TREES

Relief for the city

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Introduction

Research has provided much information about the impact of trees and other plants on air quality and general quality of life in urban surroundings. This brochure provides an overview of current knowledge. Its intention is to present this knowledge as practically as possible so that the positive functions of trees can be better exploited for air quality management in urban areas and for the design of functional vegetation.

This brochure describes the underlying principles that form a basis for better-informed choices with regards to the management of trees and shrubs in cities and the design of functional planting schemes. In order to make direct action possible, as much concrete data as possible is given about the functionality of different types of trees.

Parts of the text have already appeared in previous reports commissioned for other clients of the three authors concerned, such as the municipalities Rotterdam, Nijmegen and The Hague, and the provinces of Zuid-Holland and Rijkswaterstaat. The authors wish to thank all the clients and employees involved for their contribution to the various phases of gathering information and writing this brochure.

Malus 'Adams'

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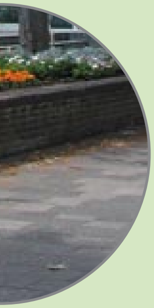


Summary

Plant-life and the poor air quality in our cities are in the spotlight right now. This brochure examines possibilities for making our cities greener and at the same time cleaner. Trees and other plants in urban areas work as fully automatic air filters which remove particulates and other pollution from the air, free-of-charge. We have tried to present the available knowledge in as practical a manner as possible so that the positive function of trees and other plants can be better exploited for management of air quality in urban areas and for devising and planting functional plant-life.

Heavy traffic is a primary cause of poor air quality in our cities. Concentrations of particulates and nitrogen dioxide exceed air quality standards in busy locations. Ozone concentrations also often exceed limits. This component is formed as sunlight causes nitrogen dioxide and other substances from exhaust emissions to react.

Trees have many leaves and form effective windbreaks. Because of this, trees are a highly efficient means of filtering pollution out of the air, thereby reducing concentrations. Leaves capture particulates on their surfaces and absorb gaseous pollution such as nitrogen dioxide and ozone through their stomata. Deciduous trees with flat, broad leaves are especially efficient at absorbing gaseous pollution. Conifers are most suitable for capturing particulates because of the pointed structure of their needles. Deciduous trees with coarse, hairy leaves are more effective for this purpose than deciduous trees with wide, flat leaves, but conifers are still more effective than either.

Trees form a physical obstacle and inhibit wind speed. They have long been used as windbreaks. Changes in local wind climate caused by trees also has a direct influence on pollution levels in the area around where they are planted. The blend of polluting substances with the surrounding air is therefore influenced. In spite of their filtering effect, the presence of trees near roads can sometimes lead to higher concentrations. The damping of wind speed in the very places where higher concentrations originate tips the scales. In these situations it can be better to make sure any trees have low foliage density in order to allow larger distribution of the polluted air. Other types of green structures such as green roofs and plant-covered walls can also be put to use. These do filter but don't dampen the wind speed. Every situation calls for its own creative solution.

The green, clean city requires an integrated design. Plants with appropriate qualities are necessary to improve air quality structurally. The principle "the right tree in the right place" needs to be implemented when making selections. The right choice is certainly necessary as we look at the air quality in our cities. Tree types which are suitable for efficient removal of different types of air pollution are indicated. Directives are also summarised with regards to how people must consider planting and maintenance of trees with the removal of particulates and gaseous air pollution as the objective.

Urban air contains of a cocktail of components. A good mix of plant types and structures is best used to deal with this cocktail. A big advantage of such an integrated approach is that it leads to a large variety of plant types, making our cities more varied and greener at the same time as becoming cleaner.

1 Greener and cleaner

The presence of plant-life in our environment is so normal to us that we tend to forget the value of it. Without plants, life on earth would be intolerable. In urban areas, plants are indispensable for creating the right social climate too. Plants are not only for decoration and recreation. Table 1 gives an overview of the positive effects of trees and other plant forms.

Plants don't just improve the quality of water and soil, the quality of our air also benefits from the presence of plant life, especially trees. Trees not only form a canopy which protects against the elements, but also have a strong positive influence on the quality of the air that we breathe. We don't just benefit from the fact that they absorb carbon dioxide, the gas responsible for global warming and for the fact they produce oxygen, but also from their ability to remove dust and gaseous air pollution.

What's more, the presence of plants has a positive influence on people's physical and psychological health and gives space for relaxation and exercise. Well thought-through planting schemes lead to 10% energy benefits in neighbouring buildings (November, 2003). Houses in the vicinity of plants are much more economical.

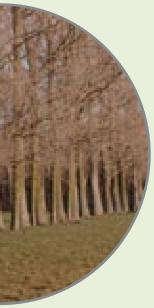
It is clear that trees improve the quality of the environment. To us, a good quality environment equates to economic vigour and flourishing cities for residents, users and visitors. It leads to bustling cities with good social development and ones which are healthy, clean, beautiful, safe and habitable, with sufficient plant-life and stimulating scenery in the immediate vicinity. Putting plant-life to good use in a broad sense also facilitates the creation of a good, multi-functional climate for investment.

TABLE 1 Overview of positive effects from trees and other plant forms on the urban climate.

AIR QUALITY	Filtering out of dust and air pollution
MICROCLIMATE	Regulation of temperature extremes (through shade and shelter) Air humidification, making it cooler and more pleasant
WATER MANAGEMENT	Water storage and reduction of peaks in drainage needs at times of precipitation
ENERGY SAVINGS	Reduction in heat loss (from indoors) and need for cooling
PROPERTY VALUES	Higher in the vicinity of plants
HEALTH	Possibilities for relaxation and activity
BIODIVERSITY	Habitat for many organisms
LIMITATION OF GREENHOUSE EFFECT	Sequestering of CO_2
LANDSCAPE	Screening of traffic and industry
AESTHETICS	Beautification of streets and neighbourhoods

Trees in urban areas work as automatic, free-to-operate air filters which remove particulates and other pollution. It is true that some trees do this better than others, but all trees and plants permanently remove dust and pollution from the air. Green areas are however decreasing due to progressive urbanisation. Reduction of green areas means a reduction in filtering capacity. The consequence of this is a deterioration of air quality and more damage to our health. Good management of existing plant-life and expanding green areas can improve air quality and with that reduce damage to health.

2 Air quality and health



2.1 Damage to health

The air contains a large range of components. Some of these are damaging to our health, while others are not. The most damaging components to the health of the population in The Netherlands are particulates and ozone. The most recent estimate (in 2003) of premature deaths associated with short term exposure to high concentrations of these components in our country was 2,300-3,500 people due to particulates and 1,100-2,200 people due to ozone. In total this adds up to around 3,400-5,700 people per year who die early as a result of short term exposure (MNP, 2005). Now many people each year are exposed to high concentrations of air pollution, and not only during short periods. For the time-being, there is a lack of information available to give a good estimation of the effects of such long-term exposure. For The Netherlands it is speculated that 12,000 to 24,000 people die early each year through these causes.

2.2 Urban air quality

People who live next to a busy road or motorway are twice as likely to die from heart and vascular disease or lung disorders (Hoek et al, 2002). Heavy traffic is especially to blame for poor air quality in cities. Exhaust emissions from this traffic are expelled at ground level and can occur in areas of high population densities. Diesel vehicles in particular produce a lot of particulates. This form of pollution has previously been the subject of much attention. Particulates, as expressed as PM10, includes all particles with a diameter of 10 μm (0.01 mm) and less. PM10 contains many toxic compounds such as heavy metals and organic matter and is therefore dangerous for public health. PM10 is especially to be found in traffic exhaust emissions, but is also derived from car tyres and brakes.

As well as particulates, exhaust emissions contain high concentrations of other important components such as nitrogen oxides (a combination of nitric oxide and nitrogen dioxide) and volatile organic compounds. Table 2 gives a brief overview of the most important air pollution components from road traffic and their threats to health.

TABLE 2
Air pollution from road traffic and the resulting damage to public health.

POLLUTION	NAME	DAMAGE TO HEALTH
Particulates	PM10	Particulates lead to impairment of health and premature death.
Nitrogen oxides	$NO + NO_2$	Ozone (O_3) is formed when sunlight causes NO_2 and VOCs to react with each other.
Volatile organic compounds	VOCs	Raised concentrations of ozone in the summer months lead to health damage and premature death.

The burning of petrol and diesel in vehicle engines at high temperatures causes nitrogen and oxygen from the air to be converted into nitric oxide. This nitric oxide becomes oxidised to form nitrogen dioxide. The burning of fossil fuels also releases volatile organic compounds.

Nitrogen dioxide and volatile organic compounds from exhaust pipes form ozone when sunlight causes them to react with each other. High ozone concentrations occur especially in the summer (summer smog) and lead to damage of the population's health, just as in the case of particulates.

2.3 Air quality standards

In recent years the air quality in The Netherlands has greatly improved and the extent of citizens' exposure to air pollution has been greatly reduced through successful management. Nevertheless air pollution is still causing damage to health and attention to further improvement of air quality remains necessary.

EU guidelines were implemented in national legislation in 2001. Particulate emissions had to meet with designated standards in 2005, for nitrogen dioxide (NO_2) this will be in 2010.

Air quality standards are made with the intention of keeping health risks to a minimum and it is illegal for ambient concentrations to exceed the standards. However it is often forgotten that standards don't necessarily equate to harmless thresholds.
The fulfilling of standards doesn't yet mean that citizens experience no further problems caused by pollution. The levels at which no danger is posed to public health have yet to be determined, particularly with regard to particulates. Every reduction in the quantity of particulates is of benefit in terms of public health. This fact is a separate matter from the discussion about whether concentrations exceed standards or not.

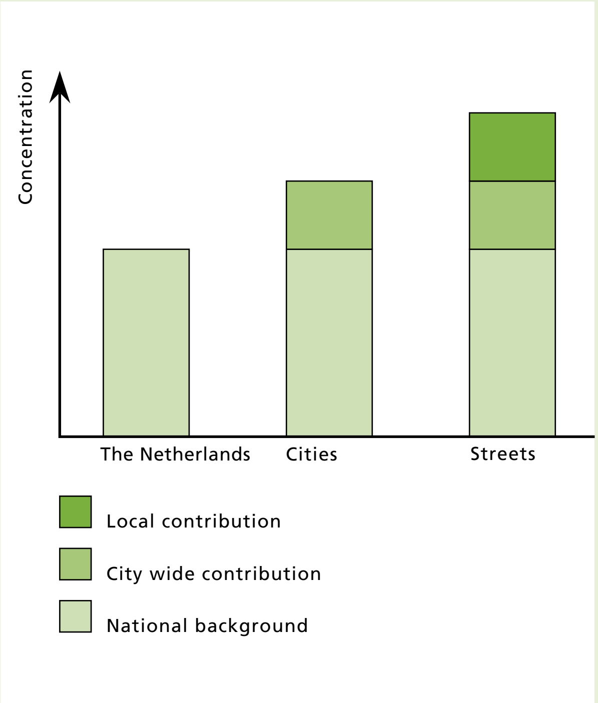
2.4 Particulates

Everywhere in The Netherlands we're breathing in dust particles. PM10 penetrates the airways and lungs. However, not all parts of this are dangerous. Sea salt and dust from soil also fall into the category of particulates. The proportion of harmful particles within PM10 increases in line with an increase in traffic. The burden from particulates is also strongly dependent on where people are located. Insight into the origins of PM10 is important in order to be able to determine regulations for reducing the concentration in a specific location.

Figure 1 shows a diagram of concentration levels of PM10 in different situations. Large amounts of particulate pollution is blown in from other countries. This sits like a blanket over The Netherlands. This so called "national background" means that a certain amount of particulate pollution is present in the air in every part of The Netherlands. Traffic in and around cities then adds to the national background level of particulates. The average concentration in cities is therefore higher than the national background. On top of this, intensive traffic in narrow streets or busy roads and local squares leads to high peaks of concentration. These places with very high levels are therefore often situated in cities and are known as "hot-spots".

Limits for particulate quantities in the air are often exceeded here. Construction projects are halted due to a lack of technical measures available to tackle the deterioration of air quality. This halt in construction leads to estimated billions of damage to the economy.

FIGURE 1
Composition of PM10 concentration in cities (revised after Oosterbaan et al, 2006)



High concentrations of particulates in a certain street therefore comprise the combined total of the national background, a contribution from the city plus a local contribution from the traffic in the street itself. Measures to reduce such high concentrations at hot-spots can therefore, in principle, be taken at different places. We can try to reduce the national background. The city contribution can also be reduced and we can implement specific measures in hot-spot locations. Whichever other measures we take, plants and trees can be used in all locations to remove particulates and other pollution from the air.

3 Planting schemes as air filters

All plants and trees remove dust and gaseous pollution from the air. Some plants do this better than others. It also doesn't matter where plants grow - outside in the city, in the countryside, inside the office or house. Trees have many leaves and are a barrier for wind. Because of this, trees are highly efficient at filtering pollution from the air and have a major influence on air concentrations. Deposits of dust from the atmosphere are 2 to 16 times greater in a wood than in areas of low-growing vegetation.

American researchers have shown that trees in the city absorb all kinds of pollution (Nowak,1995). They therefore conclude that city planting schemes are worth millions of dollars.

Recent research for Antwerp has demonstrated that where a high number of trees are present in the city, peak concentrations of ozone are 8% lower than where there are none (Benefits of Urban Green Space; www.vito.be/bugs). Estimations for the West Midlands, a large urban area in England, indicate that by doubling the amount of trees 140 less people per year will die early, because more trees absorb more particulates.

The way in which trees influence the quality of air is well-known. It occurs through two important phenomena:

1 Direct effects: Effective removal of particulates and gaseous pollution through the leaves;
2 Indirect effects: Modification of wind speed and turbulence, and with that, of local concentrations of air pollution due to the modification of the dispersal of air pollution.

These phenomena occur simultaneously to a greater or lesser degree. Knowledge about this not only gives insight into how plants work, but can also be used to determine how important existing plant-life is for air quality and how we can best make use of plants to improve the quality of the air.

Leaves are essential for effective removal of pollution from the air. For removal of particulates, stems, branches and twigs of trees and shrubs are also important. The manner by which leaves absorb pollution depends on the type of contamination. Gaseous pollution such as nitrogen oxides and ozone are absorbed internally by the leaves while particles of particulates get fixed to the external surfaces of the leaves.

TABLE 3

Absorption of different types of air pollution by leaves.

POLLUTION TYPE	MECHANISM	APPROPRIATE LEAF TYPES
Ozone, nitrogen dioxide	Absorption	Flat and broad leaves of deciduous trees
Volatile organic compounds, (PCB's, dioxins, furans)	Adsorption	Thick and sebaceous wax layer (cuticle) on the leaves, particularly conifers
Particulates (PM10)	Impaction	Pointed forms such as conifer needles. Coarse, hairy and sticky leaves of deciduous trees

Table 3 gives an overview of the different mechanisms via which leaves are effective in removal of pollution from the air. Although the mechanisms can differ, the impact on air quality in all cases is the same.

The presence of leaves leads to less pollution in the air. For all components it is the case that the more contamination there is, the more the trees take out. As long these experiences don't cause problems for the trees themselves. A tree near to a source of air pollution where concentrations are high removes more pollution than one at some distance.

3.1 Absorption of gaseous pollution

Plants can absorb gaseous components via their stomata and cuticles. The cuticle is the outermost layer of the leaf, consisting of a sebaceous substance which functions, amongst other things, to protect the plant from drying out. Stomata are closable pores in the leaf which allow for continuous gas exchange to take place between leaves and their surroundings.

Nitrogen oxides and ozone mainly get into the leaves via the stomata. We call this process absorption. Each leaf has a large network of internal cavities which connect with the outside air via the stomata. (see Figure 2). These cavities absorb carbon dioxide into the leaf cells and release oxygen and water into the surrounding air. The cavities increase the surface area within the leaf, and therefore the capacity for gas exchange is also increased enormously. By way of an example, this internal surface area for a mature Beech tree is approximately 15,000 m² – a size which can be compared to the surface of two football pitches.

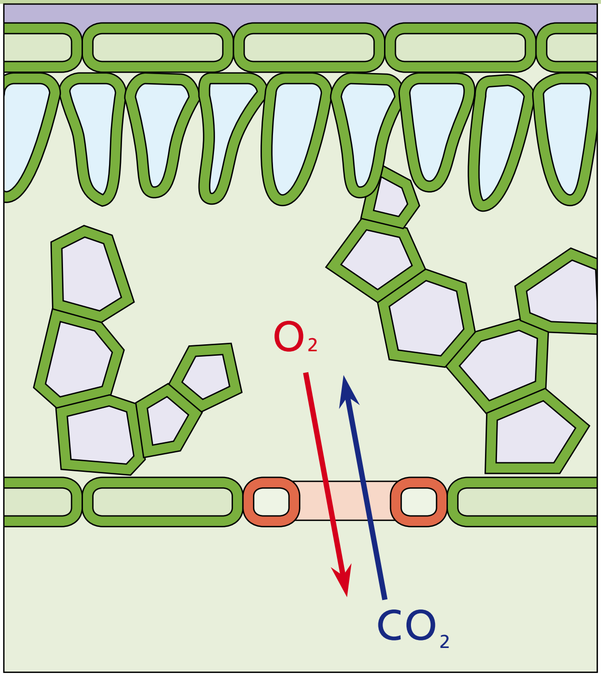


FIGURE 2
Diagram of gas exchange via a stoma on the underside of a leaf; Carbon dioxide (CO_2) is absorbed and oxygen (O_2) is released. The cuticle on the upper side of the leaf is shown in blue.

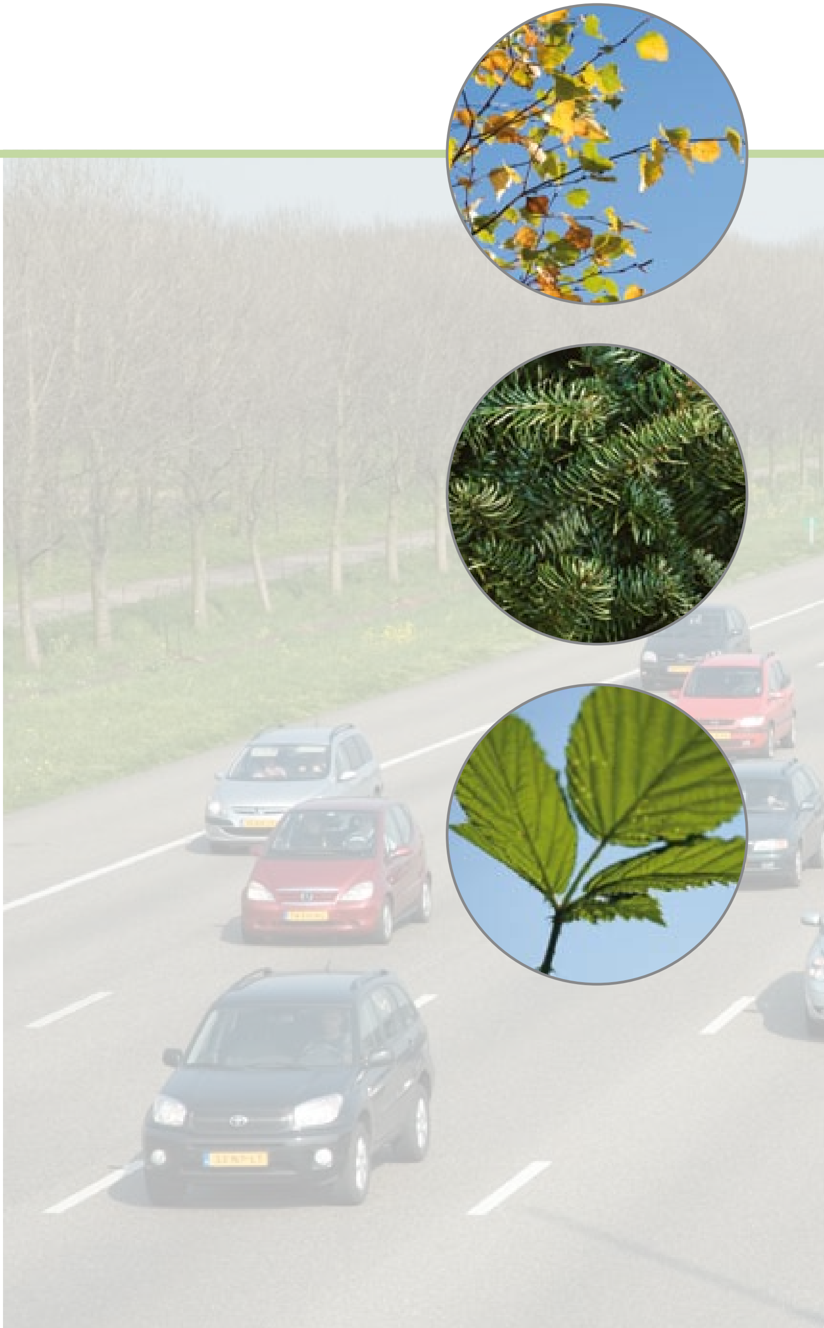
A large amount of air needs to pass through the leaf in order to absorb enough carbon dioxide. Other components in the air including gases expelled from traffic also come into contact with the inside of the leaf this way. Nitrogen oxides and ozone are easily soluble and absorbed quantities of these are easily processed by the leaf. The stomata are generally open during the day and closed at night. The removal of gaseous pollution from the air is also greater during the day than at night. Absorption is optimal when surrounding air can pass through the stomata without obstruction. The best type of leaves for this purpose are flat, broad leaves where the stomata are right on the surface.

For many volatile organic compounds such as PCB's, dioxins and furans, the cuticle forms the most important route for admission. We call this process adsorption. These substances are often not soluble in water, but are so in the fatty components of the cuticle. The advantage of adsorption via the cuticle is that it normally takes place during the night when the stomata are closed, and also during the winter months when any plants still green at this time are less active.

After being adsorbed in the cuticle the airborne organic substances gradually migrate to the inside of the leaf. Leaves with a thick cuticle consisting of many sebaceous components are very suitable for removal of these types of organic components. Examples to illustrate this are needles from conifers and also Kale and similar plants.

3.2 Removal of particulates

Particulates can either fall or get blown onto the leaf. We refer to this process as "impaction". For this purpose particulate particles need to come directly into contact with the leaf closely enough to be electrostatically attracted. This process is aided by unevenness on the leaf surface such as a coarse texture or hairs. The extent of moisture and 'stickiness' of the leaf also exerts influence.



Conifers are especially efficient at capturing particulates, due to the needle-like structure and relatively pointed form of the foliage. In addition to needles and leaves, stems, branches and twigs play a part in the disposal of particulates. A tangled branch structure also helps. Dust particles don't reach the interior of the leaves and aren't processed as is the way with gaseous components. The particles are left behind on the external surface of the tree. In principle, for capturing particulates it therefore doesn't matter if the leaves and needles on trees are dead or alive, just as long as they come into contact with contaminated air. As the season progresses, leaves hold more and more dust particles (Figure 3). In a year, an average city tree captures about 100 grams of particulates, while a mature one captures as much as 1.4 kilogram.

Some of the captured dust remains stuck on the leaves, while the rest of it comes loose again if there is a relatively strong wind or the leaves are rinsed by rain water. Once on the ground, the particulates can be washed away into the drain or become fixed in the soil where it will stay for a long time. Some compounds within the dust particles are detoxified while in the soil.

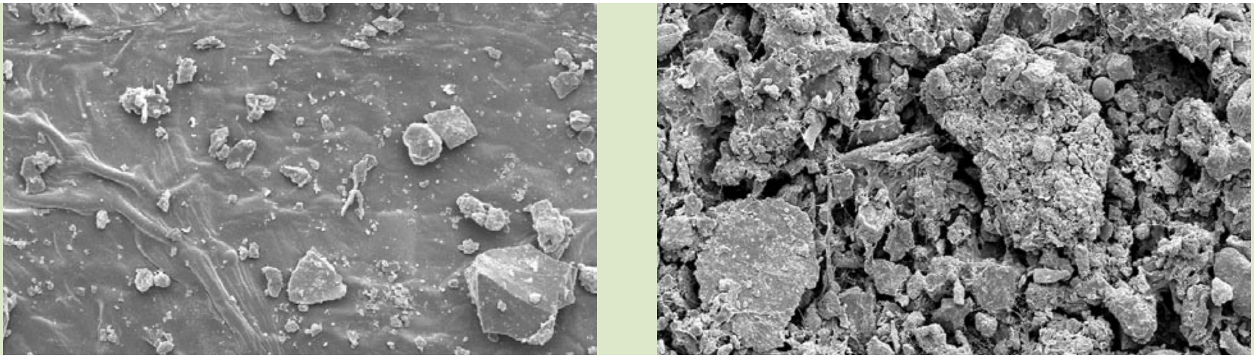


FIGURE 3
Particulates on the leaf of Parthenocissus (Virginia Creeper) in June (left) and in October (right) (From M. Thönnessen, 2005).

Pinus parviflora

4 Trees and air currents

4.1 Trees as windbreaks

The fact that needles are so effective for capturing particulate particles is due to the manner with which their pointed form influences air current. When polluted air collides with pointed needles, the air gets deflected. Particulate particles present in this air continue to be thrown along by their own momentum and thereby come into contact with the surfaces of the needles, where they get stuck.

We all know that trees form a physical obstacle and have an effect on wind speed and turbulence. Trees have therefore long been used as windbreaks. Tempering of wind speed and changes in air turbulence have an influence on how effective trees are in removing contamination from the air. In addition, such changes in the local climate also lead directly to changes in air pollution concentrations in the vicinity of planting schemes, because they influence the mix of pollution in the surrounding air.

Wind may be minimal inside a wooded area, while outside it may be blowing violently. A wood forms a barrier to the wind. At the edge of the wood the air is driven upwards, so instead of going though the woods it goes over the top. The edge of the wood therefore operates as a solid windbreak. Figure 4 shows a diagram of wind behaviour around a wood. The wind speed begins to slow even before it meets the edge of the wood. The wind speed is, however, normal just a short distance leeward of the wood (where the wind comes from).

The so-called protected area with a reduced wind speed is relatively small. The same phenomenon occurs with a natural windbreak that is very dense. Here too, the air is stopped and driven upwards, and then falls down again behind the obstacle.

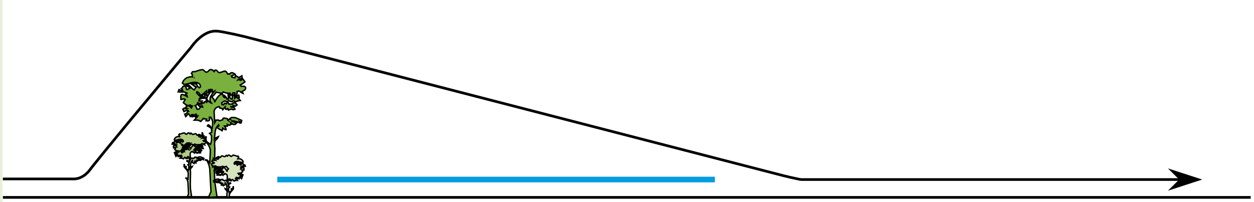
FIGURE 4
Air current over a wood. The wind blows from the left over the wood. The wind returns to normal a short distance after the wood. The scope of the protected area with a reduced wind speed is shown in blue.

Things are different with a (partly)-open row of trees. A row of trees which is open to a greater or lesser extent allows part of the wind through it, in contrast to a very dense windbreak or a wood. Wind speed is also slightly less reduced by an open green structure than by a dense windbreak. The distance behind an open row of trees to where the wind speed becomes normal again, is however much greater than that of a wood or closed windbreak. In other words, the protected area behind an open green structure within which the wind speed is reduced, is relatively large. As a general rule, the protected area behind an open row of trees has a length from 15 to 20 times the height of the trees in the row. Reduction of wind speed in this protected area can itself lead to changes in concentrations.

FIGURE 5

Air currents around a partly open row of trees. The wind approaches from the left. The scope of the protected area with a reduced wind speed is shown in blue. The protected area has a length of 15 to 20 times the height of the trees.



4.2 Air cleansing and the importance of porosity

Trees on the edge of a wood are more effective in removing contamination than trees in the middle of the wood. After all, trees on the edge also have wind blowing at them from the side while only the top of the crown of the trees inside the wood come into contact with contaminated air. Due to the buffering effect of the edge of the wood, most leaves inside the wood don't come into contact with contaminated air. For this reason freestanding trees are more effective than the screened off trees in a wood. This aspect raises a case for more


greenery in the form of freestanding trees and linear planting schemes than of woods, as they are better for reducing concentrations in specific locations. Of course woods are a sound means for removing much pollution from the air, especially as they cover a large area. Woods are therefore especially suitable for reducing the national background. It is estimated that all woods in The Netherlands together remove 7,200 tons of particulates per year (Houben et al, 2006). This is 17% of the total amount of particulates emitted each year in the Netherlands.

Contact between pollution and leaves is essential in order for trees to be effective at filtering. Trees through which contaminated air can flow are more effective than trees which are in very dense windbreaks. In a “porous” green structure, far more leaves play a part in the cleansing process than when in a dense structure. In a porous structure the leaves inside the crown of the tree also come into contact with polluted air and can do their purification work. In the case of trees with a broad crown, a lot of polluted air passes beneath and isn’t purified. Planting extra shrubs beneath such trees works well to remove pollution from the air, as their leaves will remove pollution where the trunks of the broad-topped trees won’t.

Porosity in green structures is of high importance. Porosity is a very manageable way to get an idea of how much air passes through the leaves. A crown is described as porous if blue sky can be seen through the leaves. The more blue there is, the greater the porosity. Because the degree of porosity can easily be evaluated by sight, we also refer to it as optical porosity.

Filtering by trees doesn’t always lead to lower concentrations in the place where the tree is growing. Trees situated by the road do filter but they also dampen wind speed. As a result of this, exhaust gasses get mixed with less air than they do where there are no trees. The net effect of raised concentrations due to wind speed dampening and concentration reduction due to green filtering, is often a rise in concentrations at the place where the tree is standing. This is the case for PM10 when the porosity of the planting is below 40%. Of course, the green component is still undoubtedly capturing and therefore removing PM10 particles from the air.

This effect of raising the concentration as a result of wind speed dampening by trees is also described as the ‘green tunnel effect’. In these situations, the dispersion of smaller particles in particular is limited to such an extent that plant-life filtering cannot compensate for it. The ‘green tunnel effect’ can be prevented by making sure that a planting has sufficient porosity (more than 40%). This can be achieved through cultivation of the right tree species with sufficiently open crowns, followed through with good management.

The ‘green tunnel effect’ only occurs within 100 to 150 metres of the road where exhaust emissions aren’t yet fully mixed with the surrounding air. For the greater part of The Netherlands there is therefore no talk of tunnel effect and the filter function of trees always leads to a fall in concentration. According to estimations, in average meteorological circumstances green structures capture a maximum 15-20% of the particulates (PM10).

A green structure with the right porosity can reduce the concentration of nitrogen dioxide by a maximum of 10% (Wesseling et al, 2004).

4.3 Alternative green structures

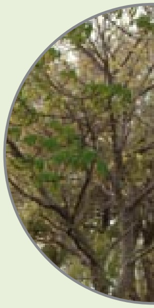
The presence of trees always leads to filtering but not always to lower concentrations in the place where the tree stands. Close to a pollution source the ‘green tunnel effect’ can lead to such a dampening of wind speed that local concentration levels become too high in spite of filtering. It can also be the case that there simply is no room to plant trees. In such situations climbing and trailing plants can offer a solution. These green structures don’t dampen wind speed and therefore also don’t lead to increase in concentrations close to the road. They do, however, remove pollution from the air. The positive functions of different types of green roofs are also increasingly being realised.

There is much interest in the application of Ivy (Hedera helix) on bare walls in streets to capture particulates. Ivy plants can place 3 to 8 square meters of leaves per square meter of wall and hold up to six grams of particulates (Dunnett and Kingsbury, 2004). In addition, this plant also stays green right through the year so can function as a filter all year round. This property is especially important for removal of particulates. With regards to bare walls, Ivy provides a wonderful increase of the filtering surface area. What’s more, the covering of bare walls with plant-life considerably improves the look of a city. In Monaco, where the population is three times as dense as in the large Dutch cities, outside walls have been used to bring more plant-life into the city since 2005. These green walls are removing pollution from the air at the same time.

TABLE 4

Important structural aspects of planting schemes

WIDTH	In the case of a wide planting (e.g. a wood) there is no protected area with reduced wind speed on the leeside. But with a smaller planting such as a line planting this is indeed the case. The protected distance depends on the height of the planting.
HEIGHT	Reduction of the wind speed behind a row of trees is measurable at a distance of 20 times the height. In this area the concentrations are also reduced. Here it can be said there is local protection against contamination.
POROSITY	For local protection near a source (busy road) there needs to be over 40% porosity for optimal purification of contaminated air and to prevent the green tunnel effect. When the porosity is lower, there is a possibility that concentrations increase locally despite filtering by trees present.
BORDER	Border effects increase turbulence and help plants to remove air pollution. Create strong contrasts where possible.
QUANTITY	The more plant-life the better. All plant-life contributes to the removal of contaminated dust from the air. This is what we refer to as bulk capture. Local protection can be optimised by planting repeated linear components at a distance of 150-200 meters of each other.
VARIETIES	Use indigenous varieties with leaf characteristics which are effective in capturing one or more air pollution components. Use a mix of varieties to capture a cocktail of air pollution.
TYPE	All plants filter pollution from the air. This also applies to plants grown on walls and roofs. Where there is a lack of space for trees, climbers and green roofs are attractive possibilities.



Picea pungens

5 Key points

5.1 In general

This chapter combines a number of directives that people must consider when planting and managing trees with the goal of removing particulates and gaseous pollution.

All trees, shrubs, woods, windbreaks and hedges have a filtering effect which, at no cost, makes a noticeable improvement in the air quality. However, not all varieties and certainly not all plant species perform this function to the same extent. In order to capture the full cocktail of air pollution, a good mix of different trees and shrubs is necessary.

Gases such as nitrogen dioxide and ozone are captured especially well by deciduous trees with broad glossy leaves. The waxy layer on the leaves (cuticle) is the most important route for capture of organic compounds. Leaves with a thick cuticle such as needles of conifers do this well. Deciduous trees with coarse, hairy, sticky leaves are suitable for capturing dust particles. These particles are held on the leaves and eventually washed away by rain. Confers, however, are the best for capturing of particulates. Conifers are often evergreen. Planting of evergreen species is a very attractive proposition because they also remove particulates from the air during the winter months. This is less important with regard to ozone because the (too) high concentrations of this are of more especially a problem during the summer months (summer smog).

In order to plant the right species, attention must naturally be paid to more properties than just the reduction of particulates and summer smog. Examples such as the fact that alder and birch can lead to allergic reactions in people also need to be taken into consideration. Also that fluff, fruit or fallen leaves can in some situations cause such a nuisance, that that needs to be an important point of consideration when selecting species. Another aspect to take into account is the sensitivity of the trees themselves to air pollution. There are big differences concerning this, which are also dependent on the type of air pollution.

Besides this, it is of course a primary requirement that the planting area is suitable for the chosen tree species and also that there is sufficient space (above and beneath the ground) for the long term healthy development of the trees, without causing a nuisance. The eventual interpretation of a design is therefore always a customised job for which specialist knowledge is necessary. For one thing, trees, their growth habits and the requirements that they have regarding their growing place need to be considered. Information about this and other things can be found in the “Utility Trial of Street Trees” (see www.straatbomen.nl). For another, knowledge of aerodynamics and the effect of trees and plants on air currents is another consideration. One example of a system based on this is the patented system by the Dutch company ES Consulting, to design green structure to improve air quality. (www.es-consulting.nl). The first worldwide methodical calculation of its kind, this system is an innovative Dutch development and is specifically intended to methodically and appropriately position green structures for energy saving, noise limitation and air quality improvement.

5.2 General guidelines for urban areas

All trees (and other types of vegetation) remove particles from the air and are effective for what we describe as regional protection. A particular aim of regional protection is the large-scale filtering of pollution from the air with the effect of improving general air quality. This is also described as ‘bulk capture’.

With regards to cities, there are a number of guidelines set out with the particular aim of maintaining and increasing the effective surface area of greenery.

TABLE 5
Effective plant-life management in the city

1	Increase the quantity of trees in order to increase the filtering capacity.
2	Healthy trees that are growing well have the biggest effect; therefore ensure good growing conditions.
3	Make sure that trees are able to grow to maturity.
4	Use trees which adapt well to city surroundings and which preferably need little maintenance.
5	Make sure there is sufficient variation in order to efficiently capture the full cocktail of pollution.
6	Use conifers (preferably evergreens) for effective capture of particulates throughout the year.
7	Use deciduous trees with coarse, hairy leaves as an alternative for capturing particulates
8	Use deciduous trees with flat, broad leaves for effective absorption of nitrogen dioxide and ozone.
9	Don’t use any types of trees which are sensitive to air pollution.
10	Limit the use of types of trees which release a lot of volatile organic compounds and minimise large scale planting of these in order not to stimulate the production of summer smog.

5.3 Near a source of air pollution

Plant-life can help to reduce local concentrations (local protection) near a source such as a busy road. Take into account that the eventual reduction in concentrations is very localised and occurs on the lee side of the tree. The protective effect can be repeated by planting a second line of trees a short distance away.

TABLE 6
Protection at the source of air pollution

1	Ensure that the crown of the tree allows contaminated air to flow through it (> 50% optical porosity), either via a good choice of tree type or via targeted management.
2	Prevent trees from dampening wind speeds too much near a source (the so-called green tunnel effect), thereby leading to higher local concentrations in spite of their air-purification ability.
3	Combine trees with broad crowns with an undergrowth of herbaceous plants and shrubs in order to have effective leaves at all levels.
4	Trees with a tangled branch structure make an extra contribution to the capturing of particulates even when there are no leaves on the tree.
5	Where possible, plant rows of trees perpendicular to the direction the polluted air comes from and repeat this throughout the area.
6	Make sure there is undisturbed sideways flow away from trees near a source of air pollution.
7	Don’t just use trees close to emission sources because of their ability to capture large volumes, but also around sensitive objects such as schools, hospitals and homes for the elderly.

5.4 Influence on local climate

Trees have an influence on the local climate. The effect of shading from individual trees is especially useful.

TABLE 7
Shading

1	Plant trees to shade parked cars so that fewer volatile organics evaporate from petrol tanks.
2	Use alternative green structures such as green walls, pergola-like structures and green roofs where there is either no space for trees or where they would restrict air circulation too much.

6 Effectiveness of trees and plants for

Good quality plant-life is necessary to structurally improve air quality. All plants contribute to improvement in air quality. However, some species of plants are more suitable than others and the effectiveness of a species is dependent on the air pollution component. Leaves form the most important place to filter gaseous air pollution and particulates. Differences in leaf structure and the quantity of foliage play a big part in the difference of effectiveness between species. A great deal of information is still lacking about the precise effectiveness of different sorts of trees and shrubs to improve the air quality. Table 8 shows estimations of effectiveness based upon the properties of the leaves, and lays out the relative differences in effectiveness between different species. After all, all plants remove pollution from the air to a greater or lesser degree.
Because some plants can stimulate the forming of ozone due to their emission of volatile organic compounds, available information about this is summarised in the last column.

6.1 Particulates (PM10)

Effectiveness with regard to particulates is evaluated by means of the following criteria:

1. Conifers are more effective in the removal of particulates than deciduous trees;
2. Within the category of deciduous trees, those with coarse hairy foliage are more effective than those with glossy flat leaves;
3. Evergreen species remove more particulates than those which are not evergreen;
4. Species with a large leaf surface capture more particulates than species with a small leaf surface. In this sense, trees are more effective than shrubs.

As far as it is known, particulate pollution isn't harmful to plants. When choosing plant types it therefore isn't necessary to take the aspect of sensitivity to particulates into account.

The effectiveness value is shown in the table on a scale of 1 (least effective) to 3 (most effective).

6.2 Nitrogen oxides

With regard to nitrogen oxides, effectiveness is assessed by means of the following criteria:

1. Deciduous trees are more effective in the absorption of nitrogen oxides than conifers;
2. Within the category of deciduous trees, those with glossy flat leaves are more effective than those with coarse hairy leaves;
3. Species with a large leaf surface absorb more nitrogen oxides than species with a small leaf surface. In this sense trees are more effective than shrubs.

The effectiveness value is shown in the table on a scale of 1 (least effective) to 3 (most effective).

Nitrogen oxides can be harmful to plants. If trees and shrubs are planted for the purpose of reducing nitrogen dioxide concentrations, aspects of sensitivity need to be taken into account.

Sensitivity also varies between species. Tree species which, according to Japanese research (Takahashi et al, 2005), are known to be suitable for planting in areas with a lot of nitrogen oxides are indicated with a (+).

improving air quality

6.3 Ozone

The effect trees have on ozone concentrations is very complex. Ozone is formed out of nitrogen dioxide and volatile organic compounds in conditions of high temperatures and the presence of sunlight. In these circumstances there are numerous ways in which tree species can influence ozone concentration:

1. As a result of the transpiration of water through the leaves, plants subdue temperature rises and inhibit the forming of ozone, in comparison to a situation without plants;
2. Trees and shrubs absorb nitrogen dioxide (column 3 in table 8) to a greater or lesser degree. The more nitrogen dioxide is absorbed, the less ozone can be formed;
3. Trees and shrubs absorb ozone to a greater or lesser degree;
4. Trees themselves emit airborne volatile organic compounds in varying quantities (see column 5 in table 8). These organic substances contribute to the forming of ozone. The more of these types of compounds are emitted, the more the production of ozone is stimulated.

Estimation of the effectiveness of trees and shrubs to absorb ozone is shown in column 4. With regard to effectiveness, the absorption of ozone runs parallel with that of nitrogen dioxide because the processes to do so are similar. The effectiveness value is also shown in the table on a scale of 1 (least effective) to 3 (most effective).

The tree species which according to English research (Donovan et al, 2005) can be effective on ozone concentrations in urban areas are shown in brackets by (+) to decrease or (-) to raise.

Species which emit a relatively high amount of volatile organic compounds (column 5 in Table 8) can lead to an increase in ozone levels. Although these species also absorb ozone, the net effect is an increase in ozone levels. If reduction in ozone concentrations is desired it is therefore better to prevent large-scale planting of these species.

TABLE 8 Estimation of effectiveness of the most important species for reduction of concentrations of particulates, nitrogen oxides and ozone in the air.

COLUMN SPECIES

* Stated properties also apply to cultivars of the stated species.

COLUMN PARTICULATES (CAPTURE), NITROGEN OXIDES (ABSORPTION) AND OZONE (ABSORPTION)

■ : Least effective
■■■ : Most effective

COLUMN NITROGEN OXIDES

+ Species which absorb a lot of nitrogen dioxide and are not sensitive to it (based on Japanese research).

COLUMN OZONE

+ Species which are effective for ozone concentration reduction in urban areas (based on English research)

– Species which raise ozone concentration in urban areas (based on English research)

COLUMN EMISSIONS OF VOLATILE ORGANIC COMPOUNDS

■ : Very limited emissions
■■■ : Considerable emissions

● Emissions of volatile organic compounds are not measurable for these species.

SOURCE

① *Takahashi et al, 2005*
② *Donovan et al, 2005*
③ *Stewart and Hewitt, 2002*
④ *Nowak et al, 2002*

SPECIES	PARTICULATES PM10	NITROGEN OXIDES $NO+NO_2$	OZONE O_3	EMISSIONS OF VOLATILE ORGANIC COMPOUNDS ③ ④
SHRUBS				
Amelanchier lamarckii	■	■	■	●
Berberis xfrikartii *	■■	■■	■■	■■
Chaenomeles	■	■■	■■	
Corylus colurna	■■	■■	■■ +	●
Euonymus (deciduous)	■	■■■ + ①	■■■	●
Euonymus (evergreen)	■■	■■■ + ①	■■■	●
Hedera	■■	■	■	●
Ilex xmeserveae	■■	■■	■■ +	●
Lonicera (deciduous)	■	■	■	●
Lonicera (evergreen)	■■	■		
Mahonia	■■	■■	■■	■■■
Potentilla fruticosa	■■	■■	■■	■
Rosa	■■	■■	■■	■
Spiraea	■	■■	■■	■
CLIMBING PLANTS				
Clematis	■	■	■	●
Fallopia	■	■■■	■■■	●
Hedera	■■■	■	■	●
Lonicera	■	■■	■■	●
Parthenocissus	■	■■	■■	●
Pyracantha	■■	■■■	■■■	●
Rosa	■■	■■	■■	■
Wisteria	■	■■	■■	●

SPECIES	PARTICULATES PM10	NITROGEN OXIDES $NO+NO_2$		OZONE O_3		EMISSIONS OF VOLATILE ORGANIC COMPOUNDS ③ ④
CONIFERS						
Ginkgo biloba *	■	■■■		■■■		🟩
Metasequoia glyptostroboides	■■■	■		■		🟩
Pinus nigra	■■■	■		■	+	🟩
Pinus sylvestris *	■■■	■		■		🟩
Taxus	■■■	■		■		🟩
HEDGES						
Carpinus betulus	■■	■■■		■■■		🟩
Fagus	■■	■■■		■■■		●
Ligustrum	■■	■■■		■■■		●
DECIDUOUS TREES						
Acer platanoides *	■	■■■		■■■	+ ❷	●
Acer pseudoplatanus *	■	■■■		■■■	+	●
Aesculus	■■	■■■		■■■		●
Ailanthus altissima	■	■■■		■■■		🟩
Alnus cordata	■	■■■		■■■	+	●
Alnus glutinosa *	■	■■■		■■■	+	●
Alnus xspaethii	■■	■■■		■■■	+	●
Betula ermanii *	■■	■■■		■■■	+	🟩
Betula nigra	■■	■■■		■■■	+	🟩
Betula pendula	■■	■■■		■■■	+	🟩
Betula utilis *	■■	■■■		■■■	+	🟩
Carpinus betulus *	■■	■■■		■■■		🟩
Crataegus xpersimilis *	■	■■■		■■■	+	●
Fagus sylvatica *	■■	■■■		■■■		●
Fraxinus angustifolia *	■	■■■		■■■		●
Fraxinus excelsior *	■	■■■		■■■	+	●
Fraxinus ornus *	■	■■■		■■■		●
Fraxinus pennsylvanica	■■	■■■		■■■		●
Gleditsia triacanthos *	■■	■■■		■■■		●
Koelreuteria paniculata	■	■■		■■		🟩🟩🟩
Liquidambar styraciflua	■■	■■■		■■■		🟩🟩🟩
Liriodendron tulipifera	■	■■■		■■■		●
Magnolia kobus	■	■■	+	■■		🟩
Malus *	■■	■■■		■■■	+	●
Parrotia persica	■■	■		■		
Platanus xhispanica *	■■	■■■		■■■		🟩🟩🟩
Populus *	■■	■■■	+	■■■	−	🟩🟩🟩
Prunus *	■■	■■■	+	■■■	+	●
Pyrus calleryana *	■	■■■		■■■		●
Quercus palustris	■■	■■■	+	■■■	−	🟩🟩🟩
Quercus robur *	■	■■■	+	■■■	−	🟩🟩🟩
Salix alba *	■■	■■■	+	■■■	−	🟩🟩🟩
Sophora japonica	■■	■■■		■■■		●
Sorbus	■■	■■■		■■■	+	🟩
Tilia cordata *	■■	■■■		■■■		🟩
Tilia europaea *	■	■■■		■■■	+	🟩
Ulmus *	■■	■■■		■■■	+	🟩

7 Green clean urban areas

Tilia xeuropaea

require integrated design

Previous chapters have explained that plant life can be exploited to improve air quality in urban areas. Plant-life in a neighbourhood is therefore not only beautiful, but also functional. It is also therefore of marketable value. From research published at the start of 2005 by the Ministry of Housing, Spatial Planning and the Environment, it appears that the most important residential wishes in The Netherlands are for affordable homes and green surroundings. Other research has demonstrated that plant-life in a neighbourhood raises the market value of houses and in addition to this has also often been shown to have a positive influence on the quality of life in the area, general safety and wellbeing of the residents.

In order to fulfil all these functions in the long-term, good quality plant-life which is functional right from the start of construction of a neighbourhood (or of another infrastructural project) is necessary. This idea is the core of the concept of the Green City. The basic assumption of the Green City is that green infrastructure in neighbourhoods raises the value right from the onset of construction or restructuring. This means that plant-life needs to be a technically and financially integrated component in the project plan. From the very start of formation of plans, the green (plants) is just as important as the red (buildings), grey (roads) and blue (water) functions. With plant-life already in place and fully established by the time area is completed, neighbourhood maintenance through greenery is guaranteed.

The selection of species should be made according to the principle “the right tree in the right place”, whereby it is advised to make use of available knowledge of the area. As we examine the air quality in our cities, we need to select carefully in accordance to what we find.

And there are plenty of options. Air pollution in cities contains a cocktail of components including (most importantly) particulates, nitrogen dioxide and ozone.

A good mix of types of green structures can be put to use to remove this cocktail. A great benefit of such incorporated treatment is that it leads to a large variation of species. Chapter 6 of this brochure shows the most important species of trees and shrubs currently available for selection, along with the ways in which they can contribute towards improvement in air quality. Chapter 6 forms a practical guide to help determine the correct planting choice. Our cities become therefore more varied, greener and also even cleaner!

RELEVANT WEBSITES

The Green City:
www.thegreencity.co.uk

De Groene Stad:
www.degroenestad.nl

Die Grüne stadt:
www.die-gruene-stadt.de

Benefits of Urban Green Space:
www.vito.be/bugs

Utility Trial of Street Trees
www.straatbomen.nl

Es Consulting:
www.es-consulting.nl

Royal Forestry Society
www.rfs.org.uk

The Green Roof Centre, Sheffield
www.thegreenroofcentre.co.uk

Trees for Cities
www.treesforcities.org/html/informationrepo/

The Green Think Tank:
http://gdt.vito.be/

Association of municipal managers for urban green space
www.galk.de

Further reading

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