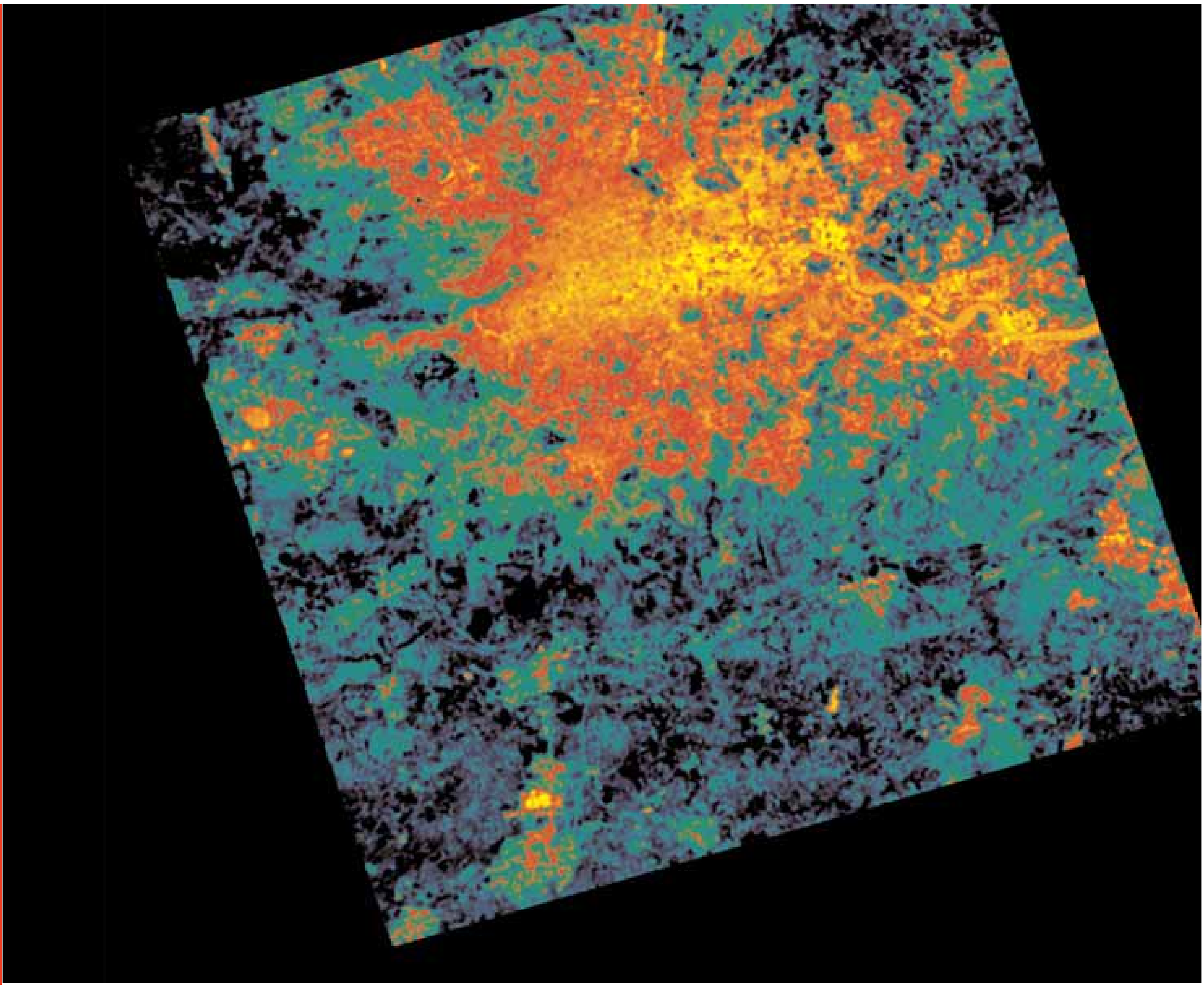
MAYOR OF LONDON

London's Urban Heat Island: A Summary for Decision Makers



October 2006

MAYOR OF LONDON

London's Urban Heat Island: A Summary for Decision Makers

October 2006

copyright

Greater London Authority
October 2006

Published by
Greater London Authority
City Hall
The Queen's Walk
London SE1 2AA
www.london.gov.uk
enquiries **020 7983 4100**
minicom **020 7983 4458**

ISBN 10: **1 85261 932 5**
ISBN 13: **978 1 85261 932 9**

The research for this report was undertaken by :
King's College London
Arup
London School of Hygiene and Tropical Medicine
University of Birmingham
Brunel University
Arizona State University

Copies of the report can be downloaded from:
www.london.gov.uk/mayor/environment/climate_change/

Cover image:
MODIS Satellite Infra-red photo of London at 21:43, 28 July 2006

Foreword

Cities not only play a large role in contributing to climate change through their green house gas emissions, but are also highly vulnerable to the consequences of a changing climate. We have experienced two heat waves in the past three years that have negatively affected the city's economy and the health of Londoners. It is predicted that by the middle of the century, most summers in London may be as hot as the 2003 heatwave.

This report is an important first step in understanding the relationship between London's microclimate, development and the predicted changes to our climate.

My vision is to make London an exemplary, world class and sustainable city. It is essential that we address the Urban Heat Island through better planning and design – new development should not intensify the problem, opportunities to offset the Urban Heat Island should be taken, and our vulnerable communities should be safeguarded.

This means that our new development needs to be designed for the climate of the future, and that it does not contribute to warming London further.

Ken Livingstone
Mayor of London

London's Urban Heat Island: A Summary for Decision Makers

Introduction

This is the summary report of a technical study, commissioned by the Mayor to investigate London's Urban Heat Island. An inter-disciplinary team of climatologists, meteorologists, geographers, engineers and public health experts have contributed to the study. The report is aimed at 'decision makers' - planners, architects, urban designers, developers and public health care professionals.

Climate change will mean that London experiences warmer, wetter winters and hotter, drier summers, with more frequent and more extreme weather events, such as heat waves, wind storms and tidal surges. Average summer temperatures are predicted to increase by 2.5 to 3.0°C by the 2050's under a high CO_2 emissions scenario whilst the number of 'hot' days (>30°C) will increase by 5-10 days per year. By the middle of the century, 'heat wave' temperatures, such as those experienced during the 2003 summer will be an average summer.

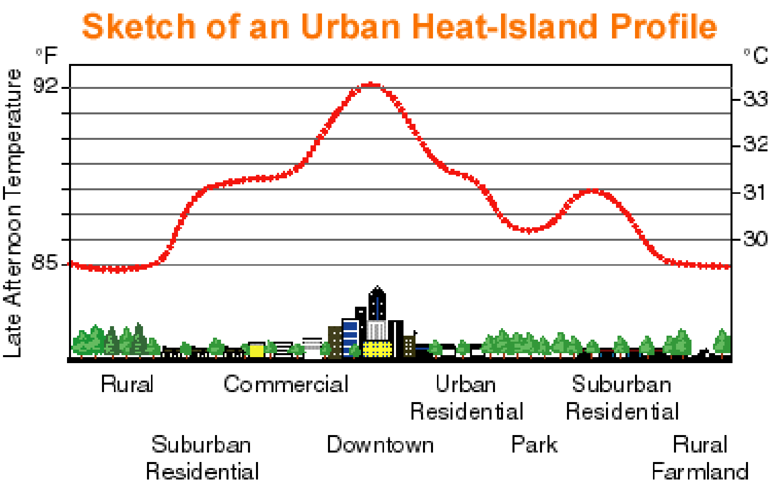
London is particularly vulnerable to high temperatures – our homes, workplaces, public buildings, public realm and transport infrastructure are not designed for high temperatures. Hot weather places additional stress on the body, raising health risks for the vulnerable and increasing discomfort for everyone. London's growth over the next decade needs to ensure that new development is located, designed and constructed to minimise, and if possible reduce it's contribution to London's urban heat island.

What is the Urban Heat Island ?

As many city residents know it is often warmer in the city than in surrounding rural areas during hot fine weather, especially at night. This phenomenon is referred to as the 'Urban Heat Island' (UHI). The UHI describes the increased temperature of urban air compared to its rural surroundings.

The term 'heat island' is used because warmer city air lies in a 'sea' of cooler rural air. Figure 1 shows an idealised heat island profile for a city, showing temperatures rising from the rural fringe and peaking in the city centre. The profile also demonstrates how temperatures can vary across a city depending on the nature of the land cover, such that urban parks and lakes are cooler than adjacent areas covered by buildings.

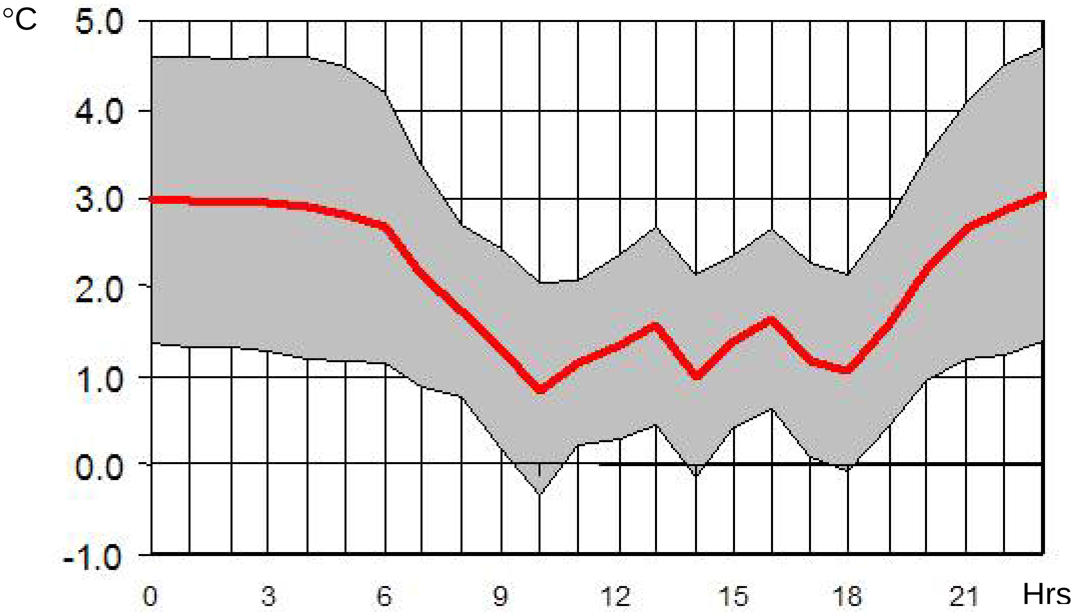
Figure 1.



The urban heat island is caused by the storage of solar energy in the urban fabric during the day and release of this energy into the atmosphere at night. The process of urbanisation and development alters the balance between the energy from the sun used for raising the air temperature (heating process) and that used for evaporation (cooling process), because the cooling effect of vegetated surfaces is replaced by impervious engineered surfaces.

The strength of the urban heat island is measured by the 'urban heat island intensity', which describes the maximum difference in temperature between urban and rural locations within a given time period. The highest values of the urban heat island intensity, in the region of 6-8°C, are often reached between about 11 o'clock at night and 3 o'clock in the morning (Figure 2). This is why the urban heat island is often referred to as a nighttime phenomenon. UHI intensities are also greater in summer than winter because of contrasts in the amount of energy received from the sun, which is absorbed by the urban surface during the day and released at night. The urban heat island keeps London warmer in winter – this can be seen in how spring occurs earlier in London and snow settles less often.

Figure 2: The variation in the UHI intensity for London over 24 hours for summer 2000. The solid red line indicates the average UHI intensity by hour while the shaded area shows the range of UHI intensity values for 68 percent of the observations.

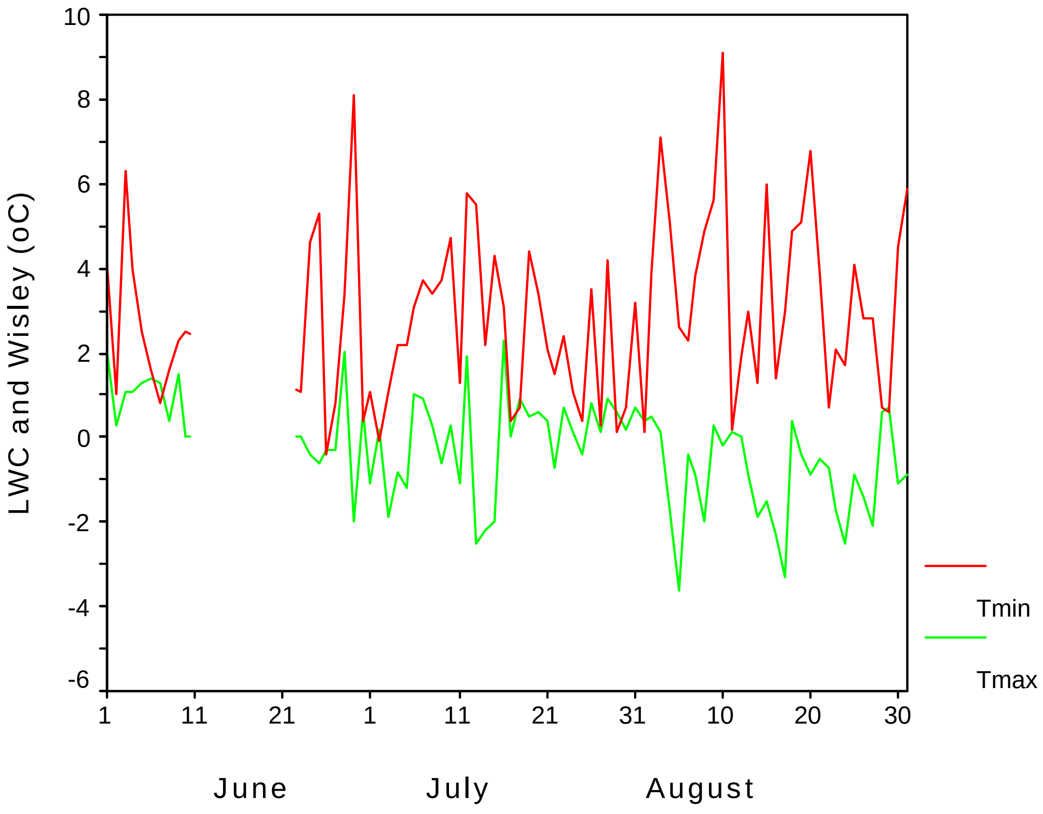


What is the Evidence for London's Urban Heat Island ?

London's UHI was first 'discovered' at the turn of the 19th century by Luke Howard, who is widely known as the man who named the types of clouds. Over the course of 9 years he noted an UHI effect of approximately 2°C (warming) during the night and -0.2°C (cooling) during the day. By the middle of the 1960's an average difference of 4-6°C in nocturnal temperature between the central city of London and its surroundings was evident. More recently urban climatologists have noted extreme UHI intensities in excess of 7°C. For example during the August 2003 heat wave, the UHI intensity reached 9°C on occasions (Figure 3).

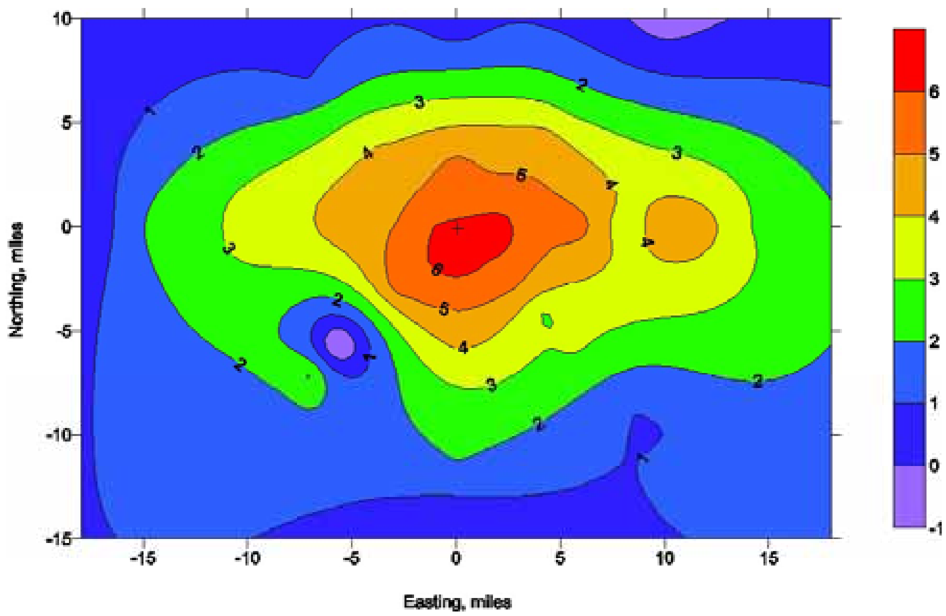
Figure 3: The difference in minimum (Tmin) and maximum (Tmax) temperature between the London Weather Centre (LWC) and the rural reference site of Wisley.

Positive values indicate that London is warmer than Wisley, while the negative values indicate that London is cooler than Wisley. As measured by nighttime minimum temperatures, the graph shows that at night during the very warm summer of 2003, temperature differences between the city and the rural reference site Wisley, reached around 8-9^{o}C on a number of occasions. Interestingly, during the day maximum city temperatures on many days were below those of the rural site. This effect was probably due to daytime shading effects and storage of solar energy in building materials (therefore not available for raising daytime temperatures).



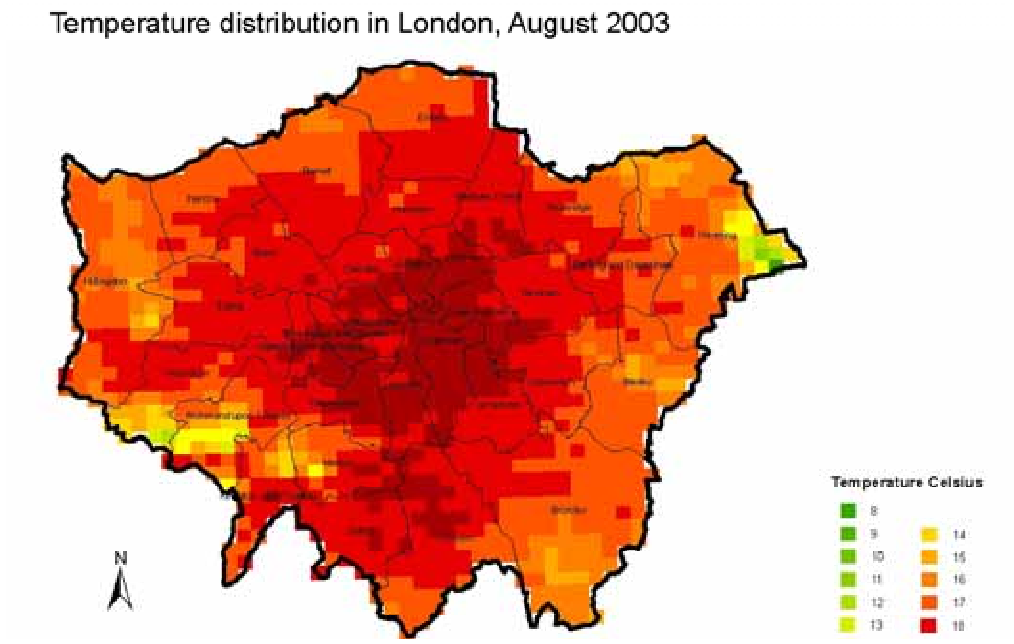
As well as measurements of the UHI intensity based on air temperature observations at a single urban and rural reference station, evidence for London's UHI comes from special observation programmes designed to map the spatial pattern of the UHI. Figure 4 shows the average pattern of the UHI across London at 0200-0300hrs for a series of calm dry nights during the summer of 2000. It is immediately apparent that there is a 'core' of the UHI located southeast of the British Museum where the average UHI intensity for six nights reached in excess of 6^{o}C. This area of high UHI intensity values coincides with the nucleus of high-density development in central London.

Figure 4: The pattern of air temperature differences between a rural reference climate station and a number of urban climate stations located across London under calm and dry conditions at 0200 – 0300hrs for six urban heat island events during the summer of 2000 (July 1st to September 30th). The central cross hairs indicate the location of the British Museum. The intensity in the central London area rises to around 3 °C, while Richmond Park (dark blue area below left) is about 1 °C cooler than its surroundings and similar to the rural reference.



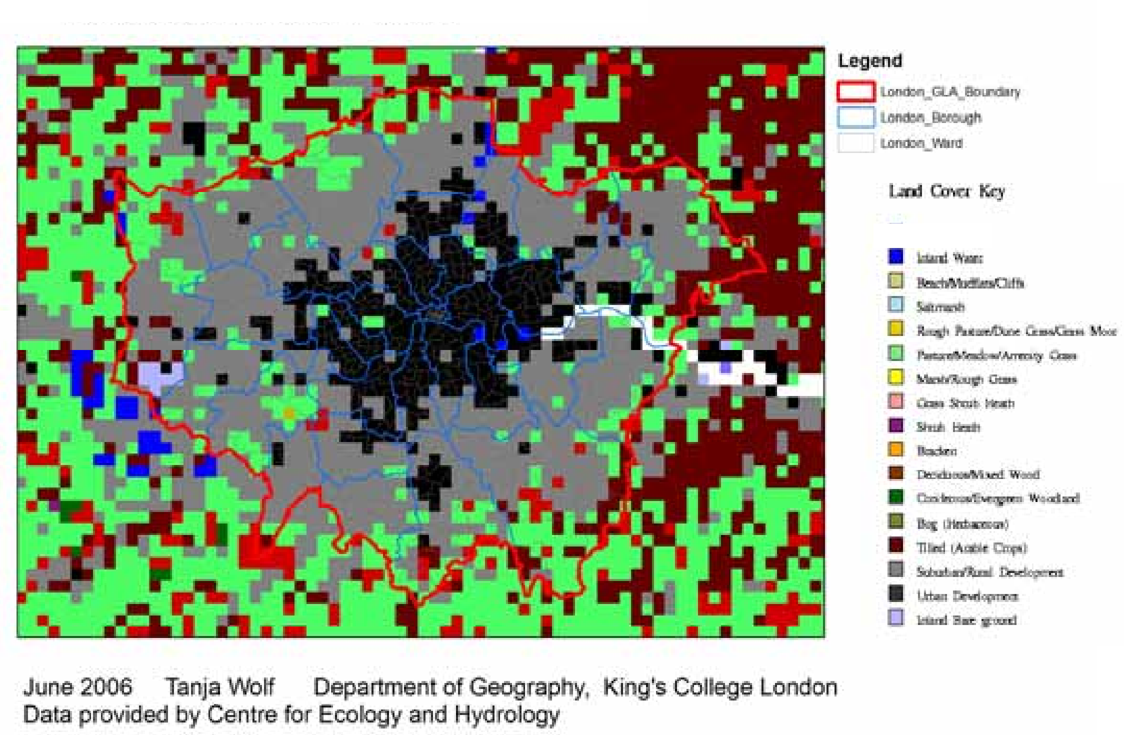
An alternative view of London's UHI can be gained from the analysis of surface temperatures as measured by infra-red cameras located on satellites. Figure 5 shows one such realisation of the surface UHI as recorded by the MODIS satellite on August 7, 2003 at 2130hrs during the August 2003 heat wave.

Figure 5: Distribution of surface temperature for 1km^2 grid squares across London at 2130hrs on August 7, 2003.



The association between high surface temperatures and high density, continuously developed areas across London (Figure 6) is clearly evident. The relatively cool areas to the southwest of the core of high surface temperatures coincide with the large open and green spaces of Richmond Park.

Figure 6: Land cover distribution across London.



What are the Principal Causes of the Urban Heat Island ?

The UHI is an ‘inadvertent’ modification of the climate, caused by changes to the form and composition of the land surface and atmosphere. When a land cover of buildings and roads replaces green space, the thermal, radiative, moisture and aerodynamic properties of the surface and the atmosphere are altered. This is because urban construction materials have different thermal (heat capacity and thermal conductivity) and radiative (reflectivity and emissivity) properties compared to surrounding rural areas, which results in more of the sun’s energy being absorbed and stored in urban compared to rural surfaces. In addition, the height of buildings and the way in which they are arranged affects the rate of escape at night of the sun’s energy absorbed during the day by building materials. The result is that urban areas cool at a much slower rate than rural areas at night, thus maintaining comparatively higher air temperatures. Urban areas also tend to be drier than their rural counterparts because of the lack of green space, a predominance of impervious surfaces and urban drainage systems, which quickly remove water from the urban surface. This combination of effects alters the energy balance of the urban environment. Consequently in urban compared to rural areas, more of the sun’s energy absorbed at the surface goes into heating the atmosphere and thus raising the air temperature than into evapotranspiration (water uptake and loss by plants), which is a cooling process.

The manner in which some of the critical urban surface characteristics affect air temperature can be investigated by conducting a number of theoretical experiments using a computer model of the urban energy balance. For example Figures 7 and 8 show the outcomes for air temperature of varying levels of moisture and surface reflectivity (albedo) on the third day of a period of fine weather. The effects of moisture are clear with lower temperatures projected for moist compared to dry surfaces. Albedo also has a significant impact on air temperature with high air temperatures associated with dark low albedo surfaces such as tarmac.

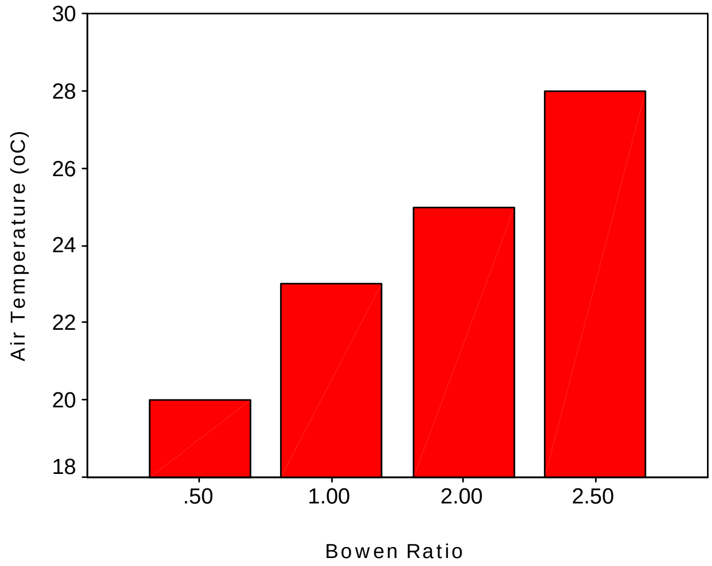


Figure 7: Theoretical changes in air temperature for a range of moisture conditions at 1200hrs on the third day of a spell of fine weather. Moisture is represented by the Bowen Ratio - the ratio between sensible (energy used for raising air temperatures) and latent (energy consumed in the process of evaporation) heat. A Bowen Ratio value of 2.0 means that twice as much of the energy available at the surface goes into heating the atmosphere as does into carrying out the process of evaporation (a cooling process). High values of the Bowen Ratio therefore imply limited availability of moisture at the surface (dry conditions).

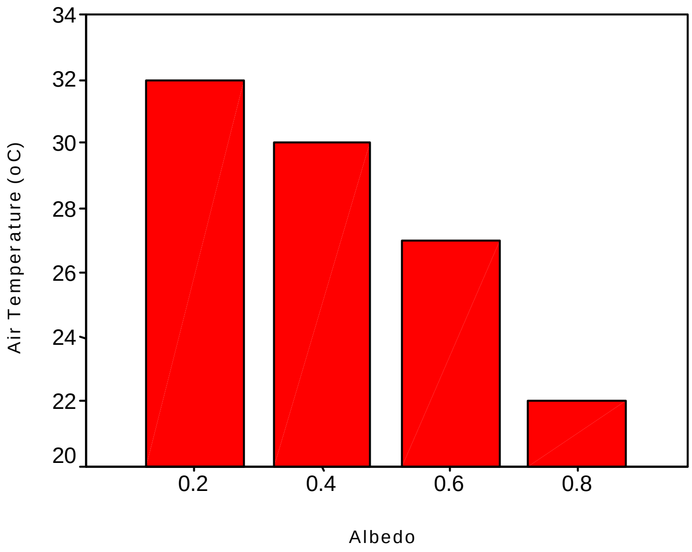


Figure 8: Theoretical changes in air temperature for a range of albedo conditions at 1200hrs on the third day of a spell of fine weather. High values of albedo mean that much of the incoming energy from the sun is reflected back into the atmosphere. This means that low albedo or non-reflective surfaces, absorb large amounts of energy from the sun. The energy is usually held or stored in the upper layers of the absorbing material and later released once air temperatures become less than the surface of the absorbing material (often after sunset).

Although the primary supply of energy to urban and rural surfaces is from the sun, urban areas potentially have a further source of energy in the form of heat produced by human activities. Often referred to as anthropogenic heat, this comes from activities such as transport, industrial processes and air conditioning. In some cities this can be a significant extra source of heat intensifying the urban heat island. Further study is required to determine the exact anthropogenic impact on London's heat island.

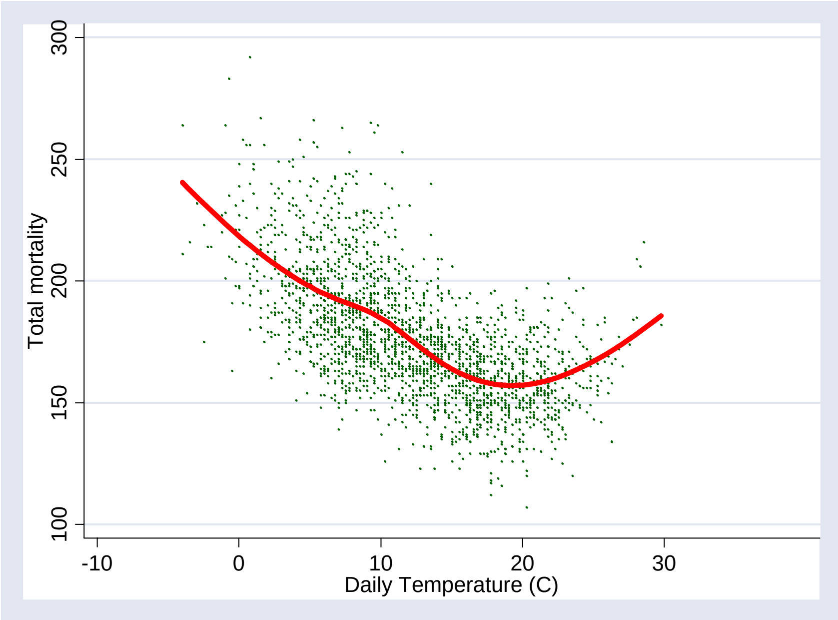
A further minor contributing factor to the urban heat island is air pollution. This is because a heavily polluted atmosphere may act to produce a local greenhouse effect.

The maximum affect of the UHI causative factors described above is achieved in calm clear conditions during very warm periods with a plentiful supply of solar radiation during the day. Under such conditions, as occur during periods of anticyclonic weather, maximum values of the UHI intensity are experienced.

What are the Main Environmental and Socio-Economic Consequences of the Urban Heat Island ?

During extreme weather events such as heat waves, the urban heat island has the potential to prevent the city from cooling down, maintaining nighttime temperatures at a level that affects human health and comfort. This is reflected in the relationship between daily temperature and mortality in London (Figure 9) as high nighttime temperatures contribute to high overall daily temperatures. During the heat wave events experienced across southeast England in August 2003 and July 2006 nighttime temperatures in London were 6-9^{o}C higher than those recorded for rural locations south of London

Figure 9: The association between daily average temperature recorded at Heathrow airport and total mortality in London. The effect of heat on mortality in London is first apparent when daily mean temperature is around 20-23°C (Source: Hajat et al., 2002).



Living in high-density urban areas, such as London, may be an important risk factor for heat related mortality and morbidity. The effects of the 2003 heat wave were greatest in London in terms of the number of deaths per head of population, especially amongst the elderly (overall there were approximately 600 all-age extra deaths in London). There is emerging evidence that UK urban populations show greater sensitivity to heat effects compared to rural regions. Many of the 2003 summer excess deaths that occurred across London during the August heat wave event may be attributable to the urban heat island effect. The evidence from the August 2003 heat wave is supported by international examples. Analyses of the 1995 Chicago heat wave have shown that the relative risk for a heat-related hospital admission in the city was much higher than in the suburbs. In 2003, heat wave mortality was greater in urban compared to suburban areas in Switzerland.

The consequences for the health of Londoners during such extreme heat island events can be severe with increased chances of heat stroke, physiological disruption, organ damage, and even death (Figure 10). A review of the literature on the factors that affect heat vulnerability has shown that the key determinants of vulnerability to heat are:

- *Age*: The greatest effects of heat and heat waves are in the elderly, in both absolute and relative terms. Excess death rates of the elderly in London increased by 45 percent compared to 17 percent for England and Wales. However, there are important differences in vulnerability within this group
- *Gender*: Women appear to suffer more than men due to socio-economic factors, but possibly also physiological reasons
- *Hospital inpatients and nursing / care home residents* are at much higher risk of heat-related mortality, both due to their general vulnerability, and the lack of ventilation and cooling in such buildings.

- *Having pre-existing health problems*: There is evidence that certain pre-existing medical conditions are risk factors for mortality in heat waves, particularly heart and respiratory disease, diabetes, fluid and electrolyte disorders and some neurological disorders.
- *Deprivation*: This may be a determinant of heat related risk in the elderly. Increased risk in groups with lower socio-economic status may be due to differences in housing, neighbourhood or the underlying prevalence of chronic disease.
- *Ethnicity*: There is no clear evidence that some ethnic groups are more at risk than others

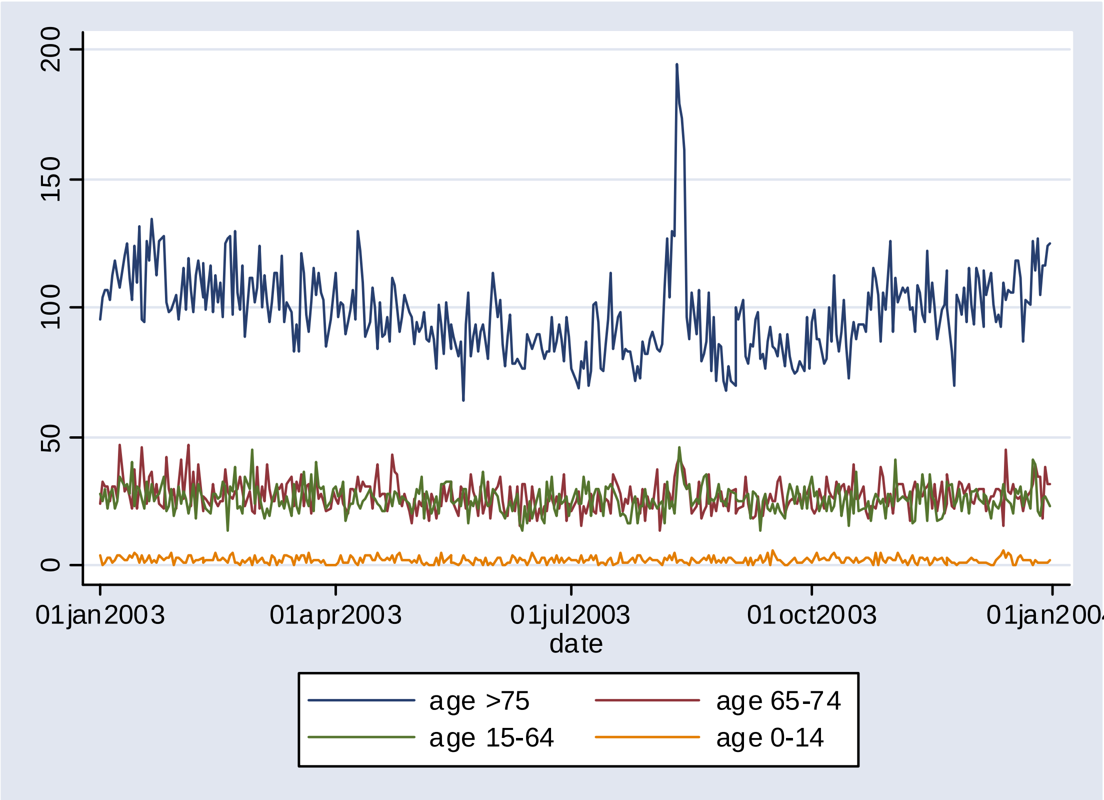


Figure 10. Total daily deaths in London, by age group in 2003 (ONS data). The peak in deaths is coincided with the August heat wave.

The hot and still anti-cyclonic weather conditions that are responsible for intense urban heat island events also produce high air pollution levels. This is because the chemical reactions that produce ozone and smog are accelerated by high temperatures whilst the low wind speeds ensure that the heat and pollution remains trapped in the city. The compound effects of high urban temperatures and poor air quality can have an impact on public health. Exposure to ozone and smog can irritate and cause inflammation of airways and can also increase a person's susceptibility to respiratory conditions. It can also aggravate pre-existing conditions such as asthma and has been linked to hospital admissions and emergency room visits in the United States.

Although air conditioning is not widely used in homes in London, high temperatures can lead to increases in energy demand for cooling buildings, increasing carbon dioxide emissions and placing strains on the energy supply infrastructure. Increased use of mechanical air conditioning, due to urban heat island related enhanced temperatures, also elevates the rate of anthropogenic heat production leading to possible further increases in air temperature. This raises some important social equity issues, where people in overcrowded, poor quality housing can experience very high temperatures, but do not have a cool public space to go to, and cannot afford to buy or run an air conditioner.

During very warm periods, the added heat from the urban heat island may lead to increases in water consumption by city residents because of increased water use either inside or outside the home. This may place considerable strain on water supply infrastructure and provoke the implementation of water restrictions especially if significant heat island events occur embedded in a period of prolonged dryness. Evapotranspiration rates will also be enhanced by high urban temperatures with the result that plants and trees will potentially extract water from the soil at greater rates than normal. This in turn will lead to a progressive drying of the soil, a positive feedback on air temperatures and ultimately an affect on vegetation health.

More pervasive effects of the urban heat island include earlier flowering times of plants and trees in cities and a prolonged growing season. This may cause discomfort for city residents who face a longer allergy season. The prolonged survival and higher reproduction rates in some animal and insect pests, the elevation of temperatures in urban water courses with the potential for algal blooms and the deterioration of historical monuments and buildings through increases in rates of temperature related chemical weathering are also possible outcomes of the urban heat island.

How Might Climate Change Affect the Urban Heat Island ?

Climate change over the next few decades and beyond is likely to have a major impact on the climate of London and potentially could affect both the frequency of occurrence and magnitude of extreme UHI events.

The latest set of climate change scenarios for the UK is the UKCIP02 scenarios. These provide projections of what the climate might be like for 50 kmsquare regions across the United Kingdom for a range of future socio-economic scenarios for the 2020s, 2050s and 2080s. The scenarios do not represent the morphology of London in any detail, nor the climatic impact of as yet unknown future land use in London. Further, the models used to produce the scenarios assume the whole land surface to have a rural land use (i.e. vegetated). Accordingly, the changes described by the UKCIP02 scenarios should be taken to be representative of changes to the rural climate surrounding London and outside of the zone of influence of the UHI.

In applying and interpreting the climate change scenarios for the UK and for London specifically, the inherent uncertainty in the scenarios needs be acknowledged. Sources of uncertainty are the climate models themselves (model physics) and assumptions about future levels of Greenhouse Gas emissions (influenced by global fossil fuel consumption, economic and population growth rates). Because of these uncertainties, the confidence that can be placed in the scenarios for different climate variables varies (Table 1). This is an important point as variables such as solar irradiance (received solar radiation), cloud cover and wind speed play an important role in setting the context for the occurrence of extreme UHI events. This makes predicting future values of the UHI intensity inherently difficult.

Table 1: Levels of confidence for projected changes in key climate variables that are important for the development of extreme urban heat island events.	
Climate Variable	**Level of Confidence**
Temperature	High confidence in average annual change but low confidence in seasonal variation of change and changes in diurnal range
Wind speed	No confidence (highly uncertain results)
Solar irradiance & cloud cover	Low confidence
Relative humidity	Medium confidence
Precipitation	High confidence for winter changes but low confidence for summer changes

Figures 11 and 12 show the climate change scenarios averaged over the four 50 km square regions that converge on the Greater London area for a low (best case) and high (worst case) emissions scenario. The principal climate changes illustrated in Figures are:

- Increased maximum and minimum daily average temperatures, with the change in the minima being slightly smaller than the maxima, resulting in a slightly increased diurnal temperature range;
- Small decreases in wind speeds (<10%)
- Moderate changes in solar irradiance (of up to 20%). These changes are due to a reduction in cloud cover – i.e. more sunny days rather than an increase in peak solar irradiance.
- Decreases in Relative Humidity in all seasons, particularly in summer (up to 15% decrease). Although Relative Humidity (which changes according to temperature) is projected to decrease, Specific Humidity (absolute air moisture content) (not shown) is projected to increase.
- Moderate increase in winter precipitation (rainfall) (up to 26% increase) and a more marked decrease in summer precipitation (up to 54% decrease).

Figure 11: Projected changes in key climate variables for the London region for a UKCIP02 low emissions scenario.

LOW

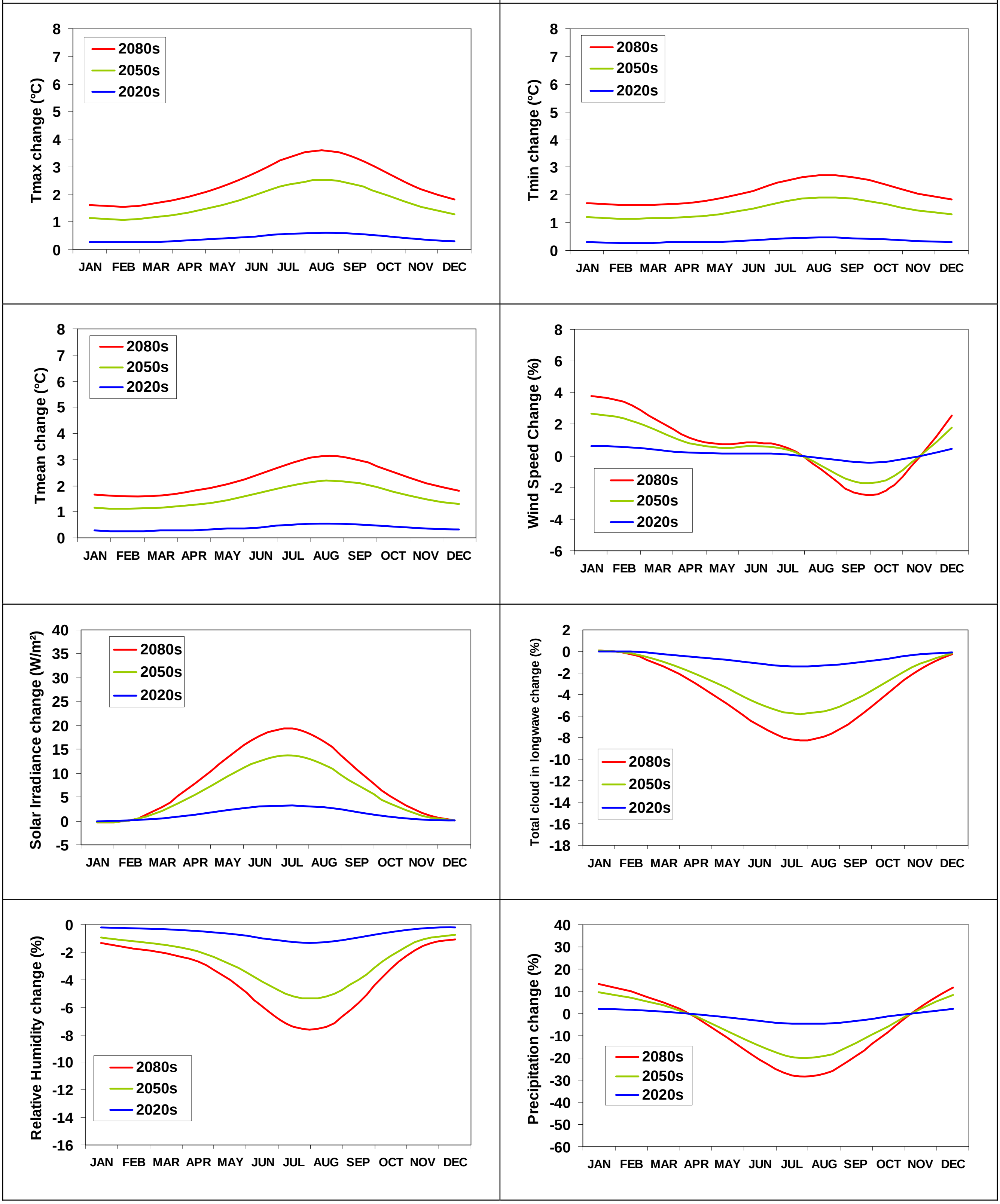
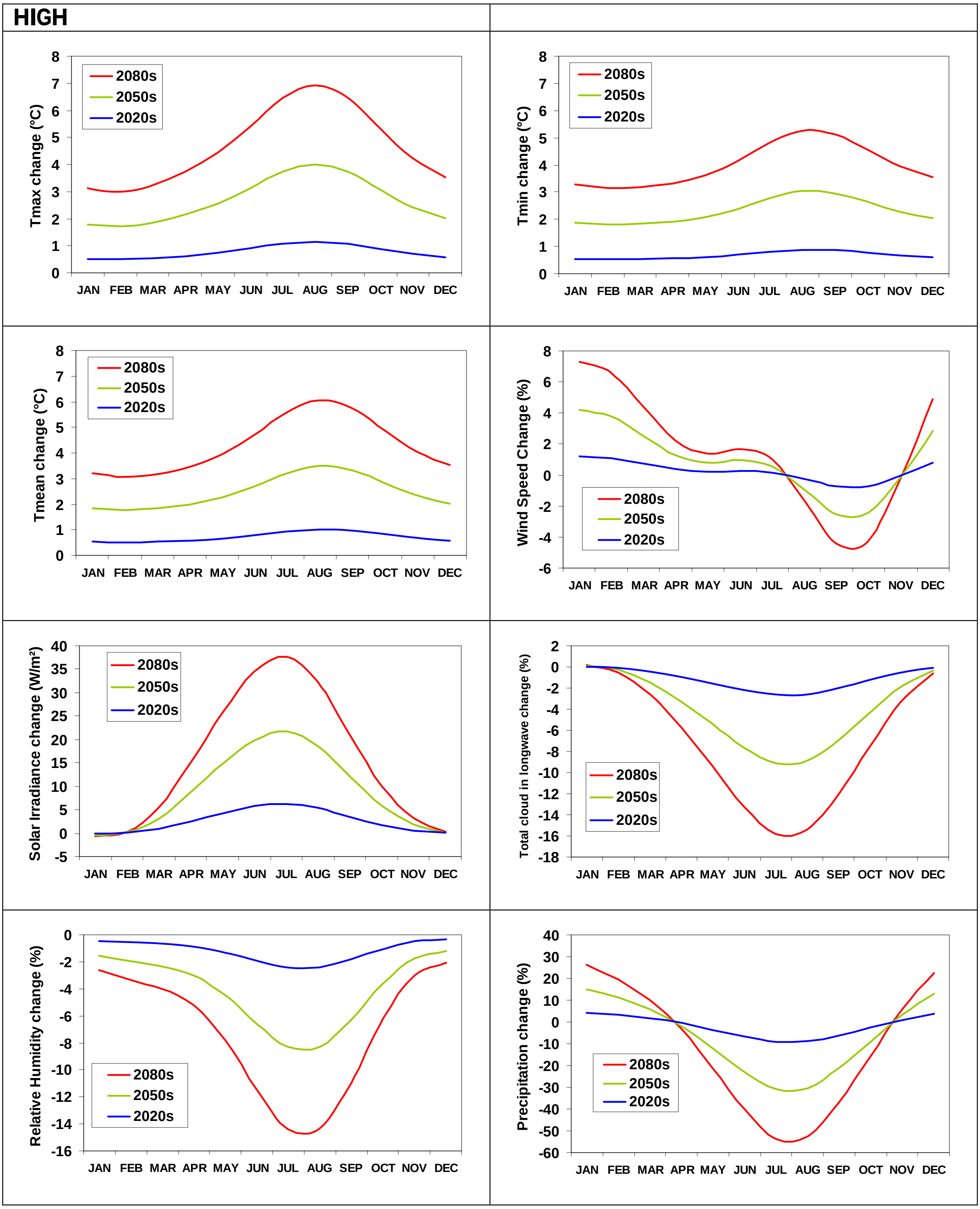


Figure 12: Projected changes in key climate variables for the London region for a UKCIP02 high emissions scenario.



By 2080, under UKCIP02 low and high emission scenarios, maximum/minimum temperatures for August, the month with the most UHI events, are likely to be 2-3 and 5-6.5°C higher than present respectively (Figure 12). For summer, climate change is likely to result in an increase in the number of cloud free days. This would be expected to increase the incidence of strong UHI events but not their peak intensity, assuming no major changes in London's land cover characteristics. With an increase in the number of dry days with climate change the duration of strong UHI events is also likely to increase.

In order to gain an insight into how climate change might affect the UHI intensity a statistical model that describes the relationship between current variations in UHI intensity and weather variables critical for UHI formation has been 'forced' with UKCIP02 projections of temperature, cloud cover and wind speed. Under a UKCIP02 high emissions scenario, a UHI intensity of 4°C is expected for around 180 hours per year by the 2080scompared to 148 hours for the present day (Figure 13). However it should be acknowledged that these differences are probably within the uncertainty of the model used for making UHI intensity projections. In addition, the model portrays the UHI intensity as the outcome of current meteorological conditions and does not account for the urban system's ability to conduct and store heat. Therefore these estimates are likely to be conservative at best.

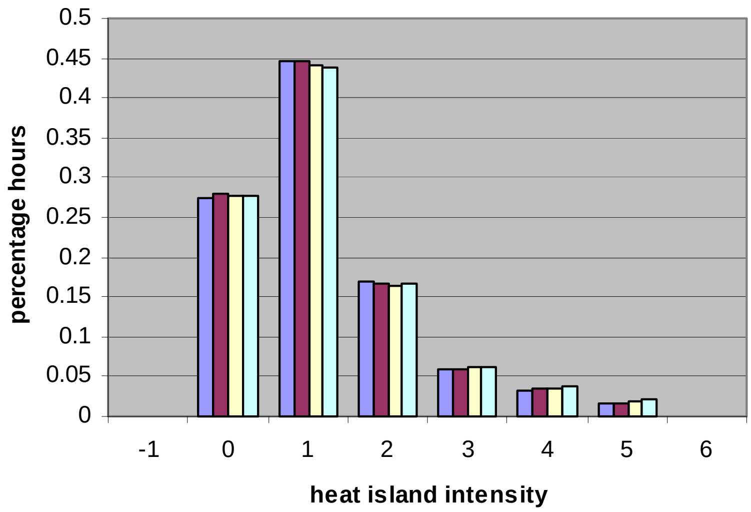


Figure 13: Projected changes in the distribution UHI intensity. The coloured bars from left to right are current conditions (blue) and projected changes for the 2020s (purple), 2050s (yellow) and 2080s (light blue) under a UKCIP02 high emissions scenario.

Changes in temperature may well have implications for future trends in the use of air conditioning and therefore anthropogenic heat as an extra heat source for the urban heat island alongside increased greenhouse gas emissions.

As the nature of land cover and the three dimensional arrangement of building elements as well as energy use is likely to exert an influence on the UHI intensity, the way in which London develops over the coming decades will play a critical role in determining the characteristics of London's UHI under climate change.

What are the Options for Managing the Urban Heat Island ?

Policies designed to reduce the UHI may need to balance the need to manage heat at the building, neighbourhood and city scales, taking into account the nature of development (new versus existing) and be conscious of what is achievable in reality. Furthermore, the climate of London is changing because of alterations to global-scale climate processes. This has implications for the planning and design of current and future urban developments from the local to city scale. Urban designers and planners need to acknowledge this, and in doing so base design criteria on data that describes the current and projected future climate of London, and be especially aware of the critical importance of minimum temperature for human thermal comfort, health and patterns of energy consumption.

The principal causes of the urban heat island are the storage by day of solar energy in the urban fabric and release of this energy into the atmosphere at night, and the fact that the process of urbanisation alters the balance between the energy from the sun used for raising the air temperature (heating process) and that used for evaporation (cooling process) because vegetated surfaces are replaced by impervious engineered ones. Given this, strategies for tackling the root causes of the UHI need to focus on controlling the absorption and release/escape of heat from the urban fabric and tipping the balance between the apportionment of available natural energy between heating and cooling of the urban atmosphere.

Because anthropogenic heat could become an important future contribution of energy for the development of the urban heat island, depending on trends in air conditioning use for example, strategies focused on managing waste heat emissions and the location of heat ejection to the atmosphere from infrastructure such as the London underground need to be given serious consideration.

In developing mitigation strategies for London's UHI, it must be borne in mind that the UHI is a city scale phenomenon and the outcome of the combination of the vast range of microclimates that exist across London. Further, as the built components of the urban system occur at different scales (e.g. individual building to industrial park to major industrial zone) any physical alteration of these will have climate impacts at different scales. Consequently the link between urban heat island management policy and urban climate scale needs to be acknowledged (Table 2).

Table 2: The link between policy and urban climate scales.

Physical Scale	**Policy Scale**	**Urban Climate Scale**
Individual Building / Street (façade and roof construction materials, design and orientation).	Building regulations and Building Control Urban design strategy Local Development Framework	1 – 10 m. Indoor climate and street canyon
Urban Design (arrangement of buildings, roads, green space)	Urban Design Strategy Area Action Plan Local Development Framework	10 – 1000 m. Neighbourhood scale, sub-urban variations of climate
City Plan (arrangement of commercial, industrial, residential, recreational and greenspace)	Sub Regional Spatial Strategy Regional Spatial Strategy	1 - 50 km. City/Metropolitan scale, UHI form and intensity.

To manage London's urban heat island form and intensity would require the alteration of existing land cover characteristics for large areas of central London. From a practical point of view this is not possible. However there are opportunities to change microclimates and therefore manage climates at the street canyon to neighbourhood scale. Over time the cumulative effects on urban heat island form and intensity of a staged programme of local scale climate modification could be significant. Effective strategies that can be implemented within the context of the existing urban structure and have impacts at the local and near local scale include cool roofs, green roofs, planting trees and vegetation and cool pavements.

Cool roofs: Many of the roofs across London are dark in colour and probably reach temperatures in excess of 50-60^{o}C on hot sunny days. Consequently they will store and release a considerable amount of energy back into the atmosphere. High roof temperatures will accelerate the deterioration of roof materials and in buildings with poor roof insulation contribute to increased demand for cooling energy and a decrease in indoor thermal comfort on upper floors. In contrast cool roofs built from materials with high solar reflectance or albedo and high thermal emittance may reach temperatures considerably lower than their low reflectance counterparts. This is because they absorb and store less solar energy during the day and thus are not major emitters of heat into the urban atmosphere at night. Apart from their reduced contribution to the development of the nocturnal heat island, cool roofs have obvious benefits for the lifetime of roofs as excessive contraction and expansion is avoided through a damped daily temperature range and absorption of ultraviolet radiation is reduced. Also there will be gains in terms of indoor thermal comfort through the reduced transfer of heat through roofs to the upper floors of buildings and reduced demand for active cooling systems. To ensure the effectiveness of cool roofs as a climate management strategy their reflectivity must be maintained as this declines with roof age and roofs need to be kept clean, as dirt and pollution lower reflectivity.

Green Roofs: Like cool roofs, green roofs, which consist of a growing medium planted over a waterproof membrane, can have a marked impact on the climate of the upper floors of buildings and their immediate environs. On hot sunny days rooftop temperatures may be up to 20-40^{o}C cooler than a conventional flat dark coloured roof. As well as the gains achieved in terms of climate through their cooling effect as a result of evapotranspiration, green roofs reduce rainwater runoff by absorbing and slowly releasing large amounts of water, act as insulators and reduce noise for upper floor occupants, increase urban biodiversity through providing habitat space for birds and small animals, increase urban aesthetics and contribute to quality of life. As the climate impacts of green roofs are likely to be greatest during prolonged periods of hot dry weather their efficacy as a microclimate management strategy will depend very much on the maintenance of a regular programme of watering and vegetation care. Once water becomes limited and vegetation health deteriorates their climate behaviour will approach that of a dry bare soil surface, which although not ideal will still maintain temperatures at a lower level than the more usual roofing mediums*)*.

Planting Trees and Vegetation: 'Urban Greening' can be a cost effective way of ameliorating harsh urban climates at the individual building to neighbourhood scale. Trees and vegetation are good modifiers of climate, as they not only provide shade (surface peak temperature reductions of 5-20^{o}C may be possible) but are natural cooling systems as they consume large amounts of available energy in the atmosphere through the process of evapotranspiration; the energy is used to convert water contained in the vegetation into water vapour which is transpired through leaves to the atmosphere. For some locations elsewhere it has been estimated that evapotranspiration can result in the reduction of peak summer temperatures by 1 – 5^{o}C. If tree and vegetation planting is integrated with a well designed programme of roof greening the potential gains for human thermal comfort at the neighbourhood scale could be significant. In the case of London the cooling effect of expansive vegetated surfaces such as Richmond, Hyde and Regent's Parks are clear. As with green roofs, additional benefits arising from urban trees are that they act as carbon stores, can reduce urban flooding through intercepting heavy rainfall, filter pollutants from the air and contribute to quality of life. In choosing the type of tree for urban greening care should be taken not to select trees that are major sources of volatile organic compounds (VOCs) as during warm weather these will enhance the formation of ozone.

Cool Pavements: Like many of London's roofs, the streets and to a lesser extent, the pavements of London are typified by dark surfaces. The installation of 'cool pavements' comprised of material with high solar reflectivity and good water permeability is potentially a very effective way of mitigating high urban temperatures through decreasing absorption of solar energy and encouraging water storage in the urban surface and thus evaporative cooling. High albedo roads and pavements may also have benefits for nighttine street lighting. As yet little is known about the climate impacts of cool pavements at the street canyon to neighbourhood scale as research on pavement climate properties is still very much in its infancy. However demonstration projects in cities such as Phoenix Arizona have clearly shown the climate benefits of cool parking lots for example. For London, discernible climate impacts of cool pavements could be achieved for large parking areas, terminal facilities, airports, and urban roadways with large expanses of paved surfaces when re-surfacing or new surfacing is planned.

Sky view factor: In addition to the above local-to-neighbourhood scale interventions, which can be applied to existing or new urban development, are those concerned with urban morphology, or the arrangement of buildings and transport routes. An important determinant of the rate of release of heat from the urban environment at night and thus the rate of urban cooling is sky view. This describes the relative openness between buildings. A restricted sky view, as found for narrow streets and tall buildings, will prevent the free escape of heat emitted from street and building surfaces. This will contribute to the accumulation of heat within 'street canyons' and thus the elevation of air temperatures. In addition, if streets are oriented at an angle that is perpendicular to the prevailing wind, during intense urban heat island events this will reduce the chances of ventilation of the street canyon and removal of heat and pollutants that accumulate between buildings. For this reason new developments should optimise sky view and consider street orientation.

Heat wave detection and preparedness: In parallel with the application of engineering options for managing the urban heat island are plans to reduce the health risks of hot weather by setting out the practical actions that the public, health and social care professionals should take in the event of a heatwave. The national Heat Wave Plan published by the Department of Health has been implemented locally and was triggered for the first time in July 2006. An evaluation of the effectiveness of the Heat Wave Plan is currently underway, and the initial feedback indicates that it had a positive impact. The Philadelphia Heatwave Preparedness Plan (Box 1) is a good example of an integrated heat wave plan.

Box 1: Philadelphia's Heatwave Preparedness Plan

The US city of Philadelphia saved 117 people during heatwaves from 1995 to 1998 through a Hot Weather Health Watch Warning System, which comprises the following components:
(i) Using mass media to encourage friends and neighbours to visit elderly people daily
(ii) Activating a telephone hotline to provide information and counselling.
(iii) Organizing visits by health authorities to people requiring attention.
(iv) Informing care homes of a high-risk heat situation.
(v) Increasing fire department and hospital emergency staffing.
(vi) Implementing daytime outreach services to homeless people.

Source: International Federation of the Red Cross and Red Crescent Societies (IFRC) 2004 *World Disasters Report*, IFRC: Geneva

What More Needs to be Known About London's Urban Heat Island ?

Although the GLA funded report upon which this document is based has synthesised the information that is available about London's urban heat island and presented the results of new research, compared to other major cities, such as Tokyo, our understanding of the causative factors, the form and intensity, and the socio-economic and environmental impacts of London's heat island remains rudimentary.

The following actions are a priority to more effective understanding and thus management of the UHI :

1) Develop a network of weather stations across London to record critical climate variables, such as short and longwave radiation, temperature, humidity, wind speed and direction
2) Use the gathered climate data to build an urban energy balance model for London that can be applied at a variety of spatial scales
3) Develop a decision support tool for planners, urban designers and architects to help identify and prioritise 'anti-UHI' interventions, such as targeted urban greening or cool material programmes
4) Assess the contribution of the UHI to heat related excess deaths, and use evidence to inform the local heat wave plan
5) Collate data on London's anthropogenic heat emissions and model future heat emissions to determine how to manage this potential extra source of heat
6) Implement a range of anti-UHI demonstration projects that apply a number of UHI mitigation strategies and collect requisite climate data to assess efficacy

Other formats and languages

For a large print, Braille, disc, sign language video or audio-tape version of this document, please contact us at the address below:

Public Liaison Unit
Greater London Authority
City Hall
The Queen's Walk
London SE1 2AA

Telephone **020 7983 4100**
Minicom **020 7983 4458**
www.london.gov.uk

You will need to supply your name, your postal address and state the format and title of the publication you require.

If you would like a summary of this document in your language, please phone the number or contact us at the address above.

Chinese

如果需要您母語版本的此文件，
請致電以下號碼或與下列地址聯絡

Hindi

यदि आप इस दस्तावेज की प्रति अपनी भाषा में चाहते हैं, तो कृपया निम्नलिखित नंबर पर फोन करें अथवा नीचे दिये गये पते पर संपर्क करें

Vietnamese

Nếu bạn muốn có văn bản tài liệu này bằng ngôn ngữ của mình, hãy liên hệ theo số điện thoại hoặc địa chỉ dưới đây.

Bengali

আপনি যদি আপনার ভাষায় এই দলিলের প্রতিলিপি (কপি) চান, তা হলে নীচের ফোন্ নম্বরে বা ঠিকানায় অনুগ্রহ করে যোগাযোগ করুন।

Greek

Αν θέλετε να αποκτήσετε αντίγραφο του παρόντος εγγράφου στη δική σας γλώσσα, παρακαλείστε να επικοινωνήσετε τηλεφωνικά στον αριθμό αυτό ή ταχυδρομικά στην παρακάτω διεύθυνση.

Urdu

اگر آپ اِس دستاویز کی نقل اپنی زبان میں چاھتے ھیں، تو براہ کرم نیچے دئے گئے نمبر پر فون کریں یا دیئے گئے پتے پر رابطہ کریں

Turkish

Bu belgenin kendi dilinizde hazırlanmış bir nüshasını edinmek için, lütfen aşağıdaki telefon numarasını arayınız

Arabic

إذا أردت نسخة من هذه الوثيقة بلغتك، يرجى الاتصال برقم الهاتف أو مراسلة العنوان أدناه

Punjabi

ਜੇ ਤੁਹਾਨੂੰ ਇਸ ਦਸਤਾਵੇਜ਼ ਦੀ ਕਾਪੀ ਤੁਹਾਡੀ ਆਪਣੀ ਭਾਸ਼ਾ ਵਿਚ ਚਾਹੀਦੀ ਹੈ, ਤਾਂ ਹੇਠ ਲਿਖੇ ਨੰਬਰ 'ਤੇ ਫ਼ੋਨ ਕਰੋ ਜਾਂ ਹੇਠ ਲਿਖੇ ਪਤੇ 'ਤੇ ਰਾਬਤਾ ਕਰੋ:

Gujarati

જો તમને આ દસ્તાવેજની નકલ તમારી ભાષામાં જોઈતી હોય તો, કૃપા કરી આપેલ નંબર ઉપર ફોન કરો અથવા નીચેના સરનામે સંપર્ક સાધો.

GREATER**LONDON**AUTHORITY

City Hall
The Queen's Walk
London SE1 2AA

www.london.gov.uk
Enquiries **020 7983 4100**
Minicom **020 7983 4458**

MoL/Oct06/MR