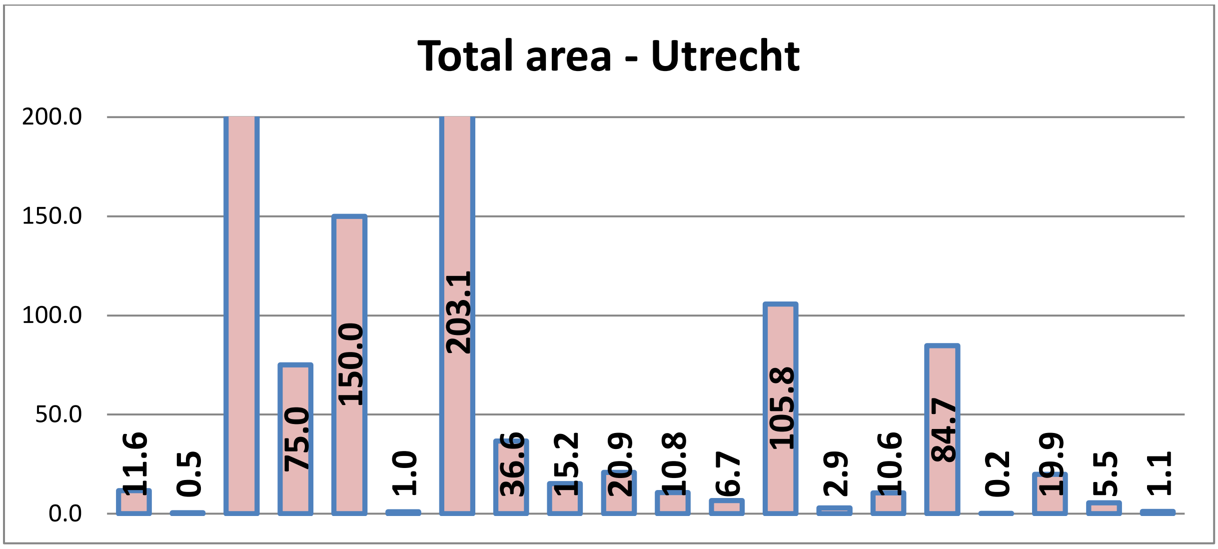


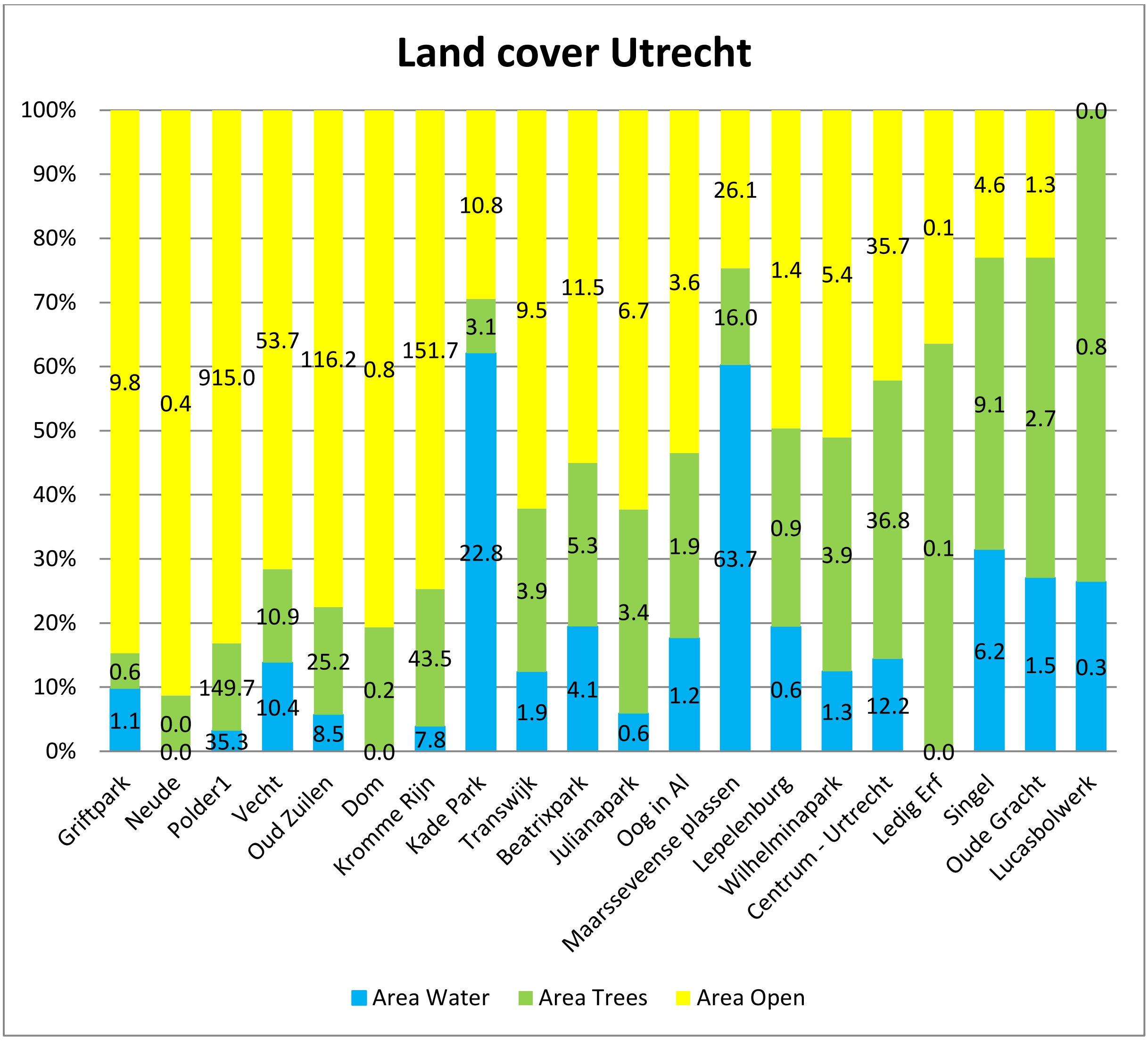




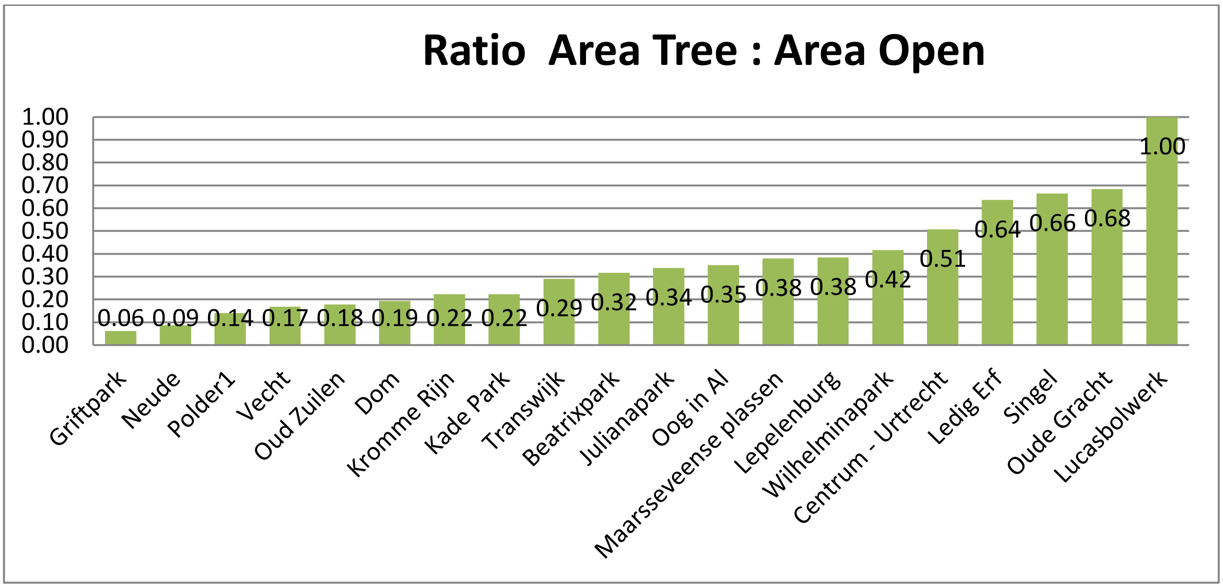
	Fraction Trees	STD	Meidan	MIN	1st quartile	3rd quartile	MAX	RANGE	Interquarile range
		Degrees							
Kralingse plas	0.12	13.5	170.3	39.9	156.8	183.8	210.1	170.2	27.0
Lage Bergsch Bos, Het	0.13	12.7	170.4	43.6	157.7	183.1	196.6	153.0	25.4
Centrum - Rotterdam	0.25	23.2	157.4	39.1	134.2	180.6	206.2	167.1	46.4
Het park	0.25	30.7	156.0	29.4	125.4	186.7	214.9	185.5	61.3
Oude haven	0.27	29.3	157.4	32.4	128.1	186.7	212.3	180.0	58.6
Vroesenpark	0.31	30.8	145.8	5.4	115.0	176.6	286.6	281.2	61.6
Zuiderpark	0.32	28.9	153.2	35.1	124.3	182.1	209.9	174.8	57.8
Bergse Voorplas	0.36	21.8	157.4	47.1	135.6	179.2	201.8	154.7	43.6
Rottemeren	0.38	28.3	149.1	32.1	120.8	177.4	207.0	174.9	56.7
Diergaarde Blijdorp	0.39	33.8	144.9	34.3	111.1	178.6	211.8	177.5	67.5
Rotte	0.41	16.5	170.7	32.4	154.2	187.1	230.0	197.6	33.0
Maasboulevard	0.43	39.9	141.8	26.1	101.9	181.7	218.7	192.6	79.8
Zevenhuizerplas	0.47	26.6	149.8	41.8	123.2	176.4	198.7	156.9	53.2

Utrecht





Land cover Utrecht – label is the area in hectares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0.90
0.80
0.70
0.60
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0.40
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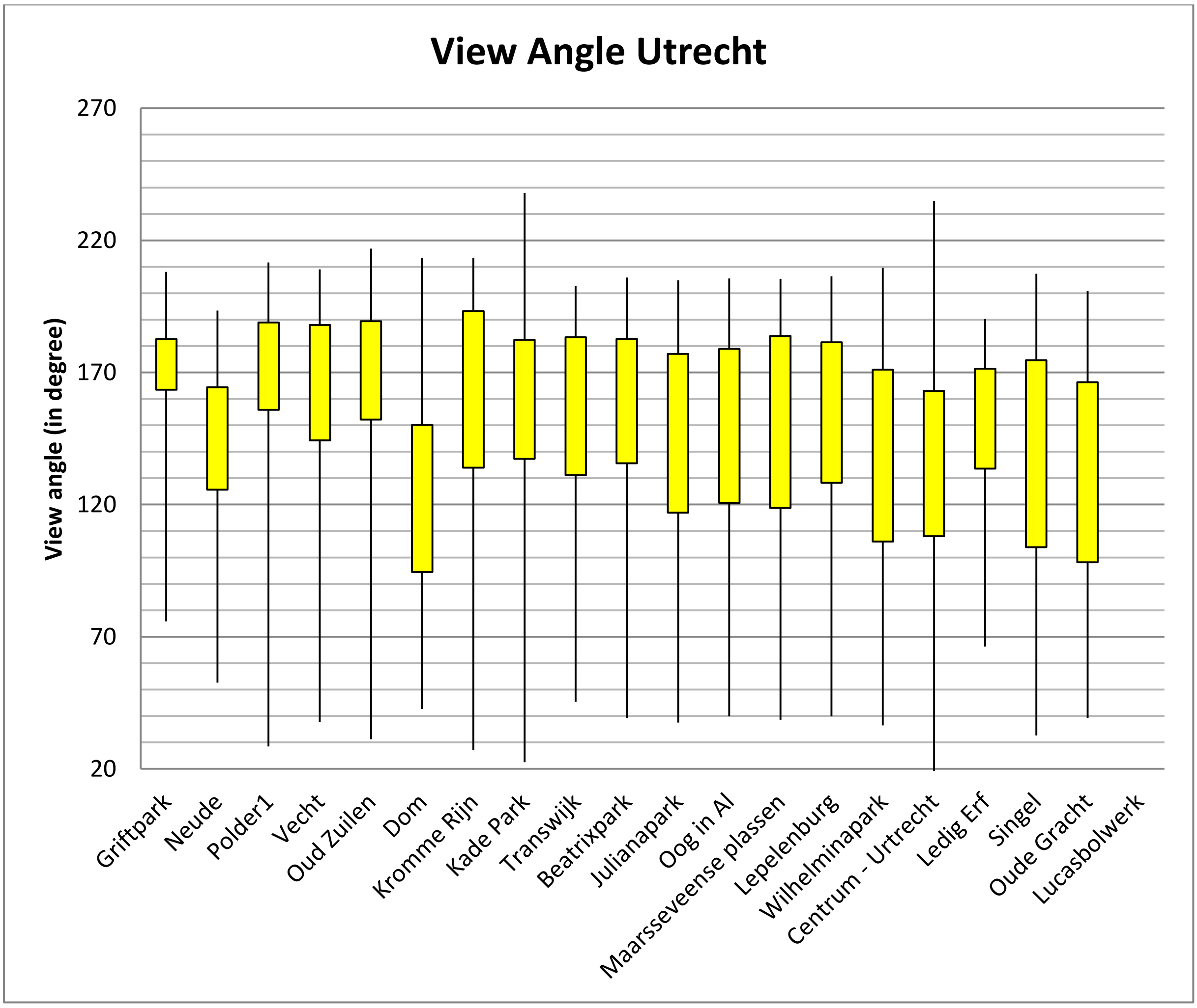
0.00
0.06 0.09 0.14 0.17 0.18 0.19 0.22 0.22 0.29 0.32 0.34 0.35 0.38 0.38 0.42 0.51 0.64 0.66 0.68 1.00
Griftpark
Neude
Polder1
Vecht
Oud Zuilen
Dom
Kromme Rijn
Kade Park
Transwijk
Beatrixpark
Julianapark
Oog in Al
Maarsseveense plassen
Lepelenburg
Wilhelminapark
Centrum - Urtrecht
Ledig Erf
Singel
Oude Gracht
Lucasbolwerk


View Angle Utrecht
View angle (in degree)
270
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170
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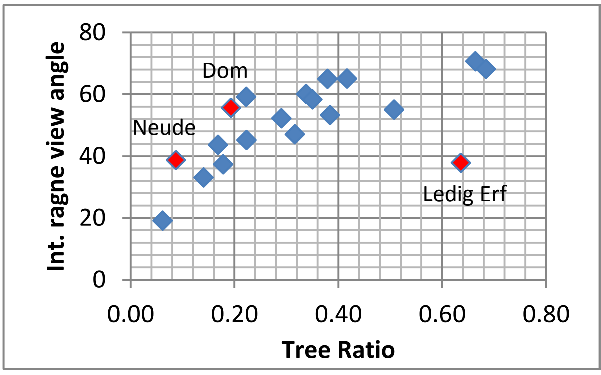
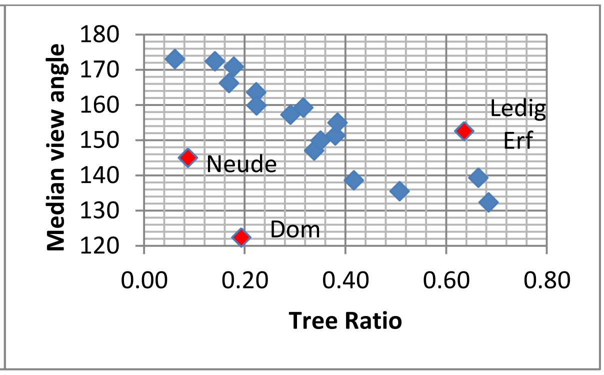
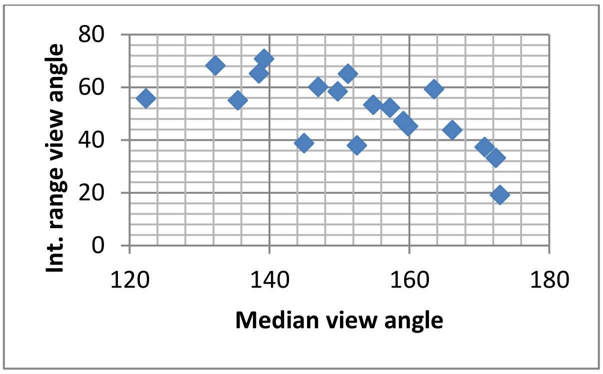
Griftpark
Neude
Polder1
Vecht
Oud Zuilen
Dom
Kromme Rijn
Kade Park
Transwijk
Beatrixpark
Julianapark
Oog in Al
Maarsseveense plassen
Lepelenburg
Wilhelminapark
Centrum - Urtrecht
Ledig Erf
Singel
Oude Gracht
Lucasbolwerk

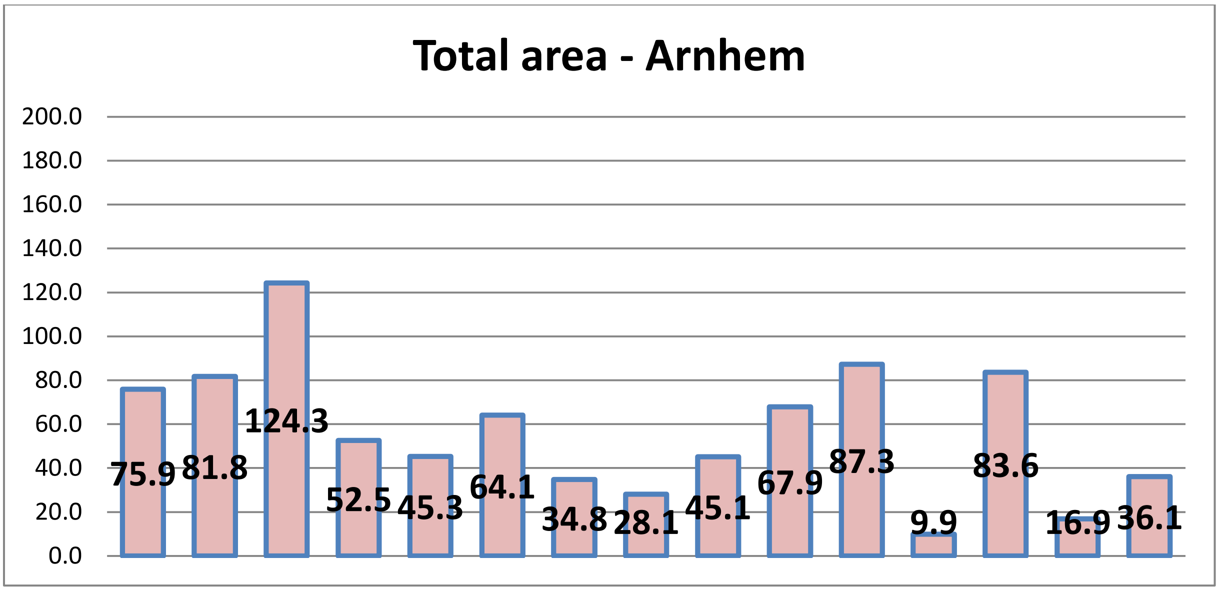


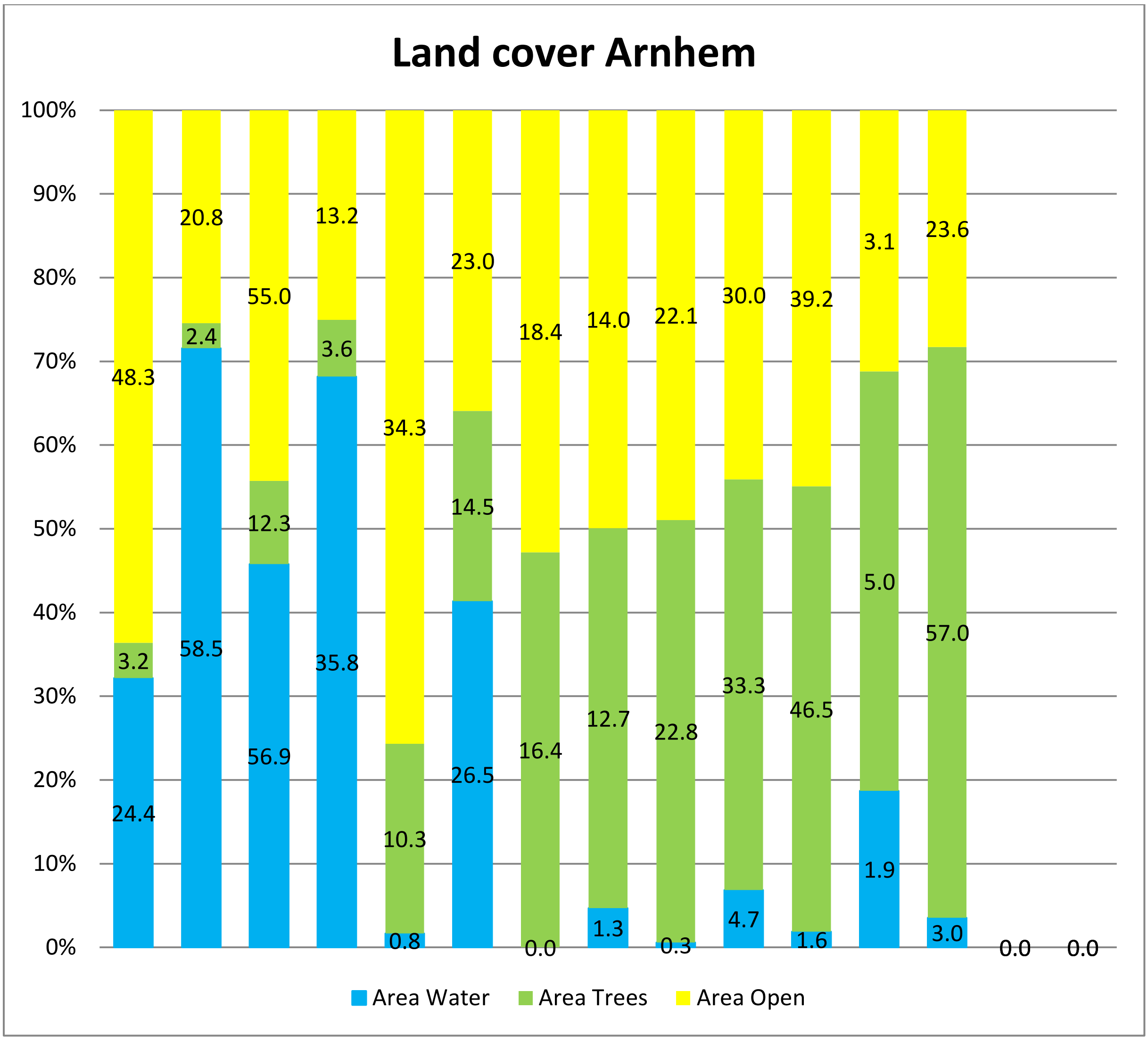




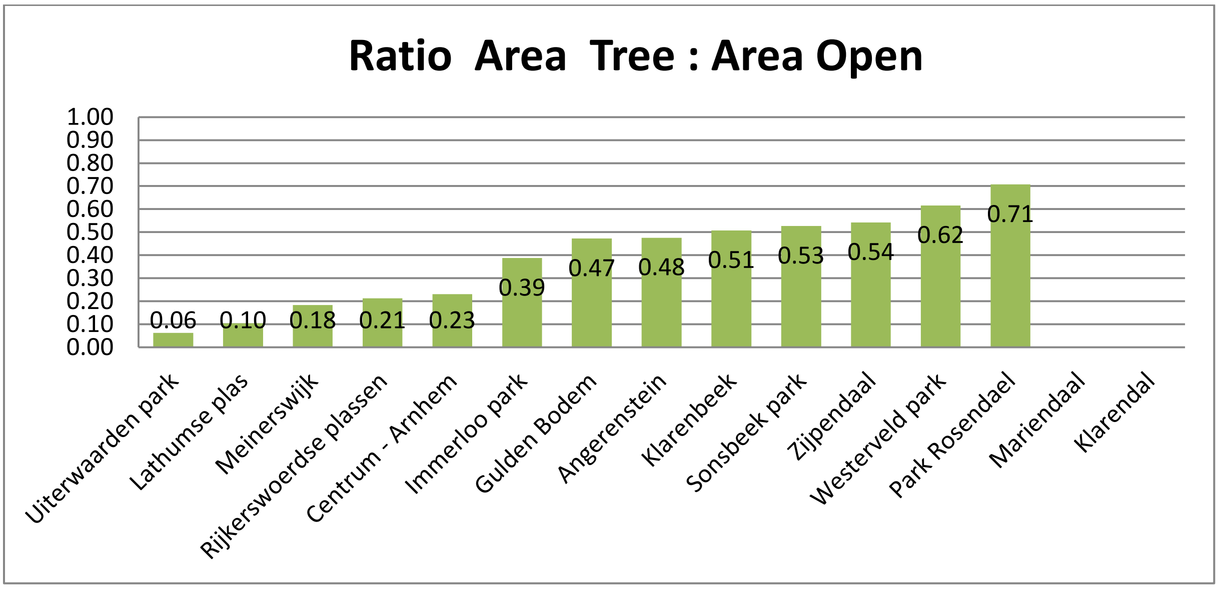
	Fraction Trees	STD	Median	MIN	1st quartile	3rd quartile	MAX	RANGE	Inter – quartile Range
		Degrees							
Dom	0.06	9.6	173.0	75.8	163.4	182.6	208.1	132.2	19.1
Oude Gracht	0.09	19.4	145.0	52.6	125.6	164.4	193.5	140.9	38.7
Centrum - Urtrecht	0.14	16.5	172.4	28.5	155.8	188.9	211.6	183.1	33.1
Wilhelminapark	0.17	21.8	166.2	37.7	144.3	188.0	209.1	171.3	43.6
Singel	0.18	18.6	170.8	31.2	152.2	189.4	216.9	185.6	37.3
Neude	0.19	27.8	122.4	42.7	94.5	150.2	213.4	170.7	55.6
Julianapark	0.22	29.6	163.5	27.1	133.9	193.1	213.3	186.1	59.2
Oog in Al	0.22	22.6	159.9	22.6	137.3	182.4	238.0	215.4	45.2
Maarsseveense p	0.29	26.1	157.2	45.3	131.1	183.3	202.8	157.4	52.2
Ledig Erf	0.32	23.5	159.2	39.2	135.7	182.7	205.9	166.7	47.1
Lepelenburg	0.34	30.0	147.0	37.5	116.9	177.0	204.9	167.3	60.1
Transwijk	0.35	29.2	149.8	39.9	120.6	179.0	205.6	165.7	58.4
Beatrixpark	0.38	32.5	151.3	38.6	118.8	183.8	205.5	166.8	65.0
Kade Park	0.38	26.6	154.9	39.9	128.3	181.5	206.4	166.5	53.2
Kromme Rijn	0.42	32.6	138.5	36.5	106.0	171.1	209.6	173.1	65.1
Vecht	0.51	27.5	135.5	15.3	108.0	163.0	234.9	219.6	55.0
Oud Zuilen	0.64	18.9	152.5	66.2	133.6	171.5	190.2	123.9	37.9
Polder1	0.66	35.3	139.3	32.6	103.9	174.6	207.3	174.7	70.7
Griftpark	0.68	34.1	132.3	39.3	98.2	166.4	200.8	161.5	68.1
Lucasbolwerk	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

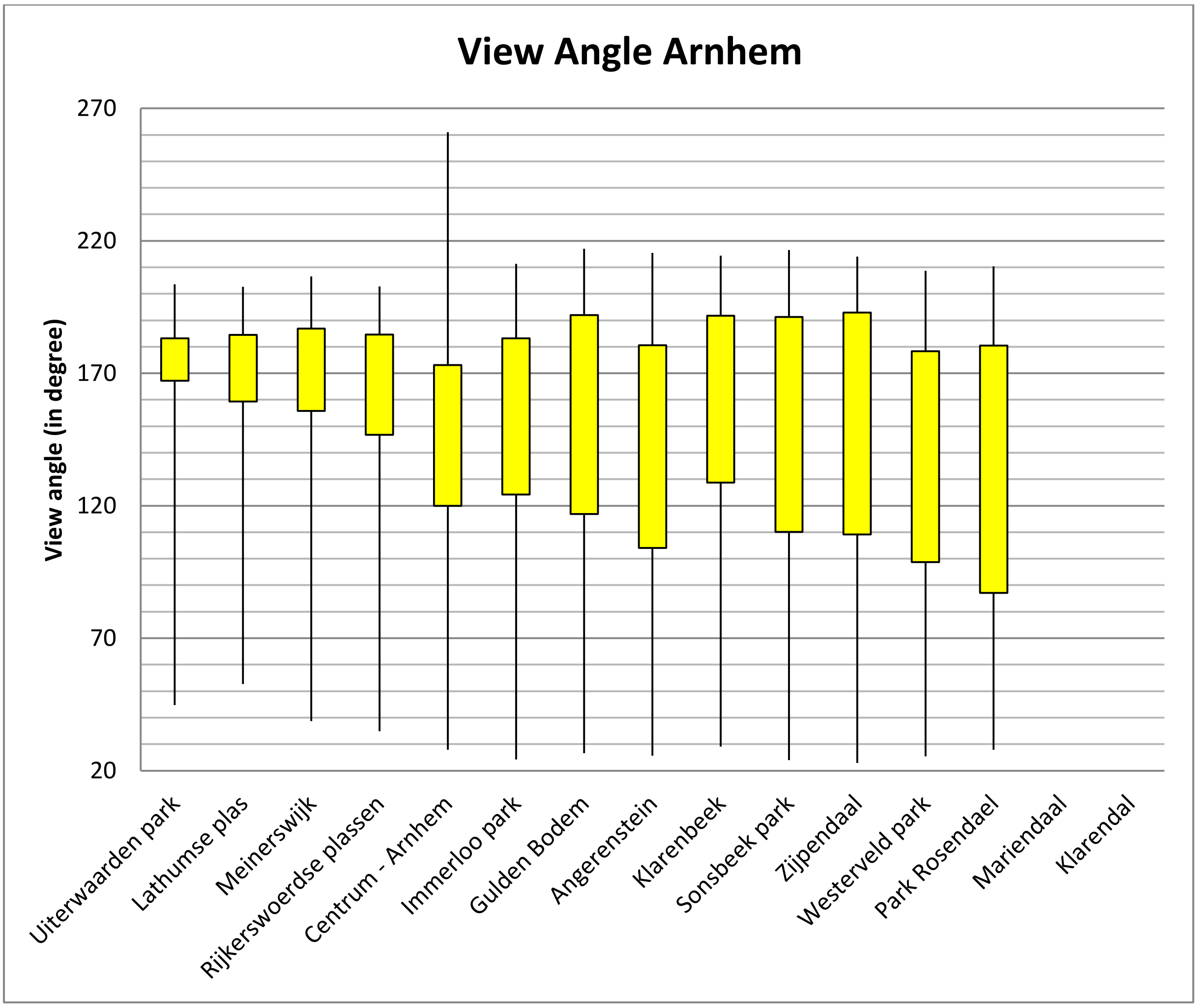
Arnhem

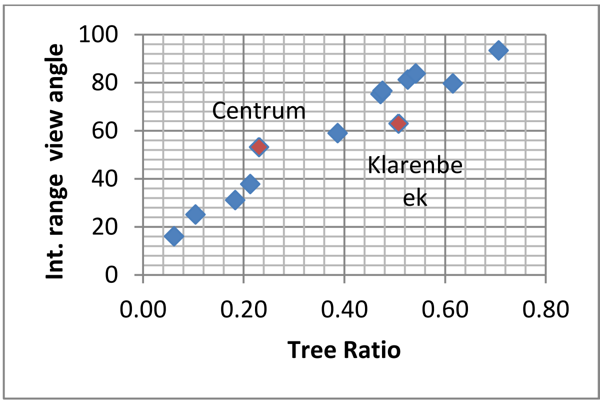


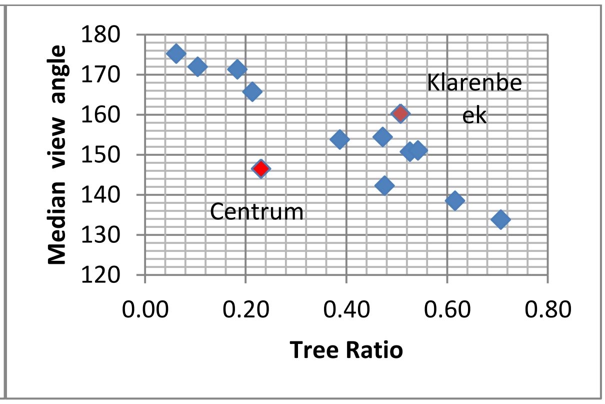


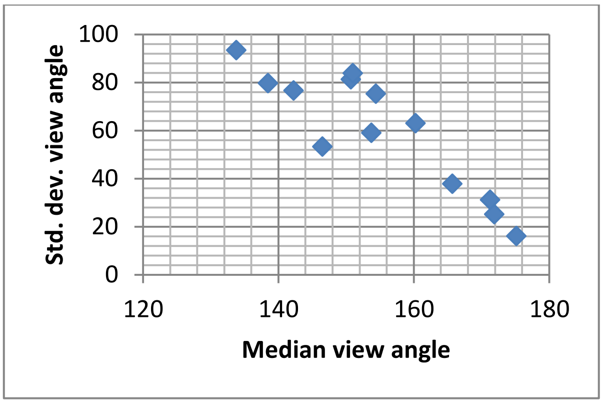
Land cover Arnhem – label is the area in hectares


Ratio Area Tree : Area Open
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.06
0.10
0.18
0.21
0.23
0.39
0.47
0.48
0.51
0.53
0.54
0.62
0.71
Uiterwaarden park
Lathumse plas
Meinerswijk
Rijkerswoerdse plassen
Centrum - Arnhem
Immerloo park
Gulden Bodem
Angerenstein
Klarenbeek
Sonsbeek park
Zijpendaal
Westerveld park
Park Rosendael
Mariendaal
Klarendal


View Angle Arnhem
View angle (in degree)
270
220
170
120
70
20
Uiterwaarden park
Lathumse plas
Meinerswijk
Rijkerswoerdse plassen
Centrum - Arnhem
Immerloo park
Gulden Bodem
Angerenstein
Klarenbeek
Sonsbeek park
Zijpendaal
Westerveld park
Park Rosendael
Mariendaal
Klarendal







	Fraction Trees	STD	Median	MIN	1st quartile	3rd quartile	MAX	RANGE	Inter-quartile range
		Degrees							
Park Rosendael	0.06	8.0	175.2	44.8	167.2	183.2	203.6	158.8	16.1
Westerveld park	0.10	12.5	171.9	52.6	159.4	184.4	202.6	150.0	25.1
Angerenstein	0.18	15.5	171.3	38.7	155.8	186.8	206.6	168.0	31.1
Centrum - Arnhem	0.21	18.9	165.7	34.9	146.8	184.6	202.8	167.8	37.8
Sonsbeek park	0.23	26.6	146.5	27.8	119.9	173.1	261.0	233.2	53.2
Zijpendaal	0.39	29.5	153.7	24.2	124.2	183.2	211.3	187.2	59.0
Immerloo park	0.47	37.6	154.4	26.6	116.8	192.0	217.0	190.4	75.2
Gulden Bodem	0.48	38.2	142.3	25.6	104.0	180.5	215.4	189.8	76.5
Klarenbeek	0.51	31.5	160.3	29.0	128.8	191.7	214.3	185.3	63.0
Rijkerswoerdse plassen	0.53	40.6	150.7	24.0	110.1	191.3	216.5	192.5	81.2
Meinerswijk	0.54	41.9	151.0	22.9	109.2	192.9	214.0	191.1	83.7
Lathumse plas	0.62	39.8	138.5	25.4	98.7	178.3	208.7	183.3	79.6
Uiterwaarden park	0.71	46.6	133.8	27.9	87.1	180.4	210.4	182.5	93.3
Mariendaal	#	#	#	#	#	#	#	#	#
Klarendal	#	#	#	#	#	#	#	#	#

Appendix H – Frequency of words mentioned per specific place of thermal comfort

Rotterdam

Bergse Voorplas		**Centrum1**		**Diergaarde blijdorp**	
Respondents	***7***	*Respondents*	***5***	*Respondents*	***4***
Shadow	2	Terrace/drink/beer	2	Sun	2
Sun	2	Friends	1	Shadow	1
Green	2	shopping	1	Green	1
Activity	2			Activity	1
Terrace/drink/beer	2			Tranquility	1
cool	1			bike	1
Tranquility	1			outside	1
Friends	1				
Swim	1				
bike	1				

Het Park		**Kralingse Plas**		**Het Lage Bergsche Bos**	
Respondents	***19***	*Respondents*	***97***	*Respondents*	***15***
Shadow	9	Shadow	47	Shadow	7
Sun	3	cool	38	Activity	7
Activity	3	Sun	27	cool	4
cool	3	Activity	16	Green	4
Green	2	Water	16	Nature	4
Close	2	Trees	14	Sun	3
Trees	2	good atmosphere	13	Trees	3
Water	2	Green	11	Wind	2
Beautiful	2	BBQ	11	Beautiful	2
Tranquility	1	Wind	11	Water	1

Maasboulevard		**Oude haven**		**Rotte**	
Respondents	***4***	*Respondents*	***11***	*Respondents*	***7***
Wind	3	Terrace/drink/beer	12	bike	3
cool	2	Water	3	cool	2
Sun	2	cool	1	Sun	2
Shadow	1	Sun	1	Beautiful	2
Activity	1	Shadow	1	Terrace/drink/beer	1
Close	1	good atmosphere	1	Activity	1
outside	1	sit-/ lay down	1	outside	1
				boat	1

Rottemeren		**Vroesenpark**		**Zevenhuizerplas**		**Zuiderpark**	
Respondents	*5*	*Respondents*	*22*	*Respondents*	*4*	*Respondents*	*15*
bike	2	Shadow	13	Shadow	3	Trees	6
Sun	2	cool	9	cool	2	Activity	5
cool	1	good atmosphere	9	Sun	2	Shadow	4
Activity	1	Sun	8	good atmosphere	1	Sun	4
boat	1	Close	4	outside	1	Green	4
Shadow	1	Space	3	Activity	1	Beautiful	3
sit-/ lay down	1	outside	3	Nature	1	good atmosphere	2
Space	1	Wind	3	Trees	1	Close	2
Swim	1	BBQ	3	Tranquility	1	cool	1
Open	1	Activity	2	bike	1	outside	1

Utrecht

Beatrixpark		**Centrum**		**Dom**		**Griftpark**	
Respondents	*9*	*Respondents*	*14*	*Respondents*	*9*	*Respondents*	*25*
Shadow	*7*	*Shadow*	*12*	*Terrace/drink/beer*	*11*	*Shadow*	*15*
Sun	*5*	*Terrace/drink/beer*	*6*	*Shadow*	*9*	*Water*	*13*
Water	*3*	*Gras*	*3*	*Wind*	*3*	*Open*	*8*
Green	3	Water	2	outside	3	Wind	7
Wind	3	Green	2	Sun	2	Green	6
Beautiful	3	Warmth	2	Trees	2	cool(ing)	6
cool(ing)	3	good atmosphere	2	changing environment	2	good atmosphere	5
Close	2	Sun	1	Parasol	2	Sun	4
Space	2	Wind	1	Warmth	1	Trees	4
outside	2	Trees	1	good atmosphere	1	Gras	4

Julianapark		**Kade park**		**Kromme Rijn**		**Ledig Erf**	
Respondents	*4*	*Respondents*	*4*	*Respondents*	*14*	*Respondents*	*20*
Shadow	*2*	*Water*	*3*	*Shadow*	*9*	*Shadow*	*12*
Water	*2*	*Wind*	*3*	*Water*	*7*	*Terrace/drink/beer*	*11*
Green	*2*	*Shadow*	*2*	*Sun*	*6*	*Green*	*5*
good atmosphere	2	Close	2	Wind	3	Wind	4
Sun	2	Green	1	changing environment	3	Close	4
Open	1	Open	1	Close	2	Parasol	4
Wind	1	(be) outside	1	Trees	2	Water	3
Tranquility	1			Beautiful	2	Sun	3
				Green	1	Open	3
				Open	1	Trees	2

Lepelenburg		**Lucasbolwerk**		**Maarsseveense plassen**		**Neude**	
Respondents	*15*	*Respondents*	*4*	*Respondents*	*19*	*Respondents*	*22*
Shadow	*7*	*Terrace/drink/beer*	*4*	*Water*	*12*	*Terrace/drink/beer*	*12*
Sun	*6*	*Open*	*2*	*cool(ing)*	*10*	*Shadow*	*10*
Warmth	*5*	*Wind*	*2*	*Shadow*	*8*	*Sun*	*5*
cool(ing)	4	Parasol	2	Warmth	5	Wind	4
Close	3	outside	2	Wind	3	Open	3
Open	3	Shadow	1	Sun	3	Parasol	3
Trees	3	Close	1	Open	1	People	3
good atmosphere	3	Trees	1	outside	1	outside	2
Activity	3	Water	1	Close	1	Trees	2
Green	2			Trees	1	Green	2

Oog in Al		Oud Zuilen		Oude Gracht		Polder1	
Respondents	5	*Respondents*	4	*Respondents*	10	*Respondents*	5
Shadow	*4*	*Wind*	*3*	*Shadow*	*8*	*Wind*	*5*
Green	*4*	*Green*	*1*	*Terrace/drink/beer*	*8*	*Open*	*3*
Water	*4*	*Water*	*1*	*cool(ing)*	*5*	*cool(ing)*	*2*
Wind	2	Beautiful	1	Trees	3	bike	2
cool(ing)	2	Trees	1	People	3	Trees	1
Beautiful	2	changing environment	1	Wind	2	Water	1
Trees	1	good atmosphere	1	Water	2	changing environment	1
Close	1	Activity	1	Sun	2	Activity	1
changing environment	1	Open	1	outside	2	Space	1
good atmosphere	1	Space	1	Green	1	old nature	1

Singel		Transwijk		Vecht		Wilhelminapark	
Respondents	13	*Respondents*	4	*Respondents*	7	*Respondents*	48
Shadow	*6*	Water	3	Open	2	Shadow	35
Trees	*5*	Wind	3	Shadow	2	Sun	19
Water	*4*	Open	3	Wind	1	Green	18
cool(ing)	2	Terrace/drink/beer	3	cool(ing)	1	Water	17
Green	2	Shadow	2	Green	1	cool(ing)	12
Parasol	2	cool(ing)	1	Nature	1	Gras	10
Wind	1	Green	1			Trees	8
Open	1					Wind	7
fresh air	1					Open	6
Sun	1					Beautiful	6

Arnhem

Angerenstein		Centrum		Gulden Bodem		Immerloo park	
Respondents	**15**	*Respondents*	**15**	*Respondents*	**5**	*Respondents*	**9**
Shadow	9	Shadow	6	Shadow	3	Close	4
Trees	5	Terrace/drink/beer	6	Sun	2	Shadow	3
Close	4	Sun	5	Tranquility	2	Trees	3
Water	3	good atmosphere	5	Plants	2	Water	3
Green	3	People	3	Trees	1	Tranquility	2
Activity	3	Friends	2	Close	1	Activity	2
Tranquility	3	cover	2	Activity	1	Sun	1
Playground	3	icecream	2	Nature	1	People	1
Warmth	3	Water	1			Green	1
Friends	3	Green	1			Wind	1

Klarenbeek		Klarendal		Lathumse plas		Mariendaal	
Respondents	**10**	*Respondents*	**5**	*Respondents*	**5**	*Respondents*	**4**
Shadow	6	Activity	6	Water	3	Shadow	2
Sun	6	Shadow	2	Sun	2	Space	1
Water	2	Water	1	Tranquility	2	Nature	1
Nature	2	Sun	1	Swim	2	Green	1
Beautiful	2	People	1	Space	2	Trees	1
Tranquility	2	Nature	1	Nature	1	Activity	1
Green	2	good atmosphere	1	Beautiful	1	Plants	1
cool(ing)	2	Friends	1	(be) outside	1		
People	1	Beautiful	1				
Close	1	Animals	1				

Meinerswijk		Park Rosendael		Rijkerswoerdse plassen		Sonsbeek park	
Respondents	**15**	*Respondents*	**10**	*Respondents*	**42**	*Respondents*	**67**
Activity	5	Trees	4	Water	19	Sun	29
Water	5	Water	3	Swim	19	Shadow	24
Nature	4	Green	3	cool(ing)	10	Green	16
Shadow	3	Shadow	2	Nature	8	Water	12
Green	3	Beautiful	2	Activity	7	Nature	11
Trees	3	Activity	1	Sun	7	Activity	8
Plants	3	Nature	1	Playground	7	lay-/sit down	8
Tranquility	3	Plants	1	Beautiful	5	Tranquility	7
Swim	2	Tranquility	1	Tranquility	5	Trees	7
Close	2	Close	1	Space	5	Beautiful	6

Uiterwaarden park		Westerveld park		Zijpendaal	
Respondents	**4**	*Respondents*	**6**	*Respondents*	**19**
Water	3	Water	2	Shadow	8
Activity	2	Activity	2	Trees	6
Tranquility	2	Tranquility	2	Sun	6
Beautiful	2	Beautiful	2	Tranquility	5
Space	2	Trees	2	Nature	5
Wind	2	Shadow	2	Green	4
Sun	1	Green	1	Activity	2
Green	1	Nature	1	Space	2
Trees	1	Close	1	cover	2
cover	1			Water	1

Top places of thermal comfort

Rotterdam

Kralingse Plas	
	97
Shadow	47
cool	38
Sun	27
Activity	16
Water	16
Trees	14
good atmosphere	13
Green	11
Wind	11
BBQ	11
Beautiful	9
sit-/ lay down	9
Close	8
Tranquility	8
outside	7
Nature	7
Warmth	7
Playground	6
Space	5
Swim	5
Gras	5
bike	3
People	3
Terrace/drink/beer	3
picknick	2
cover from wind	2
fresh air	1
Friends	1
Open	1
View	1
Animals	1
utilities	1

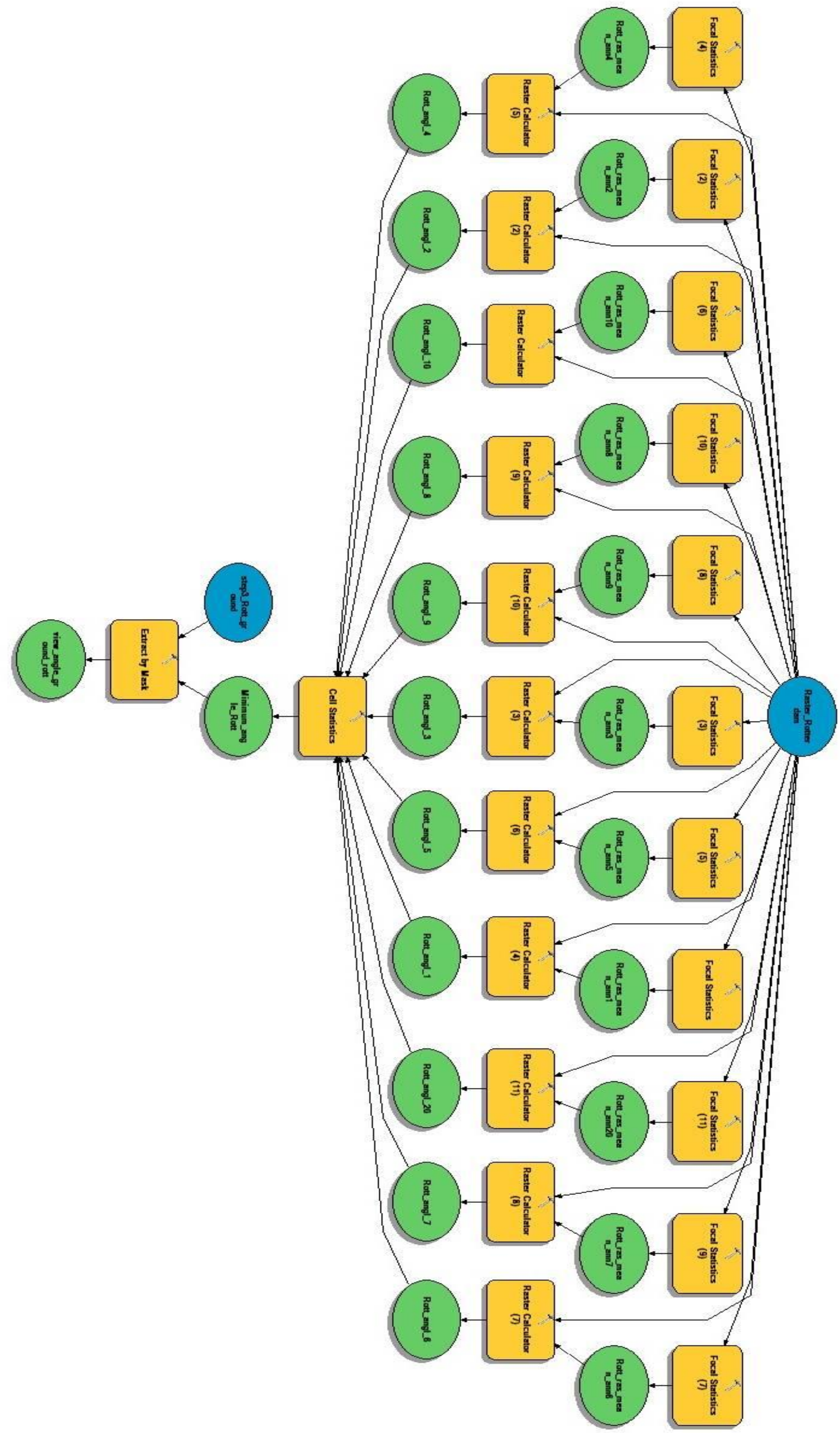
Utrecht

Wilhelminapark	
	48
Shadow	35
Sun	19
Green	18
Water	17
cool(ing)	12
Gras	10
Trees	8
Wind	7
Open	6
Beautiful	6
good atmosphere	6
Space	6
lay-/sit down	6
changing environment	5
Close	3
outside	3
Warmth	3
Tranquility	3
Terrace/drink/beer	2
People	2
Nature	1
old nature	1

Arnhem

Sonsbeek park	
	67
Sun	29
Shadow	24
Green	16
Water	12
Nature	11
Activity	8
lay-/sit down	8
Trees	7
Tranquility	7
Space	6
Beautiful	6
Close	6
good atmosphere	6
People	5
cover	3
Warmth	3
Playground	3
Friends	3
Wind	2
cool(ing)	2
Swim	2
changing environment	2
Gras	2
outside	1
Plants	1
Animals	1
height difference	1
Terrace/drink/beer	1

Appendix I – Model “View_angle_towards_sky” within ArcGIS



Appendix J – View angle towards the sky (in degrees); Utrecht centre