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Geoffrey Parsons

URBAN MICROCLIMATES

Urban areas tend to have a local and quite distinct set of climatic characteristics. These are the result of inadvertent climate modification on a relatively small scale. The urban area modifies the climate in several ways:

- wind speeds
- temperature
- clouds and precipitation
- pollution.

The larger the urban area, the greater the modification of its climate will be.

The UN estimates that by 2025, 80% of the world's population will live in urban areas. Since much of this urbanisation is at, and may continue to take place in warmer climates, then conditions in urban areas are likely to become increasingly oppressive, thanks to heat island effects and pollution.

Winds

Winds in urban areas are modified in the following ways:

- lower speeds
- greater variability
- large-scale convection.

Lower speeds

On the whole, urban areas have lower wind speeds than do outlying suburbs, on average 5% less in the city centre. This is due to the roughness of the land surface, which consists of buildings at a variety of heights, all helping to increase surface friction (Figure 1).

Greater variability

On a smaller scale, e.g. in the CBD, wind speeds are far more variable, and around some buildings winds are more gusty and strong. This is due to the layout of the buildings and building height. Straight streets lined with tall buildings can produce '**urban canyons**' (Figure 2), which funnel wind down them, producing high velocities thanks to the **venturi effect**, which is the effect of 'squeezing' the airflow, increased as buildings tend to get taller towards the city centre. Turbulence is created by high-rise buildings disrupting the flow of air.

Figure 1: Wind speed in rural and urban areas

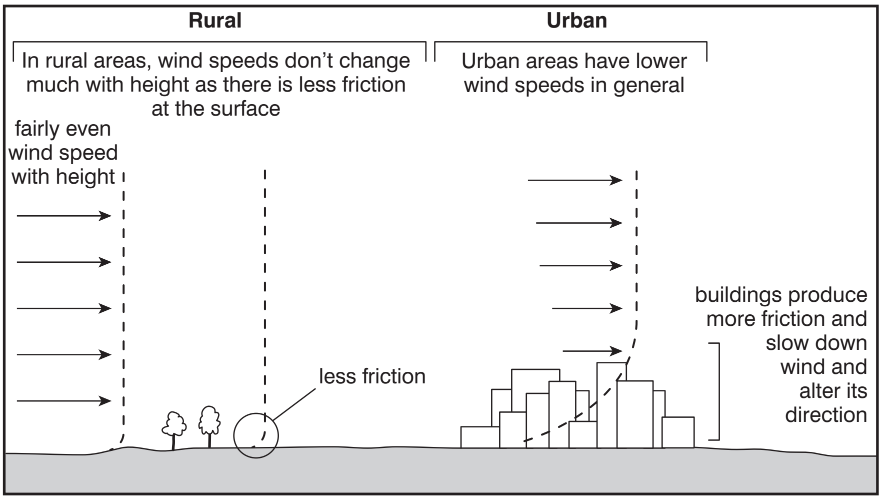


Figure 2: The urban canyon

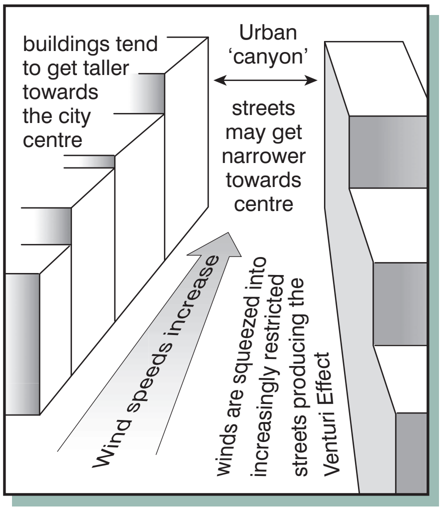
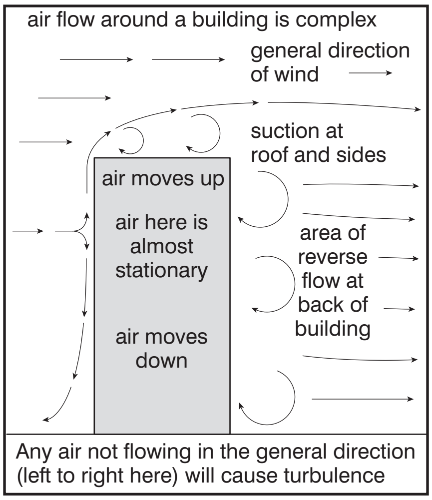


Figure 3: Airflow around a building



The detailed pattern of airflow around a building is complex, with the highest pressure experienced in the upper part of the building with air flowing down the front and over the top (Figure 3). Behind the building there is a reverse circulation as suction occurs on the roof, walls and sides of the building. This complicated pattern of airflow leads to turbulence.

Building shape and spacing all affect the behaviour of the wind. Widely spaced buildings act as single blocks, but where buildings are closer together, the airflow around one interferes with that around the next (Figure 4). In cities, buildings are densely packed and this allows air to move over the top, leaving the lower urban canopy layer with relatively less turbulence, although the picture is complicated by the different heights of buildings (Figure 5).

Both turbulence and gustiness make conditions unpleasant for pedestrians. Building design using stilts and canopies may reduce the problem, but if no mixing by turbulence occurs, then the pollutants at street level are less likely to be 'flushed out' by these winds.

Large-scale convection

The heat island effect also produces large-scale convection and uplift over the whole urban area, leading to lowering air pressure, and consequently air is drawn in from surrounding rural areas in much the same way as land or sea breezes are produced.

Temperature

The urban heat island

Urban areas are warmer than their rural surroundings. This is known as

Figure 4: Airflow with buildings widely spaced, and closer together

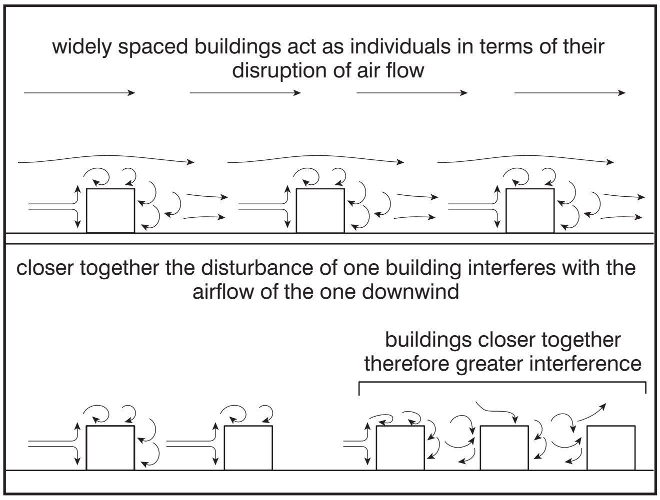
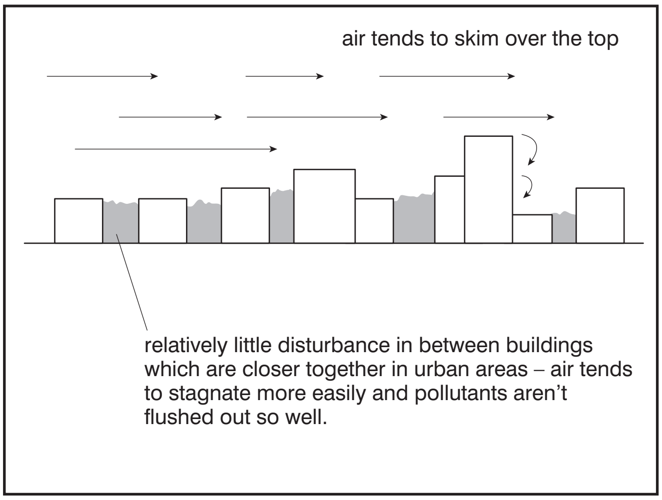


Figure 5: Airflow where buildings are close together



the '**urban heat island**', which is on average 1–2°C warmer per year than its surrounding rural areas (Met Office). For example, Melbourne's average heat island is 1.13°C. This increase in temperature is probably the most significant aspect of urban microclimates as a whole, and has knock-on effects on air movement, pollution and humidity.

The urban heat island is best thought of as a patchwork of microclimates within the urban area. The heat island is rather uneven in terms of its temperature profile; there is a sharper temperature change at the edge of the heat island, and within it there are peaks (associated with industry and the city centre) and troughs (parks, reservoirs and rivers).

The **intensity** of the urban heat island is the maximum difference between the temperature of the rural area and the peak urban temperature. During hot summer days this difference is slight as both urban and rural areas tend to be very warm, but at night the difference is greater thanks to greater cooling in rural areas.

Weather conditions also influence the intensity of the urban heat island. High-pressure systems with clear nights and still, sunny days tend to increase the intensity. The intensity will also vary seasonally, although the pattern is less clear. High-pressure systems in winter bring bitterly cold weather to places like Moscow and Montreal. Not surprisingly, people make more use of central heating then, and this helps to increase any urban heat island effect. In general, winter months tend to bring wetter, windier weather, and much of the warmer air in the **canopy layer** in between the buildings is flushed out by the colder air, which is much the same temperature as the rural air. This would explain why the *average* winter urban heat islands intensities are less. Melbourne's seasonal urban heat island shows this pattern, with a summer mean of 1.29°C compared with a winter mean of 0.98°C.

Heat islands are the result of five main factors:

- anthropogenic heat
- height and arrangement of buildings
- the nature of the building materials
- the presence of water
- pollutants.

1. Anthropogenic heat

This the heat released by human activity. Metabolic heat (body heat) is negligible, but the heat released from vehicles, central heating (alternatively, in some warmer areas, from air conditioning systems) and industrial activities is substantial. All of these inject heat into the canopy layer and the upper **boundary layer**. Some large, densely packed cities in colder areas can release more heat from human activity than the urban area receives in its net input from the sun.

2. Height and arrangement of buildings

Cities are, by their nature, very built-up areas. It is the vertical aspect of tall buildings close together that is the most important factor in generating the urban heat island. **Insolation** can warm surfaces – the degree of warming depends on the amount of insolation absorbed by the surface. This in turn depends on how much is reflected off that surface. This reflectance is the **albedo**.

Albedos for selected surfaces

Grass	16% – 26%
Deciduous forest	15% – 20%
Asphalt	5% – 20%
Concrete	10% – 35%

Source: Oke, 1987, *Boundary layer climates*, 2nd edn

Note that both rural and urban areas tend to have similar albedos and that they are all rather low. Hence both areas would absorb heat to a similar degree, all other things being equal. However, the main difference is that urban areas have more vertical surfaces, and this means that radiation will tend to be reflected off many surfaces, each one absorbing some of the energy and warming up in the process. The fact that these tall buildings are so close to each other reduces the **sky-view factor.** This is the amount of sky we can see without our view being impeded by tall buildings. In an open field it would be close to 1, whereas in Manhattan it is nearer to 0.2 (Shahgedanova and Burt, 1998). Obviously, small sky-view factors tend to 'hem in' radiation, which reduces the chance for it to escape without multiple reflections. The effect of high-rise buildings is to reduce the albedo significantly, so that on average the urban albedo is about 15%, which is lower than most rural surfaces, despite the fact that according to the above figures they are quite similar.

The height and arrangement of buildings also influences the fate of long-wave radiation (heat). Once a surface has absorbed sunlight, it will warm up and give off heat (i.e., radiate) in all directions. In cities there is a good chance of this heat being intercepted by another surface, so reducing heat losses to the atmosphere. The reduced sky-view factor has a similar effect on long-wave radiation, and tends to reduce the loss of heat.

On a smaller scale, the low sky-view values typical of urban canyons also mean that areas at ground level may receive no direct insolation, and are in shade for all of the day.

So building height and arrangement is the key factor in creating the heat island by the way it modifies the inputs (light and anthropogenic heat) and outputs (heat). If there is any surplus, then its fate will be decided by three further factors:

- the nature of the building materials
- the presence of water
- the presence of pollutants.

3. Nature of building materials
We know that most of the surplus heat in cities is lost as sensible heat. Since they have relatively little standing water, this sensible heat goes into heating the atmosphere. The picture is a little more complicated, however, as some of this heat (about 20%–30%) goes into heating the buildings themselves. Compared to rural surfaces, urban areas heat up more quickly – the **specific heat capacity** for concrete is one-third that of wet mud, and so for a given input of energy, concrete will warm more rapidly than wet mud. Also, vegetation shades soil, so that it stores less heat. In cities the surface is exposed and the surface area is larger, so it is able to store the heat and release it slowly over the night.

4. The presence of water
The surplus heat can be transmitted as either **latent heat** or as **sensible heat**. Latent heat evaporates water. It cannot be felt or measured with a thermometer. Sensible heat is heat energy which can be felt. After **evapotranspiration** has taken place, any heat 'left over' can take the form of sensible heat, to raise the temperature of the air – the more sensible heat that enters the atmosphere, the warmer it gets. Latent heat does not raise air temperature. Water is important here, since it determines how the surplus heat will be used. If there is little water at the surface, then less of the surplus heat is used for evaporation (latent heat), and the remainder of the surplus heat will take the form of sensible heat to raise the air temperature. Since cities generally have arrangements – in the form of gutters, drains and sewers – to remove surface water, there is less demand on latent heat to evaporate water, so most of the surplus heat is used as sensible heat to warm the atmosphere. In vegetated rural areas the balance is quite different: twice as much of the surplus heat is used in evaporation as is used in sensible heat. So thanks to water and vegetation, rural areas don't get as warm as urban areas.

The **sensible heat index** gives the percentage of the total heat energy at the surface used to raise the temperature of the air above it. For urban surfaces this value is 85%. For forests it is 25%.

5. Presence of pollutants
In terms of the urban heat island, pollutants have both a cooling and heating effect. The presence of dust, aerosols and gases such as CO_2, SO_2 and pollutants such as ozone and PAN (PeroxyAcetylNitrates) which are components of **photochemical smog** can alter the amount of energy flowing into and out of the urban area.

Smokey, dusty cities can reduce (**attenuate**) the amount of sunshine that reaches the city surface. In some cases where coal is burnt, soot and particulates can reduce this sunshine by 30%. Los Angeles suffers from photochemical smog, but this only reduces sunshine by about 6%.

On the other hand, the **pollutant dome** can absorb heat and prevent some of it escaping. The build up of CO_2, ozone and **particulates** helps to absorb long-wave radiation (CO_2 and ozone are greenhouse gases). In so doing, the pollutant dome warms up even more, as it was already warmed by the insolation it absorbed in the first place. The pollutant dome can now re-radiate this heat back down to the urban surface – so not only preventing heat escaping, but also adding to the heating load in urban areas.

Clouds and precipitation

Urban areas have greater cloud cover – some 5%–10% more (Met Office). This may be due to a greater concentration of **condensation nuclei**, around 100 times more than rural areas. The presence of condensation nuclei encourages cloud formation, since water vapour needs a surface onto which condensation can take place. Also, in cities, heating increases uplift of air by convection, so encouraging cloud formation.

Precipitation is more common in cities (5%—30% more than in rural areas). Not only are cities wetter, but they are also prone to more thunderstorms. The enhanced convectional uplift from the heat island effect can lead to considerable instability and thermals, giving more storms. London has between 100 and 110 days of thunder per year, compared to 60-70 days on the Kent and Sussex coasts (Met Office).

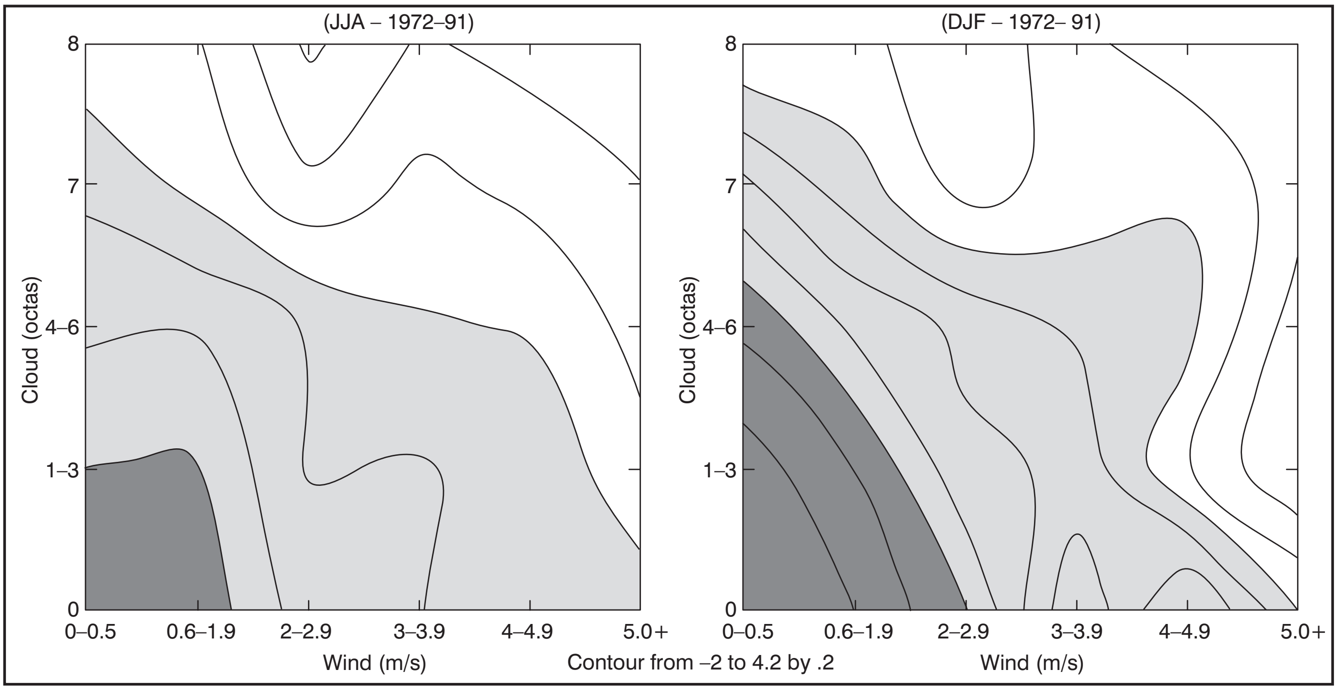
Fog is often associated with cities. 'Non-pollution' or 'ordinary' fog is less common than is usually supposed. Oke suggests that this is due to higher temperatures – fog cannot form unless the air is cooled to its dewpoint - and the presence of more condensation nuclei means that there are more, smaller droplets, which tend to discourage the formation of thick obscuring fogs.

Although rain may fall more frequently, cities are designed to remove surface water, and so humidity during the day is lower, helped also by lower evapotranspiration levels. During the night, urban humidity is higher than the rural surrounds, not through any increase of humidity, but due to the rapid drop in rural humidity. This is from condensation of dew, thereby removing it from the air and depositing it on the grass.

Pollution

Urban microclimates are certainly dirtier than their rural counterparts, although the differences are getting less. London sunshine has shown an *increase* over the past 100 years. During the latter part of the 19th century large amounts of soot were emitted from coal-fired sources. This led to considerable attenuation in the amount of sunshine received; up to 80% of the winter sunshine was lost,

Figure 6: These graphs show wind speed along the bottom and cloud cover up the side. They are from Melbourne. The shading shows the intensity of the urban heat island, and the darker the shading the greater this intensity. Note that the greatest intensities occur when wind speeds are low and there is less cloud cover. The two graphs show the intensities of the urban heat island (a) during June, July and August (JJA) which is the middle of Melbourne's winter, and (b) December, January and February (DJF - Melbourne's summer). It can be seen that the darker area of greater intensities is larger in the summer, which is (not surprisingly) associated with lighter winds and clearer skies.



and in December 1890, no sunshine was recorded in Westminster. The situation was made worse in winter as more coal was used for heating, hence more soot and smoke to weaken the sunshine. As late as 1950, inner London still only had 50% of the sunshine that rural areas enjoyed. The reduction of coal-fired space heating, trains, and power stations eventually led to a decline in the smogs that were once so common. The Clean Air Act of 1956 cleared up the air for most large urban areas.

Since then, photochemical smog has had an increasing impact. Due to strong sunlight and increased car use, some cities, such as Los Angeles, have become synonymous with photochemical smog. The urban heating effect may have made matters worse, creating conditions for more rapid chemical reactions. The rather slow moving air means that pollutants are able to stagnate within the urban canopy layer. Both PAN and ozone make breathing difficult and irritate the eyes.

Conclusion

Although climate change by cities seems unavoidable, the extent to which it is altered depends very much on planning and layout of our cities. Tree planting, and the provision of green spaces should not be beyond the wit of most planners and would do much to reduce much of the unpleasant side effects of urban microclimates.

Bibliography and recommended reading

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FOCUS QUESTIONS

1. On an A3 sheet of paper, draw a spidergram which summarises the impact of urban areas on their local weather. Each 'leg' should focus on one climatic aspect affected by urban areas. (Wind, temperature, cloud and precipitation, and pollution)

2. Discuss the idea that urban microclimates are only the result of building upwards, i.e. would we have urban heat islands if there were no skyscrapers?

3. Explain how the urban albedo is less than the rural albedo, despite the fact that the figures for the different surfaces are quite similar.

4. Assess the role of pollution in urban microclimates.

5. How might tree planting in city centres help alleviate the side effects of urban microclimates?