



MetLink
Royal Meteorological Society

Urban Climates



Background Information for Teachers

Urban areas have an impact on their climate – on the temperature, the wind patterns, the air quality and even precipitation. The table below summarises some of the differences in various weather elements in urban areas compared with rural locations.

Sunshine duration	5 to 15% less
Annual mean temperature	0.5-1.0 °C higher
Winter maximum temperatures	1 to 2 °C higher
Occurrence of frosts	2 to 3 weeks fewer
Relative humidity in winter	2% lower
Relative humidity in summer	8 to 10% lower
Total precipitation	5 to 10% more
Number of rain days	10% more
Number of days with snow	14% fewer
Cloud cover	5 to 10% more
Occurrence of fog in winter	100% more

Urban Heat Islands

An urban heat island is a metropolitan area which is significantly warmer than its surrounding rural areas. The temperature difference is usually larger at night than during the day and is most obvious when winds are weak. One of the main causes of the urban heat island is the fact that there is little bare earth and vegetation in urban areas. This means that less energy is used up evaporating water, that less of the Sun's energy is reflected and that more heat is stored by buildings and the ground in urban than in rural areas. The heat generated by heating, cooling, transport and other energy uses also contributes, particularly in winter, as does the complex three-dimensional structure of the urban landscape.

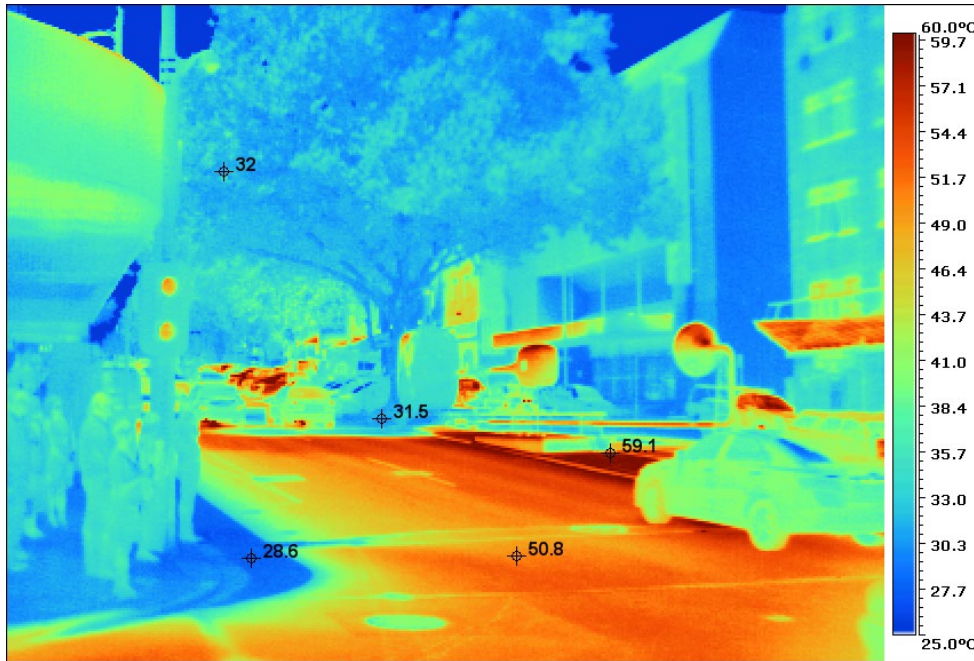
Water is constantly being lost from bare earth (evaporation) and from all sorts of vegetation (evapotranspiration). This moves energy (heat) from the surface of the ground up into the atmosphere.

In big towns and cities, there is less bare earth and vegetation than in rural areas.

In rural areas, there tend to be more lakes, ponds, streams and rivers than in urban areas. Also, when it rains, water tends to be quickly channelled into underground drains and sewers and is not left on the urban surface to cool it down.

The lighter or shinier a surface, the more of the Sun's energy gets reflected straight back out to space, without heating up the ground.

Many urban surfaces are very dark – tarmac, roofs etc. so more of the Sun's energy tends to get reflected in rural areas – although it depends a lot on what sort of rural environment you are looking at. Sand and water are much more reflective than thick woodland. Albedo is measured on a scale of 0 (nothing reflected) to 1 (everything reflected). Any of the Sun's energy that isn't reflected back into space is absorbed, heating the object up. So, the lower the albedo, the hotter the object will get.



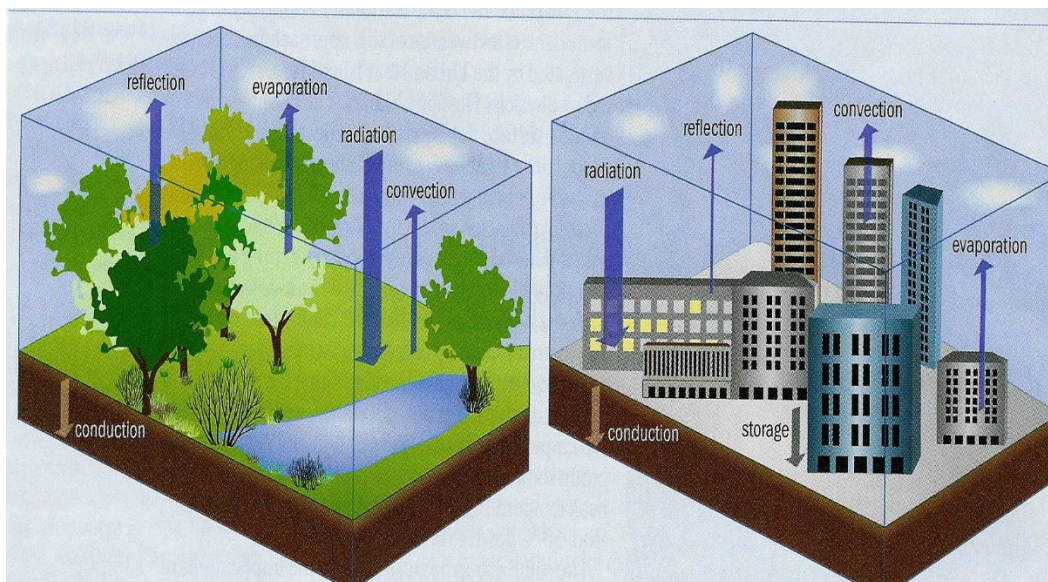
A daytime infrared image of a street in Melbourne, Australia

To make matters worse, many buildings are designed to store heat – insulation etc. means that, once they warm up, it's very hard to cool them down at night.

This means that rural areas cool down faster than urban areas at night.

Also, vehicles, heating systems, air conditioning etc all release extra heat into the urban environment.

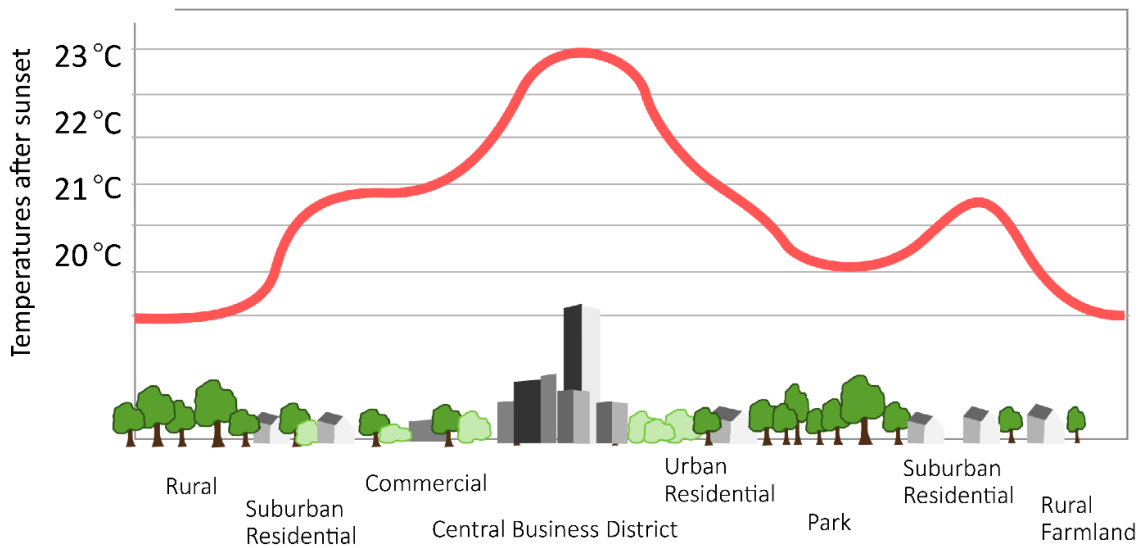
The complex three-dimensional structure of the urban landscape means that they are less well ventilated than rural areas. Heat (and pollution) can literally get trapped in streets.



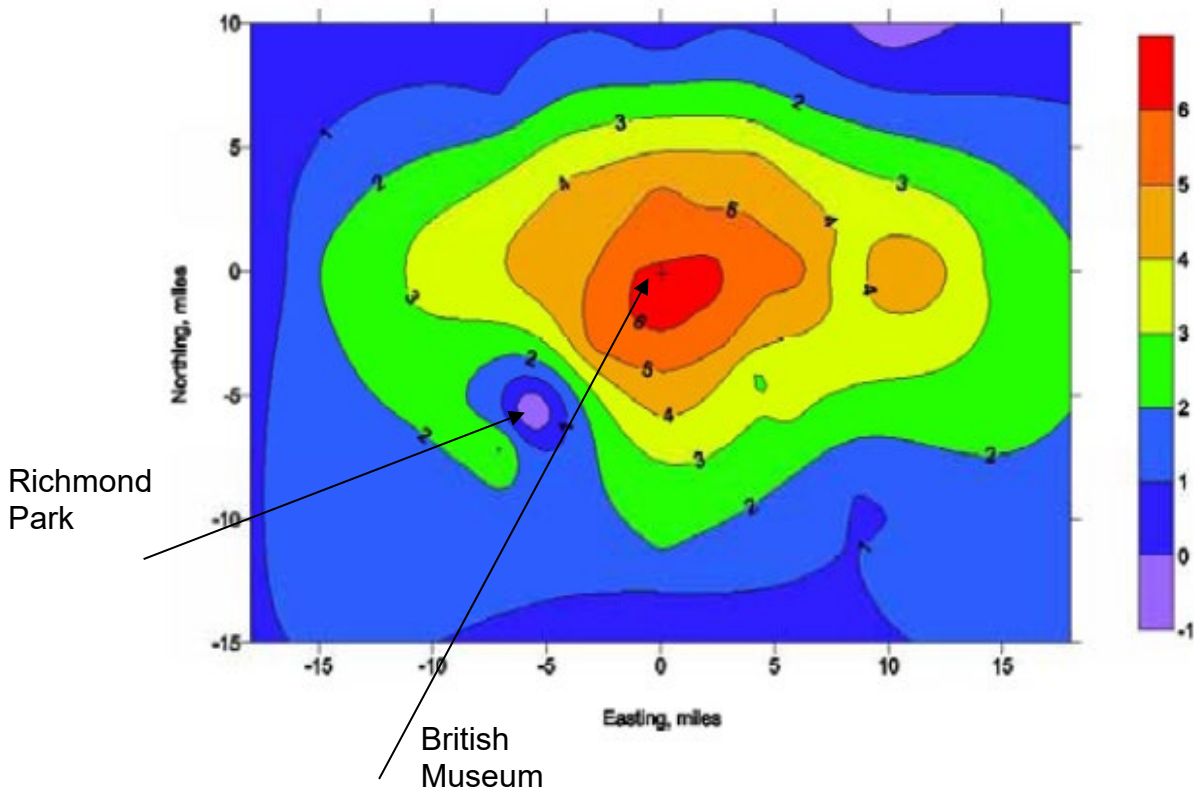
From <http://www.sustainablecitiesnet.com/2010/09/08/urban-heat-island-effect-research-collaboration/>

Towns and cities don't heat up the same amount everywhere. The more densely built up an area is, the more it heats up. AstroTurf is one of the surface materials with the greatest potential to generate an urban heat island.

URBAN HEAT ISLAND PROFILE



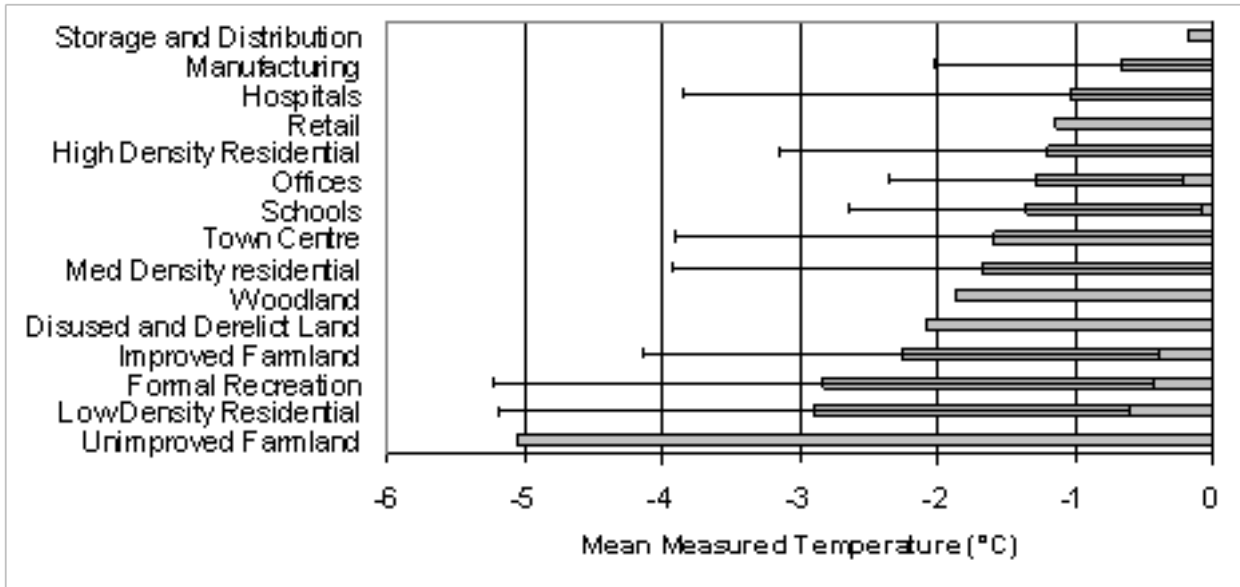
Fine scale features can be very important – a small local park can reduce the local temperatures by a couple of degrees.



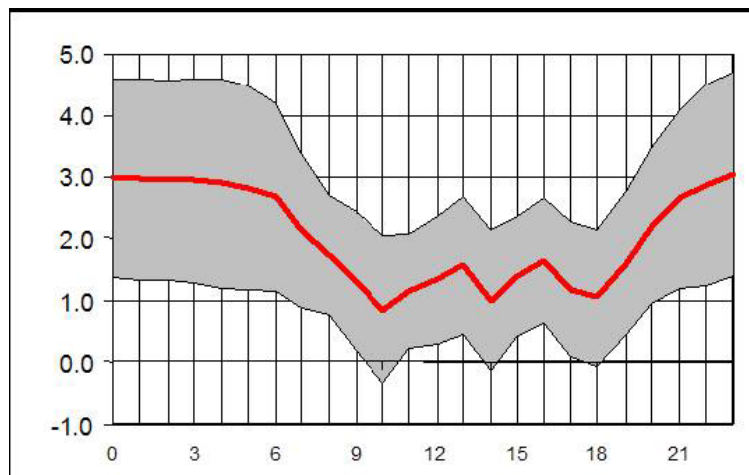
A temperature map of London on one night in 2000, showing the temperature anomaly (in °C) due to the urban heat island. Mayor of London, 2006

The following results were collected by a Royal Meteorological Society schools' experiment in 2009, showing the differences in temperature around Manchester categorised according to land use type on a night with a well-developed UHI. The grey bar shows the mean temperature recorded for each land use

type, the bar indicates a measure of uncertainty in that measurement.

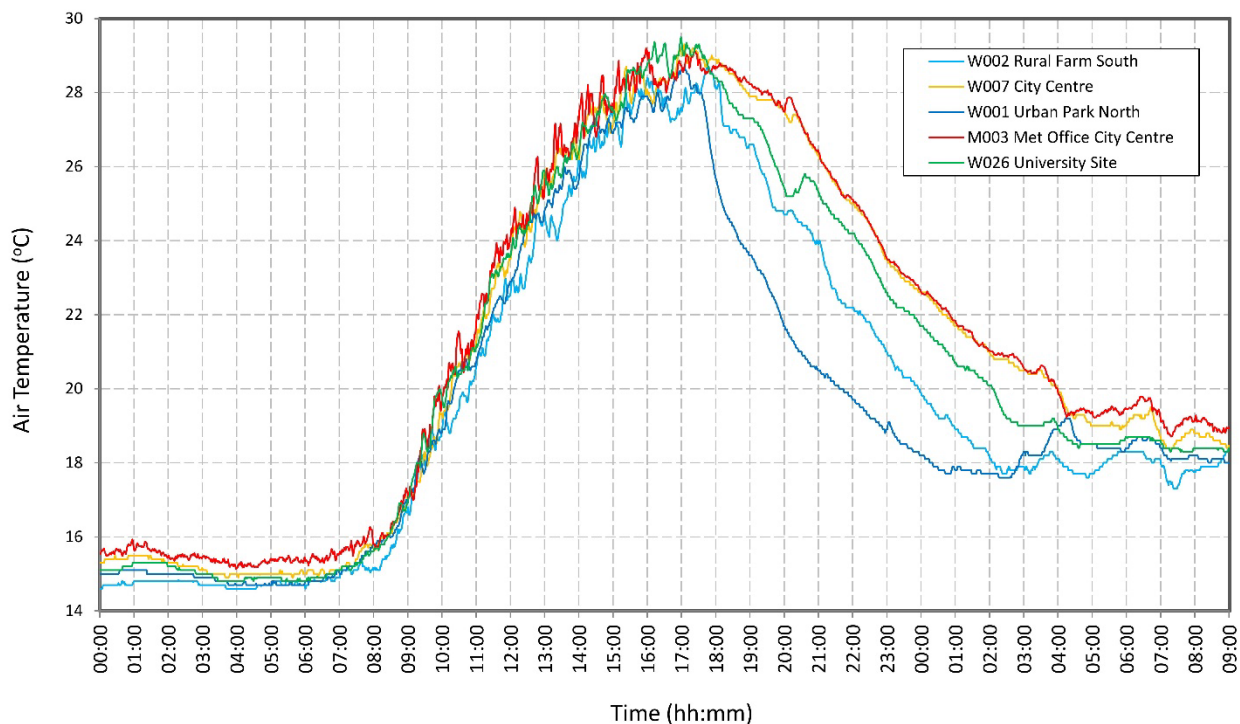


There is also a huge amount of variability depending on weather conditions – rural areas can even be warmer than the city in the middle of the day.



This graph shows difference between RHS Wisley (countryside) and central London.

The Urban Heat Island dissipates rapidly at sunrise and develops rapidly at sunset. It's the rate of cooling after sunset that sets up the UHI as well as the rate of heating after sunrise.



The

Development of Birmingham's UHI on the night of the 22nd July 2013, during a heat wave.

NASA researchers studying urban landscapes have found that the intensity of the "heat island" created by a city depends on the ecosystem it replaced and on the regional climate. Urban areas developed in arid and semi-arid regions show far less heating compared with the surrounding countryside than cities built amid forested and temperate climates.

So, the urban heat island effect is biggest:

- In a large urban area;
- At night (before sunrise);
- In the summer;
- When there is no wind;
- When the sky is clear;
- When the weather doesn't change through the night;
- In a city which replaces forest in a temperate climate.

Urban Heat Islands can have important consequences for which areas are most badly affected by fuel poverty. Also, the growing season can be up to 15 days longer in an urban area.

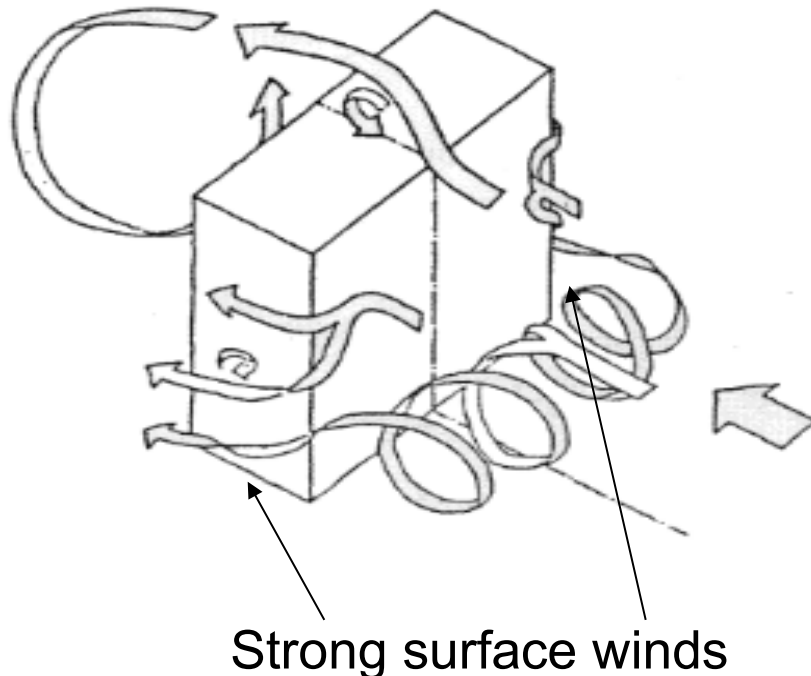
What effects do urban heat islands have on measurements of climate change?

Although most of the really long temperature records available to meteorologists come from in or near urban areas, the weather stations tend to be found in parks and open spaces which are less affected by changes in urbanisation. One study has attempted to see how much the urban heat island effect has affected long temperature records, by comparing the temperatures recorded on calm nights (big urban heat island effect) with those recorded on windy nights (less urban heat island effect). The study suggested that the long temperature records were not affected by the urban heat island effect. In other words, any long-term trends in temperature seen in the records were probably the same as if they had been recorded in a rural area. In the last few decades, data from satellites has been added to the records available to meteorologists. The IPCC concluded in their (2007) climate change report:

“Recent studies confirm that effects of urbanisation and land use change on the global temperature record are negligible (less than 0.006°C per decade over land and zero over the ocean) as far as hemispheric and continental-scale averages are concerned. All observations are subject to data quality and consistency checks to correct for potential biases. The real but local effects of urban areas are accounted for in the land temperature data sets used [both by excluding as many of the affected sites as possible from the global temperature data and by increasing the error range]. Urbanisation and land use effects are not relevant to the widespread oceanic warming that has been observed. Increasing evidence suggests that urban heat island effects also affect precipitation, cloud and diurnal temperature range.”

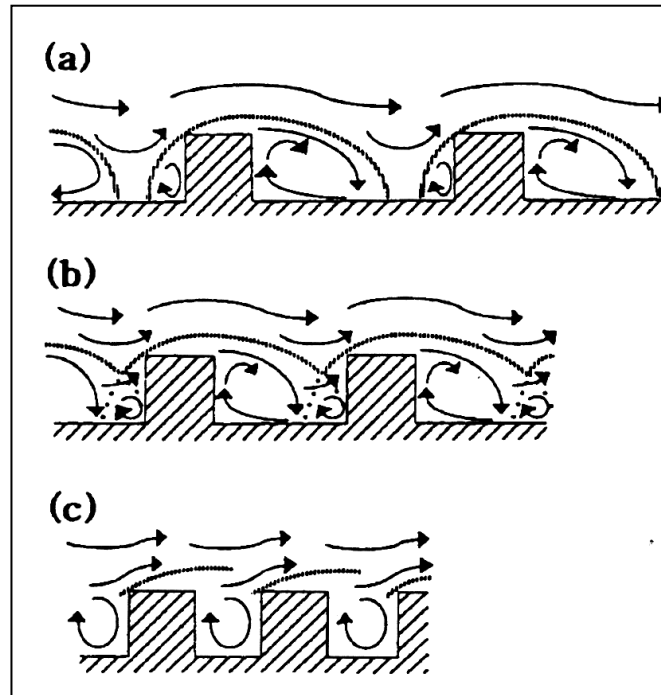
Urban Air Flow

In urban areas, tall buildings and generally rougher land surfaces have an effect on the flow of air, altering the course of the wind and producing turbulence. Turbulence causes air flow patterns to be random, rather than straight/aerodynamic. Even a simple building can produce a complex air flow pattern. This flow of air can in turn have an impact on the transport and concentration of pollution.



This is a simplified diagram showing how air is redirected around a building. In front and to the sides, there will be faster air flow on the ground – in high wind conditions, this could be a problem. The swirling air flow (turbulence) in some places means that pollution, and any litter etc., will tend to end up trapped there until the wind changes direction.

Pollution is blown around in the gusty urban environment. Obstacles cause re-circulations which act to disperse the pollution.

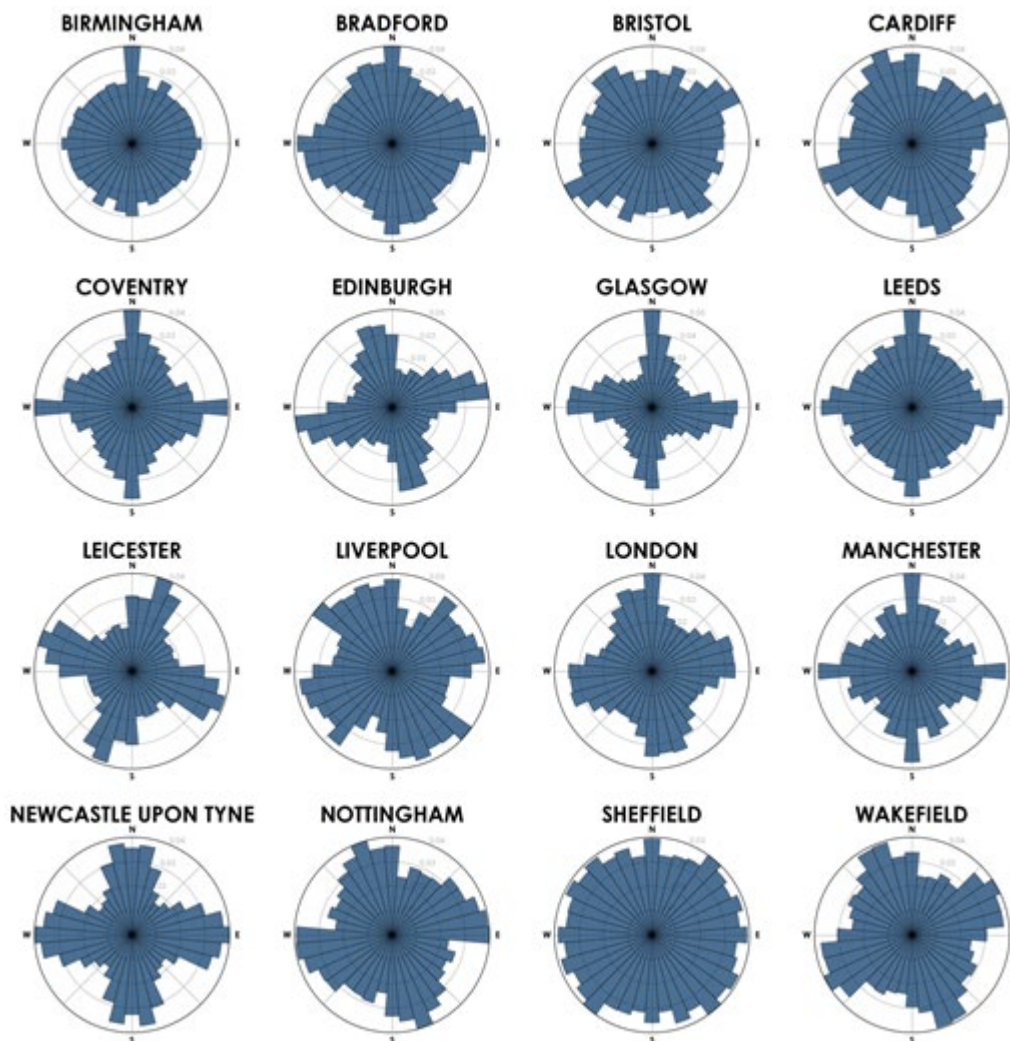


Flow along streets is even more complicated than flow around a single building. Depending on how high the buildings are and how wide the streets are, the air flow will be different and depends on the street orientation and wind direction. A lot of UK towns and cities have parallel rows of streets.

The air flow has consequences for the:

- Dispersion of pollutants – are they getting trapped in pockets? Are some areas of housing going to be particularly unhealthy because of where exhaust fumes etc. end up?
- Dispersion of heat, particularly in the summer and natural ventilation by the wind.

City Street Network Orientation



<https://geoffboeing.com/2019/09/urban-street-network-orientation/>

Boeing, G. 2019. "Urban Spatial Order: Street Network Orientation, Configuration, and Entropy." *Applied Network Science*, 4 (1), 67. doi:10.1007/s41109-019-0189-1

Urban Air Quality

Pollution has always been an issue for cities – and how the flow of air in the urban area redistributes and removes it.

Smogs were common in many British cities in the late 19th and early 20th centuries, when domestic fires, industrial furnaces and steam trains were all emitting smoke and other hygroscopic pollutants by burning fossil fuels. The smogs were particularly bad during the winter months and when temperature inversions built up under High pressure, causing the pollutants to become trapped in the lower atmosphere and for water vapour to condense around these particles.

One of the worst of these 'pea-soup fogs' was the London smog of the winter of 1952/53. Approximately 4,000 people died during the smog itself, but it is estimated that 12,000 people may have died due to its effects. As a result, the Clean Air Act of 1956 was introduced to reduce these emissions into the lower atmosphere. Taller chimney stacks and the banning of heavy industry from urban areas were just two of the measures introduced and, consequently, fewer smogs were recorded in the UK during the 1960s and 1970s.

Research in the 1990s showed, however, that another type of smog – photochemical – is now occurring in urban areas as a result of fumes from car exhausts and the build-up of other pollutants in the lower atmosphere which react with incoming solar radiation. The presence of a brown-coloured haze over urban areas is an indication of photochemical smog, and among its side effects are people experiencing breathing difficulties and asthma attacks. Early evidence suggests that people living in urban areas with poor air quality were more susceptible to fatality from the 2020 Corona virus pandemic.

Measuring Air Pollution

A 2016 letter to Nature journal suggested that

“The public is increasingly aware of the health and economic costs of air pollution. Poor air quality is linked to over three million deaths each year, and 96% of people in large cities are exposed to pollutant levels that are above recommended limits. The costs of urban air pollution amount to 2% of gross domestic product in developed countries and 5% in developing countries.

Media attention and the increasing availability of data are reinvigorating efforts in many countries to tackle air pollution, driven as much by local and national politics as by science.

In response, start-up companies are rushing to produce cheap air-monitoring sensors, costing hundreds rather than tens of thousands of pounds. Such devices bridge gaps between sparse government measurements and individuals’ wishes to track their personal exposures.”

The devices typically measure particulates, sulphur and nitrogen oxides (NO_x). However, the devices are rarely calibrated to the location and time when they are being used. At best, they can be used to “raise awareness” of pollution rather than give accurate and absolute readings.

Urban Rainfall

The greater presence of cloud condensation nuclei (see Chapter 9) over urban areas can lead to cities being wetter and having more rain days than surrounding rural areas. Indeed, it was often said that Rochdale had significantly smaller amounts of rain on Sundays when the town’s factories were closed. However, it could also be argued that on days when there is less pollution and therefore fewer condensation nuclei in the air, you end up with fewer and therefore larger cloud droplets which are more likely to fall as rain. One study suggested that the driest days in Manchester are Wednesday – Friday.

However, other factors play a major role, especially the heat islands. These can enhance convective uplift, and the strong thermals that are generated during the summer months may serve to generate or intensify thunderstorms over or downwind of urban areas. Storm cells passing over cities can be ‘refuelled’ by contact with the warm surfaces and the addition of hygroscopic particles. Both can lead to enhanced rainfall, but this usually occurs downwind of the urban area.

A 2019 study (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6514167/>) suggested that urbanisation modifies rainfall, such that mean precipitation is enhanced by 18% downwind of the city, 16% over the city, 2% on the left and 4% on the right with respect to the storm direction.

Urban Planning for Better Climate

City planners can use computer models to see how the air flows and to help plan future developments. Many city authorities are now investigating or implementing devices to improve the urban microclimate:

Cool surfaces – paint buildings and pavements light, shiny colours so that they reflect light and emit infra-red radiation (heat). The paint combines a reflective basecoat with a darker pigment and could reduce air conditioning use by over 30% and cool cities by 2°C. However, they do have to be kept clean.

Similarly, cool pavements and roads reduce the heat island effect whilst also reducing storm-water runoff, giving lower tyre noise and better night-time visibility.

Green roofs - On a hot summer day, the surface of a green, living, roof can be cooler than the air temperature, while a rooftop without plants can be warmer. Green roofs can give a 70% reduction in air conditioning costs for a 1 storey building (less for taller buildings), reduce flooding, reduce air humidity, insulate in the winter, reduce air pollution, provide a habitat for wildlife and are a nice place to be. The stronger the roof, the bigger the plants which can be grown – Sedum is most commonly used.

Plant vegetation - Large trees on the south/ west of buildings can reduce air conditioning costs by 30%. Urban trees can provide:

- Air temperature reduction
- Reduced building energy use
- Absorption of UV
- Improved water quality
- Reduced noise
- Improved human comfort and well-being
- Increased property value
- Aesthetics
- Community cohesion.

Several cities, including Chicago, have tree planting programmes.

Water features can also have a significant local impact.

Changing Urban Climate

Urban areas are particularly vulnerable to changes in the climate, and, as the world becomes increasingly urbanised, more and more people will become vulnerable to changes in climate and extreme weather events. London was up to 9°C warmer than surrounding areas during the 2003 heat wave and there were 600 heat related deaths.

Heat waves like that of 2022 are expected to become more common in the future. They will happen on average, every other summer by mid-century and if global emissions remain high, later this century that type of summer may become a cool summer.

Given the long lifetimes of buildings, urban areas etc. we need to plan urban areas now to anticipate the summer temperatures of the future.

Sources of Information

The WOW or Wunderground sites can be used to find urban data e.g. <http://wow.metoffice.gov.uk>

Detailed information about how to use this data to map an urban heat can be found here <https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/>

The IPCC's fact sheet about climate change in urban areas:

https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Urban_areas.pdf