Particulate Pollution Capture by Mobilane® Green Screens along the A38 Bristol Street in Birmingham

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Preliminary Findings

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Introduction

Improving the 'livability' of urban areas is of increasing importance, humans are becoming an urban species. In the UK over half the population now lives in cities, and the proportion is expected to continue rising. Making towns and cities attractive places to live has become increasingly important, and increasingly challenging, with competing pressure on space for buildings and infrastructure. The concentration of large numbers of people into compact cities has potential environmental benefits, for example, it is easier to move people around and provide services. Unfortunately, there are also currently many dis-benefits as well, including continued problems with air pollution and especially that arising from diesel engines and other combustion sources using fossil fuels.

Poor visual amenity can be considered a form of pollution and can have substantial impacts on mental wellbeing. Likewise, air pollution can have severe health impacts including increased mortality from a range of diseases including respiratory and cardiovascular disease, atherosclerosis, lung cancer and increased incidence of asthma. The size fractions of particular interest are PM_{10} and below (the 'thoracic' particles) and $PM_{2.5}$ and below (known as respirable particles). $PM_{2.5}$ and below can get further into the lungs and are the most harmful size fraction of the two.

Vegetation has been known to be able to capture air pollutants for some time, but conventional ground-level plantings are impractical in many urban areas. Recent developments in horticulture have resulted in a number of systems that facilitate the growing of plants vertically. Some of these are merely extensions of the trellis and wire systems used for centuries to grow plants up walls, but others are more technologically advanced such as hydroponic living wall systems that allow plants that would not normally be able to colonise vertical surfaces to be grown on walls. Other systems include green screens, whereby plants such as ivy (*Hedera helix*) are pre-grown up strong metal mesh panels in a greenhouse nursery for about 2 years before being planted on-site. In this system, the roots are supported by a 'u' shaped channel of mesh facilitating transfer from nursery to planting site. Panels are supported by vertical poles or some other infrastructure[2].

In this project green screens fitted to existing pedestrian guarding were piloted by Atkins with funding by the Southside Business Improvement District in Birmingham as a way of improving the visual amenity of the A38 (Bristol Street) as well as making a contribution to improving the air quality of the area. The Green Wall Centre at Staffordshire University provided expertise in the visualisation of particulates on leaves to demonstrate that the ivy screens were capable of capturing air-borne pollutants. In this study we examined leaves for contamination by PM_{10} to $PM_{1.0}$; smaller particulates can be visualised but would require more resources than necessary for this first evaluation of green screen effectiveness. As a baseline comparison, 'clean' leaf samples were taken from a nursery growing green screens, and compared with the particulate loads on green screens planted along the A38.

[2] For more information on the multiple values of vegetation in urban areas see Dover, J.W. (2015) *Green Infrastructure: Incorporating plants and enhancing biodiversity in buildings and urban environments.* Routledge, Abingdon.

Methodology

Leaf source- Baseline

On 28th April 2015 18 leaves were randomly sampled from ivy green screens grown in the green houses of RPG Herbs, Congleton (Plate 1). These samples were taken to act as a baseline for contamination of leaves in an environment not subjected to intense air pollution from vehicular traffic. The nursery location is in rural Cheshire. Leaf samples were stored in a sealed plastic box for transport to Staffordshire University's laboratory in Stoke-on-Trent and processed the same day. Leaves were prevented from rubbing against one another by securing their stems to the inner box surfaces using Blu-tack®

Plate 1. *Green screens grown for the Dutch company Mobilane® at RPG Herbs' nurseries in Congleton, Cheshire. Screens are (a) grown from cuttings and (b) growing shoots wound round a metal framework for two years before being (c) ready for installation; (d) leaves being stored for transport to the laboratory.*

Leaf source – Roadside trial

On the 1st May 2015 green screens, grown in the Netherlands for Mobilane, were planted up in the central reservation of the A38 (Bristol Street) in Birmingham along the southbound side. The screens were fixed to existing railings, with the plants on the strip side of the railings (Plate 2).

Plate 2. *Ivy Green Screens being installed along the southbound side of the A38 (Bristol St) in Birmingham showing (a) detail of the installation and (b) roots of the pre-grown screens in the planting trench.*

On the 6th July 2015, 18 leaves were sampled from the roadside-facing leaves of the green screens and taken to the laboratory at Stoke-on-Trent, plants were treated and stored as for the Baseline sampling. Due to Health-and-Safety considerations, plants were located from the off-road side of the central reservation and carefully removed so that they did not rub against other leaves as they were drawn through from the roadside (Plate 3). Twenty 25x25 cm quadrats were used to estimate leaf cover and an estimate of leaf area was made using Image-J image analysis software.

Plate 3. *Leaf samples being removed from the Green Screens installed along the southbound A38 (Bristol St), Birmingham.*

Processing of Leaf Samples

On return to the Environmental Scanning Electron Microscope (ESEM) Laboratory at Stoke-on-Trent leaves were prepared for visualisation (Plate 4). The samples were then focussed in the ESEM at a magnification of x250 and three separate locations imaged for the upperside of leaves and also the lower sides (Plate 5). Images were stored as .jpg files and later analysed using Image-J Image Analysis Software.

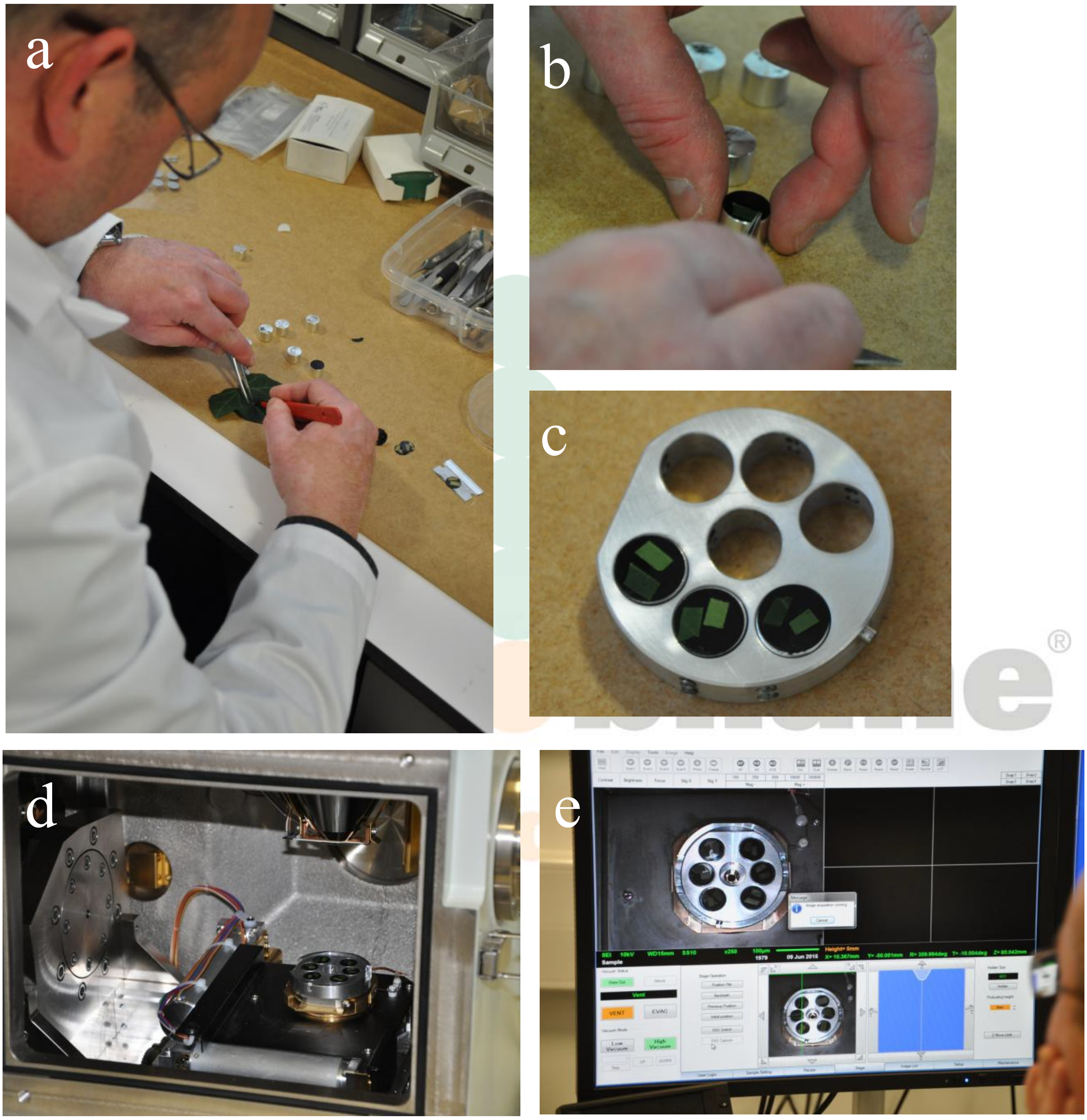


Plate 4. *Leaf sample preparation for visualisation in the ESEM. (a) Sections of leaf were carefully cut from each leaf and (b) stuck to aluminium sampling stubs using double-sided adhesive 'tabs'.*
Upperside and lowerside samples were taken separately. (c)The aluminium stubs were secured in a sample holder, (d) the vacuum chamber of the ESEM vented to room pressure, the sample holder inserted and the chamber evacuated to the operating vacuum level. (e) Preliminary visualisation of the sample holder under vacuum.

Within Image-J particulates were counted and size-ranged into the following categories: PM_{10} to $PM_{2.51}$ and $PM_{2.5}$ to $PM_{1.0}$. PM stands for 'Particulate Matter' and the number is the diameter of the particle in microns (µm); one micron = 1 $x10^{-6}$ of a metre (one millionth of a metre, or one thousandth of a millimetre). Example images from the ESEM can be found in Plate 6.

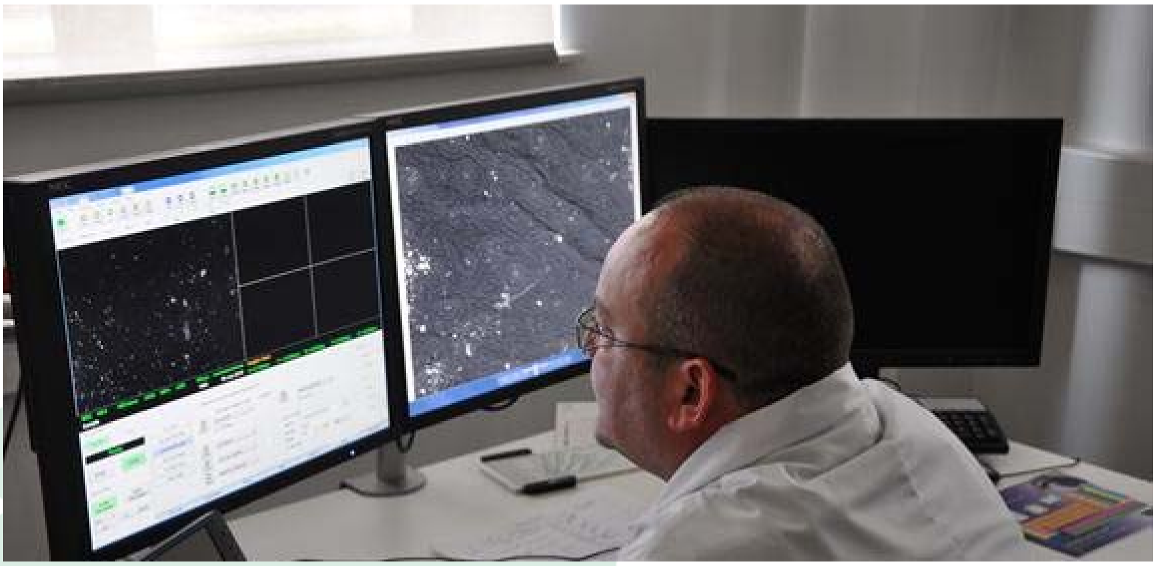
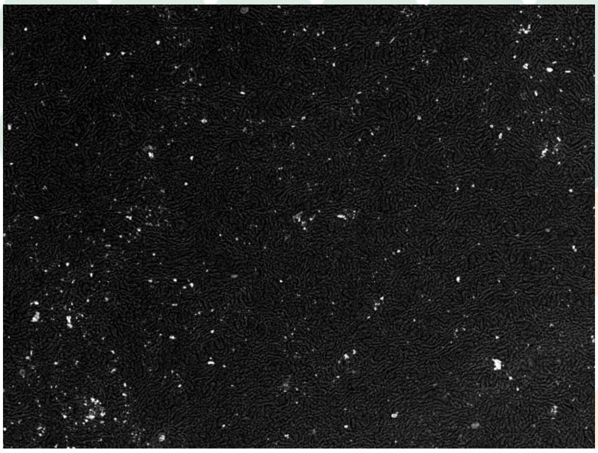


Plate 5. *Particulates on an ivy leaf surface being visualised in the ESEM*



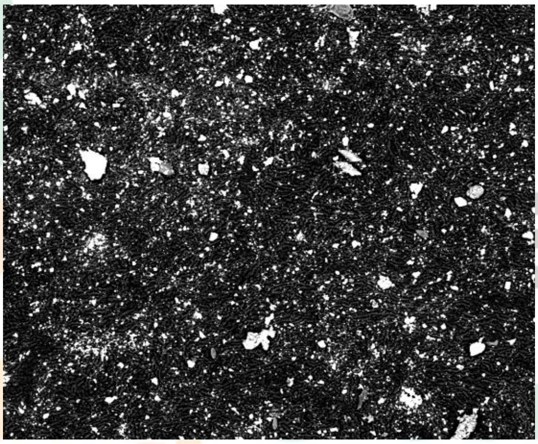


Plate 6. *Backscattered ESEM image of a) sample ivy leaves from the nursery and b) sample leaves from the Roadside of the A38 (Bristol Street) in Birmingham.*

Results

Weather conditions in Birmingham prior to roadside sampling

On 2nd July 2015 heavy to light rain showers fell throughout the day. On 5th July a shower of approximately 20 minutes duration fell at about 5 pm (Chris Rance *pers comm.*). Sampling took place mid-morning of 6th July 2015.

Leaf data

The mean leaf area (± 1 standard error), estimated from six leaves, was 32.8±0.87 cm^2. The number of leaves estimated from 20 0.25x0.25 m (0.0625 m^2) quadrats was 15.7±0.75.

Particulates

Data presented here represent the average number of particulates per leaf counted from an image size of 512 µm wide x 384 µm high. Different combinations of leaf surface and particulate size ranges are given (below) with the results visualised as column graphs. Analyses have been carried out using the non-parametric Mann-Whitney U-test due to non-normality of some of the data. Strictly, such data should be visualised as medians (as the test is carried out on median rather than mean values). However, column graphs of means and standard errors are typically easier to interpret than box and whisker plots conventionally used for display of medians, and as the differences between Nursery and Roadside data are clear and obvious, graphs of means ± SE have been used here.

Comparison of all particulates in the size range $PM_{10-1.0}$ between Nursery stock and Roadside plantings found on ivy leaves (combined upper and lower sides)

These data show very clear and large differences between the levels of particulates present on leaves (Figure 1) with four times the number of particulates on roadside plants. Using a Mann-Whitney U-test, this difference is significant at $P \leq 0.001$ (M-W U = 319.00, N= 36).

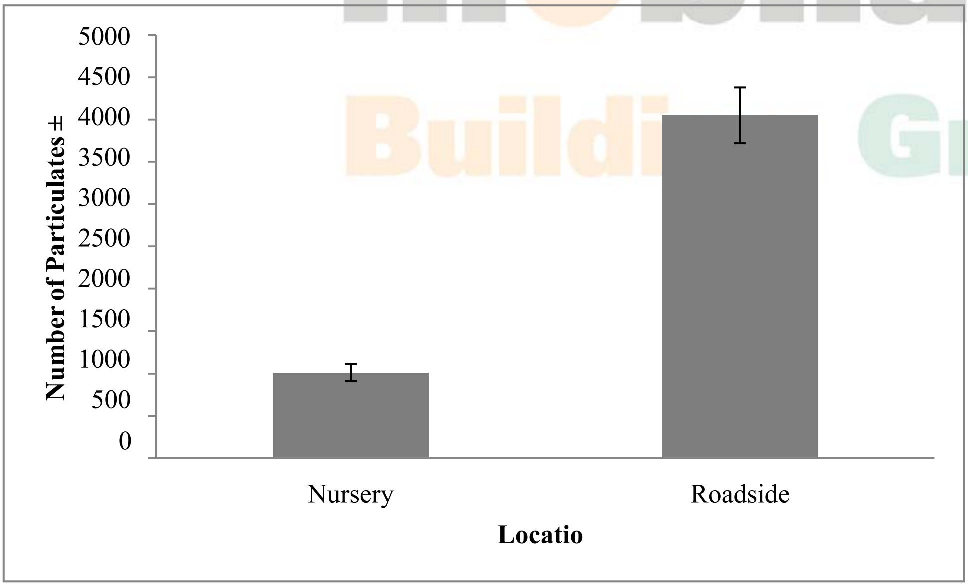


Figure 1. The mean number of particulates (PM_{10-1}) ± 1 standard error of the mean on the upper side and underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham

Comparison of all particulates in the size range $PM_{10-2.51}$ between Nursery stock and Roadside plantings found on the upper and lower side of ivy leaves

Differences were again large for this size range, with far more PMs present on roadside leaves (Figure 2), but the difference in particulate numbers was of the order of x6. The difference was significant at $P \leq 0.001$ (M-W U = 321.00, N=36).

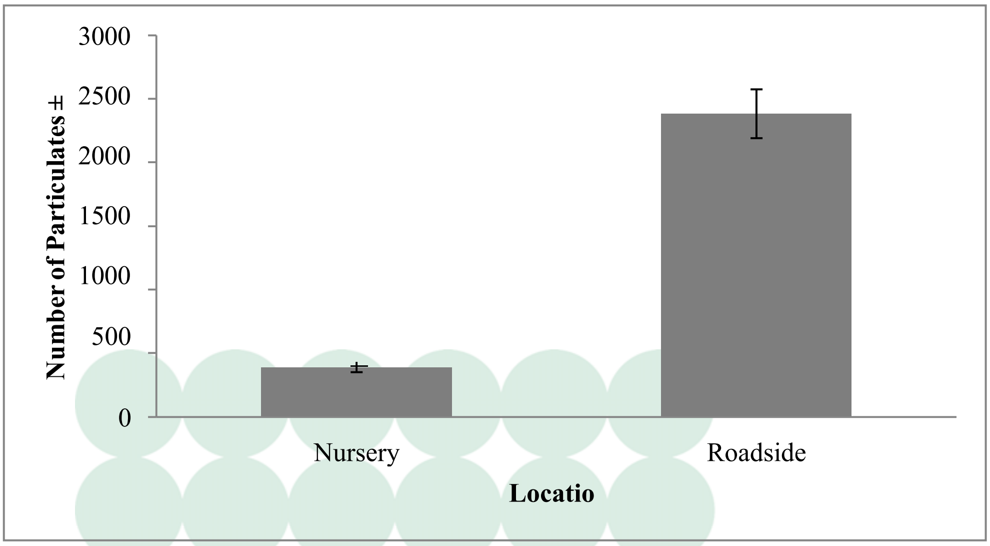


Figure 2. The mean number of particulates ($PM_{10-2.51}$) ± 1 standard error of the mean on the upper side and underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham

Comparison of all particulates in the size range $PM_{2.5-1.0}$ between Nursery stock and Roadside plantings found on the upper and lower side of ivy leaves

The differences for this category of particulates, between Nursery and Roadside plantings is lower than for the previous data at x2.7 more on the Roadside leaves (Figure 3). The difference is significant at $P \leq 0.001$ (M-W U = 309.00, N=36).

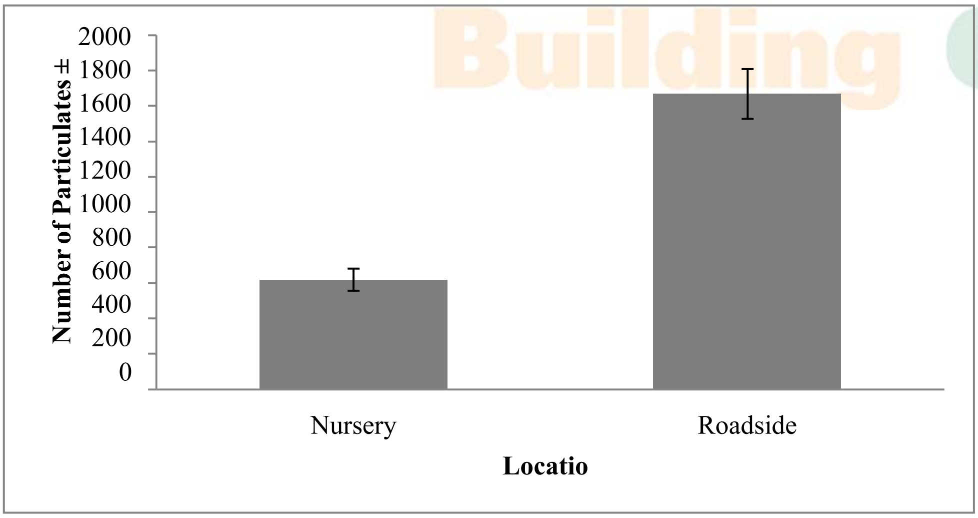


Figure 3. The mean number of particulates ($PM_{2.5-1.0}$) ± 1 standard error of the mean on the upper side and underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham

Comparison of all particulates in the size range $PM_{10\text{-}1.0}$ between Nursery stock and Roadside plantings found on the upper side of ivy leaves

The upper leaves of Roadside plantings had x3.6 the number of particulates compared with Nursery stock (Figure 4). The difference was significant at $P \leq 0.001$ (M-W U = 311.00, N= 36).

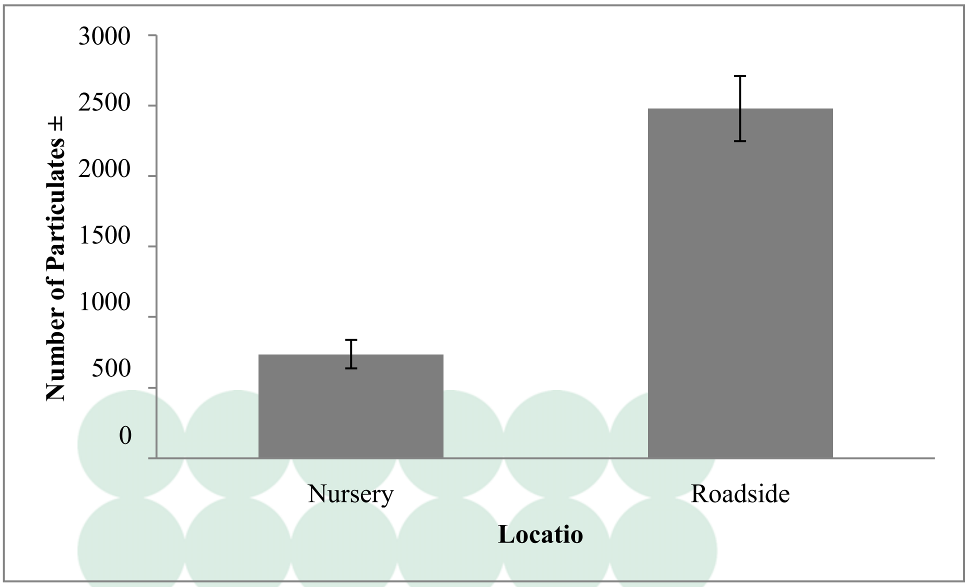


Figure 4. The mean number of particulates ($PM_{10\text{-}1.0}$) ± 1 standard error of the mean on the upper side of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham

Comparison of all particulates in the size range $PM_{10\text{-}1.0}$ between Nursery stock and Roadside plantings found on the underside of ivy leaves

There were x 5.7 more particulates on the underside of leaves from roadside plantings compared with Nursery stock (Figure 5). The difference was significant at $P \leq 0.001$ (M-W U = 304.00, N= 36).

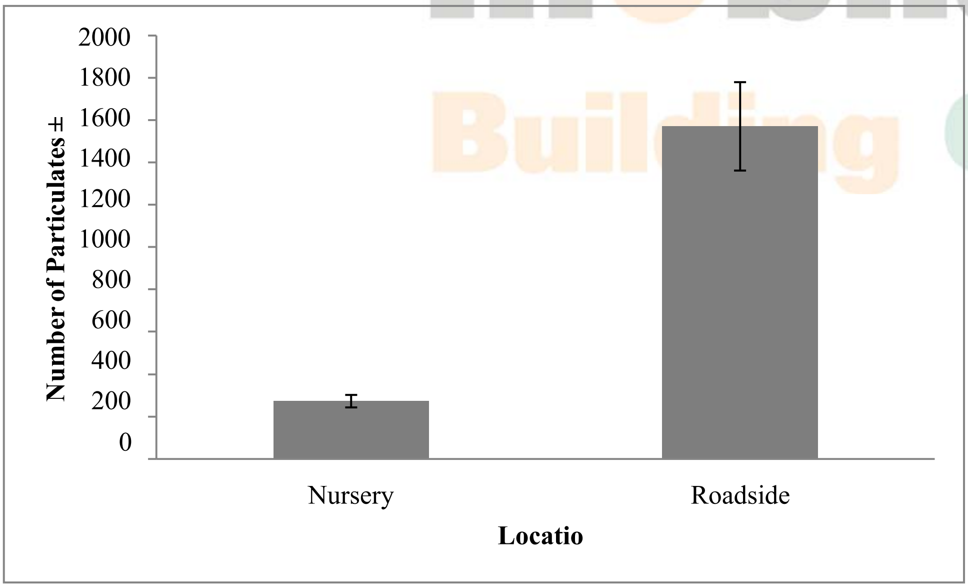


Figure 5. The mean number of particulates ($PM_{10\text{-}1.0}$) ± 1 standard error of the mean on the underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham

Comparison of all particulates in the size range $PM_{10\text{-}2.51}$ between Nursery stock and Roadside plantings found on the upper side of ivy leaves

There were x5.2 more particulates on the upper side of leaves from Roadside plantings compared with those from Nursery plantings (Figure 6). The difference was significant at $P \leq 0.001$ (M-W U = 320.00, N= 36).

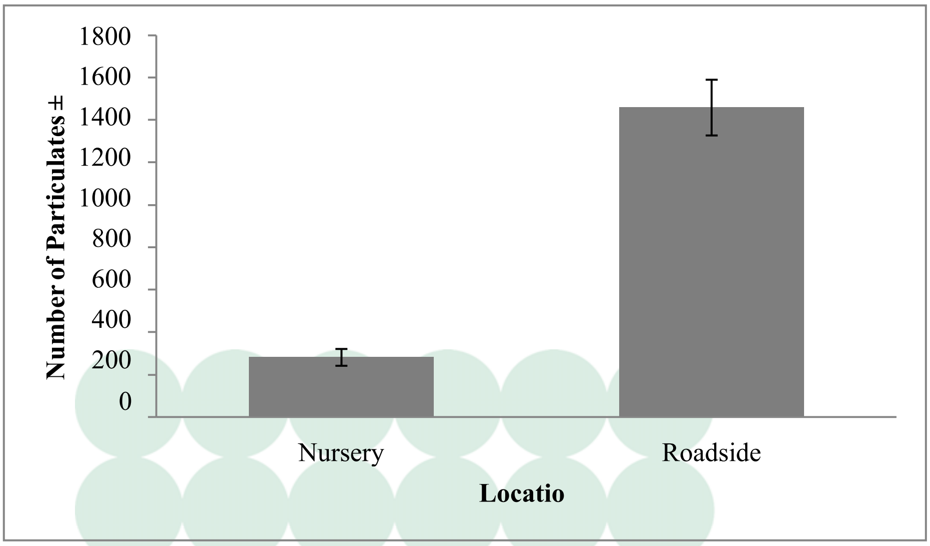


Figure 6. The mean number of particulates ($PM_{10\text{-}2.51}$) ± 1 standard error of the mean on the upper side of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham.

Comparison of all particulates in the size range $PM_{10\text{-}2.51}$ between Nursery stock and Roadside plantings found on the underside of ivy leaves

There were 8.3 times the numbers of particulates on the underside of leaves from Roadside plantings compared with Nursery stock (Figure 7). The difference was significant at $P \leq 0.001$ (M-W U = 307.00, N= 36).

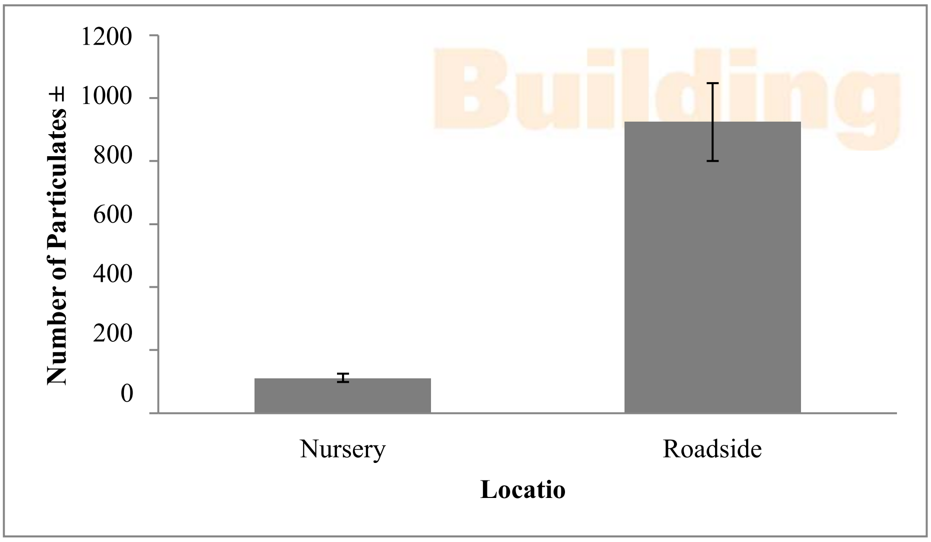


Figure 7. The mean number of particulates ($PM_{10\text{-}2.51}$) ± 1 standard error of the mean on the underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham.

Comparison of all particulates in the size range $PM_{2.5-1.0}$ between Nursery stock and Roadside plantings found on the upper side of ivy leaves

There were x2.2 more particulates on the upperside of Roadside leaves than those of nursery stock (Figure 8). The difference was significant at $P \leq 0.001$ (M-W U = 283.00, N= 36).

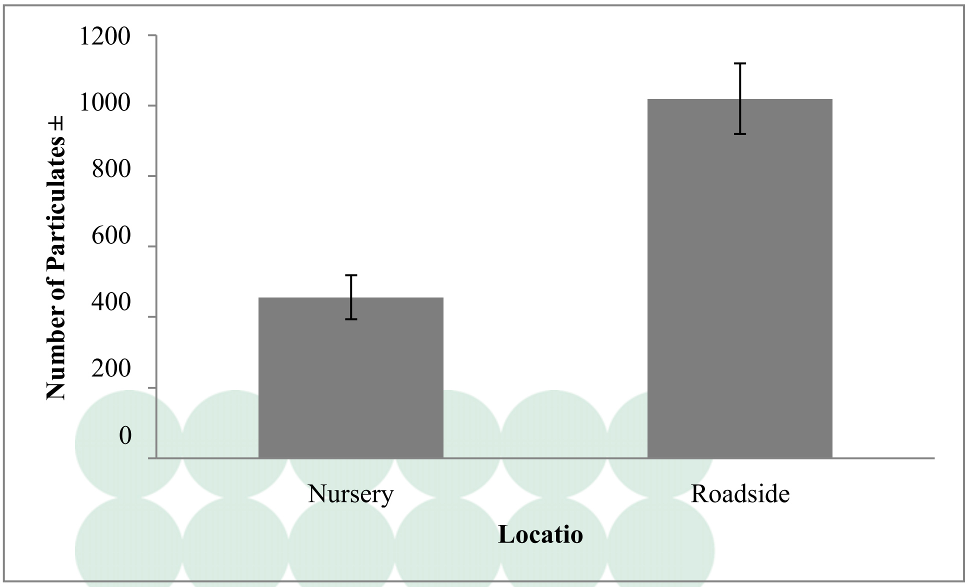


Figure 8. The mean number of particulates ($PM_{2.5-1.0}$) ± 1 standard error of the mean on the upper side of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham.

Comparison of all particulates in the size range $PM_{2.5-1.0}$ between Nursery stock and Roadside plantings found on the underside of ivy leaves

There were x4 more particulates on the underside of leaves of Roadside plantings than of those from Nursery stock (Figure 9). The difference was significant at $P \leq 0.001$ (M-W U = 2993.00, N= 36).

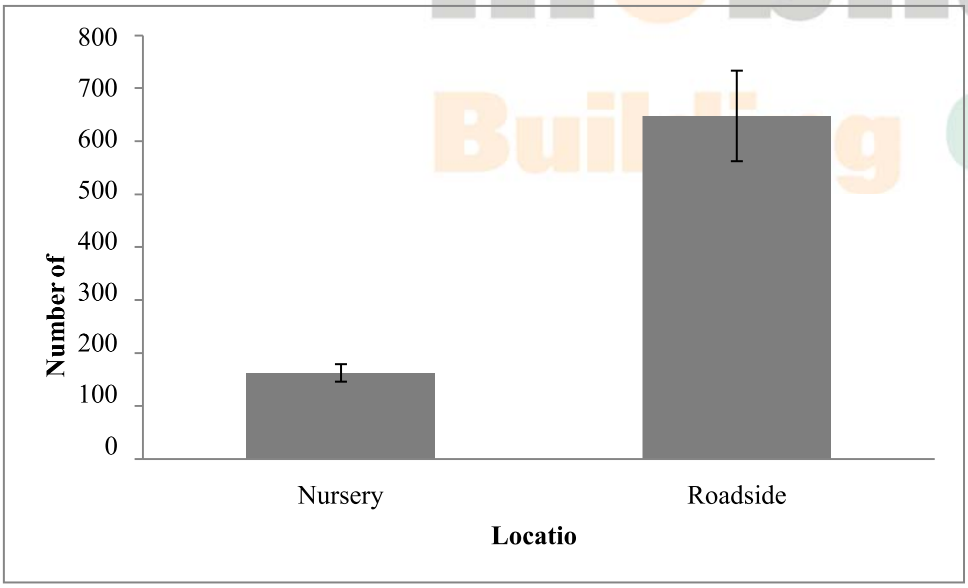


Figure 9. The mean number of particulates ($PM_{2.5-1.0}$) ± 1 standard error of the mean on the underside of ivy leaves sampled in a nursery and along the southbound A38 (Bristol Street) in Birmingham.

Discussion

The results are unambiguous, there were always far more particulates captured on the leaves of ivy plants grown on the roadside of the A38 compared with ivy leaves taken from a nursery (e.g. Plate 6). The Green Screens along the A38 can reasonably be said to be capturing particulates from the air and improving the local air quality.

The aim of this project was simply to demonstrate that planting ivy screens could capture particulates, it was not designed to accurately quantify how many were being removed over a given time period. This is for several reasons: It is well known that rainfall will wash off some, though probably not all, particulates from leaves. It is also known that different size ranges are washed off more efficiently than others (with the smaller particulates being less efficiently washed off by rain). We do not know what the differential in removal due to rain (or other processes such as wind) is in relation to the upper and lower surfaces of ivy. Though we might postulate that rainfall will remove proportionately more particulates from the upper surface than the lower, this would depend on whether the leaves are actually held horizontally (which may not be the case, especially under turbulent wind conditions). We also do not know what effect different 'strengths' of rain (duration, volume of water per unit time, velocity of rain, rain droplet size) have on particulate removal or retention.

To gain some idea of particulate removal over time would require a much more intensive monitoring programme than the snapshot approach of the present study.

The question necessarily arises, however, what does this data really mean? The uncertainties surrounding the data are given above and, as a result, the safest thing to say is that the ivy screens are definitely removing particulates and improving air quality. The images in Plate 6 make the case very clearly and, indeed, even if we assume that no particulates were removed from leaf surfaces due to rain over the two months since planting (which is extremely unlikely) it is clear that the screens are being effective in removing pollution (Box 1). It is likely, however, that rain is washing particulates off leaves, and one could speculate what this means (see Box 2). If we take the two extremes: 1) assuming that rain does not remove particulates then over the 66 days between planting and sampling leaves for particulates, a 1 m^2 section of green screen would capture something of the order of 9,552 million particles (or 145 million/day). On the other hand, 2) if we assume heavy rainfall washes almost all particulates off, then we could be looking at a removal rate of something like 3,184 million/day. The gap between these two figures is massive and shows the uncertainty in drawing too many firm conclusions from scanty data. The removal rate is likely to be higher than 145 million a day.

It is quite possible to be much more exact about how many particulates are being removed per day and the impact of rainfall in 'refreshing' leaf surfaces, but this would require a rather more detailed study than we have attempted here.

The fate of particulates captured on leaves is, of course, rather important. The two major processes for removal of particulates are wind and rain, and leaf loss (shedding) will also make a contribution. Wind will tend to remobilise particulates and return them to the air, and they can then be re-caught if they come into contact with vegetation again. Not all particulates caught on leaves are likely to be re-suspended by wind. Rainfall will wash particulates off, again not all, and the fate of the water will then impact on what happens next. If the water goes to the drains we can be pretty sure any suspended particulates will be removed from the area. If the water drips on to a pavement or road surface and pools there, when it eventually dries out, the particulates may then potentially become re-suspended by wind. If the water runs to a surface such as grass, then there is the potential for re-suspension, but the most likely (though unproven) fate is that the particulates will become trapped in the grass and may eventually be incorporated in the soil.

Conclusion

The green screens installed along Bristol Street are contributing to improved visual amenity and an improvement in air quality.

Box 1. Particulates captured on Bristol Street Screens assuming no removal by rain

If we assume that rainfall did not remove any particulates from the green screens over the roughly two month period since installation, then the number of particulates removed from the air in Bristol Street by an average ivy leaf = the number of particulates captured by a 512 µm x 384 µm section of leaf multiplied by the area of the leaf:

Calculation: number of particulates per leaf
Average number of particulates in a 512 µm x 384 µm section of leaf (upper and lower surfaces) = 4049 -1010 = 3039 (this is the number of particulates on a roadside leaf less the number found on nursery stock).
Area of Leaf = 3280 mm^2 (or 32.8 cm^2)

Area of image = 512 µm x 384 µm = 0.196608 mm^2 Number

of particulates removed = 3039 x (3280/0.196608)
= 50,698,796 **particles per leaf**

If we want to know the number of particulates removed per square metre of green screen then we need to multiply the number of particulates held on an ivy leaf by the number of leaves. But, the particulate samples were taken from the roadside only, and those on the central reservation side are unlikely to capture as many particles. A realistic assumption might be that they capture half the number of particulates than leaves facing the roadside. Let's also assume that there are equal numbers of leaves on the front (roadside) and back (central reservation side) of the green screens.

Calculation: number of particulates accumulated per m^2 of green screen
Number of leaves/m^2 =15.7 leaves in a 0.0625 m^2 quadrat, 16 quadrats per m^2 then this means that there are 251.2 leaves per m^2 of green screen; half of 251.2 = 125.6. So:

Number of particulates on the road side of the screen/m^2 = 125.6 x 50,698,796
= 6,367,768,724
= 6,367 million

Number of particulates on the 'back' of the screen/m^2 = 125.6 x (50,698,796/2)
= 3,183,884,362
= 3,184 million

Total number of particulates removed by a 1 m^2 section of green screen is approximately: 9,551,653,086 = 9,552 million particles

Box 2. Particulates captured on Bristol Street Screens assuming removal by rain

If particulates are removed from both the upper and lower leaf surfaces of ivy by heavy rainfall, then we can calculate the daily removal rate of particulates.

We could make a very crude assumption that the rainfall of 2nd July was heavy enough to remove a substantial portion of particulates held on the surfaces of the leaves, and assume that the rainfall of the 5th July did not remove very many. That would suggest that the particulates accumulated on leaves came from, roughly, a 3-day period (3rd, 4th, 5th July). The baseline number of particulates from plants grown in a nursery and watered from above (the irrigation line can be seen at the top of the poly-tunnel in Plate 1) was 1010 particulates. If we subtract that from the 4049 particulates captured by the upperside and underside of roadside leaves and assume that most were captured over a 3 day period, then we end up with a rule-of-thumb figure of about 1,000 particulates being captured per day on a section of leaf just 512 x384 microns in size.

Following this argument, and using the leaf area, leaf number and front/back capture assumptions in Box 1, then the number of particulates deposited on a single ivy leaf in a day was about:

Calculation: number of particulates per leaf/day
1013 (particles) x (3280/0.196608) = 16,899,599

= 17 million particles per leaf/day

Calculation: number of particulates accumulated per m^2 of green screen

Number of particulates on the front of the screen/m^2 = 2,122,589,575

Number of particulates on the back of the screen/m^2 = 1,061,294,787

Total number of particulates removed by a 1 m^2 section of green screen/day is approximately: 3,183,884,362 or 3,184 million