MAYOR OF LONDON

USING GREEN INFRASTRUCTURE TO PROTECT PEOPLE FROM AIR POLLUTION

April 2019

COPYRIGHT

Greater London Authority
April 2019

Published by
Greater London Authority
City Hall
The Queen's Walk
More London
London SE1 2AA
www.london.gov.uk
enquiries 020 7983 4000
minicom 020 7983 4458
ISBN

Copies of this report are available
from www.london.gov.uk

EXECUTIVE SUMMARY

This guide summarises the current best practice for how green infrastructure can reduce public exposure to air pollution in the urban environment. It has been produced in consultation with the Birmingham Institute of Forest Research (University of Birmingham), the Global Centre for Clean Air Research (University of Surrey) and Transport for London.

London's green infrastructure includes a network of parks, green spaces, gardens, woodlands, rivers and wetlands. It also includes street trees, hedges, green walls and green roofs. This guidance relates to the elements of green infrastructure found within a city's streets (e.g. street trees and hedges) and close by areas (e.g. parks and green spaces).

Green infrastructure offers many benefits for the health of both people and the environment. This guide focuses specifically on the benefit to public health from reducing exposure to the air pollution produced by vehicles (i.e. exposure to lower levels of nitrogen dioxide and particulate matter and/or exposure for shorter periods of time).

At regional and national scales, vegetation plays an important part in removing air pollutants by the process of *deposition* to leaf surfaces (see Evidence Base for definition). However, at the street scale *deposition* is of limited benefit. The main value of green infrastructure for urban air quality is not its ability to remove pollutants, but its ability to control their flow/ distribution.

Vegetation at smaller scales – street scale – can be used to control the flow/ distribution of pollutants by controlling their *dispersion*: the transport of pollutants by the wind away from the source and dilution with cleaner surrounding air. **There is no 'one size fits all' intervention (and the effects are highly localised) but the right green infrastructure in the right place can reliably reduce exposure to air pollution. A vegetation barrier** can as much as halve the levels of pollutants just behind the barrier.

To identify the right type of green infrastructure, and the right place to put it to reduce exposure, the first step is to identify the type of urban road in question:

- Street canyon – a street with buildings on both sides
- Open road – a road with buildings only on one side or detached, single-storey buildings that are widely spaced and/or set back a long way from the road

As summarised in Table 1 below, the appropriate intervention in a street canyon depends on: how the air quality at street level compares with that above the surrounding buildings; and the height/width ratio of the street canyon (i.e., height of surrounding buildings divided by width of street between). On an open road, the critical question is whether the priority is to protect people close to the roadside (e.g. pedestrians and cyclists) or people further away (e.g. children in a school playground bordering the street).

Table 1. Right green infrastructure, right place

<table>
<tr><th colspan="3">Street Canyons</th><th colspan="2">Open Roads</th></tr>
<tr><td rowspan="2">Where air quality at street level is better than above surrounding buildings: street canyons with little or no traffic</td><td colspan="2">Where air quality at street level is worse than above surrounding buildings: street canyons with moderate or heavy traffic</td><td rowspan="2">Where priority is to protect people immediately at the roadside (e.g. pedestrians and cyclists)</td><td rowspan="2">Where priority is to protect people further away (e.g. children in a school playground bordering the street)</td></tr>
<tr><td>All street canyons with moderate or heavy traffic</td><td>Canyons of this sort with height/width ratio < 2</td></tr>
<tr><td>A dense avenue of trees can provide effective protection from polluted air above and create a clean ‘green corridor’ for active travel</td><td>Addition of green open space to one side (opening up the street canyon) is always beneficial</td><td>A hedge or green wall between vehicles and people can reduce exposure in their immediate wake</td><td>A hedge or green wall between vehicles and people can as much as halve exposure in their immediate wake</td><td>A combination of hedge and dense line of trees can provide a taller vegetation barrier, offering protection over a greater distance downwind</td></tr>
</table>

Having identified the right green infrastructure and the right place to put it, the details of its implementation are critical to its success. Used as vegetation barriers, hedges and green walls should: extend from ground level to a height of at least 2m; and be as thick and dense as possible to ensure effective blocking of air flow from vehicles to people. Green walls must also be suitably maintained to remain effective at blocking the flow of air.

If a hedge and dense line of trees are combined to provide a taller vegetation barrier – to protect a greater distance downwind – the trees should: be located as close as possible to the hedge; and located as close to each other as possible to provide a continuous barrier. Evergreen trees are preferred as they will provide year-round protection (deciduous trees offer protection only when in leaf) but **borough tree officers should be consulted for species selection, not least to ensure successful long term growth.**

INTRODUCTION

In the London Environment Strategy, the Mayor committed to support and empower London and its communities, particularly the most disadvantaged, to reduce their exposure to poor air quality. As well as reducing exposure, the Mayor has pledged to take action to achieve legal compliance with the UK and EU pollution limits as soon as possible. The Mayor has also committed to help make London the world's first National Park City, where more than half its area is green, the natural environment is protected, and the network of green infrastructure is managed to benefit all Londoners.

London's "green infrastructure" is the network of parks, green spaces, gardens, woodlands, rivers and wetlands (as well as features such as street trees and green roofs) that is planned, designed and managed to:

- promote healthier living
    - encouraging walking, cycling and outdoor recreation
    - creating public spaces to improve mental and physical wellbeing
- lessen the impacts of climate change
    - removing carbon dioxide from the air
    - reducing the risk of severe weather events
    - providing sustainable urban drainage
- improve air quality and water quality
    - reducing exposure to air pollution
    - providing a safe and sustainable source of water
- improve biodiversity and ecological resilience
    - protecting and linking habitats

The use of green infrastructure to reduce exposure to air pollutants is a relatively new and fast-evolving area of research. Some interventions have already been identified that can deliver significant reductions in exposure and, therefore, improvements in public health. This guidance will ensure new green infrastructure projects follow current, evidence-based best practice.

The best way to improve urban air quality is to reduce the emissions of pollutants, such as nitrogen dioxide (NO_2) and particulate matter (PM), at the source. Reductions in emissions improve air quality both locally and regionally. In London, road transport is the main source of local air pollution, and the Mayor is taking bold action to reduce these emissions. Reducing the use of vehicles is key and green infrastructure has a role to play in incentivising 'active travel' (e.g. walking and cycling) through the creation of attractive 'green corridors' and networks of green space. However, the health impacts of road transport pollution can be further reduced by decreasing the public's exposure to what is emitted. 'Green corridors' often have better than average air quality, and the attraction of people away from busy roads into cleaner areas will reduce their exposure to road transport pollution. The remainder of this guide, however, focuses on the use of green infrastructure close to busy roads to reduce public exposure to pollution, principally at the kerbside.

Green infrastructure will play an important role in reducing exposure for many years to come as our transport system evolves. Whilst pollution from road transport is forecast to decrease significantly, an important source of ultrafine PM (the smallest particles) from road transport is the non-exhaust emissions associated with brake, tyre and road wear. In the long term, a reduction in traffic volume will be required to address these non-exhaust emissions. This is why the Mayor's Transport Strategy includes the ambitious target that 80 per cent of trips in London are made on foot, by cycle or using public transport by 2041. Meanwhile, green infrastructure can help reliably reduce exposure to ultrafine PM emissions, and their impacts on public health.

There are two key processes that explain how green infrastructure can protect people from pollution, **dispersion** and **deposition.**

Dispersion: Urban vegetation can greatly reduce the amount of emissions people are exposed to. It does this by changing the speed and distance pollutants travel before they reach people. The further the distance the more the pollution is diluted with cleaner air – this process is known as *dispersion*.

Deposition: Urban vegetation typically removes a few per cent of emissions by a process called *deposition*. This refers to when pollution lands on the surface of the leaf and is removed from the air. This process is less important for reducing exposure to air pollutants in the urban environment than *dispersion*.

The next section of this guidance summarises the scientific evidence so far. Supporting information on general planting considerations, and links to practical guidance on implementation are also included. The guidance is divided into two parts:

- Street canyons – streets with buildings on both sides

- Open roads – roads with buildings only on one side, or flanked by detached, single-storey buildings that are widely spaced and/or set back by a considerable distance

EVIDENCE BASE

This guidance summarises the current best practice, informed by scientific evidence, for using green infrastructure to reduce public exposure to road transport pollution. In 2015, the Forestry Commission established, via its London iTree Eco Project, that trees have a role to play in tackling urban air quality. Last year, the Trees and Design Action Group published practical guidance in partnership with the University of Birmingham and Lancaster University (First Steps in Urban Air Quality for Built Environment Practitioners) and the University of Surrey led a review of the scientific literature then available[1].

In July 2018 the Air Quality Expert Group (AQEG) produced a report, Impacts of Vegetation on Urban Air Pollution. The report was a comprehensive and critical review of the scientific evidence available. They found the main value of green infrastructure for urban air quality does not lie in its ability to remove pollutants, but in its ability to control their distribution. The distribution of road transport pollution is affected by the location of the source, the movement of emissions away from that source (e.g. by the wind) and the mixing of emissions with cleaner surrounding air. Urban vegetation typically removes only a low percentage of emissions by a process called ***deposition***, which is when pollution sticks to the surface of a leaf and is removed from the air. However, urban vegetation can greatly reduce the amount of emissions people are exposed to. It does this by changing the distance they must travel from the source to reach people, and the extent to which they are diluted with cleaner air along the way– this process is known as ***dispersion***.

The main messages from the AQEG report, which provides much of the evidence base for this guidance, are summarised below.

- **Large scale vegetation**, for example in rural environments, can influence air quality in three ways:

    a. air pollutants are deposited to leaf surfaces, leading to improved air quality in a process known as *deposition*;

    b. Volatile Organic Compounds (VOCs) are emitted from vegetation that, in the presence of pollution, can contribute to the formation of further pollutants, such as PM and ozone; and,

[1] Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review, Abhijith et al, (2017)

- vegetation can affect the *dispersion* of pollutants, neither removing nor adding to emissions, but changing the way they mix with the cleaner air around them. **Smaller scale vegetation**, the kind found in towns and cities, generally makes only a small contribution to the improvement of air quality via *deposition*; large parks can offer a greater benefit in this respect. However, at the smaller scale of street planting schemes, *dispersion* has a significant influence on the levels of pollutants. The influence of green infrastructure via dispersion is highly localised: regional air quality will be unaffected but, on a specific stretch of a street, green infrastructure can reduce exposure to pollution.

- **A vegetation barrier** can as much as halve the levels of pollutants just behind the barrier. The benefit largely comes from forcing the main flow of air over and around the barrier. This creates a sheltered area of air just behind the barrier (i.e., within the first few metres). Most of the polluted air then bypasses this space so the people within it are protected. The benefit of a vegetation barrier (e.g. a hedge) is mainly attributable to its effect on *dispersion*. However, vegetation barriers are not solid and even the thickest hedges will allow some air to flow through them. The *deposition* of pollutants in the air that passes through the hedge onto the leaf surfaces will have a small but beneficial effect. The levels of pollutants here may be as much as halved, but the benefit tails off with increasing distance from the hedge. This was demonstrated by one study by King's College London that found levels of NO2 reduced by 23 per cent when a green wall was placed between a busy road and a school playground. [2]

- The *deposition* of pollutants onto green infrastructure is helpful because it improves air quality both locally and regionally (downwind), but the benefit is small. Some plant species are better than others at removing pollutants by *deposition*[3]. Overall, the AQEG report concluded that *deposition* typically removes just a few percent of PM and a similarly small fraction of NO_2. Furthermore, the NO_2 that is *deposited* onto leaves is partly cancelled out by soil emissions of nitrogen monoxide (NO). In the presence of sunlight, chemical reactions rapidly convert NO_2 into NO and vice versa, and the soil emissions of NO therefore reduce the already small benefits of NO_2 *deposition*.

The emission of VOCs from green infrastructure, at the scale of urban street planting schemes, is also minor. Green Infrastructure is responsible for a small fraction of total urban VOCs, particularly when assessed over all four seasons, and their small influence on air quality is mainly felt at a distance downwind.

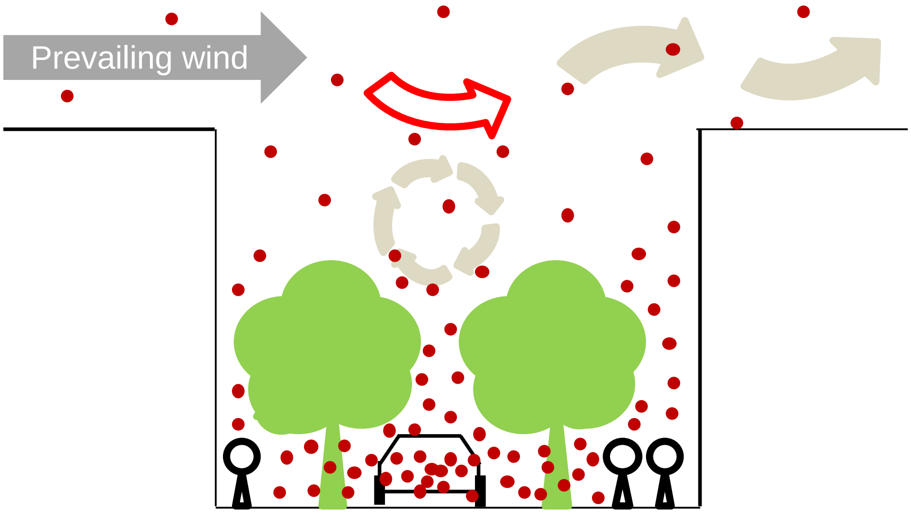
[2] For more information see: The impact of a green screen on concentrations of nitrogen dioxide at Bowes Primary School, Enfield, A Tremper, (2018)
[3] For more information see: Variation in Tree Species Ability to Capture and Retain Airborne Fine Particulate Matter (PM2.5), Chen et al, (2017)

GUIDANCE FOR STREET CANYONS

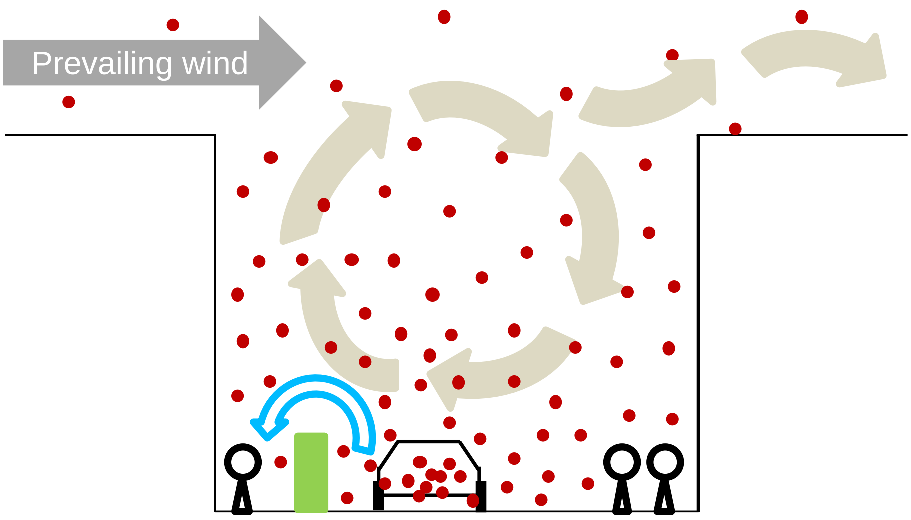
Street canyons are streets with buildings on both sides. They come in many shapes and sizes but one important consideration is the ratio of their height to their width (this will be explained in more detail later in this guidance).

When deciding what green infrastructure will be best for air quality in a street canyon, the first consideration is the difference between the air quality at street level and the air quality above the surrounding buildings. Is the air at street level more or less polluted than the air above?

(i) Street canyons: Air at street level is more polluted than the air above the buildings



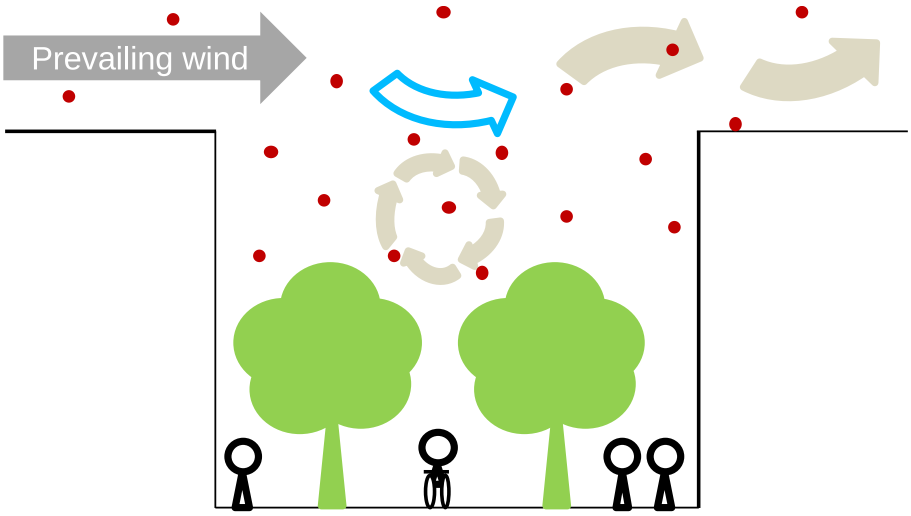
On very busy roads, the air pollution at street level is usually worse than the air above the buildings. In these canyons reducing the flow of air upwards and downwards should be avoided. A dense avenue of trees could trap the pollution emitted from vehicles at street level and prevent it from mixing with cleaner air above. However, a 'dense avenue of trees' refers to trees packed so closely together that they form an almost unbroken canopy. Trees spaced more widely will have little effect on air quality but *will* deliver the many other environmental and health benefits presented in the Introduction.



On very busy roads, where the air pollution at street level is worse than the air above, a vegetation barrier (i.e., a hedge) between the road and pedestrians may offer some protection. A vegetation barrier between vehicles and cyclists (i.e., in a separate cycle lane) can likewise reduce cyclists' exposure. As mentioned in the Evidence Base, studies have shown that in an open road environment (which will be discussed the next section), a vegetation barrier can as much as halve the levels of pollutants just behind it. The effect of a vegetation barrier in a street canyon is less certain and depends on local conditions, including wind speed and direction, the height of the buildings, and the width of the road. These factors interact to determine the flow of air within the canyon.

In general, any intervention that increases the distance pollution must travel from vehicles to pedestrians or cyclists will reduce the amount of pollution they are exposed to. However, in street canyons with narrow roads and very tall buildings it is not yet clear if installing a hedge will reduce or increase exposure, and we do not currently recommend it. As a guide, we do not currently recommend adding vegetation barriers in canyons where the height of the buildings either side is more than twice the width of the street between them (i.e., a height to width ratio > 2).

(ii) Street Canyons: Air above the buildings is more polluted than the air at street level



It is also possible to reduce public exposure to pollution using green infrastructure on very quiet roads. In a city like London, there are some roads with little or no traffic, where the air quality at street level is better than that above the surrounding buildings. We can reduce the public's exposure to the polluted air above by creating a pocket of clean air where people are. A dense avenue of trees, forming an almost unbroken canopy, provides a barrier to downward *dispersion*, reducing the flow of polluted air down to street level where people would be exposed to it.

As mentioned in the Introduction, there are many ways in which green corridors reduce exposure to air pollution. They incentivise walking and cycling, thereby helping to reduce road transport emissions; they reduce the overall public exposure to pollution by attracting people away from busier routes onto cleaner ones. This is in addition to the many other benefits of green infrastructure not related to air quality.

(iii) Street Canyons: Green roofs, green walls and green open space

The benefits of green roofs include sustainable urban drainage, mitigation of the urban heat island effect (cooling buildings and reducing energy used for air conditioning) and increased biodiversity. However, their potential for reducing exposure to road transport pollution is limited for two reasons: they have little effect on the *dispersion* of this pollution; and their relatively minor effect via the *deposition* of pollutants is focussed on the air above the buildings, not at street level.

Green walls (if they are dense enough and well maintained) can be used instead of hedges as effective vegetation barriers between pedestrians and busy roads. When they are mounted on building facades, green walls have some potential to reduce public exposure to road transport pollution, but further research is needed. Here, they might be expected to improve air quality within a street canyon solely via *deposition* of pollutants to their leaf surfaces. A computer-modelling study, however, found that the potential for *deposition* strongly depended on the average time air spends circulating within the street canyon, and that this changed when a green facade was added on both sides of the street[4]. The modelling found significant reductions in PM_{10} (and some reduction in NO_2) but the results varied a lot depending on the height and width of the street canyon. Further research is needed into the effect on air quality of green walls in street canyons.

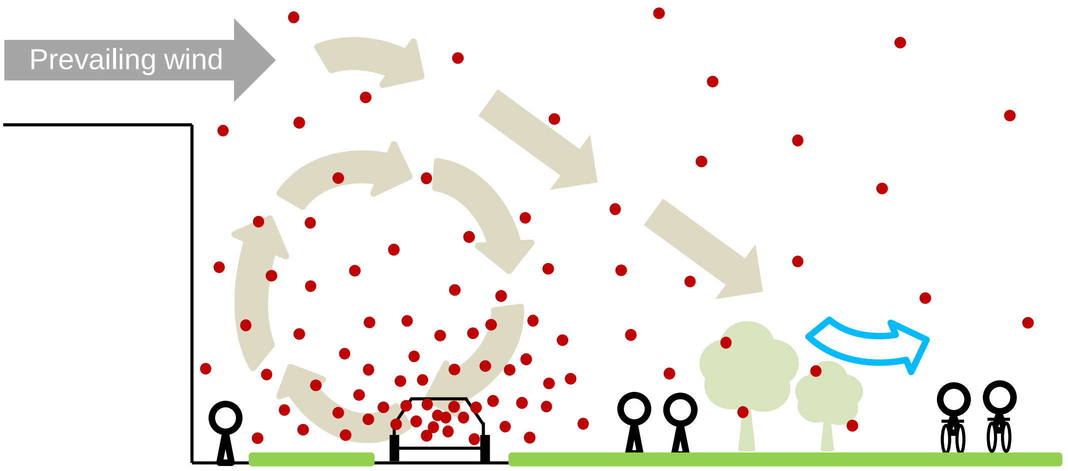
If there was an opportunity to open up one side of a street canyon onto an open space, particularly a green open space, this would greatly improve the air quality in that street; open space allows the efficient *dispersion* of road transport pollution. In effect, the street canyon would be turned into an 'open road' environment – the subject of the next section.

[4] For more information see: Pugh, T.A.M., A.R. MacKenzie, J.D. Whyatt, and C.N. Hewitt, Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons, Environ. Sci. Technol., 2012, 46 (14), pp 7692–7699

GUIDANCE FOR OPEN ROADS

The term ‘Open roads’ includes roads with buildings on one side only. It also includes roads where houses are detached, single-storey buildings with big gaps between them and/or set back a long way from the road. These are common features of the urban environment, mainly found in suburban areas, at the edges of parks and other residential areas.

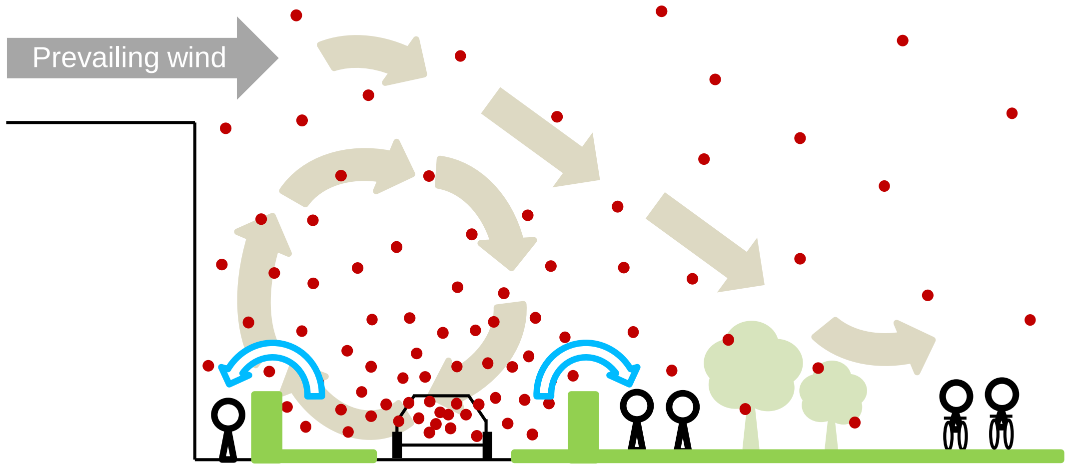
(i) Open roads: the value of open space, particularly green open space



Open space next to a road, particularly green open space such as a park, plays a vital role in reducing public exposure to road transport pollution. Open space allows pollutants to *disperse*, meaning they quickly decrease to background levels. Within parks, trees are very beneficial to the *dispersion* of pollution: they disturb the flow of air around them and increase the mixing of the more polluted air at street level with cleaner air above. Green open spaces also take the place of space that would otherwise include further sources of pollution.

Similar to green corridors, there are many benefits associated with the provision of green open space: it can form part of a network of green infrastructure that incentivises walking and cycling, and thereby help to reduce road transport emissions; and it can reduce public exposure to these emissions by attracting people away from more polluted areas into cleaner ones, and encouraging them to stop and spend time here for recreational purposes. A recent study found that children with asthma who live close to a green space present fewer asthma symptoms in later life than those who live further away.[5]

(ii) Open roads: Protecting people at the side of an open road



Hedges can provide effective barriers between cars and pedestrians to protect people close to the side of open roads. As noted in the previous section (Guidance for Street Canyons), vegetation barriers between vehicles and cyclists (i.e. in separate cycle lanes) can likewise reduce cyclists' exposure to vehicular pollution. (Cyclists sharing the road with vehicles, though not protected by a vegetation barrier will benefit from systematic interventions suchas the introduction of the Ultra Low Emission Zone in April 2019, and cleaning up the bus fleet).

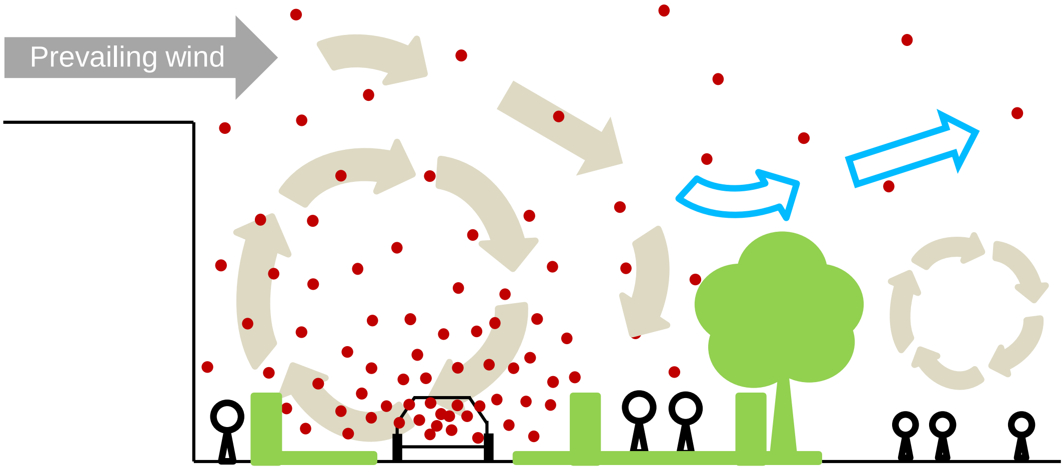
As with a street canyon, the effect of a hedge located close to neighbouring buildings (such as the hedge on the left in the diagram above) is less certain than one bordering open space (such as the hedge on the right in the picture above). The benefit of a hedge located close to buildings is that it increases the distance pollutants must travel between vehicles and, in this case, pedestrians. A hedge or green wall bordering open space, however, has the additional potential to create a sheltered region of air immediately behind it. By forcing the main flow of polluted air over and around this space, the people within it, close to the hedge, are protected. The levels of pollutants here may be as much as halved, but the benefit tails off with increasing distance from the hedge.

The cyclists (pictured to the far right, in the above diagram) are likely to be exposed to similar levels of pollutants as if there were no hedge, though much of the pollution from the vehicles will have *dispersed* before it reaches them, meaning pollution levels will already

[5] For more information see: Green space near home during childhood linked to fewer respiratory problems in adulthood, European Lung Foundation, (2018)

be much lower than at the roadside. The taller the barrier, the larger the area protected, but further research is needed to quantify the relationship between the two.

(iii) **Open roads: Protecting people further from an open road**



An additional, taller barrier is needed when the aim is to protect people occupying a larger area, further from the road, such as children in a school playground. A dense line of trees, with a hedge or green wall beneath, can provide an effective barrier. The benefit of a hedge or green wall on its own will critically depend on its height: a barrier to a height of 2m will protect children in the first few metres of the playground, but a taller barrier is needed to offer effective protection to children further away.

As a rule of thumb, a barrier of height, **H metres** can protect a distance of up to (**3H) - 3 metres** downwind under the right wind conditions. For example, a 2m high barrier can protect up to (3 x 2) – 3 = 3m downwind, whilst a 10m high barrier can protect up to (3 x 10) – 3 = 27m downwind. (This rule of thumb assumes that a sufficiently thick and dense vegetation barrier creates a sheltered region behind it similar to the ‘recirculation region’ downwind of a building).[6]

There is a risk that this taller barrier may reduce the *dispersion* of pollutants between it and the road, increasing the exposure to pollution on the road side.

When the net public health impact is considered, reduced exposure in the playground may justify a small increase in pollutant levels between the playground and the road. Considerations include; the number of people exposed either side (more children may be exposed in the playground than passersby on the road); the average length of time for which they are exposed (children may spend longer in the playground, at lunchtime and during breaks, than passersby spend walking past the school); and the vulnerability of those exposed (children are more vulnerable to the impacts of air pollution than the majority of adult passersby). Note, the elderly also tend to be more vulnerable to the impacts of air pollution, as do people with certain pre-existing medical conditions.

[6] For more information see: Scalar Fluxes from Urban Street Canyons. Part II: Model, Harman et al. (2004).

Alternatively, it may be possible to position the tall barrier (dense line of trees and a hedge) at the kerbside. This would still protect the children in the playground, albeit to a slightly lesser extent, whilst also protecting the people between the playground and the road.

(iv) **Open roads: Green roofs and green walls**

As outlined in the previous section, green roofs provide many benefits including their significant contributions to sustainable urban drainage, mitigation of the urban heat island effect (cooling buildings and reducing energy used for air conditioning) and increased biodiversity. However, at street level, they have limited potential for reducing exposure to road transport pollution.

On open roads, green walls can be used in place of hedges and trees as effective vegetation barriers between vehicles and pedestrians (if equally tall and dense, and well maintained). This is particularly the case where hedges and trees cannot be planted due to, e.g. sub-surface infrastructure constraints. However, when mounted on building facades, they are not effective at reducing exposure to road transport pollution. With no buildings on one side of the road, the average time air spends circulating close to the green facades will be short, and the benefit of *deposition* very small.

PRACTICAL CONSIDERATIONS

Supporting information regarding general planting considerations is provided in Table 2, followed by links to further guidance on practical implementation**.**

Table *2*. General planting considerations

Vegetation characteristics associated with species selection	
Seasonal effects	For an effective, year-round barrier to pollutants, evergreen plants are recommended; deciduous trees and shrubs will be less effective in winter months due to their lack of foliage. However, species selection must account for many other factors, including the likelihood of successful long-term growth, and borough tree officers should be consulted.
Stress resistance, invasiveness and allergens	The vegetation should be resistant to the effects of air pollution. Depending on local conditions, it should also be resistant to other relevant stresses, such as salt (used during winter road conditioning), drought and high wind turbulence often associated with busy roads. Invasive species should be avoided, as should poisonous species, and species responsible for the production of common allergens. For example, the planting of birches in and around schools should be avoided. For all of these considerations, London tree officers should be consulted.
Leaf surfaces for *deposition*	Although a relatively minor influence compared to the redistribution of pollution by enhanced/reduced *dispersion,* the removal of pollutants by *deposition* is greater to some leaf surfaces than others: leaves with large surface areas, and complex waxy (*e.g., Hedera helix, Juniperus chinensis*) and/or hairy surfaces (*e.g., Sorbus aria, Stachys byzantine*), are particularly good. However, species selection must account for many other factors, including the likelihood of successful long-term growth, and tree officers should be consulted.

Volatile Organic Compound (VOC) emissions	Green infrastructure is a relatively minor source of VOCs in the urban environment. Some VOCs, however, are more chemically reactive than others – isoprene is a particularly reactive one – and VOC emissions from vegetation will likely increase somewhat as the climate continues to warm. It may therefore be prudent to plant somewhat fewer trees of species known to be particularly strong sources of isoprene (e.g. oaks) and somewhat more trees known to emit little isoprene (e.g. larch), but simply planting a mixture of species will mitigate the (relatively minor) concerns regarding their emissions; guides are available such as Donovan et al.'s (2005) 'Urban Tree Air Quality Score'. Species selection must take account of many other factors, not least those governing successful long-term growth, and tree officers should be consulted.
Physical characteristics of vegetation barriers between vehicle emissions and people	
Height	To protect people in the surrounding area, hedges/ green walls should provide as complete a barrier as possible from ground level to a minimum height of 2m. Above 2m, further increasing the height of the vegetation barrier, be it a hedge, green wall, or a combination of a line of trees with a hedge at its base, will protect a greater distance downwind. As a rule of thumb, a barrier of height, **H metres** can protect a distance of up to (**3H) - 3 metres** downwind under the right wind conditions. For example, a 2m high barrier can protect up to (3 x 2) – 3 = 3m downwind, whilst a 10m high barrier can protect up to (3 x 10) – 3 = 27m downwind.
Thickness	Vegetation barriers – where recommended to reduce exposure to road transport emissions (see previous sections) should be as thick as possible: the thicker the vegetation barrier, the more effective it will be at blocking road transport emissions through it and, thereby, forcing air over it; see Evidence Base for further information.
Density	Likewise, vegetation barriers – where recommended to reduce exposure to road transport emissions (see previous sections) – should be as dense as possible: the denser the vegetation barrier, the more effective it will be at blocking transport through it and, thereby,

	forcing air over it; see Evidence Base for further information.
Continuity and **safety**	Gaps between stretches of a vegetation barrier, be it a hedge, green wall, or a combination of a line of trees with a hedge at its base, will reduce its effectiveness at blocking horizontal transport. However, **appropriate guidance must be sought to ensure all sight lines, vision splays, and any other safety provisions for drivers, cyclists and pedestrians, are maintained**. Green Infrastructure should be designed to support streets where people feel safe from crime in line with the Healthy Streets approach.
Installation and maintenance	Vegetation barriers must be properly installed for long term success, and appropriately maintained to remain effective at blocking the transport of pollution. Some types of barrier will be more expensive to install and maintain than others, and tree officers should be consulted at all stages (i.e., from early planning activities to installation and maintenance).

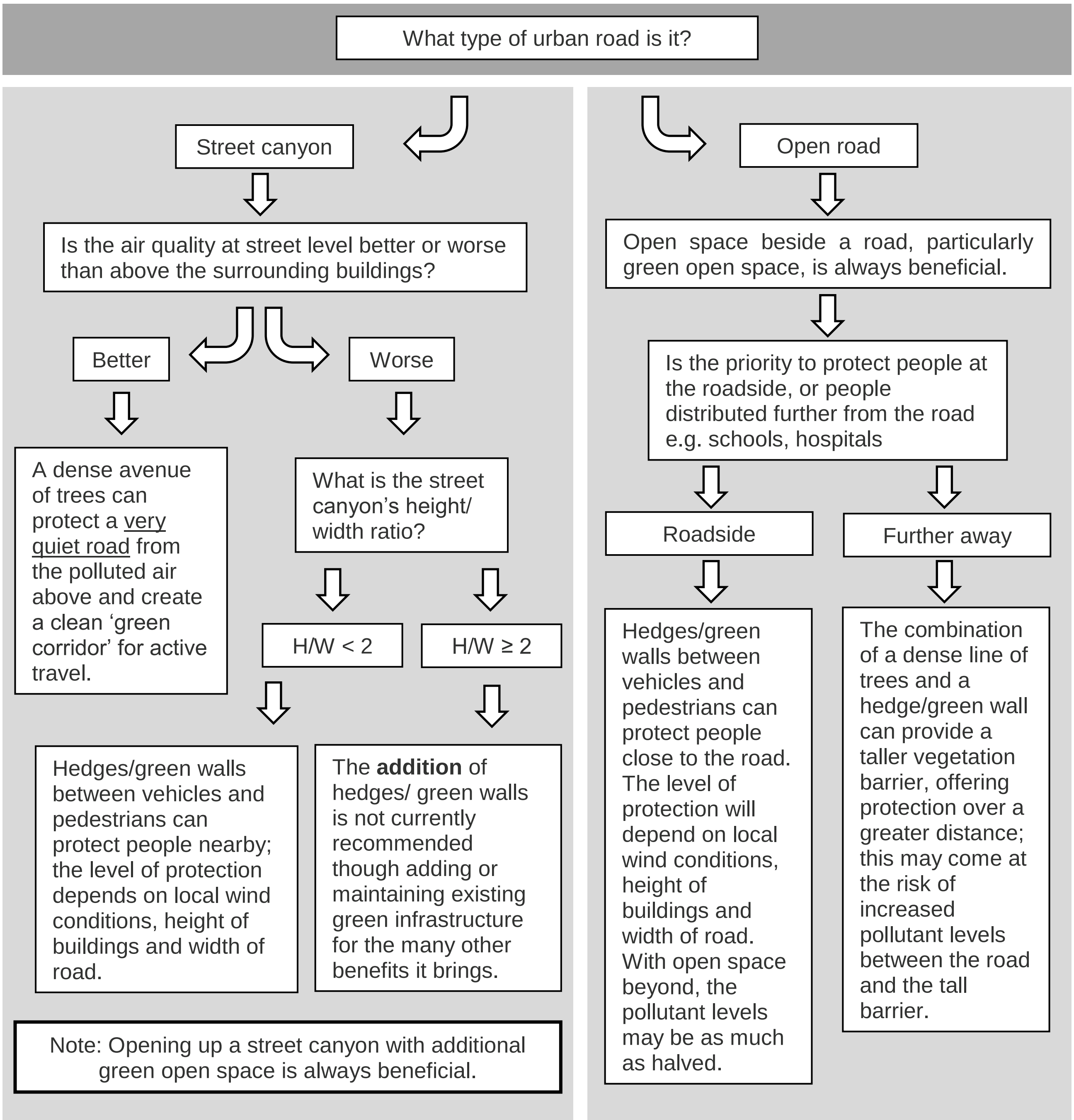
Links to further guidance on practical implementation

The planting of street trees and hedges can be challenging. Considerable space is needed to accommodate good cellular root systems, and space may be limited due to the routing of existing utilities underground (and services overhead) and the preservation of safety-critical sight lines, vision splays and so forth (e.g. at road junctions and pedestrian crossings. The Tree and Design Action Group's Trees in Hard Landscapes guide and the Forestry Commission's Urban Tree Manual offer technical guidance on integrating trees into the urban landscape. The Tree Species Selection for Green Infrastructure: A Guide for Specifiers is a guide and searchable database.

Where green walls are sought as part of an urban design, our 2008 Living Roofs and Walls Technical Guide provides further advice on their benefits and constraints, an updated version of which will be published in April 2019. Further advice and best practice on delivering high quality urban greening can be found on our website.

SUMMARY

Below is a summary of the guidance contained within this report. For further details, please refer to the preceding sections. The flowchart below is a reminder of general recommendations but local factors should always be taken into account.



Acknowledgements

This guide has been produced in consultation with the Birmingham Institute of Forest Research (University of Birmingham), the Global Centre for Clean Air Research (University of Surrey) and Transport for London.

Disclaimer

The guidance provided herein is intended to describe best practice subject to the scientific evidence available at the time of writing. Uncertainties remain, and revised guidance will be issued as these are addressed through further research.

Other formats and languages
For a large print, Braille, disc, sign language video or audio-tape version of this document, please contact us at the address below:

Greater London Authority
City Hall
The Queen's Walk
More London
London SE1 2AA

Telephone **020 7983 4000**
www.london.gov.uk

You will need to supply your name, your postal address and state the format and title of the publication you require.

If you would like a summary of this document in your language, please phone the number or contact us at the address above.