Reducing urban heat risk

A study on urban heat risk mapping and visualisation

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ARUP

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Executive summary

High temperatures in urban areas have a direct impact on human health and are associated with heat-related stress and excess summer deaths. Extreme hot weather is already considered by many experts and decision makers as a significant risk for London and major cities around the world. The frequency, magnitude and impact of hot weather events will be exacerbated by climate change; the urban heat island effect; demographic change, and increased urban development and densification.

The Urban Heat Risk Mapping and Visualisation project (final report titled "Reducing urban heat risk") is a collaborative research project between Arup and key partners - the Greater London Authority (GLA), the London Climate Change Partnership (LCCP), University College London (UCL) and the London Borough of Islington. The project ran from November 2012-July 2014. The UK Space Agency and the University of Leicester were important additional partners for certain aspects of the project.

The project:

- identifies and explains the factors which contribute to urban heat risk;
- maps and visualises the urban heat risk factors where possible using available data; and
- develops approaches and responses to address the urban heat risk factors.

The focus area is London. The London Borough of Islington was selected as a pilot area within London, and residential buildings in the social housing and care home sectors were of primary interest. However, it is considered that the contents of this report will be relevant to: other London boroughs; cities in the UK, Europe and internationally, and other building types and sectors.

Hot weather already presents a risk to people and properties in London as experienced in recent years during the summers of 2003, 2006, 2009 and 2013. Whilst cold weather causes more excess deaths than hot weather in the UK (40,000 deaths compared to 2,000 respectively during 2000-2010) (Hajat el al, 2014), the risk to public health and life in London from hot weather, or 'urban heat risk', is increasing due to:

- climate change resulting in higher average temperatures and more extreme hot weather events;
- London's urban heat island (UHI) effect which affects the ability of parts of the city to either stay cool, or cool down at night, during hot weather;
- demographic change particularly an ageing population and a growing population under 5 years old; and
- increasing urban development and densification contributing to the UHI effect and putting pressure on existing open green space and green infrastructure.

Based on the review and analysis of the available literature, the main factors which contribute to urban heat risk can be simplified and considered as falling into three categories, or a "triple risk index", summarised in Table 1.

Urban heat risk factor	Explanation of what to assess
Location within London	Proximity to an urban heat island (UHI) 'hot spot' such as a densely built area / major road junction or 'cool spot' such as a large park / water body, levels of air quality, noise, crime and socio-economic deprivation. The closer to a 'hot spot', the lower the amount of green or blue space, the lower the levels of air quality, the higher the levels of noise, crime and socio-economic deprivation, the higher the location risk.
Characteristics of building	Age of construction, materials, orientation, layout, height, storeys, deep plan, dual aspect, balcony, garden, thermal mass, shading levels and ventilation. The higher the number of characteristics which contribute to overheating and do not easily enable cooling, ventilation and respite from the heat, the higher the building risk.
Characteristics of people	Age, health, mobility, sex, socio-economic status, culture, languages spoken, awareness and perception of heat risk, levels of social connection. The higher the levels of people over 65 (particularly over 75), under 5s, people with respiratory, cardiovascular or mental health conditions, pregnant women, and the less mobile, informed and socially connected, the higher the people risk.

Table 1 Triple risk index for assessing urban heat risk.

Based on the review and analysis of the available literature and the mapping and visualisation of data for London and the pilot area, the main approaches or responses to addressing urban heat risk can be considered as falling into four categories, summarised in Table 2 below. These four categories represent a clear and simple way for decision makers at different levels of different organisations to consider the management of urban heat risk.

Approaches and responses to address urban heat risk	Explanation of what the approaches and responses cover
Physical	Involve a change, intervention or improvement to the urban environment, or a particular neighbourhood or building.
Social	Involve policies and practice relating to awareness raising, communication and behaviour change.
Strategic - before a hot weather event	Involve longer term, larger investments of time and resources with less immediate results.
Operational - during a hot weather event	Involve shorter term reactive efforts with more immediate results.

Table 2 Four main approaches or responses to address urban heat risk.

Based on the work undertaken for the project, and the outputs of the analysis, this report sets out key messages for decision makers such as politicians, members of the public, housing and public health professionals, planners, developers and insurers. Responses could be for example: linking measures to reduce urban heat risk with those to improve air quality in London; looking out for potential vulnerable friends, family, neighbours and colleagues before and during hot weather; creating 'Keep Cool' information hubs and cooling centres for members of the public to access, and planting large canopy trees now to ensure sufficient growth and coverage for shading and cooling benefit by 2050.

It then makes recommendations for further collaborative work to develop a practical urban heat risk index for London, and to further map and visualise relevant urban heat risk data.

1 Introduction

1.1 Aims of the project

The overall aim of the 'Urban heat risk mapping and visualisation project' was to respond in a practical yet creative way to key recommendations in the final report for the Heat Thresholds Project (Arup, 2012) undertaken by Arup on behalf of the Greater London Authority (GLA), the London Climate Change Partnership (LCCP) and the Environment Agency (EA). The recommendations related to a better understanding of and addressing the factors which contribute to urban heat risk in London. They focused on the development of risk registers of potentially vulnerable people; asset management, and mapping of 'hot' and 'cool' spots (areas which get hot or stay cool during hot weather).

The aims for the outputs of the project were to clearly explain and visually depict urban heat risk factors and issues for London and to inform and influence key decision makers such as politicians, planners, developers and housing and public health professionals. The outputs were initially produced for London as a whole (city scale) and for a pilot area identified as the south of the London Borough of Islington (borough scale). However, it was and still remains a strong ambition that the methodology and outputs for this specific project would be transferrable to other London boroughs and other cities with urban heat risk issues in the UK, Europe and worldwide.

As a result of the project outputs, the overall project outcome is 'to get the message across' about the factors which contribute to urban heat risk and importantly what could be done to reduce the risk by considering the role of strategic spatial planning, provision of green space and green infrastructure, housing design, refurbishment and allocations policies, public health, and emergency planning and response.

1.2 Project partners

A key aim of the project was to work collaboratively with partners whose existing knowledge and access to information was deemed valuable for the project, and who would also benefit from the project outputs and outcomes. The main project partners, and what they each brought to and gained from the project, are summarised in Table 3.

Partner	What they bring to project	What they gain from project
Greater London Authority (GLA)	Has prior experience of this subject area and these types of collaborative research projects. Has access to London wide data sources. Provides an important dissemination route for project outputs aimed at influencing London wide policy makers.	Would benefit from identification of 'multiple factor hot spots' (i.e. buildings within urban heat island, prone to overheating and with vulnerable inhabitants). Outputs could contribute to meeting policy and legislative targets for addressing climate change and the urban heat island. Would benefit from demonstration of the practical applications for and connections between outputs and outcomes of our respective research and policy work.
London Climate Change Partnership (LCCP)/Climate UK/Environment Agency	Has prior experience of this subject area and these types of collaborative research projects. Has access to London wide data sources. Provides an important dissemination route for project outputs aimed at influencing London wide policy makers.	Has been tasked with encouraging asset mapping and characterisation of all London Borough and Registered Social Landlord (RSL) property, buildings, land and green space using GIS and searchable databases.
University College London (UCL)	Significant body of published literature in this area. Access to modelled and measured air temperature data for London. Provides an important dissemination route for project outputs via publications and presentations.	Will inform a key research area of theirs. Will help to demonstrate research impact, practical applications and connections between outputs of our respective research work.
London Borough of Islington (LB Islington)	Has data specific to LB Islington including socio-economic data at a finer spatial resolution than publically available census data. Provides an important dissemination route for project outputs aimed at Borough wide policy makers, politicians and social landlords.	LBs may benefit from developing and integrating 'cool spots/cool buildings' mapping into their heat risk plan and to develop heat risk vulnerability registers which define a set of key characteristics for vulnerable residents, buildings assets or infrastructure.

Arup	Expertise in analysing and collating multiple and complex data sets (e.g. GIS). Funding for the project. Project coordination and dissemination.	Development of links between industry, academia and government. Informing and influencing decision makers about urban heat risk factors. Better understanding of the capabilities of methodologies and tools for analysing and communicating this type of work.

Table 3 Project partners and reasons for involvement in project.

1.3 Explanation of the current problem

High temperatures have a direct impact on human health and hot weather is already considered by many experts and decision makers as a significant risk for London and major cities around the world. The evidence suggests it will become an increasing risk due to climate change; the urban heat island effect; demographic change, and increased urban development and densification.

Air temperatures above 23°C are associated with heat-related stress and excess summer deaths in the UK (Department of Health, 2008). Heat-related stress currently accounts for approximately 1,100 premature deaths and over 100,000 hospital patient-days per year in the UK. These figures can increase noticeably for prolonged periods of high temperatures for example during the summers of 2003, 2006 and 2009.

- The European heatwave of 2003 has been estimated to have led to more than 15,000 additional deaths across the UK and France – mainly in Paris and London (Department of Health, 2008).
- Of the 15,000 additional deaths, 310 were reported for England and Wales between the 11th and 15th July 2003 as temperatures rose from 22°C to 30°C (equivalent to 7.8 extra deaths each day for each degree rise in temperature above 22°C).
- Later the same year, 676 extra deaths were reported in London alone as temperatures rose from 22°C to 29°C between the 4th and 13th August 2003 (equivalent to 9.6 extra deaths each day per degree temperature increase) (Johnson, et al., 2005).
- In the summer of 2006, an estimated 10.7 extra deaths per day for each degree of increase in temperature occurred in England (Department of Health, 2008).
- The mini-heatwave of the 30th June to 2nd July 2009 led to an estimated 299 extra deaths in England and Wales (Andrews, et al., 2010).

The NHS Heatwave Plan for England (NHS England, 2011) sets out regional temperature thresholds for triggering heatwave alerts in England (see Table 4). Based on Met Office advice, a heatwave is defined by two days of hot weather above a regional day time temperature threshold with an intervening night time temperature above 15°C for all regions except for London and the South East, which are 18°C and 16°C respectively.

Region	Day time temperature (°C) for >2days	Night time temperature (°C) for >2days
London	32	18
South East	31	16
South West	30	15
Eastern	30	15
West Midlands	30	15
East Midlands	30	15
North West	30	15
Yorkshire and Humber	29	15
North East	28	15

Table 4 Threshold temperatures for triggering heatwave alerts in the English regions (NHS England, 2011).

Whilst regional and indeed universal threshold temperatures are useful, it is important to note that it is not a single temperature threshold nor a maximum temperature value which contributes to ‘urban heat risk’, but the characteristics of the hot weather event itself such as duration, time of year of occurrence, what is considered “normal” and time since last hot weather event.

1.4 Why is it likely to become more of a problem?

There are three main reasons why urban heat risk is likely to become more of a problem: climate change; the urban heat island effect and urban densification; and demographic change of urban populations. Another potential driver is the energy efficient retrofit of existing buildings. Increased insulation and air tightness measures, if not well designed, may lead to unintended consequences of summer indoor overheating, thus exacerbating high outside temperature-related health risks in the summer.

1.4.1 Climate change

Climate change is happening and is projected to amplify existing climate related risks, many of which are already concentrated in urban areas around the world (IPCC WGII AR5, 2014).

Many countries worldwide experience annual heat-related deaths associated with current weather patterns. Future changes in climate may alter such risks (Hajat, et al., 2014).

In the UK, the frequency of hot days with temperatures above existing thresholds used to define hot weather, heat stress or heatwaves are projected to increase based on analyses using the UKCP09 climate change projections (Jenkins, et al., 2010). More frequent hot days, hot weather events and heatwaves are likely to have significant implications for the comfort and health of people in cities across the UK, particularly London. They will contribute to a greater prevalence of heat stress for people within buildings and the urban environment more widely.

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The number of days a year when the average UK temperature is greater than 25°C[1] is currently[2] five. This is set to increase to 26 days a year by the 2020s[3] and to 58 days a year by the 2050s. The annual number of heatwaves experienced in England (defined as 2 days with a maximum daily temp of >29˚C and a minimum daily temp of >15˚C based on the lower end of Met Office values in Table 4) is currently less than 1 a year. This number is set to increase to up to 3 a year by the 2020s and up to 7 a year by the 2050s. These analyses are based on the UKCP09 Weather Generator tool (Met Office, 2011) using the High emissions scenario at the 90% probability level which represents the upper end of climate change projections for the future (URS, 2009). If the Low emissions scenario or the 10% or 50% probability levels were used for this analysis, the values would be lower.

Work by Hacker et al. (CIBSE, 2014) provides a more detailed quantitative analysis of the return periods for selected historic hot weather events experienced in London using the UKCP09 climate change projections. The events were those which took place in the summers of 1976, 1989, 1990, 1995, 2003 and 2006.

Hot weather event	Historical return period (~1970-2000)	Current/2020s return period (~2010-2040)	2050s return period (~2030-2060)	2080s return period (~2050-2080)
1976	1 in 27 chance of occurring each year during this period	1 in 11 chance	1 in 5 chance	1 in 2 chance
1989	1 in 9 chance of occurring each year during this period	1 in 3 chance	1 in 2 chance	1 in 1 chance
1990	1 in 16 chance of occurring each year during this period	1 in 6 chance	1 in 3 chance	1 in 1 chance
1995	1 in 18 chance of occurring each year during this period	1 in 7 chance	1 in 3 chance	1 in 2 chance
2003	1 in 19 chance of occurring each year during this period	1 in 7 chance	1 in 3 chance	1 in 2 chance
2006	1 in 20 chance of occurring each year during this period	1 in 8 chance	1 in 4 chance	1 in 2 chance

Table 5 Projected future return periods for selected historical hot weather events in London under the UKCP09 Medium emissions scenario and for the 50% probability level (CIBSE, 2014).

[1] 25°C is slightly higher than the Department of Health threshold of 23°C and lower than the daily temperatures of 28°C – 30°C used by the Met Office to define a heatwave, but serves to illustrate the point.

[2] 'Historically' is more accurate than 'currently' as this figure is based on the baseline climate period of 1961-1990.

[3] Technically, the "2020s" is the period we are currently in.

Based on the characteristics of the selected historic hot weather events, the projected future return period for each was analysed using the UKCP09 Medium emission scenario and the 50% probability levels as they represent the 'central estimate' for future climate change projections. The results of this analysis are presented in Table 5.

It should be noted that London has experienced more recent hot weather events and heatwaves since this analysis was undertaken, for example the summer of 2009, the unusually warm April and October in 2011, and a particularly hot summer in 2013.

In order to provide a global perspective, hot weather events and heat-waves experienced in cities around the world within the last 5 years have highlighted the problem of heat risk. These include; the 2003 European event which saw up to 80,000 deaths (Robine, et al., 2007); the 2010 Russian event which resulted in an estimated 54,000 deaths (Revich, 2011) and more recent heatwaves in the USA (2012), Argentina (2014) and Australia (2014).

1.4.2 Urban heat island effect and urban densification

Cities frequently experience higher mean average air and land surface temperatures than surrounding rural areas and this is known as the 'urban heat island' (UHI) effect. UHI intensity varies spatially and temporally, across a city and over time.

The maximum intensity of the UHI effect in any city is typically reached several hours after sunset (Davies, 2010). For example, during the August 2003 heatwave, differences of up to 9°C in night-time air temperatures were observed between London and surrounding areas (Greater London Authority, 2006). The health effects of hot weather are most pronounced where night-time temperatures remain high (Department of Health, 2008) and so are exacerbated by the UHI as it limits night-time cooling.

Heat islands can develop in fairly large areas within a city, or in smaller 'pockets' around individual buildings or along streets. For example temperature differences of 4°C have been recorded along a single street in California (Taha, et al., 1990).

As well as being warmer than the rest of the country due to its location in the South East of England, London has a fairly pronounced UHI due to its size and density. However, this is not unique to London, other cities in the UK, Europe and globally also have an identified or defined UHI, for example: Birmingham, UK; Paris, France; New York, USA; Tokyo, Japan and Melbourne, Australia.

1.4.3 Demographic change – urbanisation, ageing population and under 5s

Globally, more people than ever before live in cities than rural areas. The turning point was in 2007 when more than 50% of people were considered to live in urban areas. This figure is set to rise to 53% by 2015 and to 60% by 2030 (United Nations Population Fund, 2007).

The UK urban population grew from 78% in 1990, to 79% in 2000 and to 80% in 2010. This trend is predicted to continue, reaching 83% by 2030 and 86% by 2050 (United Nations, 2009). London's population grew from 7.3 million people in 2001 to 8.2 million people in 2011, an increase of 12% and the fastest growing region across England and Wales (Office for National Statistics, 2012).

Most local authorities in London saw their populations increase between 2001 and 2011, with nine of the 20 local authorities with the fastest population growth in England and Wales in London, Tower Hamlets and Newham were the only authorities in England and Wales to show growth of more than 20 per cent, with the fastest growth of all being 26.4 per cent in Tower Hamlets. In addition, the 19 most densely populated local authorities in England and Wales were in London, with Islington (the pilot area for our study) the most densely populated of all with 13,873 people per square kilometre.

Globally, people are living longer. According to United Nations forecasts, individuals aged 60 years and over are expected to increase from 688 million in 2006 to 2 billion (22 per cent of the world's population) by 2050 (United Nations Population Fund, 2012). These global trends are reflected in the UK and London, with figures for London the most pronounced at both ends of the age range.

For example, 18 per cent of the population in the London Borough of Havering are over 65 but by contrast, only 6 per cent of the population in Tower Hamlets were in this age group, the lowest figure not only in London but all of England and Wales. There has also been a 13% increase (400,000) in the number of under-five-year-olds throughout England and Wales between 2001 and 2011. Again this was particularly pronounced in London; where there has been a 24% increase in under-fives between 2001 and 2011. Barking and Dagenham has the highest proportion in this age group with 10 per cent.

Implications for urban heat risk

The main causes of illness and death during periods of high temperatures are related to respiratory and cardiovascular conditions. Elderly people over 65 in urban areas (especially those over 75 or living alone as low levels of social connection increase risks during extreme weather), people with compromised health, pregnant women and children up to the age of four are also particularly at risk.

Recent research (Hajat, et al., 2014) has established that due to a combination of climate change, population growth and an ageing population the risk of heat-related mortality increases in all regions of the UK with the elderly in urban areas at most risk. In the absence of any approaches to address urban heat risk, heat-related deaths would be expected to rise by around 257%, or more than double, by the 2050s from a current annual baseline of around 2,000 deaths.

Projected National NHS costs for additional hospital admissions during heatwaves range from £51 million to £404 million per year as a changing climate and an aging population combine to increase vulnerability to urban heat risk (Department for Environment, Food and Rural Affairs, 2012). However, these costs may be offset by reduced numbers of excess deaths from cold weather.

The demographic trends described above have particular relevance for urban heat risk, and have the potential to exacerbate it. Health protection from hot weather will become increasingly necessary. The demographic changes expected this century mean that the health protection of vulnerable populations such as the elderly will be vital.

Approaches and responses to address urban heat risk should therefore focus on locations used by these more vulnerable groups (such as hospitals, care homes and nursery schools) and supporting residents of urban areas (living in both social housing and private rented accommodation) to deal with higher temperatures and the urban heat island effect will have the greatest impact.

Due to the underlying climate in the UK and seasonal patterns of weather, more people will continue to die due to cold weather than hot weather in the UK; as such measures to reduce the risks from cold weather will also remain important in the UK.

2 Methodology

2.1 Stage 1: Review of past research projects

Due in part to the recent heat-waves in London and Europe, especially the 2003 event, there has been an increase in research exploring the links between hot weather and public health. The research has highlighted that there is a clear link between hot weather events and potential health impacts.

The first stage of the methodology was to collate and review as much available existing data as possible relating to London's urban climatology, data about the characteristics of London's built form and its inhabitants, and outputs from research projects which focussed on urban heat risk such as the AWESOME (Natural Environment Research Council, 2011), CREW (Hallett, 2011) and LUCID (Davies, 2010) projects. Relevant publications and outputs from previous research projects are listed in Table 6. Some of these were the result of collaborations between one or more of the current project partners.

A summary of the collated data, research and literature was presented to all project partners in a workshop early on in the project. Whilst of relevance and significance to the project, much of the actual data used by previous projects was either not suitable or available as it was bound to those projects through licensing agreements or was time limited. Therefore there were no significant data sets which could be re-used in their entirety for this project.

Project	Aims	Outputs
AWESOME (Natural Environment Research Council, 2011) Air pollution and weather-related health impacts: methodological study based on spatio-temporally disaggregated multi-pollutant models for present day and future.	To examine the effects of air quality and climate policies on air pollutant and excess temperature exposures and health; and to assess effects of such policies on socio-economic variations in exposure and disease burden.	Mapping of indoor/outdoor pollution and temperature socio-economic status.
BIOPICCC (Curtis, 2012) Built Infrastructure for Older People in Conditions of Climate Change	To develop adaptation strategies to support older people in withstanding the harmful impacts of climate change.	Development of strategies to integrate design options into wider procedures and policies and disseminate knowledge about how to adapt built infrastructure to support older people's health and well-being under changing climatic conditions.
CREW (Hallett, 2011) Community Resilience to Extreme Weather Events	To improve community resilience to extreme weather.	Tools to improve capacity for resilience of local communities to the impacts of future extreme weather events.

LUCID (Davies, 2010) Local Urban Climate and Intelligent Development	To model the local urban climate at a high spatiotemporal resolution; to understand the impact of local climate on energy use, comfort and health.	Models of local urban temperature at different scales (citywide, neighbourhood and street level). Models which can assess and quantify the impact of specific design decisions on the local climate.
SCORCHIO (Levermore,2010) Sustainable Cities: Options for Responding to Climate Change Impacts and Outcomes	Produce assessments of vulnerability to UHI and climate change and possible adaptation options.	Computer model of urban areas using land cover type to more accurately represent urban climate.

Table 6 Previous research projects of relevance to this project.

As the project developed, outputs from other research projects and reports suggested by project partners were also looked at. A selection of these projects is listed in Table 7 below. A full list of data, research and literature reviewed for this project is provided in Section 6.

Project / publication	Author/s and date
A checklist for retrofits: measures to incorporate when planning a retrofit.	(London Climate Change Partnership, 2014)
Air temperature regulation by urban trees and green infrastructure	(Doick & Hutchings, 2013)
Individual and community resilience to extreme weather events amongst older people in south Islington: attitudes, barriers and adaptive capacity.	(Kolm-Murray, et al., 2013)
Preventing overheating: Investigating and reporting on the scale of overheating in England, including common causes and an overview of remediation techniques.	(Taylor, 2014)
Summer thermal performance of social housing in South Islington.	(Taylor, 2014)
Your social housing in a changing climate.	(London Climate Change Partnership, 2013)
The development of a heat wave vulnerability index for London, United Kingdom	(Wolf & McGregor, 2013)
Space heating demand and heatwave vulnerability: London domestic stock	(Mavrogianni, et al., 2009)

Table 7 Selected additional relevant literature.

Following the review of past research projects and available data it became clear to the project team that there was a need for this project. However the objectives and audience needed to be carefully considered.

2.2 Stage 2: Identification of objectives for project

After the initial data scoping, review and collation phase, a workshop was held in December 2012 at Arup's offices in London. This workshop was attended by all of the project partners (except London Borough of Islington who were yet to be approached). The key outcomes of this workshop were:

- project objectives were formalised;
- each project partner presented their existing knowledge and capabilities, what they could contribute to the project and what they wanted from it;
- it was decided that an open document should be created which each project partner could populate with the sources of data known and available to them; and
- it was determined that it was important to get a London Borough on board as a project partner to provide a pilot area for the study.

2.3 Stage 3: Identification of availability of data

Each of the project partners identified the sources of relevant data they had access to the following information about the data was collated in an open document accessible to all project partners:

- type;
- format;
- source;
- spatial scale;
- temporal scale;
- cost; and
- any licencing agreements.

2.4 Stage 4: Identification of pilot area

It was decided that a pilot area should be selected and used to demonstrate the factors contributing to urban heat risk issues in London.

The wards of Clerkenwell and Bunhill within the London Borough of Islington (shown in green below in Figure 1) were selected for this pilot study as they are located within the area of London's urban heat island (UHI), they contain a high density of high rise flats and social housing, and have a low density of open green space and green infrastructure. They were also the subject of research exploring social attitudes towards hot weather amongst older people (Kolm-Murray, et al., 2013), which was considered to be highly relevant to the project.

Although Clerkenwell and Bunhill have been used as a pilot area, the work presented here has relevance for other London boroughs, London as a whole and to other cities which experience urban heat risk issues in the UK, Europe and internationally.

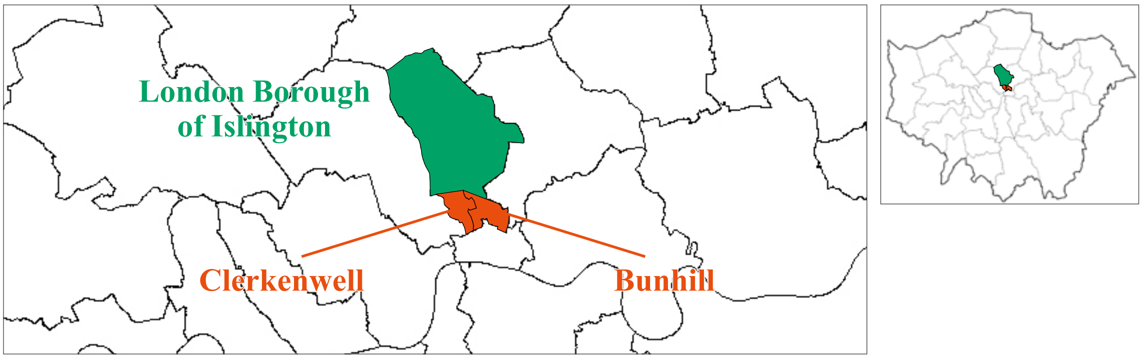


Figure 1 Pilot area within London Borough of Islington. ©Arup

2.5 Stage 5: Collation of data and tools for analysis of the risk factors

Relevant data sets, data layers and information needed to map, visualise and support the analysis of urban heat risk factors were obtained. Collectively these data sets, layers and information would comprise the foundations of a Geographic Information System (GIS) database. This database could be developed to support the analysis of urban heat risk factors and to develop proportionate responses to them.

The data sets which were obtained included:

UKMap® data

A significant amount of data was obtained from UKMap® for the southern part of the London Borough of Islington. The agreement allowed the use of this data by all project partners for 1 year. The data had a number of layers which were directly usable in a GIS database:

- detailed topographic map;
- topographic features such as trees;
- addresses;
- land use;
- building heights; and
- terrain.

Land surface temperature data

A parallel collaboration between Arup the UK Space Agency was developed. The UK Space Agency put Arup in contact with the Earth Observation satellite experts at The University of Leicester. Arup representatives visited the facilities at The University of Leicester in early February 2013 and were given the opportunity to see first-hand how satellite data can be accessed and processed. The experts provided the project team with an in-depth guide as to the range of Land Surface Temperature data available from Earth Observation satellites. A summary of which is provided in Table 8.

Name	Spatial scale	Temporal scale	Cost	Notes
ATSR (Along Track Scanning Radiometer) - Public European	1km grid squares	Daily between March 2002 -April 2012.	Data is free and is straight forward to obtain from University of Leicester.	Good cloud masking routines, can get monthly averages as well.
Modis Data (Moderate Resolution Imaging Spectroradiometer) – Public USA	1km grid squares	x2 daily x2 nightly (10:30am, 2:30pm, 10:30pm, 2:30am).	Data is free to download from NASA.	Coverage less accurate than ATSR, cloud masking, not as good as ATSR and also it will mask out aerosol (a problem in London), slightly colder than ATSR data.
LandSat – Public USA	120m grid square	Daily (when possible) every 16 days is typical since 1972.	Raw data is free from glovis, obtaining useful LST may require additional fee.	Can derive LST from this data, but will require additional work regarding emissivities, can be a very low temporal scale – every 16 days is typical. More useful for qualitative, rather than quantitative understanding. Can be gaps at edges of swaths.
ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) – Commercial USA	90m grid square	Daily –if cloud cover permits- every 16 days is typical. The higher the spatial resolution, the lower the opportunity for obtaining data.	Commercial enterprise.	ASTER will derive and process data to give you LST data in format you desire. Needs substantial processing to get LST data.
SEVIRI- Public European	5-6km grid square	Every 15mins.	Data is freely available from LandSaf.	Data comes from a geostationary satellite can result in inaccuracies due to the angle it is obtaining its data at. Tends to be warmer than ATSR. Most useful in conjunction with another data source.

Table 8 Land surface temperature data sources.

Through discussions with the experts at The University of Leicester and the other project partners it was decided that the ATSR and LandSat land surface temperature data would be the most relevant data sources for this project. This data was provided to the project free of charge and under a non-disclosure licensing agreement between the project partners and the University of Leicester. The data was provided in a format suitable for use in a GIS database, a series of GeoTiff images time stamped were provided, these images give a snapshot of London coloured by land surface temperature.

Comparison is made between the ATSR and the LandSat data in Appendix 7.2. It can be seen that the spatial resolution of the LandSat data is improved upon the ATSR data, although the ATSR data has a greater temporal resolution. For analysis which is on the borough or neighbourhood scale the LandSat data would be preferred.

Air quality data
Air quality data and air quality management area data were provided by the GLA. This data was provided free of charge for use in this project and by all project partners.

The air quality data was provided as Mapinfo workspace data and contained the annual NO_2 annual mean levels for the 187 UK based air quality management focus areas, this includes most London boroughs. The output requires some conversion for use in GIS.

Air temperature data
Air temperature data was provided by UCL; this data had previously been used in the LUCID project (Davies, 2010) and was compiled by the University of Reading. The dataset was produced through the use of the Met Office Unified model. The modelled average, minimum and maximum air temperatures were provided as point data, 10m above the ground and at a spatial resolution of $1km^2$ for the entirety of London. The temperatures represent the period 16/5/2006-19/7/2006.

The data was provided in a format suitable for use in a GIS database. It was provided for use in the project and by the project partners free of charge.

Socio-economic data
A wealth of socio-economic data is available from the London LSOA Atlas (Greater London Authority, 2014). This provides a great deal of information at the Lower Super Output Area (LSOA) level. The information presented in this report was taken from the 2001 census, however the 2011 census data is available and it is intended that it will be used in any future work. The London LSOA Atlas provides indices of social deprivation such as:

- population density;
- vacant dwellings;
- dwelling type;
- crime numbers and rates;
- number of people claiming a State Pension;
- number of people claiming a Pension Credit;
- number of people claiming Incapacity Benefit;
- number of people claiming Disability Living Allowance;
- fuel poverty; and
- indices of deprivation.

The London Borough of Islington also provided information relating to the number of social housing residents over 65 in each of the postcodes in the pilot study focus area.

Urban green and blue infrastructure data
Data and information about green and blue spaces in London is managed by the Greenspace

Information for Greater London (GiGL) records centre (a link to their website is provided in Section 6). Overall, London is a relatively green city with approximately 47% of its total area considered to be green, 39% multi-functional open space, 33% vegetated green space, 18% public open space and 14% vegetated private, domestic garden green space. Blue space, such as rivers, canals and reservoirs comprises approximately 2.5% of Greater London's area (GiGL, 2014). Different types of green and blue space provide different types of cooling and shading benefits for London. Some boroughs and wards are less green than others.

The London Borough of Islington has the lowest ratio of open space to built-up areas of any London borough. Its 91 parks and gardens cover a total area of 53 hectares (Land Use Consultants and PMP, 2009). This accounts for 53.5% of the open space provision in Islington and equates to 0.28ha per 1,000 population. Of the 91 sites in the London Borough of Islington, the vast majority (80 in total, representing 97% of the total area) are fully accessible (Land Use Consultants and PMP, 2009). Other types of open and green space in the borough include natural and semi-natural green space, green corridors, outdoor sports facilities, amenity green space, community gardens and allotments and civic spaces. The Clerkenwell and Bunhill wards, our pilot study area, are designated as priority areas for increasing quality and functionality of existing open green spaces.

The London Borough of Islington owns and manages approximately 4,000 trees on its land, but it is not known how many trees are on private land. Some information comparing street trees per square kilometre in each of the London boroughs is available through the GLA (Greater London Authority, 2011) and there are figures available which estimate the greenspace land-use in terms of total area and percentage of total borough area. There is no systematic data on green roofs in Islington, but a distinct mapping exercise could be undertaken based on planning consents or aerial imagery could be used to identify installations.

Blue space in the borough comprises parts of the Regent's Canal and New River, and a few small ponds in Highbury and Barnsbury. Two small reservoirs at Dartmouth Park and Claremont Square are both covered. None of the blue spaces are located within the Clerkenwell and Bunhill wards.

3D model of the pilot area

A 3D model of the pilot area was provided by Blom3D™ (BLOM, 2014) this information was provided as an .obj file and a .shp file to be used either in CAD programs or in ArcGIS. The extent of the 3D model is shown in Figure 2. The purchased UKMap® data also contained building height information and from this it was possible to extrude building plans and obtain a 3D model of the area.

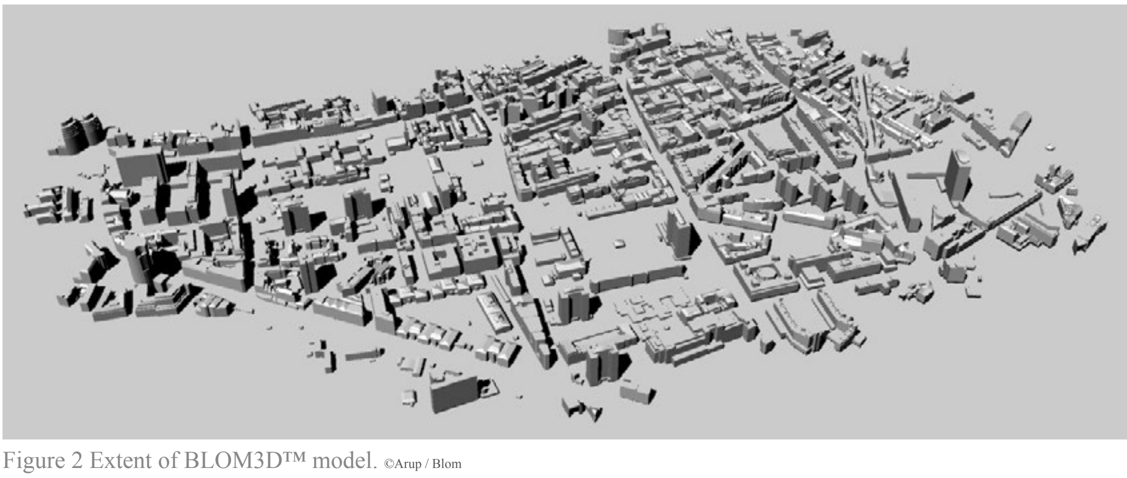


Figure 2 Extent of BLOM3D™ model. ©Arup / Blom

2.6 Stage 6: Communication of the risk factors and responses to them

Once the sources and formats of available data had been established and licensing agreements put in place, the final stage of the methodology was to analyse, process this data and transform it into useful information to disseminate.

This stage required interpretation and effective communication to make the message relevant and accessible to key decision makers.

The outputs of the study have potential relevance to strategic spatial planning, provision of green space and green infrastructure, housing design, refurbishment and allocations policies, public health, and emergency planning and response. Therefore it was important that the messages were tailored for maximum impact.

The **outputs** of this project were:

- the foundations for a GIS database;
- a summary report;
- an interactive PDF;
- a PowerPoint presentation; and
- infographic and annotated diagram.

The **outcome** of the project is that important information on urban heat risk is effectively communicated to key decision makers and policy makers at city and neighbourhood levels. In other words we ‘get the message across’ about urban heat risk and what to do about it.

3 Outputs and outcomes of the project

This Section focuses on Stages 5 and 6 of the methodology outlined in Section 2. The approach taken here is to visualise the datasets acquired in Stage 5 at a range of spatial scales (city, borough and neighbourhood).

The initial aim was to provide outputs for London as a whole (city scale) and a pilot area identified as the southern part of the London Borough of Islington (borough or neighbourhood scale). It is however a strong ambition that this methodology and similar outputs could be produced for other London boroughs and other cities in the UK, Europe and internationally.

Physical factors such as temperature may coincide with building forms conducive to heat risk and potentially vulnerable people. For example a large concentration of elderly residents in one bedroom top floor flats. Where these areas of high vulnerability co-occur with areas of high heat risk is of particular interest. In the following sections, co-occurrence of one or more than one of these factors is mapped and visualised.

3.1 Mapping and visualising the problem – city scale outputs

At a city scale, visualisations depicting the spatial variation of air temperature and land surface temperature over the whole of Greater London were produced (Figure 3 and Figure 4). These images give an immediate indication of high heat risk.

The difference in both air and land temperature between Greater London and the surrounding counties is quite evident from these images. As you move away from central London temperatures are seen to decrease significantly.

In addition it is possible to pick out the cooler spots around large scale parks and green spaces such as Hyde Park, Richmond Park and Regents Park, especially from the land surface temperature visualisation.

The air temperature image is produced from modelled data representing the period May-July 2006 which was during a particularly warm summer in London. The land surface temperature image was taken from the LandSat satellite data on the 26 June 2011 which again was a particularly warm day. However, it should be noted that neither of these summers were as hot as the heatwave of the summer of 2003.

In Figure 4 the land surface temperature in Richmond Park on the 26th June 2011 was recorded to be 27°C while in the West End it was recorded to be 31°C, a difference of 4°C.

It should be emphasised that the shape and intensity of the urban heat island and the distribution of heat exposure will change with different large scale weather conditions (Wolf & McGregor, 2013). However these images provide a striking visual depiction of the spatial variation of temperature within and in the proximity of a large city.

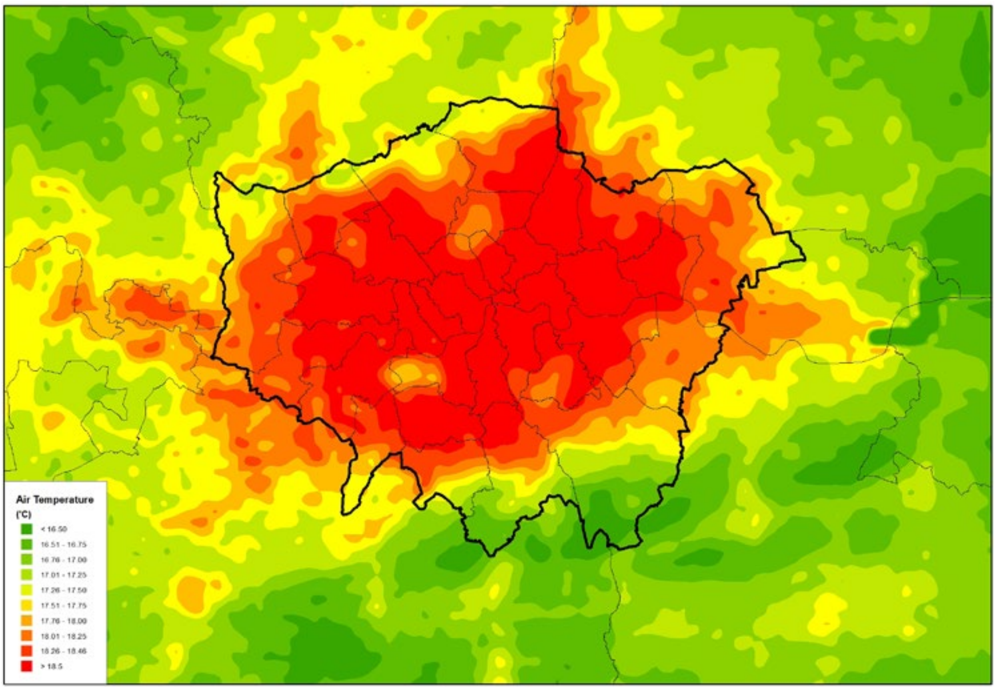


Figure 3 Modelled average air temperature (May-July 2006) with Greater London area border overlaid.

©Arup / University College London

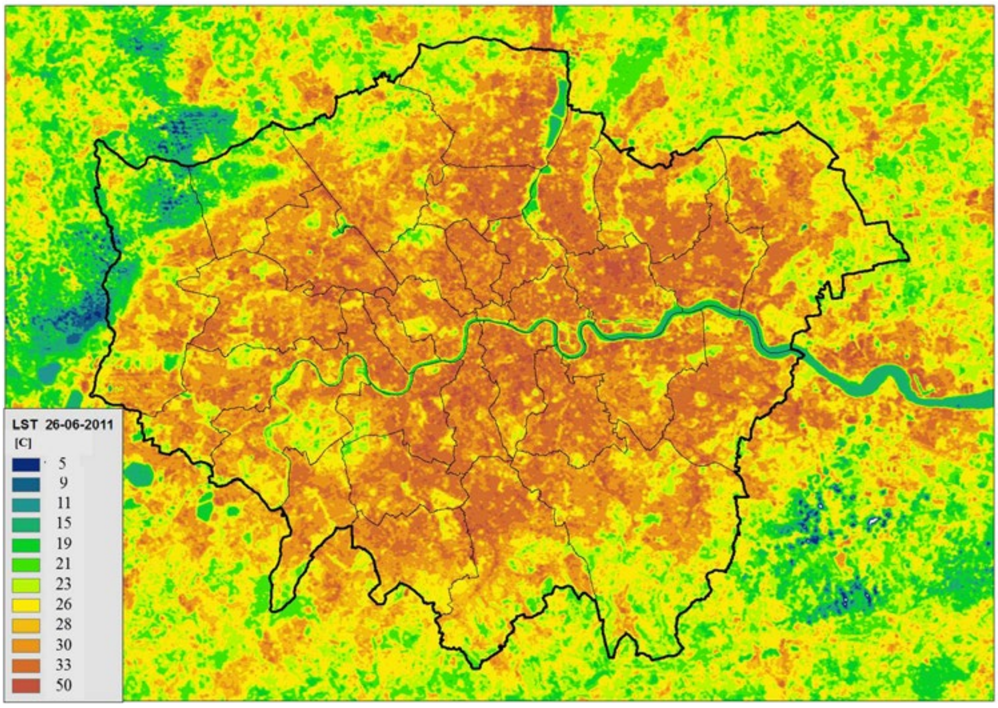


Figure 4 LandSat image of land surface temperature (June 2011) with Greater London area border overlaid.

©Arup / UK Space Agency

The All London Green Grid (ALGG) plan showing the major green spaces in London demonstrates the value of green infrastructure – it corresponds almost perfectly with the cooler areas in the land surface temperature image in Figure 4 showing that we need to increase the amount of trees and greenery within the 'warmer areas' to provide better cooling along streets and in urban spaces.

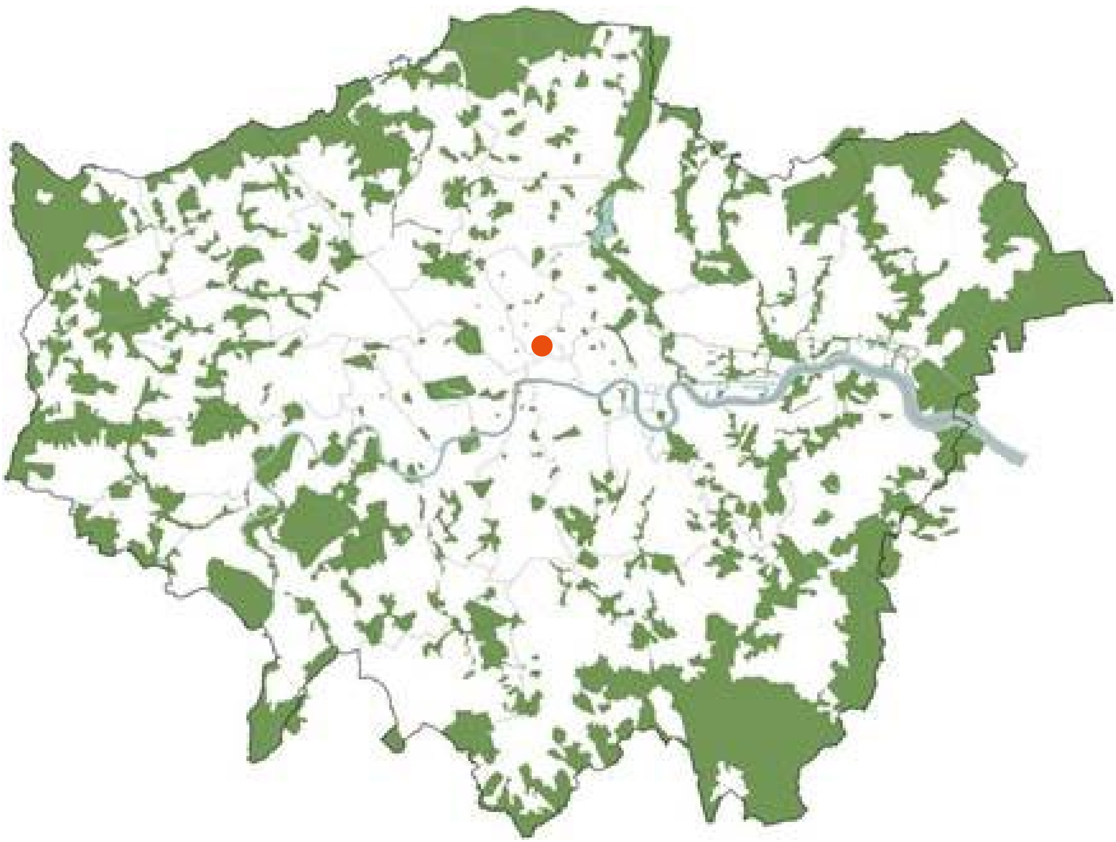


Figure 5 All London Green Grid (ALGG) plan showing the major green spaces in London. Pilot area of LB Islington shown by the red dot. ©Greater London Authority

3.2 Mapping and visualising the risk factors – borough scale outputs

The pilot area which was identified in Stage 4 of the methodology was the south of the London Borough of Islington. This pilot area is shown in the context of Greater London in red in Figure 6.

At the city scale the distribution of potential additional heat risk as a result of air and land surface temperature was mapped and quite clearly visualised. The pilot area is well within the central London urban heat island and as a result is potentially at risk from the associated additional heat. Looking at a finer spatial scale, other factors can be identified which relate to social vulnerability or to smaller scale geographical features other than large parks or large built up areas.

Figure 6 Location of pilot area in south Islington (Bunhill and Clerkenwell wards are shown in red). This represents the borough scale. ©Arup / UK Map

This area has a low density of green space compared to other parts of London, see Figure 5. It is of interest therefore to visualise this. If green space is mapped in combination with the land surface temperature the co-occurrence of low density of green space and high land surface temperatures is an indicator of greater heat risk.

In Figure 7, the green spaces in the wards of Bunhill and Clerkenwell are identified using green hatching. The green space data layer for London is overlaid onto the land surface temperature data layer and we have then 'zoomed in' to the pilot area within Islington.

It can be seen that there are no really cool areas within the pilot area. Whilst there are some areas where the green space and relatively lower land surface temperature do coincide is difficult to see a direct correlation between the land surface temperature and green space in this image. Further verification of the data would certainly be required.

Most of the green space shown in Figure 7 is in small patches, it would be expected that larger interconnected green spaces would produce a more significant reduction in the land surface temperatures, compared to the surroundings. This appears to be an indication that areas of green space need to be of a significant size to achieve a cooling effect which is in agreement with the LUCID project findings (Davies, 2010).

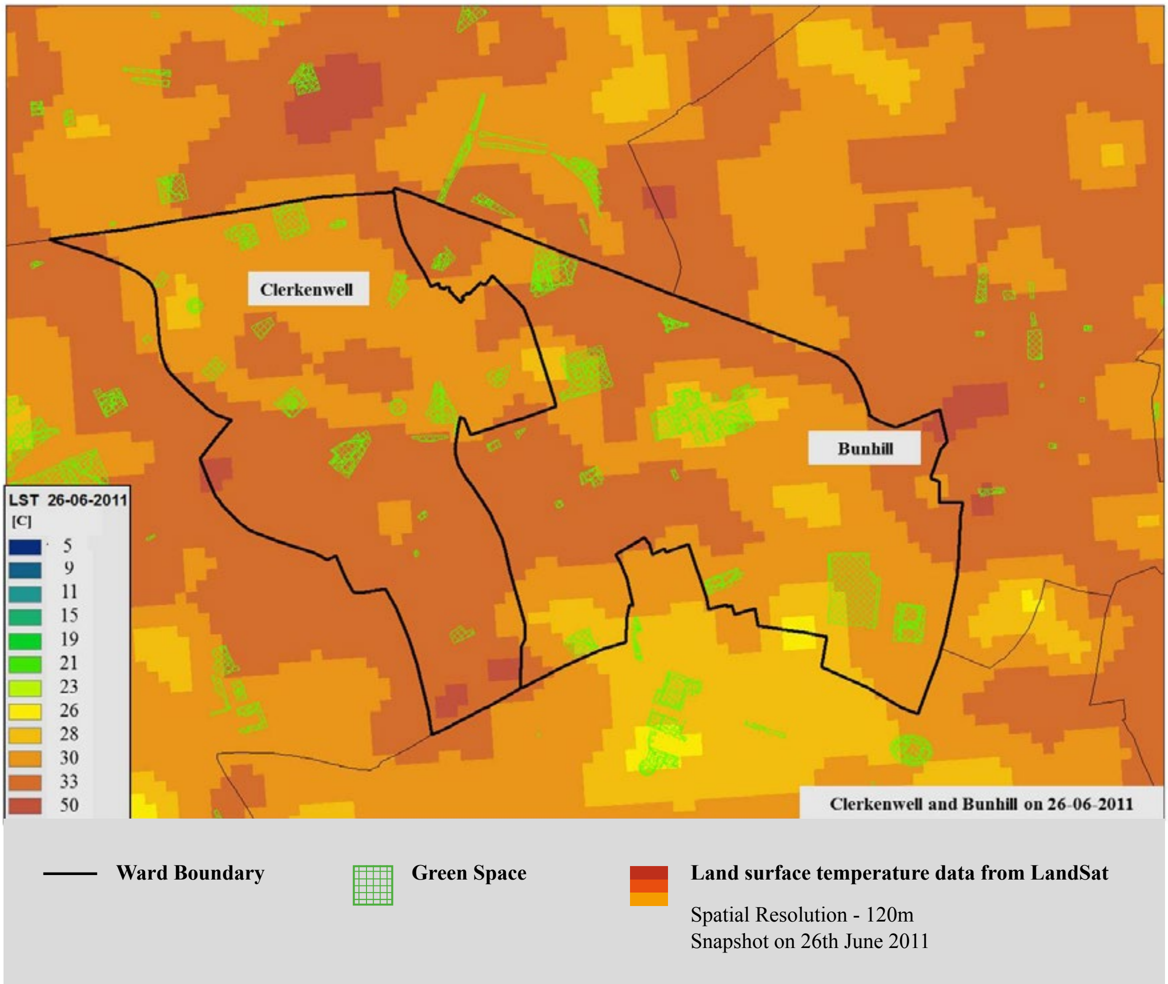


Figure 7 LandSat land surface temperature data overlaid with UKMap Data® of green space in pilot study area.
©Arup / UK Space Agency

It is useful to consider vulnerability to heat risk at the Super Output Area (SOA) scale. The SOAs are a set of geographical areas of consistent size, whose boundaries do not change (unlike electoral wards) and are suitable for the publication of data such as the Indices of Deprivation. It has been found (Wolf & McGregor, 2013) that vulnerability to heat risk is higher in SOAs in central London and in particular in the boroughs north of the River Thames.

In Figure 8, Indices of Multiple Deprivation (IMD) are plotted. IMD is an overall measure of deprivation experienced by people living in an area and is calculated for every SOA in England. IMD can be used to rank every SOA in England according to their relative level of deprivation. With IMD it is possible to identify SOAs which may be most vulnerable to heat risk in south Islington. Small circles in this image represent those SOAs which are most vulnerable, it can be seen that south Islington has quite a few SOA which are at the very extreme of the IMD most deprived scale.

The combination of being in the Urban Heat Island, having a low density of green space and this added layer of also being amongst the most socially deprived SOAs in England potentially puts residents in south Islington at particular risk of hot weather.

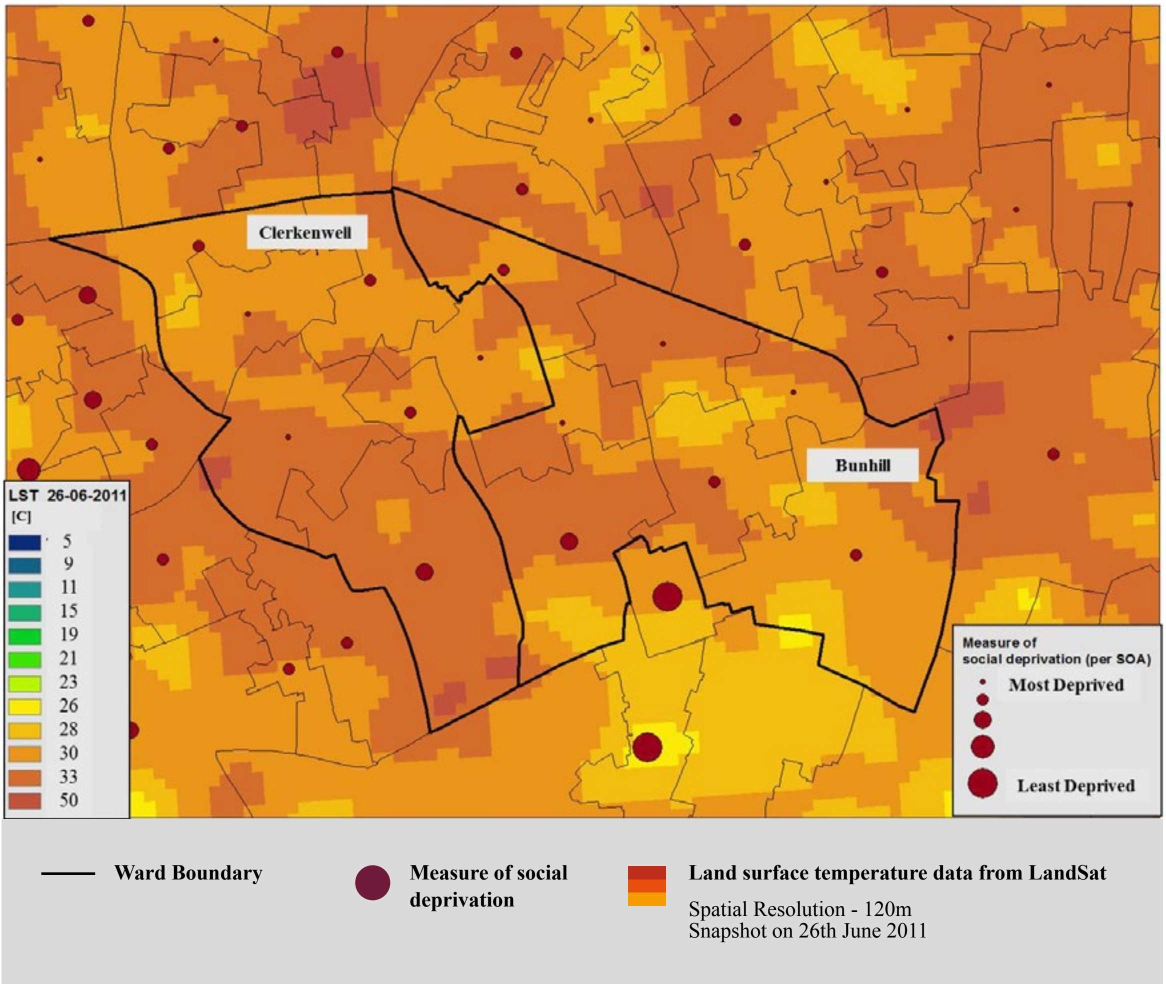


Figure 8 LandSat land surface temperature data overlaid with a measure of social deprivation at the super output area level. ©Arup / UK Space Agency

3.3 Mapping and visualising the risk factors – neighbourhood scale outputs

Looking now at an even finer spatial resolution of neighbourhood scale, further details about the vulnerability of buildings and particular groups of residents can be identified.

In Figure 9 the neighbourhood area within south Islington which is focused in on is identified by the blue square.

Urban heat risk is known to be greater on the highest floors of multi-storey buildings (Semenza, et al., 1996). Therefore to map and visualise this risk it was considered relevant to understand the location of buildings over 40 and 60 metres high. In Figure 10a any buildings which are higher

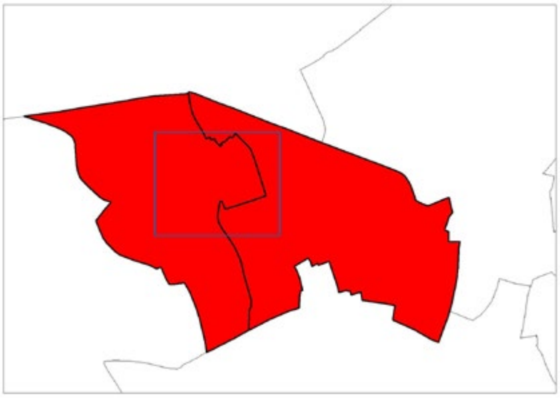


Figure 9 Neighbourhood scale area of interest. ©Arup / UK Map

Figure 10a UKMap® map of neighbourhood within pilot area, buildings over 40m (10-15 storeys) shown in blue. ©Arup / UK Map

Figure 10b UKMap® map of neighbourhood within pilot area, buildings over 60m (15-20 storeys) shown in blue. ©Arup / UK Map

Figure 11 LandSat land surface temperature data (June 2011) overlaid with UKMap® street map of pilot area. ©Arup / UK Space Agency

than 40m (10-15 storeys) and in Figure 10b buildings higher than 60m (15-20 storeys) are shown in blue. Residents on the upper floors of these high rise buildings may potentially be at greater risk as a result of hot weather than residents on the lower floors or in lower rise buildings. Another method to explore this risk would be to produce a thematic map of all building heights in the area, rather than use specific cut-off values of 40m or 60m. This would highlight residents potentially at risk in top-floor flats of buildings still considered high rise but lower than 40m or 60m.

In Figure 11 the LandSat land surface temperature data for June 2011 was combined with the UKMap® street map of the neighbourhood which has been focused in on. Again additional detail of streets and buildings can be seen which if combined with socio-economic data for SOAs and residential properties in this area can help to identify which residents may be at most risk.

It is apparent that by using these data sets together, it is possible to reveal the interactions between combinations of data. For example the propensity of heat risk is known to be much greater for occupants of high rise buildings, with little access to green space. Furthermore, using all of this information in combination it should be possible to quantify heat risk.

Although the datasets enable visually striking and clear illustration of the potential urban heat risk factors, their real value will be when they are used in conjunction with contextual knowledge of the local area, other datasets which are either not publically accessible or cannot be easily mapped and wider discussions with relevant decision makers.

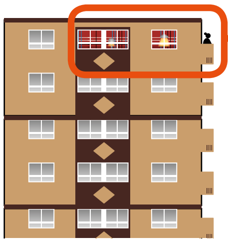
3.4 Clarification of the risk factors

Table 9 below summarises the three main types of criteria for assessing urban heat risk for people and residential properties. It should be noted that in order to simply and clarify what the key risks are, and what can be done about them these tables have been distilled from the significant body of literature on these topics reviewed in the Heat Thresholds Project (Arup, 2012) – for example (Lindley, et al., 2011); (Benzie, et al., 2011); (NHS England, 2011); (Greater London Authority, 2011); (Met Office, 2011); (Energy Saving Trust, 2005); (Health and Safety Executive, 2013); (Wolf & McGregor, 2013); (Mavrogianni, et al., 2009); (Wolf, et al., 2013); CIBSE Guide A; CIBSE TM36; CIBSE TM37 and CIBSE TM48.

Urban heat risk criteria	Explanation of what to assess
Location within London	Proximity to an urban heat island (UHI) 'hot spot' such as a densely built area or major road junction or a 'cool spot' such as a large park, streets or open/ urban spaces with effective tree canopy cover or water body. Levels of traffic, noise, air pollution and crime.
Characteristics of building	Age of construction, materials, orientation, layout, height, storeys, deep plan, single/dual aspect, balcony, garden, glazed areas, insulation, thermal mass, shading levels and ventilation.
Characteristics of people	Age, health, mobility, sex, socio-economic status, culture, languages spoken, awareness and experience of hot weather, perception of heat risk, levels of social connection. Existing risk profile and adaptive capacity issues.

Table 9 Triple risk index approach to assessing urban heat risk.

Three examples are provided below of how the triple risk approach to assessing urban heat risk can be used to create an overall risk profile for particular people in particular types of housing. It should be noted that although three risk criteria have been identified their relative importance has not been determined. Acquiring the data to define the significance of each of these factors would be an important next step for this research.

High risk example #1	
Location within London	Building within the UHI Close to a main road and busy road junction with associated noise and air pollution No green / blue space or mature tree canopy cover in the local area High levels of crime
Characteristics of building	Top floor flat of a tower block Poorly insulated walls and roof South / west facing windows and balcony No external shading Single aspect
Characteristics of people	An old person with mobility issues and a respiratory condition Spends the day at home with few visitors.

High risk example

Ms X is 68 years old with limited mobility and a respiratory condition. Her days are spent mostly at home with occasional visitors. Her top floor flat is in a tower block with poorly insulated walls, south facing windows and balcony and no external shading. She lives within a UHI, close to a main road with no green or blue space in the area.

Figure 12 High urban heat risk example. ©Arup

Medium risk example #2	
Location within London	Building within the UHI Close to a main road and busy road junction with associated noise and air pollution No or little green / blue space or mature tree canopy cover in the local area and/or along streets Moderate level of crime
Characteristics of building	Top floor flat of a converted terraced house Poorly insulated walls and roof South / west facing windows No external shading Dual aspect but no garden
Characteristics of people	A young family with two under 5 year olds, one with asthma One parent and both children spend most of the day at home.

Medium risk example

Mr and Mrs Y are both 36 with two children, both under five years old. Mr Y works from home in the evenings and during the day, looks after the children, one of which suffers from asthma. They live in a top floor flat of a converted terraced house which has poorly insulated walls and roof. It is dual aspect but with no garden, no external shading and west facing windows. Situated within a UHI, there is no green or blue space or mature trees in the local area.

Figure 13 Medium urban heat risk example. ©Arup

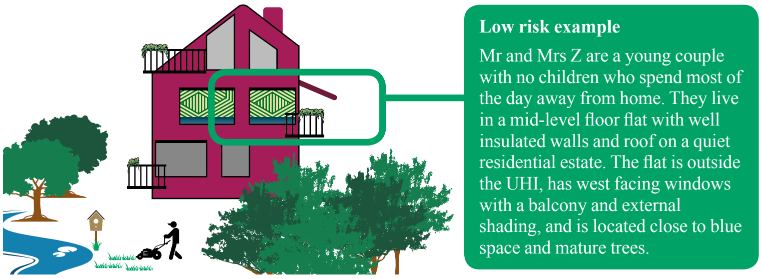
Low risk example #3	
Location within London	Building outside the UHI Quiet residential estate Green / blue space and significant mature tree canopy cover in the area and/or along streets Low levels of crime
Characteristics of building	Mid-level floor flat in a tower block Well insulated walls and roof South / west facing windows with balcony External shading Dual aspect
Characteristics of people	A young couple with no children yet Spend most of the day out of the home at work.

Figure 14 Low urban heat risk example. ©Arup

3.5 Identification of approaches and responses to address the problem and the risk factors

It is clear that in order to address the problem of urban heat risk and manage the individual risk factors, there is a need to understand what the various approaches and responses to doing so are.

For the purposes of this report approaches have been categorised as physical or social and strategic or operational and are interchangable with responses. Working definitions of what we mean by **physical, social, strategic** and **operational** approaches, or responses, are provided in Table 10, along with generic examples of each.

Some approaches and responses may not be as easy to categorise as others, but it is considered that this is a useful way of beginning to think about them. Combinations of these approaches can be useful for managing urban heat risk and combined with other measures for example reducing air pollution, traffic, noise and crime in London.

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Approaches and responses to addressing urban heat risk	Explanation of what approaches and responses cover
Strategic – before a hot weather event.	Involve longer term, larger investments of time and resources with less immediate results. BEFORE heatwave.
Operational – during a hot weather event.	Involve shorter term reactive efforts with more immediate results. DURING heatwave.
Physical	Involve a change, intervention or improvement to the urban environment, or a particular neighbourhood or building.
Social	Involve policies and practices relating to awareness raising, communication and behaviour change.

Table 10 Four main approaches or responses to address urban heat risk.

Examples of **strategic physical** responses would be the increased planting of trees and provision of well irrigated green space in urban neighbourhoods, or ensuring the integration of physical measures to reduce urban heat risk into planned refurbishment and upgrade works to residential properties.

An example of a **strategic social** response would be the development of policies for action following a heatwave which could be utilised during the next heatwave with relatively low additional investment.

Examples of **operational physical** responses would be the provision of fans or even temporary air conditioning units for known vulnerable residents during a heatwave, or the opening of windows at the right times of day to allow ventilation and cooling without letting in heat.

Examples of an **operational social** response would be the resourcing of a dedicated hot weather emergency telephone line during the summer for residents who needed advice or visits to help them deal with the effects of hot weather.

If operational responses are undertaken without any strategic thinking, they may have limited effectiveness over the long term or may cause unexpected additional short term costs and challenges. For example, if there are no readily available fans due to the fact none were purchased in advance; getting hold of them quickly might be expensive or difficult. If the locations of most vulnerable residents are not mapped and known in advance, it will be difficult to respond to their needs in a timely way during a heatwave.

Similarly if physical responses are undertaken without any additional social measures, people may not experience the full intended benefits of them. For example, new window openings or blinds provided to residents for ventilation and shading purposes without explanation or guidance about what times of the day to open or close them, may mean they are ineffective at best and exacerbate the problem at worst.

More specific examples of approaches and responses to addressing urban heat risk and managing the risk factors which have been identified throughout the course of this project are summarised in Table 15-Table 18 in Appendix 7.1.

3.6 Approaches and responses to addressing the problem and risk factors –multi-scale

Based on the outputs produced by the project, and the review and analysis of the available literature, approaches to addressing urban heat risk can be considered as falling into four main categories: physical; social; strategic, and operational. These approaches can also be considered as relevant to four spatial scales: the city scale; the borough or neighbourhood scale; the building or block scale, and the community or individual scale. These approaches and spatial scales are summarised in Table 11-Table 14 below. The sources from which these are derived are included in Appendix 7.1.

3.6.1 City scale approaches

At the city scale most approaches will necessarily be strategic, and will involve consideration of the spatial distribution of urban heat risk across the city. Table 11 summarises some of the approaches for addressing heat risk at a city scale.

Many of the physical approaches involve managing, enhancing and creating more trees and green spaces in London. Trees and green space provide a significant and essential resource in providing protection for urban citizens from heat and other effects of climate change. An estimated 20% of London's land area is currently under the canopy of trees (Greater London Authority, 2010) and about 38% of its land area is designated as 'green space' (Department for Communities and Local Government, 2005); (Greater London Authority, 2010). The areas of London that are relatively better endowed with trees and green spaces benefit from their cooling function, but there are also many areas that suffer from no or poor coverage, lack of green space and tree canopy protection. This contrast is depicted by the land surface temperature image (Figure 4) and as development pressure grows there will be a greater need to protect this existing resource and further develop significant areas of green space, street trees and canopy cover in London to counter the effects of urban heat. However, there is a need to ensure the right tree species are planted in the right locations for the right climate (Doick & Hutchings, 2013).

Studies show that air temperatures and surface temperatures in cities can be reduced by between 2–8°C as a result of the shading and evapotranspiration provided by trees and green spaces (Arup, 2014). If London's current provision of trees and wider green infrastructure is therefore assumed to provide a 2-8°C 'temperature buffer' during hot weather events, investing in improving and increasing the number and types of green spaces, at a range of spatial scales and locations throughout the city would appear to be a good strategic investment. In order to achieve cooling beyond the immediate site of an individual tree or green space, guidelines suggest that green spaces should be a minimum of 0.5 hectares in size (Doick & Hutchings, 2013).

Regarding the significance of urban trees and green space the Government's White Paper (UK Government Natural Environment White Paper – 50 year Vision for the Natural Environment) on the natural environment recognises the range of benefits that green infrastructure provides and highlights the importance of effective management to realise them. The white paper also states that the 'natural environment underpins our economic prosperity, health and well-being'. To support the delivery of these outcomes the Greater London Council has produced the All London Green Grid (ALGG) Supplementary Planning Guidance (SPG). This provides guidance on the implementation of London Plan policy to:

- Protect, conserve and enhance London's strategic network of green and open natural and cultural spaces.
- Encourage greater use of, and engagement with, London's green infrastructure and extending and upgrading the walking and cycling networks in between to promote a sense of place and ownership for all who work in, visit and live in London.
- Secure a network of high quality, well designed and multifunctional green and open spaces to establish a crucial component of urban infrastructure able to address the environmental challenges of the 21st century – most notably climate change.

This is an important initiative in terms of protecting this existing resource and further developing and increasing the percentage of canopy coverage to provide adequate protection and resilience into the future from urban heat risk.

Other more radical approaches could involve reducing traffic or having traffic free days in central London, or putting traffic underground along strategic routes.

	Strategic	Operational
Physical	**Planting and management of trees** – right tree, right place and increasing the % of canopy cover **Creation of water bodies and water features** where lacking and appropriate Consideration of the **spatial scales of cooling by different types of green spaces** e.g. green roofs, green walls where space is limited or 0.5ha green spaces for wider cooling benefits. **Reduce sources of air and noise pollution** in central London during hottest three months of the year. e.g. by car free days	N/A
Social	**Incorporate measures for addressing urban heat risk into key plans and policies** for London. Encapsulate **targets for planting trees** and enhancing existing or creating **new green spaces into plans and policies** for London. Place **requirements upon developers to enhance or create green space** in any major planning or redevelopment opportunity.	

Table 11 City scale approaches for addressing problems and risks factors.

3.6.2 Borough / neighbourhood scale approaches

At the borough and neighbourhood scale, many of the strategic and physical approaches are versions of those developed at the city scale, but due to the closer connection with local residents, there is more overlap with operational and social approaches too, these are summarised in Table 12.

	Strategic	Operational
Physical	**Planting and management of trees -** right tree, right place and increasing the % of canopy cover. **Create water bodies and water features** where lacking and appropriate. Consideration of the **spatial scales of cooling by different types of green spaces** e.g. green roofs, green walls where space is limited or 0.5ha green spaces for wider cooling benefits. **Shading of streets and external spaces areas by other structures/materials** e.g. pergolas, retractable canopies, shading devices fixed to buildings. Put in place a plan to **reduce sources of air and noise pollution** during hottest three months of the year Put in place a plan to **switch surfaces from grey to green** and impermeable to permeable. Replacing hard surfacing with green (e.g. grass) in urban areas will help with urban cooling.	**Water bodies and water features**. Paddling pools and fountains filled and turned on during hot weather. **Shading by other structures/materials**. Retractable canopies brought into use during hot weather. Actually **reduce sources of air and noise pollution** during hottest three months of the year
Social	Produce localised addendums to the NHS National Heatwave Plan.	

Table 12 Borough/neighbourhood scale approaches for addressing problems and risk factors.

3.6.3 Building / block scale approaches

At the building or block scale, most approaches are strategic and physical and often related to planned upgrades and major refurbishment as well as adhoc opportunities to make improvements. Some have overlaps with operational approaches, but all social approaches are considered under the community / individual category, these are summarised in Table 13.

	Strategic	Operational
Physical	**Internal and external wall insulation** to keep building's cool in summer and warm in winter. N.B. There is evidence that some types of internal insulation might actually increase indoor temperatures if no sufficient ventilation is provided. **Ventilation and cooling** – passive systems if possible and mechanical if necessary. **Flat roof refurbishment** – improved insulation to keep building cool in summer and warm in winter, green roof or white reflective paint. **Green roofs, walls and climbing plants** on buildings. **Shading of streets and external spaces areas by other structures/ materials** e.g. pergolas, retractable canopies, shading devices fixed to buildings. **Installation of water efficient taps and showers.** **Security proof and pest proof windows** so they can be left open for ventilation without fear of crime or animal entry. **Undertake and learn from temperature monitoring and modelling** of urban heat risk reduction measures in residential properties, care homes and day centres. **Double or Triple glazing** to keep building cool in summer and warm in winter. **Mechanical extract ventilation** to keep building's cool in summer. **Heat reflective exterior** to reduce solar gain in buildings. **Implementing green and permeable surfacing** rather than hard surfacing will help with urban cooling.	**Ventilation and cooling – passive and mechanical.** Systems need to work during hot weather. **Understandable technologies** e.g. mechanical cooling or ventilation systems need to be easy to use. **Water efficient taps and showers.** Allows residents to take regular cool showers during hot weather.
Social	Communication of risks and responses.	N/A

Table 13 Building/block scale approaches for addressing problems and risk factors.

3.6.4 Community / individual scale approaches

At the community / individual scale approaches are very much linked to strategic and social approaches at the borough / neighbourhood scale, and those at the building / block scale. There is much more of a focus on communication and awareness, and on how to respond to hot weather events when they happen, as summarised in Table 14.

	Strategic	Operational
Physical	Establish **supply and procurement of energy efficient electric or mechanical fans.** **Identification of local 'cooling' centres** such as leisure centres, community centres or cafes known to be cool or which have additional cooling provision.	Implementation of **window, curtain and blinds management.** Provision and use of energy efficient electric or mechanical fans. Use of local 'cooling' centres.
Social	**Provision of reliable means of communication and broadband** - to residential properties, care homes and day centres. **Understandable technologies** e.g. mechanical cooling or ventilation systems need to be easy to use. **In-home overheating reduction advice** from energy advisors. **Heatwave broadcasts and alerts** to partner services. Develop **'Keep Cool' information materials for residents** which include advice on: hydration; clothing; sun safety; avoiding hottest times of day; sleeping environment; switching off appliances and window, curtain and blinds management. **Develop capability for a 'Hot weather hotline'** and social visits during hot weather.	**Use of reliable means of communication and broadband –** residents can stay informed and keep in touch with key people during hot weather. NICE guidance (on preventing excess cold weather deaths) suggests integrating Telecare monitors with smart meter technology (NICE, 2014). This could be extended to guidance on preventing excess hot weather deaths. **Air quality alerts** via airTEXT **Heatwave broadcasts and alerts** to partner services. Staffing of a **"Hot weather hotline' and social visits** during hot weather. **Distribute 'Keep Cool' information materials for residents** which include advice on: hydration; clothing; sun safety; avoiding hottest times of day; sleeping environment; switching off appliances and window, curtain and blinds management. **Distribute'Keep Cool' packs for vulnerable residents** which include: a hat; mini fan; portable water cooler mist spray (refillable non aerosol); reusable cool gel packs - for forehead or frozen can be added to a bowl of water to cool feet; thermos mug, and thermometer card.

Table 14 Community/individual scale approaches for addressing problems and risk factors.

Figure 15 summarises the main risks and problems and provides examples of approaches and responses to addressing them.

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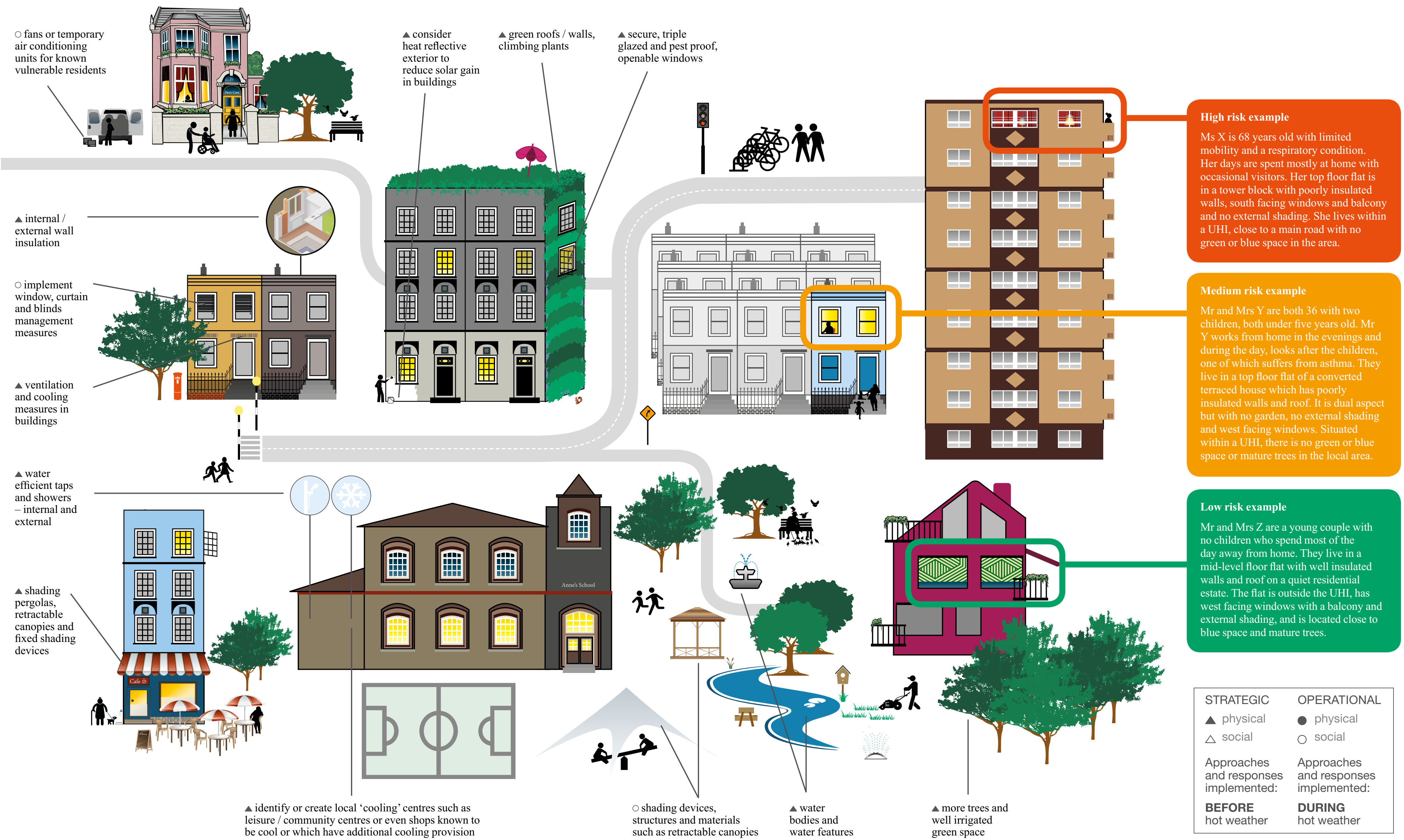

Figure 15 Infographic depicting approaches and responses to reducing urban heat risk. ©Arup

4 Distillation of key messages for decision makers

It is apparent that the number of studies and reports about understanding and responding to urban heat risk in large cities such as London is growing. This is in response to direct experiences of hot weather and the urban heat island effect in these cities, and based upon projections for climate change, population growth, demographic change, urban development and densification.

This project builds upon existing studies and reports, and working collaboratively with project partners has begun to identify, map and visualise the factors which contribute to urban heat risk in London. This is what Section 2 and 3 of this report set out, and what the project outputs summarised in Sections 3.1 – 3.3 have sought to do.

Having identified, mapped and visualised these factors, a clear menu of approaches (categorised by physical, social, strategic and operational, and by spatial scale) to address the individual risk factors and the problem of urban heat risk as a whole has been set out. This is what the Tables and infographic in Sections 3.4 – 3.6 do.

Based upon the work we have done and the outputs we have produced the key messages for all decision makers in London can be distilled as follows:

- **Urban heat risk is already an issue for London and is projected to increase** due to climate change, population growth, demographic change (an ageing population and growing number of under 5 year olds), urban development and densification in the capital.
- The **areas of London which are most at risk** are those within the existing urban heat island, with high population density, noise and air pollution due to traffic, crime and security issues, hard surfaces and lack of tree canopy or green space, limited access to water bodies and water features.
- The **buildings within London which are most at risk** tend to be those which are in the high risk areas identified above, have poor insulation, are exposed to direct sunshine, large areas of glazing, often south/west facing or un-shaded, are less able to be ventilated naturally i.e. single aspect, have little or no outdoor space.
- The **people within London who are most at risk** are the elderly and the under-fives, and those with existing respiratory, cardio-vascular or mental health conditions living in the buildings and the areas identified above.

The 'triple risk index' approach to understanding the urban heat risk factors is a useful way of thinking about the potential problem. The concept of an 'urban heat risk index' for London should be developed further. The strategic, operational, physical and social approaches and responses to addressing urban heat risk before and during a hot weather event should focus on these areas, these buildings and these people.

Key messages for specific groups of policy and decision makers are summarised below:

- **Mayor of London**
  Ensure that managing urban heat risk continues to be reflected within relevant plans, policies and strategy documents such as the London Plan and the Climate Change Adaptation Strategy. Ensure that approaches to addressing urban heat risk continue to be clarified and strengthened

with increasing requirements and pressure on planners and developers to incorporate them into redevelopment projects as essential requirements. There may be a need for legislation and regulation to enforce policy. Link measures to reduce urban heat risk to measures to improve air quality in London for example the Street Tree initiative, RE:LEAF and the Low Emissions Zone.

- **Members of the public**
  Most people who live, work or visit London enjoy hot weather when we get it. But hot weather can also pose serious risks to us all if we are not aware of basic measures to reduce them as explained in the 'Keep Cool' information and pack (Public Health England, 2014). As urban heat risk is more of an issue for older people, under-five year olds and people with existing respiratory, cardio-vascular or mental health conditions, look out for friends, family, neighbours and colleagues who fall into these groups during hot weather.

- **Public health professionals**
  Cold weather still poses more of a risk to vulnerable residents than hot weather, but urban heat risk is now a significant issue leading to heat related stress and excess deaths and is clearly an increasing issue in London. Consider dealing with hot and cold weather events as part of a wider Seasonal Management Plan. Create information hubs for the 'Keep Cool' guidance, and signpost members of the public to relevant information and cooling centres.

- **Housing professionals**
  Consider all of the physical and social measures for reducing urban heat risk for buildings and people detailed in Section 3.6 and assess which ones might be viable and cost effective given planned upgrades and refurbishment plans, and which ones might require engagement and communication with local residents. Create information hubs for the 'Keep Cool' guidance, and signpost residents to relevant information and cooling centres.

- **Planners and developers**
  Make the most of opportunities provided by planning applications and redevelopments to incorporate urban heat risk reduction measures including urban greening. It is recommended that priority be given to multi-functional green infrastructure design approaches, fulfilling the objectives of planning guidance like the All London Green Grid and planting large species trees to significantly increase the canopy cover of the city where possible. It takes 15 - 40 years, and the right species, for a tree to grow large enough to deliver meaningful cooling benefits (as well rainwater management and biodiversity benefits) so planting trees and increasing canopy cover now will be essential to reduce the increased urban heat risk for London in the future.

- **Local politicians**
  Older people and parents with young children are voters. Demonstrating that there is a local understanding of urban heat risk issues, and that approaches to addressing them are specific to their needs and are being developed and implemented, will engender confidence amongst your constituents.

- **Insurers**
  Urban heat risk may have implications for buildings insurance and health insurance policies. Informing clients and customers about the potential risks and what can be done to reduce them may be beneficial.

5 Recommendations for further work

The methodology and outputs of this project have provided valuable insights, information and tools for the analysis, communication and management of urban heat risk.

Based on the methodology and outputs which have been produced as part of this project we would make three recommendations for further work, they are detailed in Sections 5.1-5.3.

5.1 Further development of a web-based interactive urban heat risk database for London and its boroughs

Further development of a web-based interactive database which provides a platform to host all of the data collated in relation to urban heat risk in London as part of this project. The data should be geographically based and able to be presented in map format. This could have potential links to existing resources such as:

Strategic Health Asset Planning and Evaluation (SHAPE) database
http://shape.dh.gov.uk/

SHAPE is a web-enabled, evidence-based application which informs and supports the strategic planning of services and physical assets across a whole health economy. It links national datasets for clinical analysis, public health, primary care and demographic data with estates performance and facilities location, and enables interactive investigations by Local Area Teams, Providing Trusts, Clinical Commission Groups (CCGs), GP practices and Local Authorities.

During the course of the project we had a conversation with SHAPE about whether our data layers might be of use and interest to them. Their initial response was positive. We would recommend that conversations with SHAPE are re-established.

London Data Store
http://data.london.gov.uk/datastore/useful-links

The London Datastore has been created by the Greater London Authority (GLA) as an innovation towards freeing London’s data. It wants citizens to be able access the data that the GLA and other public sector organisations hold, and to use that data however they see fit – free of charge. The GLA is committed to influencing and encouraging other public sector organisations to share their data here too. Releasing data though is just half the battle, raw data often doesn’t tell you anything until it has been presented in a meaningful way. The GLA wants to encourage the masses of technical talent that exists in London to transform rows of text and numbers into apps, websites or mobile products which people can actually find useful.

It would seem that the data identified, collated and analysed as part of this project could be shared with the London Data Store where it fits the criteria of being free for the public to access. The technical talent available in London may have further ideas about how to make this data even more useful and engaging than this project has.

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All London Green Grid (ALGG)
http://www.london.gov.uk/priorities/environment/greening-london/improving-londons-parks-green-spaces/all-london-green-grid#

The All London Green Grid (ALGG) is a policy framework to promote the design and delivery of green infrastructure across London. It has been developed to support London Plan policies on green infrastructure and urban greening, and those relating to open spaces, biodiversity, trees and woodland, and river corridors. It comprises the ALGG Supplementary Planning Guidance and a series of ALGG Area Frameworks which identify objectives and projects at a sub-regional level.

The map of urban greenspaces which comprise the ALGG matches up almost exactly with the cooler areas of the land surface temperature satellite image of London, Figure 5 and Figure 4 respectively. Satellite data obtained for this project, and further additional requests for specific satellite data capture from the UK Space Agency, could contribute to greater understanding of the distribution and characteristics of urban green space in London.

Greenspace Information for Greater London (GiGL)
http://www.gigl.org.uk/

GiGL is the capital's environmental records centre – it collates, manages and makes available detailed information on London's wildlife, parks, nature reserves, gardens and other open spaces.

Satellite data obtained for this project, and further additional requests for specific satellite data captured from the UK Space Agency, could contribute to greater understanding of the distribution and characteristics of urban green space in London.

5.2 Further development of an urban heat risk index for London and its boroughs

Building specifically on the work of this report and that of Wolf and McGregor (2014) and Mavrogianni et al. (2009) an Urban Heat Risk Index should be developed further at the London wide city scale and at the borough scale. This could be combined with work carried out as part of the AWESOME project on mapping indoor overheating and air pollutant exposure. The Wellcome Trust's Sustaining Health programme and the EU LIFE Programme may be potential viable sources of funding to develop this index further.

5.3 Targeted monitoring and measurement of relevant data

Continued and increased monitoring and measurement of relevant data for London such as air temperatures and land surface temperatures and the number, characteristics and value of trees and green spaces. This could have potential links to:

The London Climate Data Portal (LCDP)
http://climatelondon.org.uk/publications/observing-london/

The London Climate Data Portal is proposed to house information and utilise existing web sites (i.e. provide links rather than duplicating content). However, given the large number of short term projects that have collected valuable data, there would be the capability to archive information about these and the data they have collected to ensure these are not lost. This may include: data, reports, metadata, names of individuals who were involved etc. The portal would act to facilitate archiving in a common way and future-proof this.

The intelligent search engine would facilitate those looking for data and select what would be appropriate for particular applications (e.g. purchased freely available, metadata, siting characteristics, quality control) and provide links across the different user communities for relevant information to specific applications. Also the portal will provide links to further information about other key aspects of the analysis of meteorological and climate data (e.g. gap filling or conversion of formats). Thus it would act as a network of networks: for meteorological stations, data providers (raw and value added) and data users.

The RE:LEAF London Partnership i-Tree Project 2014 Tree and Woodland Survey of Greater London
http://www.treeconomics.co.uk/i-tree/i-tree-eco

The RE:LEAF London Partnership is undertaking a survey of London's trees and woodlands during Summer 2014, to establish the benefits they provide and put a value on them. This will include their cooling potential. It is anticipated that the results of this survey will be captured digitally and geospatially which would allow new data layers to be added to existing GIS databases for London.

UK Space Agency / University of Leicester

Further engagement with the UK Space Agency could allow for more targeted requests for satellite and geospatial data being made. They could potentially be approached to monitor specific locations in London over an agreed timeframe so that satellite data could be obtained more systematically than it is currently.

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7 Appendices

7.1 Measures for addressing urban heat risk

Many of the approaches in Section 3 of the report which this project has categorised as: strategic; operational; physical, and social and city scale; borough / neighbourhood scale; building / block scale, and community / individual scale have been drawn from the sources of information contained in Table 15-Table 18 below.

Measure	Strategic	Operational
Internal wall insulation	In certain circumstances, particularly in top floor flats occupied during the day, internal wall insulation may increase risks of overheating as temperatures rise. Homes (particularly tower blocks and top floor flats) with single aspect ventilation, large south facing windows and/or communal heating systems are particularly vulnerable. It is particularly important to consider this issue where people may have less adaptive capacity such as dwellings with vulnerable, elderly and/or bed-ridden occupants.	Shutters and shading, internal blinds, external wall insulation and roof insulation can all help reduce the likelihood of overheating. External shading and shutters should be the preferred option, where possible. Internal shading tends to be less effective in general as the solar gains are still trapped within the building envelope.

Ventila-tion	Effective ventilation can increase thermal comfort as well as reducing damp and humidity. Air-conditioning can be very effective but produces carbon emissions, uses energy and creates waste heat. This increases the potential for fuel poverty, exacerbates the urban heat island effect and impacts of climate change. When the external temperature lies below the internal temperature night time purging of heat is possible. This difference is, however, likely to become lower under future climate change scenarios. Security, outdoor air pollution, vermin and noise concerns in urban environments can also hinder night time purging. There may be times when air conditioning is appropriate (especially for vulnerable residents during heat waves), however future planning can provide cost and energy effective alternatives to air conditioning.	Increasing cross ventilation in combination with passive measures such as shading, additional glazing, wall insulation and internal hot water pipe insulation, can significantly reduce heat gain. Mechanical ventilation, particularly where cross ventilation is not possible, can be used in some retrofits to improve performance. Ensure installers take the time to educate users. Provision of clear easy to follow visual guides is essential. Ensure issues such as summer bypass and filter maintenance, are considered. Where possible follow the cooling hierarchy: minimise internal heat generation through energy efficient design to reduce heat entering the building in summer through shading, albedo, fenestration, insulation and green roofs and walls. Manage the heat within the building through exposed internal thermal mass and high ceilings. Passive ventilation versus mechanical ventilation; choose the lowest carbon option when considering active cooling systems.
Trees	The tangible impacts of trees on internal comfort can be easily overlooked. Natural shading, particularly for homes with extensive southern aspect glazing, will become increasingly important as temperatures rise. Natural shade can reduce the urban heat island effect, improve air quality and absorb surface water runoff, which can reduce flood risk.	Broad leaf deciduous trees are preferred. They let more light in during winter months and their road leaves have a greater surface area to absorb incoming solar radiation and airborne pollutants. Certain species are more effective in absorbing airborne PM10 particles –lime and beech are a good choice of species. Thoughtful use of trees, can increase happiness and mental and physical wellbeing and add monetary value to an area.
Flat roof refurbish-ment	Traditional flat roofs at the end of their life present opportunities to integrate a number of roofing options. They could be in areas of high surface water flood risk, low cloud cover and/or high rainfall.	Replacing traditional roofs with a green roof can offer water management and ecological benefits. Often roofs can be strengthened if the design load bearing capacity is not sufficient to hold the additional weight of a green roof. Where this is not an option an albedo roof (or white roof) could be considered and assist in reducing overheating in the building.

External environ-ment / landscap-ing	Poor planning design and management of landscape areas can exacerbate surface water flooding and reduce effectiveness of cooling air temperatures through shading and evapotranspiration.	Integrate Sustainable Urban Drainage Systems (SUDS) or Water Sensitive Urban Design (WSUD) into the landscape design to create multi-functional bio-diverse amenity space that also mitigates flood risk. This can also help in reducing the local temperature a potential benefit in communities suffering high summer time temperatures.
Commu-nication / broad-band	In a changing climate we may also have to adapt our behaviours – communication can be as, or more effective than expensive technologies. Energy efficiency pilots have proven that awareness training, can improve the results of technological investments.	
Under-standable technolo-gies	Performance of new technologies can be highly dependent on the design, quality of installation and appropriate control by users. Technologies that are hard to understand cause problems. This is particularly relevant where maintenance teams, residents or installers are likely to have a high turnover, or have a low understanding of new technologies.	Ensure that any new technologies are combined with passive measures such as increased insulation and ventilation as well understandable and user-friendly controls. Also consider on-going support.
Water efficient taps and showers	A simple choice of fitting can reduce water usage and save energy with little or no impact on quality. Cool showers or baths may be one way people choose to stay cool during hot weather.	Research has shown that aerated shower heads with flow rates of 8 litres per minute are widely accepted, and can even improve performance. Low flow aerated shower heads can save 22 litres of water per person per day and £26 per person per year in energy bills. Water efficient taps, toilets and baths are also available.

Table 15 Measures to address urban heat risk which could be incorporated when planning retrofits of social housing. Adapted from (London Climate Change Partnership, 2014).

Measure	Description
Evaporative cooling and transpiration of plants	Through evaporation, incoming energy from the sun is used to convert water into water vapour. The sun's energy is used to drive the evaporation process rather than being transferred to the sensible heat that we feel, so that air temperatures are lower (Oke, 1987). Where the water is within a plant, on its surfaces or in the soil, the process is termed evapotranspiration.

Reflectance / albedo of greenery	The extent to which energy from the sun heats the urban environment is linked to surface albedo, or reflectance of radiation. Dark matt surfaces such as asphalt and concrete have low reflectance or lower albedo values. This means that more energy is absorbed and stored which warms the local environment. Lighter more reflective surfaces, including greenery, have a higher albedo therefore reflect more heat away from the local environment. Changing the albedo of the materials of buildings, car park surfaces and pavements will also have an impact on the heat absorption and reflectance of a building and its surrounding environment. The use of highly reflective materials in buildings, pavements and car parks are feasible options to reduce the UHI, yet have seen limited integration in UK cities (Mills, 2005).
Shading from urban trees	Shading combats the UHI in three complementary and cumulative ways. Firstly, by limiting solar penetration shading restricts energy storage and the heating of the local environment that subsequently occurs. Secondly, shading reduces the direct gain of energy through windows and the resultant 'internal' greenhouse effect. Lowering electric fan use or air-conditioning demand leads to energy and cost savings and reduces the emission of waste heat energy. Finally, shading shelters people from direct exposure to the sun, which is important as thermal discomfort has been suggested to relate more to higher radiation exposure than higher air temperatures (Emmanuel, 2005). The magnitude of cooling from shade-effect trees depends upon crown shape (broad being best) and density. In temperate climates the contribution to cooling of shading and evapotranspiration from trees are approximately equal. Trees placed close enough to directly shade buildings (termed shade-effect trees) can lower summertime energy demand for cooling a building's indoor climate. At UK latitudes, trees on the west-facing side of a building provide good amounts of shade in summer (when it's needed) and comparatively little in winter (when it's not). Trees that do not provide direct shade to buildings but are located close enough to influence the local microclimate are termed climate-effect trees. These trees cool the local microclimate through evapotranspiration, leading to summertime air-conditioning energy savings.

Spatial scales of cooling by urban green spaces	The surface temperature within a green space may be 15–20°C lower than that of the surrounding urban area, giving rise to 2–8 °C cooler air temperatures and a cooling effect that extends out into the city (Taha, et al., 1988); (Satio, 1991). The cooling impact of a large park (500 hectares) in Mexico City reached a distance of about 2 km, (Jauregui, 1991). A medium size 60 hectare park can reduce noon-time air temperature by up to 1.5°C for up to 1 km distance, in a leeward breeze (Ca, et al., 1998). A small 0.5 ha park in Haifa, Israel, created a cooling zone of 1.5°C which extended up to 150 m (Givoni, 1998). A 0.24 hectare greenspace in Kumamoto City, Japan created a cooling band of 1–2 °C which extended some 20m around the park (Satio, 1991). In addition to the role of greenspace size, the extent of the cooled area around a greenspace is influenced by the type and composition of vegetation in the greenspace. The relative mix of hard and soft surfaces is also important. Wind strength and direction can affect the size of the cooled area around a greenspace. When arranged throughout a city as street trees, green roofs, gardens and greenspaces, vegetation and water features have a collective net cooling impact on average city-wide temperature (Ca, et al., 1998); (Yu & Hien, 2006).
Right tree, right place	The extent to which trees and vegetation cool the urban climate depends on species selection and strategic placement. Not all tree species have the same cooling effect; leaf type and surface temperature affects cooling ability, canopy size is critical and the structure and density influence the extent of shading and protection. Health and vitality of trees and vegetation are critical to the delivery of cooling benefit. Species selection should therefore consider the following: • Heat tolerance (especially at extreme ambient temperatures); • Drought tolerance; • Pest, disease and pollution tolerance; and • Rooting zone availability and sensitivity to compaction. Under prolonged hot and dry conditions, evapotranspiration slows. When vegetation becomes parched it shuts down, and the cooling effect of vegetation is effectively switched off. Water efficient irrigation systems are vital to help ensure that evapotranspiration cooling by trees continues. Species vary in their suitability to cool the local environment under different conditions and the critical role of species selection is to identify a suitable match for the site conditions, both now and in the future.

Green roofs, walls and bio-shade	Vegetation may be used as part of a building's fabric or landscape to reduce direct heating by solar radiation. Where there are no existing green spaces or no space to create new ones at ground level, the greening of flat roofs and walls can provide cooling for building surfaces and local air temperatures. Bio-shade is a collective term for shade-casting pot plants and plant-draped pergolas. These are distinct from green roofs and walls in the sense that they are not fixed systems. In both cases, they alter a building's microclimate by providing a surface for evaporative cooling and by limiting solar warming, thereby reducing internal temperatures. Wider benefits of green roofs, walls and bio-shade include supported biodiversity and improved air quality.
Water bodies	Water bodies can have a significant cooling impact, especially on their leeward side as may ornamental water features (Spronken-Smith & Oke, 1998). Their reflective surface lowers the amount of solar energy retained, and they increase the ratio of energy used in evaporative cooling rather than in warming the air.

Table 16 Measures to regulate air temperatures using urban trees and green infrastructure. Adapted from (Doick & Hutchings, 2013).

Measures to reduce urban heat risk at borough and building scale
In-home overheating reduction advice from energy advisors
airTEXT
Heatwave broadcasts to partner services (using network developed for winter health work)
Window, curtain and blinds management
Hydration awareness
Avoiding the sun during hottest part of day
Provision and use of fans
Pilot the idea of local 'cooling' centres
'Hot weather hotline' and social visits
Reduce noise pollution during hottest three months of the year
Security proof windows
Work with pest control to develop ways of countering animal entry through open windows
Developing and distributing information materials for residents
Learning from temperature monitoring and intervention modelling of residential properties, care homes and day centres
Seasonal Resilience Plan and Toolkit
Developing summer health interventions

Table 17 Measures to reduce urban heat risk through advice, awareness and communication in the London Borough of Islington, adapted from (Kolm-Murray, et al., 2013).

Measure	Description
General strategies for reducing internal and external heat gains and for improved cooling	Reducing large areas of glazing Shade the south, west and east facing glazing using blinds or external shading Avoid densely populated dwellings (people or equipment) Provide adequate ventilation such as secure windows or mechanical ventilation
Driving behavioural change	Keep curtains closed during the day Open windows at night Use more efficient appliances which generate less heat and use them less often
Retrofit/converting flats/houses	Insulating roofs Repairing and replacing windows Encourage cross ventilation
Good design of new flats/houses	Install bespoke ventilation systems Use some opaque panels where full height glazing exists Educate building caretakers to open windows in common areas in the summer months Education of residents on overheating risks Encourage passive cooling in design
Policy	Review current policy for new homes Include consideration of overheating risks in planning applications

Table 18 Preventing overheating in homes, an overview of remediation techniques. Adapted from (Taylor, 2014).

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7.2 Comparison between ATSR and LandSat data

Figure 16 shows a comparison between the LandSat and ATSR data. The spatial resolution is of particular interest with these two satellite images. Note that the images are not taken on the same day – so quantitatively it is not possible to compare values of land surface temperature.

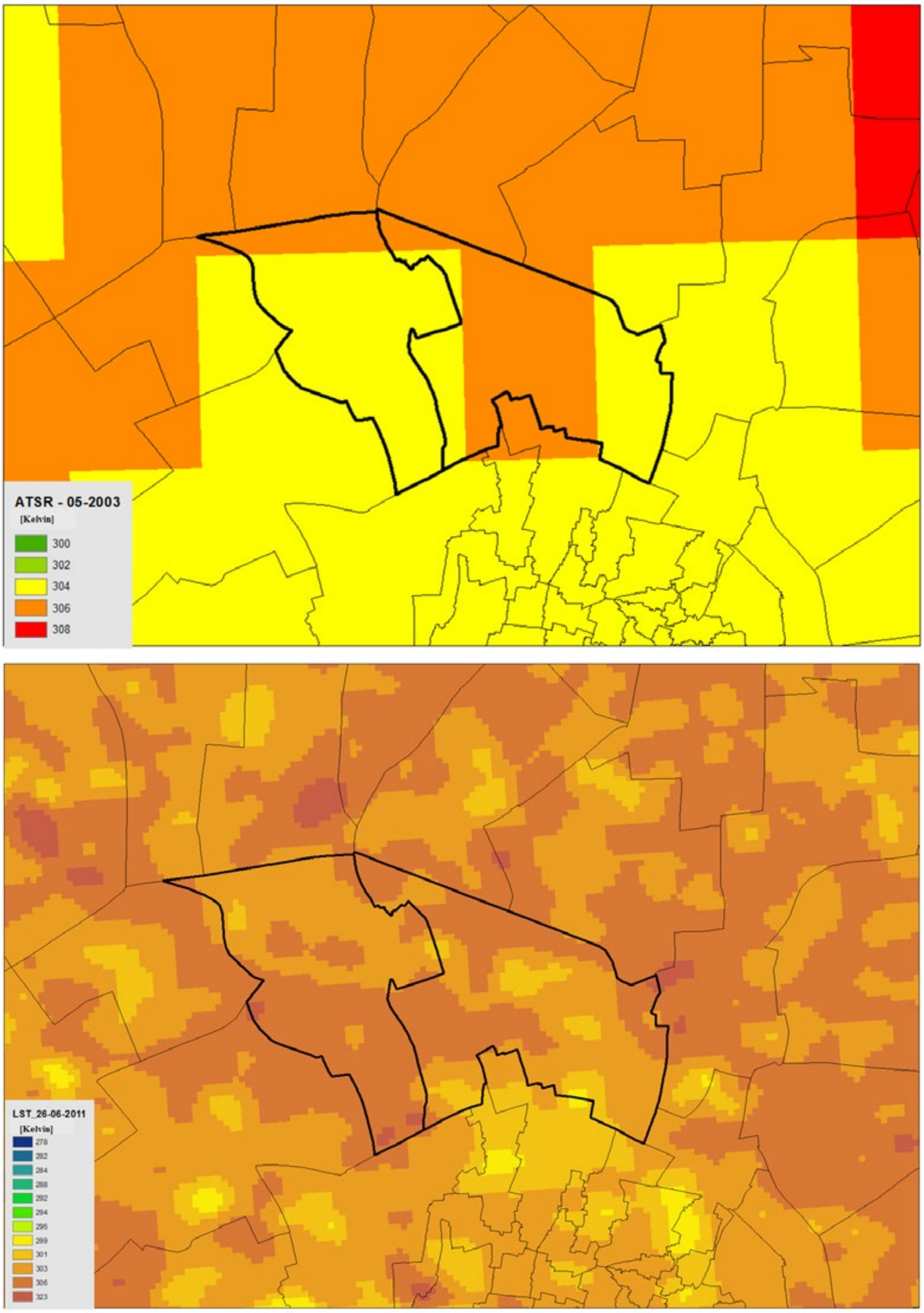

Figure 16 Comparison between ATSR (top) and LandSat (bottom) satellite data. Note that the ATSR data is taken from data acquired in May 2003, while the LandSat image is from a data acquired in June 2011.

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