Transport for London
Surface Transport

Delivering Vertical Greening

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Document Summary

This report summarises the lessons TfL have learned in delivering two green walls and outlines the research into the benefits of these green walls.

Introduction

The Clean Air Fund (CAF) was a £5m grant from the Department of Transport (DfT) to Transport for London (TfL) for the implementation of short-term local air quality improvement measures. CAF enabled measures to be implemented during 2011 and 2012 at priority locations at risk of exceeding EU limits for levels of particulate matter (PM), specifically PM10. Research has shown that vegetation (green infrastructure) has the potential to trap PM and is therefore suitable for introduction or enhancement in places where air pollution is of concern. The method by which green infrastructure (GI) traps PM, and the amount it could help in improving local air quality, is discussed in the Green wall benefits section.

From the CAF budget, £1m was allocated for additional GI at PM_{10} priority locations. The majority of the money has been used for additional tree and shrub planting but the Fund has also allowed TfL to trial the potential benefits of green walls and green screens in trapping particulate matter, which is a commitment made in the Mayor's Air Quality Strategy (paragraph 3.8.21).

A green wall is a building façade or other internal or external wall intentionally covered with vegetation for aesthetic or functional purposes. They are also often known as 'Living Walls' or 'Vertical Greening Systems'. A green wall can be modular, or a trellis-type system and can be attached to an existing building façade, or be a free standing structure. See the Planting Design section for a description and illustration of the different types of green walls.

This document sets out the process followed, lessons learned and anticipated benefits from delivering the green wall onto the previously blank SSE facing wall of TfL's Edgware Road (Bakerloo) London Underground (LU) station, and elevations above the subway entrance, at the junction of Marylebone Road and Edgware Road. The wall has a modular structure and includes 15 different species of plants covering an area of approximately 200 square metres and was installed in November 2011.

Figure 1 shows the SSE wall of Edgware Road London Underground Station before and after construction

Figure 1: Edgware Road LU station before and after construction

The CAF programme has also facilitated the installation of a green wall on The Mermaid (theatre and events centre) on the wall facing Upper Thames Street and green screens in place of hoardings at some Crossrail construction sites.

Delivery Process

The five stages involved in delivering a green wall will be discussed in this section, they are:

- Site selection and approval
- Procurement
- Design and assurance
- Construction
- Maintenance

Site selection and approval

Site selection

General Comment
It is possible to introduce plants on the façades of most buildings as there are a number of different methods of vertical greening (see the Planting Design section). Constraints such as land ownership and liability issues may dictate whether landlords are willing to allow a green wall on their property. Heritage considerations must always be taken into account, and planting must avoid concealing any part of façades with historical or aesthetic importance.

It may be possible to install a green wall on a grade listed building despite major restrictions on fixing into historic fabric. An extended listed building consent process with approvals from English Heritage and the local authority will be required. Planting may be used to enhance protected or significant buildings, especially if there are expanses of unrelieved elevations. Through carefully designed planting, 'Brutalist' architecture may be softened.

At Edgware Road LU station
Approximately 200m^2 of vegetation now covers the whole SSE facing walls of Edgware Road LU (Bakerloo) station, including the elevations above the subway. The location is at the junction of the A501, A5 and start of A40 and adjacent to Marylebone Road, one of the three air quality priority locations identified in the Mayor's Air Quality Strategy (Figure 2, next page). A TfL-owned or managed location for the green wall trial was sought in order to demonstrate leadership, and also to reduce the implementation time by keeping building approvals within TfL control.

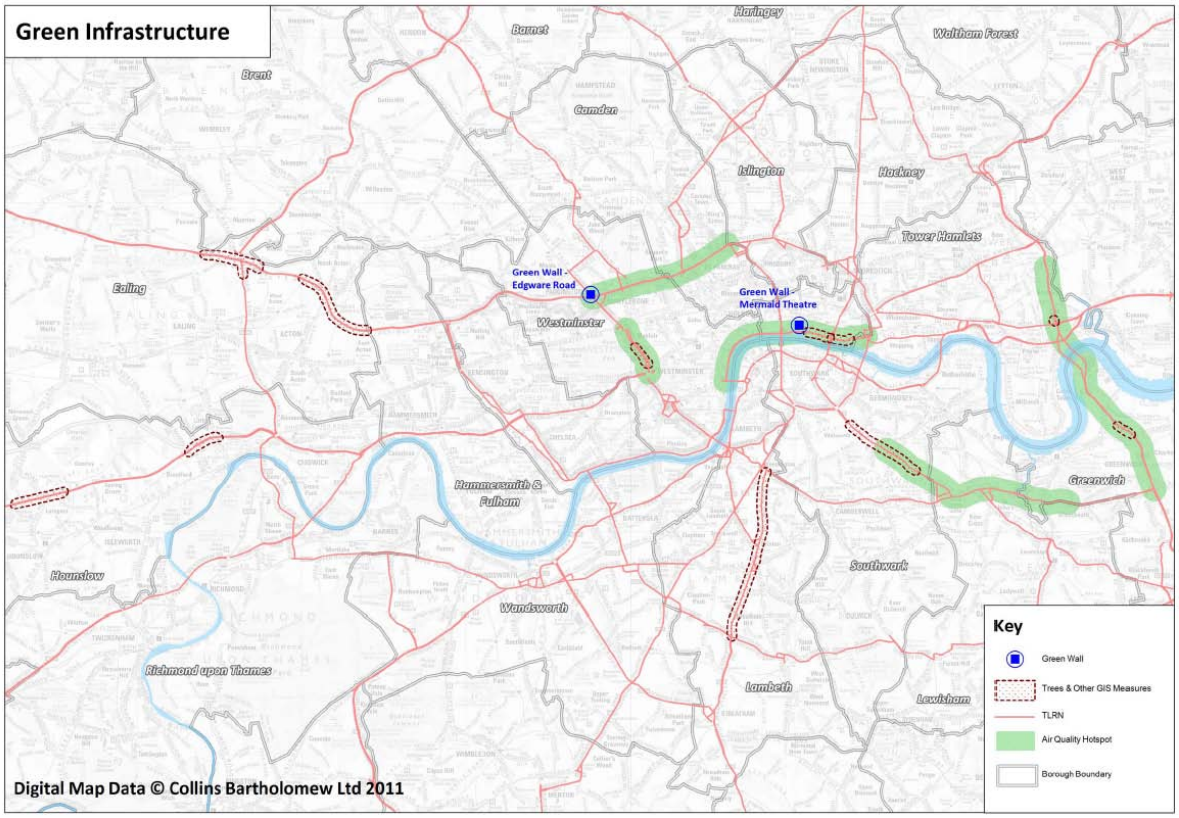

Figure 2: Mayors Air Quality priority areas with locations of green infrastructure delivered under the Clean Air Fund

Planning Permission

General comment
The need for planning permission must always be considered on a site specific basis. Experience shows many local planning authorities to be sympathetic towards applications for vertical greening; some authorities have in fact specified green walls as a planning condition. Additional time may be required to obtain any required consents if the proposal is in a Conservation Area.

At Edgware Road LU station
TfL considers the green wall at Edgware Road LU station to be Permitted Development under Part 13 of the Town and Country Planning General Permitted Development Order (Maintenance and Improvement of the Highway).

At The Mermaid
All planning activities were undertaken by The Mermaid. In this case, the Local Planning Authority required assurance regarding the irrigation system, based on their experience with another green wall in the past.

Building Control

General comment
Although green walls tend to be relatively lightweight structures, with minimal construction activity required to erect them, Building Control regulations may apply. The Local Planning Authority will advise on requirements and may charge for this advice.

At Edgware Rd LU station
Westminster County Council is the local planning authority at the site of the Edgware Rd green wall. The green wall is attached to a London Underground (LU) building and TfL considers it to be classed as a 'highway structure' for Planning, Structural Assurance and funding purposes. With the exception of the pump cabinet, the structure does not require support from the land adjacent to the wall. As the Building Control authority for all works on LU stations, LU carried out the building control function and is satisfied that the arrangements for scrutiny of the design were appropriate.

Ownership issues

General comment
When embarking on any vertical greening project it is important to identify ownership (landowners, leaseholders and freeholders) of;

- the wall or structure to be installed, including the main frame and the facade
- the adjacent land

If the green wall promoter is not the owner of either element, it may be necessary to enter into official agreements between parties.

Vertical greening attached to a building is likely to protrude over adjacent land. If there is no (or a very small) curtilage, an agreement is likely to be needed with the landowner for the airspace encroachment and any structural footprint. The level of formality and financial arrangements are at the discretion of the respective parties.

At Edgware Rd LU station
TfL's property ownership of Edgware Road (Bakerloo) LU station ends at the building line (although includes parts of the subway). TfL is the Highway Authority for the carriageway and footway on Marylebone Road and Edgware Road. The land between the station wall and footway is owned by British Telecom.

TfL has entered into a licence agreement with BT for access onto and over their land during the construction period, for maintenance purposes post completion and a peppercorn rent for the airspace encroachment (c. 50mm) of the green wall and the footprint of the pump cabinet.

At the Museum of London
TfL and the Museum of London explored the potential for installing vertical greening on the exterior face of the museum's rotunda at the junction of London Wall and Aldersgate Street (see Figure 3, next page).

Figure 3: Museum of London rotunda, a potential site for a green wall.

A number of projects have recently been undertaken by the Museum to increase biodiversity and visual interest including a green roof and bee garden. The proposal to plant the rotunda was a subsequent phase in these environmental improvement works. The Museum of London leases its building from the City of London. However, it transpired that although the rotunda building is part of the lease, its external brickwork is not part of the Museum's demise. Resolving the structural responsibility for the brickwork should a green wall be installed on the façade would have taken longer than the CAF programme allowed. TfL therefore sought an alternative location for a second green wall.

At The Mermaid
The Mermaid building is immediately to the east of Blackfriars station and has a façade adjacent to Upper Thames Street, one of the three air quality priority areas identified in the Mayor's Air Quality Strategy. The Mermaid has ambitious plans for green walls and was very receptive to the installation of a 125 square meter green wall. An agreement between TfL and The Mermaid Conference & Events Ltd allowed The Mermaid to install a green wall in July 2012. Future maintenance will be the responsibility of The Mermaid.

Procurement and suppliers

General comment
It is advisable to explore the market to obtain best value for a specific project. TfL showed that the procurement process can be relatively quick. Depending on the scope of works, suppliers can reasonably be expected to put together a bid within 2 or 3 weeks. If public funding is being provided to a 3rd party to deliver vertical greening, the funder may need to confirm that the 3rd party has undertaken a satisfactory procurement processes.

At Edgware Rd LU station
The procurement programme is outlined in Table 1:

Write and agree procurement strategy	1 week
Write and publish Pre Qualification Questionnaire (PQQ) and receive responses by a given deadline.	2 weeks
Write and issue full Invitation to Tender and receive responses by a given deadline.	2 weeks
Evaluate bids, seek clarifications and award contract.	1 week

Table 1: Procurement process for Edgware Road LU station green wall.

Four companies responded satisfactorily to the PQQ and were all invited to tender. Submissions were given weighted scores against criteria in the tender specification as shown in Table 2.

Specification element	**Max. score**
Technical elements	25
Design Features *Air quality improvement potential* *Structural Integrity* *Security considerations* *Materials and planning* *Water and Electricity arrangements*	
Delivery timeframe, programme and resources	20
Construction techniques including H&S and risk management	10
Environmental Sustainability	5
Price	40
TOTAL	**100**

Table 2: Tender evaluation weighting.

The main feedback themes to unsuccessful bidders were
- insufficient depth in one or several sections of the response
- submission inadequate to meet the technical specification
- emphasis needed to focus more on the environmental aspects of the project
- general information about the company swamped any project and site specific interpretation

At The Mermaid
All procurement activities were undertaken by The Mermaid. The Mermaid have plans for further green walls and roofs, which are expected to be funded by advertising within the plant design. Figure 4 (next page) provides an example of how it might look.

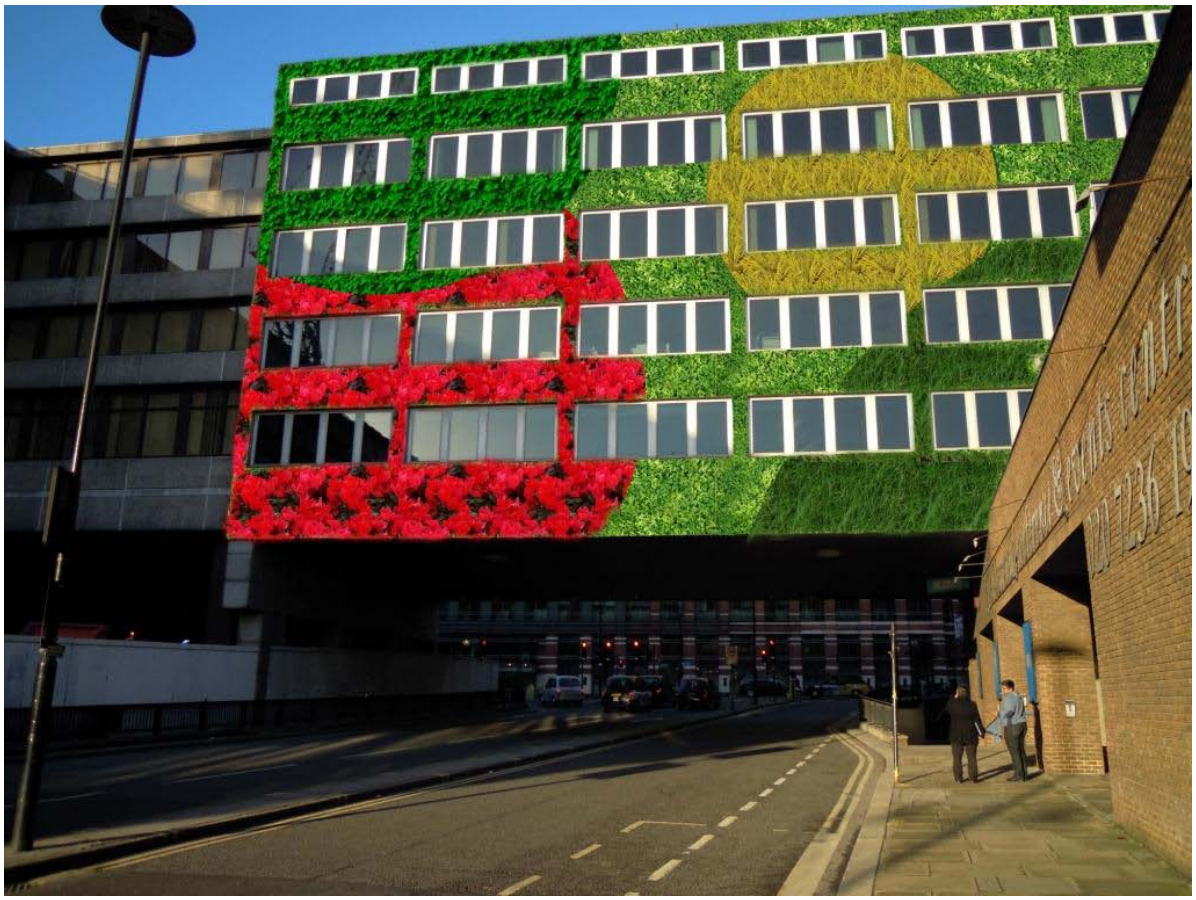

Figure 4: Example of how further greening at The Mermaid might incorporate advertising in the planting design.

Design and assurance

Planting Design

General comment

For best visual impact, a green wall should be designed to provide continuous living cover in all seasons. The aspect of the wall and the micro-climate will influence the type of plants that will establish and thrive.

Some academic studies have researched the performance of vertical greening as a particulate trap; however, climatic differences limit the direct transfer of known high-performing species in the plant selection for vertical greening in London. Previous studies have focused on climbing plants so there was limited knowledge of the particulate capture ability of plants which can grow vertically with a hydroponic system.

Varying the type, location and density of plants within a green wall can increase the opportunities for particulate capture. Creating texture across the wall by using a variety of plants increases the air turbulence in and around the vegetation, which has been shown to increase the rate of particulate deposition. The particulate capture ability of plants depends on the size, shape and surface texture of leaves:

- **Hairy**, **rough** and/or **ridged** leaves are effective in trapping particles.
- **Waxy** leaves are also effective in trapping particles.

- Plants that **attract aphids** could be appropriate for inclusion as the sticky secretion of aphids deposited on leaves will retain particles.
- **Evergreen** vegetation offers a year-round particulate-trapping surface but this may be to the detriment of some evergreen plant species.
- Plants with **smaller** leaves have greater density of foliage and branches. The capability in which plants are able to adsorb particles is positively related with the leaf area index (m^2/m^2).

Ivy is a fast growing, resilient, evergreen plant, able to grow in harsh environments therefore ideal for vertical planting in urban areas – with which it already has a long association, albeit mainly for aesthetic purposes. The current prevalence of Ivy has made it the subject of numerous studies which demonstrate its potential as an effective particulate trap. However, research which compares the particulate capture ability of different shrub species, suggests that other plants may be more effective than ivy.

The design of vertical greening projects delivered under the CAF programme are informed by limited research about how plants used within green walls act as a 'particulate sink'. The CAF therefore contributes to understanding and knowledge in this area.

At Edgware Rd LU station
The wall has a south and east aspect and a mixture of evergreen and perennial plants were chosen for their known ability to establish and thrive in a highway environment and to provide a continuous living surface in all seasons. The survival of the plants is essential to enable year-round particulate capture. Plants with smaller leaf types and different textures have been included. The plants will be fully mature within one growing season and are outlined in Table 3:

Latin name	**Common name**
Lavandula 'Munsted'	Lavender
Erysimum 'Bowles Mauve'	Wallflower
Geranium 'Max Frei'	Geranium
Stachys 'Silver Carpet'	Lamb's Ears
Carex testacea	Sedge
Heuchera 'Plum Pudding'	Coral flower
Veronica 'Waterperry Blue'	Speedwell
Vinca minor 'La Grave'	Periwinkle
Waldsteinia ternate	Waldsteinia
Euphorbia 'Humpty Dumpty'	Spurge
Liriope spicata 'Big Blue'	Lilyturf
Acorus 'Ogon'	Sweet Flag
Lonicera pileata. 'Maigrun'	box-leaved honeysuckle
Euonymus 'Emerald n' Gold'	shrubby Spindle
Euonymus 'Emerald Gaiety'	shrubby Spindle

Table 3: Green wall species

The planting design (Figure 5) intentionally creates a variety of textures across the wall to interrupt air flow and encourage particle deposition.

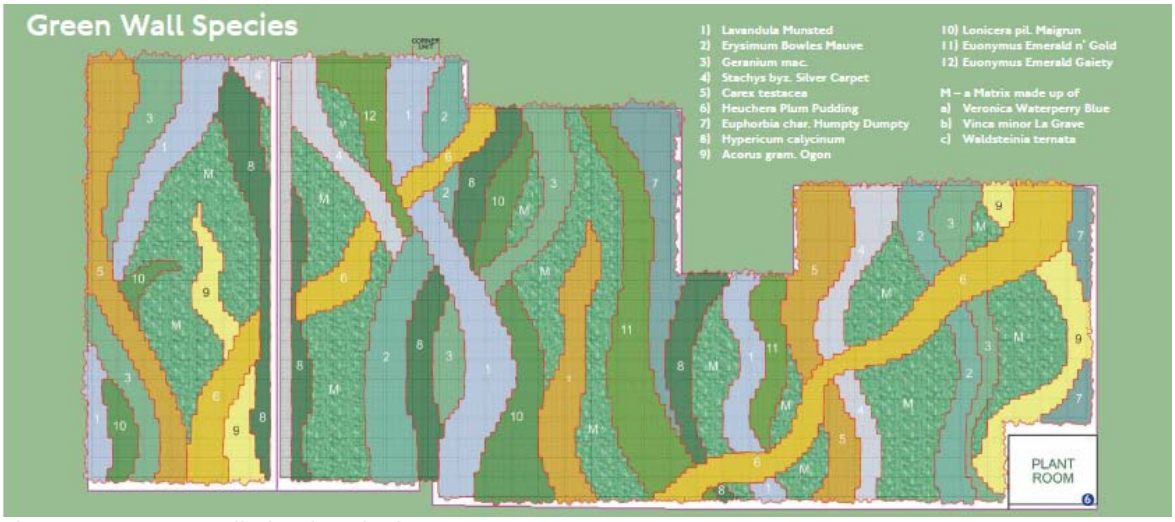

Figure 5: Green Wall planting design

Species are planted in a matrix format with the same plants repeated at different heights within the wall to enable comparison of deposition. 10 to 20 percent of species are deciduous, the remainder evergreen, to maintain high level of vegetation coverage all year round and provide some colour during winter.

Structural design

General comment
There are three main ways of enabling plants to grow up or on the side of a building or structure. The need to inspect buildings or structures must be taken into account when designing a green wall.

Climbing plants with adventitious roots; the plants cling directly to the surface (Figure 6, next page).

Although this is the least structurally complex, achieving a large vegetated surface area may take several years and the choice of species is limited to those which can support themselves independently on the wall. The assertion that growing plants up a building in this way causes structural damage to its external materials is disputed in academic literature.

Figure 6: Green wall with self-supporting climbing plants

Trellis systems (Figure 7).

A ‘curtain effect’ can be achieved through providing tensioned cables for plants to climb by twining. Depending on the height of the wall, it could take 3-5 years or longer before total vegetation coverage is achieved. The materials required makes this approach cheaper than a modular option. Again, species are limited to those which climb by twining.

Figure 7: Trellis system

Modular systems (Figure 8, next page).

A framework is built onto the wall to support modules that contain the growing plants and an irrigation system. The design must ensure the additional loading can be supported by the building and green wall framework.

All systems need a substrate for the plants to root in. This may be directly into the ground, a container with soil or an alternative rooting medium for use with hydroponic growing techniques. The subterranean environment should be considered as part of the structural design.

It is necessary to check for underground services and cellars or voids, to safeguard against pavement collapse during the construction process and also to identify local utilities if the water and/or power supply connection needs to be created from a highway main supply.

Figure 8: Modular type system.

At Edgware Rd LU station

The green wall uses Biotecture Ltd's modular system called Biowall (Figure 9, next page).

Cladding rails and a waterproof backing board support the planting modules. The Biowall panels comprise a horticultural rockwool substrate within a regenerated plastic case with pre-cut apertures on the face that host the plants. Plants are grown hydroponically in a peat-free rockwool substrate which has achieved the European Ecolabel for sustainability and is chemically inert and dimensionally stable. The waterproof backing 'Ecosheet' is a 100% closed loop UK manufactured recycled material. Planting panels are fabricated from regenerated plastic sources.

Subterranean Environment: TfL undertook a buried services check and obtained comprehensive utility information which was provided to the supplier. To the best of

TfL's knowledge there were no sub-surface services or cavities that could be affected by or affect the green wall project.

Figure 9: Biowall modular system.

At the Museum of London
The Museum's rotunda wall is cylindrical and on a camber which makes assembly of a green wall more difficult. Nevertheless there are a number of solutions which would enable plants to be grown up and around the rotunda should the project be taken forward in future.

At the Mermaid
The Mermaid green wall is a modular structural design using the ANS living wall system which is designed to grow plants vertically, using natural, organic compost. The ANS system allows plant roots to migrate within the modules.

Structural Assurance

General comment
It is advisable to employ a structural engineer for any green wall project. This capability may be procured by the client if the supplier does not have the necessary professional qualifications.

Building Control may be conditional on obtaining recognised Structural Assurance. A Structural Engineer will need to confirm that a) the suitability of the wall or structure to host vertical greening and b) the project construction diagrams and fixing details are appropriate and in accordance with recognised professional guidance.

At Edgware Rd LU station
On the advice of the Structures Team (Roads Directorate) TfL used a framework contractor to provide the necessary structural assurance. The contracted Structural Engineer signed a Design and Check certificate for the green wall designs in accordance with the standard HA66/95 - Environmental Barriers and first principles. The Structural Engineer liaised with the supplier to confirm that the proposal to fix the cabinet down to a 75mm thick in situ concrete slab was satisfactory and will meet BT's requirement to allow access to the gas main on their land. The cabinet was deemed not to need buried foundations and could be supported on ground surface-bearing concrete slabs, thus avoiding the need for excavation.

Irrigation design

General comment
Providing a regular and reliable water supply to the plants is essential for their survival. With a modular green wall system this supply is achieved by installing a controllable pump which will deliver a prescribed amount of water to different parts of the wall.

The pump requires an electricity as well as water connection. A pump system is ideally located at ground or basement level and will require adequate space for maintenance access.

At Edgware Road LU station
The pump system is enclosed in a lockable on-street cabinet (Figure 10).

Figure 10: The pump cabinet

The irrigation system includes a web based remote sensing and remote control facility which allows the supplier Biotecture Ltd to operate and manage the irrigation system from their offices. Automatic alerts are generated if there are any interruptions to the supply or deviations from prescribed parameters.

As the plants are grown hydroponically, the pump system also serves to supply nutrients to the plants at the appropriate time of year. See Figure 11 (next page) for an annotated diagram of the cabinet contents.

Figure 11: Edgware Road Green Wall irrigation plant

Water

General comment

It is possible to use rainwater to irrigate the plants on a green wall, in fact plants prefer it to a filtered supply, but rainfall is not always reliable and periods of heavy rain often do not coincide with the peak water demands of the green wall. There may not always be space available for the size of storage tank that would be required. As the reliability of supply is fundamental to the success of the wall, a connection to mains supply will still be required if harvested rainwater is used for irrigation. Although rainwater is ideal for irrigating green walls, it is not always a more environmentally sustainable option than using a mains water supply due to the need for tank construction and onsite filtering. As well as the considerations to ensure environmental authenticity, a rainwater harvesting system may not be financially viable if the costs of installing and maintaining the system outweigh the savings on mains water.

As the volume of water entering the wall is controlled, runoff should be minimal although the drainage arrangements need to be considered.

At Edgware Rd LU station

Water Supply

It was decided not to irrigate the green wall with harvested rainwater from the roof of Edgware Road station for four reasons:

- The downpipe is not readily accessible.

- It is unlikely there would be sufficient room for the size of storage tank required; it would probably have to be buried and would have required excavation work within the construction programme.
- Arranging for rainwater capture and storage would have delayed the project.
- The environmental benefits are questionable and a mains connection would still have been required.

However, the irrigation system installed does not preclude future adaption to use harvested rainwater.

The water is sourced from the main station supply and has been teed off from the station mess room. The water supply has been designed with an inline isolator valve backed up with a double checked valve at the source.

Water use

Biotecture Ltd who designed, constructed and maintain the green wall at Edgware Road have a strong commitment to sustainability and have stated that their system uses no more than 2 litres per m^2 per 24hr period in the summer, and in the winter the quantity is anticipated to be half this amount as the system is not irrigated constantly. Therefore over a year, Biotecture's hydroponic system provides vertical greening at an average of 1 litre per m^2 per day. In the summer there are likely to be three periods of irrigation per day and two in the winter.

Drainage and runoff

To keep the green wall irrigation system flushed through, Biotecture has planned that 10 percent of the water put into the wall runs off the bottom and becomes surface water. During the summer period, very little water will exit the base of the wall due to natural transpiration,. The green wall is designed with a continuous gutter along its base which collects runoff water. The gulley tapers to the centre from each end so that it can discharge centrally (via a shoe) towards the drainage point on BT's land (Figure 12, next page).

Figure 12: Drainage from the Green Wall onto BT land.

The maximum runoff from the green wall is around 21 litres per day. This is a very small amount compared to even minimum rainfall conditions: 1 cm of rainfall in an hour over the 98m^2 paved area in front of the wall will produce 980 litres of water. Despite there being a minimal amount of runoff expected, drainage to the site is currently limited to one 100 mm diameter surface gully. To ensure optimum drainage and to avoid surface water ponding, TfL cleared the drain when the green wall was installed.

Green walls are liable for a rebate from sewerage charge, however as the total savings associated with this are minimal TfL (London Underground) decided not to apply for the rebate.

Electricity

General comment

A very low level of electricity is required to operate a green wall irrigation system, power requirements are comparable to that of a domestic light bulb. Due to the very low levels of electricity consumed, it is unlikely that a PV installation is necessary or would make the project more sustainable. The criticality of an uninterrupted energy supply also means that powering the irrigation system using photovoltaic cells is unlikely to be the most reliable option.

Clients for whom it is important to minimise the net energy consumption of a green wall are advised to seek energy savings within the host building which equal or exceed the energy consumed by the green wall's pump system. This could be as simple as replacing light bulbs for a lower energy variety.

At Edgware Rd LU station
The irrigation system at Edgware Road is driven by a 4 bar pressure pump rated at 0.8kW which requires a single phase 13 Amp power supply. The amount the pump operates during the year is weather dependent. During summer months it may operate for up to 27 minutes per day. During the winter months this will likely reduce to approximately 3 minutes per day. An annual average of 12 minutes per day is estimated. 12 minutes x 365 days = 4,380 minutes of pump use per year, which is equivalent to 73 pump hours. 73 hours x 0.8kW = just under 60kWh annually. This is roughly equivalent to a 60W light bulb being on for 3 hours a day.

Construction

General comment
Erecting a modular green wall involves a moderately unobtrusive construction process. The planted panels are grown offsite and assembled using lightweight power tools. The method of elevation to fix the uppermost panels (eg ladder, scaffold, cherry picker, scissor lift) will depend on the height and location of the wall.

The requirements of the Construction (Design and Management) Regulations 2007 apply to green wall projects. Suppliers should be required to submit a draft Method Statement and Risk Assessment as part of the procurement process which is then updated and agreed prior to works beginning onsite. This document may also be necessary for any licence agreements.

It is recommended that suppliers are registered with CHAS (Contractors Health and Safety Assessment Scheme).

The following should be arranged and agreed between the client and supplier if required, including responsibility for any costs as applicable

- Local power (110v & 240v) and water supply during the course of the works
- Unobstructed access to all work areas
- Establishing a secure worksite
- Adequate site storage
- Welfare facilities
- Waste disposal and recycling
- Hours of working

Permits will be required if construction activity requires driving over the footway to access the wall and/or vehicles stopping on the carriageway to make deliveries (except in designated loading bays). Any barriers and signage must be erected by suitably qualified personnel in accordance with Chapter 8 of the Traffic Signs manual.

Green wall projects and any associated equipment and signage should be reviewed by Community Safety Officers to ensure that crime and disorder issues have been addressed during the design stage.

At Edgware Rd LU station
The Edgware Road green wall was registered as a 'non-notifiable' project on TfL's CDM Datastore and the working hours were agreed as 8am – 5pm. The contractor was required to submit a Method Statement and Risk Assessment before construction and maintenance activities could commence.

The site compound (Figure 13), the temporary closure of one of the subway exits and traffic management were provided by Ringway Jacobs, TfL's highway contractor for the central area.


Figure 13: Showing the construction of the site compound.

Ongoing Maintenance and monitoring

General comment
Provision for ongoing maintenance is crucial for the health of the plants and survival of the wall. It is unlikely that a 100 percent survival guarantee will be given for the wall unless the maintenance contract is awarded to the supplier. The terms of a maintenance agreement should cover:

- Scope of assets within the agreement ie pump facility, structure and plants
- Frequency of inspections
- Details of annual horticultural activities

As per the construction period, formal access arrangements for staff, equipment and materials are required for maintenance activity.

Experience from London and nationwide suggests that vandalism of green walls is rare and security breaches (ie via climbing) are extremely difficult. As a security

measure, clients may consider not extending the green wall to street level, perhaps starting 3 metres above the ground, but this would be to the detriment of the design and potentially exacerbate fear of crime.

To evaluate the benefits of a green wall, clients may want to collect data before and after installation such as:

- Energy use for heating and cooling the internal spaces immediately behind the planted wall
- Particulate deposition on the blank wall and on the leaves after planting
- Perceptions of the local environment
- Thermal imaging to identify heat loss and solar gain

At Edgware Rd LU station
TfL have entered into a maintenance contract with Biotecture Ltd, initially for 3 years, which provides a 100 percent survival guarantee subject to the provisions of the agreement.

TfL commissioned Imperial College London collected leaf samples to measure the particulate deposition and investigate the ability of the plants trap particulate matter from Feb to May 2012. Although this was a short period for research, dictated by the CAF programme, the research study identified those species which were better at trapping PM.

Green wall benefits

TfL sought advice from the Air Pollution Research in London (APRIL) group on evaluating the air quality and wider environmental and climatic benefits of green infrastructure measures. The anticipated reduction in particulates through increasing vegetation at air quality priority locations has been evaluated through a literature review and practical research in conjunction with Imperial College London via APRIL. TfL also commissioned market research to understand the views of local businesses and members of the public

The following sections of this report summarise the anticipated air quality and wider environmental benefits from installing green walls in urban areas. Many of these benefits are applicable to GI (urban greening) in general and are not exclusive to green walls.

TfL's academic partners stressed the importance of recognising the accumulated benefits that GI can provide as ecosystem services, as illustrated in Figure 14 (Next page).

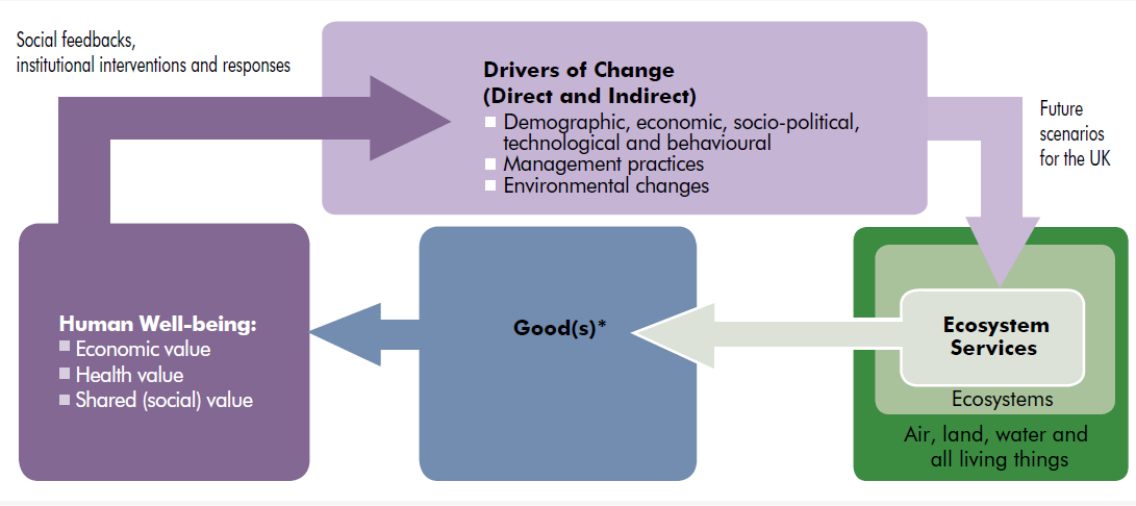

Figure 14: Conceptual framework showing the wider benefits of green infrastructure. Taken from the UK National Ecosystem Association.

Air Quality

Vegetation has the ability to remove substances from the air that are harmful to human health and damaging to structural materials.

An MSc student at Imperial College London undertook a literature review of publications covering the deposition of particulate matter to vegetation, a short study to assess particulate deposition concentrations on the leaves of selected shrubs in the vicinity of Marylebone Road, and a brief assessment of the value of increased planting within the broader context of ecosystem services.

Results from this initial work showed that leaves which are waxy, hairy or deep-veined are better at trapping particulate matter than smooth and supple leaves. A full version of the MSc thesis is available on request from Imperial College London.

TfL commissioned Imperial College London to undertake further research to establish the ability of different species planted under the CAF programme to trap PM_{10}. Owing to the time and seasonal constraints of the programme, leaf samples could only be taken from certain species and locations. This included the green wall at Edgware Road tube station, although it was not possible to take leaf samples from higher locations in the green wall.

The study found a great disparity in the ability of different plant species to capture PM_{10}. The shrub Convulvulus cneorum performed far better than any other species. The herbaceous plant Stachys byzantine (Lambs ears) in the green wall was the next highest, with the climber Hedera helix (Ivy) being the poorest performing species. The best performing species were those with the highest hair densities on the leaf surface, and smaller leaf surface area. Plant orientation was found to have no significant effect. Over a three month period, the total PM_{10} capture from the green wall at Edgware Road tube station was calculated to be 515g.

The study report refers to the wider environmental benefits of green walls and GI and makes recommendations for further research to further the understanding of the benefits of GI. The report also refers to the cost-benefit of urban greening measures and explores the benefit in terms of pollutant capture and the cost of GI measures to implement and maintain and also asks if urban greening offers value for money when measured against other measures of pollutant reduction. The cost effectiveness of green walls is the subject of another MSc thesis at Imperial College London.

It has been shown by modelling conducted by Mackenzie et al that increasing deposition by the planting of vegetation in street canyons can reduce street-level concentrations in those canyons by as much as 40% for NO_2 and 60% for PM. Their report states that the judicious use of vegetation can create an efficient urban pollution filter, yielding rapid and sustained improvements in street-level air quality in dense urban areas.

Whilst TfL has no funding to commission further research on the relationship between GI and air quality at the time of writing this report, it is expected that the above studies will increase understanding of the air quality and wider benefits of green walls and other GI and will help to inform further academic research. An important next step is to examine the contribution of green walls and other GI in reducing pollutant concentrations.

Through the delivery of the different work-streams, the CAF has helped to compare the effectiveness and ease of implementation of a range of local measures.

Other Environmental Benefits

The results from the above studies suggest that GI can be used as a supplementary measure to emissions reduction, but should be viewed in the context of its wider environmental benefits. An ecosystem services evaluation considers the wider benefits of green infrastructure, including biodiversity amenity and human wellbeing, as shown in Figure 15 (next page).

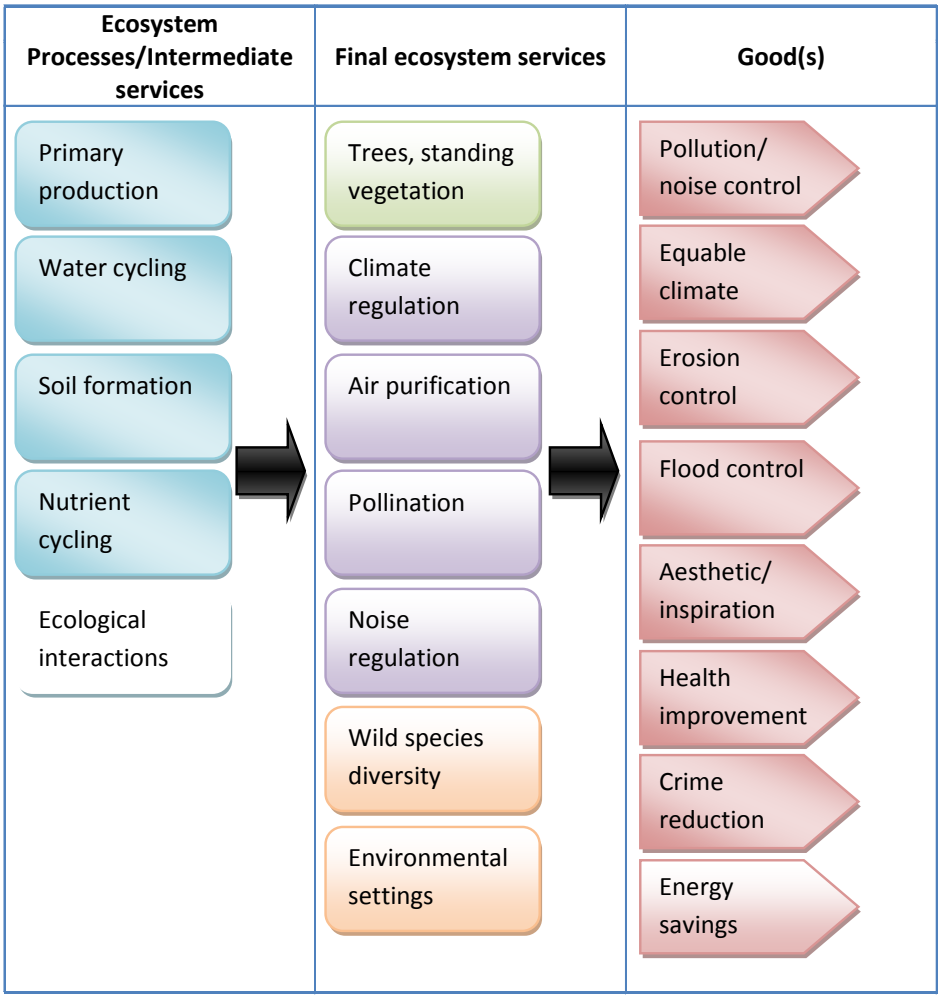

Figure 15: Ecosystem processes, services and goods provided by urban greening

The wider environmental benefits include improvements to regulating ecosystem services. GI can regulate climate by lowering temperatures through transpiration and shading, decrease flood risk by increasing surface areas for water drainage and the increased uptake of rain water by vegetated surfaces. Further benefits accrue from increased biodiversity both directly from additional vegetation as a habitat but also from the provision of food sources for wildlife.

TfL commissioned customer research to seek the views of people passing by or working close to the green wall at Edgware Road tube station and the planted towers on Lower Thames Street. Clean air was seen as an important issue for Londoners and businesses, and most supported the installation of further green walls and planted towers in their local areas.

Cultural benefits are of prime importance with aesthetics being one of the main benefits mentioned by people living and working in the vicinity of green walls. The results are summarised in Figure 16 (next page).

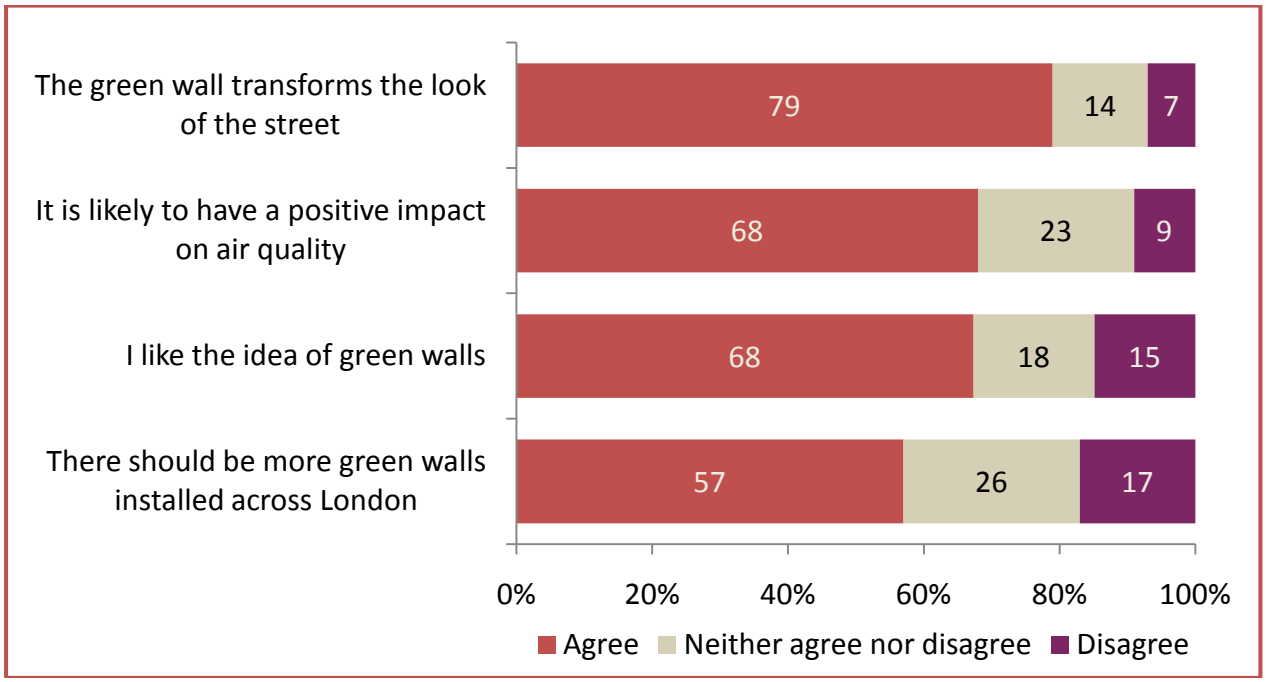

Figure 16: Customer research at Edgware Road Green Wall

Conclusions

TfL has installed two green walls in London and the benefits they provide for Londoners and the environment have been outlined in this report. The report also shows how the difficulties experienced in the installation process can be overcome by careful design and planning. It is hoped that the experience and lessons learned by TfL will help to inform further green wall development.

The expectation that plants with smaller and hairy leaves are able to trap PM_{10} better than plants with different characteristics have been borne out by the research carried out within the time available. The research and associated studies will inform future studies and research into the relationship between GI and air quality.

As a result of the Clean Air Fund, the wider environmental benefits of GI are better understood and the green walls in particular have created interest and helped to raise awareness of the benefits.

Further information

Contacts

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