2 Urban climate and climate change[3]

The industrial revolution brought us wealth and growth. The higher standard of life is now concerned as 'basic' in the western world and gradually increased the society's dependency on highly exergetic energy resources. The combustion of these energy resources results in exhaust of fumes containing dangerous pathogens such as carbon monoxide, sulphur dioxide, nitrogen dioxide, benzene and formaldehyde (Perry, 2015). The effect on people's health and the depletion of fossil fuels resulted in innovations to increase the efficiency of combustion and reduce harmful fumes.

Today's concern is especially focussed on the exhaust of particulate matter and the emission of CO_2. The awareness on mitigation, preventing CO_2 emissions in the atmosphere, started with the report of the World Commission on Environment and Development, which introduced the definition of sustainable development: "A development that meets the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs" (Brundtland, 1987). The emission of CO_2 influences the global climate, so much is clear by now: consensus about the relationship between CO_2 emissions and global warming is very strong (IPCC, 2014b). Emissions from the past century are expected to already have an irreversible global warming effect that will especially affect the generation of our children and grandchildren. Effects often manifest on another location in the world than the places where most of the CO_2 is emitted. Moreover, places that contribute less to high CO_2 levels often have less means to protect themselves against climate hazards. Therefore, Machiel van Dorst added the importance of place to the Brundtland definition of sustainable development: "A development that meets the needs of here and now without compromising the ability of others to meet their own needs there and then" (Dorst, 2010).

This chapter outlines the context of this research and answers the following research question:

What is the impact of climate change on the urban environment in the Netherlands?

Sub-questions are:

- What is the expected impact of the occurrence of climate change in The Netherlands?
- How do people perceive the city's microclimate, especially heat?
- What is the effect of high(er) temperatures on the microclimate in Dutch cities?
- What are the effects of high(er) temperatures on health, energy and economical aspects?

---

[3] Several passages in this chapter are originally published in Kleerekoper, L. (2009), Urban Heat. Design principles for Urban Heat Management in the Netherlands, TU Delft.

TOC

§ 2.1 Climate change predictions

§ 2.1.1 Global climate change

The rising levels of CO_2 in the atmosphere, which are predominantly caused by the combustion of fossil fuels, reinforce the naturally occurring greenhouse effect. This causes the earth's atmosphere to warm up. This is called global warming. The temperature rises more rapidly than ever before. This causes the ice on the planet to melt and leads to sea level rise, changes in wind patterns, changes in the ocean conveyor belt, etc. A record minimum of ice extend was measured in 2007, with little recovery in the years thereafter (Perovich, 2011). Some climate effects follow a linear course, but others can suddenly stop or invert. For instance, the ocean conveyer belt is based on a natural pump system called the *thermohaline circulation* that is generated by fronts of warm (thermos) and salt (haline) water, of which the latter sinks due to a higher density when cooled due to a front of fresh (less salty) water (Moinbiot, 2007). These changes influence ecosystems and affect the lives of flora and fauna and more than 40% of the human population (Dow & Downing, 2006).

The current climate models predict a global temperature rise of 1.5 to >2°C in 2100 (IPCC, 2014a). Although these models do not include scenarios with mitigation strategies which might diminish the global temperature rise, it is not likely that mitigation strategies will be able to prevent an increase of 2°C globally. This implies that we will have to adapt to climate effects caused by a global warming of at least 2°C. However, it is more likely the temperature level will not stay below 3, or even 4°C. According to the same Fifth Assessment Report by the IPCC "It is very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur" (IPCC, 2014a) page 10.

Destruction of water cycles
The global climate change affects regional and local climates such as urban climates. The other way around, a city can also (locally) influence its regional climate. As Kravčík et al. (2007) describe, the UHI effect causes a decrease in precipitation in the periphery of the city because it destroys the system of small water cycles. A small water cycle is the water circulation in which water from land evaporates and precipitates on the same area, see Figure 2.1 for a schematic representation. Such small water cycles occur over land, fresh water bodies, seas and oceans.

Urban environments interrupt small water cycles, resulting in rising radiant flows that push clouds to a cooler environment, leaving the periphery with less rainfall, see Figure 2.2. The rising warm air reinforces rainfall beyond the periphery. This effect is visible for the larger cities in The Netherlands (Rotterdam, Amsterdam and Utrecht) where the prevailing leeward side (North-East) receives more precipitation than the windward side (South-West) (KNMI, 2009). The warmer and dry soil of urbanised areas also accelerates the water run-off, which indirectly causes a higher sea level. Also water resource issues and the global water cycle are influenced by land use change (Harding & Blyth, 2011).

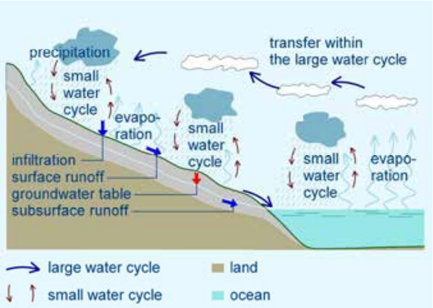


FIGURE 2.1 The large and small water cycles on land (Kravčík et al., 2007).

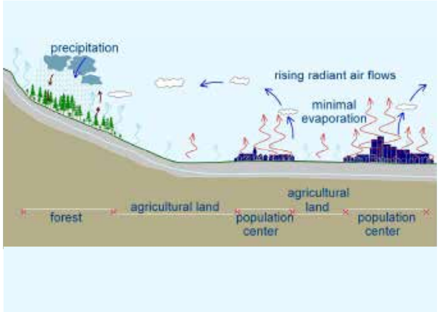


FIGURE 2.2 The impact urban areas can have on the destruction of small water cycles (Kravčík et al., 2007)

Urbanized areas do not have a direct impact on global warming due to anthropogenic heat fluxes, because they cover less than 1% of the Earth's surface and the energy released in cities is much less significant than the energy received by earth from the sun, according to Alcoforado & Andrade (2008). However, they write that most authors agree that warming of the urban atmospheres does have a slight contribution to the computation of global warming. And indirectly, cities contribute to global warming because they are a very important source of greenhouse gases. Furthermore, although its influence on global climate change may be limited, the anthropogenic heat fluxes can have a significant local impact on the urban climate.

Additional insights in the course of this research
After the first inventory of climate change predictions at the start of this research predictions and insights have evolved. Have the former predictions been adjusted and in which direction?

A study by Barriopedro et al. (2011) predicts an increase of the probability of the occurrence of 'mega-heatwaves' over highly populated areas of western Europe with a factor five to ten within the coming four decades. And other projections suggest a northward extend of heatwaves in Europe and an overall increase in extreme heat stress by the end of the 21st century: up to 30 days in duration and 7°C in amplitude

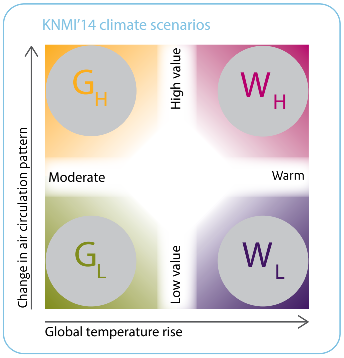
(Amengual et al., 2014). Within the same time span large changes in hourly precipitation extremes are projected: an increase of the areal average of 60 to 80% for western Europe (Lenderink et al., 2011b) and a 50% increase of the intensity of hourly precipitation extremes for The Netherlands (Lenderink et al., 2011a).

From the findings above we can conclude that the earlier climate change predictions have been endorsed by more recent studies. With greater confidence we can state that the global warming trend will lead to increasing 'heat stress' in Europe.

§ 2.1.2 Climate change predictions for The Netherlands

Global climate change and the impact on local areas vary a lot. For the Netherlands global warming does not just entail a milder climate, but also a higher frequency of weather extremes, including heat waves. The expectations are an increase in number of warm days (25°C or more) and tropical nights (20°C or more), longer warm periods (heat waves), more and longer dry periods, heavier rainfall and a chance of an increase in precipitation (Ligtvoet et al., 2015). Cities, as a result, will have to deal with heat stress and water abundance more frequently.

With respect to 1981-2010 the average temperature in the Netherlands will increase by 1.0 to 2.3°C by 2050 and by up to 3.5°C by 2085 (Ligtvoet et al., 2015). KNMI, the royal Dutch meteorological institute does not predict a future climate but gives four probable scenarios as shown in Figure 2.3.



G_L-moderate: 1°C temperature increase in 2050 and 1.5°C in 2085, low influence of changes in airflow patterns West Europe;

G_H- moderate: 1°C temperature increase in 2050 and 1.5°C in 2085, softer and wetter winters caused by more winds from the west, warmer and dryer summers caused by more winds from the east;

W_L-warm: 2°C temperature increase in 2050 and 3.5°C in 2085, low influence of changes in airflow patterns West Europe;

W_H- warm: 2°C temperature increase in 2050 and 3.5°C in 2085, softer and wetter winters caused by more winds from the west, warmer and dryer summers caused by more winds from the east.

FIGURE 2.3 KNMI climate scenarios: the vertical axis indicates the wind circulation patterns from low influence to high influence. The horizontal axis indicates the world temperature difference for 2050 compared to 1981-2010 (Ligtvoet et al., 2015).

To put the temperature increase in perspective: in The Netherlands temperatures measured in 2006 and 2007 are comparable to the temperatures in central France around 1900. In 2050 summers with three weeks of heatwave are expected to occur once every two years coinciding with a lack of fresh water regularly. The KNMI considers the W and W+ scenarios as the most probable for the coming decades. After 2050 Global Warming will accelerate as will the melting of ice caps according to the Delta commission 2008 (Hof, 2009). Temperature extremes are higher around 2100 and may go up to 44°C with a chance of once in a 100 years (Sterl et al., 2010).

For the future, annual precipitation is expected to increase on average with 2.5 to 5.5 percent in 2050. Rainfall will vary more throughout the year, with longer periods of drought and intensive showers in summertime and with long wet periods in fall and winter (Ligtvoet et al., 2015).

Climate change also affects salinization due to draughts and sea level rise (Jonkhoff et al., 2008). Salt water will penetrate more easily and further into the Dutch Delta. This has a negative effect on agriculture, drink water supply and nature development.

Although climate change predictions point to both, more extremes in heat waves and precipitation, the focus of this study is on heat. As explained in the introduction chapter 1, there is a lack of knowledge about urban heat stress in Dutch cities. The following sections give insight in outdoor thermal comfort, urban heat accumulation and the related problems and opportunities.

§ 2.2 Thermal comfort

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

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

In general, wind has a large negative influence on thermal comfort. Only when air temperatures exceed 21°C a stronger air flow starts to increase comfort conditions

TOC

(Olgyay, 1963). In the Netherlands the coldest winter and spring winds are North-Easterly winds, while the cooling sea breeze in summer comes from the opposite side, the South-West. This implies an important constraint when designing to use wind to cool cities in summer, this is further explained in section 3.3. The Dutch standard for wind comfort is a maximum acceptable wind speed of 5 m/s, more than 3 Beaufort, and for wind danger 15 m/s, more than 7 Beaufort (NEN, 2006). As with temperature, wind comfort is also highly dependent on the kind of activity (see Table 2.1).

ACTIVITY	APPLICABLE FOR	RELATIVE COMFORT AT WINDSPEEDS ACCORDING TO BEAUFORT			
		PLEASANT	ADMISSIBLE	UNPLEASANT	DANGEROUS
walking fast	walkway	5	6	7	8
strolling, skating	parking, building entrances	4	5	6	8
standing still or sitting down for a short period of time	parking, squares, shopping malls	3	4	5	8
standing stil or sitting down for a long period of time	open air theater, terraces, stadions, recreation areas	2	3	4	8

TABLE 2.1 Comfort criteria according to Devonport for an air temperature above 10°C (Verhoeven, 1987).

A recent study in Utrecht during a warm period in august, showed that indoor air temperatures are experienced as too warm when they reach 25 to 30°C. Moreover, 25% of the correspondents indicated 20 to 25°C as too warm. For the outdoor temperature the threshold was five degrees higher; above 25°C was perceived as too warm and more than 40% indicated 30 to 35°C as too warm outside (Helden, 2013).

Thermal comfort index PET

Although most researchers indicate effects of adaptation measures due to air temperature only, Shashua-Bar et al. (2011) observe that wind, humidity and radiation are often dominant in human comfort sensation. Comfort indicators have been developed to approximate human experience of the microclimate. They were first developed for indoor conditions, an example is Fanger's Predicted Meat Vote (PMV) (Fanger, 1970). Later, attention to the outdoor microclimate increased and outdoor comfort indicators began to be developed for specific climate zones. The appropriate indices for the temperate climate are the Universal Thermal Climate Index (UTCI) (Jendritzky et al., 2001, Fiala et al., 2012) and the Physiological Equivalent Temperature (PET) (Mayer & Höppe, 1987). One difference between these two indices is their sensitivity on wind speed fluctuations. PET responds stronger to a reduction in wind speed while UTCI is modified stronger by an increase in wind speed (Fröhlich &

TOC

Matzarakis, 2014). During hot weather, modifications in lower wind speed are more significant because lower winds speeds often occur with this type of weather.

In the PET indicator parameters, such as air temperature Ta, mean radiant temperature $Tmrt$, air velocity v and water vapour pressured VP are weighed to the human perception of climate circumstances (Mayer & Höppe, 1987, Höppe, 1999). This indicator uses the heat-balance model MEMI, which is based on the energy-balance model for individuals.

The basis for PET calculation is the basic heat balance equation (1) for the human body (Höppe, 1999):

$$M+W+R+C+E\mathrm{D}+E\mathrm{Re}+E\mathrm{Sw}+S=0 \tag{1}$$

M = metabolic rate
W = physical work output
R = net radiation of the body
C = convective heat flow
$E\mathrm{D}$ = latent heat flow to evaporate water into water vapour diffusing through the skin
$E\mathrm{Re}$ = sum of heat flows for heating and humidifying the inhaled air
$E\mathrm{Sw}$ = heat flow due to evaporation of sweat
S = storage heat flow for heating or cooling the body mass

PET (°C)	THERMAL PERCEPTION	GRADE OF PHYSIOLOGICAL STRESS
	Very cold	Extreme cold stress
4		
	Cold	Strong cold stress
8		
	Cool	Moderate cold stress
13		
	Slightly cool	Slight cold stress
23		
	Slightly warm	Slight heat stress
29		
	Warm	Moderate heat stress
35		
	Hot	Strong heat stress
41		
	Very hot	Extreme heat stress

TABLE 2.2 Ranges of the thermal index physiological equivalent temperature (PET) for different grades of thermal perception by human beings and physiological stress on human beings; internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo (Matzarakis et al., 1999).

This study opted for the PET index as its accuracy was demonstrated by Matzarakis & Amelung (2008) for the assessment of the effects of climate change on human health and well-being. Another advantage is that the indicator has been used in many other studies, which makes it possible to compare results with other data. Additionally, the choice for this comfort indicator is in agreement with other research groups that are connected to this study within the Climate Proof Cities (CPC) project (Albers et al., 2015). And finally, it is also an understandable indicator for designers and policy makers because it gives values in the commonly known degrees Celsius.

§ 2.3 The urban heat island effect in the Netherlands

Data from The Netherlands and other countries shows that rural areas often have a considerably lower temperature than downtown areas. This so-called Urban Heat Island (UHI) effect assumes that cities accumulate heat and are consequently warmer than their surroundings (Oke, 1982). During the evening and at night the difference is at its maximum when the countryside has cooled down but the city still retains the heat that has accumulated during the day. The temperature difference with the countryside can reach +10°C. The extent of the temperature differences vary in time and place as a result of meteorological, locational and urban characteristics, see Figure 2.4.

Accumulation of heat occurs in urban areas because higher levels of solar radiation are absorbed by the materials used in cities than by natural vegetation and soils of rural areas. Due to the built form less heat radiation can escape upwards. Especially at night when the air temperature lowers, materials radiate back the heat that was absorbed during the day. In rural areas the absorbed heat can radiate back at many angles up to 180 degrees, whereas in cities a large part of the sky is obstructed by buildings. Besides radiation at night, buildings also obstruct the reflection of sunlight back into the sky. Instead, reflected sunlight is largely blocked by facades which absorb the heat. Another important factor is the lack of vegetation in urban areas. Trees provide shade and cooling by evapotranspiration. A further contribution of the UHI effect comes from transport, heating and cooling systems and industrial activities. In addition, barriers in cities block the cooling effect of wind. Chapter 3 explains the contribution to or decrease of heat accumulation through different elements in cities.

TOC

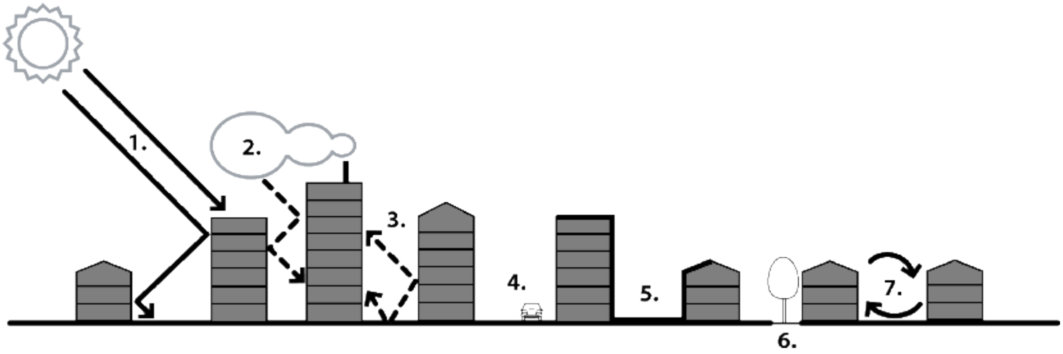


FIGURE 2.4 Causes for urban heat islands (Kleerekoper et al., 2012).

THE URBAN HEAT ISLAND EFFECT HAS THE FOLLOWING CAUSES (OKE, 1987, SANTAMOURIS & ASIMAKOPOULOS, 2001):

1. Absorption of short-wave radiation from the sun in low albedo (reflection) materials and trapping by multiple reflections between buildings and street surface.
2. Air pollution in the urban atmosphere absorbs and re-emits longwave 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.

The physical parameters influencing heat accumulation in cities, described above, can be indicated by for example building density or the sky view factor. Oke (1973) shows that population density can be sufficient to indicate a cities UHI, especially on the neighbourhood level because this corresponds better to building densities (Steeneveld et al., 2011).

The UHI effect is not a recent phenomenon, temperature measurements of the soil under cities confirm urban heat patterns and even reveal some urban history as the depth of the minimum temperature is greatest under the oldest parts of a city (Ferguson & Woodbury, 2004). In The Netherlands, weather stations are all situated in the countryside or in the vicinity of airports in order to reduce variations caused by the built-up environment. Official temperature data from inner cities are not available and this has led to ignorance about the effects of heat collection in Dutch cities.

§ 2.3.1 Measuring heat in Utrecht and Rotterdam

The first study of the UHI effect in The Netherlands has been done by Conrads (1975) who performed measurements in Utrecht in 1970-1971. This study shows a significant difference between the rural (measurement station of The Bilt) and urban temperatures particularly in daily minimum temperatures. In winter the average difference of the daily minimum temperature was 1.7°C, in Summer 2.7°C. Minimum night-temperature differences measured up to a maximum of 8°C.

After the study of Conrads, new measurements in Utrecht were done with traverse measurements by bike between 1993 and 2000 in mornings and afternoons (Brandsma et al., 2003, Brandsma, 2010). And during the CPC project, Heusinkveld (2013) organised a team to continuously measure air temperatures traversing the city by bike on a typical summer day in July 2012. Temperature differences between city and 'rural' measured up to 5.3°C in the evening and 3.3°C at the highest daytime temperature of 30.3°C. The chosen routing and the fact that it was a typical summer day and not an extreme hot day may have led to an underestimation the UHI effect of Utrecht. Since 1971 the maximum values of the UHI effect in Utrecht have probably increased due to the following changes:

TOC

- Utrecht has grown, not just in size and population, but particularly in terms of paved surface and density of buildings;
- Human activity has changed: more traffic, higher energy consumption, more industrial activities, a 24-hour society;
- Climate change might have changed the magnitude of the UHI effect;
- Building styles, height, materials and roofing have changed, i.e. there may be an alteration in albedo (reflection level) and wind patterns;
- Dutch cities are located fairly close to one another and the countryside is continuously in a process of urbanisation. Areas that were rural in 1970 are now also dealing with the UHI effect. This implies that the rural reference station Conrads used in 1970 no longer measures temperatures isolated from urban areas (Salcedo, 2008).

The latter point implies that the UHI effect may have increased even more than indicated by the measurements. The same applies to the actual heat stress that might have increased due to higher temperatures in both city and rural area due to climate change.

In a measurement campaign amongst residents the MNU (environmental agency of the province of Utrecht) found a relation between the amount of green and in- and outdoor temperatures. Especially high temperatures in bed rooms are indicated by residents as uncomfortable. These often exceeded 25°C (Berg, 2013).

In Rotterdam Heusinkveld & Holtslag (2010) measured a maximum air temperature difference of 7°C between city and rural areas. From the traverse measurements a thermal comfort value was calculated in the Physiological Equivalent Temperature (PET). On a hot afternoon in August 2009 the PET ranged from 25 to over 50°C. In Figure 2.5 the spatial PET distribution clearly shows a hotter city centre compared to the rural area in the evening.

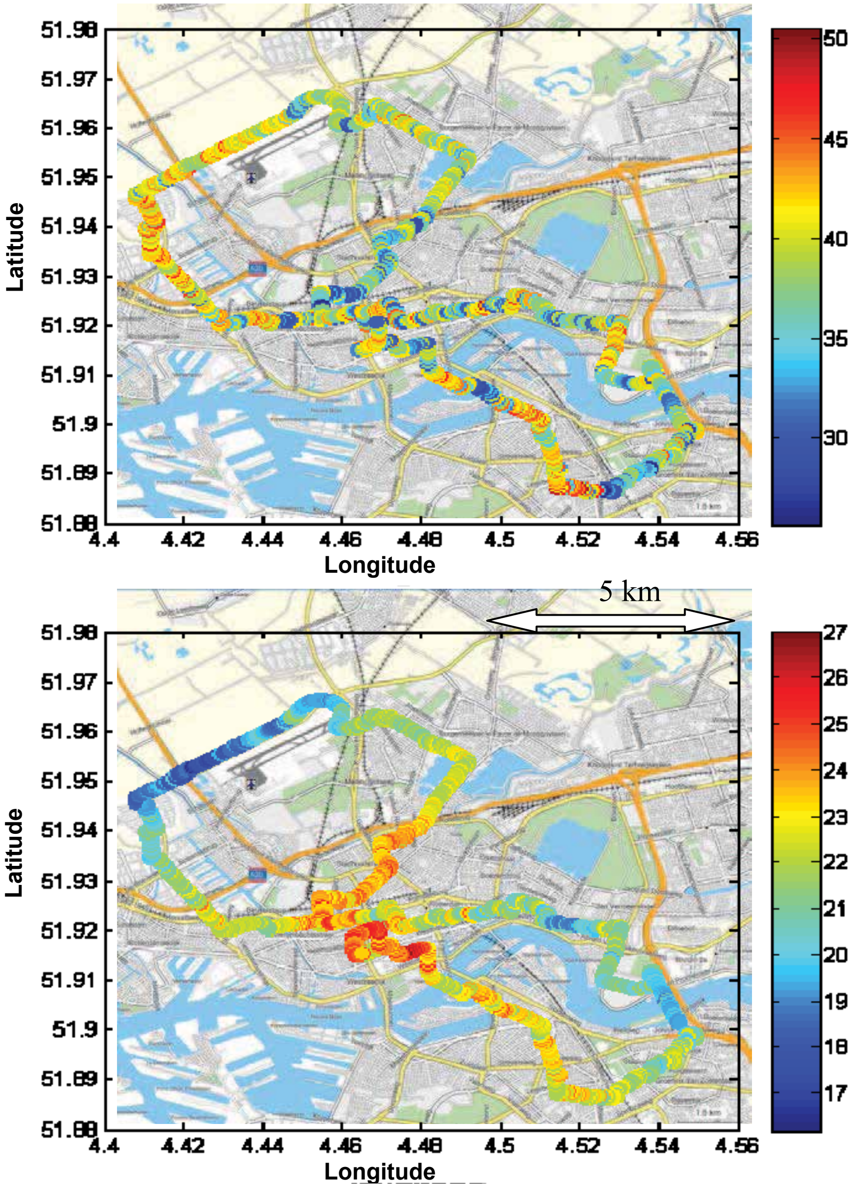


FIGURE 2.5 Traverse measurement data in PET between 14:00-16:00 h (above) and 22:00-24:00h (under) on the 6th of August 2009 in Rotterdam , The Netherlands (Heusinkveld & Holtslag, 2010).

Another source of temperature data in cities are amateur weather stations spread over all cities in The Netherlands. In an analysis by Steeneveld et al. (2011) data from over 200 amateur weather stations was collected of which only 19 stations could meet all the requirements for the analysis. According to this study most Dutch cities have a mean daily maximum UHI of 2.3°C and a 95 percentile of 5.3°C. The largest difference in heat accumulation is found in the evening, with low wind speed and little cloud cover.

TOC

§ 2.3.2 Mapping urban heat

The traverse measurements presented in Figure 2.5 in the previous section is one of the options to map urban heat. In fact, the presented PET measurements provide a lot of information about the spatial distribution of thermal comfort throughout the city. On the other hand, the method requires very specific measurement equipment, a lot of time and manpower and the retrieved data covers only a short period.

Another way to analyse heat accumulation in cities is the use of satellite imagery that show surface temperatures (Klok et al., 2012). Within the CPC project van der Hoeven and Wandl analysed the vulnerability to heat stress in the cities of Amsterdam (Hoeven & Wandl, 2013) and Rotterdam (3TU, 2014). Firstly, heat accumulation in these cities was analysed based on: surface temperatures, amount of pavement, vegetation index, percentage of space occupied by traffic and water, the building envelope index, albedo value and the average energy label. Secondly, the risk group of people experiencing problems with heat were mapped, including the unborn, new-borns and people above the age 75. Finally, the areas with a concentration of labour activities were indicated because they are expected to use more energy for cooling.

An alternative to measurements is the prediction of an urban microclimate based on physical parameters such as land use, building morphology, vegetation and pavement. A method developed by the University of Stuttgart maps heat accumulation and the most important wind situations is based on these physical parameters. This so-called 'climatope' concept gives a temperature prediction according to typical microclimate aspects (Lenzholzer, 2013, Stadtklima, 2008). The wind situation has to follow from weather stations in the vicinity of the city, where data about the strong wind situations and during hot days can be retrieved. The first climatope maps for The Netherlands were developed within the European research project 'Future Cities' to give an indication of the hot and cool areas. In The Hague, see Figure 2.6, the wind situation was not considered (Slabbers et al., 2010), while for Arnhem wind was a large component, see Figure 2.7.

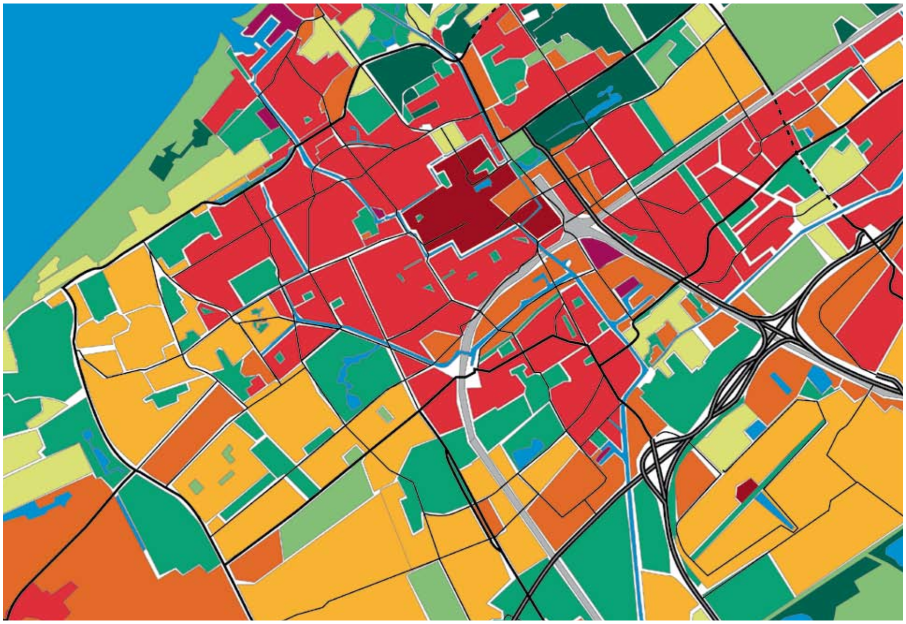


FIGURE 2.6 Climatope map of The Hague with an indication of heat islands in dark red (Slabbers et al., 2010).

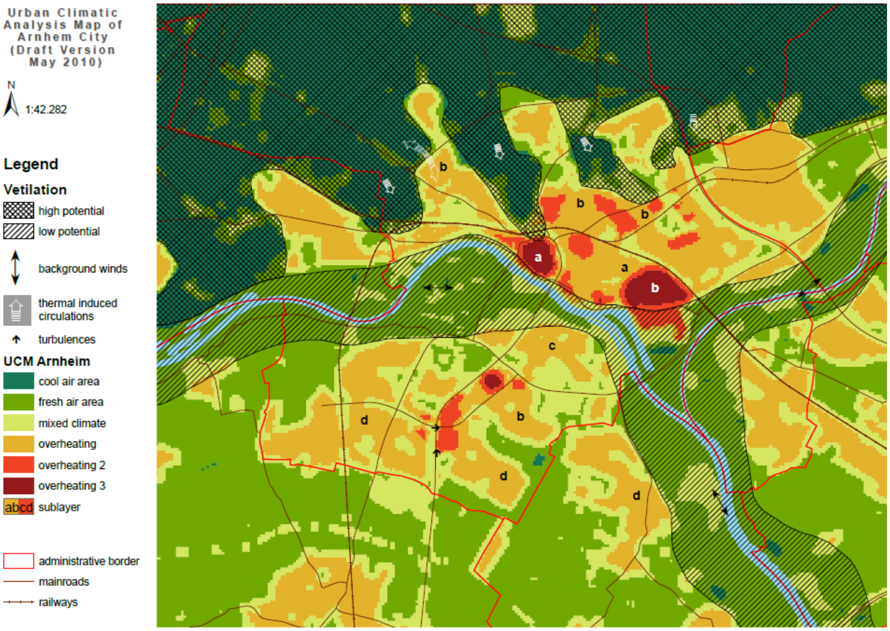


FIGURE 2.7 Urban climatic analysis map of the city of Arnhem (Heerkens, 2010).

The urban climatic analysis map (UC-AnMap) of Arnhem was further developed into an Urban Climatic Map (UCMap) system (Ren et al., 2012). The UCMap system basically translates climatic understanding from the UC-AnMap into suggestions for climate sensitive planning in a planning recommendation map (UC-ReMap) presented in Figure 2.8.

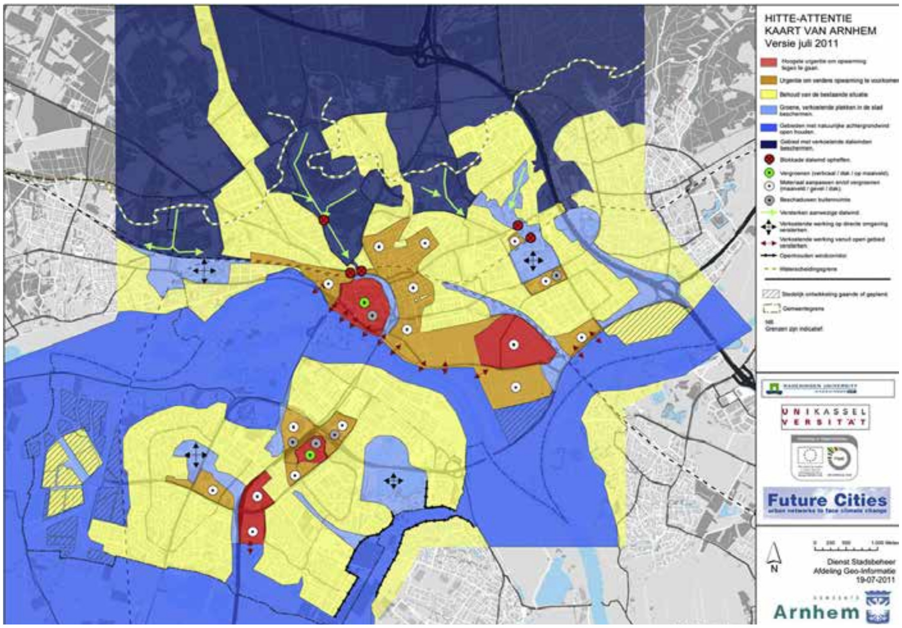


FIGURE 2.8 Planning recommendation map for the city of Arnhem (Ren et al., 2012).

Informed by the vulnerability and climatope maps problematic areas can be indicated and general recommendations can be formulated for structural visions and zoning plans. Further guidance in climate adaptation design on the smaller neighbourhood scale is provided in chapter 7 and 8.

TOC

§ 2.4 Is urban heat stress a problem?

The Dutch government plans to realise 80,000 new dwellings per year between 2012 and 2020 (Programmadirectie Verstedelijking, 2009; PBL, 2011). In the Dutch western Randstad region, at least 40% has to be realised in existing urban areas, and in the rest of the country the inner city share is 25 to 40%. As a pilot project, some office buildings will be transformed into apartments, although the majority of these new dwellings will be realised on new building sites within and outside cities. Expansion and densification of cities lead to an increase of the Urban Heat Island (UHI) effect (Oke, 1973, Rizwan et al., 2008, Steeneveld & Hove, 2010, Arnfield, 2003), together with increasing air pollution and problems with water drainage.

Together with the gradual temperature rise in the Netherlands the increasing UHI effect implies a high predictability of a warmer urban climate. Adaptation of cities and buildings to higher temperatures is important because of the following additional developments that continue to increase: air pollution, number of air-conditioners, aging of the population, less cooling of the outdoor environment due to droughts (Roggema, 2009) and densification in cities. What will happen when Dutch cities have to cope with warmer weather? Which problems can we expect? Could we benefit from this temperature rise? We need to prepare the urban environment for the changing climate in the coming 50 years and, if possible, try to create flexibility for the coming 100 years. This section discusses the risks and opportunities related to increasing temperatures in cities.

§ 2.4.1 Heat stress

When exposed to heat, humans can suffer from severe health problems. The worst effect of heat stress is temperature-related mortality, but heat stress mainly causes illness. In the Netherlands 25°C can be taken as a starting point for heat stress. According to the KNMI a heat wave occurs when the outside air temperature is 25°C or more during five consecutive days, including three consecutive days of 30°C or more (KNMI, 2013). Beside the air temperature also wind speed is relevant: during hot weather mortality decreases with higher wind speeds (Kunst et al., 1993).

A study by Daalen & Riet (2010) in the Dutch city of Tilburg indicates the largest hindrance during warm weather for elderly with health or sociological problems. This result is endorsed by a study of Kovats & Hajat (2008). These two studies indicate a general higher risk during heat waves for the following groups:

TOC

- Infants, elderly above 65 years, people who are ill, take medicines, alcohol or drugs, have overweight and pregnant women;
- Patients suffering from cardiovascular diseases and subject to the additional risk of heart failure.
- People who are unaware of the problems associated with extreme heat and do not adapt their clothing or do not take extra fluids;
- People who are unable to move from overheated places.

The following paragraphs provide more in-depth information about the effect of heat on disease, mortality, sleep and productivity and social behaviour.

Heat effects on disease

Approaching heat from the side of thermophysiology it is seen as a large stress factor for the cardiovascular system. The human body tries to release internal heat through enlarging the flow through the skin, resulting in a faster heartbeat to compensate for the lower venous return. If this primary reaction is insufficient the strong cooling mechanism is switched on: sweating (Daanen et al., 2010). When these two mechanisms fail or cannot compensate for the extreme external conditions (sometimes in combination with risk groups) there are four main diseases that can occur on the short term: heat rash, heat cramps, heat exhaustion and heat stroke (Howe & Boden, 2007).

On the long term people are very capable of acclimatization to heat. But problems occur especially when a heatwave succeeds a relatively cool period. Climate change is predicted to enlarge thermal extremes, thus the chance of explosion to heat without acclimatization increases. Nevertheless, exposition to extreme heat can have consequences on the long term. These are related to a low birth weight and congenital anomalies (Daanen et al., 2010).

Heat effects on mortality

The optimal outdoor temperature related to health, defined by the lowest mortality ratio, is 16.5°C first presented by Huynen et al. (2001). In figure 2.9 the relation between mortality and temperature in The Netherlands is given (Huynen et al., 2008). The relation implies that climate change as a negative result causes an increase in deaths due to more heatwaves, and as a positive result leads to a decrease in deaths due to milder winters. It is therefore important to strive for measures to mitigate heat stress that have low or no temperature decreasing effect in winter, e.g. trees that actually have an increasing temperature effect in winter.

TOC

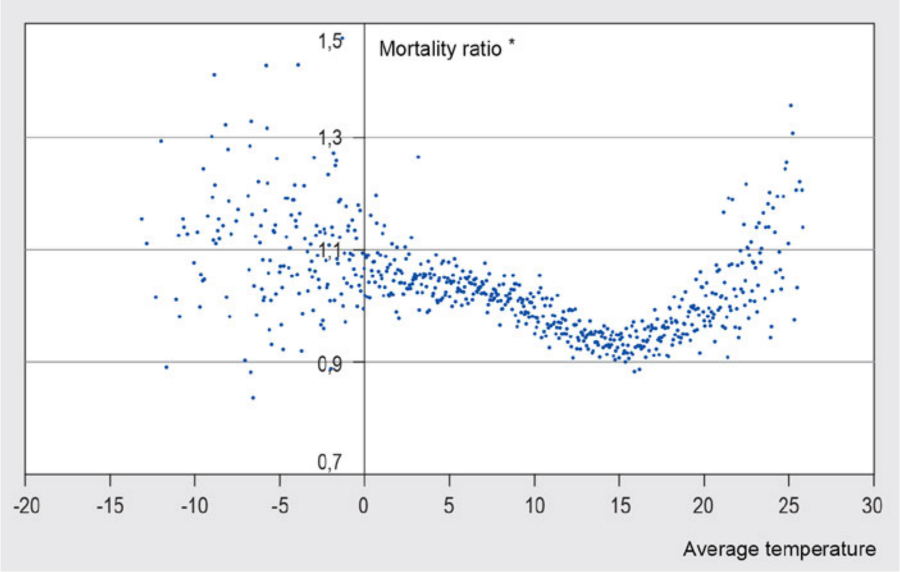


FIGURE 2.9 The relation between average temperature and mortality in The Netherlands, that was measured between 1979-1997 (*mortality ratio = observed number of deaths on day x / mean number of deaths over the whole study period) (Huynen et al., 2008).

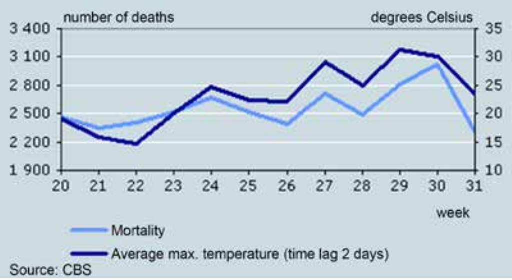
In the period of 1979-1997 higher temperatures during heatwaves resulted in 40 additional deaths per day, an increase of 12% (Huynen et al., 2001). In 2003 a severe heatwave occurred in Europe, causing 15.000 extra deaths in France. Only a small number could be explained by the so-called *harvest effect* (Pirard et al., 2005). The harvest effect means that people die a few months earlier than they would have naturally. Also Le Tertre et al. (2006) and Kovats & Hajat (2008) conclude there was no harvest effect in 2003. The maximum temperatures in 2003 in The Netherlands were lower than in other European countries, nevertheless around 1400 deaths can be attributed to heat stress in that year (Fischer et al., 2004, Garssen et al., 2005).

In 2006 the month of July was extremely warm in The Netherlands which led to many more heat-related deaths than usual. This heat wave was rated as the world's fifth worst natural disaster in terms of actual deaths in 2006 (Table 2.3). This comparison is not entirely proportional since the deaths caused by an earthquake concerns a cross-section of the population, while extreme temperatures mainly hits the weak from society.

	DISASTER TYPE	COUNTRY	NUMBER OF KILLED
1	Earthquake (Yogyakarta)	Indonesia	5,778
2	Wind Storm (Typhoon Durian)	Philippines	1,399
3	Extreme Temperature (heat-wave)	France	1,388
4	Slides (landslide)	Philippines	1,126
5	Extreme Temperature (heat-wave)	Netherlands	1,000
6	Extreme Temperature (heat-wave)	Belgium	940
7	Wind Storm (Typhoon Bilis)	China P. Rep.	820
8	Wave/Surge (tsunami	Indonesia	802
9	Extreme Temperature (cold-wave)	Ukraine	801
10	Flood	Ethiopia	498

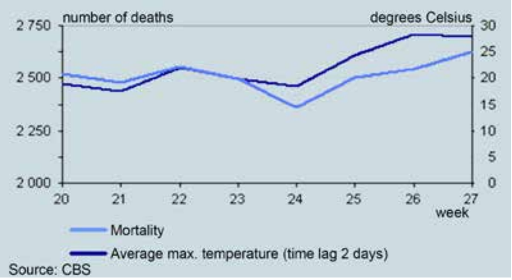
TABLE 2.3 Top 10 of most significant natural disasters by number of deaths in 2006 (Hoyois et al., 2007)

Based on the data from the warm summer in 2006 the Dutch Central Bureau for Statistics (CBS) calculated that the increase of the average temperature by one degree Celsius leads to an extra mortality of about 31 persons per week. Temperature-related mortality in the Netherlands from May to August 2006 is shown in Figure 2.10 and from May to July 2010 in Figure 2.11. Garssen & Harmsen (2006 and 2010), estimate 1000 and 500 additional deaths due to the heatwaves in respectively 2006 and 2010. Temperature-related deaths are higher at an older age, especially over 80 years of age,



Source: CBS

FIGURE 2.10 Mortality (light blue) in relation to the maximum average temperature (dark blue) during week 20 to 31 of 2006 (Harmsen & Garssen, 2006)



Source: CBS

FIGURE 2.11 Mortality (light blue) in relation to the maximum average temperature (dark blue) during week 20 to 27 of 2010 (Garssen & Harmsen, 2010).

Heat effects on sleep and productivity

Sufficient sleep is essential for human's health, alertness, cognitive performance, immune system and hormonal system. With high temperatures people sleep shorter and wake up more frequently, whereby falling asleep takes longer (Buguet, 2007). A laboratory study by Raymann et al. (2008) shows that only a small change in skin

TOC

temperature of less than 1°C can have a large impact on sleeping quality. Figure 2.12 presents results from a study amongst a large group of elderly in the city of Rotterdam found a significant influence of high temperatures on sleep time and efficiency (Janssen et al., 2011).

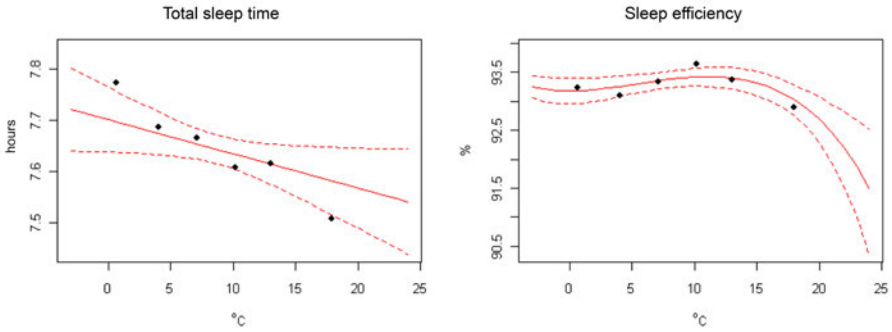


FIGURE 2.12 Total sleep time and sleep efficiency in relation to air temperature (Janssen et al., 2011).

Heat can have an influence on human performance and cause reduction in speed and increase the amount of mistakes (Hancock et al., 2007). Another known effect of increasing temperatures is the decrease of efficiency. One degree increase of the core temperature results in 1% reduction in working efficiency (Daanen et al., 2006).

When you are able to adjust your activities and adjust the work-rest regime during warm weather there will be less discomfort. This so-called self-pacing automatically occurs and illustrates the labour productivity loss due to heat. However, self-pacing is actually the best method to prevent overheating according to Mairiaux & Malchaire (1985). The method can only be effective when the task has no urgent character and does not involve productivity incentives. People that are used to work in hot conditions are better capable in choosing a regular pacing strategy (Daanen et al., 2010). An example where the method will not be effective is at extreme sport performances. The arena built for the World Cup 2014 inside the city centre of Manaus and in the extreme humid and hot climate of the Amazone should have been acclimatized much better or not built on that location in the first place. “At times it felt like I was having hallucinations due to the heat,” Italian Player Claudio Marchisio said after his team defeated England in Manaus (Voogt, 2014).

For office employees self-pacing is usually not an option, which means that the temperature in the working space needs to be adjusted. The building stock in the Netherlands is not very well equipped for warm weather and offices are often too warm and unable to get rid of this heat. The productivity decreases when the temperature exceeds 25°C. Above this temperature every degree extra leads to 2% productivity

TOC

loss in an office environment (Kurvers & Leijten, 2007). Another aspect for the office climate is the remarkable difference in accepted indoor temperatures for buildings with and without extensive climate installations. In buildings that are not equipped with air treatment installations and openable windows higher temperatures are accepted in summer compared to buildings with air-conditioning and limited options to adjust to personal comfort experience (Kurvers & Leijten, 2007). A building with more freedom to adjust climate conditions to personal needs can save on energy for cooling.

A positive impact of higher temperatures on health is that people will exercise more outside (Boer et al., 2006), i.e. going on foot or by bike and do outdoor sports. This requires sufficient park and recreational space and attractive routings through the city and parks.

Heat effects on social behaviour

Not only physical factors play a role in vulnerability to heat. A correlation analysis by Scherber et al. (2014) for Berlin shows a positive relation between relative risks for hospital admissions among > 64-year-olds with respiratory diseases and population density, socio-economic conditions and the annual mean number of hot days based on the period 1971-2000. The vulnerability of an area to heat is also linked to the urban function; it is important to know whether people are working or sleeping in the area (Van Someren et al., 2002).

Adapting daily and work activities in extremely warm periods is an important factor in staying healthy and sound. Therefore, it is important to know how to act. In The Netherlands all municipalities have their own health service institute, the GGD. In 2007 a national heat emergency plan (Biggelaar et al., 2007) was developed by the GGD to support inhabitants in taking the right actions. The five most important recommendations are the following:

1. drink at least 2 litres per day;
2. avoid heavy labour between 12:00 and 16:00h;
3. stay inside or in the shade between 12:00 and 16:00h;
4. cool your body with cold water and cool spaces by closing sun blinds and, when the outside temperature is higher than inside, close windows;
5. take care of each other, especially elderly and ill people.

Especially recommendation 3 and 4 are depending on the existence of sufficient and accessible cool indoor and outdoor spaces. This underpins the necessity to integrate thermal comfort in urban design.

Climate change can also lead to indirect health risks due to changes in flora and fauna. More about this topic is described in section 2.4.4.

§ 2.4.2 Air pollution

Summer smog (ozone at street level) occurs during heat waves. The sun is the motor for smog production: the chemical reaction of sunlight with nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the atmosphere leaves airborne particles (particulate matter) and ground-level ozone. During hot periods wind is usually scarce, which means that air pollution is not dispersed or reduced in these periods.

Air pollution is the cause of 10-25% of the increased mortality registered during heat waves in the Netherlands (Duijm, 2006). As 40% of the inhabitants in this country lives in an urban environment and 20% in a moderate urban environment the effect of air pollution is much larger than in other countries with relatively more inhabitants in rural areas (Erwich & Vliegen, 2001). Health problems caused by the bad microclimate in cities are a social problem, but also an economic problem in terms of productivity (disability insurance) and financial consequences (health insurance). Table 2.4 ranks the Netherlands as second in premature deaths due to particulate matter in European countries per year. A study of air pollution-related deaths in the Netherlands concludes that during the summer of 2003 ozone related deaths were 1400 and deaths related to particulate matter (PM) concentrations 1460 (Fischer et al., 2004). An analysis by Kunst et al. (1993) concludes that air pollution has only a negligible effect on heat-related mortality.

Hungary	11.067	0.111%
Netherlands	13.123	0.080%
Germany	65.088	0.079%
Czech Republic	7.996	0.077%
Poland	27.934	0.073%
Italy	39.436	0.066%
Belgium	10.669	0.064%
France	36.868	0.057%
Austria	4.634	0.056%
UK	32.652	0.053%
Spain	13.939	0.030%

TABLE 2.4 Premature deaths due to particulate matter in Europe per year (EU_Member_States_2000, 2005).

TOC

§ 2.4.3 Energy consumption

The building stock in the Netherlands is mainly prepared for cold periods. The predicted milder winter climate due to climate change, the balance will shift from heating to cooling. High thermal insulation values prevent loss of heat, large windows admit sunlight and generate a comfortable climate during cold periods. However, a great area of window surface, lack of prevention against solar radiation and no passive cooling systems causes overheating of buildings in warmer periods. The building stock in The Netherlands and surrounding countries is not built for warmer summer situations. Schmidt et al. (2007) show that increasing temperatures due to climate change will probably increase CO_2 emissions due to additional mechanical cooling, see Figure 2.13. In a graph from the European Commission that forecasts an increase of CO_2 emissions by 350% by 2020 for Northern countries such as Germany. The same trend of increasing temperatures and additional cooling loads is found for cities in the US where an increase of the UHI with 1°C leads to an increase of the peak electricity demand by 3 to 6% (Bretz et al., 1998).

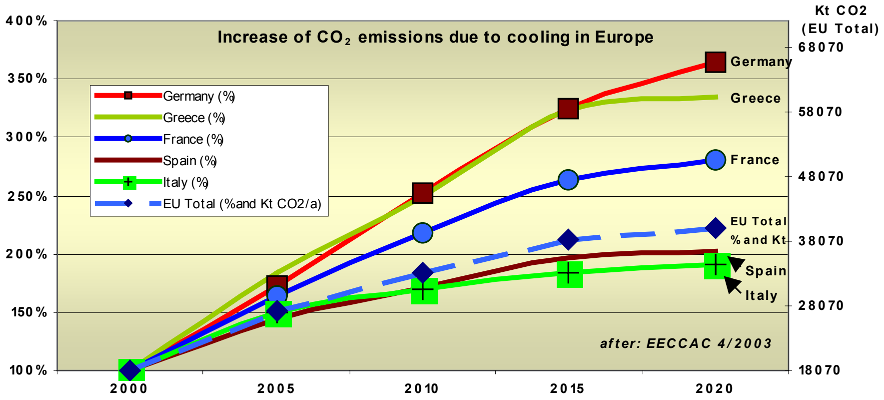


FIGURE 2.13 Increase of CO_2 emissions due to mechanical cooling in buildings in Europe (Schmidt et al., 2007).

Modern western office buildings with large glass surfaces already need to switch on their air conditioning system when the outdoor temperature rises above 12-15°C. The heat exhaust from the air conditioners warms up the city even more and contributes indirectly to an extra cooling demand. Households also tend to obtain air conditioning systems. Currently only 1% of the households is equipped with air conditioning, but in the next years this is expected to increase to 3%. More use of electricity increases the amount of greenhouse gasses which contributes to global warming. Locally, the electricity production by conventional plants causes more pollution.

Another problem occurring when electricity plants need to produce at their maximum during warm periods, is the lack of cooling water. In winter, open water is cold, which means one litre can absorb more heat than is possible with tepid water in summer; the higher the water temperature, the more water is needed to cool by one degree. Regulations in the Netherlands set limits to the water temperature that is discharged to open water, to protect the aquatic ecosystem. This cannot exceed temperatures around 30°C. According to Roggema (2009) the energy supply by power plants becomes problematic when temperatures rise above 23°C. In France the heatwave in 2003 lead to a complete shutdown of six power plants and inadequate cold storage systems of 25-30% of all food related establishments (Létard et al., 2004 in Bobylev, 2009). An intelligent energy system needs to be responsive to alterations in climatic conditions, the weather and other circumstances (Dobbelsteen et al., 2010). Cities should adapt their energy systems to be able to respond on more extreme climate conditions.

Beside energy for cooling in summer, Dutch buildings need energy for heating in winter in spite of the predicted milder winter climates. The energy systems in cities can be more efficient when supply and demand of heat and cold are realized in local and decentralized connexions. For example the use of ‘waste heat’ from industrial processes can supply dwellings with heat and a pool can receive the heat that is produced to cool an ice rink (Tillie et al., 2009).

There are high potentials in energy consumption reduction by storing heat in summer and using this in winter. With heat pumps that deliver cold in summer, heat is a by-product. This heat can be stored in a seasonal storage such as aquifers that can deliver heat in winter. Instead of using a storage a large mass can be used as heat or cold source. An example is the use of water from the Maas river that has a rather constant temperature year-round. With heat pumps heat or cold are extracted from the water to regulate the indoor climate of the Maas tower. An extra advantage in both examples is that heat exhaust from cooling systems does not add to the urban warming. This principle can be applied to the building and neighbourhood level (Jong, 2010).

A basic step in increasing efficiency in energy consumption is to use the exergy approach. The exergy approach can ensure a better utilization of the quality of energy, which ultimately reduces the demand for high quality sources. Exergy expresses what is the amount of work that can be delivered from a given amount of energy or material, in its environment. This is also known as the quality of the energy (Jansen, 2013).

TOC

§ 2.4.4 Organic life

With a milder climate, changes occur in flora and fauna. A positive change is the increase of production of agricultural land due to higher temperatures and an extension of the growing season[4]. In the course of the twentieth century the growing season has extended with approximately 25 days (Klein Tank & Sluijter, 2003). More areas will be suitable for the production of wine and other (heat-tolerant) crops. And due to the warmer city climate during winter non–indigenous species can survive increasing biodiversity. Think of the colony of previously domestic parakeets in the Vondelpark in Amsterdam and in an increasing amount of other Dutch cities. The exotic parrot specie from tropical Africa and South-Asia was introduced as an aviary bird. Released or escaped birds were able to reproduce and settle in urban environments in The Netherlands, Germany and Belgium.

The risks for humans in changes in flora and fauna are mainly related to spreading of viruses and bacteria. These pathogenic micro-organisms often have an optimum, generally higher, temperature to become effective. Also the species (called vectors hereafter) that transfer these micro-organisms, such as mosquitos, ticks, sand flies and midges, prefer a warm and humid climate (Daanen et al., 2010). In an overview of the influence of climate change on the vector related diseases by Lier et al. (2007) especially the tick is expected to spread more pathogens. When Southern tick species spread northward rickettsioses can be introduced. The most common virus, causing Lyme's disease, has greatly increased morbidity in The Netherlands. This is partly related to milder winters and increased temperatures, but also to more small and large mammals and birds in cities and nature reserves that spread the disease and increase the tick density. The increase of tourism in natural tick habitats is also associated with the increase of Lyme's disease. After ticks the mosquito is the next most dangerous vector to transfer viruses; an example is the West Nile Virus, which spread rapidly in the USA.

Other changes that might cause nuisance include occurrence of insects earlier in the year and in greater numbers, migration and multiplying species, abundant vegetation may cause an increase in allergies. In addition, draught, heat and salinization are a threat for the availability and quality of drinking water. A decrease in supply from upstream or from precipitation increases the concentration of pollutants demanding more from the purification process. Water for drinking may not exceed 25 °C in the pumping station (Slabbers et al., 2010) because higher temperatures increase the chance of bacteria growth such as legionella.

---

[4] Growing season: number of days between first period after the 1st of January of 6 consecutive days of 5 °C or more and the first period after the 1st of July of 6 consecutive days of 5 °C or less (Klein Tank and Sluijter, 2003).

TOC

§ 2.5 Conclusion

This chapter discussed the impact of climate change on the urban environment and arguments the relevance of climate adaptation.

The expected impact of climate change in The Netherlands has a significant effect on the occurrence and intensity of heat waves, rainfall and periods of drought. These climate effects will have a larger impact on cities due to the physical conditions, resulting in a lower capability to cope with heat and water than rural and natural environments, and the large population that is affected. The more excessive impact on urban areas increases the urgency to adapt and amplify the importance to consider thermal comfort in urban areas in hot weather conditions. The perception of outdoor thermal comfort is a rather new area of interest in Dutch spatial planning. Without taking action, we risk heat stress related health issues and productivity loss, more air pollution, an increase in energy consumption and consequences from bacterial growth. Moreover, chances to profit from heat remain unexploited.

Although the consensus about climate change predictions is increasing, there is still a chance unlikely scenarios will determine the course of the future climate. Two reasons not to get discouraged by the uncertainties are: also the current city climate would profit from more attention to the urban microclimate and the many additional benefits related to health, energy and economical aspects turns the risk factor into a window of opportunities.

Cities have the opportunity to reduce emissions and water and heat related risks in combination with many other assets. As Schwartz (2013) states: "*Climate change action by local governments around the world is creating wealthier, healthier cities*". This finding is based on analysed data from members of the C40 Cities Climate Leadership Group in 110 cities around the world, including Tokyo, New York, and London. The engagement of the cities on the issue of climate change, has led to the result of saving money, creating more attractive investment environments, and enabling citizens to live healthier lives. Moreover, integrating climate adaptation from the initial stage of a development plan leads to no or little additional costs, with potentially high benefits (Pijnappels & Sedee, 2010). This was concluded after analysing over a hundred development projects in the Netherlands where climate adaptation and spatial planning were considered.

Climate adaptation should be seen as a chance to improve our urban environments on many levels. A consensus on the best way to develop climate adaptive urban environments is however not constituted yet. In the first place, uncertainties and insufficient knowledge about the effect of measures for the temperate climate creates reluctance in implementation. In the following chapter the effects known from literature are given. Thereafter follow three chapters that study some specific measures through simulations and measurements.

TOC

§ 2.6 References

3TU (2014), “Sensing Hotterdam”. Available at: http://www.3tu.nl/bouw/en/lighthouse2014/sensinghotterdam/, http://www.hotterdam.eu/archive 2015].

Albers, R.A.W., Blocken, B. and Bosch, P.R. (2015), “Overview of challenges and achievements in the Climate Proof Cities program”. *Building and Environment*, Vol. 83, pp. 1-10.

Alcoforado, M. and Andrade, H. (2008), “Global Warming and the Urban Heat Island”. *Urban Ecology*, pp. 249-262.

Amengual, A., Homar, V., Romero, R., Brooks, H.E., Ramis, C., Gordaliza, M. and Alonso, S. (2014), “Projections of heat waves with high impact on human health in Europe”. *Global and Planetary Change*, Vol. 119, No. 0, pp. 71-84.

Arnfield, A. (2003), “Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island”. *International Journal of Climatology*, Vol. 23, No. 1, pp. 1-26.

Barriopedro, D., Fischer, E.M., Luterbacher, J., Trigo, R.M. and GarcÌa-Herrera, R. (2011), “The Hot Summer of 2010: Redrawing the Temperature Record Map of Europe”. *Science (New York, NY)*.

Berg, P. (2013), “Samenvatting resultaten onderzoeken hitte in de stad in de provincie Utrecht”, MNU.

Biggelaar, M. v.d., Huijnen, F., Plug, K., Willems, N., Bruggen, M.v., Stom, C., Bögels, A., Timmermans, J., Roessel, W.v., Vink, W. and Zierleyn, A. (2007), “Nationaal Hitteplan 2007”, Ministerie van Volksgezondheid, Welzijn en Sport, RIVM, GGD.

Bobylev, N. 2009. Urban underground infrastructure and climate change: oppotunities and threats. *Fifth Urban Research Symposium 2009*. Marseille, France: World Bank.

Boer, R., Zheng, Y., Overton, A., Ridgeway, G., Cohen, D. and Design, N. (2006), “How Neighborhoods Can Reduce the Risk of Obesity”. *Pediatrics*, Vol. 118, No. 5, pp. e1381-e1389.

Brandsma, T. 2010. Warmte-eilandeffect van de stad Utrecht. *Zenit*.

Brandsma, T., Konnen, G. and Wessels, H. (2003), “Empirical estimation of the effect of urban heat advection on the temperature series of De Bilt (The Netherlands)”. *International Journal of Climatology*, Vol. 23, No. 7, pp. 829-845.

Bretz, S., Akbari, H. and Rosenfeld, A. (1998), “Practical issues for using solar-reflective materials to mitigate urban heat islands”. *Atmospheric Environment*, Vol. 32, No. 1, pp. 95-101.

Brundtland, G.H. (1987), “Our Common Future—Call for Action”. *Environmental Conservation*, Vol. 14, No. 04, pp. 291-294.

Buguet, A. (2007), ”Sleep under extreme environments: Effects of heat and cold exposure, altitude, hyperbaric pressure and microgravity in space”. *Journal of the Neurological Sciences*, Vol. 262, No. 1–2, pp. 145-152.

Conrads, L. (1975), Observations of meteorological urban effects. The heat island of Utrecht, PhD thesis, University of Utrecht, Utrecht.

Daalen, E. v. and Riet, N. v. (2010), “Ouderen en hittebeleving”, Bureau Gezondheid, Milieu & Veiligheid GGD’ en Brabant/Zeeland, Tilburg.

Daanen, H., Es, E. v. and Graaf, J. d. (2006), “Heat strain and gross efficiency during endurance exercise after lower, upper, or whole body precooling in the heat”. *International journal of sports medicine*, Vol. 27, No. 5, pp. 379-388.

Daanen, H.A.M., Simons, M. and Janssen, S.A. (2010), “De invloed van hitte op de gezondheid, toegespitst op de stad Rotterdam”, TNO, Soesterberg.

Dobbelsteen, A.A.J.F. v.d., Keeffe, G., Tillie, N. and Kleerekoper, L. 2010. From autistic to autonomous: cities as energy-intelligent organisms. TU Delft.

Dorst, M.J. v. (2010), “Sustainable Liveability”. *Environment, Health, and Sustainable Development*, Vol. 1, pp. 111.

Dow, K. and Downing, T.E. (2006), The Atlas of Climate Change, Mapping the world’s greatest challenge, Earthscan, Myriad Editions.

Duijm, F. (2006), “Hittegolf met de dag gevaarlijker”, Kenniscentrum Milieu & Gezondheid, GGD Groningen, 04-06-2006.

Erwich, B. and Vliegen, M. (2001), “Stedeling en plattelander”, CBS.

EU_Member_States_2000 (2005), “Air pollution causes early deaths”: BBC. Available at: http://news.bbc.co.uk/2/hi/health/4283295.stm 2015].

Fanger, P.O. (1970), Thermal Comfort. Analysis and Applications in Environmental Engineering., Danish Technical Press, Copenhagen.

Ferguson, G. and Woodbury, A. (2004), "Subsurface heat flow in an urban environment". *J. Geophys. Res,* Vol. 109, pp. B02402.

Fiala, D., Havenith, G., Bröde, P., Kampmann, B. and Jendritzky, G. (2012), "UTCI-Fiala multi-node model of human heat transfer and temperature regulation". *International journal of biometeorology,* Vol. 56, No. 3, pp. 429-441.

Fischer, P., Brunekreef, B. and Lebret, E. (2004), "Air pollution related deaths during the 2003 heat wave in the Netherlands". *Atmospheric Environment,* Vol. 38, No. 8, pp. 1083-1085.

Fröhlich, D. and Matzarakis, A. 2014. Human-biometeorological estimation of adaptation- and mitigation potential of urban green in Southwest Germany. *Third International Conference on Countermeasures to Urban Heat Island*. Venice, Italy.

Garssen, J. and Harmsen, C. (2010), "Door recente hitte 500 extra doden": CBS. Available at: http://www.cbs.nl/nl-NL/menu/themas/bevolking/publicaties/artikelen/archief/2010/2010-3172-wm.htm [Accessed 19 July 2010.

Garssen, J., Harmsen, C. and De Beer, J. (2005), "The effect of the summer 2003 heat wave on mortality in the Netherlands". *Euro Surveill,* Vol. 10, No. 7, pp. 165-8.

Hancock, P.A., Ross, J.M. and Szalma, J.L. (2007), "A meta-analysis of performance response under thermal stressors". *Human Factors: The Journal of the Human Factors and Ergonomics Society,* Vol. 49, No. 5, pp. 851-877.

Harding, R. and Blyth, E. 2011. Researchers provide extensive analysis of the world's water cycle. NERC - Centre for Ecology & Hydrology.

Harmsen, C. and Garssen, J. (2006), "Door hitte in juli duizend extra doden": CBS. Available at: http://www.cbs.nl/nr/exeres/CA1F091F-F641-47E6-AB18-D517143A609D.htm 2015].

Heerkens, M. 2010. de Urban Climate Map voor Arnhem.

Helden, L. v. (2013), "Hittemeting", NMU.

Heusinkveld, B. (2013), "Stedelijk warmte-eiland Utrecht", Wageningen University.

Heusinkveld, B. and Holtslag, A. (2010), "Use of a mobile platform for assessing urban heat stress in The Netherlands". *7th Conference on Biometeorology, Freiburg, 12-14 April 2010 2010*, pp. 433-438.

Hoeven, F. v.d. and Wandl, A. (2013), Amsterwarm. Gebiedstypologie warmte-eiland Amsterdam, TU Delft.

Hof, S. v.t. (2009), "Klimaateffectatlas: inspelen op klimaatverandering", Interprovinciaal Overleg.

Höppe, P. (1999), "The physiological equivalent temperature–a universal index for the biometeorological assessment of the thermal environment". *International Journal of Biometeorology,* Vol. 43, No. 2, pp. 71-75.

Howe, A.S. and Boden, B.P. (2007), "Heat-related illness in athletes". *The American journal of sports medicine,* Vol. 35, No. 8, pp. 1384-1395.

Hoyois, P., Below, R., Scheuren, J.-M. and Guha-Sapir, D. (2007), "Annual Disaster Statistical Review: Numbers and Trends 2006", Centre for Research on the Epidemiology of Disasters (CRED), School of Public Health, Catholic University of Louvain Brussels, Belgium, Brussels.

Huynen, M., Hollander, A.d., Martens, P. and Mackenbach, J. (2008), "Mondiale milieuveranderingen en volksgezondheid: stand van de kennis". *Bilthoven: RIVM*.

Huynen, M., Martens, P., Schram, D., Weijenberg, M. and Kunst, A. (2001), "The impact of heat waves and cold spells on mortality rates in the Dutch population". *Environmental health perspectives,* Vol. 109, No. 5, pp. 463.

IPCC (2014a), "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ", Geneva, Switserland.

IPCC (2014b), "Summary for policymakers", Cambridge, United Kingdom and New York, NY, USA.

Jansen, S. (2013), Exergy in the built environment. The added value of exergy in the assessment and development of energy systems for the built environment., Delft University of Technology.

Janssen, S.A., Vos, H., Kluizenaar, Y. d., Berg, J.F. v.d., Hofman, A. and Tiemeijer, H. (2011), "De relatie tussen omgevingstemperatuur en slaapkwaliteit van ouderen", De relatie tussen omgevingstemperatuur en slaapkwaliteit van ouderen, TNO.

Jendritzky, G., Maarouf, A. and Staiger, H. 2001. Looking for a Universal Thermal Climate Index UTCI for Outdoor Applications. *Windsor-Conference on Thermal Standards.* Windsor, UK.

Jong, K. d. (2010), Warmte in Nederland. Warmte- en koudenetten in de praktijk, mauritsgroen mgmc.

Jonkhoff, W., Koops, O., Krogt, R.A.A.v.d., Oude-Essink, G.H.P. and Rietveld, E. (2008), "Economische effecten van klimaatverandering. Overstroming en verzilting in scenario's, modellen en cases", 2008-D-R0711/A, TNO Bouw en Ondergrond.

Kleerekoper, L. (2009), Urban Heat. Design principles for Urban Heat Management in the Netherlands, TU Delft.

Kleerekoper, L., Esch, M. v. 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.

Klein Tank, A.M.G. and Sluijter, R. (2003), "Nederland is verder opgewarmd. De toestand van het klimaat in Nederland 2003": KNMI. Available at: http://www.knmi.nl/cms/content/71542/nederland_is_verder_opgewarmd 2015].

Klok, L., Schaminee, S., Duyzer, J. and Steeneveld, G.J. (2012), "De stedelijke hitte-eilanden van Nederland in kaart gebracht met sattelietbeelden", TNO, Climate Proof Cities, Kennis voor Klimaat.

KNMI (2009), "Klimaatschetsboek Nederland, het huidige en toekomstige klimaat", De Bilt.

KNMI (2013), "Hittegolf. Nader verklaard". Available at: http://www.knmi.nl/cms/content/28253/hittegolf 2015].

Kovats, R.S. and Hajat, S. (2008), "Heat stress and public health: a critical review". *Annu. Rev. Public Health,* Vol. 29, pp. 41-55.

Kravčík, M., Pokorny, J., Kohutiar, J., Kovac, M. and Toth, E. (2007), "Water for the Recovery of the Climate-A New Water Paradigm".

Kunst, A.E., Looman, C.W. and Mackenbach, J.P. (1993), "Outdoor air temperature and mortality in the Netherlands: a time-series analysis". *American Journal of epidemiology,* Vol. 137, No. 3, pp. 331-341.

Kurvers, S. and Leijten, J. 2007. Zomerwarmte in kantoren. *NVvA, Thema: Warmte belasting*. Nederlandse Vereniging voor Arbeidshygiene.

Le Tertre, A., Lefranc, A., Eilstein, D., Declercq, C., Medina, S., Blanchard, M., Chardon, B., Fabre, P., Filleul, L. and Jusot, J. (2006), "Impact of the 2003 heatwave on all-cause mortality in 9 French cities". *Epidemiology,* Vol. 17, No. 1, pp. 75.

Lenderink, G., Mok, H., Lee, T. and Van Oldenborgh, G. (2011a), "Scaling and trends of hourly precipitation extremes in two different climate zones–Hong Kong and the Netherlands". *Hydrology and Earth System Sciences,* Vol. 15, No. 9, pp. 3033-3041.

Lenderink, G., Oldenborgh, G.J.v., Meijgaard, E.v. and Attema, J. (2011b), "Intensiteit van extreme neerslag in een veranderend klimaat", KNMI.

Lenzholzer, S. (2013), Het weer in de stad. Hoe ontwerp het stadsklimaat bepaalt, Nai010 uitgevers, Rotterdam.

Lier, A. v., Rahamat-Langendoen, J. and Vliet, H. v. (2007), *Staat van Infectieziekten in Nederland 2006*, RIVM [Host].

Ligtvoet, W., Bregman, B., Dorland, R. v., Brinke, W. t., Vos, R. d., Petersen, A. and Visser, H. (2015), "Klimaatverandering. Samenvatting van het vijfde IPCC-assessment en een vertaling naar Nederland", ISBN: 978-94-91506-89-5, PBL (Planbureau voor de Leefomgeving), KNMI (Koninklijk Nederlands Meteorologisch Instituut), Den Haag.

Mairiaux, P. and Malchaire, J. (1985), "Workers self-pacing in hot conditions: A case study". *Applied Ergonomics,* Vol. 16, No. 2, pp. 85-90.

Matzarakis, A. and Amelung, B. 2008. Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans. *Seasonal Forecasts, Climatic Change and Human Health*. Netherlands: Springer.

Matzarakis, A., Mayer, H. and Iziomon, M.G. (1999), "Applications of a universal thermal index: physiological equivalent temperature". *International Journal of Biometeorology,* Vol. 43, No. 2, pp. 76-84.

Mayer, H. and Höppe, P. (1987), "Thermal comfort of man in different urban environments". *Theoretical and Applied Climatology,* Vol. 38, No. 1, pp. 43-49.

Moinbiot, G. (2007), *Hitte*, Jan van Arkel, Utrecht.

Oke, T.R. (1973), "City size and the urban heat island". *Atmospheric Environment (1967),* Vol. 7, No. 8, pp. 769-779.

Oke, T.R. (1982), "The energetic basis of the urban heat island". *Quarterly Journal of the Royal Meteorological Society,* Vol. 108, No. 455, pp. 1-24.

Oke, T.R. (1987), *Boundary Layer Climates*, Routledge, New York.

Olgyay, V. (1963), Design with climate. Bioclimatic approach to architectional regionalism, Princeton University Press, Princeton, New Jersey.

PBL (2011), "Hoeveel nieuwe woningen moeten er in de komende tien jaar nog worden gebouwd in Nederland?". Available at: http://www.pbl.nl/nl/dossiers/wonen/veelgestelde_vragen [Accessed 19 January 2011.

Perovich, D.K. (2011), "The changing Arctic sea ice cover". *Oceanography,* Vol. 24, No. 3, pp. 162-173.

Perry, M. (2015), "Dangers of Exhaust Fumes". Available at: http://www.healthguidance.org/entry/14639/1/Dangers-of-Exhaust-Fumes.html 2015].

Pijnappels, M.H.J. and Sedee, A.G.J. (2010), "Klimaat als kans. Adaptatie aan klimaatverandering in de ruimtelijke ordening", VROM.

Pirard, P., Vandentorren, S., Pascal, M., Laaidi, K., Le Tertre, A., Cassadou, S. and Ledrans, M. (2005), "Summary of the mortality impact assessment of the 2003 heat wave in France". *Euro surveillance: bulletin europÈen sur les maladies transmissibles= European communicable disease bulletin,* Vol. 10, No. 7, pp. 153.

Programmadirectie Verstedelijking (2009), "Rijksreferentiekader Verstedelijking, Een overzicht van prioriteiten, ambties en mogelijke rijksbijdragen ter bepaling van de rijksinzet bij de verstedelijingsafspraken 2010-2020", VROM, WWI, V&W, LNV, EZ en FIN.

Raymann, R.J.E.M., Swaab, D.F. and Someren, E.J.W. v. (2008), "Skin deep: enhanced sleep depth by cutaneous temperature manipulation". *Brain,* Vol. 131, No. 2, pp. 500-513.

Ren, C., Spit, T., Lenzholzer, S., Yim, H.L.S., Heusinkveld, B., Hove, B. v., Chen, L., Kupski, S., Burghard, R. and Katzschner, L. (2012), "Urban Climate Map System for Dutch spatial planning". *International Journal of Applied Earth Observation and Geoinformation,* Vol. 18, pp. 207-221.

Rizwan, A.M., Dennis, L.Y.C. and Liu, C. (2008), "A review on the generation, determination and mitigation of Urban Heat Island". *Journal of Environmental Sciences,* Vol. 20, No. 1, pp. 120-128.

Roggema, R. (2009), Adaptation to Climate Change: A Spatial Challenge, Springer, page 309.

Santamouris, M. and Asimakopoulos, D. (2001), *Energy and climate in the urban built environment*, James & James London.

Scherber, K., Langner, M. and Endlicher, W. (2014), "Spatial analysis of hospital admissions for respiratory diseases during summer months in Berlin taking bioclimatic and socio-economic aspects into account". *DIE ERDE–Journal of the Geographical Society of Berlin,* Vol. 144, No. 3-4, pp. 217-237.

Schmidt, M., Reichmann, B. and Steffan, C. (2007), "Rainwater harvesting and evaporation for stormwater management and energy conservation". *2007*, pp. 07.

Schwartz, A. (2013), "Can The Threat Of Climate Change Make Cities Richer And Healthier?": Fast company. Available at: http://www.fastcoexist.com/1682421/can-the-threat-of-climate-change-make-cities-richer-and-healthier.

Shashua-Bar, L., Pearlmutter, D. and Erell, E. (2011), "The influence of trees and grass on outdoor thermal comfort in a hot-arid environment". *International Journal of Climatology,* Vol. 31, No. 10, pp. 1498-1506.

Slabbers, S., Klemm, W. and Verburg, A. (2010), "Proeftuin Den Haag en Arnhem", Ministerie van VROM.

Stadtklima (2008), Climate Booklet for Urban Development Online - Stadtebauliche Klimafibel online, Ministry of Economy Baden-Wuerttemberg

Environmental Protection Department of Stuttgart, Stuttgart.

Steeneveld, G. and Hove, L.W.A. v. (2010), "Een eerste inschatting van het 'Urban Heat Island' effect voor Rotterdam en omgeving: Een modelstudie", Wageningen University and Research centre.

Steeneveld, G., Koopmans, S., Heusinkveld, B., Hove, L. v. and Holtslag, A. (2011), "Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands". *J. Geophys. Res,* Vol. 116, pp. D20129.

Sterl, A., Oldenborgh, G.J.v., Hazeleger, W. and Dijkstra, H. (2010), "Klimaat wereld Extreme maximum temperaturen in de toekomst". Available at: http://www.knmi.nl/cms/content/81151/extreme_maximum_temperaturen_in_de_toekomst.

Tillie, N., Dobbelsteen, A.A.J.F. v.d., Doepel, D., Joubert, M., Jager, W.d. and Mayenburg, D. (2009), "Towards CO2 neutral urban planning: presenting the Rotterdam Energy Approach and Planning (REAP)". *Journal of Green Building,* Vol. 4, No. 3, pp. 103-112.

Van Someren, E.J.W., Raymann, R.J.E.M., Scherder, E.J.A., Daanen, H.A.M. and Swaab, D.F. (2002), "Circadian and age-related modulation of thermoreception and temperature regulation: mechanisms and functional implications". *Ageing Research Reviews,* Vol. 1, No. 4, pp. 721-778.

Verhoeven, A. (1987), *Bouwfysisch tabellarium*, TU Delft.

Voogt, J. 2014. Extreme heat threatens Lives Of World Cup Players. *Urban Climate News*.

TOC