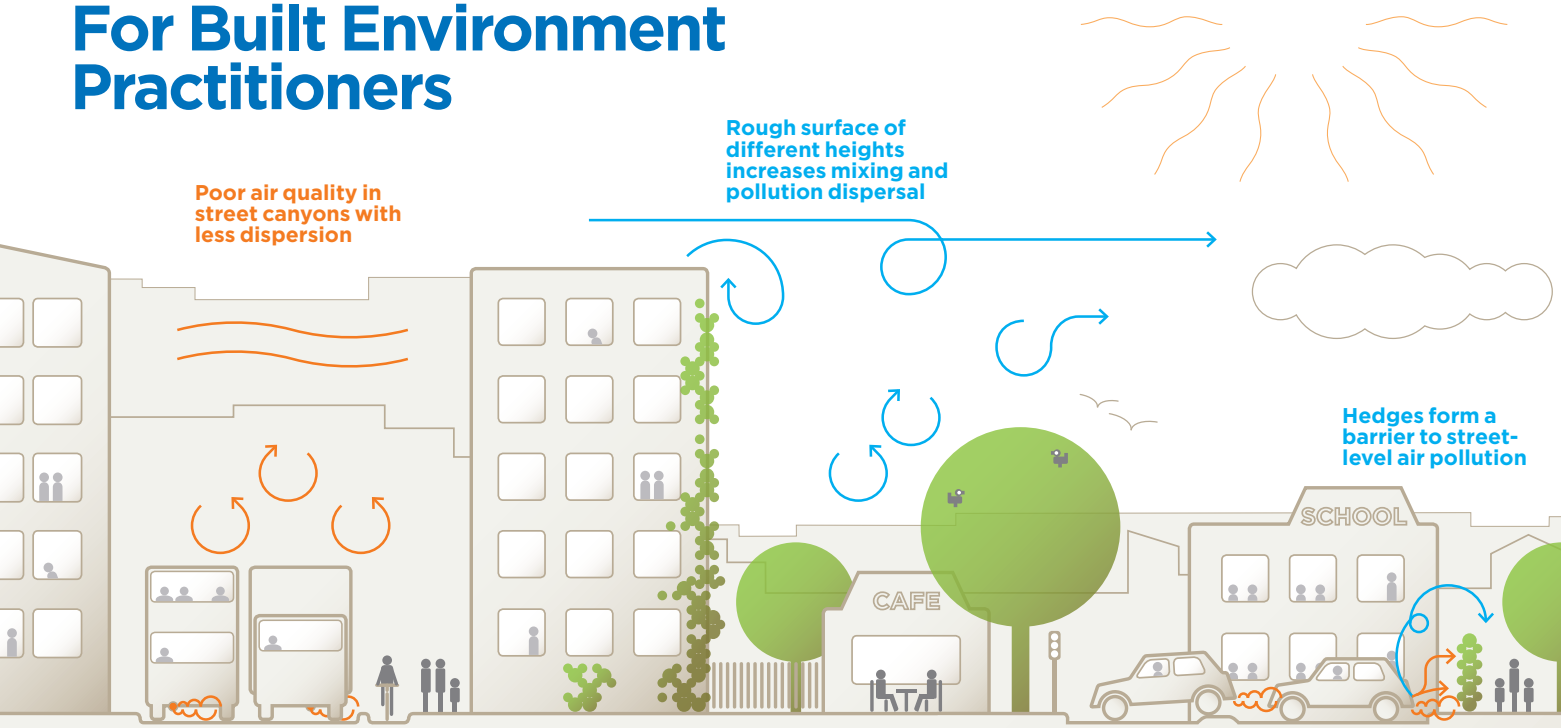
First Steps in Urban Air Quality

For Built Environment Practitioners



Green infrastructure provides a comparatively large surface area for pollutant deposition

Parkland has fewer emission sources and therefore cleaner air

Air pollution greater where traffic regularly idles

Breaking and accelerating increases vehicle emissions

Children closer to vehicle exhaust and higher pollutant concentration

Trees & Design Action Group

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Air pollution is the biggest environmental risk to health. Globally, nine out of ten people live in a city that does not comply with WHO air quality standards[1]. Within the UK, poor outdoor air quality is linked to 50,000 deaths each year[2]. The most vulnerable are children, the elderly, or those with pre-existing medical conditions. The design of our urban infrastructure – including Green Infrastructure (GI) such as trees, parks, and green walls – determines where air pollution is produced, and how it disperses. Built environment professionals should consider air quality at all stages of urban design and development.

Air Pollutants and their Sources

Most air pollution is caused by industrial and domestic combustion of fuels for heat, electricity and transport (Table 1). Road transport emissions are now the largest source of air pollution in urban areas in the UK. Petrol and diesel engines emit several types of pollutants including reactive oxides of nitrogen (NO_x), and microscopic particulate matter (PM). The abrasion (wear and tear) of brakes and tyres and resuspension of road dust, are also sources of PM. Solid fuel heating is an increasing source of NO_x and PM in UK cities[3]. In strong sunlight, NO_x and volatile organic compounds react to form ozone, a highly toxic pollutant at ground level.

UK Air Quality Strategy

The UK Air Quality Strategy has legally binding standards for PM, NO_2, ozone (Table 1), and other pollutants: benzene, 1,3-butadiene, carbon monoxide, polycyclic aromatic hydrocarbons (PAH), and lead[5]. Air quality standards are designed to protect human health from long-term exposure to air pollution (via limits for annual mean concentrations), and short-term exposure to higher levels of air pollution (via limits for daily or shorter mean concentrations).

Local Authorities are responsible for monitoring air quality in their area, and are required to designate Air Quality Management Areas (AQMAs) where air quality standards are, or may be, exceeded. Most AQMAs are currently declared for NO_2 exceedances, although there is growing concern about levels of PM across the UK. Ozone seldom exceeds air quality standards, but this could change as the mix of pollutant emissions alter and heatwaves become more frequent in the future[6]. The UK-AIR portal[7] provides support for air quality assessment including data archive, maps of key pollutants (NO_x, NO_2, PM_{10} and $PM_{2.5}$), air quality forecasts, and details of monitoring networks.

Table 1 **The sources and health impacts of key urban pollutants[4]**

Pollutant	Source	Health impact
Particulate matter (PM; classified by particle diameter,d) PM_{10} (d < 10µm) $PM_{2.5}$ (d < 2.5µm)	PM can be liquid or solid and has many natural (e.g. sea spray, spores, Saharan dust) and human (e.g. brake & tyre wear, combustion) sources. Some PM is emitted directly into the air; other PM forms from gaseous reactions in the air. The biggest sources of directly emitted PM in urban areas are **combustion and road transport**.	Short-term and long-term exposure to PM is linked to respiratory and cardiovascular illness and mortality, and other ill-health effects. Currently, it is not possible to derive a minimum threshold below which there are no health impacts. Smaller particles ($PM_{2.5}$ and below) have a stronger link with negative health impacts.
NO_x is nitrogen dioxide (NO_2) and nitric oxide (NO)	NO_2 and NO interchange very rapidly in air so are usually considered together as NO_x. NO_x is produced from combustion, lightning, and microbial activity in soils. The biggest source in the UK is road transport, followed by electricity generation, and other industry.	NO_2 is linked to poor health including cardiovascular and respiratory illnesses. NO_x contributes to the formation of PM and ozone.
Ozone (O_3)	Ozone is not emitted directly. It is produced by reactions in strong sunlight between NO_x and volatile organic compounds. This is enhanced under hot stagnant conditions. Ozone formation may occur hundreds of kilometres away from the original emission.	The ozone layer protects us from UV radiation, but ground-level ozone is toxic. Short-duration exposure (e.g. during a heatwave) can cause eye and nose irritation, and is linked to respiratory and cardiac mortality. Long-term exposure leads to respiratory illness.

1 WHO. 2016. Ambient air pollution: a global assessment of exposure and burden of disease. Ambient air pollution: a global assessment of exposure and burden of disease. World Health Organization.

2 Landrigan, P., et al. (2017). The Lancet Commission on pollution and health. *The Lancet*.

3 Defra. 2016. Emissions of air pollutants in the UK 1970 to 2015. London: Department for Environment, Farming & Rural Affairs.

4 Defra. [no date]. What are the causes of air Pollution? London: Department for Environment, Farming & Rural Affairs.

5 Defra. [no date]. National air quality objectives and European Directive limit and target values for the protection of human health. London: Department for Environment, Farming & Rural Affairs.

6 Fowler, D., Amann, M., Anderson, F., Ashmore, M., Cox, P., Depledge, M., Derwent, D., Grennfelt, P., Hewitt, N., Hov, O. and Jenkin, M. 2008. Ground-level ozone in the 21st century: future trends, impacts and policy implications. *Royal Society Science Policy Report*. **15**(08).

7 UK-AIR: Air Information Resource. London: Department for Environment, Farming & Rural Affairs.

Urban Form and Air Quality

Urban form strongly influences air quality on centimetre to kilometre scales, from roadside to neighbourhood. As road transport is currently the largest source of air pollution in UK urban areas, higher levels of directly emitted air pollutants occur beside and along the busiest roads. Large areas of green space are often associated with better air quality, simply because they contain fewer roads and therefore lower emissions from road transport. The health impact of air pollution at any location depends on the emission source, the atmospheric pathway, and the vulnerability of the receptor (Table 2, see overleaf).

Green Infrastructure and Air Quality (GI4AQ)[8]

As part of the urban infrastructure, GI influences pollution dispersal and deposition. As a living thing, GI interacts with pollution formation and removal at regional and local scales. If strategically designed, GI can mitigate poor air quality on a local-scale[9], but GI can never remove all the pollutants from air, and becomes less and less efficient as the distance from the pollutant source increases. Direct experimental evidence of air pollution decreasing as a result of GI is scarce and difficult to generalise, but computer models suggest the following.

- GI, particularly trees, produce natural volatile organic compounds that can form ozone and PM (Table 1). To be significant in terms of poor air quality this takes several hours, and needs many millions of trees, and strong sunlight. This effect is large-scale (not local street-level), and only relevant when increasing the total urban tree population by more than 10%[8].
- Large areas of GI, such as parks, generally have cleaner air as they contain fewer roads and traffic emissions.
- Trees and other GI influence wind flow. The combination of parklands, buildings, trees, and gardens creates a rough surface of different heights creating turbulence that increases mixing, and pollutant dispersion (Fig. 1).
- Dense avenues of trees can trap air in narrow, enclosed streets ('street canyons') limiting mixing. If the pollution source is located inside the canyon this causes fumigation. If the source is located outside of the canyon this prevents mixing into the canyon, creating locally cleaner air (Fig. 2).
- GI, such as hedges, can be used as a barrier to increase the pathway between pollution source and receptor, which increases mixing and reduces pollutant concentration (Fig. 3 and Table 2).
- In comparison to similarly sized grey infrastructure, GI has a far greater surface area for pollutant deposition and thereby removes more PM, NO_2, and O_3 from the ambient air than bare surfaces[10] (Fig. 3).

Fig. 1 **Urban form and surface roughness**

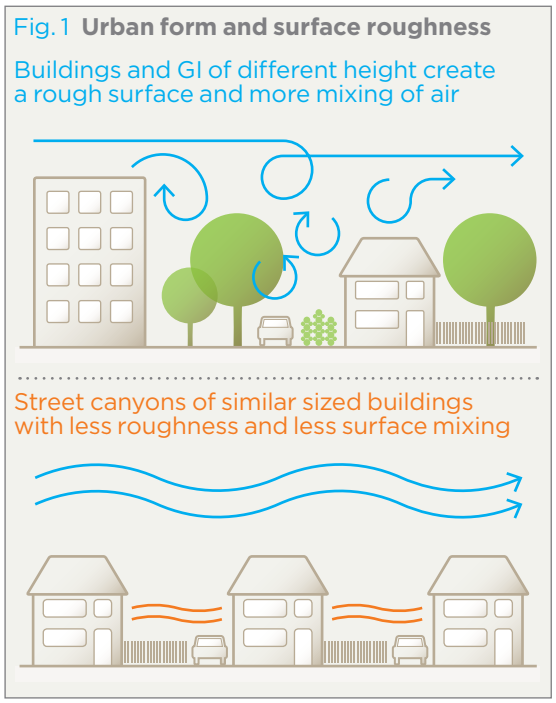


Fig. 2 **The tree canopy and street-level air**

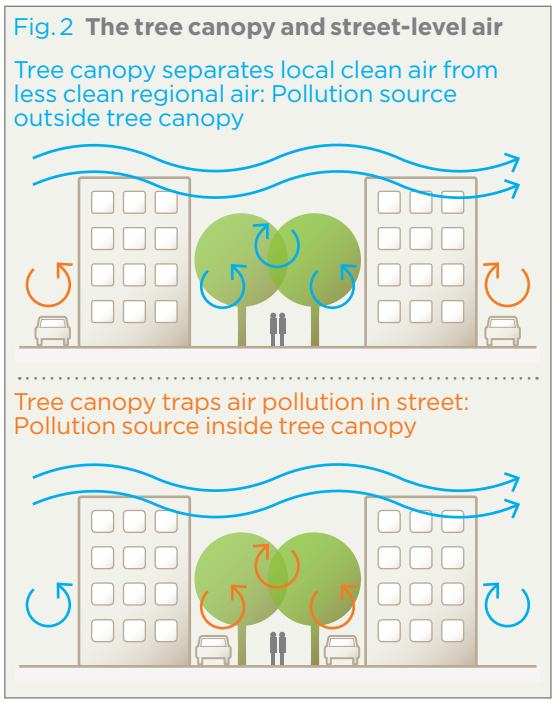
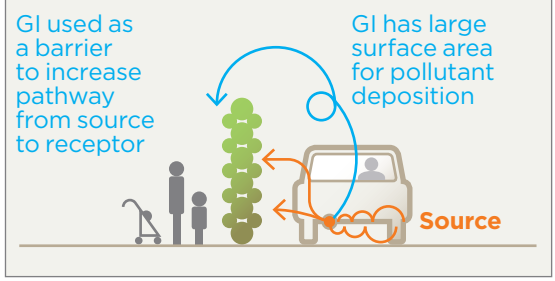


Fig. 3 **GI can increase the pathway between source and receptor and provides a comparatively large surface area for pollutant deposition**



8 Hewitt, C.N., Ashworth K., and MacKenzie, A.R. <in prep> Using green infrastructure to improve urban air quality (GI4AQ).

9 Abhijith, K.V., Kumar, P., Gallagher, J., McNabola, A., Baldauf, R., Pilla, F., Broaderick, B., Di Sabatino, S., and Pulvirenti, B. 2017. Air Pollution Abatement Performances of Green Infrastructure in Open Road and Built-up Street Canyon Environments – A Review. *Atmospheric Environment*. **162**, pp. 71-86.

10 Pugh, T.A., MacKenzie, A.R., Whyatt, J.D. and Hewitt, C.N. 2012. Effectiveness of green infrastructure for improvement of air quality in urban street canyons. *Environmental science & technology*, **46**(14), pp.7692-7699.

The Role of Built Environment Practitioners

Built environment professionals should consider air quality at all stages of urban design and development. To lower city-average pollution levels requires concerted strategic action. Locally, individual design decisions can create relatively cleaner 'oases' or relatively dirtier 'hotspots'. Information on local air quality in the UK can be obtained from the UK-AIR information portal[7] and there is planning guidance from the Department for Communities and Local Government[11]. Urban air quality is highly complex and can vary widely within an individual street. Determining the exact pollutant concentration requires high-resolution monitoring, or atmospheric chemistry or computational fluid dynamic (CFD) modelling. **However, it is possible to use good urban design to reduce air pollution without knowing the exact pollutant concentrations**. In the first instance, built environment professionals should consider reducing or removing the source of pollution. Where this is not possible, urban design should increase the pathway from pollution source to human receptor. GI can be used strategically to mitigate poor air quality on a local-scale using the available guidance documents[8,12,13]. The most effective way to improve urban air quality is to use emissions controls to reduce road transport emissions.

Table 2 **Key concepts: source, pathway, dispersion, receptor, exposure, susceptibility**

Source

- Road transport emissions are the largest **source** of air pollution in urban areas.
- Vehicle braking and accelerating cause emissions from brake and tyre wear, and from inefficient fuel combustion. Air pollution may be greater where drivers regularly brake or accelerate, for example at intersections, bus stops, roundabouts, or speed bumps.
- Air pollution increases where traffic regularly idles due to traffic congestion, or at regular drop off/collection points such as outside schools, hospitals and care homes, where vulnerable groups may congregate[14].

Pathway

- The concentration of air pollution is much higher closer to the source, where the **pathway** from source to receptor is shorter and less mixing has taken place. Higher wind speeds create more mixing.
- When **dispersion** is efficient, the source-receptor pathway is longer, the concentration decreases rapidly to the overall city average over a distance of tens of metres as the pollutant dilutes by mixing with cleaner air.
- The height and density of buildings modify wind flow and the dispersion of air pollution from its source (Fig 1).
- Street canyons – neighbourhoods and streets containing rows of similar mid- and high-rise buildings inhibit mixing and pollutant dispersal (Fig. 1). Downwind mixing and dispersion may be less efficient in streets that are at an angle to the prevailing wind direction[15].
- Small children and those in pushchairs or wheelchairs are often exposed to higher levels of pollution because they are closer to vehicle exhausts and other ground-level sources.

Receptor

- **Exposure:** Negative health impacts are associated with both long-term (chronic) and short-term (acute) exposure. Reducing exposure, i.e. breathing in cleaner air, is always beneficial for health.
- **Susceptibility:** Anyone can suffer adverse health impacts from air pollution, but children (under 14), older people (over 65), and those with chronic health problems (e.g. chronic obstructive pulmonary disease (COPD), asthma) are more vulnerable[14].

11 DCLG. 2014. Principles on how planning can take account of the impact of new development on air quality. London: Department for Communities and Local Government.

12 i-Tree Eco is a software application to quantify the structure and environmental effects of urban trees, and calculate their value to society.

13 United States Environmental Protection Agency. 2016. Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality.

14 National Institute for Health and Care Excellence. 2017. Air pollution: outdoor air quality and health. London: Department of Health.

15 Jeanjean, A.P., Hinchliffe, G., McMullan, W.A., Monks, P.S.and Leigh, R.J. 2015. A CFD study on the effectiveness of trees to disperse road traffic emissions at a city scale. *Atmospheric Environment*. **120**, pp.1-14.

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Trees and Design Action Group: www.tdag.org.uk