Heat mitigation in Dutch cities by the design of two case studies

L. Kleerekoper[1]

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The climate of a city influences the health and comfort of its city dwellers and the ways in which its outdoor spaces are used. Due to a predicted global temperature rise, the climate is likely to be more uncomfortable in the Netherlands, especially in summer, when an increase in heat stress is expected. As the phenomenon of urban heat islands (UHI) aggravates heat stresses, the effects will be more severe in urban environments. Since the spatial characteristics of a city influence its climate, urban design can be deployed to mitigate the combined effects of climate change and UHI's. This paper explores these effects and tries to provide tools for urban design and strategies for implementation. Consequently, the applicability of the design tools is tested in a design for two existing Dutch neighbourhoods.

Introduction

The effect of global climate change on local areas differs a lot. Global average temperatures are estimated to increase with 0.6 up to 3.6 °C (Solomon et al., 2007). The average summer temperature in the Netherlands will increase with 1.7 up to 5.6 °C in 2100 compared to 1990 (1.7-4.6 °C in winter) (KNMI, 2009). This does not entail a milder climate, but an occurrence of more weather extremes including heat waves. Effects of heat expand in urban areas. The extent of the temperature differences vary in time and place as a result of meteorological, locational and urban characteristics. The heat accumulation in cities, the so-called Urban Heat Island (UHI) effect, may cause extreme warming in urban areas. The UHI effect has the following causes (Oke, 1987, Santamouris and Asimakopoulos, 2001):

1. Absorption of short-wave radiation from the sun in low albedo (reflection) materials and trapping by multiple reflections between buildings and street surface.
2. Air pollution in the urban atmosphere absorbs and re-emits long-wave radiation to the urban environment.
3. Obstruction of the sky by buildings results in a decreased long-wave radiative heat loss from street canyons. The heat is intercepted by the obstructing surfaces, and absorbed or radiated back to the urban tissue.
4. Anthropogenic heat is released by combustion processes, such as traffic, space heating and industries.

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[1] TU Delft, Climate Design

5. Increased heat storage by building materials with large thermal admittance. Furthermore, cities have a larger surface area compared to rural areas and therefore more heat can be stored.
6. The evaporation from urban areas is decreased because of ‘waterproofed surfaces’ – less permeable materials, and less vegetation compared to rural areas. As a consequence, more energy is put into sensible heat and less into latent heat.
7. The turbulent heat transport from within streets is decreased by a reduction of wind speed.

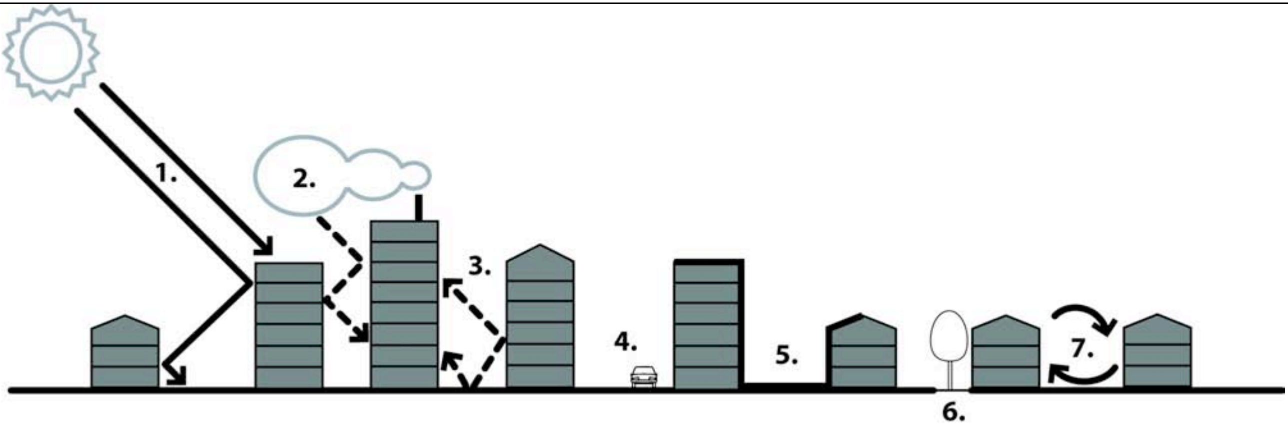


Figure 1: causes urban heat islands (Kleerekoper et al., 2009)

The UHI effect in the Netherlands is studied by Conrads in the city Utrecht in 1970-1971. This study shows a difference between the rural and urban temperatures. In winter the average difference was 1.7 °C, in summer 2.7 °C. Minimum temperature differences during the night measured up to a maximum of 8 °C (Conrads, 1975). A recent study in the city of Rotterdam showed a maximum UHI of 7 °C difference after sunset (Heusinkveld and Holtslag, 2010). Climate change and the UHI effect together can thus imply a future temperature increase of 3.4 to 8.3 °C, up to 13.6°C at night.

Occurring problems in Dutch cities during warm weather concern: thermal discomfort, heat stress, air pollution, increase in energy consumption, lack of sweet water, more bacterial growth. Despite the seriousness and high predictability of the occurrence of the UHI effect in Dutch cities, no clear spatial means or strategies are available for urban designers to guide them in how to act towards this phenomenon.

This paper gives an overview of heat mitigation measures and their effects for urban areas. And aims to provide insight in the applicability of these measures in Dutch cities, by answering the following question:

Which heat mitigation measures are available, effective and appropriate for Dutch cities?

Sub-questions:

a. What climate adaptations measures do we know and what could be possible in the near future to reduce the negative effects of heat in cities?

b. What knowledge is available on the effectiveness of climate adaptation measures and what can we learn from applied measures in the Netherlands and countries with similar climate conditions?

c. What are priority neighbourhoods in the Netherlands and how can climate adaptation measures be applied in these neighbourhoods?

In the next paragraph is explained how these questions will be researched. After which heat mitigation measures and examples from practice are described; followed by a typological analyses and neighbourhood design.

Methods

Many cities over the world cope with heat stress. The occurring problems with heat stress in these cities have lead to heat mitigation measures by research and traditional design. The UHI effect has been studied in big cities like New York and Tokyo, the generic aspects provide information for the Netherlands. Studies on the effectiveness of heat mitigation measures give a first indication on quantities. An inventory of the most important measures to counteract the UHI effect in summer forms the first part of the paper and is addressed to answer the first two sub- questions. The inventory is based on existing literature. Most information comes from scientific journals and research reports. Cities like London and Chicago strive to sustainability and started with ambitious plans, their strategies can be an example on how to deal with adaptation issues.

The second part of this paper is addressed to answer the last sub-question. Before a heat mitigation strategy can be developed, first the problematic locations must be identified. These will be identified by an analysis of several urban typologies that are common for Dutch cities. The analyses are mostly based on land use patterns, height/width ratios and materialisation. For the data on land use two sources from the University of Wageningen are used. To come to appropriate design principles for Dutch neighbourhoods the available and effective heat mitigation measures from part one, also need to be applicable in these areas. Through research by design the applicability of the measures is tested in two priority neighbourhoods. These design studies also function as inspirational examples of heat robust neighbourhoods.

Mitigation of Urban Heat Islands

By diminishing the accumulation of heat and applying cooling techniques cities can mitigate[2] their UHI effect. The causes of the UHI effect described in the introduction should be decreased or compensated for. Decreasing all causes resulting in no UHI effect would be the same as eliminating the city. Therefore a balance needs to be found between the city's characteristics and success factors on one hand and a healthy and comfortable in- and outdoor environment on the other. Heat mitigation measures vary in effectiveness, and, per location, in costs. Urban designers have the responsibility to develop a healthy and comfortable city environment. However, not all heat mitigation measures lie within the scope of their work field. Also policymakers, housing corporations and residents themselves have possibilities to improve their city environment. The measures discussed in this first part of the paper are not addressed to a specific work field, but do have a focus on that of the urban designer.

Mitigation measures

The following heat mitigating measures start at the category city structure, followed by vegetation, materials, water and anthropogenic heat.

City structure

The size, composition and orientation of a city affect the UHI effect. The larger the city, the bigger the difference in temperature between urban and rural. With the following formula the maximum difference of the rural and the urban temperature in European cities can be predicted according to the amount of inhabitants; $\Delta T_{u-r(\max)} = 2.01 \log P - 4.06$ (Oke, 1973).

When the composition of buildings is taken into account in relation to cooling, both sun and wind orientation is relevant. Since the Netherlands has a cold winter climate sun and wind have other parameters in summer and winter.

The main wind direction in summer is from the South-West in the Netherlands, but in winter we have the coldest wind from the North-East. Generating wind for ventilation in summer can result in an undesired situation in winter. Another way to improve ventilation is to generate a mix of the air in the canopy layer[3] with the air from the boundary layer[4]. One way to obtain this mix is adjusting the canopy layout. When the height/width ratio is around 0.5 the best ventilation is acquired. At a H/W of more than 2 there is almost no mix of the canopy and boundary layer (Xiaomin et al., 2006, Esch et al., 2007). The mix of the two layers also takes place with slanted roofs. These generate affective natural wind ventilation at the 'mouth' openings of urban street canyons. This is a much more effective means for improving natural ventilation than increasing building spacing. (Rafailidis, 1997)

[2] taking actions to reduce the temperature differente between urban and rural areas
[3] the air space in a street profile
[4] the overall layer of the earth, above the surface, forest, cities, etc.

Overheating by solar radiation in summer can be reduced with high H/W ratios (Futcher, 2008). However this also implies less airflow, multiple solar reflections and a lower sky view factor which traps heat. These last negative effects may do more harm than the positive effects of the measure itself. Even if the measure would help in summer, in winter even more buildings will overshadow other buildings. In a cold winter climate this leads to uncomfortable situations. Individual buildings need to be designed to collect the sun and not shade others (Keeffe and Martin, 2007). A better alternative for shading from the sun are deciduous trees whose leaves shade in summer and let through the sun in winter or technological systems that can adjust to seasonal changes.

Vegetation

Evaporative cooling effects, by a matrix of green corridors, smaller open spaces, street trees, and green or living roofs and walls, are important for cities to be climate proof. The kind of green application appropriate depends on the scale and urban characteristics. The temperature difference between a park and its urban environment is generally about 1 - 6˚C depending on amount, kind and organisation of vegetation (Shashua-Bar and Hoffman, 2000; Upmanis et al., 1998). Trees cool mainly by evapotranspiration (ET) but also by shading, reflecting radiation and absorbing heat. On a sunny day the ET alone already cools with a power equal to 20-30 kW, power comparable to that of more than 10 air-conditioning units (Kravčík et al., 2007). For cooling urban areas using parks, the effect on the surroundings is very important. The effect is variable, depending on airflow and other climatological circumstances and urban characteristics. The studies measured an effect at 100 meters distance from the park in Tel Aviv and an effect at 1100 meters in Göteborg (Shashua-Bar and Hoffman 2000; (Upmanis et al., 1998).

In a review of studies, the effect of greening facades was measured for the outdoor temperature and the effect on air-conditioner cooling savings. The greening leads to an average decrease of 0.2–3.3 ˚C in the near-ground or -wall temperature and results in a cooling energy saving of 4-40%. (Kikegawa et al., 2006) and (Wong et al., 2010).

Green roofs also mitigate the UHI effect, they retain water that cools by evaporation and ET, and they maintain surface temperatures lower than black (33°C cooler) and white (16°C cooler) roofs. (Gaffin et al., 2010)

Other suggestions to improve the application of vegetation: 1) The availability of water is of great importance for a green cooling effect; 2) Shading of windows and west-facing walls provides the most savings in cooling energy; 3) On trees selected for shade, crown shape can be more important than crown density; 4) Energy and water prices determine the extend to which it is economical to substitute ET cooling for electric air conditioning; 5) Effects of tree shade on winter heating demand can be substantial with non-deciduous trees. (McPherson, 1994)

In Dutch cities vegetation is often lacking on the street and neighbourhood scale. A study by TNO shows that a change in the current situation in Rotterdam of a surface transformation of 10% from paved/built to green or vice versa results in 1-1.3°C temperature difference on the neighbourhood scale. At street level this might be different. (Klok et al., 2010)

Water

In urban areas water can cool by evaporation or by absorbing heat when there is a large water mass (buffer) or when the water is moving as in rivers (heat transport out of the city). In the Netherlands warm weather usually comes together with high moist concentrations in the air. Therefore might be presumed that cooling with water is not effective, this is a misunderstanding. A high moist concentration in the air does slow down the evaporation process (Park, 2001), pag292), however is an important cooling factor on street and regional level. Even more important is the supply of water in warm and dry periods.

Cooling with water, as with parks, is dependent on weather circumstances and the type of water application. A small pond can have a cooling of about 1°C at 30 meters distance (Robitu et al., 2004). While streaming water has a larger cooling effect, dispersed water like a fountain has the largest effect. A reduction of approximately 3 °C is measured on the leeward side at 35meters of a fountain. (Nishimura et al., 1998)
In Japan a tradition called 'Uchimizu' cools cities by sprinkling water on the streets. This method proved most effective in mornings and late afternoons in direct sunlight. The temperature drops 2-4°C by sprinkling 1L/m^2 per half hour. (Takahashi et al., 2010)

Traditionally many cities in the Netherlands were built along rivers and canals because these were important transport routes, so was the sea. But water also brought the danger of flooding. Next to transport routes more canals were made to manage the water level in cities and agricultural land. The Netherlands, as no other country, has a long history of water management. This history has lead to an enormous variation in water applications. Water applications have, next to heat mitigation, also a possibility to adapt to the future increase of extreme rainfalls. A challenging combination herein is to provide storage for peak rainfalls (also in summer) and buffer water for periods with draught.

Materials

The low albedo[5] (reflectivity) and longer cooling time-lag of materials used in urbanized areas make successively accumulate and retain heat. By white washing building surfaces, using light-coloured dyes or using light sand in paving materials, the albedo of large areas of the city can be increased. Various studies indicate a large temperature difference between green and paved surfaces. The average daily surface temperature of green is about 10 °C lower than pavement and the maximum daily temperature is 20-33 °C lower. Temperature differences due to albedo have been measured at black an white roofs; with an average

[5] the amount of diffusely reflected light by a material

daily maximum surface temperature difference of 8-17 °C. With an increasing city-wide albedo from 25 to 40 percent an air temperature drop of 1-4°C can be achieved, this can lead to enormous reductions in cooling energy demand. White roofs do not show any 'winter heat penalty' relative to black roofs. (Gaffin et al., 2010)

The traditional materials in the Netherlands, for both buildings and pavement, are red bricks and roof tiles. When building with dark colours or a heat accumulating material, green applications (trees or a green facade) can shade these surfaces or compensate heat by ET. Light surfaces require an area many times greater than green roofs to achieve comparable cooling (Rosenzweig, 2006).

Anthropogenic heat

The increase of 1.0 ˚C of the outdoor temperature leads to 3-6% extra electric energy demand in cities in the United States and Tokyo (Kondo and Kikegawa, 2003). Given this knowledge the mechanism of an air-conditioning system is rather odd. While using a lot of energy for cooling an indoor space, an air conditioner blows more heat into the outdoor than it cools the indoor. This is an accumulating problem since, the ongoing growth of cities, bad architecture design and wealth lead to more energy consumption of air conditioners.

A study in Germany focussed on the anthropogenic heat release from the highly industrialized and populated Ruhr area region. A permanent warming ranging from 0.15˚C over land area up to 0.5˚C over the Ruhr area (Block, et al 2004).

Anthropogenic heat exhaust can be reduced by diminishing energy consumption in cities, make use of waste heat and by heat storage. A system of cascading energy qualities, for example a swimming pool and an ice-skate balance their heat and cool demand, can improve our energy system by a factor of 6 (Tillie et al., 2009). Cascading energy requires an efficient hybrid network. In the Netherlands some cities already have an extensive network for city heating. However, municipalities and developers are not willing to invest in a hybrid network, due to uncertainties in a long payback time. (Roos, 2010)
During the last decade buildings in the Netherlands start to manage their internal heat distribution by storing heat underground in summer and using this in winter. This is another way to reduce anthropogenic heat exhaust, in fact heat can be harvested. This is done through WKO[6] installations that reduce energy consumption by 40-80% (ruimtexmilieu, 2010). Besides anthropogenic heat from buildings, also the heat production by traffic, green houses and all other kind of human activity could be used in the same way.

WKO installations are not applicable at all sites, in the Netherlands 90% of the soil is fit for the purpose. Determining are the thickness of the earth layers and the permeability of the earth. There are also

[6] Warmte-Koude Opslag: Storage of heat and cold water

constraining juridical factors;
- dispersion of pollution;
- danger for ecological values;
- interference with groundwater absorption;
- interference with other energy storage systems;
- salination of sweet water or sweetening of salt water;
- danger for subsidence;
- not aloud in drink water source areas.

These last factors leave 27% of the Netherlands free for the installation of WKO installations. (Zwart, 2007)

Examples from practice

Policy strategies from London, Manchester, New York and Chicago illustrate the applicability of different design principles in general.

London has recently experienced heat waves that have caused deaths, discomfort and economic losses. Also here hot weather will become more frequent and more intense. The Mayor proposes the following key actions to manage overheating in London:
- Undertake an 'urban greening programme' to cool the city using green spaces, street trees and urban design.
- Create an 'Urban Heat Island Action Area' where new development must contribute to offsetting the urban heat island effect.
- Provide London-specific design guidance to enable architects and developers to reduce the risk of new development overheating in future summers.
- Facilitate public access to cool buildings during heat waves to help vulnerable people avoid and recover from the heat.
- Undertake a scoping study for a London-wide network of weather stations to better understand and monitor London's climate. (GreaterLondonAuthotrity, 2006)

Research in Manchester in the ASCCUE project has shown that increasing green space cover by ten per cent in high-density developed areas could keep surface temperatures in the city by the end of the century at or below those experienced from 1961 to 1990 (Walsh et al., 2007), page 49)

The city of New York determined in a research in mitigation solution for the UHI effect, that the cooling potential per area was highest for street trees, followed by living roofs, light covered surface, and open space planting. From the standpoint of cost effectiveness, light surfaces, light roofs, and curb side planting have lower costs per temperature reduction (Rosenzweig 2006).

A study in Chicago concluded that planting trees in residential yards and public housing is most cost-effective from all other positive benefit-cost ratios found for plantings at parks, yards, streets and highways. Trees in yards were relatively inexpensive to establish, had low mortality rates, showed vigorous growth, and accrued large energy savings. By capitalizing on the many opportunities for yard-tree planting in Chicago, residents on whose property such trees are located receive direct benefits (e.g. lower energy bills, increased property value), yet benefits accrue to the community as well; improvement of air quality, reduced storm water runoff, removal of atmospheric CO_2 and an attractive local landscape. (McPherson et al., 1997)

Case studies

The design principles discussed in the previous paragraphs can be applied to any built up environment, but not all of these areas have the same urgency. In order to find out which areas in Dutch cities have the highest priority in the reduction of heat accumulation, six neighbourhoods from various periods are analysed in a Typological Study (Kleerekoper, 2009).

Analyses of priority neighbourhoods in two cities in the Netherlands

The six analysed neighbourhoods for this study are located in two cities with a different orientation, The Hague and Utrecht. The Hague is close to the sea, Utrecht is situated in a central part of the country. The analysed neighbourhoods have the same typologies in both cities: a historical part of the city, a neighbourhood from around 1930 and from around 1960. The chosen neighbourhoods for Utrecht are in the same sequence: Oudegracht, Ondiep and Kanaleneiland; and for The Hague: Voorhout, Transvaal and Moerwijk. In the next paragraphs the six neighbourhoods are briefly introduced per city with a short conclusion per design principle. Followed by a conclusion on the heat mitigation priority of the neighbourhoods.

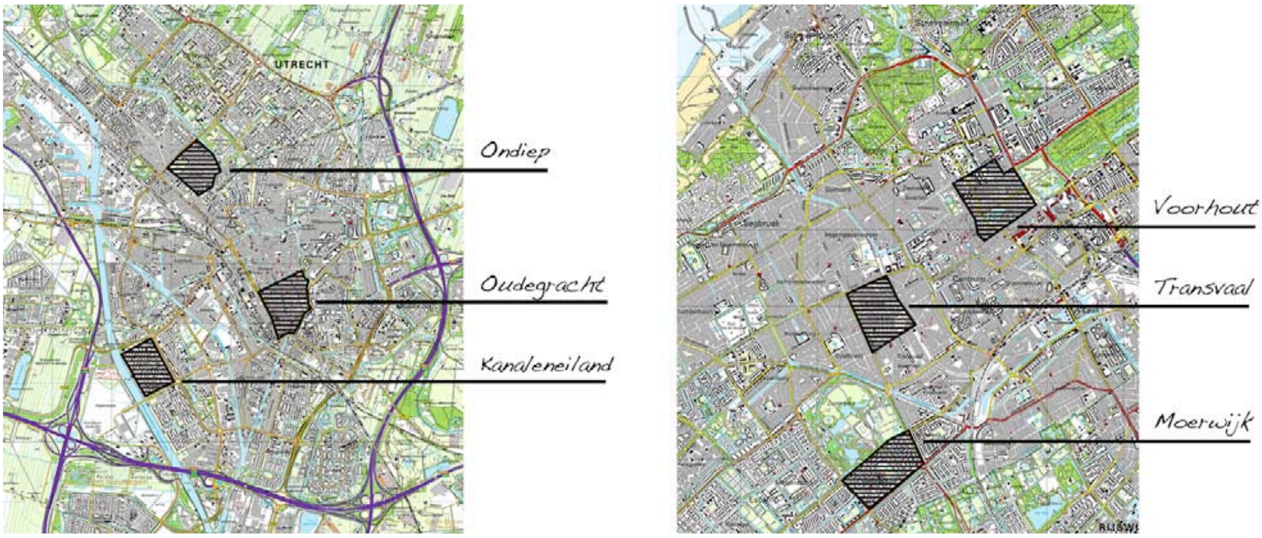


Figure 2: Utrecht with the neighbourhoods Ondiep, Oudegracht and Kanaleneiland on the left, Den Hague with the neighbourhoods Voorhout, Transvaal and Moerwijk on the right.

Utrecht

Utrecht has a historical centre enclosed by water that used to be the defence line of the city. The canal *Oudegracht* has been meandering through the old centre since the 12th century. The special building style and the unique use of the space between buildings cannot be changed because of their historical value. The building blocks are also old constructions with national heritage status. Even so, the heat accumulation here is interesting in comparison to that in other areas.

More to the north, the neighbourhood *Ondiep* from around 1930 is a working class neighbourhood. The area is situated in the former basin of the river Vecht. The built area consists of mostly one-family homes inhabited by the working class. Recently, more students are coming to the neighbourhood. The dwellings are mainly owned by the housing corporation Mitros (82%).

The Government has identified *Ondiep* as one of the 40 problematic urban areas in the Netherlands. Because of the local social, physical and economic problems more attention and money has been allocated over the next few years to improve social coherence. If it is possible to solve heat accumulation here in combination with social, physical and economic problems, plans become more feasible and stand a better chance of being financed and implemented.

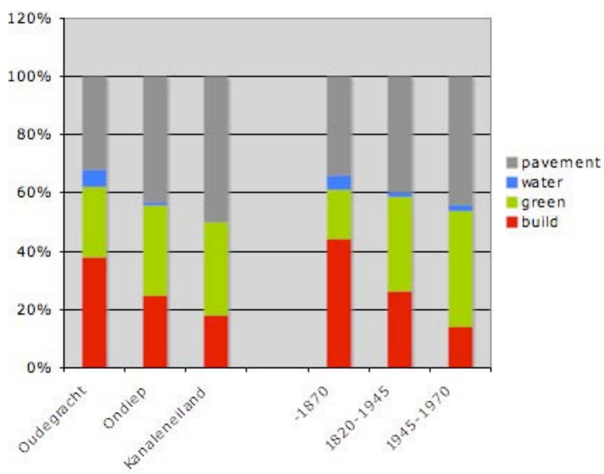
Another deprived neighbourhood , *Kanaleneiland*, was built around 1960 on the west-side of Utrecht. The monotonous building style characterizes this solely residential area. There is a commercial centre on the edge. This neighbourhood is characterised by many different ethnic backgrounds; 76% are of immigrant origin. Unemployment rates are high, the health situation is below average and crime is high. The three urban areas introduced here are quantified in Table 1.

The Hague

The old city centre of The Hague is situated on the North-East side of the city. Adjacent lies the *Haagsche Bosch*, a large green area and the *Hofvijfer*, a substantial lake. Because of the immense historical value of this area making changes will not be simple.

A bit further to the South-West the neighbourhood *Transvaal* is a deprived neighbourhood that goes back to 1914. The population is a mix of many ethnical backgrounds: Turkish, Surinam, Moroccan, 80% is of immigrant origin..

Moerwijk was built around 1960 and is situated to the South of The Hague. The monotonous building style characterises the neighbourhood that is mainly a residential area. This neighbourhood is characterised by a multi-ethnic population (55%). The three urban areas introduced here are quantified in Table 2 (Drost, 2003, Koning, 2004).



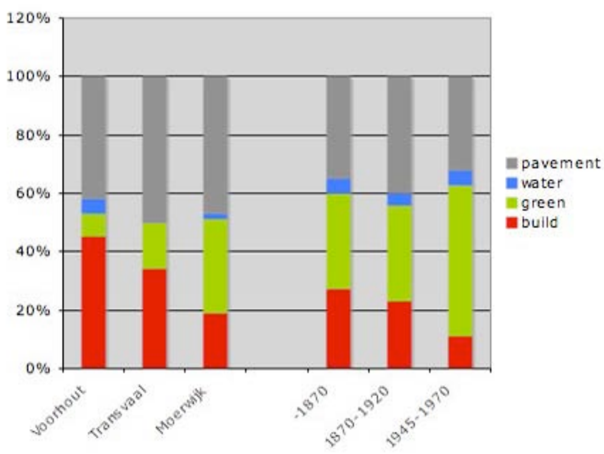


Table 1:
In the three left columns the percentage of built-up ground floor space, green, water and paved surface per neighbourhood, on the right the average surface use of all neighbourhoods in Utrecht in that period. (Koning, 2004)

Table 2:
In the three left columns the percentage of built-up ground floor space, green, water and paved surface per neighbourhood, on the right the average surface use of all neighbourhoods in The Hague in that period. (Drost, 2003).

Table 1 and 2 show that neighbourhoods in both Utrecht and The Hague have become greener over time. But also the quality and use of green varies between built-up areas from different periods. Before 1870 monumental green lanes were built to give the city status and aesthetic value. Later, green becomes the concern of the individual garden owner and more green space is dedicated for sports facilities. The future strategy for green might be their cooling function.
Table 2 shows a significant difference between the green of the analysed neighbourhoods and the average amount of green of that period. The percentage of green in Voorhout is much smaller than in the average pre-1870 neighbourhood of The Hague. The explanation for this difference is the *Haagsche Bosch* whih is

included in the survey as pre-1870 green. This area is very different from the adjacent compact built-up areas. The figure for Voorhout is therefore more representative than the average figure.

Water is not present in the neighbourhoods Ondiep, Kanaleneiland and Transvaal. However they all have nearby open water resources. Not using the surrounding water is a missed chance, water should be combined with green. This is actually happening only in Moerwijk.

Clearly the percentage of built-up surface in the analysed neighbourhoods decreases in time. The building form changes from pre 1870 compact city, to terraced houses between 1870-1945, and to apartment blocks between 1945-1970. If the built-up surface decreases, what kind of surface occupation can we expect? In the period 1870-1945 built-up surface is replaced with pavement and a little more green. In the period 1945-1970 built-up surface is replaced with green and a little more pavement.
Spacing increases also in time. The compact city had street widths of about 5 metres, the terraced streets have 10 metres width and the apartment blocks have streets as wide as 40 metres.
The H/W ratio tells almost the same story, but this also relates to the height of the constructions. The compact city has H/W ratios from 1.0 to 3.5, the terraced streets have a H/W ratio of 0.75 - 1.4 and for the apartment blocks the ratio is between 0.3 to 0.7. Only the apartment blocks enjoy the effects of optimal ventilation because the H/W ratios are close to 0.5.
For cooling effects from vegetation and water, airflow from these cool spaces should be guided to flow into the streets. In most situations streets are parallel to a park or canal, in which case the first housing row is blocking the cool airflow.

Pavement has increased in time, but the total amount of hard surface (building and pavement) has decreased. *Voorhout* has 42% paved surface, but because it has a high building density the total amount of hard surface turns out much higher than in *Moerwijk* that has almost the same percentage of paved surface. In Utrecht this becomes even more evident where the compact centre has only 38% paved surface in comparison to 51% in *Kanaleneiland*, but has less hard surface in total. *Transvaal* and *Ondiep* both have a high percentage paved surface, but the row houses also generate a high building density. The buildings are less compact, which levels these neighbourhoods at almost the same total hard surface material as the old city centres. (See Table 3)

	moerwijk	transvaal	voorhout
pavement	46%	56%	42%
total pavement+roof+façade	**77%**	**92%**	**91%**

	kanaleneiland	ondiep	geertebuurt
pavement	51%	51%	38%
total pavement+roof+façade	**75%**	**80%**	**85%**

Table 3: Percentage of pavement and total hard surface material.

The large amount of hard surface in *Transvaal* and *Ondiep* is almost equal to that in the city centre, but warms up more. Due to the higher H/W ratio in the centre, these surfaces are shadowed more by the buildings and therefore they stay cooler. This effect is most distinctive in the morning heating rate (Watkins et al., 2002). On the contrary a high H/W ratio leads to slower cooling at night due to the diminished sky-view factor (radiation to the sky).

Priority neighbourhoods

Ondiep – **Utrecht**

From the three neighbourhoods in Utrecht that are described above, heat will accumulate most in Ondiep. It has rows of two storey one-family houses. Streets have few trees and a lot of pavement. Backyards are often paved as well.

The total area contains 80% hard material from pavement, facades and roofs. The way in which these aspects are related to each other influences the amount of heat accumulation in the paved and built-up surfaces and the cooling effects of green and water. Figure 3 shows that Ondiep does not have a consistent structure but consists of four parts with different layouts. On the edge of the neighbourhood at the north-west side a large area is occupied by sports fields and public grass fields.

Fig. 3: Left: Green in Ondiep. Right: Typical street in Ondiep.

Most streets in Ondiep have a width of 10 metres faced with 2 to 3 storey buildings. The H/W ration is around 0.75 for the residential streets. The backyards are a bit more spacious with a H/W ratio between 0.35 and 0.25. The main roads have a lower ratio.

Streets in Ondiep are scarcely planted; sometimes trees have been planted just on one side of the street, sometimes not at all or with a lot of space in between. The main streets have more and larger trees. There is

no other kind of green in the streets. Even though the houses are all one-family dwellings almost none of them have a front garden. If there is a front garden this is usually paved, just like the backyards.
At the north edge there are some fields, he row of houses along this green is fencing off the green visually, but also prevents cooled air to enter the neighbourhood. The same goes for the sports fields on the west side.

Because Ondiep is situated along the river Vecht there is a constant water supply running along the neighbourhood. Except from the houses directly on the Vecht, no one else can see the water. The cooling influence from the Vecht is therefore minimal.

Transvaal – **The Hague**

In Transvaal heat accumulates more than in the other neighbourhoods. It was also built in the 30s like Ondiep in Utrecht. Transvaal has very little green in both the streets and the inner courtyards. The neighbourhood is a crowded area because of the 'Haagse markt' and other commercial and cultural activities. The total area contains 92 % hard material consisting of pavement, façades and roofs.

Fig. 4: Left: Green in Transvaal. Right: Neighbourhoud park Transvaal.

The main roads in Transvaal have trams running through and cars are parked everywhere. The inside of the building blocks are often paved, built and/or have little shading. Transvaal does not have much green as you can see from Figure 4. The square to the north is completely paved with the exception of some triangular grass patches. This recently constructed neighbourhood park is not contributing to the heat problem in this neighbourhood, which is a missed opportunity.

In Transvaal there is almost no green to be found in the streets. Here and there a lonely young tree can be spotted, there is no grass and no shrubs. Also private plots in building blocks have little green. Nevertheless there will be some cooling from the Zuiderpark on the South-West side. The cool effect of this park will not reach further than a third of the whole area at the most.

Water is not present.

The streets have a width of 7 to 16 metres depending on the function or history of the roads. For example, the diagonal Paul Krugerlaan used to be a connection to the historical city centre. The height of the buildings are over the whole neighbourhood the same, 3 to 4 layers and streets have a H/W ratio of around 1.33.
The orientation of streets in Transvaal is parallel to the wind direction. This means sufficient ventilation in summer (for this wind direction), but can lead to uncomfortable and dangerous situations during heavy weather.

Mititgating the development of the UHI effect in two priority neighbourhoods
The two priority neighbourhoods from the previous paragraphs are both from the thirties, but these are not designed according to the 'garden' concept, which are usually based on a large green structure. The typology of the garden cities de not have the same problems related heat accumulation, even though they originate from the same period. In the analysed neighbourhoods green is actually lacking in both public space and private 'gardens'. For the neighbourhoods from the thirties a design proposition to diminish heat accumulation is made. In order to be able to verify whether a design proposition offers sufficient improvement, design criteria were formulated based on the theories and measurements described in the first section (Kleerekoper, 2009):

- All dwellings are to be situated within 200m from a green area with a minimum size of 0.15 ha;
- The preferred street orientation is perpendicular to green areas;
- Green filters are to be placed in streets with a high traffic pressure;
- Combinations of green with water should be made where possible;
- A lack of greening possibilities in streets should be compensated with surface water, green façades and permeable pavements;
- Flat roofs should be transformed to green roofs or be covered with a reflecting light surface;
- Slanted roofs should have PV-T panels or a reflecting light surface;

As additional criteria for both neighbourhoods is set that the amount of dwelling surface should not decrease. The design plans for the neighbourhoods of Ondiep and Transvaal show how the design principles can be applied in a practical situation. For both neighbourhoods a renovation plan is described in which demolition is kept to a minimum. The applied measures might not be the most effective ones with regard to minimizing heat accumulation, but the best in relation to the existing spatial situation and the impact on social and financial aspects.

Ondiep in Utrecht

Ondiep is situated at 1,5 kilometres from the city centre of Utrecht. It forms a transit area for inhabitants from Zuilen and commuters. There are three different routings; a commercial street connecting the area to the west side of Utrecht, a car and bus route connecting the city centre to the ring road through Ondiep, and a route along the river Vecht.

Fig. 5: Left: Green in Ondiep with a circle of 200 meters. Right: Design for green zones and water system.

Considering the criterion 'all dwellings are to be situated within 200m from a green area', a large part in the middle of the neighbourhood does not meet this standard in the current situation. Since there are very few (green) open spaces in this particular part, it will be difficult to create them without decreasing the amount of dwellings while preserving the characteristics of the neighbourhood.

The design plan for Ondiep is based on improving the routings described before with green zones in combination with other heat diminishing measures.

Building plan

Implementing green in the form of green zones and routes demands space. The car and bus route has a width of 25 to 30 meters and does not offer the amount of space that is needed. To create space for green the dwellings along the north side of the street will be shifted backwards. The existing dwellings have two or three building layers, new dwellings with four layers have to compensate for the amount of demolished dwellings along this route.

When streets are widened and the amount of building layers is changed the H/W ratio is influenced as well. The lowered H/W ratio improves natural ventilation, which is extra stimulated by the slanted roofs. Thanks

to the favourable street orientation in Ondiep (every street receives solar radiation in the late morning or early afternoon) and the slanted roofs, the houses are very suitable for PV-T[7] panels.
In the 'Witte Wijk' (translation: white neighbourhood) a recent developed white coating[8] will be applied on the roofs. White roofs emphasize the image of this particular area. The coating reflects sunlight and keeps its high albedo because it repels dirt.

Green plan

The green zones all have a different character. The green areas differ in usage, ambiance, presence of water, and intensity of use.

The streets that form the car and bus route cut through the whole neighbourhood. The green added in this zone has an important cooling function, but also needs to filter out air pollution. The natural green filter in this zone is based on a research done by Alterra Wageningen UR.
In the street profile half of the surface is covered with green. In order to optimize the cooling capacity of the trees, a water storage system under the street supplies trees with enough water. In the Netherlands, a street accompanied by coniferous (non-deciduous) trees is very unusual. In the busy car and bus route these trees are however necessary, since the air needs to be filtered in both summer and winter.

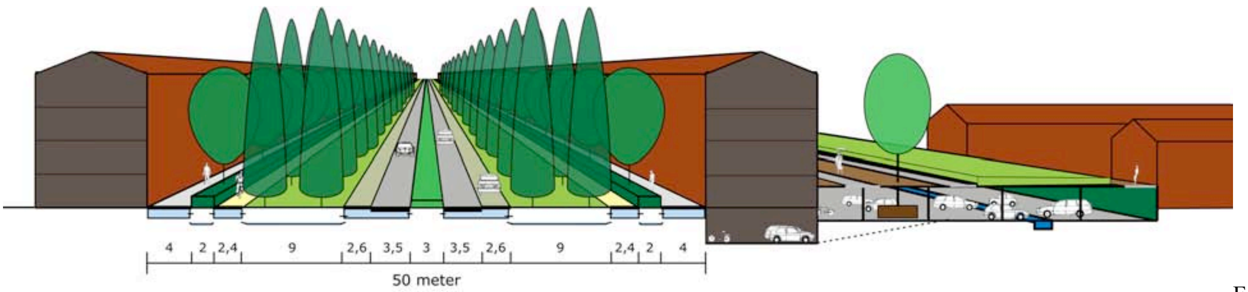


Fig. 6: Section of the car and bus route.

Along the river *Vecht* a quiet and recreational green zone forms a picturesque and pleasant route for cyclists, but also for locals to stroll, let the children play or the dog run. This green zone improves the microclimate in Ondiep, offers more recreational space and stimulates bicycle use.

Another additional green zone is situated in between strips of single-family houses. Here an intimate peaceful area will be created with for example Malus (Apple) trees and a car-free zone with space for a water canal with one sloping edge and one hard quay to stroll along.

7 PV-T: a combination between photovoltaic and thermal solar panel.
8 Ecoseal EP White (Single-PLY Systems website).

Water plan

In the design for Ondiep the main function of water applications is to supply trees with enough water to maximize their cooling capacity. Next to this, the water cools the outdoor environment. An integral water plan is also calculated to incorporate other aspects of a sustainable water system, like the re-use of water for household activities like toilet flushing. The dwellings discharge all wastewater, except for toilet flushing, onto the surface water where helophyte plants clean it.
The water system has a fluctuation of 800mm to deal with heavy rainfall. Seasonal storage and water for trees and households is all taken into account in the calculation for extra storage.

Water needs to circulate in order to preserve a good quality. Water also demands a lot of space, especially when the edges need to be natural slopes. In many streets this space is simply not available. However, there are other possibilities; instead of surface water it is possible to lift the water up to street level. This so called 'shallow water' has to be pumped up from the surface water to a shallow canal that ensures a water circulation. Rainwater from roofs and pavement streams into a drain at surface level and is collected in the shallow canals.

Transvaal in The Hague

Ondiep and Transvaal are both constructed in the same period. Both have social issues, but there is an essential difference. The dwelling density in Ondiep is quite high: 44 dwellings per hectare. However, this is low in comparison to Transvaal where 98 dwellings occupy a hectare. Transvaal has a larger area and counts 18.000 inhabitants. This is more than three times the amount of inhabitants in Ondiep. Because of this difference Transvaal is much more lively. In Ondiep many traffic only passes by, but Transvaal is also a destination for people not living there.

As for the multicultural Transvaal neighbourhood, another approach is chosen to test if the design principles are generically applicable. This neighbourhood has a higher density that causes pressure on public space. There is litter on the streets and hardly any green except for some lonely young trees.

Building plan

In Transvaal the renovation process has already started with the main square and some housing projects. A part of the houses is being rebuilt, another part is being demolished. The new square is working quite well in social respect, but in terms of heat accumulation it is a missed chance. Especially regarding the name of the square, 'Wijkpark', you would expect much more green.

The most cost-effective measure for this square is to maintain the layout and to fill the large paved open space with water and add water jets that switch on when it is a warm day.

Fig. 7: Green in Transvaal with strategic renovation plan.

Green plan

In the rest of the neighbourhood there are many stony open spaces. There is a lot of pressure on the public space. Streets have no green, no front gardens, just pavement and cars. The little green in the squares is too tiny to hold out against the intense (ab)use. As a consequence squares are designed with only stony elements and have no shelter from sun, wind or rain. These areas can become cooling islands if they are designed with more green, water and shading. There are quite a lot of little squares spread over the whole neighbourhood.

More than 95% of the buildings have a flat roof, which creates the potential to form a green roof landscape. When the measures of greening the squares and creating green roofs are combined the area will meet the criteria '200m from green'. An extra advantage of roof gardens in this neighbourhood is the creation of more space. In the current situation roof surfaces are not used, but green roofs can function as a garden. This extra created space is also safe from intruders and does not suffer from the high pressure on the public space at street level.

In addition to green roofs and extra vegetation on squares there is an excellent solution for this busy neighbourhood in green facades. There are some alleys cutting through building blocks that can transform into an oasis of peace - surrounding the citizens with green and flowering walls.

Next to the 'Haagsche markt' one building block will be demolished to create space for a public park. A green walkway cutting through building blocks connects the rest of the neighbourhood to the park and the Haagsche markt. The demolished dwellings will be compensated for at the North side of Transvaal that is now a pavement desert with some industrial activities. The current activities like paper recycling, a bakery, etc. do not conflict with dwellings. The ground floor space will mainly be occupied by these light industrial activities, and on top of this layer seven storeys with apartments with a view over the green roof landscape are added. . The new apartment buildings have a green façade(a vertical garden) so that they become part of the green roof landscape.

Water plan

In Transvaal, the introduction of water connects the *Zuiderpark* at the South with a canal in the North. Just like in Ondiep there is not enough space for the implementation of surface water. Here too the water is pumped up into shallow canals, but the canals are not as wide as in Ondiep and do not run through grass but through paved surface. At crossings and busy areas the canal is covered with a decorative grill.

Fig. 8: Transvaal with green squares, green roofs, new building typology and water system.

The shallow canals lead the water to some squares along the main street where it is pumped up by fountains or other water applications.

A part of the neighbourhood will be demolished and newly built. This brings the opportunity to reserve space for seasonal water storage that allows trees to cool at their maximum. Furthermore, in a new design there is a possibility for the re-use of water for toilet flushing. The new structure of the site differs a lot from the rest of Transvaal. Square building blocks of three to four storeys high are surrounded by trees. It feels as living on the edge of a forest with a view on a lake or canal. The surrounding trees are deciduous, allowing sunlight through in winter and shading facades and windows in summer.

Results/ Discussion

The overheating of urban areas can be diminished when during the design of a redevelopment plan the following design principles are taken into account:
- compositions and orientations related to the wind and sun have the danger to bring discomfort in winter. Adjusting the H/W ratio and applying slanted roofs generate ventilation for cooling, and trees or adjustable shading devices prevent the accumulation of heat;
- parks have an average cooling effect of 1-6 °C that spreads 100 to 1000 meters into an urban area. A green facade or roof cools the outdoor environment with 0.5–3 ˚C. However this is very dependent on the amount of water the plant or tree has available;

- water has an average cooling effect of 1-3°C to an extend of about 35 meters, a bigger cooling effect is achieved when it successively has a large mass, is streaming or is dispersed like a fountain;
- increasing the albedo of surface materials of a building can lead to a cooling energy and the temperature difference between a dark or light surface is about 8 to 17°C. Light surfaces require an area many times greater than green roofs to achieve comparable cooling;
- anthropogenic heat output must be avoided, re-using waste heat within a heat distribution network or re-use heat from summer in winter through a storage system;
- policy makers aim mostly at the cooling effect of vegetation in order to counterbalance the UHI effect.

Conclusions

The UHI effect is already present in Dutch cities, and will continue to increase due to ongoing expansion, densification and increasing use of fossil fuels. When adaptation measures against heat accumulation are necessary depends on the following aspects; amount of green, water and pavement/hard facade material, composition of buildings and the location in the city.

The appropriateness of heat mitigation measures depends on site-specific conditions. The two design plans for Ondiep and Transvaal show that there are various possibilities to apply measures to diminish the accumulation of heat. When a neighbourhood needs to be renovated anyway, measures against heat accumulation can be combined with other measures that are necessary to improve the social, physical or economical condition.

The freedom urban designers and policymakers have in the way they implement the principles will stimulate designers to come up with creative solutions of their own. When there is not such flexibility or freedom, they will be reluctant to use them.

Policymakers seem to hesitate in working with the design principles because of a lack of quantification. Firstly, the heat accumulation of an area needs to be quantified. Secondly, an acceptable level of heat accumulation needs to be defined, and finally, a quantification of the required measures is needed, for example, the necessary amount of green to upgrade the area to this level. Policy makers need to be able to set targets and evaluate them. This is not possible yet, especially the quantification of the result in temperature drop after implementation of multiple measures on a neighbourhood scale, needs to be developed still.

A climate adaptation plan can only be successful when it is also addressing social, economical and spatial aspects. If an adaptation measure leads to a solution on various levels we don't even need all the quantifications. If we take green as an example, besides cooling it has a positive effect on the human psyche in preventing depressions etc. Green also produces oxygen and filters particulate matter and ozone out of the air. With an increase of green routes through a city bicycle use is stimulated, green forms a habitat for fauna and makes a city more attractive and improves it's image.

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