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Heat in the city

An inventory of knowledge and knowledge deficiencies regarding heat stress in Dutch cities and options for its mitigation

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Contents

Executive Summary

Climate change has an effect on human well-being. Weather extremes, heat waves in particular, are occurring more often. Heat waves cause increases in hospitalisation and mortality rates as well as reductions in labour productivity and comfort levels. These effects become apparent with retrospective statistical analysis.

Cities are warmer than their surrounding rural areas. The difference in temperature is greatest at night, especially after sunny daytime conditions, and can reach about 10°C. In winter, this 'urban heat island' (UHI) effect keeps cities warm and therefore saves energy.

Recently, throughout north-western Europe, summers have been extremely hot. During the last six years, six heat waves were recorded in the Netherlands. Public health authorities have mounted special information campaigns to warn vulnerable groups such as the elderly, the infirm and children of the risks of heat stress.

Traditionally, northern and mid-European city buildings are built to withstand cold and are not usually air-conditioned. However, as a result of the recent hot summers, sales of air-conditioners are growing rapidly. What promising options are available that could curb a strong rise in energy consumption for summer cooling in north and mid-European cities?

Summer heat reduction in urban areas can be carried out at various levels, including:
passive energy or energy-efficient cooling equipment;
building materials, roofing and construction;
building orientation and environs: shading, vegetation and pavement;
city planning: building density, parks, ponds, canals.

The construction sector has long been focused on the conservation of heat. Many buildings and blocks have been constructed with the utilisation of passive solar energy in mind. Obviously, solutions for urban heat problems must also take the problems of winter into account. In this report we discuss possible solutions for urban heat in terms of their compatibility with other demands.

For example, increasing the amount of urban vegetation and number of ponds as well as improving heat insulation in buildings could be win-win

options. However, these should be implemented carefully to achieve their optimal benefits and reduce the risk of negative side effects. Increasing solar reflection in an urban area can be done at relatively low cost but this option may have aesthetic considerations as well as a probable impact on safety. It will increase winter energy consumption slightly.

1. Introduction

This report gives an overview of heat stress problems in urban areas of the Netherlands and various options for mitigating this stress. Climate change is causing more occurrences of heat waves. Urban areas in particular will suffer the most, as they are warmer than the countryside.

- What is known about the magnitude of heat stress in Dutch urban areas?
- What are the consequences?
- What research is needed to clarify its effects?
- Which options in particular could do with further study in order to prevent fatalities, maintain comfort levels and avoid increases in energy consumption for summer cooling?

This report aims at identifying:

- the foreseeable problems of urban heat in the Netherlands;
- the specifics (geographic, cultural, economic, technological) that apply to the Netherlands;
- the most promising options for mitigating urban heat; and
- the priorities for further research.

The report is the result of a joint project by TU Delft and SBR called 'Heat in the city' and sponsored by the national research programme, Climate changes Spatial Planning (*Klimaat voor Ruimte*). The project had a twofold aim. Besides identifying knowledge deficiencies and research targets, it was also aimed at identifying 'no regret' options that can be implemented at once since their benefits are already proven.

The report is also based on data culled from a literature study, an international symposium in Amsterdam held on 25-26 October, 2007, and 10 interviews carried out between December 2007 and February 2008. We gratefully acknowledge the cooperation of all the interviewees listed in Appendix B.

Heat, how will it strike us?

Climate change is gradually being accepted as a fact. The world is becoming warmer. The IPCC expects that in the 21st century global average temperatures will rise between 1.1ºC and 6.4ºC. Dutch weather statistics are well in line with this trend. The years 2007 and 2006 were the hottest, ever since weather data has been recorded in the Netherlands. [1, 2]

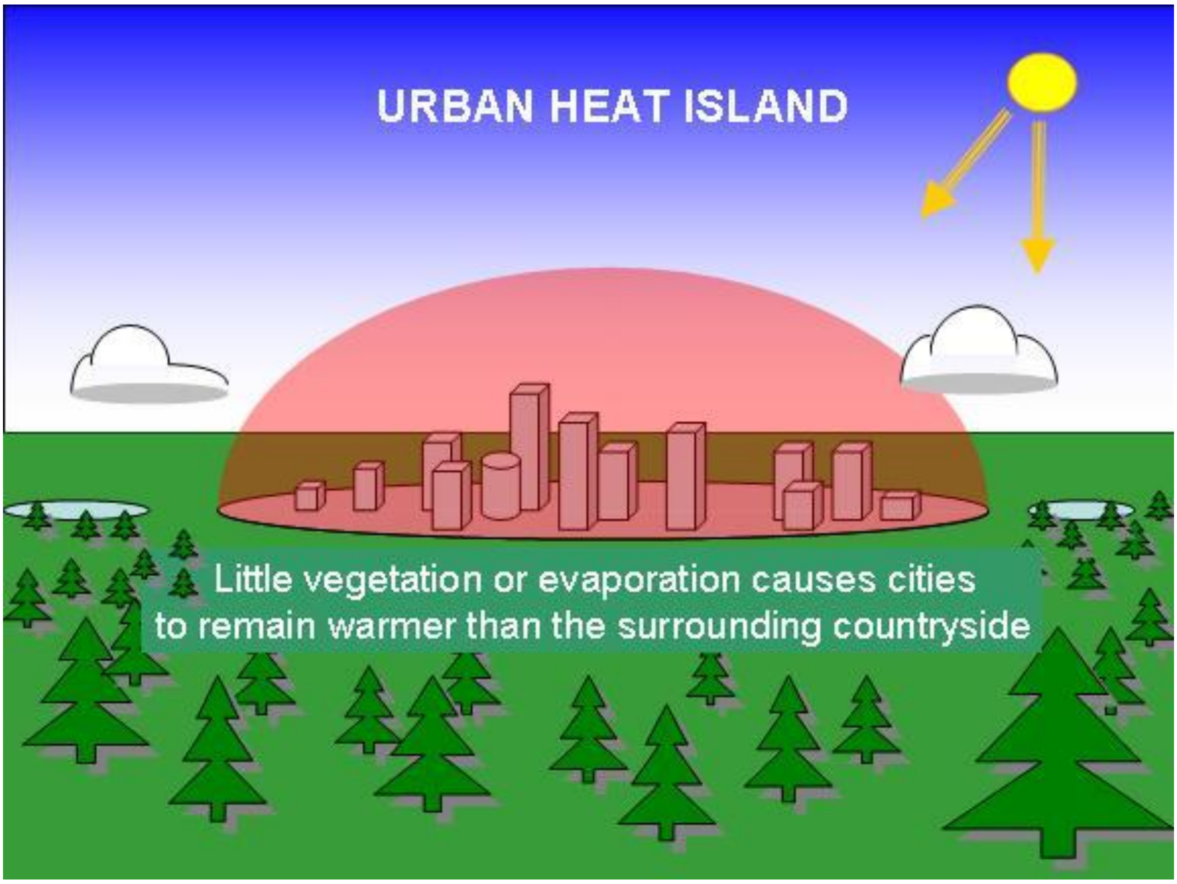
Many Dutch people will prefer a somewhat milder climate. But temperatures do not rise (or fall) at our beck and call. Weather extremes are occurring more often and this includes heat waves.

Since 1901, 38 heat waves have been recorded at the weather station in De Bilt[1]. However, seven have been recorded in only the last decade. [3]
In the Netherlands, the mean temperature generally differs between the northern, south-eastern and western regions by only a few degrees depending upon the season. However, there is also a less well-known temperature variation, and that is the difference between rural and urban temperatures. Urban areas may be considerably warmer than rural areas and as cities are the most densely populated, they are the place where the stressful effects of climate change will affect us most.

1) A heat wave is defined as at least five consecutive days with maximum temperatures of over 25°C, including three days with maximum temperatures of over 30°C.

2. Defining the urban heat island

Dutch weather stations are often situated in the countryside or by airports. Air temperatures measured by weather stations do not include the temperatures found in city centres. Data from other countries show that rural areas often have considerably lower temperatures than downtown areas. This urban heat island (UHI) effect states that cities accumulate heat and consequently are warmer than their surroundings. The effect is most significant during night and can have maximum values of up to 10ºC. [4]



The UHI effect arises because higher levels of solar radiation are absorbed by the materials used in the city than by the natural vegetation and soils of the countryside. Solar heat is stored in the material (the actual amount is determined by the particular thermal capacity of concrete, asphalt, bricks, etc.) and released gradually as infrared heat radiation while cooling down at night. The UHI effect, namely the temperature gap between city and countryside, is at its maximum during the evening and night when the countryside cools down faster than the city because it still retains the heat that has accumulated during the day.

Another cause of the UHI effect is the lack of vegetation in urban areas. Vegetation provides shade and provides cooling by evapotranspiration: shade prevents heat from accumulating and the evaporation of water withdraws heat from the environment. Water bodies such as ponds, canals and especially fountains and cascades stimulate evaporation and thus have an important cooling effect.

A further contribution to the UHI effect comes from the barriers placed to stop winds crossing through the city, which means winds are unable to reach the city centre and blow away its stored heat. Transport, heating and cooling systems as well as industrial activities all add additional heat in the city.

The UHI effect is nothing new. It causes the soil under cities to gradually change its temperature. In general, barren soil temperatures are constant at depths over one meter. If soil is homogeneous and its surface barren, the lowest soil temperature, during summer, is at the depth where the seasons have no further influence. This can be understood by the constant flow of heat from the earth's core to the surface. One effect of the current climate change is that this minimum has moved somewhat deeper. Temperature measurements of the soil under cities confirm urban heat patterns and even reflect some urban history as the depth of the minimum temperature is greatest under the oldest parts of a city. [5, 6]

The UHI effect is well known. It was first documented in the 19th century by Howard (1833) and analysed in depth by Oke (1982) and Landsberg (1981). Since then it has been studied and measured in various cities and with different methodologies all around the world: Atlanta, Athens, Barcelona, London and Seoul are just a few examples. Established in 2000, the International Association for Urban Climate offers guidance for obtaining representative meteorological observations at urban sites. Urban heat data for 2006 have been published by the World Meteorological Association. [7-16]

The case in the Netherlands

The UHI effect has been studied in the Netherlands only up to 1971. In 1975, Conrads defended a PhD thesis at Utrecht University on measurements carried out in the province of Utrecht in 1970-1971. These measurements show that in particular the daily minimum temperatures differ between the city centre and nearby rural areas. In winter the average difference between the daily minimum temperatures was 1.7ºC; in summer the average difference was 2.7ºC. The difference in minimum temperatures (city/rural) during the night measured up to 8ºC at maximum. [17]

There are many reasons for assuming that since 1970-1971 these values may have changed:

- Utrecht has grown, not just in population, but particularly in terms of paved surface and buildings;
- human activity has changed: more traffic, higher energy consumption;
- climate change may also have changed the magnitude of the UHI effect;
- building styles, height, materials and roofing might have changed, i.e. there may be a change in albedo (reflection level) and wind patterns;
- Dutch cities are located fairly close to one another and the countryside is continually urbanising. The on-going growth of cities and villages in the vicinity of Utrecht (e.g. Houten, Nieuwegein, Bunnik, Amersfoort, Hilversum and Zeist) means that 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.

Thus, the UHI effect today could be different (over 40 years since the Conrads study). The city characteristics that Conrads listed in his thesis (p. 17) have certainly changed considerably. The increased amount of buildings and paved surface area might have an affect on urban heat absorption. Increased heat absorption, in combination with changes in air humidity, has a stronger impact on human health.

Since Conrads, only one study relevant to the UHI effect has been undertaken. It was aimed at establishing the long-term validity of the KNMI temperature time series with regard to the UHI effect of Utrecht. New research might provide an opportunity to establish the influence of various city characteristics upon the UHI effect. [18]

3. The impact of climate change on the urban heat island

Climate change is expected to raise temperatures around the world with the magnitude varying according to local circumstances. Global climate change may even strengthen the UHI effect slightly (Brazel, 2007) because natural cooling of the city will become more difficult and the anticipated increase in sunshine hours in summer will increase the inflow of heat by solar radiation. For London, in terms of a medium-to-high emission scenario, Wilby has predicted an increase in the annual mean night-time UHI intensity of 0.26^{o}C by 2080. Although this is considerably less than the anticipated increase for London (3,5 - 4^{o}C maximum) one should be aware that it is an annual average and so the increase of the UHI effect could be far greater during heat waves. Given the increased UHI effect and climate change itself, heat in cities will be a growing problem. [19-21]
With regard to the impact of heat on health there is also an indirect effect as a warmer climate will increase air pollution (summer smog) and as a result it will be more harmful. [22]

The case in the Netherlands
The KNMI has been working on climate scenarios for the Netherlands and continues generating scenarios at the regional level. Average temperatures are expected to rise around 1 - 2ºC by 2050. If wind patterns change (according to scenarios G+ and W+), the total amount of precipitation will probably decrease, having less rain in summer but more during winter. In case winter patterns don't change
(scenarios G- and W-), then total precipitation will increase, especially during summer. In all cases extreme precipitation will be more intense. [23, 24]

Alterra has made an initial review of climate change effects and possible infrastructure adaptations that will be necessary to deal with those effects. The review only marginally analyses the dangers of heat stress and does not regard urban heat as an issue in climate change adaptations. [25]

4. The effects of heat

Heat affects human beings in various respects. To analyse it we distinguish between thermal comfort, that is, the feeling of not being uncomfortable, and heat stress that implies more severe health problems. In addition, there are the detrimental effects of heat on air pollution levels and on plant and animal life. Finally, heat is increasingly leading to peaks in summertime electrical energy demand.

4.1 Thermal comfort

Thermal comfort is the state of mind that expresses satisfaction with the surrounding environment. Several coefficients have been developed to measure thermal comfort for humans. Most coefficients take into account the same four physical variables:

- air temperature
- water vapour pressure
- wind speed
- mean radiation temperature

Thermal comfort is also influenced by individual behaviour and personal characteristics. Clothing, sex, age, activity level and previously experienced temperatures all play a role in the perception of thermal comfort. A common practice for calibrating the thermal comfort value is to interview the population in the place of study.

Many studies of indoor and outdoor thermal comfort have been carried out in recent decades. Hundreds of studies have been done on indoor climate, with stable conditions, and several standards have been published, for example the standard '55' of the ASHRAE, American Society of Heating, Refrigerating and Air Conditioning Engineers. Research in this field continues. Recent models are trying to take into account the psychological effect of temperatures experienced the day before and the possibility for users to control the indoor temperature, for example, by being able to open a window. Having any form of control over their conditions can make people accept a wide range of temperatures. [26, 27]

Not as much research has been done on outdoor thermal comfort. Thermal conditions have a broad range of values which means more variables need to be introduced into the various models that analyse human thermal comfort. Some surveys on indoor comfort are being used to evaluate predictive models of human perception of outdoor thermal comfort. The effort differs substantially from one country to another. Groups working in urban meteorology are usually the ones dealing with this parameter. For example, the University of Kassel and the University of Freiburg in Germany, the University of Bath in the UK and the University of Gothenburg in Sweden all have research groups working on thermal comfort research projects. [28-31]

RUROS, Rediscovering the Urban Realm, was an interesting research project (2001-2004) involving several countries (UK, Germany, Greece, Italy and Switzerland). From the results in the UK and Germany it can be inferred that wind has a large negative influence on thermal comfort in winter. This could be an important constraint in the Netherlands when designing wind corridors for cooling cities in summer heat waves, as easterly winds prevail in our country in both cold and hot weather extremes. [32]

These studies and models have led to the development of guidelines for urban planners, as is shown by the list of possible actions at the city level (see section 5.2 of this report).

4.2 Heat stress

Heat stress arises when temperatures affect people not only psychologically but also physiologically. Heat stress is evaluated with the same physical variables as thermal comfort. It is determined by air temperature and humidity (which has an impact on the ability of the body to release heat by sweating) and solar radiation (which directly heats the body).
Heat stress also depends on a person’s work load as that will determine his or her metabolic heat production. The US Occupational Safety & Health Administration has set permissible heat exposure threshold limit values according to work load.

Work/rest regimen	Light	Moderate	Heavy
Continuous work	30.0°C	26.7°C	25.0°C
75% Work, 25% rest, each hour	30.6°C	28.0°C	25.9°C
50% Work, 50% rest, each hour	31.4°C	29.4°C	27.9°C
25% Work, 75% rest, each hour	32.2°C	31.1°C	30.0°C

*Values are in °C, Wet Bulb Global Temperature.

Table 1. US Department of Labour, Occupational Safety & Health Administration [33]

With regard to temperature-related mortality – the worst effect of heat stress – the optimal outdoor temperature in the Netherlands is 16.5 ºC. There is no fixed temperature beyond which heat stress starts as this depends on various factors but 25ºC can be taken as a general starting point. A period of five consecutive days with a maximum temperature at or above 25ºC, including three consecutive days with maximum temperatures at or above 30°C, is considered a heat wave in the Netherlands (KNMI). [3, 34]

At higher temperatures, the body may be unable to get rid of excess heat. The symptoms are irritability, thirst, exhaustion, dizziness and sometimes muscular spasms. Prolonged subjection to elevated temperatures may induce stroke. The occurrence of these symptoms is not only related to heat. Moisture and wind also play a significant role. [35]

When heat stress occurs, special groups are at risk. These groups are:

- unaware of the problems associated with extreme heat and do not adapt their behaviour or their clothing or do not take in extra fluids;
- unable to move from overheated places;
- babies, young children and ill and elderly people;
- patients suffering from cardiovascular diseases and subject to the additional risk of heart failure.

Heat stress usually starts to become a real problem when people cannot sleep properly for more than three days in a row. Under these circumstances exhaustion may have fatal consequences.

Heat waves

Extreme heat stress under heat wave conditions with dramatic consequences occurred in the US in 1995. The European heat wave of 2003 probably caused more than 80.000 heat-related deaths. Various countries, such as France and England, have developed emergency plans in order to prevent dramatic fatalities arising from heat waves. [36-39]

Six heat waves were recorded in the Netherlands in the period 2001-2006. This is remarkable as there have only been 38 heat waves in the Netherlands in 105 years of recording. In 2003 there were between 1400 and 2200 heat-related deaths and another 1000 deaths during the two heat waves of 2006. The National Heat Plan was updated in 2007 and is mainly targeted at warning the population and specifically at risk groups such as people in hospitals and retirement homes. The Netherlands Board of Healthcare Institutions has also published a report on adaptation measures for dwellings in hot weather conditions. [3, 40-43]

Strikingly, public awareness of the problem is very low in the Netherlands. Our two heat waves of 2006 rated as the world's 5th worst natural disaster in terms of actual deaths. However, few people seem to know of this fact and even fewer tend to worry about it. Compared to the French response to the 2003 heat wave in France – widespread media attention for its high mortality rate and subsequent changes made to government policy – the issue of heat stress is almost completely neglected in the Netherlands.

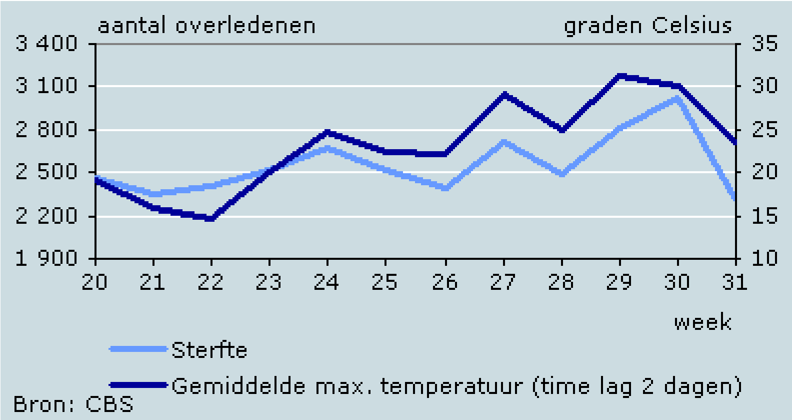


Figure 1. Number of people deceased per week in the Netherlands (x- axis, light blue line) and mean maximum temperature (time lag: 2 days), summer 2006. (CBS web magazine, 2006)

Many people take the excess mortality of heat waves not too seriously as they regard it as a natural ‘harvesting’ (a brief temporal increase of mortality among persons who run a high risk of dying). If this were true, then excess mortality would have to be followed by a decrease in mortality afterwards[2]. This effect can be studied by examining the intermediate and long-term mortality data, rather than concentrating on short-term effects only. The results however are unclear. In terms of air pollution, harvesting has been demonstrated for chronic pulmonary diseases but not for cardiovascular-induced mortality. Research results do not support a harvesting effect induced by heat. A harvesting effect could not be detected in the mortality caused by the French 2003 heat wave. [44, 45]

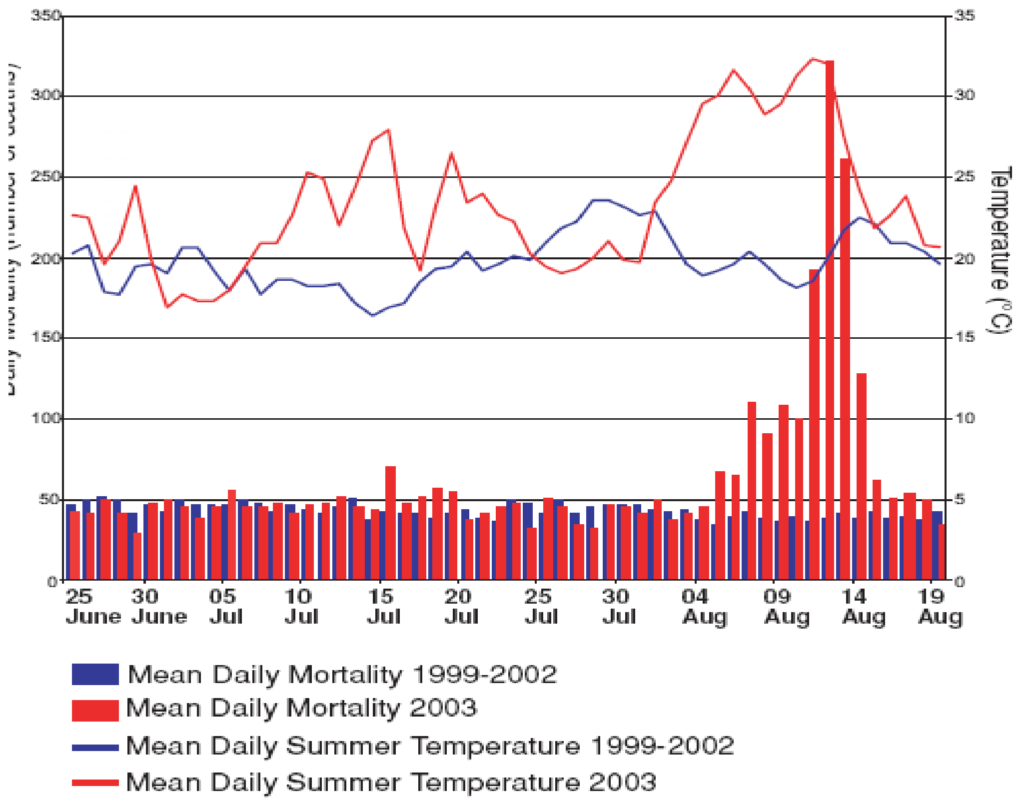


Figure 2. Daily mortality, Paris 2003 (IPCC presentation, www.ipcc.ch)

Increased mortality and greater discomfort are not necessarily directly related to heat: high temperatures cause various changes in human behaviour. In Northern Europe, swimming and sunbathing increase and people spend more time living outdoors. This might have an effect on health. Many studies have analysed the relation between aggression and temperature. To a certain level, aggression grows with temperature

[2] One should of course note that any death at one point in time means one death less later on, as everyone dies once. So, in the long term, there will always be harvesting. In practice, we only speak of harvesting if increased mortality is compensated by decreased mortality within six months.

(especially in combination with other stressors such as loud noises and crowded conditions). However, when certain levels are exceeded, heat leads to lethargy. Establishing the cause of death is crucial for decisions on effective countermeasures. Cooling might only be effective if heat is the actual cause of death. An analysis of various other effects of heat waves on public health can be found in Kirch et al. (2005). [46-48]

4.3 Air pollution

Heat waves often coincide with summer smog (ozone at street level) and increased levels of particulate matter (airborne particles smaller than 10 µm). Hot periods usually coincide with a low wind speed, which normally would disperse and dilute air pollution. This is the main reason for high pollution levels in urban areas, especially particulate matter, that have been recorded during hot periods. [49, 50]

Air pollution effects are estimated to be the cause of some 30-40% of the increased mortality registered during heat waves. Studies from England, France and the Netherlands have all shown figures in the same range. [51-53]

A study on the French 2003 heat wave showed significant ozone levels for those cities that suffered the least from the heat wave. For Paris and Lyon, the cities that most suffered from the heat, air pollution probably only accounted for less than 10% of the heat victims. This appears to indicate that heat plays a more significant role in mortality under more severe conditions of heat stress. [44]

Other factors that are probably important but subject to further study include:

- mortality is not just influenced by outside temperatures. Inside temperatures are important too and are not directly related to outside temperatures. For example, trees cool at street level, but have no effect upon indoor temperatures on the higher floors of apartment buildings. Heat in buildings rises only gradually as there is a certain inertia caused by the mass of the building;

- reduction of night-time temperatures is at least as important as reduction of daytime temperatures, but might require other measures; [54]

- air humidity also plays a role in mortality rates. Higher humidity prevents the skin from releasing heat by evaporation, and so sweat builds up on our skins. The role of humidity in heat-induced mortality is often acknowledged but not clearly quantified in studies. It played a role in the excess mortality of the Chicago heat wave of 1995. A New Zealand study also confirmed its role in Auckland mortality data for 1992-1996. Higher air humidity also means that stimulating evaporation (by vegetation or open water) becomes less effective as the actual air temperatures are too close to the dew point temperature at which evaporation comes to a stop. [55, 56]

4.4 Organic life

Heat has an impact on wildlife with, for example, greater numbers of insects occurring earlier in the year. Some wildlife species could migrate and produce nuisances. Non-indigenous species might survive in colder regions and those able to adapt to an urban environment might flourish in cities due to the UHI effect. Vegetation could also be affected. Abundant vegetation may cause an increase in allergies.

Foto Ad Tijbosch

More bacterial life as result of high temperature can produce increases in food infections such as salmonella, or problems with water storage, such as legionella infections in cooling towers. These problems have not played a significant role in the Netherlands thus far but when we compare our country to warmer regions, it is to be expected that these problems will become more severe. [57-59]

4.5 Energy consumption

The air conditioning market has been growing rapidly in recent years with spectacular growth in southern Europe. Key factors are the simplicity of installation and low prices of small models, usually between 1 and 4kW. In 2007, one million new units were sold in Spain for the household market. The new cooling equipment is increasing the demand for electricity enormously and peaks of electricity demand are moving to the summer period, as has happened in Greece in 2006. [60, 61]

In 1988, Southern California Edison (Los Angeles area) calculated the increase in peak load as 400 MW/°C (225 MW/°F). Akbari et al. (2001) calculated that downtown Los Angeles was 2.5°C warmer than in 1920, and this has led to an increase in electricity demand of 1500 MW. In the USA, mitigation of urban heat islands could potentially save over $10 billion per year in energy use. UHI reduction strategies could potentially lower peak electricity demand by 250 MW in the greater Toronto area, saving 150 GWh annually. [62, 63]

In Dutch office buildings of today, air conditioning is relatively common. Due to high comfort standards, large glass surfaces, the constraints on natural ventilation (security, noise, air currents), and increased heat production in offices (IT equipment), air conditioning is generally needed when outside temperatures rise above 12-15°C. Many office buildings are equipped with reversible heat pump systems; 9597 office installations were estimated for 2006. The annual increase has been up to 30% in the past four years. The air-conditioning market for households is just starting in Netherlands. Some 1% of all households have an air conditioner but this percentage is expected to grow to 3% in a few years. The presence of more than 20 manufacturers of relevant equipment and technology indicates that the sector anticipates further increasing sales. [64, 65]

Summer electricity demand peaks may create new problems. Power stations might be unable to release their cooling water to open water during prolonged heat waves. According to EU Directive 2006/44/EC, thermal releases are forbidden when the water temperature exceeds 28°C (Cyprinid waters) or 21.5°C (Salmonid waters). Temperature differences of thermal discharges may not exceed 3°C (Cyprinid waters) or 1.5°C (Salmonid waters), which means that vast amounts of cooling water are required. As heat waves often coincide with droughts, this amount of cooling water might not be available at inland power stations. [66]

5. Options for mitigating the urban heat island

To mitigate the effects of an urban heat island various options are available:

- reduce the number of surfaces in the city that are exposed to solar radiation by building densely and orientating buildings carefully;
- reduce the heat that is absorbed in the city by increasing reflection levels (albedo) or solar energy conversion;
- improve the natural cooling mechanisms (city and building ventilation, evapotranspiration by vegetation and open water).

Fotografie: Noor van Mierlo, Utrecht

Action can be taken at the building level, affecting mainly indoor comfort, and at the neighbourhood level, affecting mainly the outdoor climate. Measures can also be taken at the city or regional levels, but due to the tremendous investments that may be required, these measures are only relevant when large urban extensions are being planned.

Contributions to reductions in the urban heat island effect can be made on every level, each of which involves different actors participating in the decision-making process. However, one must realise that heat problems occur during a relatively limited period of the year and the impact of anti-heat measures in the remainder of the year should always be taken into account. For example, shading may increase energy consumption during the cold season while stimulating city breezes will create great discomfort during the more windy seasons. Deciduous trees have the advantage that their seasonal rhythm, and therefore their shading and cooling capacity, coincides with city heating and cooling requirements.

Administrative & behavioural measures

Administrative measures are often inexpensive, although not always easy to implement. The ingrained habits of individuals or groups are often hard to influence. Providing information and administrative guidelines could reduce some of the burden. Behavioural measures might be aimed at:

- closing blinds and shutters in time;
- moistening flat roofs in order to stimulate evaporation and solar reflection;
- ventilating buildings during coolest hours and shutting it off during the hottest hours;
- reducing heat production by switching off unnecessary equipment and lights;
- encouraging employers and unions to schedule work breaks during the hottest hours.

One might think a step ahead by considering lifestyle adaptations, which might reduce the number of heat fatalities considerably. As they are more complex behavioural patterns, however, lifestyles are seldom influenced by government policy and even trying to do so might create political controversy.

5.1 Building level

There are various technical options to improve the efficiency of buildings in warm periods. To reduce energy consumption levels, building designs should take into account orientation, insulation, shading and the use of climate-proof materials. Guidelines for energy-efficient design and implementation of this type of building are not new. Several manuals have been published in the last 50 years. An actualised list of thumb rules for the building construction avoiding heat, “Praktijkboek Gezonde Gebouwen”, will be edited for SBR as a complement to this report. [67-70]

The common problem is that buildings are not usually designed to utilise all available options offered by these guidelines because of economical, aesthetical or even social factors. This is why the solutions proposed in this chapter focus first on specific cooling strategies and technologies that offer the best performance and continue with the building infrastructure that offers considerable improvement and can be promoted as a general solution. There is no analysis of the characteristics of building materials, this kind of information can be found in the "Praktijkboek Gezonde Gebouwen" published by SBR.

5.1.1 Cooling strategies

To maintain an acceptable indoor comfort level under hot weather conditions, cooling strategies are needed to remove heat from a building. Passive energy systems are preferred in general as they do not consume energy resources, require little maintenance, and produce no noise. Whenever passive systems are unable to maintain the required conditions, mechanical systems are required.
There are several guidelines on the best cooling systems. Studies on the implementation of energy-saving measures advise installing a good control system that enables the integration of both natural and mechanical cooling systems. Especially interesting because of their plain and simple language are the guidelines published by the Carbon Trust organisation. [71, 72]

5.1.1.1 Natural ventilation

Natural ventilation generally means an open window that admits air currents to cool down an indoor space when it is too hot. This simple strategy nevertheless has many constraints that must be solved before one can take full advantage of its benefits. Openings in the exterior façade must allow for sufficient air inflow and the indoor opening must allow air circulation throughout the entire space. The apertures must not compromise security (crime) or allow the entrance of dirt or rainwater and should support anti-noise insulation. This technique is only useful when the outdoor temperature is lower than the indoor one.
Even considering its long list of constraints, the thermal and economic gains of natural ventilation are still tremendous and thus the best option so far. Not all of its constraints apply, depending on the type of construction. Several strategies, including building design and passive mechanisms, have been developed to avoid its constraints. Psychological studies reveal that if users can open windows for themselves their perceived range of comfortable temperature becomes greater. [73-75]

Under certain conditions, natural ventilation strategies will be insufficient to cover the cooling needs. In this case, it is important to integrate natural ventilation options into the mechanical temperature control strategy. Such a hybrid system (mechanical cooling + natural ventilation) can achieve far greater energy efficiency.

Night ventilation

As natural ventilation is only useful when the outdoor temperature is below the indoor temperature, cooling during the night can be a good solution. This strategy will derive substantial gains if the building has a thermal mass (the capacity to store heat offered by heavy construction materials such as concrete) that allows the maintenance of this cooling effect for some hours of the day. Several studies on the benefits of this technique on all types of buildings have been carried out in various climates proving that this is one of the best solutions in terms of cost per cooling results obtained. [76, 77]

Solar chimneys

Solar chimneys are a way of improving daytime natural ventilation. The simplest design of this type of passive mechanism is a black chimney on a roof warmed by solar radiation. This heats up the air inside the chimney and the suction created at the base of the chimney can be used to ventilate the building.

This ancient technique was already in use in Roman times. In recent years there have been several initiatives to improve the efficiency and the design of solar chimneys. Different roof and wall-chimney models have been developed aiming at integrating a chimney into the building structure. These new designs have been implemented and tested in various locations. [78-80]

Passive downdraught, evaporative cooling

Spraying water from above, scattered pools of water or fountains are ways of using evapotranspiration to cool the insides of buildings. The cooling effect is beneficial in hot arid climates but has some constraints in hot and humid climates. As with the other natural forms of ventilation, this solution has its origins in the olden days. Indoor fountains have long been used in the Middle East. [81, 82]

Nowadays this solution cannot be applied in many cases because it needs a specially configured building that permits the installation of such a system and thus allows the corresponding ventilation. However, in addition to its good cooling performance, water often has a pleasing aesthetic factor that makes it a very interesting option. The performance of evapotranspiration systems has been tested in various buildings and is seen as a really promising option for moderate climates. [83-85]

5.1.1.2 Heat pumps and heat/cold sources

When it becomes impossible to maintain indoor comfort values by natural means, mechanical systems come into play. The mechanical cooling system used most often is the air conditioner, which is in fact a heat pump. The simple version of this machine (cools air indoors and releases heat outdoors) is cheap and produces good results. However, massive use of air conditioners in summer is leading to an enormous increase in electricity demand (cf. section 4.5) and is adding more heat to the outdoor space.

More advanced heat pumps can be used for cooling and heating purposes. The efficiency of heat pumps depends on their working temperature. Highest efficiencies can be obtained with a heat source and heat sink with the smallest possible difference in temperature. Options for reducing the temperature gap include groundwater reservoirs (aquifers) which could be used as a source of either heat or cold. Aquifers and deep lakes, such as Amsterdam's *Nieuwe Meer*, or even sea water, such as water from Scheveningen harbour, could also be used for this purpose as their temperature is higher in winter and lower in summer than the air above them. [86, 87]

During summer, when the source temperature is lower than required, a heat pump system can be run without its compressor, an option known as ‘free cooling’. When the heat load becomes too high the machine will start using the compressor again.

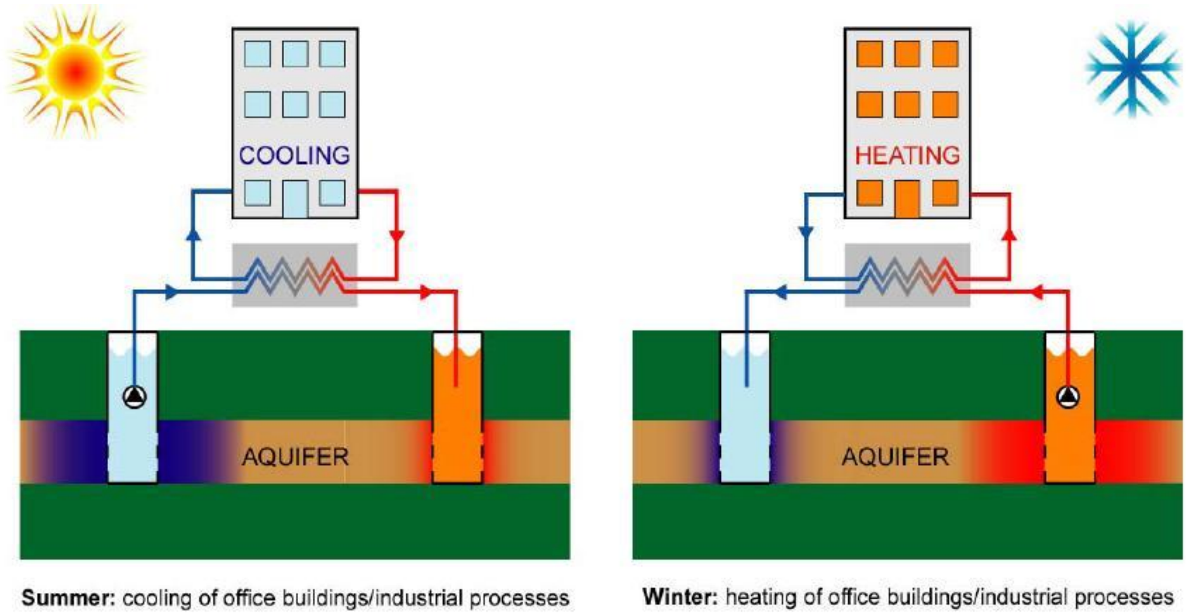


Figure 3. Aquifer thermal energy storage. [88-90]

The aquifer is another interesting option (see Figure 3, above). One can use this system in an open loop, taking in water from one side of the underground reservoir, exchanging the heat and returning the water to another spot. Running such a system creates hot and cold spots, which can be used for thermal energy storage, improving the total performance even more. Aquifers are accessible in most parts of the Netherlands, making them an attractive option.

Two technical specifications must be taken into account:
Water must be returned to the aquifer in the same physical condition. The temperature in the reservoir must not exceed 25ºC because of the risk of an explosion in bacterial life. In the past decade, aquifer systems have been successfully installed in several Dutch buildings, including such offices as the ING Group headquarters in Amsterdam and the Nike headquarters in Hilversum. The pay-back time is approximately five years. [91-93]
The other factor is the sink temperature. If interchangers can provide the same degree of cooling using water only slightly colder than room temperature, then system efficiency can be much improved. Large convectors, such as radiant floors, ceilings or walls (containing the

cooling water) are yet another option. However, radiant systems have constraints as moisture might condense if they are used for cooling. [94]

Heat pumps with fan coils generally work with a higher temperature gradient but can be used for both heating and cooling. New systems with greatly improved performance are available, such as the Fiwihex interchanger developed by dr. Noor van Andel, now being applied in green houses. The claim is that green houses in the Netherlands could become energy producers instead of consumers as they can capture and store excess (summer) solar heat to be used for heating in winter. [95, 96]

Using the heat and cold of heat sources and sinks, one can improve the coefficient of performance – COP, ratio between output (heating/cooling) and input (required electric energy) of cooling and heating systems – from the usual 2-2.5 of air-air heat pumps (e.g. simple air conditioners) to 4-5 for a combined heating and cooling heat-pump system with ground storage.

5.1.1.3 Absorption heat pumps and waste heat sources

Common heat pumps move heat with a compressor that consumes electricity. Absorption heat pumps move heat without a compressor. Instead, this system uses heat to drive its cycle: the heat evaporates water from a salt solution. At the spot where the cooling is needed, water is added again. Dissolving the salt requires heat and so at this point heat is extracted from the surroundings. The system needs no electrical energy to produce cold. The absorption cooler can operate on relatively low-quality heat. In subtropical areas it might, for instance, use solar heat.

Absorption heat pumps have a relatively low COP compared to the heat pumps described above (on average 0.7). This means that heat absorption cooling is only interesting when the heat it uses is freely available or very cheap, that is, waste heat. Industrial waste heat is used sometimes for district heating, but there is no use for this heat in summer time. Absorption heat pumps can be an option to utilise this excess heat for cooling. This option is being studied in several places. An additional benefit might be that a demand for waste heat during heat waves might prove a relief to industry. Waste heat discharge may not be permitted during heat waves (cf. Section 4.5) but if this resource were fed into district heating systems, it would become interesting. [97,98]

Waste heat-fuelled absorption heat pumps in sizes relevant to domestic use are not available on the market. Further development of this technology is an interesting subject for further research.

5.1.2 Insulation and shading

Insulation and shading are main factors that work to improve the passive energy climate performance of buildings. The better a building is insulated, the better its energy performance throughout the year. However, well-insulated spaces must provide ventilation to maintain air quality standards in winter and allow the release of excess heat in summer.

Shading reduces the surface area exposed to solar radiation and thereby reduces heating. Shading is of crucial importance for windows, as solar heat enters but does not escape through them. The inflow of solar heat, combined with the internal heat produced by office machinery, often necessitates the use air conditioners when the outdoor temperature exceeds temperatures as low as 12ºC.

Shading and insulation should therefore be applied in combination. There are numerous possibilities to improve both insulation and shading. In the following section we introduce a few easily applied options that have a large impact on both indoor and outdoor comfort levels.

5.1.2.1 Green roofs

Green roofs offer many benefits:

- good thermal and noise insulation;
- lower albedo;
- vegetation intercepts particulate matter;
- evapotranspiration cools the air; the roof acts as water buffer in that it retains rainwater for a while, helping the city's water discharge system in the case of strong rainfall.

Green roofs affect both indoor and outdoor climates and have positive aesthetic qualities, making them a rather complete solution. Numerous articles from all over the world have analysed the possibilities of this solution. [99, 100] This is a truly transparent solution with a good reputation.

Green roofs are promoted in the United States by hundreds of companies working in the field. 'Green Roofs for Healthy Cities' is a network of public and private organisations whose mission is to increase public awareness of the benefits of green roofs. A web site presents a tool for calculating the energy savings of implementing a green roof. [101]

The Dutch cities of Arnhem, Nijmegen, Utrecht, Groningen, Amsterdam, Rotterdam and Maastricht have shown an interest in promoting this type of roof. The municipality of Rotterdam published a report on it in 2006. The *Vereniging Bouwwerk Begroeners* (Green Roof Construction Association) promotes green roofs nationally. [102, 103]

However, green roofs also have their disadvantages:
a green roof is a heavy component that cannot be placed on most existing Dutch buildings. The majority of dwellings in the Netherlands are rather light constructions. Lighter green roofs do exist but they offer fewer benefits;

- green roofs need maintenance;
- roofs with a steeper slope angle are technically difficult to 'green'. Watering, if needed in dry spells, can be as much of a problem as maintenance;
- fertiliser might be needed to maintain the vegetation, but it might wash out and create eutrophication; [104, 105]
- green roofs are expensive.

5.1.2.2 Cool roofs

Changing the absorption coefficient of the surfaces exposed to solar radiation is an economical solution. Low levels of maintenance are required and there are no problems with weight. However, there is the aesthetic issue and no cooling by evapotranspiration. Adding a layer of paint is an easy and cheap way of changing the albedo of a roof or façade although it will require washing to maintain its reflectivity. Changing building materials is also an interesting option, for example black tiles could be replaced by light red ones.

A list of the albedo properties of different materials can be found on the web site of the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory. The materials used in a roof may strongly influence the temperature difference between roof and air (see Figure 4). [106]

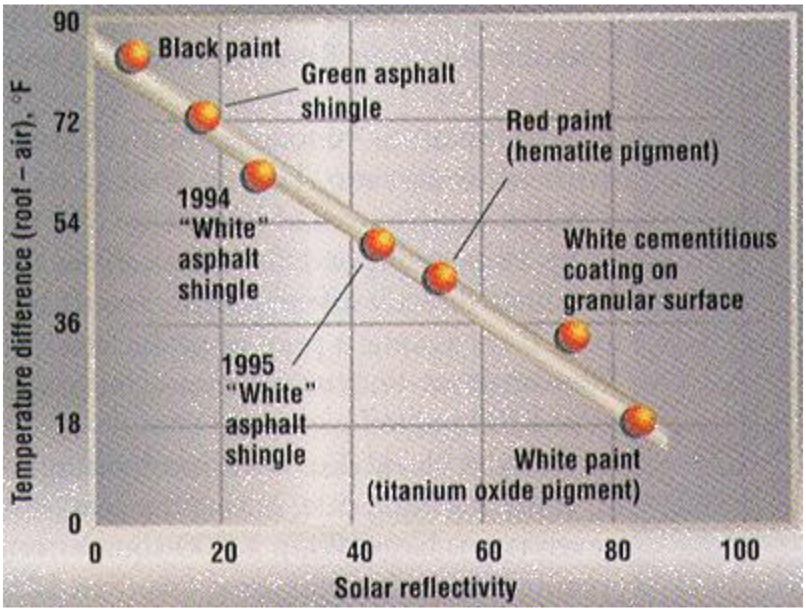


Figure 4. Roof-air temperature differences for materials with solar reflectivity. Solar reflectivity is measured according to ASTM E903. (Source: http://eetd.lbl.gov/Heatisland/CoolRoofs/)

Several studies have been undertaken on the effectiveness and impact of cool roofs, including recent investigations on how to create buildings materials in different colours but with low rates of absorption; some companies have already put some of these products on the market. [107-109]

5.1.2.3 Shading devices

Shading devices over windows prevent overheating. Some shading devices can also be used to provide additional insulation during cold seasons. Placing a shading device outdoors results in better performance than when it is located inside the building. However, the device must be easy to operate and not catch too much wind. Sunshades and awnings have the disadvantage of catching wind, but their main benefit is that they are completely controllable by the user. Static shading devices will not achieve the best shading performance, but might reduce the solar influx without operational and maintenance costs. Blinds offer shade and insulation at required times and don't suffer wind resistance. They can offer security and be operated automatically. Nevertheless this mechanism is implemented far less often in the Netherlands than sunshades and awnings, probably because of social and aesthetic reasons. Curtains are the shading device most often used in Netherlands. These have by far the worst performance but they are readily available everywhere. [110, 111]

It is a common misunderstanding that large south-facing windows are energy-saving. In general, they lose far more heat on overcast winter days than they allow to enter on sunny winter days. They are also the principal cause of overheating on sunny summer days. Proper information on this issue, not only for the general public but also among architects and project developers, may lead to design improvements. The social and organisational patterns responsible for the inadequate utilisation of shading and passive solar energy in the Dutch dwelling sector need to be analysed in order to develop and implement an effective policy for passive solar energy use. [112]

For glass façade buildings, such as offices, the image the building presents is regarded as more important than its energy consumption. Double façades and glass that change transmittance values depending on the radiation values are available options although these are expensive and less effective. [113-115]

5.2 City level

Urban planning strategies can have a large impact on the urban microclimate. The precise impacts of urban planning strategies on a city's microclimate have not been studied and evaluated over prolonged periods. This remains a big challenge for microclimatologists.

Some pioneer cities in the field of climate-proof urban design, such as London, New York, Chicago and Stuttgart, have produced guidelines and reports on the impact of strategies for tackling the urban heat problem. [116-120]

5.2.1 Vegetation

Trees and vegetation offer shade, prevent the pavement from capturing heat, and provide air cooling through evapotranspiration: water transpired by leaves evaporates which takes heat from the air. By the same process, however, air humidity increases, which may lead to discomfort and health problems.

Deciduous trees do not block the heat of the winter sun, which makes them ideal from an energy perspective. Trees have additional advantages in the urban environment, such as capturing particulate matter, reducing noise and making the city look more attractive.

At the same time tree roots can endanger the foundations of buildings and damage roads and other infrastructures. Trees can fall over in storms, attract wild life that may be considered a nuisance and be responsible for increases in allergies. It must be taken into account that green structures in a city require considerable maintenance.

For all these reasons the design process of the green city structure is very important. Choosing the most appropriate type of vegetation and planting locations can optimise the advantages and avoid part of the disadvantages. Unfortunately, one frequently observes that not enough effort is put into the design process of green structures in a city. [121, 122]

Increasing vegetation in a city is not a new concept. In the European overview of the COST C11 action on green structures and urban planning (2005) one can find various experiences dealing with this issue. There exist some guidelines about concepts and recommendations for planning the outdoor space for thermal comfort, but the specific effect of vegetation on urban heat and urban comfort has not been fully studied as there are no thumb rules with quantifications of the effects expected applying this techniques. [123-125]

Green structures are by far one of the best solutions that can be easily applied in a wide range of cities. As is shown in a study by Manchester University, a 10% increase in green space can reduce the surface temperatures in the urban environment by 4ºC [88-90]. Several experiments have been carried out but only a few have been fully analysed or quantified.

Chicago started a greening program in the 1990s and nowadays is the leading city with regard to green building in the United States. [88-90]

5.2.2 Pavements

In the past 50 years, cities around the world have been increasing their paved surfaces. Not only does this mean more roads and streets, but more car parks and more garden terraces. Pavement surface has a greater radiation absorption coefficient then gardens, meadows or barren land and a lower retention capacity. The entire ‘hard’ surface works as a solar collector for the whole city.

Reducing the paved ratio of the city surface is a difficult task to accomplish and has several disadvantages. The alternative is to reduce the heat storage of pavement. The albedo of this surface can be reduced by changing the colour of the materials used or in some cases by changing the materials themselves. This aspect has been analysed in depth by the Urban Heat Island group of the Lawrence Berkeley National Laboratory, United States. [126]

The Netherlands has already seen a change of colour and a change of materials being applied for other purposes, and so these aspects can be implemented. Red-coloured asphalt is commonly used to denote bicycle paths. Lighter colours can also be used (e.g. yellow), however these will get dirty and need cleaning. Naturally, there are aesthetic considerations as well.

In residential streets and parking zones, bricks are the most commonly used and accepted material. Bricks are easy to maintain and stop cars from travelling at high speeds. Brick surfaces have a good permeability that allows water to seep underground. The Belgian Road Research Centre recently finalised a study of brick pavements and similar studies have been done by the Concrete Masonry Association of Australia. Seattle City Council has published guidelines on the construction of green car parks. Vancouver city is promoting permeable pavements and not only for use in car parks. [127-130]

One interesting idea that takes the solar influx of the big black road surface into account uses the road as a solar-energy collector. Water pipes under the road produce hot water in summer and cool down the road surface as well. The technology was developed by Ooms in

Avenhorn and is being applied by *Rijkswaterstaat*. The system is being used to heat road surfaces in winter to prevent road surface damage and accidents as well as the negative environmental effects of spreading salt to melt the snow) and for cooling the surface in summer to prevent heat damage. A ground source heat pump has been added to the system. [131]

Fotografie: Noor van Mierlo, Utrecht

5.2.3 City structure

Depending on the size and placement of buildings, the width of the streets and the geographical properties of the city (mountains, rivers, parks), one can utilise winds and shade to increase comfort. Both wind and shade influence the comfort level of city outdoor spaces.

Winds can be promoted to bring fresh air into the city. Shading keeps summer temperatures down. However, both measures cannot be combined: if buildings are placed close enough to shade one another, they will block the wind from entering the city.

Table 2. Categories of urban geometry and greenness for London. (*Source*: Watkins, 2002)

Category	*Height/Width ratio of street, x*	*Surface*	*Description*
1	$x = 0$	Grass, etc.	Rural fields, or large park, or trees
2	$x = 0$	Hard and grass	Housing near park or field
3	$x = 0$	Hard	Urban derelict or unbuilt area or car park
4	$0 <= x < 0.3$	Hard, very wide gorge	Low-density residential area
5	$0.3 <= x < 0.5$	Hard, wide gorge	Medium-density urban area
6	$0.5 <= x < 1$	Hard, wide gorge	High-density urban area; around focus
7	$1 <= x < 2$	Hard, medium gorge	City centre with tall buildings
8	$x >= 2$	Hard, narrow gorge	Narrow 'back streets' with medium tall (6 storeys) buildings

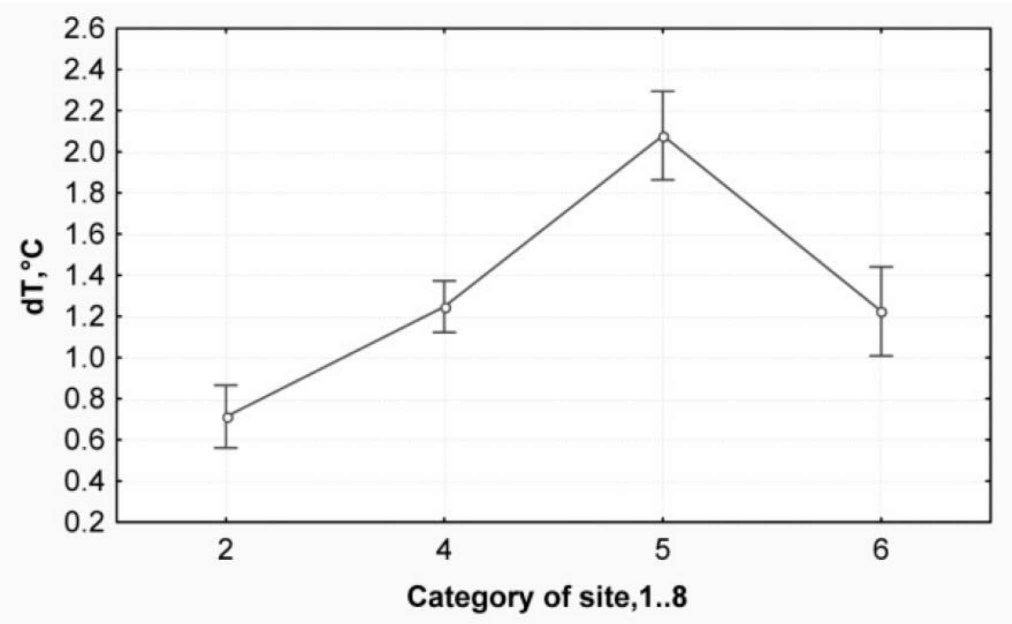


Figure 5. The variation of mean local heat island intensity, dT, in London when measurements are grouped by site category, for a given radial distance (Xr = 2 miles in this example) from the city centre. Summertime daytime data selected for periods that were relatively calm, dry, and sunny. [88-90]

Both wind and shade strategies can be valid and have their advantages and disadvantages. A park-like residential neighbourhood has a low UHI effect similar to a densely built Mediterranean city centre. In the first case, this is caused by the wind and evapotranspiration. In the latter case, this is caused by the narrow street gorges, with plenty of shading and a relatively high canopy. The midpoint of these two extremes is the worst in terms of thermal comfort. The UHI effect, as shown by recent studies in London is worst in residential areas that are caught in between the two extremes: no shading, no wind and no space for trees (see Figure 5, above). This city configuration is commonly found in north-European cities. One possible solution is to reconfigure neighbourhoods in order to combine high building density with parks and green corridors, in an attempt to optimise the effects of wind and shade in the urban area. [20, 132]

Wind

Wind utilisation on the city level depends on the specific characteristics of every single location. Local geographical and structural aspects influence the wind map of a city. Once such a wind map is drawn, it is extremely useful to city planners in the design process, helping them to improve the outdoor climate and preventing the design of uncomfortable open spaces.

Germany has extensive experience in wind-mapping. Stuttgart has carried out several interesting experiments in the field. Nevertheless the results are not transferable to other places as the local geographical aspects will be completely different.

Depending solely on wind-driven solutions probably has severe disadvantages. In the Ruros project, wind was identified as the most disturbing factor to comfort. Using wind patterns to cool down Dutch cities in the summer could actually be detrimental in the cold season. In the Netherlands, as the warmest wind pattern in summer (the usual during heat waves) and the coldest wind pattern in winter come from the same direction, east, it is probably not advisable to enhance winds by introducing open wind corridors in cities. [32, 133]

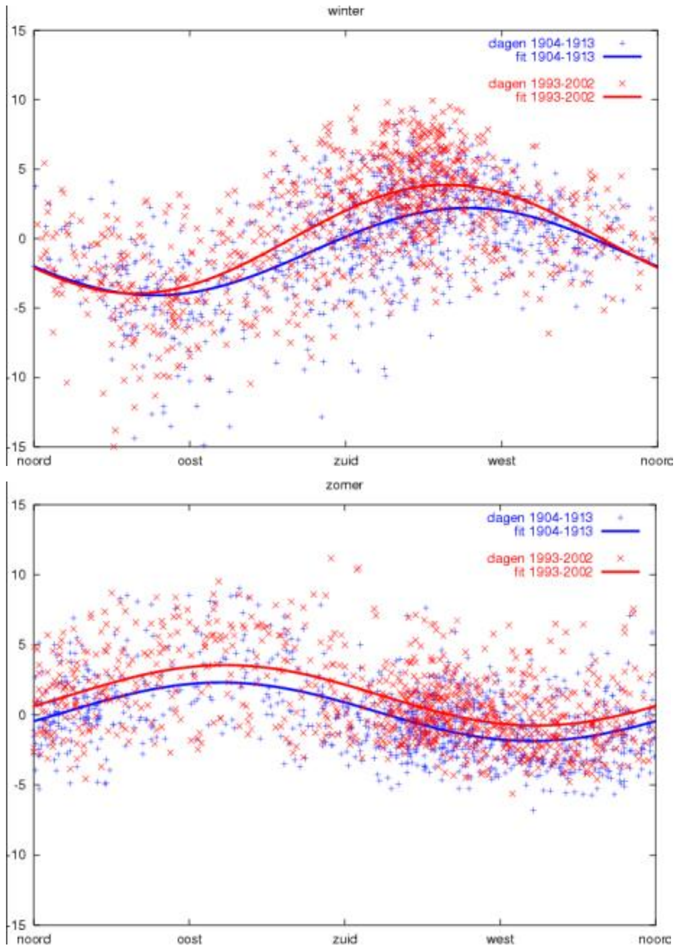


Figure 6. Comparison of mean average temperature of summer and winter days of the periods 1904-1913 against 1993-2002 in the Netherlands depending on the wind direction. [88-90]

Nevertheless, it seems that wind patterns are starting to change, and this is the prediction for two of the four possible scenarios for the Netherlands. The tendency is to have more south-west wind during summer and winter, giving a more moderated temperature all year long and more rain. So even if the wind pattern changes, east wind will bring warmest and coldest temperatures. [134]

Shading

Various shading options are available, depending on the city structure. In low density cities, green structures could be the best option as there is enough space for them. In more dense cities, buildings can shade one another and extra outdoor shading could be implemented. Shading streets with awnings is a common practice in some Mediterranean cities, Seville for instance. This option is used only in the summer and is technically possible only in narrow streets. Some city squares employ this technique by installing a range of shading devices that also have an aesthetic value. In both cases this is a seasonal infrastructure, which can be incompatible with the strong winds that often occur in the Netherlands.

More research on the optimal structure for a climate-proof city should be carried out, taking the specificities of Dutch geography and weather into account.

5.2.4 Water applications

Evapotranspiration cools the air. The effect can be achieved by blueing the city with ponds or by splashing water in fountains or similar devices. The cooling effect of ponds was proven in an experiment in downtown Bucharest. A small pond (4 x 4 m) had a cooling effect of about 1 °C at a height of 1 m, at a distance of 30 meters. The surrounding surface was asphalt and concrete. A fountain in the middle of a square probably has a greater cooling effect on the surroundings. During extreme heat, splashing water in city centres might help to decrease temperatures at street level. [135]

This solution is a commonly used in cities with hot and dry climates. It could be an option in Netherlands too during periods of intense heat when humidity is usually low. Yet it is uncertain whether it can be applied more permanently to reduce city temperatures in summer, as humidity levels in the Netherlands are quite high, and contribute to discomfort. Under these conditions evapotranspiration is less effective.
There is a lack of information about the possible limits of water use for public cooling in humid climates. As this applies especially to the Netherlands, the effectiveness of water for urban cooling and its public health effects are interesting topics to be studied further.

6. The situation in the Netherlands and its implications

Heat-related problems currently receive very little attention in the Netherlands. The death tolls of the 2003 and 2006 heat waves attracted hardly any national media attention, especially when compared with the situations in France, the UK and Germany.

This lack of interest is reflected by an absence of significant research in the Netherlands. The last significant Dutch scientific report on UHI was published in 1975. Since then, only marginal scientific attention has been paid to UHI effects. In Germany and England, countries with a similar climate, various research units have been working on this topic for quite a while. Their experience and results could be very helpful in the Dutch situation.[17]

As recent national data are scarce, there is no actual certainty that our urban heat situation is similar to those found in Germany or the UK. The first priority should be to substantiate the assumption that our UHI effect is indeed similar to the one in London, or in such German cities as Freiburg, Kassel or Stuttgart. A comparative analysis of the data from abroad with the 1970 data on Utrecht might help us to acquire an idea of the impact of urban change on the UHI effect.

In setting up Dutch research into the urban heat problem, it might not be wise to aim directly at catching up with the more experienced research units abroad as we have no leading experts on the subject. Building up our own scientific capacity should be a priority. Legitimising the effort might be made simpler if research were concentrated on the Dutch specificities of the UHI effect, thereby creating a scientific niche. The societal relevance of this investment in new scientific activities would be undeniable if the specifics of the Netherlands situation were made the first priority.

6.1 Geography and weather conditions

Humidity and strong winds are among the prevailing characteristics of weather conditions in the Netherlands. This is caused by the flat geography, proximity to the North Sea and abundance of water in major parts of the country. These factors must be taken into account in the selection of research priorities.

As strong winds are generally considered a nuisance all year around, except during heat waves, urban-planning measures aimed at creating wind corridors would not be acceptable. The role of humidity in urban heat is exceedingly relevant to the Dutch situation and of great scientific interest: evaporation cools the air, but generates higher humidity levels that create discomfort. It would be interesting to study these counteracting effects during a heat wave as then the humidity level is usually low.

6.2 The built environment

The Netherlands has a widespread grid of medium-sized cities, particularly in the polycentric conurbation region of the Randstad. In residential zones we differentiate between two types of city structure: zones of 2-4 storey buildings and zones of taller buildings with green areas surrounding each building. In both cases the buildings offer no shade to each other. Only in the centres of such larger cities as Rotterdam and Eindhoven are there denser zones of tall buildings offering mutual shade.

Buildings of 2-4 storeys usually have a low thermal mass and sloping roofs. Higher residential buildings and offices are usually heavy constructions with considerable thermal mass and flat roofs. Most dwellings have big windows. External shading devices are generally limited to the living room or absent.

Thermal mass (heat storage capacity of structural elements) is an important property to take into account in the design of cooling strategies as many technologies are based on it. The slope of the roof is a constraining factor for green roofs. The limited use of shading devices should be studied further.

6.3 Legislation

All EU countries are adapting their energy efficiency regulations in the building sector to meet the European Energy Performance Regulation of the EPBD. Some countries have employed this process to renew the value of their standards. Other countries have made compulsory the use of simulation software to analyse thermal needs in the building design process. Reports from all EU countries can be found on the EPBD web site. [136]

In the Netherlands, national standards were already close to the parameters demanded by the EPBD and thus needed only small changes. Instead of opting for the compulsory use of software to analyse thermal needs, as implemented in several European countries, the Netherlands chose a simplified analysis of thermal needs together with an analysis of thermal equipment to calculate a certain EPC coefficient. This was done to avoid putting additional administrative demands on an already stressed sector. [137-139]

This legislation has two possible pitfalls that could prevent improvements in the energy performance of buildings. First, the joint analysis of needs and the mechanisms to fulfil those needs permits builders to not insulate their buildings properly and put in highly efficient thermal equipment instead. However, while insulation is permanent, this equipment must be renewed after a while. The second pitfall is the fact that overheating is not getting analysed. The new regulations give some directives on preventing overheating but a thermal simulation is not compulsory and no account is being taken of the effect of climate change.

7. Comparative tables of possible options

Building level	Investment	Comfort improvement	Social acceptance	Applicability	Technical research	Social research
Natural ventilation	Low	High	High	High	Medium	Medium
Heat pumps	Medium	High	Medium	High	Medium	Medium
Absorption HP	High	High	Medium	Medium	High	Medium
Green roofs	High	High	High	Medium	Medium	Low
Cool roofs	Low	High	High	High	Low	Low
Insulation and shading devices	Medium	High	Low	High	Low	High

Investment	monetary investment needed to implement these technologies.
Comfort improvement	thermal comfort improvement
Social acceptance	knowledge and confidence of the general public in regard to these technologies.
Applicability	possibilities to apply these technologies without sever changes on the actual system
Technical Research	Technological research needed to be able to implement these solutions successfully
Social Research	Social studies needed to assure the implementation of these solutions without mistrust of the general public

Block level and city level	Investment	Comfort improvement	Social acceptance	Applicability	Technical research	Social research
Vegetation	Medium	High	High	Medium	High	Low
Pavements	Medium	Medium	Medium	High	Medium	Low
Water applications	High	Medium	?	Low	High	Medium
Neighbourhood structure	High	Medium	?	Low	Medium	Medium
City structure	Extreme -ly High	Medium	?	Low	Medium	Medium

Investment	monetary investment needed to implement these technologies.
Comfort improvement	thermal comfort improvement
Social acceptance	knowledge and confidence of the general public in regard to these technologies.
Applicability	possibilities to apply these technologies without sever changes on the actual system
Technical Research	Technological research needed to be able to implement these solutions successfully
Social Research	Social studies needed to assure the implementation of these solutions without mistrust of the general public

8. What more needs to be known?

This final chapter of the report provides an inventory of current knowledge and knowledge deficiencies regarding heat stress in Dutch cities and various solutions for mitigation of heat stress and enhancement of climate control. This chapter concludes with a summary of suggested topics for further research.

Definition of the problem	
Urban heat island effect	Measurements and analysis of the actual impact of an urban heat island in a Dutch city. Additional study regarding the magnitude of this effect in other locations in the Netherlands.
Heat-effect implications for thermal comfort	Analysis of Dutch specifics, especially humidity levels, and their implications for outdoor comfort levels. Analysis of economic impacts of labour productivity lossess due to heat stress.
Heat-effect implications for public health	Analysis of Dutch specifics, especially humidity levels and their impact on chemical reactions, on public health under heat stress and the targeting of regions and communities at high risk.
Energy consumption	Measurement and forecasting of electricity/energy demand levels due to the increased use of air conditioners. Analysis of heat and cooling storage options and their savings on total energy consumption.

Implementation of possible solutions at block and city levels

Vegetation

- Measurement of the impact of green structures on outdoor and indoor comfort levels.
- Analysis of green structures for optimal outdoor and indoor comfort at various levels (building, block, city and region).
- Analysis of the optimal type of vegetation to be used in the Netherlands to avoid allergies and other possible nuisances associated with green structures in the built environment.
- Analysis of the growth conditions of vegetation in the built environment.

Pavements

- Measurement of the impact of using more reflective pavement materials and analysis of the economical implications.
- Analysis of possible solutions in the pavement sector to increase reflectivity and permeability without compromising functionality and security.
- Analysis of the options for using pavement for energy storage.

Water applications

- Analysis of the possible options for using water to cool down cities.
- Impact of moisture on outdoor thermal comfort.

City structure

- Optimisation of city structure, density, building height, positioning and dimensions of parks for an optimally climate-proof city.

Implementation of possible solutions at building level

Natural ventilation

- Minimum requirements and possibilities of using thermal mass in Dutch constructions.
- Development of methods and mechanisms to facilitate natural ventilation without compromising security and avoiding other possible inconveniences.

Heat pumps and heat/cold sources

- What is the energy capacity of aquifers,
- what are the long-term environmental effects of thermal energy storage in aquifers and
- what legal problems might emerge if aquifer usage increases?

Absorption heat pumps and waste heat sources

- Improving the performance of the absorption heat pumps.
- Analysis of the economical and technical viability of using absorption heat pumps in a waste heat-based district-heating grid.

Green roofs

- Adaptation of green roofs to light Dutch constructions with sloping roofs.
- Environmental analysis of the maintenance and operation of a green roof.

Cool roofs

- Estimation of operational costs and aesthetic effects of mass implementation of cool roofs.

Shading devices

- Analysis of the most appropriate strategy to promote the use of external shading devices in the Netherlands.

General subjects for further study:

These research questions are important for making Dutch cities climate-proof. However, not all of them are equally scientifically challenging. Some questions could be considered to belong in the public domain, while others could be seen as the responsibility of private industry. More general questions that could be considered a public responsibility include:

Microclimatology and public health:

There is a clear relationship between outside air temperatures and mortality. However, the causalities behind this relationship are only partially known. Clearly, air pollution (partly caused by sunshine and higher temperatures) plays a role. Hot weather results in behavioural changes (outdoor life, aggression, travel, sun bathing, outdoor dining) that may result in higher mortality and cause increases in microbiological activity. It is crucial to establish the causalities between temperature and mortality as only then effective adaptation and mitigation measures might be designed.

Spatial planning and public spaces:

There are two distinctly optimal conditions for heat-resistant cities:
The *wealthy suburb*.

> A green, open and park-like city where the vegetation, ponds and winds bring cooling. Obviously, this option takes up lots of space.

The *Mediterranean city*.

> The classic Mediterranean city had a high building density with buildings of more or less the same height. In effect, the canopy of this city was almost closed. Hence, solar heat did not reach down to street level. Unfortunately, this urban pattern is disappearing as air-conditioning can cool any building that would have been too hot in the past.

The challenge lies in combining areas with higher densities and a closed canopy with attractive green structures.

- Can low-energy urban districts be created that are both attractive and provide thermal comfort?
- On which level should this be applied?
- How do you integrate this with the demands of modern society (traffic, shopping, etc.)?
- What side effects might occur?

- Are options available for existing cities?

Fostering innovation. Innovation is not just a matter of developing technological solutions to single, well-defined problems. Particularly with regard to urban heat, ‘solutions’ often have to be balanced against other demands. The building sector has to cope with both public and non-public stakeholders. Architects are limited by financial restrictions. Strong paradigms lead the design activities of both architects and urban planners. Scope for experiment at neighbourhood or suburban level is extremely limited. Most importantly, there is little sense of urgency in the Netherlands to prepare the built environment for more frequent occurrences of catastrophic heat waves. The question remains: how do you implement solutions that mitigate urban heat?

Appendix A. List of research organizations in the field

Various research organisations are investing resources in factors that affect the UHI phenomenon. This list is not exhaustive but it is representative of the kinds of organisations involved.

Dutch organisations

Climate and Biosphere Centre, Wageningen UR www2.wau.nl/ccb

Energy Research Centre of the Netherlands www.ecn.nl

EPBD, Energy Performance of Building Directive, Dutch implementation www.epbd.nl

Klimaat voor Ruimte, www.klimaatvoorruimte.nl
National Research Programme on Climate Changes and Spatial Planning

KNMI, Koninklijk Nederlands Meteorologisch Instituut www.knmi.nl
National Meteorological Institute

SenterNovem, www.senternovem.nl
Agency of the Dutch Ministry of Economic Affairs to promote sustainable development and innovation.

TNO, Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, www.bouw.tno.nl
The Netherlands Organisation for Applied Scientific Research includes a group focused on Building and Construction Research.

European Organisations

Belgian Building Research Institute (BBRI), Belgium www.bbri.be

Belgian Road Research Centre (BRRD), Belgium www.brrc.be

Carbon Trust, UK. www.carbontrust.co.uk
A private company set up by the UK government to reduce carbon emissions. One of its activities is the edition of guidelines to achieve energy efficiency in various processes, including the building sector.

Centre Scientifique et Technique du Bâtiment (CSTB), France
www.cstb.fr
Research Institute for Building Technology in France.

Energy Performance of the Building Directive, Buildings Platform, Europe
www.buildingsplatform.org
European web site of the EPBD directive with reports on the experiences of all European countries.

Fraunhofer Institute for Building Physics (FhG-IBP), Germany
www.ibp.fhg.de

UK Climate Impacts Programme (UKCIP), U.K. www.ukcip.org.uk
This UK government organisation has a good database on articles in this field.

Non-European Organisations

Air Infiltration and Ventilation Center (AIVC), international www.aivc.org
Offers industry and research organisations technical support aimed at optimising ventilation technology.

American Meteorological Association, US www.ametsoc.org
Database of articles from several meteorological journals, with numerous entries in UHI studies.

C40 cities. www.c40cities.org
Group of cities committed to tackling climate change. Really interesting list of best practices.

Environmental Protection Agency (EPA), US www.epa.gov/heatisland
This US government agency has a line of research on the UHI. A pilot project is running across five cities, and all sorts of guidelines can be found on their resources.

International Association for Urban Climate, international www.urban-climate.org

Solar Heating and Cooling Programme of the International Energy Agency www.iea-shc.org
Established in 1977, this agency has a long list of interesting publications dealing with all sorts of solar technologies for heating and cooling purposes.

Heat Island Group, Lawrence Berkeley National Laboratory
http://eetd.lbl.gov/HeatIsland/

Companies working in the Netherlands on topics related to UHI

ARUP, UK www.arup.com
Build Desk, Netherlands www.builddesk.nl
Deltasync, www.deltasync.nl
DHV Engineering Company www.dhv.nl
IF Technology, ground source heat pumps www.iftechnology.nl
ES Consulting, green structures www.es-consulting.nl
Roofs & Garden, www.roofengarden.nl
Ooms Nederland Holding bv, civil engineering and building construction.
Pavement experts www.ooms.nl
Kristinsson, architects and engineers, www.kristinsson.nl
Techniplan, engineering www.techniplan.nl

Appendix B. Interviewees involved in this study

For the making of this report many people from various institutions and companies were interviewed in the period from December 2007 to February 2008. We gratefully acknowledge the cooperation of all our interviewees.

- Arian de Bondt, R&D manager, Ooms Nederland Holding.
- J.J.M. Cauberg, managing director, *Cauberg-Huygen Raadgevende Ingenieurs* (Engineering Consultants) and Climate Design & Sustainability professor, TU Delft.
- Andy van den Dobbelsteen, assistant professor in Climate Design & Environment, TU Delft.
- Frans Duijm, Groningen Health Service.
- Anke van Hal, professor in Sustainable Housing Transformation at TU Delft.
- Bert van Hove, researcher in the Environmental Sciences Group at Wageningen UR.
- Pieter-Paul de Kluiver, director/senior consultant at ES Consulting.
- Stanley R. Kurvers, researcher in Climate Design & Environment at TU Delft.
- A.C. van der Linden, assistant professor in Climate Design & Environment at TU Delft.
- Hans Phaff, researcher in the Built Environment and Geosciences Group at TNO.
- Cees Plug, specialist binder/asphalt mixtures, Ooms Nederland Holding.
- Hanneke van Schijndel, environmental, energy and services consultant at ARUP.
- Henk Swaagstra, directeur/senior consultant at ES Consulting.

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