3 Inventory of climate adaptation measures[5]

Following up the effects of climate change in urban areas in the previous chapter, this chapter gives an inventory of the possible measures to improve urban areas in relation to thermal comfort. Many adaptation measures to improve thermal comfort also adress other climate adaptation aspects such as water nuisance and draught. This inventory comprises the effects of the adaptation measures vegetation, water, urban geometry and materials and colour. Effects are given in various parameters such as air temperature, mean radiant temperature, energy reduction and range of influence. Described effects are based on literature studies and results from the *Climate Proof Cities* program. Each sub-section concludes with strategies for implementation in which the feasibility and applicatbility are described by examples from practise when available.

This answers the following research question:

Which urban design measures can contribute to climate adaptation, especially in terms of heat?

Sub-questions are:

- Which urban design measures can contribute to thermal comfort and heat mitigation?
- What are the effects on air temperature and human comfort according to literature?

§ 3.1 Vegetation

Vegetation cools the environment by evaporation and transpiration (evapotranspiration) and by shading surfaces that otherwise would have absorbed short-wave radiation. During the night the high sky view factor of open fields allows heat to escape fast through long-wave radiation.

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[5] This section is an elaborated and updated version of the Journal article: Kleerekoper, L., van Esch, M. and Salcedo, T.B. (2012), "How to make a city climate-proof, addressing the urban heat island effect". Resources, Conservation and Recycling, Vol. 64, No. 0, pp. 30-38.

There are different types of application of vegetation in urban areas: urban forests (parks), street trees, grassland, private green in gardens and green roofs or façades. Vegetation has an average cooling effect on the air temperature of 1-6°C, but is highly dependent on the amount of water the plant or tree has available (Schmidt, 2006). In the Netherlands an extensive study amongst weather amateurs indicates a decrease of the UHI with increase of vegetation cover, with the largest impact on extremely hot days (Steeneveld et al., 2011). For the city of Rotterdam 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 according to Klok et al. (2010).

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. In Figure 3.1 an overview of the average, and the range of the cooling effect of a park is given. A green area doesn't have to be particularly large in order to generate a cooling effect. According to a study in Tel Aviv, a park of only 0.15 ha had an average cooling effect of 1,5˚C and at noon reached a 3˚C difference (Shashua-Bar & 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). A measurement with an optic fibre cable in Rotterdam, the Netherlands shows a cooling effect of trees up to 5˚C (Slingerland, 2012). Important to mention is that the trees show a larger cooling affect than buildings/shadow alone. This attempt to indicate a general effect of vegetation on human thermal comfort by analysing measurements presented in literature does give some indication of cooling effects, however, fail in comparing green measures due to a limitation in thermal comfort indicators. The most common indicator in the literature studies to measure effects is air temperature. While T_{mrt}, wind speed and relative humidity are as important. In fact, a thermal comfort indicator should be used instead, as explained in Chapter 2. Recent studies: in Utrecht traverse bicycle measurements have been performed to analyse thermal comfort. Two days of measurements on the 24th of July and 18th of August 2012 show a maximum difference between park and urban area of (Klemm et al., 2015)

When using PCI for cooling, the effect on the periphery is very important. The effect is variable, depending on airflow and other climatological circumstances. The studies mentioned above show an effect at 100 meters distance from the PCI in Tel Aviv and an effect at 1100 meters distance from Göteborg's PCI. The average range of the effect is 630 m based on the studies in Figure 3.1 (above). The effect of a PCI on the surrounding built-up area is not only depending on the size of the park. So do buildings parallel to the park border prevent intrusion of air from the park into the built-up area next to it (Upmanis et al., 1998). The park design is also playing a role: many trees providing shade whilst blocking airflow or green meadows receiving full radiation loads but cooling down quickly at night. Small and spread green has the potential to

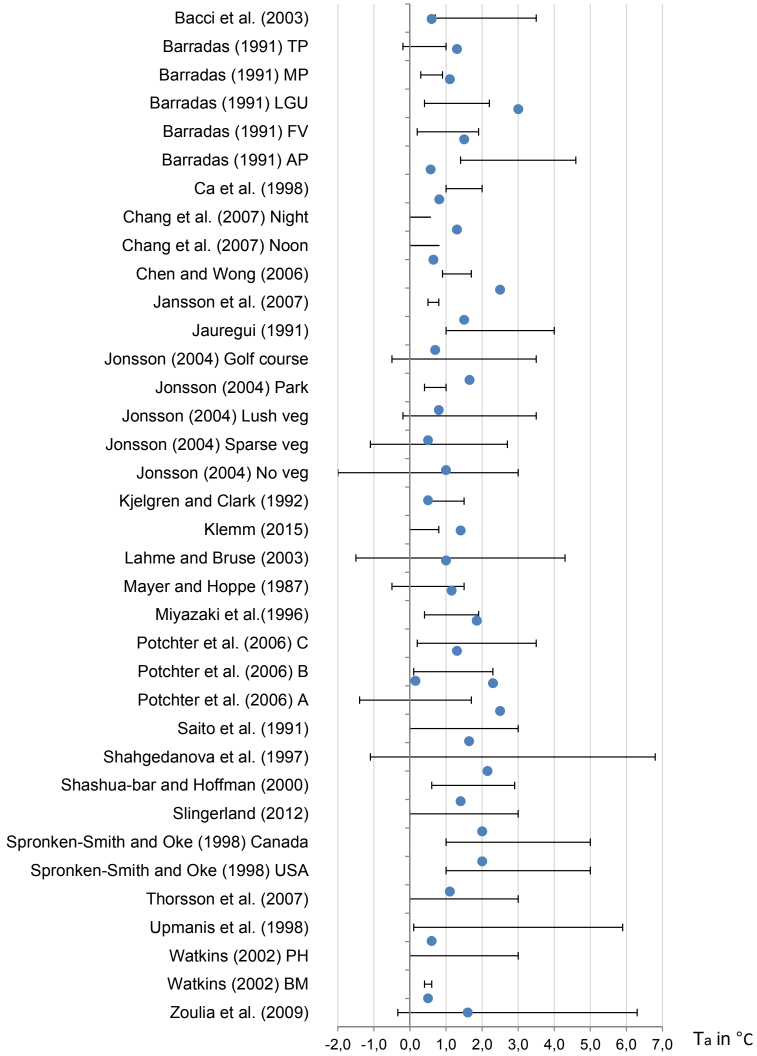

FIGURE 3.1 Park Cool Island effect measured in air temperature (Ta) in °C, an updated version of a graph by Bowler et al. (2010).

cool more urban surface than large parks with the same size in in total (Kuypers et al., 2008), see Figure 3.2.

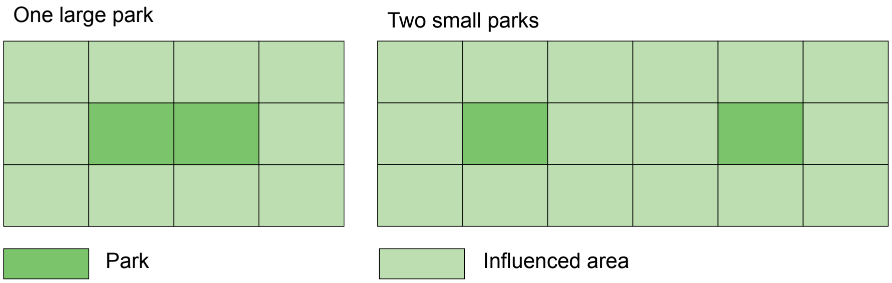

FIGURE 3.2 Two small parks may have a larger cooling influence than one large park of the same size in total (Kuypers et al., 2008).

Street trees

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). Measurements by Shashua-Bar et al. (2011) show an effect of three mature trees compared to no trees: the normalized index of thermal stress (ITS) reaches 520W without trees and 180W with trees. Trees show to have the best cooling performance in relation to thermal comfort. When looking at a larger area model runs for different climate scenarios for the Greater Manchester area in the UK show that an addition of 10% green cover (street trees and green corridors) will keep temperatures at or below current temperatures for a high emission scenario up to 2080. But a 10% decrease in urban green, which is in line with current developments, results in an increase of maximum surface temperatures of up to 8.2°C under a high emission scenario (Walsh et al., 2007). More about the effect of green on surface temperatures is described in section 3.4.

Street trees do have unwanted side effects when they, for example, block the sun in late autumn, winter or early spring or when trees damage or dirty parked cars. Such side effects can be minimised by carfull selection of tree species per location. For a tree to shade a large surface of the canopy for cooling and not blocking sun for heating indoors in the cooler seasons a study of shadow patterns by Hotkevica (2013) can assist in selecting tree species and location, see Figure 3.3.

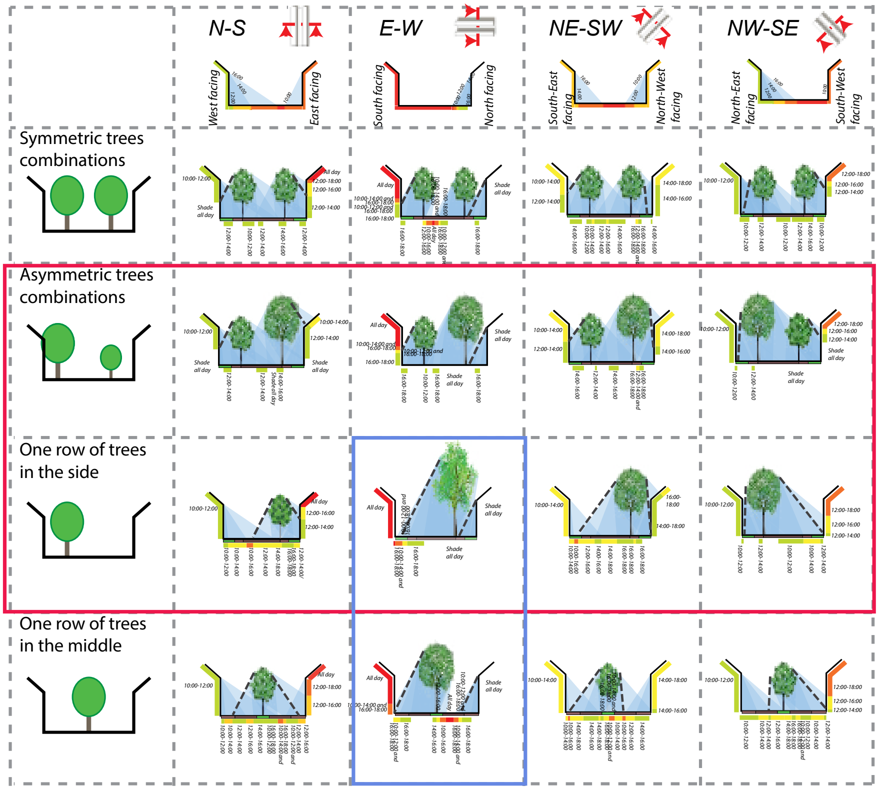

FIGURE 3.3 Selection of the most suitable solutions for street shading and keeping the solar access for the walls/windows (Hotkevica, 2013)

Cooling or not?

Vegetation is not always cooler than its surrounding built environment. In winter, trees (and other objects like buildings) break the wind and obstruct long wave radiation, providing shelter and slowing down heat loss to the atmosphere. The same process occurs in summer after sunset causing areas with a lot of trees to cool down slower than areas without trees. The difference in thermal comfort between streets with and without trees is limited because of the shadow casts by the trees during the day (Wong et al., 2007), preventing heating of the stony surfaces. A meadow is, opposite to trees, cooling fast after sunset due to the large sky view factor[6], and it has a short period after sunrise in which it is cooling the environment. A drained and mowed field has a higher surface temperature than a natural field, with a maximum difference of 23 °C (Kravčík et al., 2007).

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[6] The fraction of sky visible when viewed from the ground up from: Watson, I. and Johnson, G. (1987), "Graphical estimation of sky view⌧factors in urban environments". Journal of climatology, Vol. 7, No. 2, pp. 193-197..

However, after most water is evaporated a natural grass field is not much cooler than bare soil. Note that artificial turf, like the rubber mats used on soccer fields have a reverse effect and heat up their environment more than bare soil and even built-up areas (Arrau, 2005), see Figure 3.4.

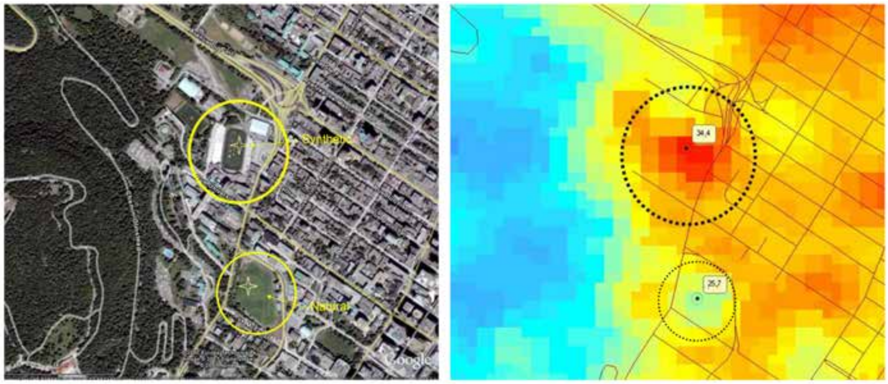

FIGURE 3.4 Areal picture (left) and Landsat image (right) indicating the surface temperature difference between a synthetic and a natural soccer field in Montreal (Arrau, 2005).

Psychological effects

Thermal comfort is not only determined by physical processes, also psychological aspects play a role. Green urban spaces are perceived more comfortable than built environments without green (Klemm et al., 2015). Already the sight of green can improve thermal comfort. This can be all kind of green, however the green at eye level is most effective (Klemm et al., 2013). Therefore, green in front gardens or vertical façade greening can be more effective compared to (high) street trees.

Green roofs and facades

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 green roof or facade 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 and 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. A measurement study in Singapore shows a maximum cooling effect of 3.3°C at 0.15 m from the green façade (Todorovic, 2013). In a review of studies done by Kikegawa et al. (2006), 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 air temperature and results in a cooling energy saving of 4-40%. A study by Alexandri & Jones (2008) shows an even larger effect of green facades on energy savings ranging from 90% to 35% depending on the climate. Surface temperatures reduce a lot, for example 10-12˚C by climbing vines (Givoni, 1991). A study by wonen.nl (2010) indicates that roughly two green facades have the same cooling and air filtering capacity compared to ten mature trees. The shading of windows and west-facing walls provides the most savings in cooling energy (McPherson, 1994). A measurement study performed in the Netherlands by Ottelé et al. (2010) shows a reduction of the air temperature of 6˚C at 10cm from a green façade, which is reduced to 1˚C cooling at a meter distance. Numerous studies stress the importance of irrigation of green facades (Fallmann & Emeis, 2014, Schmidt, 2006). One litre per day per m^2 is sufficient for effective cooling (Hoelscher et al., 2014).

In a study by Köhler et al. (2002) an extensive green roof in Germany is tested and shows a lower surface temperature of 10˚C compared to the conventional bitumen roof. Here the cooling due to the evaporation of water is visible in the surface temperature, after all water is evaporated the isolation value of the substrate prevents the indoor spaces from heating up. Note that green roofs on high-rise buildings are not affecting thermal comfort at ground floor pedestrian levels (Ng et al., 2012).

Urban agriculture

For all different types of green, urban agriculture can be a feasible option to add green. The difference in effect on the UHI and thermal comfort is larger due to the irrigation of crop fields (Schwarz et al., 2012). When crops are harvested the effect of green is gone as well, nevertheless, bare soil is still an improvement in relation to the microclimate compared to a sealing of pavement, as described in paragraph 3.4. An additional advantage of growing crops in and around urban areas is the opportunity to lower a cities carbon footprint by decreasing the transportation of food (Havaligi, 2009, Okalebo et al., 2009).

Large scale effects

When looking at the larger scale, the cities surroundings are of influence on the inner-city climate. Although the UHI may increase with a cooler surrounding landscape, the average temperatures in urban areas may be lower. A forest or a desert like surrounding play a large role in the actual UHI value. If the aim is to control urban microclimates and prevent overheating, how should we organize the cities surroundings? Should we keep the surroundings of cities open, grow forests or create wetlands to profit from cooling in the urbanized areas? There is not a clear general answer to this matter. However, specific cases show for example that irrigated landscapes and the amount of vegetation have a cooling effect. A study by Gober et al. (2009) in Phoenix, USA, found that increasing irrigated landscapes lowers night time temperatures. Wetlands around

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Beijing are 1-5°C cooler compared to downtown (Sun et al., 2012). And another study in China shows that urbanisation of rural areas does not affect temperatures when waterbodies and vegetation is kept at the same level. While temperatures do increase significantly when the urbanisation coincides with less vegetation or water (He et al., 2007). In section 3.2 about water, the relation between water and cooling effects is described more elaborately.

Additional benefits of vegetation

Air pollution reduction is an important ecosystem service vegetation provides for. The capture of particulate matter (PM) is a result of positively charged particles that are attracted by the negatively charged plants and trees. This link is stronger than the power of heavy rainfall or wind (Ottelé et al., 2010). Thus, so far all experts agree in general on the reduction of pollutants by vegetation. However, in the vicinity (0-100 m) of trees wind is obstructed and causes higher concentrations of NOx and PM. Only with a zone of about a kilometre wide green can significantly contribute to a decrease of pollutants (Kraai et al., 2009). Measurements along a highway indicate a reduction of pollution up to 200 meters. At a further distance the influence of background concentrations becomes dominant (Hofschreuder et al., 2010). With this research Rijkswaterstaat (Ministry of Infrastructure and the Environment) has proved there is no need to plant trees for them because this would not lead to a decrease in their responsibility area. However, urban areas close to highways will benefit from the effect of trees along the highway but this is the responsibility of VROM (Schildwacht, 2010).

A sound barrier can be designed to reduce pollutants as well, using blackthorn branches and salted water (Blokland et al., 2009) or using high voltage wired screens (Ottelé et al., 2010). Within urban areas a mix of species should be planted that effectively filters out PM, nitrogen oxides ($NO+NO_2$), ozone (O_3) and volatile organic compounds (VOC's) (Hiemstra et al., 2008). In Table 3.1 the effectiveness per specie is given. Another way in which trees reduce air pollution is the emission reduction from cars parked in the shade (Scott et al., 1999). Besides the capture of unhealthy elements, vegetation also binds CO_2. Interestingly trees in cities grow eight times faster in urban than in rural areas (Searle et al., 2012), resulting in more CO_2 reduction per tree in cities.

Pine trees are better in filtering the air than Lime trees, respectively 19% and 10% (Hofschreuder et al., 2010).

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Next to the reduction of air pollution, vegetation also reduces water pollution. Vegetation has the capability to bind heavy metals and nutrients in the soil and prevents discharge into groundwater or streams and rivers. A study by (Johnston & Newton, 2004) shows a decrease of 95% of cadmium, copper and lead can be taken out of rainwater and 16% of zinc. Also nitrogen levels reduce dramatically.

Vegetation has the potential to reduce energy consumption for cooling. Decreasing the outdoor temperature with 1˚C leads to a reduction of 6.6% electric energy demand to cool indoor in a city like Tokyo (Kondo & Kikegawa, 2003).

Urban green provides special habitats and increases biodiversity (McPherson et al., 1997). In Zurich, Switzerland, studies show that locally and regionally endangered species benefit from green roofs with natural soils from nearby and varying substrate thickness (Brenneisen, 2006). A study by Jokimaki (1999) in Oulu, Finland, indicates an increase of breeding bird species with an increase of park size, however, some species are more abundant in the smaller than in the larger parks. Many bird species have difficulties surviving the sealed and bare city landscapes. A green façade offers both resting and nesting place to the house sparrow, blackbird, song thrush, robin, starling, wren and chickadees (wonen.nl, 2010).

Water management and maintenance of biodiversity are crucial services that are anchored in landscape design. A better incorporation of the landscape as part of urban design offers great potential "to achieve identity and a sense of place" (Lehmann, 2007, page 70). The work by architects and landscape designers such as MVRDV, Ken Yeang or West 8 is aiming at this connection with the landscape and at introducing innovative green concept in buildings. "More green can make people care more about their neighbourhood and therefore are willing to work for it", is the conclusion from a study by McCunn & Gifford (2014). Neighbourhood commitment was significantly associated with the number of 'green' neighbourhood attributes.

The connections we as humans subconsciously seek with nature are rooted in our biology according to Kellert & Wilson (1993). Biophilia, an hypothesis they believe in, is the innately emotional affiliation of human beings to other living organisms. "It

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SPECIE	PARTICULATE MATTER PM10	NITROGEN OXIDES NO+NO$_2$		OZONE O$_3$		EMISSION OF VOLATILE ORGANIC COMPOUNDS
SHRUB						
Amelanchier lamarckii	■	■		■		●
Berberis xfrikartii *	■■	■■		■■		🟩🟩
Chaenomeles	■	■■		■■		
Corylus colurna	■■	■■		■■	+	●
Euonymus (bladverliezend)	■	■■■	+	■■■		●
Euonymus (bladhoudend)	■■	■■■	+	■■■		●
Hedera	■■	■		■		●
Ilex xmeserveae	■■	■■		■■	+	●
Lonicera (bladverliezend)	■	■		■		●
Lonicera (bladhoudend)	■■	■				
Mahonia	■■	■■		■■		🟩🟩🟩
Potentilla fruticosa	■■	■■		■■		🟩
Rosa	■■	■■		■■		🟩
Spiraea	■	■■		■■		🟩
CLIMBING PLANT						
Clematis	■	■		■		●
Fallopia	■	■■■		■■■		●
Hedera	■■■	■		■		●
Lonicera	■	■■		■■		●
Parthenocissus	■	■■		■■		●
Pyracantha	■■	■■■		■■■		●
Rosa	■■	■■		■■		🟩
Wisteria	■	■■		■■		●
CONIFEROUS TREE						
Ginkgo biloba *	■	■■■		■■■		🟩
Metasequoia glyptostroboides	■■■	■		■		🟩
Pinus nigra	■■■	■		■	+	🟩
Pinus sylvestris *	■■■	■		■		🟩
Taxus	■■■	■		■		🟩
HEDGE						
Carpinus betulus	■■	■■■		■■■		🟩
Fagus	■■	■■■		■■■		●
Ligustrum	■■	■■■		■■■		●
DECIDUOUS TREE						
Acer platanoides *	■	■■■		■■■	+	●
Acer pseudoplatanus *	■	■■■		■■■	+	●
Aesculus	■■	■■■		■■■		●
Ailanthus altissima	■	■■■		■■■		🟩
Alnus cordata	■	■■■		■■■	+	●
Alnus glutinosa *	■	■■■		■■■	+	●
Alnus xspaethii	■■	■■■		■■■	+	●
Betula ermanii *	■■	■■■		■■■	+	🟩
Betula nigra	■■	■■■		■■■	+	🟩
Betula pendula	■■	■■■		■■■	+	🟩
Betula utilis *	■■	■■■		■■■	+	🟩
Carpinus betulus *	■■	■■■		■■■		🟩
Crataegus xpersimilis *	■	■■■		■■■	+	●
Fagus sylvatica *	■■	■■■		■■■		●
Fraxinus angustifolia *	■	■■■		■■■		●
Fraxinus excelsior *	■	■■■		■■■	+	●
Fraxinus ornus *	■	■■■		■■■		●
Fraxinus pennsylvanica	■■	■■■		■■■		●
Gleditsia triacanthos *	■■	■■■		■■■		●
Koelreuteria paniculata	■	■■		■■		🟩🟩🟩
Liquidambar styraciflua	■■	■■■		■■■		🟩🟩🟩
Liriodendron tulipifera	■	■■■		■■■		●
Magnolia kobus	■	■■	+	■■		🟩
Malus *	■■	■■■		■■■	+	●
Parrotia persica	■■	■		■		
Platanus xhispanica *	■■	■■■		■■■		🟩🟩🟩
Populus *	■■	■■■	+	■■■	−	🟩🟩🟩
Prunus *	■■	■■■	+	■■■	+	●
Pyrus calleryana *	■	■■■		■■■		●
Quercus palustris	■■	■■■	+	■■■	−	🟩🟩🟩
Quercus robur *	■	■■■	+	■■■	−	🟩🟩🟩
Salix alba *	■■	■■■	+	■■■	−	🟩🟩🟩
Sophora japonica	■■	■■■		■■■		●
Sorbus	■■	■■■		■■■	+	🟩
Tilia cordata *	■■	■■■		■■■		🟩
Tilia europaea *	■	■■■		■■■	+	🟩
Ulmus *	■■	■■■		■■■	+	🟩

* Given indicators are also valid for cultivars of the specie	■ : Least effective	+ Species that absorb high amounts of NO-NO2
	■■■ : Most effective	+ Species that lower ozone concentrations in urban areas effectively
	🟩 : Low emission	− Species that increase ozone concentrations in urban areas
	🟩🟩🟩 : High emission	● The emmision of VOC's is not measurable for these species

TABLE 3.1 Effectiveness of most common species to lower the concentrations of PM, nitrogen oxides and ozone in the air (Hiemstra et al., 2008), based on studies by Donovan et al. (2005), Nowak (1995) and (Takahashi et al., 2005).

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suggests that when human beings remove themselves from the natural environment, the biophilic learning rules are not replaced by modern versions equally well adapted to artefacts. Instead, they persist from generation to generation, atrophied and fitfully manifested in the artificial new environments into which technology has catapulted humanity”. Therefore, humans still benefit from natural elements which manifests in for example the cost reduction for health care and medicines by green (Meier-Boschaart, 2011). This is partly related to the mental aspect, partly to the capability of green to reduce air pollution and to reduce temperatures. The numbers of heat related mortality described in paragraph 2.4.1 can be reduced by green according to a study in Melbourne; an increase of the vegetation coverage from 15% to 33% may reduce the average heat related mortality rate between 5% to 28% (Chen et al., 2014).

Green increases real estate values. Housing values can increase with 5% by greening the neighbourhood (Meier-Boschaart, 2011). Additional green has the potential to boost the existing housing stock in areas with a lot of vacancy due to shrinking. Some practical examples are given in the following sub-section.

CO-BENEFITS OF GREEN:

supports the recreational, experiential and health requirements of local people, as well as visitors;
- contributes to the way they encourage people to spend leisure time locally by reducing vehicle usage;
- increases neighbourhood commitment;
- allows urban dwellers the opportunity of being in places experienced as relatively quiet and ‘different’ from the city streets;
- fosters a feeling of community pride in a local area;
- supports the development and maintenance of biodiversity in urban areas;
- supports the local management of water flows and quality (rainwater drainage, sewage treatment);
- allows local composting of biodegradable waste;
- contributes to cleaning particulates out of the air, through their tree and shrub cover;
- contributes to cleaning pollutants from water;
- helps reduce the urban ‘heat island’ effect;
- helps reducing noise nuisance;
- increases the economic attractiveness of a city. For instance, attractive green areas can influence the decision-making processes of entrepreneurs seeking new locations for businesses, developers deciding where to invest, and tourists deciding where to visit;
- reduces energy consumption in especially summer when placed in right position;
- binds CO2, and therefore, can be part of CO2 reduction strategies;
- lengthens the lifespan of roofs in case of green roofs.

Beer et al., 2003, Bolund & Hunhammar, 1999) and others

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Strategies for implementation

Applying more green in public spaces has a relative low cost and high acceptance among citizens. Projected benefits when planting trees is nearly three times the value of projected costs with payback periods ranging from 9 to 18 years (McPherson et al., 1997). The most effective green elements are street trees (Rosenzweig, 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 that developed green urban design guidelines (Daley, 2008) and the city of Edinburgh council that developed a quality assessment system for parks together with the organisation of partnerships, communication, promotion, finance and maintenance planning (Cairns, 2006).

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). Public participation 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). An option could be to locate part of the returns from new developments into a fund or an owners association that is responsible for the installation and maintenance of green (Meier-Boschaart, 2011). The most famous park in The Netherlands, The Vondelpark in Amsterdam was also an initiative from inhabitants to maintain their housing values, which was more than successful.

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. Increasing tree cover in this city with 10% or planting about three trees per building lot saves annual heating and cooling costs by an estimated $50 to $90 per dwelling according to (McPherson et al., 1997). The free tree planting service of the City of Chicago (2014) investigates the area where you want the tree to be planted and you can indicate which specie has your preference.

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 surfaces exposed to solar radiation. In that case, initiatives like the one in Paris promoting green façades and green terraces (Artus & Roulet, 2014), the new law in Basil, Switzerland that requires a green roof on all new buildings with a flat roof (Brenneisen, 2006), or the subsidy program of green roofs in Rotterdam are defining the future trend of adaptation strategies (Gemeente Rotterdam, 2014). The municipalities of Tilburg and Sittard-Geleen have published an overview of green measures that counteract heating of urban areas to inform and convince more people of the urgency to act (Brink, 2013).

§ 3.2 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 30-50 meters. 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 and on the urban context. Water does not always have a cooling effect. The largest waterbody in The Netherlands, the North Sea, has a tempering effect on extreme temperatures. During warm summer periods the sea is cooler than the land surface at daytime , this reverses at night to a warmer sea than land surface, as illustrated in Figure 3.5. The role of water is therefore ambiguous, for it can cool through evaporation or possibly warm the city because stagnant water bodies store heat (Albers et al., 2015).

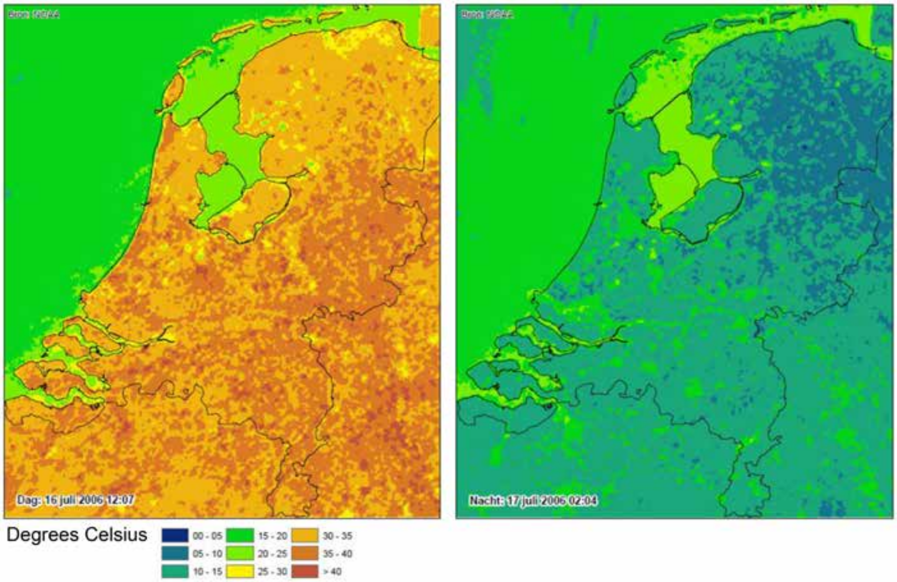

FIGURE 3.5 Surface temperature images (NOAA-AVRR) for the 16th of July 2006 on midday (left) and the 17th of July 2006 at night (right) (Klok et al., 2012).

A numerical model was developed to model the cooling effect of a water pond (Robitu et al., 2006). This study shows a cooling of the surface temperature with 29°C and an effective cooling by evaporation with sufficient air flow above the pond. In Japan, a study at a riverside showed a cooling of 2°C at a distance of 50 meters from the shore (Sukopp & Wittig, 1998) in (Milošovičová, 2010). Measurements at a small river running through the urban environment in Sheffield, UK, indicate a cooling effect of 1°C during temperatures higher than 20°C. The cooling effect reached beyond the 30 meters from the river, while at 40 meters became negligible (Hathway & Sharples, 2012). While flowing water has a larger cooling effect than stagnant water, dispersed water like from a fountain has the biggest cooling effect. Another 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 hours) up to 35 m distance (Nishimura et al., 1998).

Figure 3.6 shows the amount of solar energy reaching the earth by radiation in one year in relation with the energy flux of the total amount of evaporation in one year. This energy flux is enormous in comparison to the world's energy consumption of one year (Schmidt, 2006). It demonstrates the importance of the evaporation of water for the temperature on our planet. Also on the smaller neighbourhood or street scale evaporation of water has a significant cooling effect due to both evaporation and absorption.

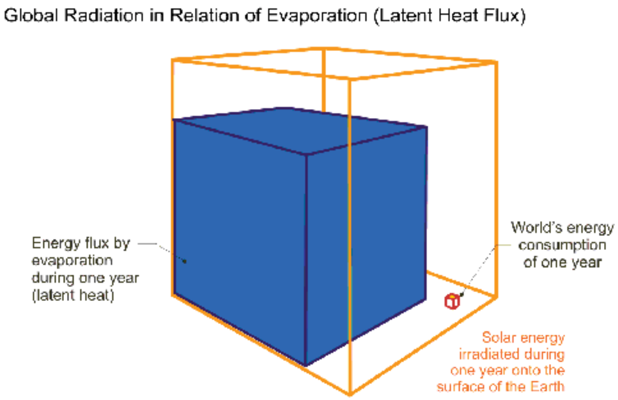

FIGURE 3.6 The amount of solar energy reaching the earth by radiation in one year in relation with the energy flux of the total amount of evaporation and the world's energy consumption in one year (Schmidt, 2006)

The Japanese have the tradition sprinkling water on the streets to cool there urban spaces. Figure 3.7 demonstrates this so called 'Uchimizu' tradition. This method proves most effective in mornings and late afternoons in direct sunlight. The temperatures drops 2-4°C by sprinkling 1L/m^2 per half an hour (Takahashi et al., 2010). In France preliminary test results in Lyon show a temperature reduction of

5-8°C (Wikhydro, 2013). A test in the Netherlands shows this principle is also effective for Dutch urban areas. In a test where water was sprinkled over asphalt the cooling effect was 2°C close to the ground and 1°C at a height of 2 meters when 1 mm of water evaporates. When infinite amount of water is available the cooling effect increases up to 6°C close to the ground and 2°C at a height of 2 meters (Slingerland, 2012).

FIGURE 3.7 Japanese tradition of watering the streets 'Uchimizu' (Wordpress, 2010).

Instead of a green roof, water on rooftops can have a significant cooling effect on the indoor air temperatures. Important for water on roofs is a shading device with preferably a low emissivity that prevents rapid heating of the water. A simulation study shows a decrease in the mean maximum indoor air temperature from 31.7°C to 29°C with a ventilated roof pond with an aluminium cover (AIVC, 2013, page 400 and 635).

Cooling with water has its limitations; a high moist concentration in the air slows down the evaporation process (Park, 2001, page 292). An often heard argument stating that evaporation of water is decreasing thermal comfort due to the increase of humidity is rather confusing. In fact, this is mixing up two aspects. Firstly, the increase of humidity can slow down the perspiration rate by the skin (when air temperature is above 24°C and humidity above 60% (Ihle, 2006)) and therefore decrease comfort. Secondly, the evaporation of water results in both increase of humidity and decrease of air temperature, the latter is usually more dominant in the thermal comfort sensation (Djamila et al., 2014). Nevertheless, water often has a small effect on the microclimate but it does influence the subjective perception as being felt cooler (Katzschner, 2009). Large water bodies respond slowly to heating during the day, but also cool down slowly. Therefore they can support the urban heat island effect at night (Steeneveld et al., 2011).

An analysis of surface temperatures in the 73 largest cities in the Netherlands shows that cities with a larger water surface have a larger Surface Heat Island (SHI) at night. An increase of 10% surface water increases the SHI on average with 1.3°C (Klok et al., 2012).

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 effective 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.

The cooling effect of large water elements is more significant in the built-up area at the lee-ward side of the water and wider streets enhance this cooling effect (Sukopp & Wittig, 1998 in Milošovičová, 2010). The design of the waterfront has a large impact on the cooling effect of a river at a height of 1.5 m. A study by Murakawa et al. (1991) demonstrates that a 4.3 m high embankment shortens the range of the cooling effect by about 70 metres.

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 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.

FACTS ABOUT WATER USE BY PLANTS AND THE RELATION BETWEEN IRRIGATION AND COOLING:

On average plants transpire 5mm (several litres per square meter per day) on a sunny day in the temperate climate zone when sufficient water is available. However, some plants are able to evaporate as much as 20 litres of water per day (Kravčík et al., 2007);

Sap flow measurements show an increase of evaporation going further into the growing season starting from about 10 litre per day towards over 500 litres a day per tree;

Increasing irrigated landscaping lowers night time temperatures in the city of Phoenix, USA. The greatest reductions occur in the least vegetated neighbourhoods (Gober et al., 2009);

When both the city and countryside are wet, differences in the energy balance between them will be small. In dry conditions the city tends to heat up more than the countryside, while urban irrigation can mitigate (perhaps even reverse) this (Oke, 1982).

Promoting the use of permeable pavement and temporary water 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 multifunctional public space for storage of rainwater surplus initiated by Urbanisten (Boer et al., 2010). The first realisation of this concept is the Bellamyplein (Figure 3.8.1) and a larger and very prestigious follow-up is the Benthemplein (Figure 3.8.2) where water storage is combined with a basketball court, skating park and outdoor theatre.

FIGURE 3.8 The neighbourhood water square Bellamyplein (1) - photo from Wijnbergh (2013) - and the city centre water square Benthemplein (2) - photo from Schubert (2014) - in Rotterdam.

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. In the City of Portland, Oregon, green streets, ecoroofs, trees, and other green infrastructure is used to manage stormwater, protect water quality and improve watershed health (Hauth, 2014). In Germany all water falling on the Postdammerplatz needs to evaporate or used in the adjacent buildings (Köhler et al., 2002). In The Netherlands the platform Amsterdam Rainproof involves citizens, policymakers, companies and entrepreneurs in the water management of their direct environment (Rainproof, 2014). On the website you can find examples, participate in projects and join the community via social media. Municipalities have the ability to set a clause on the drainage of rainwater from private terrain. A directive is to cope with rainfall of at least 25 mm in one hour on private property. Solutions can be technical such as a large storage tank without benefit for the local climate. But when they are adding more natural surface – such as de-paving, more vegetation or green roofs – thermal comfort will improve likewise.

Many guidelines, toolboxes and technical solutions are available for sustainable urban water management. In Appendix A you find a selection of these.

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§ 3.3 Urban geometry

The built form has a relation with several heat accumulation parameters. This section starts with describing the relation of the built form with direct solar radiation, shading and radiative interaction, followed by its influence on air flow. The third relation described, concerns the volume/surface ratio and the heat accumulation in stony surfaces.

Radiation and shading

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. In the morning the shadow casting of constructions cause a delay in heating (Pietersen-Theeuwes 2015). 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. Energy consumption is therefore related to urban configuration: an increase in urban density leads to an increase of inter-building effects. Especially energy consumption in dwellings, more than for example office buildings, depends on the surrounding building density and typology. Here the inter-building effect determines more than 70% of the energy demand (Pisello et al., 2014).

Overheating by solar radiation in summer can be reduced with high ratios of street height to street width (H/W) (Futcher, 2008). As in many Mediterranean cities the narrow streets create shadow (Nickson, 2007). However this may also reduce air flow, promote multiple solar reflections, trap anthropogenic heat and lower the sky view factor. These last negative effects may do more harm than the positive shading effect. 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. Therefore increasing street width is preferable to maximize solar gain in winter (Esch et al., 2012). Here individual buildings need to be designed to collect the sun and not shade others (Dobbelsteen et al., 2010, Keeffe & Martin, 2007). 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.

The previous paragraph already suggests that there is not one optimal H/W ratio general applicable in all conditions. According to Emmanuel (2005) and Oke (1988) in most cases we can aim for a H/W ratio of 0.4-0.6 if the streetscape does not consist of dark, impermeable paving and of buildings built with conventional, heat-absorbing materials but would involve sufficient greening measures, low-albedo surfaces and rainwater catchment elements (Milošovičová, 2010).

The morphology of the building blocks in cities have an influence on outdoor thermal comfort. A study that considered five urban forms in the climate of The Netherlands shows that the closed urban block (courtyard) provides the highest thermal comfort conditions. The main influencing factors are duration of direct sun and T_{mrt} (mean radiant temperature) (Taleghani et al., 2015).

The radiation load in a street is also dependent on the orientation of the street. According to a study in an idealized urban canyon by Herrmann & Matzarakis (2010) a North-South oriented street has highest values of T_{mrt} and East-West lowest values during midday. The Figure 3.9 composed by Hotkevica (2013) shows the diurnal solar exposure for summer and winter and four different H/W ratios. East-West oriented streets have a high radiation load in summer, where the South facing façade gets the full load and the North facing side of the streets remains unexposed. This offers pedestrians the choice to be in the shade or sun. In winter the radiation load is very limited. In North-South oriented streets the radiation load is higher and more distributed throughout the street over the whole day. In winter the spread and higher radiation load increases outdoor and indoor comfort and reduces energy demand for heating.

The use of arcades, or overhanging facades, is a common urban geometry in warm countries. These are most efficient for N-S and NW-SE oriented streets (Ali-Toudert & Mayer, 2007). An important side effect is the reduction of indoor daylight, especially for the higher latitude. Therefore, too much shade must be avoided (Lin et al., 2010).

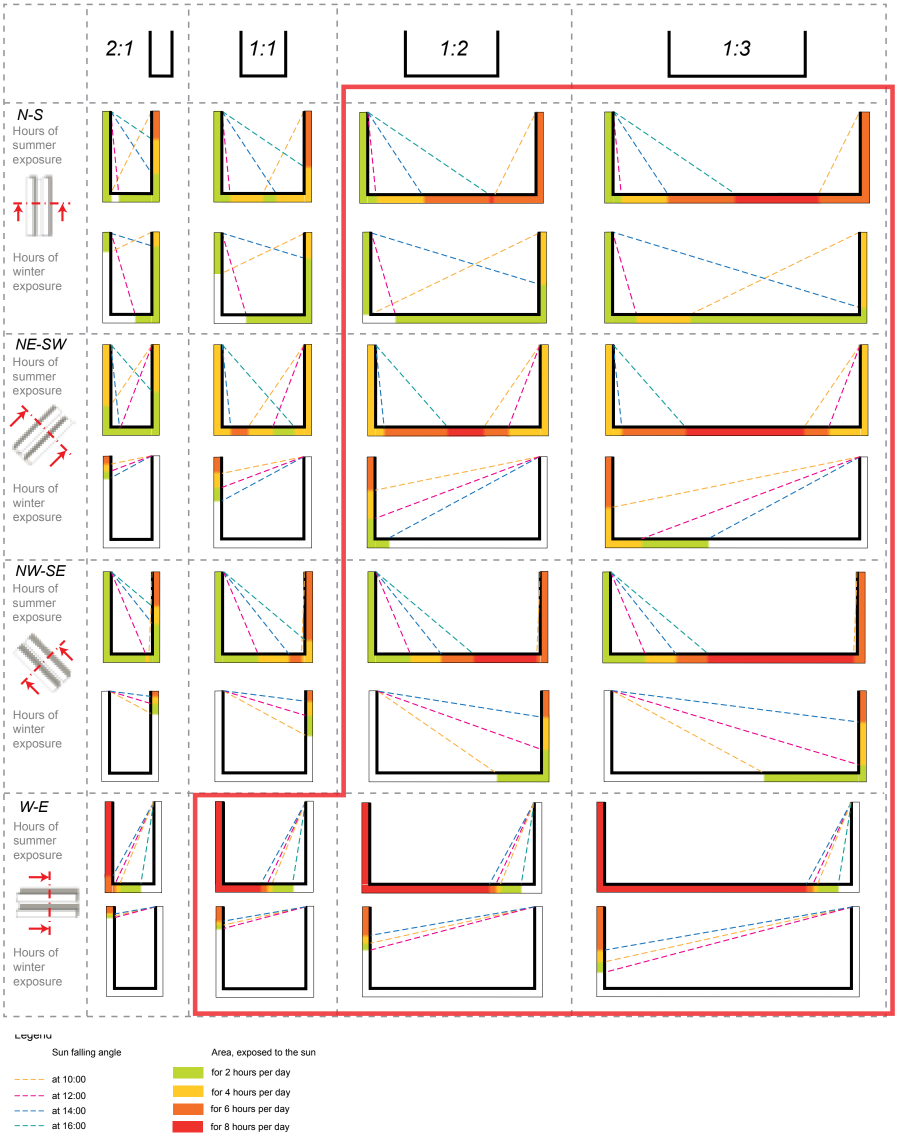

FIGURE 3.9 Diurnal solar exposure analysis of street canyons (Hotkevica, 2013).

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Air flow

Built form also influences 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 controversial measure for cooling. Stimulating wind for ventilation in summer can lead to a very unpleasant or even dangerous situation in winter. The orientation of streets will therefore bring some design challenges, especially taking into account both solar and wind orientation.

Another way to improve ventilation is to generate a mix of the air in the canopy layer[7] with the air from the boundary layer[8]. One way to obtain this mix is to adjust the canopy layout. Figure 3.10 gives the relation between H/W ratio and type of wind pattern that occurs is in a canopy with wind form the side. Ventilation in street canyons is preserved at a height to width ratio up to 0.6 due to the wake interference flow regime. Streets with a H/W ratio of 0.2 or lower have a good air mixing over the entire width of the street. A H/W ratio of 0.2 and 1.6 leads to a small isolated circulation field on the leeward side which contains less fresh air. Figure 3.11 shows the characteristic vortices in relation to the H/W ratio. At a height to width ratio of more than 1.6 there is almost no mix of the canopy and boundary layer (Xiaomin et al., 2006). Another way to increase the exchange of air between the canopy and boundary layer is to introduce a mix of high and low buildings (Givoni, 1998, p. 284). 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 according to Rafailidis (1997).

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[7] the air space in a street profile

[8] the layer of air above the roughness elements of a surface (forest, cities, etc.)

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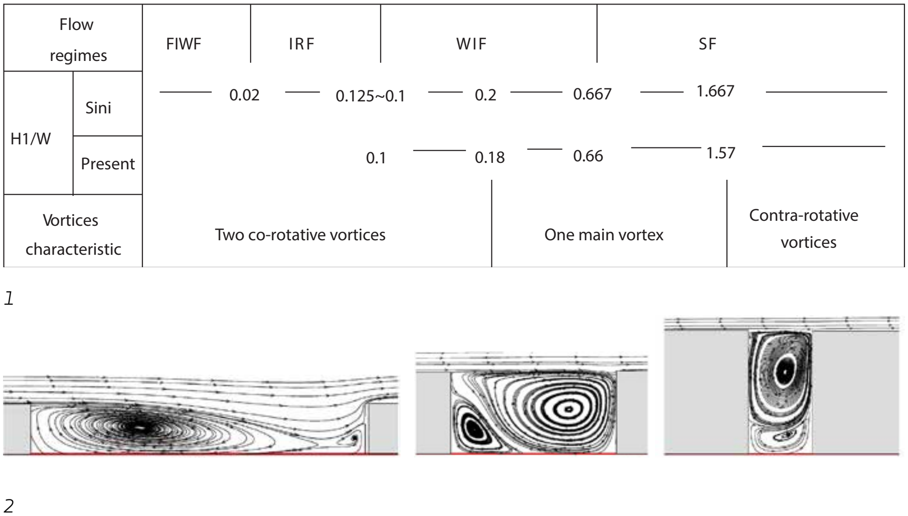

FIGURE 3.10 Wind patterns in a street profile in relation with the H/W ration (1) and wind patterns for H/W ratios of 0.17 (left), 0.5 (middle), 2 (right) (2) (Xiaomin et al., 2006)..

When trees placed in the street these have a large influence on the wind pattern. Trees with a dense crown placed close to each other will deflect wind currents, while an open crown will decrease wind speed. Trees can decrease ventilation in streets, with lots of traffic this will lead to poor air quality. Because trees also provide shade and active cooling by evapotranspiration the effect on thermal comfort is not unambiguous.

To increase ventilation streets can also be oriented to the prevailing wind direction. In the Netherlands this is not favourable because of the negative effects during the winter months. During heat waves the North-Eastern wind prevails in the Netherlands. However, the yearly prevailing wind comes from the opposite direction (South-West) and during periods of cold weather, the wind, even comes from the same (South-West) direction, see Figure 3.11. Thereby, the wind speed is often very low during a heat wave which implies a limited cooling potential. Locally, there may be other prevailing wind directions, when using the prevailing wind direction also study the local prevailing direction during cold waves and stormy weather.

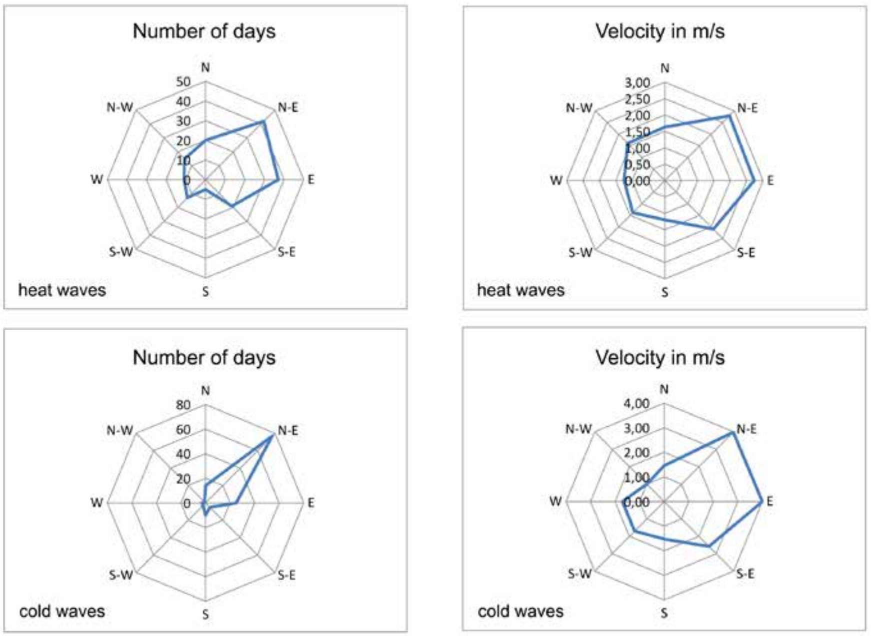

FIGURE 3.11 Wind rose giving the number of days (left) and the average wind speed (right) per cardinal direction during heat waves (above) and cold waves (below) between 1950 and 2011, based on KNMI data.

Next to varying the H/W ratio of streets, alternative building structures can modify air flow patterns. With open urban blocks or buildings in an open field deeper penetration of air into the built-up area is possible (Sukopp and Wittig, 1998, p. 158 in Milošovičová, 2010, pag 29).

In a temperate climate air flow generated due to differences in heated surfaces has a significant advantage above orienting or guiding airflow because it only increases airflow when desired. A study originally focussed on decreasing air pollution indicates that higher surface temperatures can increase the mixture of air in canopy with upper air layer when leeward side and ground is heated, when the windward side is heated an opposed recirculation motion tends to develop which causes less vertical exchange (Sini et al. 1996). Therefore, especially South-West facing facades are suitable in the generation of airflow because these are heated the most by solar radiance and are the leeward side when the prevailing wind is coming from the North-East during heatwaves.

Another principle based on airflow generation between hot and cool spots is the 'park breeze effect'. This effect can be developed within 250 meters from a park border and is most pronounced from two to six hours after sunset (Eliasson & Upmanis, 2000). This principle can therefore be used to support the summer-night cooling of indoor environments.

Volume/surface ratio

All city elements are interrelated. When we conclude that low-density urban areas accumulate more heat than compact high-density areas because the low buildings and large space between buildings allow more solar exposure, the analysis is too superficial. In reality higher building density often coincides with a lower presence of vegetation, a lower wind speed, less radiation to the sky (trapped by building walls) and a higher heat load from buildings and increased outdoor activities. All this affects the heat storage, resulting in higher temperatures and slower cooling at night time in high-density areas (Givoni 1998, p. 269). Other studies by Oke (1988) and Pisello et al. (2014) strengthens this conclusion by showing respectively, an empirical relationship between larger H/W ratios and a higher maximum UHI and the relation between increasing densities and energy consumption due to inter-building effects. A study by Hamilton et al. (2009) illustrates the contribution of anthropogenic heat with the finding of an annual average heat emission across London of around 9 W/m^2. In street canyons with high densities this constitutes a large part of the total energy input.

City size is not an adjustable feature, but can play a role in policy making. The larger the city, the bigger the UHI effect. In this respect sprawled developments should be avoided. 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). According to this method the predicted UHI effect for Utrecht with around 300.000 inhabitants would be 6.9°C and for Rotterdam with around 610.000 inhabitants 7.6°C. Especially for Rotterdam this corresponds with recent traverse measurements that resulted in an UHI effect of 7°C Rotterdam Heusinkveld & Holtslag (2010). A policy that could result from the prediction model is a maximum acceptable UHI and therefore a maximum to the population growth of a city. Note that population density is best applied on the neighbourhood level because this corresponds better to building densities (Steeneveld et al., 2011).

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. Instead of population densities or even building densities, heat accumulation is more related to the FSI (Floor Space Index). The FSI is the ratio between the total floor space (adding building layers) and the built foot print (Berghauser Pont & Haupt, 2009). A study by Milošovičová (2010) for Berlin recommends to keep the FSI under 3.5 for the sake of urban heating.

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 et al., 2012). 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 topography in vast zones of the country. Moreover, new developments starting from scratch, can easily take spatial parameters into account.

§ 3.4 Material and colour

The evaporation from urban areas is decreased because of 'sealing 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 percent, 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 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 hours. 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. The hollow block wall cooled at the fastest rate (Wong et al., 2004). The thermal admittance of materials also plays a significant role. Materials like brick store more heat, and radiate this heat into the air during night time until sunrise. Hollow block concrete has a smaller thermal admittance and therefore stores less heat.

Researchers from Lawrence Berkeley National Laboratory (LBNL), USA, estimate that: "if all buildings in the greater Los Angeles area had a cool roof system, the total energy and smog savings (i.e., lower hospital bills and fewer lost workdays caused by smog inhalation) would be about half a billion dollars per year" (Akbari & Bretz, 1998).

To control climate indoors, phase change materials (PCM's) in walls and construction materials are available on the market. PCM's have the capability to absorb or release heat when the material changes from solid to liquid and vice versa. In fact, we can say PCM's form a latent heat storage system. Would they be useful in outdoor climate conditioning as well? When applied in outdoor façade and roofing claddings the materials could store even more heat. This is only desirable if the material changes from liquid to solid (releasing heat) under 20 degrees Celsius. This is possible with for example salt capsules (Thermusol, 2015). Note that if the transition temperature is higher than 20 degrees, the UHI effect would be aggravated at night.

The absorbed heat at the façade and roof surfaces for outdoor cooling has the potential to produce heat or electricity. Panels with photovoltaics (PV) produce electricity and form a shadow device for roofs which lowers the energy demand for cooling (Kapsalis et al., 2013). PV pavement has proved to decrease surface temperatures with 5°C and ambient temperatures with 2°C (AIVC, 2013, page 946). Solar collectors are surfaces where water tubes run along that absorb heat and transport the heat to a heat exchanger where this heat can be used or stored. Collectors in roads are developed to keep roads from freezing in winter. It turns out that only 20 percent of the stored heat in summer is needed for the road. This leaves enough heat for 600 households (Cuiper, 2007). The same collector is also able to generate cold. The inside temperature in an elderly home does not exceed 23°C with outdoor temperatures above 30°C for several days.

The influence of the colour of pavement and claddings reaches further than surface temperature and radiation load. Colours can also influence airflow. As explained in section 3.3 about ventilation, airflow can be generated (on calm, sunny days) between a cool place such as a park and a hot space such as a dark paved square. Colour induced airflow is elaborately explained in chapter 6. A dark surface in combination with a solar chimneys increases the rate of air movement even more (Bronsema, 2013).

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.

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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 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 the 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 isn't 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).

Regardless the place where solar collectors are applied - on roofs, facades or roads – all have the double benefit to contribute to the climate control indoor and outdoor. An average single family home consumes about 45 Gigajoule (GJ) per year for space heating and hot water. For new constructed and renovated dwellings an average of 28 GJ is a common heat demand. One square meter of asphalt collector delivers about 0.8 GJ. This leads to a required collector surface of 35- 60 m^2 with an additional heat pump to supply one dwelling (Dijkink, 2008). This great potential should be exploited better.

§ 3.5 Conclusion

This chapter provides an overview of measures that influence the urban microclimate. These are measures that can contribute to the adaptation to higher temperatures and extreme heat stress. The measures are categorised in vegetation, water, urban geometry and material and colour. This leaves out measures in relation to social behaviour such as drinking enough water, look for cool spots and adapt clothing, activities and daily rhythm to higher temperatures. These aspects have been discussed in the previous chapter.

Most literature indicates effects in air temperature, some in surface temperature and only a few in a human thermal comfort index. The local context and conditions in which effects are analysed and the method to analyse play a large role. Comparing effects, therefore, is not found useful.

Form the four sections in this chapter some general conclusions can be extracted:

- Vegetation has the largest cooling potential for daytime heat stress;
- Water is especially important in supporting vegetation;
- The cooling effect of green and water are large because they affect the physical and mental perception of thermal comfort;
- A broad street with a height to width ratio of at least 0.66 is favourable to narrow streets in the Dutch climate. This is only true if the street design provides sufficient shadow devices (e.g. trees) and cool pavement.
- Pavement, facades and roofs can be transformed from uncontrolled heat accumulators into climate regulators.

Climate resilience in relation to heat stress is not only a matter of creating the coolest place possible. It opens a window of opportunities to utilise climate change in meeting energy ambitions or in coping with extreme rainfall.

The findings in this chapter are input for the factsheets introduced hereafter, at the end of part one. This is a means to translate the scientific knowledge from this and the previous chapter for practitioners. The second part of this thesis aims to increase insight in the effect of measures in relation to thermal comfort. The effects are studied through numerical simulations and measurements.

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