



How to make a city climate-proof, addressing the urban heat island effect

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ABSTRACT

The climate of a city influences the ways in which its outdoor spaces are used. Especially public spaces intended for use by pedestrians and cyclists, such as parks, squares, residential and shopping streets, and foot- and cycle-paths will be used and enjoyed more frequently when they have a comfortable and healthy climate. 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.

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1. Cities and climate – causes of the urban heat island effect

The relationship between climate and city is reciprocal: the climate influences the ways in which the city space is being used and the climatic performance and needs of buildings. In its turn, the city influences its climate. On the large scale the city as a whole modifies the regional climate conditions, which results in differences between the city and its surrounding (rural) area in cloud cover, precipitation, solar irradiation, air temperature and wind speed. On a smaller scale, the geometry, spacing and orientation of buildings and outdoor spaces strongly influence the microclimate in the city. The microclimate can vary significantly in a distance of even a few metres. One of the best known effects of the influence of the urban environment on its climate is the urban heat island effect (UHI effect). This is the phenomenon that the urban air temperature is higher than that of the surrounding rural environment. The extent of the temperature differences vary in time and place as a result of meteorological, locational and urban characteristics. The urban heat island effect has the following causes (Oke, 1987; Santamouris, 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.
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. See Fig. 1 for illustrations.

This paper aims to explore the effects of climate change for the urban environment and aims to provide tools for urban design and strategies for implementation. First an introduction of the problem field and climate change effects is given, followed by a review on climate adaptation measures, these are categorized in four themes: vegetation, water, built form and materials. The next section describes the transfer of scientific knowledge into practise. In the last section the applicability of the climate adaptation measures from the second section are tested in a design for two existing Dutch neighbourhoods. The review is directed to the general field of climate adaptation, while the test designs have the specific context of the Netherlands and therefore provide insights for

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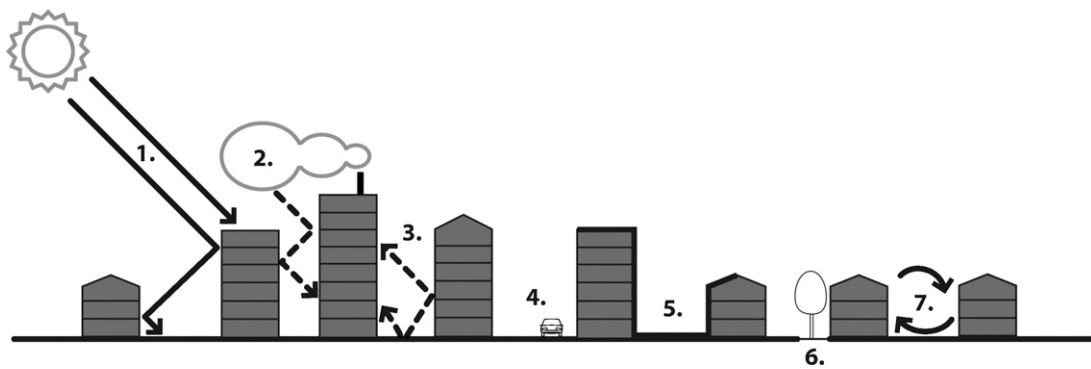


Fig. 1. Causes urban heat islands.

locations with similar climate and latitude and similar urban characteristics.

1.1. Health effects of heat stress

Physical well-being can be significantly influenced by the meteorological climate in general and by the urban microclimate more specifically. The body gains heat by absorption from radiation from the sun and sky – directly or by reflection –, but also from objects warmer than the body. Furthermore, the body produces heat itself through metabolic processes and by performing activities (walking, running, and such). The body can also gain heat by conduction from air above skin temperature – which in the Netherlands is rare – or from direct contact with hotter objects, such as the street surface. In the outdoor environment this contribution is usually negligible. The body can lose heat through respiration (exhaled air is usually warmer and more moist than inhaled air), evaporation from the skin, radiation to the sky and colder surfaces, and by conduction from the body to air below skin temperature, hastened by convection, and by contact to colder surfaces.

The body has a thermoregulatory system of various mechanisms to deal with an imbalance between heat gains and losses. These mechanisms include vasoconstriction and vasodilation to regulate the flow of blood to the skin, shivering and muscle tensioning to produce heat, sweating to lose heat, changes in respiratory rate and heart rate, and the production of hormones. Extreme temperatures can place significant stresses on the thermoregulatory system, with discomfort or even health danger as a result. Considering the climate predictions for the Netherlands, the largest threat lies in heat stress. Heat stress can cause illnesses such as heat syncope, caused by a failure of the circulation to maintain blood pressure and supply oxygen to the brain, cardiovascular stress and thermal exhaustion, or even heat stroke. A heat stroke can lead to respiratory distress syndrome, kidney failure, liver failure and disseminated intravascular coagulation (blood clots). These complications in turn may lead to death. The optimal outdoor temperature related to the lowest mortality is 17 °C (Hoyois et al., 2007).

HVAC systems (heating, ventilation and air conditioning) make thermal stresses virtually obsolete indoors – with a substantial rise in energy consumption and anthropogenic waste heat as a result – but outdoors they remain. Moreover, due to the predicted climate change heat stresses will increase as a result of a global temperature rise, and an increase in hot extremes and heat waves. Combined with urban heat island effects, these conditions are likely to result in uncomfortable and unhealthy heat stresses, and more alarmingly, a significant increase in heat-related mortality. The heat wave in the summer of 2006 caused about a thousand heat-related deaths in The Netherlands and was rated the fifth natural disaster of that year (Hoyois et al., 2007).

Another harmful effect of higher temperatures is the stimulation of the formation of ground-level ozone in urban areas, which can lead to or aggravate cardio-respiratory diseases such as lung inflammation and decreased lung function (WHO, 2004).

1.2. Climate change and predicted effects

The International Panel on Climate Change (IPCC, 2007) predicts a global surface air warming of between 1.1 and 6.4 °C for the 21st century, and an increase in hot extremes and heat waves. Based on this prediction and supplemented with its own climate models, The Royal Dutch Meteorological Institute (KNMI) has made predictions for the climate in The Netherlands in 2050. They predict that the winters will be warmer and moister and that summers will be warmer and dryer. Further predictions are an increase in extreme precipitation events all year round, but a decrease in the number of days with precipitation in summer. The rise in temperature in the Netherlands is already higher than the mean global temperature rise, and this is thought to continue in the future. This higher warming rate is mainly due to the position of the Netherlands close to the land mass of Eurasia, which warms significantly more (almost twice as fast) than the global mean. As a result of this warming there will be stronger westerly winds in winter and more easterly winds in summer (KNMI, 2006, 2009).

The accuracy of these predictions is subject to several uncertainties, such as the quality of the climate models, but also the unknown development of human activities considering greenhouse gas concentrations in the atmosphere and land use, and the response of the climate system on these changes. The best way to deal with these uncertainties regarding the future climate is to build new urban expansions as well as adapt existing urban environments in a robust way, dealing with all causes of urban warming.

2. Tools for urban design and strategies for implementation

By diminishing the accumulation of heat and applying cooling techniques, cities can mitigate¹ their UHI effect. Here, design principles for Dutch cities are described in four categories: vegetation, water, built form and material.

2.1. Vegetation

Vegetation cools the environment actively by evaporation and transpiration (evapotranspiration²) and passively by shading surfaces that otherwise would have absorbed short-wave radiation.

¹ Taking actions to reduce the temperature difference between urban and rural areas.

² ET: Evaporation and transpiration of vegetation.

During the night the high sky view factor of open fields allows heat to escape fast through long-wave radiation.

There are four different types of application of vegetation in urban areas: urban forests (parks), street trees, private green in gardens and green roofs or façades. Vegetation has an average cooling effect of 1–4.7 °C that spreads 100–1000 m into an urban area, but is highly dependent on the amount of water the plant or tree has available (Schmidt, 2006).

An urban forest or a park is a green area within an urbanised environment. These areas have a lower air and surface temperature and thus form a PCI (Park Cool Island). In numerous studies it is shown that vegetated areas result in PCI's. A green area does not have to be particularly large in order to generate a cooling effect. According to a study in Tel Aviv, a park of only 0.15 ha had an average cooling effect of 1.5 °C and at noon reached a 3 °C difference (Shashua-Bar and Hoffman, 2000). A study in Göteborg shows that a large green area does generate a large cooling effect. A maximum difference of 5.9 °C in summer in a green area of 156 ha was measured there (Upmanis et al., 1998).

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

Street trees might seem to have a low impact on the temperature within the city because they are so dispersed, but since there are so many they actually have a big impact. On a sunny day the evapotranspiration of a tree alone cools with a power equal to 20–30 kW, a power comparable to that of more than 10 air-conditioning units (Kravčík et al., 2007).

Covering a roof or façade with vegetation has a cooling effect on the urban environment and the building itself. The responsible cooling mechanisms of a roof are: evapotranspiration of the leaves, converting heat into latent heat by evaporation from the soil and preventing the absorption of short-wave radiation by low albedo materials through shading. The indoor temperature also reduces because of the high insulation value of the green package, which will keep the heat outside in summer and inside in the winter.

In a review of studies done by Yukihiro Kikegawa, and others, the effect of green facades was measured for the outdoor temperature and the effect on air-conditioner savings. The greening leads to an average decrease of 0.2–1.2 °C in the near-ground temperature and results in a cooling energy saving of 4–40% (Yukihiro et al., 2006).

Other suggestions to improve the application of vegetation are: (1) shading of windows and west-facing walls provides the most savings in cooling energy. (2) With regard to shading, the tree's crown shape can be more important than its crown density. (3) Energy and water rates determine the extent to which it is economical to substitute electric air conditioning with cooling by vegetation. (4) Effects of tree shade on winter heating demand can be substantial with non-deciduous trees (McPherson, 1994).

2.1.1. Strategies for implementation

Applying more green in public spaces has a relative low cost and high acceptance among citizens. The most effective green elements are street trees (Rosenzweig et al., 2006), therefore, the greening policies of different pioneer cities have had clear goals concerning the increase of the total number of trees and their heterogeneity to assure resistance to vegetal diseases (ill trees rarely affect trees from different families). Examples of these policies are given by cities like Chicago (Ferkenhooft, 2006) and Edinburgh (The City of Edinburgh Council, 2001).

Even though greening public spaces is mainly a responsibility of the municipality, it is feasible and recommendable to involve citizens in the initiative as this topic has a high public acceptance (Greenspace, 2005). This has been successfully achieved in different

greening initiatives. In Paris, for example, where gardening around trees was encouraged. In the Netherlands there is no special program to encourage the participation of citizens into greening the public space, however, it is commonly done and it is visible in cities like Amsterdam where some of the bricks of the sidewalks have been removed to give space to ornamental plants (Fassbinder, 2009).

The involvement of citizens is even more important in long time span initiatives as in Chicago, where the first programs were mainly focused on the public space, but after 15 years of greening the city the focus nowadays is on private spaces (Chicago Trees Initiative, 2009).

The promotion of green in private spaces has a higher relevance in the case of high density cities, as the municipality is not the owner of the major part of the surface exposed to the solar radiation. In that case, initiatives like the one in Paris promoting green façades and green terraces (Mairie de Paris, 2009), or the subsidy program of green roofs in Rotterdam are defining the future trend of adaptation strategies (Waterplan Rotterdam, 2008).

2.2. Water

Water can cool by evaporation, by absorbing heat when there is a large water mass – which functions as a heat buffer – or by transporting heat out of the area by moving, as in rivers. This is already happening in Dutch cities due to existing water applications.

Water has an average cooling effect of 1–3 °C to an extent of about 30–35 m. Water applications in general are more effective when they have a large surface, or when the water is flowing or dispersed, like from a fountain. The effect of cooling by water evaporation depends on the airflow that replaces the cooled air through the city. Cooling with water, as with PCI, is dependent on weather circumstances.

A study done in Bucharest shows the cooling effect of a pond of 4 m × 4 m. The cooling effect was about 1 °C at a height of 1 m, measured at 30 m distance (Robitu et al., 2004).

While flowing water has a larger cooling effect than stagnant water, dispersed water like from a fountain has the biggest cooling effect. A study in Japan shows air temperature measurements on the leeward side of a fountain with a reduction of approximately 3 °C. The effect of the water system can be felt (from 14.00 to 15.00 h) up to 35 m distance (Nishimura et al., 1998).

2.2.1. Strategies for implementation

From a strategic point of view, the promotion of the use of water infrastructures to benefit from the evapotranspiration effect is difficult due to the high costs involved. Only the implementation of fountains can be seen as a good cost/effect option in specific spaces with a high use, like commercial streets or squares. With a smart fountain design it is possible to use the same space for other purposes in winter time.

In addition to the cooling effect from evaporation, water plays another crucial role in heat adaptation due its contribution to the increase of green infrastructure. More vegetation adds extra water buffering capacity, which is useful in case of heavy rain fall, and it increases the effectiveness of the evapotranspiration from the vegetation, which depends on the amount of water available. That is why the promotion of green infrastructure must go together with the promotion of better rain water management.

Promoting the use of permeable pavement and storage infrastructure is a beneficial strategy in case of droughts and flooding. Water storage in public spaces is one of the proposals of the city of Rotterdam in the design of new development areas of the city. Some of the designs include multifunctional spaces as in the case of the "water plaza"; a public space for storage of rainwater surplus that will be presented in the city pavilion of the World Expo 2010.

On a lower scale, several municipalities in the United States are creating reference guides about pavement options for low used traffic zones, like private paths, terraces and parking spaces (City of Portland, 2008).

2.3. Built form

Building density and geometry are composition variables that influence the incidence of radiation on materials that can store heat, and the trapping of radiation by multiple reflections between buildings and street surface. 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 canyon.

Overheating by solar radiation in summer can be reduced with high ratios of street height to street width (Fletcher, 2008). However this may also reduce air flow, promote multiple solar reflections and lower the sky view factor which leads to the trapping of 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 cool winter climate this leads to uncomfortable situations.

A better alternative to shade buildings are trees and green walls, which are green in summer and transparent in winter. Also, operable shading devices can be used in summer and can be easily removed in winter.

Built form also reduces wind speed. Wind transports the turbulent heat out of a street canyon. Designing with wind can lead to effective cooling of buildings and urban areas. In many warm countries wind is an important cooling factor. In the Netherlands, wind is a dangerous measure for cooling. Stimulating wind for ventilation in summer can lead to a very unpleasant or even dangerous situation in winter. The main wind direction is from the South-West, but in winter we have the coldest winds from the North-East. According to the future climate predictions, the strongest winds (not the coldest) in winter will come from the west. The strongest winds in summer will come from the east, which will also bring the warmest air. The orientation of streets will therefore bring some design challenges, especially taking into account both solar and wind orientation (Esch et al., 2007).

Another way to improve ventilation is to generate a mix of the air in the canopy layer³ with the air from the boundary layer.⁴ One way to obtain this mix is to adjust the canopy layout. The best ventilation is acquired at a height to width ratio of around 0.5. At a height to width ratio of more than 2 there is almost no mix of the canopy and boundary layer (Xiaomin et al., 2006). The mix of the two layers also takes place with slanted roofs. These generate effective natural wind ventilation at the 'mouth' openings of urban street canyons. This is a much more effective means for improving natural ventilation than increasing building spacing (Rafailidis, 1997).

City size is not an adjustable feature, but can play a role in policy making. The larger the city, the bigger the UHI effect. T.R. Oke has developed a prediction method of the UHI effect for the European city. With the following equation the maximum difference between the rural and the urban temperature can be predicted according to the amount of inhabitants; $\Delta T_u - r(\max) = 2.01 \log P - 4.06$ (Oke, 1973).

Cities have a larger surface area compared to rural areas and therefore more heat can be stored. Compact buildings have less external facades and therefore less heat storage.

2.3.1. Strategies for implementation

Influencing the built form of a city from a policy standpoint is rather difficult and more using climatic parameters. Nevertheless certain cities have included clear and rigorous spatial parameters in their urban planning guidelines. The city of Stuttgart has published an interesting booklet of climate change adaptation for urban planners (Baumüller, 2008). Only cities with enough resources have the opportunity to develop this kind of guidelines as they are completely site dependant. However, in the case of the Netherlands, some results could be extrapolated to other cities because of the similar orography in vast zones of the country. Moreover, there are several new developments starting from scratch, that can easily take spatial parameters into account.

2.4. Material

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.

While permeable materials allow cooling by evaporation, hard materials accumulate heat. Next to that short-wave radiation is absorbed in low albedo materials. Results of increasing albedo were computed in a simulation model for Sacramento, California. By increasing the albedo city-wide from 25 to 40%, a temperature drop of 1–4 °C can be achieved. Increasing the building albedo from 9 to 70% can reduce the annual cooling demand with 19%. Simulations showed a reduction of 62% in cooling energy demand when both the city-wide albedo and building albedo are increased (Taha et al., 1988).

The thermal admittance of materials also plays a significant role. Materials like brick store more heat, and radiate this heat into the air during nighttime until sunrise. Hollow block concrete has a smaller thermal admittance and therefore stores less heat.

The temperature difference between materials can be very large. During heat waves the temperature in cities can accumulate day by day when there is no cooling wind or enough green to compensate. A research project in Singapore focussed on the difference in temperature on building facades due to dark or light colours. A maximum temperature difference of 8 °C to 10 °C on the external wall was measured during 13.00 and 16.00 h. Also the façade material in relation to the cooling time-lag was studied in Singapore. Three types were tested; a brick, a concrete and a hollow block wall. The brick wall had the longest time lag, followed by the concrete wall and the hollow block wall cooled at the fastest rate (Wong Nyuk, 2007).

2.4.1. Strategies for implementation

Changing the thermal property of the different surface materials of the city is the cheapest way to reduce the urban heat island effect. Even though the effects of this strategy are lower than the effects achieved using vegetation, the price and the technical feasibility allow covering bigger surfaces, achieving better results (Rosenzweig et al., 2006).

Even though all surfaces exposed to solar radiation have the potential to improve their thermal properties, the most common strategies carried by different municipalities are based mainly on the change of street pavement and roofs, commonly known as cool pavements and cool roofs.

Numerous research projects have been carried around the properties of the cool pavements. Several cities have introduced this strategy in their plans to mitigate the UHI effect, as in the case of Houston (Hitchcock, 2004). Unfortunately there are no experiences yet of implementation on a large scale.

The pavement of spaces with a low use rate like parking spaces or private roads could be different to allow for a higher

³ The air space in a street profile.

⁴ The layer of air above the roughness elements of a surface (forest, cities, etc.).

permeability; bricks instead of asphalt, or even bricks with holes allowing grass to grow in them. This strategy is mainly promoted among private users, individuals and companies as has been already mentioned in Section 4.2 referred to water issues.

Applying cool roofs has been pointed by several studies as a very good strategy to deal with the urban heat island effect, nevertheless, this strategy is not as popular among politicians as greening the city, which is the common trend at the moment. Nevertheless, in California cool roofs have been introduced in the Building Energy Efficiency Standard regulation of the state, and will be in effect on the first of January 2010 (California Energy Commission, 2009).

3. Transfer of knowledge

As has been pointed out in the previous pages, there is already quite some knowledge available on the causes and effects of the UHI effect. Furthermore, several tools and strategies to counteract the UHI effect are available and some of them have been already successfully implemented in several cities around the world. Nevertheless one of the biggest problems faced is the transfer of this knowledge to the urban planning process.

The urban planning process takes place in a multi-actor environment; there is collaboration between principals, urban designers, architects, residents, real estate developers, experts from various fields, institutions, municipalities and other authorities. All these participants contribute to the planning process with a certain activity, which can be categorized under three headings: design, science and deliberation (Müller et al., 2005). The fields related to these different activities usually use a different 'language' due to their difference in focus and aim. Design focuses on developing design solutions to problems, science focuses on describing and explaining certain phenomena, and deliberation focuses on evaluation and interpretation, having a normative goal. In coherence with their focus, each field also has a main form of expression. The field of design mainly uses drawings and other visualizations, whereas in the field of science numbers and statistics are more important, and in deliberation language is the primary form of expression.

Most of the available knowledge on UHI effects comes from scientific studies that are by nature theoretical rather than practical. Furthermore, the results of the different research projects are quite spread and often take into account only one or two specific aspects of the UHI problem, so it requires some time until the results are collected, integrated and written down in a practical way. In order for this information to be useful for design and communication purposes in the planning process it should be presented in a way that corresponds to the focus and forms of expression of the information receivers. Guidelines for design, an overview of basic principles, policies and examples of good practice would be helpful in the urban planning process. Using multiple forms of expression – visualizations, numbers and words – in presenting these kinds of practical information increases the chance of mutual understanding, which is not only beneficial for communication between participants but also for the whole planning process and its outcome.

A good example of how to integrate climate knowledge in the urban planning process is given by the city of Stuttgart, Germany. Stuttgart has set up a set of guidelines that are used for the design and restructuring of the city.

Climate change is already a powerful leading force to implement spatial measures at governance level. A better transfer of knowledge from science to practice and a signal from the general public indicating they perceive the topic of UHI effects as important might make politicians decide to give priority to these matters.

4. Case study of existing urban fabrics in Den Haag en Utrecht

By assessing the amount of green and water, the amount and kinds of material and built form, neighbourhoods can be compared in their heat accumulation. Such an assessment of six neighbourhoods from different periods (the old city centre, 1930 and 1960) in Utrecht and Den Haag (three in each city), shows that the neighbourhoods from the thirties have the highest probability of accumulating heat. These are not the neighbourhoods designed according to the 'garden' concept which are usually based on a large green structure. In the analysed neighbourhoods green is actually lacking in both public space and private 'gardens'. Private yards are often paved or built. In addition to the large amount of paved surface, these neighbourhoods have relatively narrow streets where natural ventilation is low. For the neighbourhoods from the thirties a design proposition to diminish heat accumulation is made.

Based on the theories and measurements described above, the following design criteria were formulated:

- All dwellings are to be situated within 200 m from a green area with a minimum size of 0.15 ha;
- The preferred street orientation is perpendicular to green areas;
- Green filter are to be placed in streets with a high traffic pressure;
- New dwellings should replace an equal amount of dwellings or more, but with a larger dwelling surface;
- 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.

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.

4.1. Ondiep

Ondiep is situated at 1.5 km 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 connected to the ring road through Ondiep, and a route along the river Vecht.

Considering the criterion 'all dwellings are to be situated within 200 m from a green area', a large part in the middle of the neighbourhood does not meet this standard in the current situation as shown in Fig. 2. 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.

4.1.1. Building plan

Implementing green in the form of green zones and routes demands space. The car and bus route has a width of 25–30 m and does not offer the amount of space that is needed. To create



Fig. 2. Left: Green in Ondiep with a circle indicating a distance of 200 m from the green border. Right: Green zones and water system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

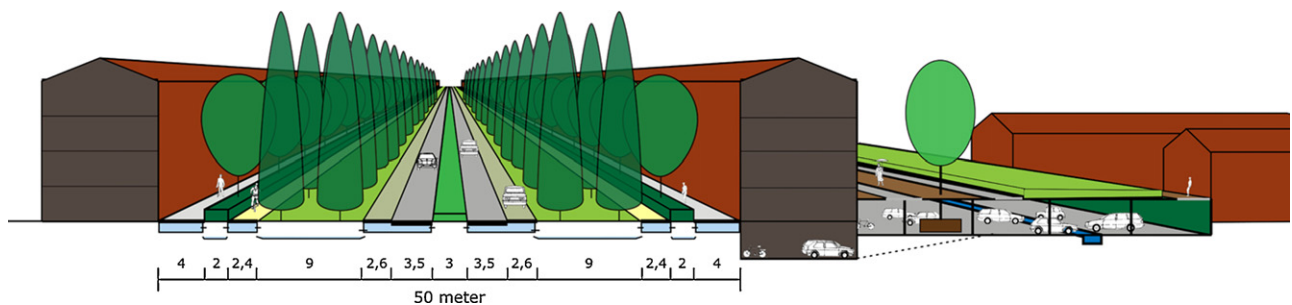


Fig. 3. Section of the car and bus route.

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 height to width ratio is influenced as well. The lowered height to width 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–T⁵ panels.

In the ‘Witte Wijk’ (white neighbourhood) a recent developed white coating⁶ 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.

4.1.2. Green plan

The green zones all have a different character. The green areas differ in usage, ambiance, combination with water, traffic frequency and kind of traffic.

A six-storey high building with a green facade forms the entrance of the neighbourhood from the centre. The facade could look like the one Patrick Blanc designed for the Caixa Forum in Madrid.

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 from Fig. 3 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.

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. An extension of this green zone would improve the microclimate in Ondiep, offer more recreational space and stimulate bicycle use.

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

⁵ PV–T: a combination between photovoltaic and thermal solar panel.

⁶ Ecosol EP White (Single-PLY Systems website).

4.1.3. 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 800 mm 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.

4.2. Transvaal

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, has tramlines, commercial streets and a market. 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.

4.2.1. Building plan

In Transvaal the renovation process has already started with the main square and some housing projects. As shown in Fig. 4 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.

4.2.2. 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 '200 m 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

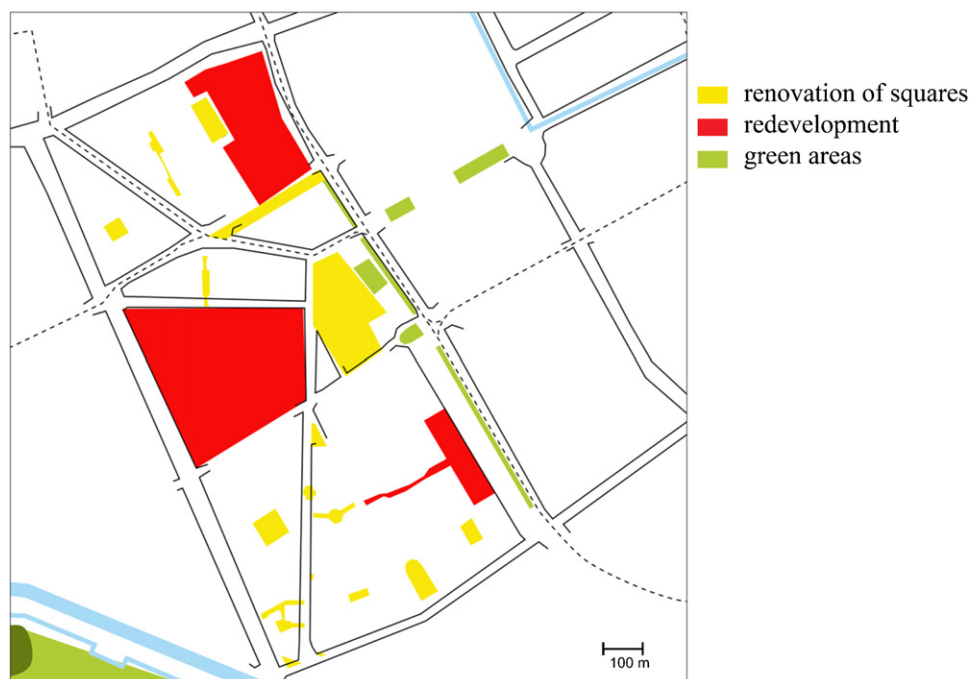


Fig. 4. Green in Transvaal with strategic renovation plan. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)



Fig. 5. Transvaal with green squares, green roofs, new building typology and water system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

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.

4.2.3. 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.

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. Fig. 5 shows the overall design for the Transvaal neighbourhood.

5. Conclusion

The two design plans for Ondiep and Transvaal show that there are enough possibilities to apply the design principles 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 needed measures is needed, for example, the amount of green to upgrade the area to this level. Policy makers need to be able to set targets and evaluate them.

A climate adaptation plan can only be successful when it is also addressing social, economical and spatial aspects. If an adaptation measure leads to solution on various levels we do not 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 its image.

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