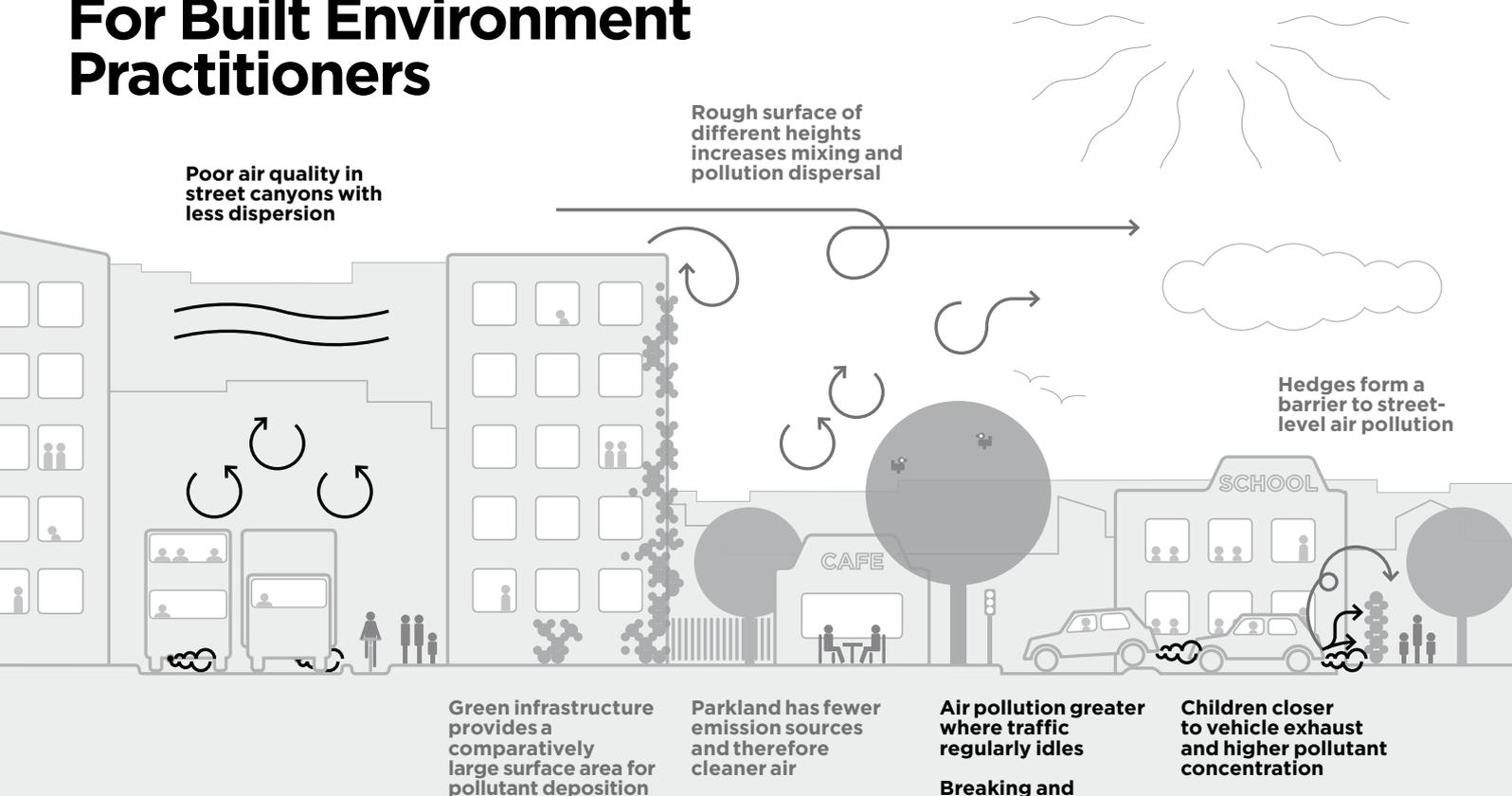


First Steps in Urban Air Quality

For Built Environment Practitioners





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.



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 standards¹. Within the UK, poor outdoor air quality is linked to 50,000 deaths each year². 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. Urban GI can also create environments that are conducive to a greater uptake of walking and cycling, thereby helping to reducing the amount of road transport pollution. 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 cities³. 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, NO₂, ozone (Table 1), and other pollutants: benzene, 1,3-butadiene, carbon monoxide, polycyclic aromatic hydrocarbons (PAH), and lead⁵. 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 NO₂ 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 future⁶. The UK-AIR portal⁷ provides support for air quality assessment including data archive, maps of key pollutants (NO_x, NO₂, PM₁₀ and PM_{2.5}), air quality forecasts, and details of monitoring networks.

Table 1 **The sources and health impacts of key urban pollutants⁴**

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.

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. If strategically designed, GI can mitigate poor air quality on a local-scale⁹, 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).
- A dense avenue of trees in a narrow, enclosed street ('street canyon') reduces mixing between street-level air and the air aloft (Fig. 2). On a lightly trafficked street this can protect relatively clean air from the import of polluted air aloft. On a heavily trafficked street it can trap street-level pollution (i.e., fumigation).
- 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, NO₂, and O₃ from the ambient air than bare surfaces¹⁰ (Fig. 3).

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.



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

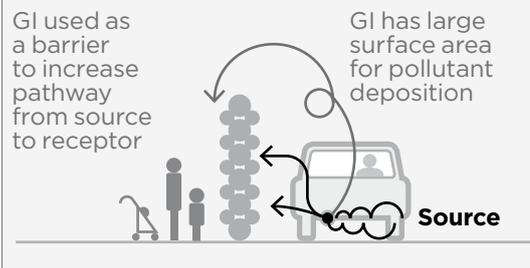


Fig. 1 Urban form and surface roughness

Buildings and GI of different height create a rough surface and more mixing of air

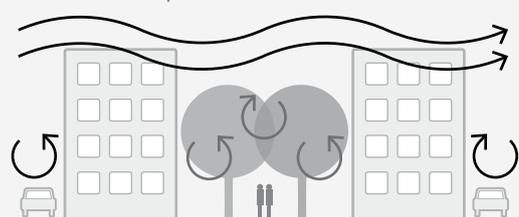


Street canyons of similar sized buildings with less roughness and less surface mixing

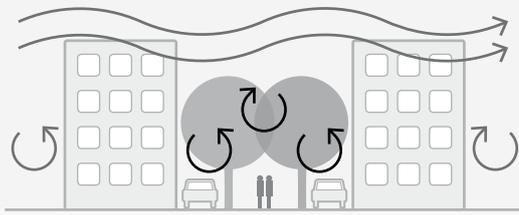


Fig. 2 The tree canopy and street-level air

Pollution source outside tree canopy: a dense tree canopy protects street-level air from more polluted air aloft



Pollution source inside tree canopy: a dense tree canopy risks trapping more polluted air at street level





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.



The Role of Built Environment Practitioners

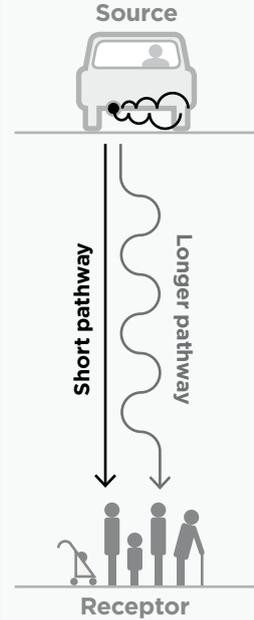
Built environment professionals should consider air quality at all stages of urban design and development. To lower city-average pollution levels requires concerted strategic action. Locally, individual design decisions can create relatively cleaner 'oases' or relatively dirtier 'hotspots'. Information on local air quality in the UK can be obtained from the UK-AIR information portal⁷ and there is planning guidance from the Department for Communities and Local Government¹¹. 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 extend the pathway from pollution source to human receptor. Urban design to improve air quality can be summarised in three key concepts, applied in this order of priority:

- 1. Reduce:** emissions, particularly from road transport
- 2. Extend:** the distance between emissions source and human receptor
- 3. Protect:** the most vulnerable people.

In summary, the most effective way to improve urban air quality is to use emissions controls to reduce road transport emissions. GI can be used to help **Reduce** emissions by creating spaces that encourage active transport such as walking and cycling, or the uptake of public transport. GI can be used strategically to mitigate poor air quality on a local-scale by using the available guidance documents to **Extend** and **Protect**^{8,12,13}.

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

 <p>Short pathway = Less dispersion</p> <p>Longer pathway = More dispersion</p>	<p>Source</p> <ul style="list-style-type: none"> - 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 congregate¹⁴. <p>Pathway</p> <ul style="list-style-type: none"> - 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 direction¹⁵. - 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. <p>Receptor</p> <ul style="list-style-type: none"> - 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 vulnerable¹⁴.
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