Living Roofs and Walls

Technical Report: Supporting London Plan Policy

Design for London

MAYOR OF LONDON

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Foreword

Across the world there is a rapid increase in urban living and an ever greater understanding of the consequences of global climate change. London is experiencing warmer, wetter winters, hotter, drier summers and we can expect much greater changes in the decades ahead. As London's population increases we are developing more sustainable approaches to development, using natural systems to shape and support growth. London is avoiding suburban sprawl into the Green Belt and delivering high quality, more compact development – closely linked to good public transport and other amenities.

Excellent architecture and urban design is required if London is to adapt to the extremes of climate change. Living roofs and walls – green roofs, roof terraces and roof gardens – are key. They can provide additional living space and can bring the dual benefit of limiting the impact of climate change by keeping the city cooler while at the same time reducing energy use and carbon dioxide emissions. Living roofs also enhance biodiversity, reduce flood risk (by absorbing heavy rainfall), provide insulation and improve the appearance of our city.

New construction techniques allow for a multitude of different types of 'Living roof', from natural meadows, brownfield habitat and allotments, to formal gardens arranged with planters and seating space and even rooftop farms. Despite these benefits 'living roofs' are not as common a feature in London as they are in other European and American cities. This is because the wider benefits are not well understood, and the UK planning system seems to actively work against providing living roofs. To help deliver more living roofs and combat climate change the most recent alterations to the London Plan now 'expect major developments to incorporate living roofs and walls where feasible.'

This technical document investigates the practical benefits of living roofs and explores the different barriers to their implementation. It helps support the delivery of the new London Plan policy, build a greener London and in turn make our roofs places for life.

Ken Livingstone
Mayor of London

Richard Rogers
Chief Advisor
on Architecture
and Urbanism

Peter Bishop
Director of
Design for London

Sponsor's Message

In the last 15 years the concept of Green Roofs has moved from the margins of visionary schemes in to the considerations of mainstream design. This transition has been driven primarily by sound economic and environmental objectives, but has also been championed by UK Green roof system suppliers with increased investment in development of products and support services. In this capacity Alumasc Exterior Building Products were delighted to receive the invitation to be exclusive sponsors of the Greater London Authority's research paper into the subject of living roofs.

Having been at the forefront of living roof developments in the UK for over 15 years, we believed that Alumasc's experience of a wide variety of projects of many different sizes and specifications could make a useful and considered contribution to a document, which would ultimately extend the development of living roofs for the long term benefit of our building landscape.

The road to fully understanding the specific benefits of living roofs as part of the UK built environment has been a long one, and it has taken the leadership of individuals and belief of Government to bring the issue of sustainable design to the fore. The opportunity now exists to continue this good work and keep living roofs very much within the public focus, as the consequences for our environment, built and otherwise if we do not, is the onset of a future dominated by dwindling natural resources and global warming.

As leading industry representatives during the research, Alumasc were keen to present an unbiased a view based on realistic industry knowledge, in the pursuit of a document that would bear close scrutiny and form the basis for further development of the green roof cause. The breadth of the original team involved and the scope of research for this document, coupled with periodic peer review, has ensured that the ideas put forward by this publication have come from a background of strong consensus within the construction and environmental industries, making take up of the messages a reality and the continued change to our building landscape a certainty.

The recognition and support for the installation of living roofs, from both ecological experts and the general construction design arena alike, is brought together in this publication. Its proposals will undoubtedly help to reinforce the sustainable construction message by highlighting the importance for due consideration of a green roof on any building, where feasible, as a viable alternative to more traditional forms of construction. In the longer term this will ultimately aid London and the wider UK community in recognising the need for more living roofs in urban landscapes, and help to provide the benefits already enjoyed in many cities across Europe.

Robert Littlewood
Managing Director,
Alumasc Exterior Building Products Ltd

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EXTERIOR BUILDING PRODUCTS

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Jubilee School, Tulse Hill
Photo: AHMM Architects

Executive Summary

London will experience increasing risks of flooding, overheating and drought, through hotter drier summers and warmer wetter winters.

Living roofs and walls – green roofs, roof terraces and roof gardens – are key to providing living space, adapting the city to the more extreme climatic conditions and reducing energy use and CO_2 emissions.

Living roofs have the potential to improve London's resilience to the impacts of climate change by reducing storm water run-off velocity and volumes, and by increasing the cooling effect during London's hotter summers. They also bring many other wider environmental benefits.

To date, insufficient policy support for living roofs and walls in London has been one of the barriers to their wider adoption.

Living roofs is a broad term defined by the GLA to include green roofs, roof terraces and roof gardens. The term includes roofs and structures that may be accessible by workers or residents, and that may be intensively or extensively vegetated. Living roofs comprise two main types – green roofs and recreational roofs.

- Green roofs range from intensively vegetated (intensive) to extensively vegetated (extensive).
- Recreational living roofs provide amenity benefit.

Intensive green roofs are those made up of lush vegetation and based on a relatively nutrient rich and deep substrate. They are principally designed to provide amenity and are normally accessible for recreational use. They may be referred to as roof gardens or terraces. Extensive green roofs normally have a shallow growing medium and are designed to be relatively self-sustaining. Between intensive and extensive is a range of intermediate treatments that are typically referred to as semi or simple-intensive.

There are already many examples of living roofs in London including at Canary Wharf, Bishops Square, the Laban Centre, Deptford and Offord Street, Islington.

The principal benefits of living roofs to London are:

1. Helping London to adapt to climate change – Living roofs will help improve London's resilience to future climate impacts. Predicted climate change will mean that London will experience increasing risks of flooding, overheating and drought, manifested through hotter drier summers and warmer wetter winters. In general, climate change is likely to increase the severity, frequency and duration of certain weather patterns and extreme events. Living roofs are a mechanism for reducing the negative effects of climate change and greatly improving many of London's sustainability objectives.

2. Improving building energy balance and reducing CO_2 emissions – Estimates suggest that the adoption of living roof technology throughout the capital could result in a reduction of thousands of tonnes of carbon dioxide (CO_2) emissions. The use of vegetation on a roof surface ameliorates the negative thermal effects of conventional roofing surfaces through the cooling effect of evapotranspiration. It can also provide benefit in the form of insulation, and therefore a reduction in energy use and CO_2 emissions.

3. Reducing Urban Heat Island Effect – All urban areas experience an Urban Heat Island Effect (UHIE): this is the increased temperature of a built-up area compared to its rural surroundings. A modelling scenario undertaken in New York by the New York Heat Island Initiative determined that providing 50 per cent green roof cover within the metropolitan area would lead to an average 0.1-0.8°C reduction in surface temperatures. It noted that for every degree reduction in the UHIE roughly 495 million KWh of energy would be saved. There is no reason to doubt that comparable reductions could be achieved in London.

4. Enhancing amenity value – Accessible roof space provides necessary outdoor living space in London. This will become particularly important as planning policies start to drive a more compact and denser urban form with proportionally less space for immediate gardens. As such, accessible roof space can be viewed as an integral element of a well-designed, high quality, high density, more efficient, attractive and liveable city.

5. Conserving and improving biodiversity – The biodiversity benefits of green roofs to London are manifold. The greening of a roof can support rare and interesting types of plant, which in turn can host or provide suitable habitat for a variety of rare and interesting invertebrates. London Biodiversity Action Plan species, such as the black redstart or house sparrow, can benefit from the creation of roof top habitat.

6. Improving storm water attenuation – Green roofs can form part of an effective sustainable drainage (SUDS) solution by reducing the amounts of storm water run-off and attenuating peak flow rates. Consequently this proven source control technique reduces the downstream need for expensive underground drainage infrastructure and also cuts the risk of localised flooding events. In the summer a green roof can typically retain between 70-80 per cent of rainfall run-off.

Perceived barriers to the implementation of living roofs in London include:
- lack of a national and local policy framework that encourages the installation of living roofs and walls
- lack of a common standard for living roofs
- fire hazard
- maintenance
- cost
- structural issues
- leakage and damage to waterproofing
- lack of expertise and skills.

However, these are largely misleading. In some cases the opposite is true in that living roofs can actually be beneficial rather than being a problem, for example, in respect to fire hazard.

Living walls are those covered in some form of vegetation. Generally they are made up of climbing plants and are constructed so as to provide for vegetation actually planted into the structure of the wall itself or some form of additional structure attached to the wall on which climbing plants are supported. They offer environmental benefits by enhancing biodiversity, improving the thermal insulation and cooling properties of the building, can help improve air quality, improving noise attenuation properties and improving visual amenity. High quality designs for 'green walls' incorporating vegetation over a majority of a building's vertical surfaces should be considered where living roofs are difficult to achieve.

The implementation of living roofs and walls is taking place in major cities throughout the world. For at least twelve of these cities, policy drivers and/or financial incentives are why living roofs and walls are being implemented so vigorously.

An earlier draft of this report, 'Research in support of an amendment to the Further Alterations to the London Plan with regard to a policy on Living Roofs and Walls' was submitted to the Further Alterations to the London Plan Examination in Public to provide the evidence base for a future policy on living roofs. The Examination in Public Panel report recommended the adoption of a living roofs policy. The policy is worded as follows:

Policy Living Roofs and Walls
The Mayor will and boroughs should expect major developments to incorporate living roofs and walls where feasible and reflect this principle in LDF policies. It is expected that this will include roof and wall planting that delivers as many of these objectives as possible:
- *accessible roof space*
- *adapting to and mitigating climate change*
- *sustainable urban drainage*
- *enhancing biodiversity*
- *improved appearance.*

Boroughs should also encourage the use of living roofs in smaller developments and extensions where the opportunity arises.

Living roofs can take differing forms in order to maximise their benefits in a given location. Vegetated roofs, including terraces and gardens, can improve the thermal performance of the building, reduce the Urban Heat Island Effect, absorb rainfall to reduce flash flooding, enhance biodiversity, provide amenity for residents who may not have access to private gardens and improve appearance.

The research findings and proposals contained in this document supported the development of a more supportive policy position for living roofs in London as part of the Further Alterations to the London Plan. They also serves to inform the forthcoming revision to the Sustainable Design and Construction Supplementary Planning (SPG) to the London Plan.

Musée du quai Branly
Photo: Gary Grant

Introduction

London faces many environmental challenges, not least of which is the predicted change in its climate. The GLA recognises that a variety of methods will be needed to tackle climate change and its consequences, and that living roofs and walls can play a significant role in this.

Living roofs and walls can enhance biodiversity, reduce the risk of flooding (by absorbing rainfall), improve a building's thermal performance, thus reducing associated energy costs, help counter the Urban Heat Island Effect, support higher density more sustainable development and improve the appearance of the city.

However, despite these potential benefits, take up in London has been a lot slower than in other European and American cities.

A lack of positive policy support, concerns over development costs and a lack of technical standards have all been cited as possible reasons.

As part of the requirement to keep the London Plan up to date, the Mayor has reviewed the strategy of the plan and concluded that its direction holds. However, commitments were made to give more emphasis to the issue of climate change including sustainable design and construction and carbon dioxide emissions.

The Mayor's Chief Advisor on Architecture and Urbanism, Richard Rogers, has stated that a requirement for living roofs to be part of all major development would deliver a step change in the battle against climate change and the delivery of a more liveable city. It is understood from other cities that many of the obstacles to living roofs are overcome when new policy drives demand and the subsequent growth of new markets. Furthermore, there are a limited number of existing referable schemes that are already providing living roofs; it is important to reinforce and systematise this trend with thorough planning policy and preferred standards.

This report clarifies the various types of living roofs and the environmental and social advantages each type can deliver. It goes on to address the specific benefits of living roofs and some of the perceived barriers to their take up.

The development of a more positive policy framework for living roofs and walls will enable London to balance its forecast growth in population and development with the environmental challenges ahead, in order to deliver a compact, resilient and liveable city that sets a new agenda for cities worldwide.

New Providence Wharf
Photo: Alumasc

1. Typology

Living roofs is a broad term defined by the GLA and design for London to include green roofs, roof terraces and roof gardens. It includes roofs and structures that may be accessible by workers or residents, and that may be intensively or extensively vegetated. None of these terms are mutually exclusive, although particular types of roof treatment may be more appropriate for certain kinds of use as shown in Table 1 on page 15.

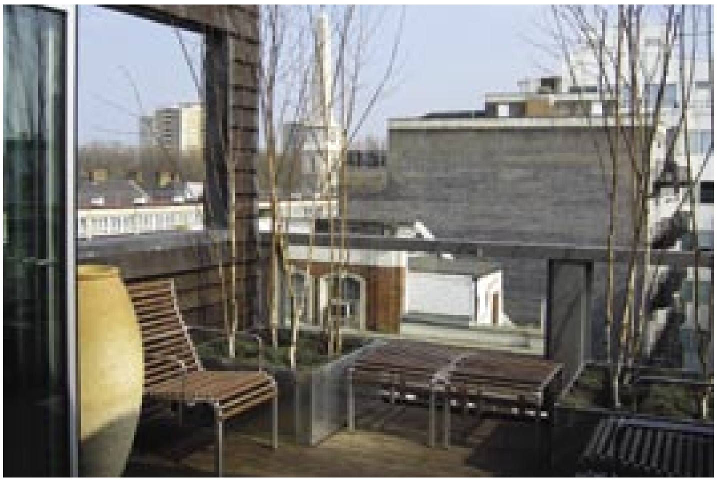
A typology has been adopted, largely based on living roof construction and use, and to reflect the benefits to individuals and society as a whole. This typology refers to intensive and extensive green roofs, and recreation roofs.

Jubilee Park, Canary Wharf. Photo: © G Kadas

Jubilee Park

Intensive Green Roofs
Intensive green roofs are principally designed to provide amenity and are normally accessible for recreational use. They may be referred to as roof gardens or terraces.

Generally intensive green roofs comprise a lush growth of vegetation and are based on a relatively nutrient rich and deep substrate. They allow for the establishment of large plants and conventional lawns. Intensive roofs traditionally require higher levels of maintenance, regular irrigation and applications of fertiliser. Due to the plants used, and the combined growing and drainage properties of the substrate, the weight of the intensive green roof system can be considerable. Substantial reinforcement of an existing roof structure or inclusion of extra building structural support may be required.



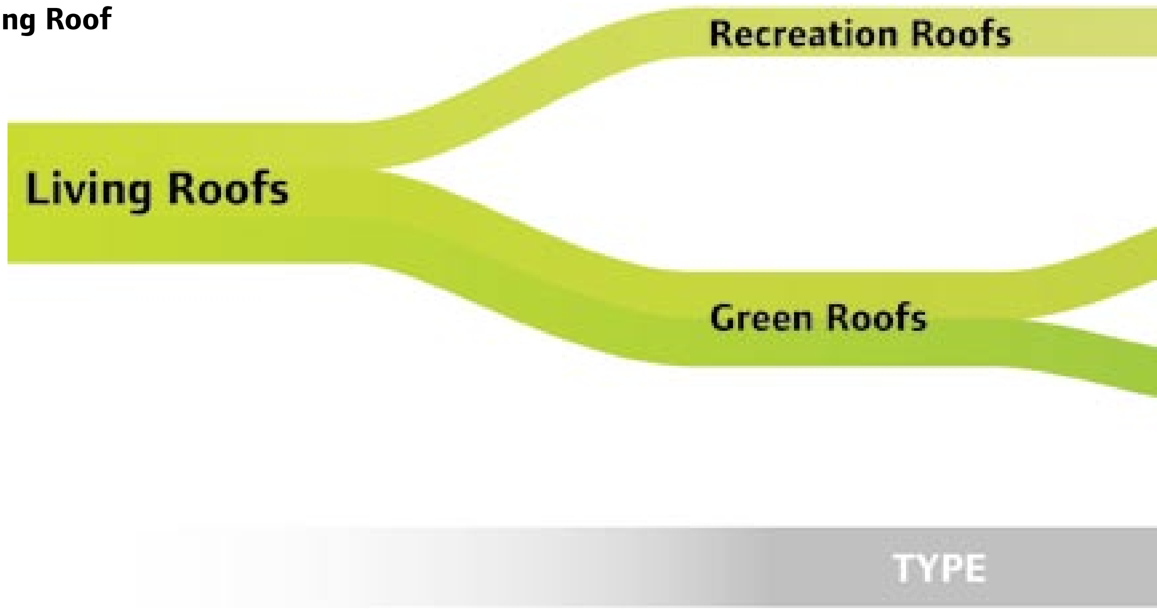
Golden Lane, USE Architects

Cannon Street Station

Examples of such roofs in London include the roof garden at Barkers of Kensington, the roof garden above Cannon Street Station and the roof treatment to the tube station at Canary Wharf (see above).

Extensive Green Roofs
Extensive green roofs generally provide greater biodiversity interest than intensive roofs, but are considered to be less appropriate in providing amenity and recreation benefits. In most cases they are planted with, or colonised by, mosses, succulents, wild flowers and grasses that are able to survive on the shallow low-nutrient substrates that form their growing medium. They receive minimal management and usually no irrigation or fertilisation although it may be required initially until plants become established. They are usually

Figure 1. Relationship and Potential Use of Various Types of Living Roof



cheaper to install than intensive green roofs and are less costly to maintain. In the UK there are two types of extensive green roofs:

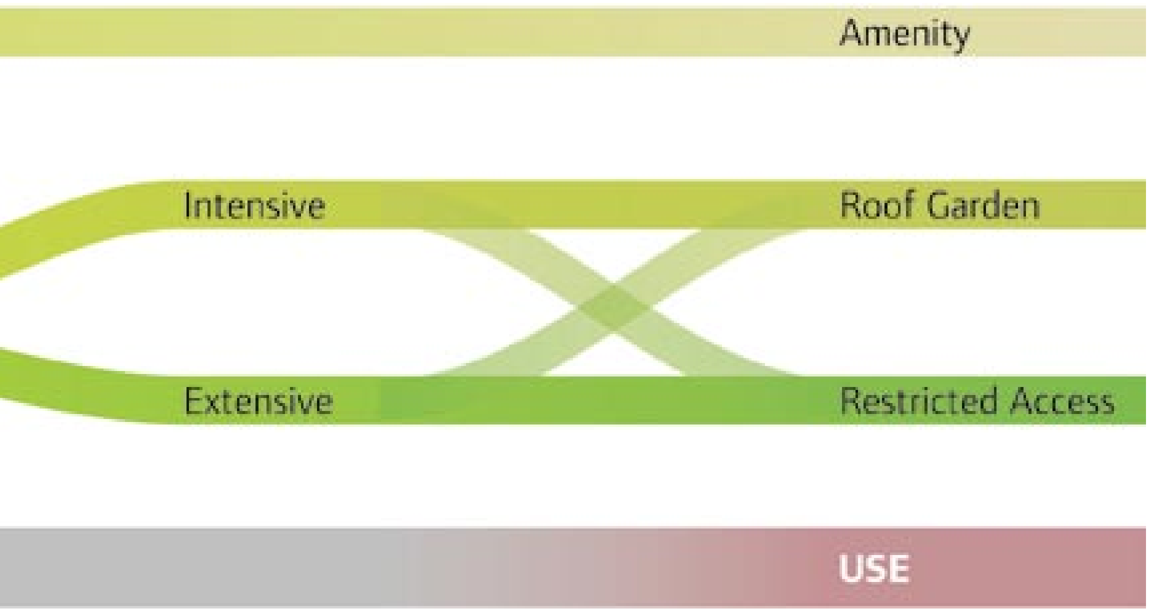
- **mat based systems** – have very shallow soils, typically between 20-40mm, are pre-grown to provide 100 per cent instant cover and generally consist of Sedum species. However, a number of suppliers are now pre-seeding their mats with a wider selection of hardy plants. The shallow substrates of mat based systems retain less rainfall and have less thermal mass. They are also restricted in the advantages they deliver for biodiversity
- **substrate based systems** – are generally between 75mm and 150mm in depth, consisting of either a porous substrate or similar reused aggregates. In the UK such systems are generally planted with a variety of Sedum species, whether as plugs, cuttings or seeded, although on continental Europe it is more common to use species of wildflowers that are typical of dry meadow habitats. As substrate based systems are deeper than those that are mat based, they have potential to support a greater variety of species, hold significantly more rainfall, have a greater thermal mass and have greater evapotranspiration properties. A potential disadvantage is that they are heavier than mat based systems and take time to establish full vegetation cover, should that be required.

Extensive green roofs are less likely to provide amenity space for the public/residents, but are suitable for higher-level roofs in new developments and for retrofitting onto existing buildings. Currently in the UK most existing buildings are only able to use a lightweight sedum blanket type system because of structural considerations. However, where existing roofs are covered in gravel, shingle or paving slabs, wild flower plug or hydro seeded systems could be implemented by replacing the existing covering above the waterproofing with a substrate-based system. In Germany substrate based systems are now available with a load bearing of only 60kg/m^2.

On new build schemes where additional structural loading can be taken into account during the design and construction process, substrate systems (which can comprise recycled materials) are preferred because of the greater environmental benefits they bring.

Extensive Roofs don't have to be restricted access Canary Wharf – sedum plug roof. Photo: Livingroofs.org

Between intensive and extensive is a spectrum of intermediate treatments that are typically referred to as semi or simple-intensive.




Sedum Roof, Lille Road. Photo: Mathew Frith


Springbok Works, Hackney. Photo: Jon Buck

Recreation Roofs
Recreation Roofs are designed specifically for recreation, although the inclusion of vegetation in planters (such as on terraces or balconies) is often used to enhance their visual attractiveness. Recreation roofs are those that have no substrate and no intentionally vegetated part to their construction. Because of this they have limited SUDS (sustainable urban drainage systems) or climate change adaptation benefit, (except cool roofs – see below) and no biodiversity value.

Recreation roofs, where there is adequate space available, are well suited for sports such as ball games.

Examples of recreation roofs in London can be found at Hanover school Islington and at Springbok Works, Hackney.


5-a-side soccer centre on car park roof, Star City, Birmingham. Photo: © Goals Soccer Centres

These living roof types, and all the other variants in between, can bring a variety of environmental benefits including climate change adaptation, enhanced building energy balance, Urban Heat Island Effect, biodiversity, sustainable drainage, and amenity. These are illustrated in Figure 1 above and Table 1 page 15.

Cool Roofs

One further roof type that it is useful to define is the cool roof, although these are not considered in any detail beyond this point. Cool roofs are a form of roof where the materials used are deliberately selected for their high solar reflectance (albedo) and high thermal emittance. They absorb, and consequently store, less solar energy during the day and thus are not major emitters of heat into the urban atmosphere at night. Cool roofs reach temperatures considerably lower than their low reflectance counterparts. They can extend the lifetime of roof materials by damping the daily temperature range and thus reducing excessive contraction and expansion, and by reducing the absorption of damaging ultraviolet. To ensure the effectiveness of cool roofs their reflectivity must be maintained as it declines with age, and they need to be kept clean as dirt and pollution lower reflectivity.

Living Walls

Living walls are those covered in some form of vegetation. Generally they are comprised of climbing plants of one kind or another, and are designed so as to support such vegetation. More radically, living walls are now being constructed that provide an additional structure into which vegetation can actually be planted. Depending on the species used living walls can provide environmental benefit in the form of biodiversity, thermal insulation and cooling benefit to the building, and noise attenuation.

Musée du quai Branly, Paris. Photo: Gary Grant

The Potential Contribution of Living Roofs and Walls to London

Living roofs of all types can be found throughout London, and have been noted in the city since at least the early 20th century [Ref:3.1]. The GLA have collected a number of recent case studies including examples at: Springbok Works, Dalston; New Providence Wharf, Docklands; Bishops Square, Spitalfields; Jubilee Gardens, Canary Wharf; Clearwater Yard, Camden; Ethelred Estate, Lambeth; Laban Dance Centre, Deptford and One SE8, Deals Gateway also in Deptford. [Ref: 3.2] (See also Appendix 2 Case Study Matrix).

Existing and new developments offer an opportunity to dramatically increase the amount of living roof and wall space throughout London and by so doing deliver substantial social and environmental benefits. Clearly, there is an interest and a commitment to include living roofs in new development as the case studies included in this report detail. With additional policy support the number of installations and retrofits, and the necessary skills to provide them, are bound to increase significantly.

The environmental and economic benefit to London of living roofs and walls is hard to ignore. Consider the potential impact on the city's energy budget: the GLA estimate that buildings cover 24,000 hectares or 16 per cent of Greater London [Ref: 3.3]. Crude calculations of the potential for green roofs in four areas of central London (see section 2.7) suggest that a surface area of 10 million m^2, 3.2 million m^2 had the potential to be greened. This would give a potential energy saving of 19,200 MWh per year or the equivalent of 8,256 CO_2 e tonnes, and a capacity to store in the region of 80,000m^3 of rainwater at roof level, the equivalent to, approximately, the volume of water needed for 35 Olympic swimming pools.

Accessible roof space can provide much needed amenity and visual quality as part of the increasingly dense urban form of London. By supporting a more compact city, living roofs can support the use of less land, a smaller building envelope, lower volume of materials, reduced energy consumption and lower construction costs. They can also help reduce energy requirements. For example in H.R.Presig et al., Okolgische Baukompetenz, Zurich 1999, research demonstrated that a block of eight flats consumed 68 per cent of the energy consumed by eight separate and dispersed houses of comparable volume.

There are many variables that could change these figures one-way or another but there is no doubt that the contribution of living roofs (to say nothing of the contribution of living walls or even a combined approach) in this respect would be overwhelmingly positive and substantial.

This report collates the evidence of the benefits of living roofs and walls and suggests the case for additional policy support is compelling.

Paradise Park DSDHA Architects
and Marie Clarke Studio
Photo: Edmund Sumner

Amsterdam Museum Park
Photo: ANP

2. Benefits of Living Roofs and Walls

Introduction

Using the typology described above living roofs separate into two main categories:

- green roofs
- recreation roofs.

Of these two categories, green roofs provide the most substantial environmental benefit and recreation roofs provide the highest social benefit. Recreation roofs are used mainly for amenity and recreation and in particular, have great potential for sports use where hard courts are required. However, if they are supplemented with vegetation or surfaced with highly reflective materials they can have additional environmental benefits.

The principal environmental benefits of green roofs are:

- helping London adapt to climate change
- improving building energy balance
- reducing Urban Heat Island Effect
- improving storm water attenuation
- conserving and enhancing biodiversity
- enhancing amenity value.

These are dealt with in greater detail below. Table 1

Other potential and related benefits include:

i) greenhouse gas reduction – indirectly through reduced energy demand
ii) amenity space – roof gardens, etc
iii) aesthetic – softening, greening and enhancing the cityscape
iv) well-being – restoring the link between humans and nature
v) cost – extending the life of the roof membrane and reducing energy costs of the building
vi) enhanced rental values – for buildings of superior image and amenity
vii) fire resistance – green roofs provide a fire-resistant top-layer
viii) noise attenuation – on airport flight paths, etc
ix) electro-magnetic insulation – on buildings under or near high voltage electricity transmission lines
x) food production – roof allotments
xi) Support for more compact urban form and related resource efficiency.

2.1 Benefits for Climate Change Adaptation

Predicted climate change will mean that London will experience increasing risks of flooding, overheating and drought, manifested through hotter drier summers and warmer wetter winters. Climate change will increase the seasonality of rainfall and water availability, and the number and frequency of hot days. In general, climate change is likely to increase the severity, frequency and duration of certain weather patterns and extreme events. Living roofs are a mechanism for reducing the negative effects of climate change and greatly improving many of London's sustainability objectives.

Rainfall and Water Availability

London already faces limited water resources, and climate change is likely to significantly decrease the amount of water available to London during the summer when demand is highest.

Future rainfall is expected to become more seasonal, with more rainfall falling in winter (up to 30 per cent more by 2080s) and less in summer (up to 50 per cent less by 2080s). Although the annual average volume of precipitation is not expected to decrease, it will fall less evenly throughout the year than currently experienced, with a greater proportion falling in intense downpour events.

Table 1: Matrix of Roof Type vs. Potential Environmental Benefit

Roof Type	Potential Benefit: Climate Change	Building Energy Balance	UHIE	SUDS	Biodiversity	Amenity
Intensive	✓✓	✓✓	✓✓✓	✓✓✓	✓	✓✓✓ (visual)
Extensive – mat-based <40mm	✓	✓	✓	✓	✓	✓ (visual)
Extensive – substrate-based >75mm	✓✓	✓✓	✓✓	✓✓	✓✓✓	✓ (visual)
Recreation	✓ *	✓ *	-	-	-	✓✓✓ (sports/play)

* These advantages are only realised on recreation roofs if vegetation, introduced in the form of planters and cool roof technology, are also utilised.

The pressures on water resources will be further increased due to London's population growth, with forecasts showing an increase from 7.3 million in 2001 to around 8.2 million by 2021.

Living roofs have the potential to mitigate the effects of runoff and storm water events, thus reducing the negative downstream impacts on drainage infrastructure. These benefits are of course enhanced by designing living roofs without the need for irrigation.

Flood Risk

Climate change will see a predicted increase in winter rainfall and extreme rainfall events. Due to the large areas of impermeable and hard surface development, plus the limited capacity of London's storm drains and combined sewer system, the consequence of more intense rainfall will be an increase in surface and sewer flooding.

At the same time, the consequence of flooding will also increase as the amount and value of development in flood risk areas continues to grow. The government has recognised the importance of taking an integrated approach to storm water management through 'Making Space for Water 2004' [Ref:3.4]. Living roofs are a proven source control technique and as such can make a positive contribution to the increased risk of flooding in London caused by our changing climate.

Temperatures

London has already experienced episodes of significantly high temperatures that have affected the capital's health, economy and environment. Climate change will cause average summer temperatures to rise to a point where our current extreme events will be average summer temperatures by the middle of the century, and heat waves will be even hotter. Summer temperatures for the South East are predicted to be up to 3.5°C warmer by the 2050s and up to 5°C warmer by the 2080s (United Kingdom Climate Impacts Programme 2002, UKCIP02).

All urban areas experience an Urban Heat Island Effect (UHIE): this is the increased temperature of a built-up area compared to its rural surroundings. The centre of London can experience temperatures up to 9°C higher than the surrounding greenbelt and climate change is likely to increase the frequency and duration of these effects. [Ref: 3.5]

The 'Green Roof Effect'

Conventional roofing surfaces, hence referred to as 'warm-roofs', absorb sunlight and heat-up quickly. The absorption of radiation and the release of the radiation back to the atmosphere during the night is a major factor in UHIE. Where a building has poor insulation and poor ventilation this can lead to increased use of air conditioning and therefore increased energy use (thus green roofs make an indirect contribution to climate change mitigation, as well as adaptation. [Ref 3.1])

The performance of green roofs can benefit both the buildings on which they are installed and the wider environment. Both are interrelated as outlined below. Energy use within a building may exacerbate the effect of the UHIE. Conversely a positive reduction in the UHIE is likely to lead to a reduction in the need for energy for summer cooling within a building. The details of these benefits are described in sections 2.2 and 2.3.

Energy balance and UHIE reduction are likely to become increasingly important considerations for building professionals within the capital. Elsewhere in the world, in North America and the Far East, green roofs are being considered as an important element in how cities can cope with the UHIE and reduce energy demand within buildings. Over the last few years the implications of climate change are becoming more pressing and, as is the case elsewhere in the world, green roofs are likely to be an integral element of building design in the future for both policy makers and businesses as they develop strategies to adapt to climate change.

2.2 Energy Balance and CO_2 Reduction

Green roofs have a substantial thermal mass and a moderate insulation value. These combined properties significantly reduce diurnal temperatures at the boundary between green roof and building structure (the diurnal temperature being the daily maximum to minimum temperature range).

The diurnal temperature range for a conventional construction 'warm-roof' waterproof layer can be very large; for example, the surface of a typical bitumen waterproof layer may exceed 50°C during a sunny summer's day, whilst falling to just above 0°C at night. A roof with a low level of insulation below the waterproof layer will allow the space below to heat up quickly in hot, sunny weather. The increased internal temperatures in the floor below the roof contribute to making the internal building environment uncomfortable for the building's occupants. Overheating can lead to increased use of air-conditioning, which in turn will lead to an increase in energy consumption. During cold weather, the opposite effect applies, resulting in a demand for extra heating of the floor directly below the roof and, hence increased energy consumption. The energy used for heating and cooling has a financial as well as an environmental impact.

The green roof has the same energy providers as a conventional roof, but it has the additional energy consumers of evapotranspiration and photosynthesis. Unlike a conventional roof, the green roof is a living system that reacts to the environment in a number of important ways:

- water is stored within the substrate and is used in evapotranspiration by the vegetation layer; this process utilises a considerable proportion of the incoming solar radiation in comparison to a non-green roof

- the green roof has a large thermal mass, which stores energy and delays the transfer of heat to or from the building fabric
- plants absorb solar radiation for photosynthesis
- plants have a higher albedo (solar radiation reflectivity) than many standard roof surfaces.

The use of a green roof compared to conventional surfaces can have a significant impact on the energy balance within a given building and on the immediate environment surrounding the building. This is particularly relevant if a building has poor insulation and poor ventilation, which can lead to more use of air conditioning and therefore increased energy use. [Ref: 3.1]

Studies have shown that the membrane temperature beneath a green roof can be significantly lower than where the membrane is exposed. Table 2 shows the average temperatures under the membrane of a conventional roof and that of membrane under green roofs in a study undertaken at Nottingham Trent University.

Table 2: Study of Temperatures Under Membranes of a Conventional and a Green Roof
(www.greenroofs.co.uk)

	Winter	**Summer**
Mean Temperature	0°C	18.4°C
Temperature under membrane of conventional roof	0.2°C	32°C
Temperature under membrane of green roof	4.7°C	17.1°C

Another study in Ottawa, Canada, by the National Research Council of Canada noted that temperature variations during spring and summer on a conventional roof were of the order of 45°C whilst under a green roof the fluctuations were in the order of 6°C. [Ref: 3.6]

This comparative analysis demonstrated that the green roof not only protected the membrane from the effects of UV, frost and sunlight, but also moderated the heat flow through a building by shading, insulation, evapotranspiration and thermal mass.

Although green roofs do provide potential energy savings by improving building insulation characteristics, these are often considered difficult to assess due to the varying climatic conditions throughout the winter months, and will be minimal on already well-insulated buildings. Studies in Germany have provided various approximates. Figures attributed to ZinCo estimate that 2 litres of fuel oil are saved per m^2 of green roof per year. A more recent study of domestic buildings with flat roofs suggests that there is a 3-10 per cent winter saving on fuel bills. The results of the study suggest that there is a maximum saving of 6.8kWh/m^2 [1.5kg/m^2 CO_2 e tonnes] and a minimum saving of 2.0kWh/m^2 [0.44kg/m^2 CO_2 e tonnes]. This study did not consider any summer savings due to cooling. [Ref: 3.3]

This correlates with the Ottawa study referred to above, which compared a conventional roof system with a green roof system. [Ref: 3.6]

'The average daily energy demand for space conditioning caused by the reference roof system was 20,500 BTU to 25,600 BTU (6 kWh to 8 kWh). However, the green roof system's growing medium and plants modified the heat flow and reduced the average daily energy demand to less than 5,100 BTU (2 kWh) – a reduction of more than 75 per cent.'

Sedum/Herb Roof Berlin. Photo: Livingroofs.org

A study in Toronto [Ref: 3.7] estimated that the direct energy savings citywide, through reduced energy for cooling as a consequence of whole scale greening, would be in the order of $22 million, equivalent to 4.15kWh/m^2 per year [CO_2 emission saving of 1.7kg/m^2. The study also concluded that there would be a reduction in peak demand in the order of 114.6MW leading to fossil fuel reductions in the region of 56,300 metric tonnes per year.

An energy study undertaken by the City of Chicago estimated that, with whole scale greening of the cities rooftops, energy to the value of $100M could be saved each year due to the reduced demand for air conditioning. This would equate to a reduction in peak demand in the order of 720MW. [Ref: 3.8]

Studies by Environment Canada have shown that energy savings can be calculated for a building using a complex formula. In essence this was achieved by undertaking energy calculations for those parts of a building envelope that is 'greened' and comparing them with those parts that are not. Reference buildings modelled on this basis suggest that the upper floor of a building with a green roof is likely to save 25 per cent of that floor's energy demand through reduction in cooling needs.
(Pers.comm. Dr. Brad Bass Environment Canada)

A 1999 study undertaken by the city of Chicago estimated that the greening of all of the city's roofs would save $100 million worth of energy each year, especially due to a reduction in the need for air conditioning costs – the equivalent energy consumption of several coal-fired generating stations or one small nuclear power plant. [Ref: 3.9]

Information for a building in Canary Wharf in London, suggests that an 850m^2 retrofitted green roof has achieved an estimated reduction of 25,920kWh [11.46 CO_2 e tonnes] a year through a reduction in heating and cooling of the spaces below the roof. The green roof was estimated to be saving up to £4,000-£5,000 per year in electricity. [pers.comm. Tony Partington Canary Wharf Co.]
1 e tonnes = emission tonnes

Paradise Park Children's Centre:
The building has been built with a green roof over the habitable area principally for biodiversity, over the habitable area. This has provided a small increase in the thermal insulation properties of the roof. Of greater benefit than reducing heat loss, however, has been the increased thermal inertia of the roof due to its mass. This thermal mass delays the flow of heat into the building when there is a heat gain due to a high sun altitude. The depth of the brown roof is approximately 150mm and its thermal mass slows the transfer of heat through the roof by about one hour for every 25mm of dense material. Thus with a depth of 150mm of high mass material the solar gain through the roof during the summer is slowed by up to six hours. The highest gain through a flat roof in the summer is at noon, the maximum flow of heat through the roof is therefore during early evening. As the building normally closes at 5pm the occupants will no longer be overheated in the building, so obviating the need for air-conditioning.

The heat gain for the building is approx 28kW and the electrical energy that would be used during the period of heat gain would be about 9.4kW per hour. If air-conditioning were used over a summer period the approximate energy use would be 3,800kW/hrs, the equivalent of about 1.6 CO_2 e tonnes per annum.

The green wall exterior also has a dramatic effect on solar gain as it provides shading to the walls. They also provide more mass, more insulation, and the fact that they are irrigated leads to more evaporative cooling.

Richard Pearce Building Services Engineer – Paradise Park Children's Centre

Paradise Park. Photo: Edmund Sumner

2.3 Urban Heat Island Effect and Indirect Energy Savings

'Summers by 2050 will be 1.5-3.5°C hotter...in central London the urban heat island currently adds 5-6°C to summer night time temperatures and will intensify in the future. [Ref: 3.10]

Urban areas can have a higher average temperature than surrounding rural areas; this difference in temperatures is called the UHIE and is caused by the reduction in green space through urbanisation and the large amount of hard surfaces that provide high thermal mass. The dark surfaces of roofs exacerbate the UHIE by absorbing summer heat and radiating it back to the atmosphere during the night. As summer temperatures rise due to climate change and more intense UHIE episodes are experienced, demand for air-conditioning will increase, increasing the energy demand. Heatwave periods often coincide with poor air quality episodes and intense urban heat island episodes which collectively exacerbate health problems, especially in the old, young and vulnerable.

The evaporation and evapotranspiration from a green roof cools the air. Furthermore by providing a cooler surface at roof level the green roof and better thermal insulation reduces the need for air conditioning during periods of higher than normal temperatures. The combined effect is to reduce the UHIE.

One study [Ref:3.11] concludes that 'Sustainable Urban Futures' demand the use of vegetation, with the greatest benefit to be had when both green roofs and green walls are utilised, enveloping the whole building fabric in vegetation. Such an approach could lead to an 84 per cent reduction in cooling demands.

A further study considers the appropriateness of using green roofs and green walls as a mitigation technique in various European cities. The report concludes that:

'For all climates examined, green walls have a stronger effect than green roofs... Nonetheless, green roofs have a greater effect at roof level and, consequently, at the

urban scale...if applied to the whole city scale, they could mitigate raised urban temperatures, which can lead to significant energy savings, more "human friendly" urban spaces, ensuring a viable future, from a thermal point of view, for urban dwellers.' [Ref: 3.12]

A modelling scenario undertaken in New York by the New York Heat Island Initiative determined that providing 50 per cent green roof cover within the metropolitan area would lead to an average 0.1-0.8°C reduction in surface temperatures. It noted that for every degree reduction in the UHIE roughly 495 million kWh of energy would be saved. The same study also looked at various mitigation strategies other than green roofs, including urban forestry and cool roofs, and noted that green roofs provided greater benefits than white or 'cool roofs'. It was clear from the study that a combination of various mitigation strategies for UHIE, including green roofs, should be considered by the city. [Ref: 3.13]

A study in Toronto estimated that the city comprised 50 million m^2 of potential roof space that could be greened. Overall it was estimated that the effect of greening the rooftops would lead to 0.5-2°C decrease in the UHIE. The study estimated that a reduction of this magnitude would lead to indirect energy savings citywide from reduced energy for cooling of $12 million, equivalent to 2.37 kWh/m^2 per year and that this would reduce peak demand at a rate of 0.0023 kWh/m^2. [Ref: 3.7]

As a result of this work the city of Toronto has developed a green roof policy in order to encourage green roof uptake within the city. [Ref: 3.7]. [See Appendix 1]

The US city of Chicago has been promoting green roofs at a city level for a number of years. A study undertaken on a hot summer's day in 2001 noted that the temperature on a conventional roof was 28°C higher than that on a green roof. Chicago has a number of policy initiatives to encourage and provide incentives for the use of green roofs specifically as a means of mitigating against the negative impacts of UHIE. [Ref: 3.8] [See Appendix 3]

Green Roof, Chicago City Hall One of first to be installed in programme to reduce UHIE. Photo: Mathew Frith

In Japan, many cities suffer from the severe effects of the UHIE. The average annual temperature in Tokyo has increased by 3°C in the last century. This is four times higher than what could be explained by to the effects of global warming. [Ref: 3.14]

'The Tokyo based Organisation for Landscape and Urban Greenery Technology Development estimates that if half of the roofs in the city were planted with gardens, daytime temperatures in summer would fall by 0.84°C, which would save 110 million Yen on air conditioning costs.' [Ref: 3.15]

The city has introduced policies that require green roofs to be installed on 20 per cent of all new flat surfaces on government buildings and 10 per cent of all flat roofs on private dwellings. [Ref: 3.1] [See Appendix 1]

Green Roofs and Photovoltaic Solar Panels

There is a perception that a building can either have green roofs or solar production at roof level but not both. However, it is possible to take a more pluralistic approach and use both technologies in tandem. In fact there is substantial evidence from Germany that the use of both solar/photovoltaics and green roofs provides dual benefits in terms of energy production and energy saved.

Solar/Photovoltaic (PV) A-Frame panels at roof level are known to work more efficiently when installed on a green roof rather than a on a conventional surface. The green roof element not only saves energy during the summer time (see above) but can also increase efficiency of PV by reducing fluctuation of temperatures at roof level and by maintaining a more efficient microclimate around the PV Panels. Crystalline silicon photovoltaic panels, as a rule of thumb, lose 0.5 per cent/°C in efficiency above 25°C. The green roof serves as a natural cooling mechanism, thereby maintaining the panels' efficiency. [Ref 3.16]

Photovoltaics and Green Roofs, Switzerland. Photo: Livingroofs.org

By reducing the temperatures around the PV and by helping reduce the need for air conditioning in spaces beneath the green roof, the combination of the technologies should be as one of positive interaction and not one of competition in terms of use of roof space. [Ref: 3.17]

Largest A Frame PV Roof in Europe on a green roof, Switzerland. Photo: Livingroofs.org

The evidence outlined above demonstrates that there are substantial benefits to installing green roofs in regard to energy related issues. Although the focus may be on new developments there is a great deal of potential to realise green roofs on many existing buildings in Central London, with little or no structural alteration. The central core of London, if greened, would deliver real and tangible mitigation to the effects of a likely increase in the UHIE and reduce energy demand within the buildings themselves.

The provision of green roofs on existing and new buildings will provide, at a 'micro level', a reduction in energy used within a building through a reduction in the need for air conditioning, and to a certain extent winter fuel, and at the 'macro level' a reduction in the effect of the UHIE. These two elements are interconnected. The more energy used increases UHIE, a reduction in UHIE leads to less energy being consumed. Ensuring that buildings perform better in terms of their energy load will lead to 'better' buildings but also better environments at both the building scale for people, through the provision of parks, terraces and areas of wild space and a city level through an improved city climate.

2.4 Amenity

Architects, environmentalists, planners and developers are rapidly concluding that a sustainable future for our cities has to include increased population densities and a move away from the detached house set in its own grounds to the 'compact city'.

Such a model provides environmental benefits at many levels – energy conservation, water management, transport etc. With the increasing density of new developments there is proportionally less green space at ground level to the number of residents. The current levels of accessible green space/recreational space, and associated wider benefits, soil permeability and biodiversity are not necessarily maintained.

However this imbalance can be redressed through the provision of integrated accessible roof space. As such they should be a prerequisite of higher density development.

Observations from one green roof in Portland, Oregon noted a number of activities going on such as dog walking, clothes drying, cooking, eating and drinking, and even the setting off of fireworks [Ref. 3.38]. Golf courses, football pitches and even farms have been implemented at roof level in other parts of the world.

Roofs provide a valuable amenity benefit; the Springbok Works in Dalston and the Gap Project in Golden Lane both provide valuable open space for residents within developments where any other form of amenity space was impossible.

The provision of green space on new developments can increase the 'value' of property and be a market driver. Studies in North America and Britain have shown that good tree cover can increase the value of a property by between 6-15 per cent.

Many schools dating from the Victorian era have playgrounds at roof level, although not all are in use anymore. In one case, North Harringay Primary School, such a playground has been transformed into a roof garden, planted with a variety of species to reflect the ethnic diversity of the school. Other schools are investigating, or have received, funds to transform rooftop playgrounds into living roofs in order to provide an educational resource, e.g. Burdett Coutts and Portman Early Learning Centre, Westminster.

Green space is recognised as being beneficial to health; reducing stress levels and providing 'escape' from the stresses of urban living. This benefit is exploited by hospitals especially in Germany where such buildings commonly have living roofs.

Purely recreational roofs that comprise little or no vegetation are clearly limited in terms of the other benefits associated with living roofs. For this reason many public models to assess living roofs elsewhere in the world have strict criteria regarding the amount of green space that needs to be achieved at roof level to ensure maximum environmental co-benefit.

By supporting the compact city model living roofs can support the use of less land, a smaller building envelope, lower volume of materials, reduced energy consumption and lower construction costs. They can also help reduce energy requirements. Without such features the compact city will never succeed in being the liveable city.

North Harringay Primary School. Photo: Livingroofs.org

2.5 The Benefits of Green Roofs for Stormwater Attenuation

The combined impact of ongoing development within urban areas and climate change has created higher peak storm water flows leading to an increased occurrence of downstream flooding and pollution.

As a consequence, Sustainable Drainage Systems (SUDS) are now required to minimise the impact of both new and existing development. They are designed to manage the adverse environmental consequences resulting from urban stormwater runoff, and to contribute to environmental enhancement wherever possible. The use of green roofs can provide a pivotal role in achieving this as they successfully achieve source control, which is the fundamental concept of SUDS, i.e. the control of rainfall at, or as close as possible to, its source.

Around 30 to 40 per cent of rainfall events are sufficiently small that there is no measurable runoff taking place from greenfield areas (it all infiltrates or evaporates). In contrast, runoff from developed areas takes place for virtually every rainfall event. This means that streams and rivers are more subject to overload. In addition, whereas for greenfield areas small events would be treated through natural filtration processes, development runoff can flush surface pollutants directly into the receiving waters. Where it is possible to provide replication of the natural behaviour of a greenfield site (described as interception storage) then this should be provided.

By using green roofs as a source control technique, the volume of runoff entering the underground sewerage system, and thus the amount of storage capacity required within this system, can be reduced considerably. This is particularly important in dense urban developments where space for surface level SUDS components such as ponds and wetlands will be limited or in areas where infiltration is not possible because of ground conditions. It is also an important consideration when looking at the true cost implications of installing a green roof as the reduction in underground drainage infrastructure should be taken into account as well as the reduced number of down pipes and the smaller pipe network, etc.

When rain falls on a green roof it will first pass into the substrate and possibly pass through until the absorbency of the soil is activated (although through-flow will generally be low). It is then adsorbed by the substrate (i.e. only held on the surface of the substrate, not absorbed) and taken up by plants in the same manner as on a greenfield site.

For most small storm events the volume of rainfall is removed by evapotranspiration. Only when the soil is fully saturated will water percolate through to the underlying drainage layer in significant quantity. The processes involved in the operation of a green roof are [Ref. 3.18]:

- retention of rainwater in substrate and drainage layers
- uptake of water and release by plants as vapour (transpiration)
- uptake of water and biochemical incorporation by plants (photosynthesis)
- evaporation from substrate due to wind and sun.

There is a wealth of published information that demonstrates the performance of green roofs in attenuating storm water runoff by reducing peak flow rates and volumes. The German FLL guidance contains details of annual retention values depending on the type of substrate and its depth [Ref: 3.19].

Although there is a variation in performance, depending on rainfall patterns, this is no different to other SUDS components such as pervious pavements, or indeed greenfield catchments.

The drainage performance of green roofs can be summarised as follows.

1. A green roof will typically intercept the first 5mm and more of rainfall (i.e. provide interception storage).

2. The amount of storm water stored and evaporated is primarily dependent upon the depth of the growing medium and type of planting. In the summer a green roof can typically retain between 70-80 per cent of the runoff. [Ref: 3.18]

3. In Germany it has been demonstrated that between 40-100 per cent of rainfall can be retained – dependent upon the season. [Ref: 3.20]

4. Seventy-five per cent of rain falling on extensive green roofs can be retained in the short term and up to 20 per cent can be retained for up to two months. [Ref: 3.21]

5. As the rainfall events become longer or more intense, the positive effect of a green roof remains, as there is still a significant reduction in peak runoff rates. This increase in the 'time of concentration' means that a green roof will be beneficial throughout a wide range of rainfall conditions. [Ref: 3.22]

6. The above benefits collectively mean that, by incorporating a green roof into new development, there will be a reduction in the amount and cost of the overall drainage infrastructure required to serve that development.

Potsdamer Platz, Berlin. Zero Discharge and Rainfall Recycled. Photo: Livingroofs.org

Part Roof Lake used to recycled water
Potsdamer Platz, Berlin. Photo: Livingroofs.org

Green Roofs and Pollution Removal from Stormwater Runoff
Green roofs retain, bind and treat contaminants that are introduced to the surface either as dust or suspended/dissolved in rainwater.

A London Ecology Unit publication (Ref: 3.23) stated that 95 per cent of heavy metals are removed from runoff by green roofs and nitrogen levels can also be reduced.

In addition, Auckland Regional Council [Ref: 3.24] advises that green roofs are accepted as removing 75 per cent of total suspended solids. Their study showed a reduction in nitrogen (total discharge from green roofs of between 10 and 80mg/m^3 during the monitoring period) and phosphate was also removed from the runoff (total discharge of between 75 and 100mg/m^3). The total discharge of nitrogen and phosphate from the conventional roof was 265mg/m^3 and 145mg/m^3 respectively.

Clearwater Yard, Camden. Photo: AHMM Architects

2.6 Benefits of Green Roofs for Biodiversity
Green roofs have been installed in Germany and Switzerland since the early 1970s with the conservation of biodiversity being one of their principal objectives. In Switzerland in particular nature conservation has been a key issue [Ref: 3.25] with local seeds and substrates being used to ensure that the habitat characteristics are relevant to location.

This approach is now being explored in individual projects in the UK and North America. However, any form of green roof whether it is intensive or extensive, or any of the variants between, will provide habitat for some common species, and provide valuable green links and stepping stones for animals such as birds and invertebrates.

English Nature [Ref: 3.20] recognises the potential biodiversity benefits of green roofs as:
- helping to remedy areas of deficiency, i.e. providing new habitat in areas which are currently lacking in wildlife habitat
- creating new links in an intermittent network of habitats, thereby facilitating movement and dispersal of wildlife
- providing additional habitat for rare, protected or otherwise important species.

In London the use of green roofs to help meet policies and targets in both the Mayor's Biodiversity Strategy [Ref: 3.3] and the London Biodiversity Action Plan [Ref: 3.26] is ongoing. In particular there is a lot of interest in the use of green roofs to mitigate for the loss of valuable wasteland habitats on brownfield sites that can be a valuable habitat in their own right and yet are under increasing pressure for development. Good wasteland habitats are well drained and low in nutrients; two important characteristics of extensive green roofs [Ref: 3.27]. Extensive green roofs could make a significant contribution to the target for wasteland habitat in the Further Alterations to the London Plan. In addition, green roofs could play an important part in the creation of a green grid network.

Plant Communities
In theory, it is possible to replicate any habitat on a roof whether it is a sand dune, a birch forest or natural grassland. However, in the main, grassland and pioneer communities are developed on extensive green roof systems, with trees and shrubs being better suited to intensive systems [Ref: 3.28]. Extensive green roofs tend to become naturally self-sustaining grassland and herb rich communities as the system will not allow for further succession, whilst intensive roofs require high levels of management and maintenance if the system is to perform as it was designed to.

A number of studies both in the UK and abroad have determined more specifically the benefits to plants and animals. Nationally scarce mosses have been recorded on one roof in south-east London, whilst a range of common and less common moss species have been recorded on roofs elsewhere. 135 species of higher plants have been recorded spontaneously growing on roofs and wartime pillboxes in East Anglia.

Moss and Lichen – Okowerk Water Treatment Plant, Berlin. Photo: Livingroofs.org

In Germany and Switzerland the species used to create green roofs generally comprise important and valuable limestone meadow and alpine flora. Many of these species would be as desirable and appropriate on roofs in the UK.

A study of green roofs in 2005 noted that a number of plants of conservation interest were seeded onto the Eden Project roof with good results, including horseshoe and kidney vetch. These two species are important food plants for a number of butterflies and also are considered important food plants for rare invertebrates such as the brown-banded bumble bee (Bombus humilis). [Ref. 3.29]

Ongoing research at Sheffield University is investigating the most appropriate plant mix for the UK climate. This research is looking at naturalistic plantings with a mix of native and exotic species [Ref: 3.30]. Both natives and non-natives are being considered to balance the needs of biodiversity and aesthetics, many of which are important as forage plants for a number of rare invertebrates.

Soames Centre, Mile End. Photo: Livingroofs.org

Invertebrates
In recent years research has been carried out in Switzerland and the UK into the benefits of green roofs for rare invertebrates that are typically associated with brownfield land. Research by Oliver Gilbert in the early 1980s and 1990s in the UK recognised the value of these 'post-industrial sites' for their flora and invertebrates, particularly when such sites were in the early stages of succession [Ref. 3.31]. As entomologists continue to investigate these sites they are uncovering many rare and scarce species of invertebrate [Ref. 3.32]. In the East Thames Corridor, a series of shallow gravel workings and derelict land in the Thames Estuary support a remarkable concentration of nationally restricted species of invertebrates [Ref. 3.33] including the brown banded bumble bee (Bombus humilis) and shrill carder bee (Bombus sylvarum), both UK BAP (Biodiversity Action Plan species) (GLA, 2001).

In a London context, providing flower rich habitat and the right edaphic conditions for Bombus humilis, has the potential to meet the London Biodiversity Partnership's statement for the species. A number of rare invertebrates have been identified as being potential beneficiaries of green roofs on new developments, especially in the Thames Gateway area of London.

In 2002 English Nature [Ref: 3.34] commissioned a survey of eight green roofs in the London area that recorded 136 invertebrate species. A number of unusual and uncommon species were recorded, especially those associated with certain dry habitats, including some not previously recorded in the London area. One of the conclusions of the study was that whilst conventional green roof systems [i.e. sedum mats] used in the London area do support an interesting invertebrate fauna, such systems do not provide refuge for some of the rarer invertebrates associated with brownfield sites which are better catered for on bespoke designed roofs. [Ref. 3.34]

A study [Ref: 3.36] running simultaneously to the above focussed on spiders, and collected samples from ten green roofs and three brownfield sites in the London area. During the study over 3,000 individual spiders were collected with 59 species represented, consisting of nine per cent of the total UK and 26 per cent of the Greater London spider fauna [Ref. 3.35; Ref 3.36]. Six new species were recorded for Greater London.

Birds
Green roofs can potentially provide substantial benefits for birds. Studies have shown that generic green roofs provide habitat for more common species, whilst roofs specifically designed to mimic habitats within the urban fabric will benefit uncommon species such as the black redstart. The potential of large green roofs for common, scarce and declining species of ground nesting birds is evident through a handful of studies carried out both in the UK and Europe.

Research shows that green roofs do appear to offer the opportunity to benefit local biodiversity action plans within London (black redstart, house sparrow) and potentially a number of UK BAP species including the skylark.

Green Roof designed for lizards, Zurich, Switzerland. Photo: Livingroofs.org

Limitations
Unlike other benefits such as storm water amelioration and thermal performance assessing the benefits of green roofs for biodiversity is more complicated. All systems, whatever the depth and planting regime, benefit wildlife per se. However, there is a need for ecological design input to ensure that any green roof being included in a development as mitigation meets a specific habitat or species requirement. All too often this design input does not happen, and generic green roof systems are used as opposed to preferred bespoke systems. [Ref: 3.36]

Green roofs will not necessarily perform in exactly the same way as habitats at ground level, and certain elements within a habitat at ground level may be inappropriate in a roof situation. Therefore replication is the key word here as opposed to restoration. Wherever possible the use of similar soils at similar depths with local and appropriate seed mixes will provide the basis for replicating habitat at ground level. Vigorous plants such as bramble and butterfly bush, can have a detrimental effect on a roof and would therefore not be appropriate, even though they may have been an important element at ground level. English Nature clarify the limitations of green roofs as habitat replacement by recognising that although the soil conditions on a roof can replace those at ground level, the habitat is likely to be smaller in area, may be too heavy for the proposed building, may not be able to be replaced quickly enough after demolition, and creating habitat at roof level may lead to habitat fragmentation and isolation. [Ref. 3.20]

Kangaroo House, London Zoo. Photo: Livingroofs.org

Barclays HQ, London. Photo: Livingroofs.org

2.7 The Benefits for London – the Possibilities

It is difficult to arrive at figures on how much roof space in London could be converted to green roof space, although it has been estimated that 24,000 hectares of buildings (and therefore roofs) cover Greater London. This is equivalent to 16 per cent of the surface area of the capital or 16 times the size of Richmond Park [Ref: 3.20]. In London, flat roof space, however, does not predominate, and even in the centre there is a mix of roof types.

To estimate the extent of flat roofs in central London, the areas that appeared to be finished with paving or shingle ballast was calculated using aerial photographs. These roofs were free of other items such as industrial coolers etc. and, therefore were considered potentially suitable for green roof treatment. The amount of green roof space was then calculated as a percentage of the total roof space in the selected area. For the four areas of central London selected, it was estimated that an average of 32 per cent potentially could be greened.

Table 3: Potential Green Roof Area in Four Areas of London

Area	Total Area (m^2)	Potential Roof Area (m^2)	%
Cannon Street	193,000	61,255	31
Oxford Street	143,000	46,330	32
Tottenham Court Road	118,787	49,150	41
Canary Wharf	292,000	70,015	24
Average per cent			**32**

Aerial View Canary Wharf

Aerial View Cannon St Area

Four larger sample areas were then considered along with an estimate of what the benefits would be if 32 per cent of the roof space were used for living roofs. The sample areas were:

- City of London
- part of the London Borough of Hackney
- part of the London Borough of Tower Hamlets
- part of the West End.

The total surface area of these was calculated to be 10 million m^2 and thus it was assumed that 3.2 million m^2 had the potential to be covered in living roofs.

Assuming a rate of $6kWh/m^2/yr$ of potential energy savings, 3.2 million m^2 would give an overall energy saving of 19,200 MWh per year or the equivalent of 8,256 CO_2 e tonnes. Assuming that $0.025m^3/m^2/yr$ of water could be held at roof level, then 3.2 million m^2 would have the capacity to store in the region of $80,000m^3$ of rainwater at roof level, the equivalent to, approximately the volume of water needed for 35 Olympic swimming pools. The same area, assuming that 80 per cent is extensive and 20 per cent is intensive, would provide 256 hectares of 'habitat' of dry meadow, an area larger than Hyde and Kensington Gardens combined or 142 football pitches, and 64 hectares of green amenity space, equivalent to about 35 football pitches.

It was assumed that potential energy savings were in the order of 10.15 and $6.15kWh/m^2/yr$. This was derived by adding data from Canada [for summer – $4.15kWh/m^2/yr$] and Germany [winter 6-2 $kWh/m^2/yr$]. It was decided to take a conservative approach and use a figure of $6kWh/m^2/yr$ of potential energy savings when a green roof is installed on a new or old building.

With a total surface area of 320 hectares it is assumed that 50 per cent of this area would be buildings. Assuming that 75 per cent of these buildings would be greened [creating 120 hectares of green roofs], 7200 MWh/yr of electricity could be potentially saved, leading to a reduction of 3,096 CO_2 e tonnes/yr, 30,000m^3 of rainwater could be held at roof level per year, equivalent to the volume of water needed for 12 Olympic swimming pools, and 96 hectares of 'habitat' and 24 hectares of amenity space could be created.

Greenwich Peninsula

Barking Riverside

Silver Quays and Minoco Wharf, Newham

The impact of a green roof policy on new developments in London was also researched. Taking the surface area of several development zones, it was assumed that 50 per cent of these zones would be buildings and in this case, as new builds, it was assumed that 75 per cent of the roof space could be greened.

Convoys Wharf, Lewisham

Peruvian Wharf, LB Newham

2.8 Benefits of Living Walls

Whereas roofs are not always a visible feature, especially in the inner city, we are constantly aware of and guided by the presence of walls in our towns and cities. Many of these are often blank and featureless, and provide an opportunity for creating green or living walls. Living walls utilise plants to derive benefits not only in visual terms, but also in regard to amenity, biodiversity, thermal efficiency and amelioration of pollutants, all for a very small ground level footprint.

As with living roofs, there is nothing new in the concept of using plants to green buildings, but rather the variety of modern designs and techniques or enable the concept of living walls to be used far more creatively today.

Living walls can be separated into a number of categories (Ref 4.3) including:

- supported by a wall – self-supporting climbers
- supported by a structure on a wall – trellis etc.

- supported by a self-standing structure away from a wall – frameworks, etc.
- hanging walls – allowing plants to hang from a height
- walls with plants growing within them.

Each of these categories provides similar environmental and amenity benefits.

2.8.1 Benefits of Living Walls for Climate Change Adaptation

By providing shading from the sun, living walls can significantly reduce the external temperature of a building. The effectiveness of this cooling effect is related primarily to the total area shaded and evapotranspiration effects of the vegetation, rather than the thickness of the climber [Ref. 4.1]. Together with the insulation effect, diurnal temperature fluctuations at the wall surface can be reduced from between 10°C and 60°C to between 5°C and 30°C. [Ref. 4.2]

Living Walls can also provide a certain amount of winter insulation although the effectiveness of this will depend on the type and structure of the Living Wall and the overall energy performance of the building itself. Research has demonstrated that by creating a zone of still air adjacent to the wall, evergreen plants can reduce convection at the wall surface by up to 75 per cent and heating demand by up to 25 per cent [Ref. 4.2]. In general, the effectiveness of winter insulation is related to the thickness and coverage of plant growth.

On certain types of wall vegetation can reduce wall wetting thus reducing the amount of cooling through evaporation at the wall's surface, which would otherwise result in energy loss through the building fabric.

Living walls can also help reduce UHIE through the interception of both light and heat radiation which would otherwise be largely absorbed and converted to heat by the building surfaces and then radiated back into the surrounding streetscape.

Contrary to received wisdom, climbers on buildings can actually help to protect the surface of the building from damage, particularly from very heavy driving rainfall and hail, and can possibly play some role in intercepting and temporarily holding water during rainstorms, in the way that green roofs do. They also help to shield the surface from ultra-violet light, which might be an important consideration for certain modern cladding materials.

2.8.2 Benefits of Living Walls for Biodiversity

Plants on buildings can potentially provide a food source for invertebrates on which, in turn, other invertebrates and birds may feed. They also provide breeding and nesting habitat for invertebrates, birds (including the house sparrow, a London biodiversity action plan priority species) and possibly bats and are ideal for including artificial animal breeding structures such as nest boxes or bat roosting boxes. Careful choice of species and the orientation of the wall will increase the potential of a living wall to harbour other forms of wildlife. For example, our native ivy (Hedera helix) is a valuable food source for innumerable invertebrates which feed on its leaves, flowers and nectar, and it also provides valuable over-wintering and hibernation habitat. In addition a living wall can be part of an overall city greening strategy linking ground level open space with street trees, water courses and living roofs.

2.8.1 Other Benefits of Living Walls

Living walls have a number of other potential benefits including 'bioshading' – reducing sunlight penetration through windows, and trapping dust and other pollutants from both the air and rainfall on the leaves of plants. Research carried out alongside motorways in Germany [Ref. 4.1] measured the percentage of particulate coverage on the leaf surface of plants such as ivy. It was found that particulates and dust covered 40 per cent of leaf surface with the leaf veins having up to 100 per cent coverage.

Living walls also provide visual amenity, resulting in a green and organic skin to what otherwise may be a 'cold' and unattractive wall. In some cases architects may contest that such a living wall will detract from the overall aesthetic of the building. Clearly, living walls have to be designed so as to contribute aesthetically not only to the building itself but to the overall environment in which it sits. The involvement of architects, landscape architects and ecologists at the earliest possible stage in the design process is critical in achieving the greatest visual amenity advantage.

For further detailed guidance on living walls refer to Building Greener. [Ref: 4.3]

Virginia Creeper, Blackheath. Photo: Livingroofs.org

New Providence Wharf
Photo: Alumasc

3. Case Studies

Case Study 1

The Radisson Hotel & New Providence Wharf
(Courtesy of Alumasc Exterior Building Products Ltd)

Roof Area: 418m^2

Build Cost: Waterproofing & Green Roof: £54,000 approx. conventional Inverted Roof: £24,250 approx.

Client Name: Ballymore Properties Ltd

Development Type: Hotel – Mixed Use Development

Date Completed: June 2006

System Supplier: Alumasc Exterior Building Products Ltd

Architect: Skidmore, Owings, Merrill – London

Environmental Consultants: RPS Group

Landscape Architects: TBA Architects

Key Drivers: To meet planning requirements, this project required a biodiverse vegetative mix to attract aphids and invertebrates whilst leaving a degree of exposure to the substrate to allow ground-nesting birds the opportunity to nest amongst the vegetation. Areas where standing water could arise were created to provide a water source for fledgling chicks.

In addition to the need to meet ecological/bio-diversity requirements, the planting had to be planned to look attractive when viewed from above, as the roof is overlooked by some of the most expensive apartments in the Docklands area.

Thermal Calculations: "U" value at 0.25 – plant room immediately beneath.

Development Benefits: Black redstarts identified on the roof. Visual appearance is attractive through much of the spring, summer and early autumn.

Barriers Faced: The roof structure was designed to carry a specific load, which precluded using crushed concrete building rubble given the vegetation requirement.

Significance to London: This was the first mixed purpose biodiverse/green roof development in the London area where appearance was as important as the need for bio¬diversity.

Further Information: www.alumasc-exteriors.co.uk

Case Study 2
Gold Lane, Edgware

Roof Area: 400m^2 (over 8 units)

Build Cost: £1.1M

Client Name: Notting Hill Housing Group

Development Type: Social Housing

Specialist Contractor: Blackdown Horticultural

Date Completed: 2003

Architectural/Landscape Consultants: AEA/Project 35 English and Konu Architects

Key Drivers: To create habitable and human environment and deliver a range of environmental benefits.

Thermal Calculations: TBA

Development Benefits: Aesthetics, reducing surface water run off. Residents have noted that they barely have to turn the heating on and their children enjoy butterflies bees.

Barriers Faced: Using a single supplier for all roofing elements enabled comprehensive warranties – which had been a client issue.

Significance to London: London's first green roofed social housing project; helped bring living roofs into contemporary housing design.

Planning Authority: London Borough of Barnet

Developer: Notting Hill Housing Group, Bugler Developments.

Awards: RIBA Housing Design Award 2002 Civic Trust Award 2006, Grand Design Magazine Award 2006.

Further Information: www.project35.com

Case Study 3

North Harringay Junior School, Haringey

(Courtesy of Alumasc Exterior Building Products Ltd)

Roof Area: 190m^2

Build Cost: Waterproofing & Green Roof: £16,000, conventional Renewal of Waterproofing: £8,000

Client Name: LB Haringey

Development Type: Junior School

Specialist Contractor: Tilbury Contracts

Date Completed: June 2005

Environmental Consultants: London Herbalists Society

System Supplier: Alumasc Exterior Building Products Ltd

Key Drivers: The pressures in modern day education to upgrade the teaching facilities of the school lead to the planned replacement of the portable classroom with a new-build, permanent classroom that would take up the space of both the existing structure and the garden, so a valuable amenity was to be lost.

An alternative location was found: the roof of the second floor gymnasium, which was being used for storage and had become a bit of a dumping ground for a variety of old school equipment. After an initial survey confirmed that the structure could take the proposed loading, a scheme was drawn up to upgrade the existing roof waterproofing to incorporate a root barrier and to install a green roof to the finished structure.

The end result has been to return an unused area of the school footprint to a really useful teaching and recreational amenity for both the school and the local community.

Thermal Calculations: N/A

Development Benefits: This development has turned an unused roof area into a valued teaching and recreational amenity for the school.

Barriers Faced: The principal barrier to this project was funding. But various departments within Haringey Council were persuaded to find money from various budgets to allow the project to proceed.

Significance to London: This is a prime example of how a part of the footprint of an existing building can be returned back to the local environment whilst also providing a significant amenity gain.

Further Information: www.alumasc-exteriors.co.uk

Case Study 4
Beaufort Court, Lillie Road, Fulham

Roof Area: Not known

Build Cost: £7.5 million

Client Name: Peabody Trust

Development Type: Social Housing

Specialist Contractor: Llewellyn ROK

Date Completed: July 2003

Architectural/Landscape Consultants: Feilden Clegg Bradley Architects LLP

Environmental Consultants: Grant Associates

Key Drivers: To deliver the governments sustainable communities agenda – high quality high density accommodation split between shared ownership, key worker and rental provision.

Development Benefits: The living roof reduces surface water run-off, visual amenity, and enhances thermal and acoustic performance.

Significance to London: There is a strong sustainability agenda with the building fabric (including the roof) providing a high thermal and acoustic performance and The sedum roofs reduce water run-off.

Planning Authority: London Borough of Hammersmith and Fulham.

Awards: RIBA Housing Design National Project Award 2004, CABE Building for Life Award Gold Standard 2004, Structural Steel Award Certificate of Merit 2004, National Homebuilder Design Awards (Best Social Housing Development) 2004
The Housing Corporation's Best Example of Affordable Housing 2004
World Habitat Awards 2005 Runner up

"The construction is highly innovative. The dwellings themselves are skilfully planned, far exceeding current building regulations standards. With provision for rental, shared ownership, key workers, rehabilitation and disability, this is a significant pacemaker in so many areas for the new generation of social housing."
Housing Design Awards 2004

Further Information: www.peabody.org.uk

Case Study 5

Bishops Square, Spitalfields
(Courtesy of Alumasc Exterior Building Products Ltd)

Roof Area: 2,500m^2 on 3 levels

Build Cost: Waterproofing & Green Roof: £400,000, conventional Inverted Roof: £180,000 approx.

Client Name: British Land

Development Type: Offices

Date Completed: Spring 2005

Architect: Foster & Partners – London
Landscape Architects: RPS Group

System Supplier: Alumasc Exterior Building Products Ltd

Key Drivers: The client requirement for the three terraced areas was to provide a high quality, visually impressive but calming landscape to compliment the views over the London skyline, both from the adjacent offices and when stood on the terraces.

Thermal Calculations: Nominal "U" value at 0.25 – Offices immediately below each roof.

Development Benefits: The external terrace areas offer an attractive and calming vista, whilst also providing a welcome amenity area for the employees working in the adjacent offices.

Barriers Faced: The height of the roofs coupled with the high level of reflectivity from the adjacent facades created significant problems both with heat build-up and wind swirl.

Significance to London: This is a prime example of where an element of the countryside has been brought into the city for the benefit of both the staff and the local ecology. Whilst the vegetation was developed initially for its visual aesthetics, it has attracted a good number of aphids and invertebrates, which are the foodstuffs of the urban avian population.

Further Information: www.alumasc-exteriors.co.uk

Case Study 6
Northern Line Control Centre, Highgate

Roof Area: 1,950m^2

Build Cost: Waterproofing & Green Roof: £250,000

Client Name: Tube Lines

Development Type: Operational Railway Building

Specialist Contractor: Cambridge Polymer Roof Ltd
Blackdown Horticultural Consultants Limited

Date Completed: August 2007

Architectural/Landscape Consultants: Tube Lines

Environmental Consultants: Tube Lines
Blackdown Horticultural Consultants Limited

Key Drivers: The original design for the building included a traditional pitched roof. Discussion and engagement with the local community, Corporation of London, Haringey Council and the London Bat Group led to an improved design reduced in height and incorporating a living roof. As the building is surrounded by residential housing and woodland the structure needed to be unobtrusive to residents, people and wildlife.

Thermal Calculations: Not calculated for this building but identified as saving approximately 0.5 tonnes of CO_2 emissions per m^2 of the building (Source AEA Technology).

Development Benefits: This development has sensitively transformed an area of surplus railway land, complementing the local environment and providing additional habitat for local biodiversity. Structurally the low maintenance roof acts to stabilise internal temperatures and as a successful natural soakaway.

Case Study 7
Springbok Works, Dalston

Client Name: Buck Family

Development Type: Mixed Use Business (B1) and Residential

Specialist Contractor: Self Build

Date Completed: 2000

Architectural/Landscape Consultants: Cullinan and Buck Architects

Structural Engineer: Rodrigues Associates

Key Drivers: With a plot ratio of 3-1 the redevelopment required additional amenity space, and a safe environment for children's play. The owners were keen to access the long distant views across the Dalston roofscape.

Thermal Calculations: High levels of thermal insulation (U value 0.6-0.85) were achieved through a significant layer of waterproofing and insulation, underneath the paving.

Development Benefits: External space, playground and garden for dwelling.

Barriers Faced: A reasonably straight forward process with sympathetic planning authority, although there were issues around point loading which meant the paving slabs had to be unloaded and laid one at a time.

Significance to London: Springbok Works was built in 1932 as a spring mattress factory and retained a business use until 1998, when it was converted into an apartment, a studio and a workshop. The three-storey high, 90m^2 flat roof is the only associated outdoor amenity space. In summer a camouflage net is thrown over the cage for shade. Conversions of this type are not unique and the accessible play space on the roof serves to make a dense re-development very liveable.

Planning Authority: London Borough of Hackney.

Further Information: cabal@cullinanbuck.co.uk

Case Study 8
Jubilee School, Tulse Hill

Roof Area: 1230m^2

Build Cost: £5M

Client Name: London Borough of Lambeth

Development Type: Education

Specialist Contractor: Ballast Wiltshire

Date Completed: September 2002

Architectural/Landscape Consultants: Allford Hall Monaghan Morris

Environmental Consultants: Atelier Ten

Development Benefits: Building performance, visual amenity

Significance to London: A £4.5m, 420 place community primary school, nursery and 'Surestart' facility on the site of the existing Brockwell Primary School on Tulse Hill. The design encompasses many of the sustainable issues prevalent in the Notley Green Primary School and has involved wide consultation with the community and educational specialists.

Planning Authority: London Borough of Lambeth.

Developer: Lambeth Education

Awards: RIBA Award for Architecture 2003, AIA

Further Information: info@ahmm.co.uk

Case Study 9
Adelaide Wharf, Haggerston

Roof Area: 460m²

Build Cost: £22M

Client Name: First Base Ltd and English Partnerships

Development Type: Mixed Use

Specialist Contractor: Bovis Lend Lease

Date Completed: October 2007

Architectural/Landscape Consultants: Allford Hall Monaghan Morris

Environmental Consultants: Ecology Solutions

Key Drivers: Requirement for biodiversity adjacent to Regent's Canal wildlife corridor

Thermal Calculations: To part L (2005)

Development Benefits: See notes above.

Barriers Faced: Integration with rooftop service distribution resulted in the areas of cobbles dividing the brown roof.

Significance to London: Providing increased habitat for local species, particularly the Black Redstart (see above).

Planning Authority: London Borough of Hackney.

Awards: Shortlisted for the Residential MIPIM Architectural Awards 2008

Further Information: info@ahmm.co.uk

Clearwater Yard, Camden
Photo: AHMM Architects

4. Barriers to Implementation

4.1 Introduction

There are a number of perceived barriers to full-scale implementation of green roofs. A survey in 2002 in London of architects, ecologists, local planners and engineers identified a number of concerns regarding green roofs [Ref. 5.1]. Most of these concerns arise due to the fact that green roofs are a relatively new technology for the mainstream UK construction industry.

The main concerns are:

- lack of common standard
- fire hazard
- maintenance
- cost
- structural Issues
- leakage and damage to waterproofing
- lack of expertise
- lack of policy.

4.2 Lack of Common Standards

The lack of a British Standard is often cited as a real barrier to whole-scale uptake of green roofs. The major suppliers of green roofs in the UK are fully signed up members of the German FLL – the Landscape Research, Development & Construction Society [Ref: 3.19]. This body provides standards for landscaping in Germany, whilst standards used in Switzerland, Austria, Hungary and Italy, are variations on the FLL. Japanese and North American standards are also based on the FLL.

The FLL covers all aspects of green roofs from waterproofing, soils, vegetation, treatment on intensive green roofs [tree planters, etc], balconies, installation methods and procedures, and maintenance. The guidance stipulates DIN (German Institute for Standardisation) standards for specific areas of greening. These standards are seen by some to be over rigorous – a point accepted by the FLL [pers. comm. Gedge 2004].

Therefore the lack of standards in the UK is only likely to be an issue where a supplier is either not an affiliate of, or does not work to, FLL standards. Over the last 2 years a number of the largest green roof suppliers in Germany and Switzerland have set up partnerships with UK waterproofing companies and the majority of these abide by or are affiliates to the FLL. The largest companies supplying green roofs in the UK have been in operation for much longer than this and are recognised as leading green roof suppliers both in the UK and Germany.

4.3 Fire Hazard

Although there is a perception that dry vegetation during the summer months could lead to fires being started on green roofs, the FLL standards also have strict guidelines on this issue. These include high levels of fire resistance and fire proofing for membranes and other layers beneath the soils and vegetation. Furthermore there are strict guidelines regarding the use of firebreaks and the amount of combustible material permitted in green roof soils.

Extensive roofs are only considered to be fire resistant if:

- the substrate/soil is at least 30mm deep
- the substrate/soil contains less than 20 per cent organic matter
- there is a 1m wide gravel or slab 'fire break' every 40m
- gravel/shingle strips are provided around all structures penetrating the roof covering. These gravel/shingle strips should be at least 300-500mm in width, or 1m in width where they are to act as firebreaks on large roof areas.

In Germany the use of a green roof is considered to provide a protective barrier preventing waterproofing elements from catching alight. For this reason it is possible for building owners to get a reduction of 10-20 per cent on fire insurance in Germany.

Millions of square metres of green roofs have been installed in Germany and Switzerland over the last 25 years to these standards, thus it is clear that fire hazard should not be viewed as a real barrier to uptake in London.

4.4 Maintenance

Maintenance of a green roof will depend on the roof system and what is desired from it. Intensive and semi-intensive green roofs are in many ways a high-rise version of a garden, and therefore will require similar level of upkeep. This will include weeding, mowing, hedge trimming, fertilising and watering.

Semi-intensive wildflower meadows need an annual mow to maintain floristic diversity. However, it is possible for this to be a neglected aspect and there are a number of instances in London where such management has not been undertaken. This 'lack' of maintenance has had no impact on the building, but merely reduced the value of the meadows from an ecological point of view.

Extensive green roofs, which are generally not amenity spaces, need very low maintenance. A one to two year inspection will normally suffice to weed out unwanted plants, remove deep roots and, if necessary provide fertilisation. For the first year such work is generally covered by the installation team, after which it becomes the responsibility of the building owner or the building management team.

Contrary to common perception the use of a green roof can have a positive impact on maintenance in that intentional vegetation within the system keeps out unwanted vegetation that can harm the integrity of the building's fabric. On grey roofs and other conventional green roof systems butterfly bush and other shrubs can become established and potentially cause problems. The presence of a root barrier and competition from other plants can limit this significantly.

4.5 Cost

The cost of a green roof will vary depending on the system used. It will also depend on the height of the building, number of intrusions, size and type of system, depth of insulation required and many other factors.

Intensive green roofs can vary in cost depending on the amount of vegetation cover and the type of vegetation. An indicative cost is £140/m^2 inclusive of waterproofing and insulation. The use of large trees, furniture, planters and irrigation will increase costs – for example, a planting scheme of this nature at Jubilee Park in Canary Wharf that included trees, fountains, irrigation system, etc. resulted in costs as high as £453/m^2 (pers. comm. Tony Partington). However, these costs may be balanced to a certain extent by increased building 'value'.

An indicative cost for a semi-intensive green roof is in the region of £120-140/m^2, but again could be more depending on the types of plants used, water features and furniture.

An indicative cost for an extensive green roof will depend on the type of system used. The cost will also vary depending on whether it is a warm or cold roof.

Table 4 outlines some indicative figures for green roofs, including waterproofing and insulation. These costs will vary depending on the factors outlined above:

Table 4: Indicative Costs for Green Roofs

Type of Build Up	Cost (Installed) per m^2
Warm roof (non green roof)	£55
Warm roof (sedum blanket)	£110
Inverted (shingle)	£60
Inverted (paving)	£70
Inverted (Substrate based green roof systems without additional substrate)	£110

For comparison the costs in Table 4 are taken from an article in Building Magazine [Ref: 5.2] for green roof areas ranging from 100 to 1000m^2. The rates include specialist contractor costs but exclude allowances for main contractors' preliminaries, and overheads and profits:

- Warm deck – Insulation is placed between the exterior waterproof layer of the roof and the roof deck (the deck being the surface that supports the waterproof layer and transfers roof surface loads to structural members). A vapour control layer is placed between insulation and roof deck to reduce condensation. No internal ventilation of the roof interior is required.
- Inverted warm deck – The insulation is located on the exterior of the roof waterproof layer. The waterproof layer now becomes the vapour control layer preventing condensation between itself and the deck. The thermal insulation protects the waterproof layer from extremes of temperature. The thermal insulation is commonly retained in place by ballast consisting of paving slabs or gravel.
- Cold deck – The insulation is located on the interior side of the deck. The deck is not warmed by the building interior and ventilation is required above the insulating layer to reduce condensation. In the relatively humid climate of the UK the cold deck roof is generally not preferred.

Warm roofs maybe restricted to a sedum blanket unless there is greater capacity for structural loading, and the cost of a green roof on a warm roof is always likely to be at least double the normal cost of the roof. However, when an inverted roof system is used, the structural capacity to hold a green roof substrate-based system is already present, although water absorption would also need to be considered. In fact an inverted roof needs ballast, which conventionally is shingle or paving. Hence, in regard to an inverted roof, the additional cost is only in the region of 50 per cent extra. Furthermore a substrate-based roof can result in other cost savings due to the reduction in the number of drainage outlets and in the amount of storm water amelioration at ground level. Further savings can be factored in when the reduced energy needs within the building are also taken into account. In Germany, for similar reasons, it is recognised that a green roof is the most cost-effective method of roofing over a 25-year period.

A recent study in Birmingham (Ref 3.21) estimated that a single plot with a green roof could realise a saving of £173,000 through a reduction in surface water amelioration costs. The study then considered the cost of increase structural requirements for the buildings in question to hold a substrate based green roof; these were considered conservative at £53,000. The cost saving to the plot, through the use of a green roof to reduce storm water storage, was thus in the order of £120,000.

Green roof costs vary according to the factors peculiar to any one project. For example, a green roof on a single storey south coast youth club led to a three per cent increase in its total build cost, significantly more than the examples illustrated above. It is not clear why this was, but it could have been due to the detailing required to blend the roof into the building form.

4.5 Whole Life Cost

To fully assess the financial impact of a green roof over its life-time not only does capital cost or purchase price need to be considered, but also the running costs incurred and financial benefits achieved. For example, if we increase the depth of insulation in a building from 200mm to 250mm there is an additional purchase cost incurred, but there are also additional savings on energy costs from the thicker insulation.

This combination of capital costs and in use costs is called "Whole Life Costs" (WLC), and is defined as: – *the analysis of all relevant and identifiable cash flows regarding the acquisition and use of an asset. [Definition of Whole Life Costs, The Whole Life Cost Forum] see Appendix 3 for Study results.*

A study carried out as part of the work that informed this report (Refer to Appendix 3) utilised a form of WLC termed Net Present Value (NPV). Taking account of a variety of factors and assuming a discount value of eight per cent the study achieved the results shown in Table 5 below for both a bare roof and various green roof systems.

NPV Appraisal Results
The capital costs used are an average across three suppliers and indicative only, as real costs will depend on project-specific elements. However, the NPV outcomes will remain essentially the same as the base price moves up or down for all options.

In this case all the NPVs are negative since there is no direct income to offset the costs. Therefore, the lowest negative NPV is the preferred investment option.

Base Data for the NPV Analysis:	
• Roof size	850m^2
• Insulation 'U' value	0.25
• Cost of energy (average)	17p/kWh
• Discount Rate	8 per cent
• CO_2 conversion rates from DEFRA web site October 2007 general grid supply	

In the NPV calculations, a non specific roof waterproofing with a 25 year life when exposed and a 50 year life when part of a green roof, has been used. See Table 5, NPV results overleaf.

The calculation did not include project specific costs or benefits including:
- increased property values of around 0.5 per cent
- reduced initial let and re-letting void periods
- performance improvements from air handing units and solar heating in areas of Green Roofs
- benefits to occupiers' business performance from accessible Green Roofs
- project specific cost reductions from reduced drainage requirements
- or community benefits;
  - o From CO_2 reductions
  - o Reduced Urban Heat Island Effect.

As we are working with negative NPVs, the lower the negative amount the better the investment. The table thus illustrates that:
- all extensive roofs provide better returns on investment than shingle or paving based inverted roofs
- extensive substrate based roofs that are either hydro-seeded or bio-diverse provide better returns on investment than a basic bare roof
- semi-extensive roofs also provide better returns on investment than paving based inverted roofs.

The results are a clear justification to use green roofs.

Figure 3 overleaf: Comparisons of NPV for Green Roofs

All green roofs save carbon dioxide when compared with bare and inverted roofs. In the GLA study, the sedum mat roof is thinner than the substrate roof, and therefore is less insulating and saves a lower amount of carbon dioxide.

Conclusions on Whole Life Costings
Living roofs are cost effective when the cost in use is applied over the life of the asset. If the roof is also accessible to occupiers, then the financial argument is even more compelling.

For owner-occupiers, the benefits will accrue directly to them throughout the life of the building. If staff have access to the green roof the benefits are even greater.

For developers with the focus of property investment funds, a green roof will enhance the sale and translate into better yields.

For planners and the wider community, the aggregate effect of numbers of living roofs means there is:
- reduced surface water run-off from the building
- lower risks of flooding
- reduced CO_2 in the local climate
- reduced Urban Heat Island Effect reducing air conditioning energy requirements
- reduced energy consumption.

4.6 Structural Issues
Below are the loadings of the various roof coverings available. They exclude those for an exposed standard warm roof i.e. without any additional roof treatment:

Table 6: Indicative Structural Loading for Various Types of Roof

Roof Type	**Loading**
Gravel surface	90-150 Kg/m^2
Paving slabs	160-220 Kg/m^2
Vehicle surface	from 550 Kg/m^2
Extensive green roof [sedum mat]	60-90 Kg/m^2
Extensive green roof [substrate based]	80-150kg/m^2
Intensive green roof	200-500 Kg/m^2

NOTE: loads are fully saturated.

Table 5. Reference			NPV	Capital Cost	Maintenance	Energy	CO_2
Bare			-60,250	44,200	850	0	0
	Paving		-85,504	62,050	1,275	0	0
	Shingle		-75,763	53,550	1,275	0	0

Green Roof			NPV	Capital Cost	Maintenance	Energy	CO_2
Extensive							
Mat based	Insulation under	Sedum mat	-72,933	80,750	2,975	21,250	9
Substrate based	Insulation under	Sedum mat	-73,460	80,750	2,975	21,250	9
		Sedum plug	-75,156	89,250	3,825	29,750	13
		Hydro seeded	-51,467	85,000	2,125	29,750	13
		Bio diverse	-42,967	76,500	2,125	29,750	13
	Insulation over	Sedum mat	-86,210	93,500	2,975	21,250	9
		Sedum plug	-79,406	93,500	3,825	29,750	13
		Hydro seeded	-55,340	89,250	2,125	29,750	13
		Bio diverse	-51,090	85,000	2,125	29,750	13
Semi Extensive							
	Insulation under	Sedum plug	-83,656	97,750	3,825	29,750	13
		Hydro seeded	-77,577	106,250	2,550	29,750	13
		Bio diverse	-76,967	110,500	2,125	29,750	13
Intensive							
	Insulation under	Lawned	-158,365	119,000	8,500	29,750	13

Structural issues are linked to cost as outlined above. In the case of an inverted substrate based green roof there should be relatively limited or zero need for extra structural load.

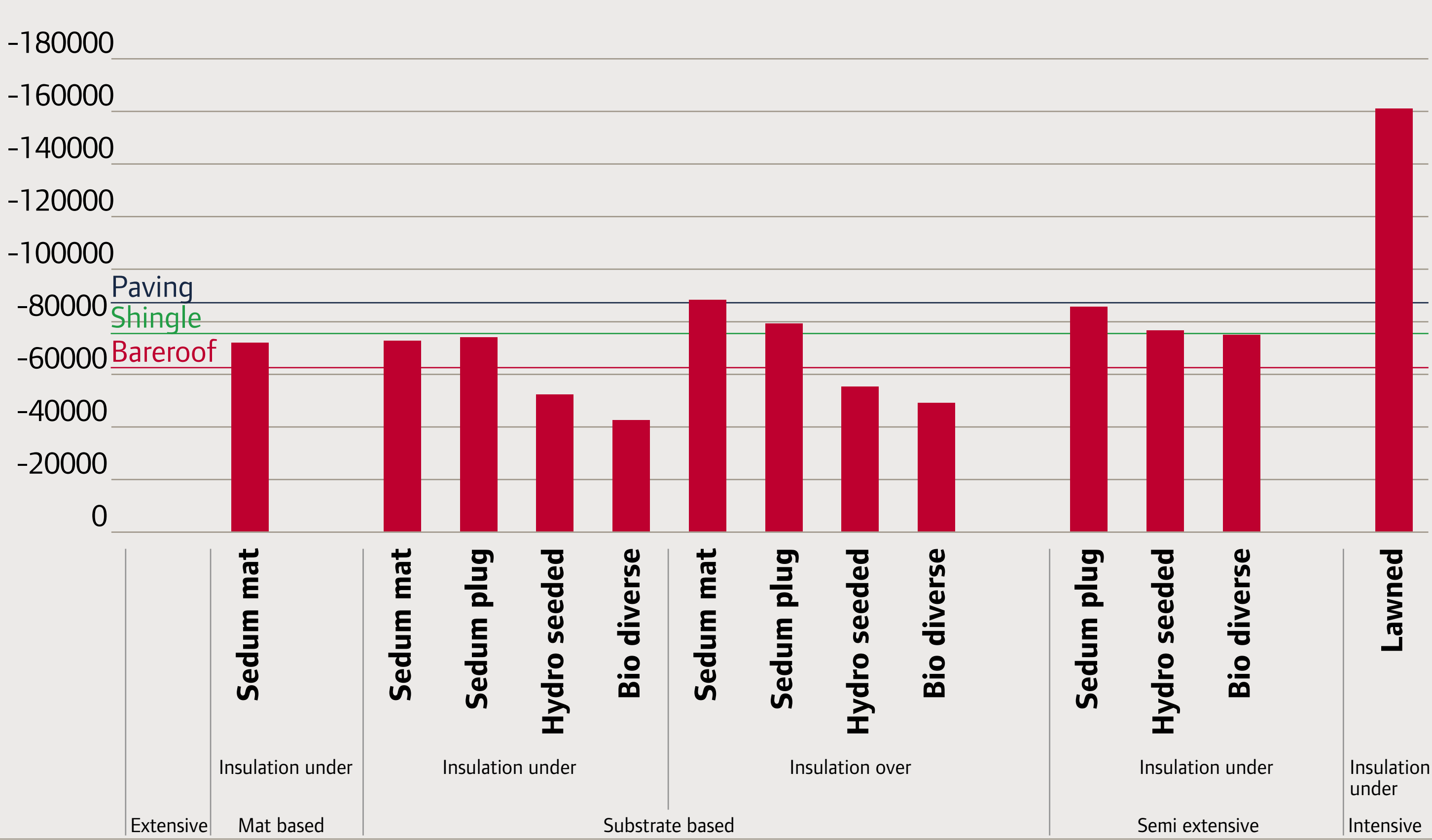
There can be issues regarding green roofs and structural loads on lightweight industrial buildings that can lead to increased costs. However, savings in the need for storm water amelioration tanks could well balance out the extra cost for a green roof.

4.7 Damage to Waterproofing

Concerns are often expressed that green roofs will leak. Historically flat roofs are perceived as more vulnerable to leakage due to the effects of the climate (UV, frost and ponding) on waterproofing systems.
Most established green roof suppliers provide FLL rated root barriers, which protect water-proofing membranes from the potential negative impact of roots. Furthermore, established companies will leak test before the implementation of the green roof element. In London, where waterproofing has leaked under a green roof build up, this has typically been a result of poor workmanship, or a non-FLL approved supplier, and not necessarily due to the green roof element at all.

Contrary to perceived wisdom in the UK, in Germany it is accepted that a green roof adds value to the waterproofing by protecting membranes from the effects of climatic factors. In general a green roof can extend the life of a membrane by a factor of two if not longer (this is dependent on the quality of the waterproofing, installation and green roof system).

Figure 3. NPV Comparisons of Green Roofs



However, extended warranties and guarantees are not offered as a consequence.

4.8 Lack of Expertise

Roof gardens and terraces are not new to London: the Queen Elizabeth Hall has a series of roof gardens, the roof garden at Barkers of Kensington was installed in the 1930s, and 1 Poultry has a lawn at roof level, to name but a few. A walk around central London reveals that roof gardens are more common than may be first realised.

Number 1 Poultry. Photo: Alumasc

The large-scale use of extensive and semi-intensive green roofs though is relatively new especially at a commercial level. A number of projects were completed in London in the late 1980s and early 1990s, but the use of green roofs in new developments has only risen to the fore in the last five to ten years. In this time, companies in the UK have gained an excellent track record of delivering green roofs, although there continues to be a lack of understanding and expertise of the full range and performance of green roof systems outside of the industry. However, the overall perception that there is a lack of expertise in the UK regarding the provision and implementation of green roofs is false.

4.9 Lack of Policy

A number of living roofs have been built in London in recent years and many more are planned. However, these are being implemented in a piecemeal fashion on a project-by-project basis, very often as a result of developer interest or the need to mitigate for impacts on biodiversity. For example, it is estimated that around eight hectares of green roof are planned in London as mitigation for black redstarts where the birds nesting or foraging habitat is under threat from development [pers. comm. Dusty Gedge].

The implementation of living roofs is not being informed by policy guidance. Very few are being established in order to capture the energy and water management related benefits that can accrue. For these benefits, and particularly those relating to climate change, to be achieved to the full, there has to be wide scale uptake of the technology across London; something that will only happen when firm policy guidance is issued.

Springbok Works
Photo: Cullinan and Buck Architects

5. Conclusions: Supportive Policy and Standards

5.1 Introduction

This chapter concludes the study by examining the basis for a living roofs policy in the London Plan and developing a preferred standard for their implementation.

Appendix 1 to this report summarises financial incentives employed in twelve cities overseas to promote living roofs. These examples serve to illustrate the practical applicability of living roofs policies in cities similar in scale and complexity to London. Whilst these provide encouragement, the legal and regulatory context in London is different and demands the need for a bespoke policy for London that is robust and reflects the GOL (Government Office for London) guidance on the content of the Mayor's spatial strategy.

5.2 National Policy

As yet, there is no explicit statement of national policy requiring or encouraging the use of living roofs and walls. However, it will be evident from the account of the benefits of living roofs explained in earlier chapters of this report that living roofs would support a range of key national policies. These include Securing the Future, the UK government's sustainable development strategy (2005) (Ref: 6.1) and Climate Change: the UK Programme (2006) (Ref: 6.2). In planning terms, the use of Living Roofs would be consistent with a range of policy guidance, including:

- PPS1 *Delivering Sustainable Development* – which amongst other things identifies sustainable development as the core purpose underpinning planning;
- PPG2 *Green Belts* – which are protected where better use can be made of land and buildings within existing urban areas;
- PPS3 *Housing* – which promotes more sustainable modes of construction and delivery;
- PPS9 *Biodiversity and geological conservation*;
- PPG17 *Planning for open space, sport and recreation* – to which recreational roofs can make a useful contribution;
- PPS25 *Development and Flood Risk* – having regard to the SUDS benefits that living roofs and walls can afford.

5.3 The Statutory Basis for a Living Roofs Policy in the London Plan

The examination in public of the London Plan alterations has demonstrated that the living roofs policy in the London Plan complies with the guidance on the general provenance and scope of policies set out in GOL Circular 1/2000 Strategic Planning in London (Ref: 6.3). This circular includes the following relevant advice.

Para 2.3
The spatial development strategy (SDS) may 'contain policies and criteria for determining the acceptability of development proposals, where these raise issues of strategic importance. However, it should not incorporate detail more appropriate for borough development plans'.

Para. 2.7
This describes the 'principal purposes' of the GLA and other legal obligations to which the Mayor must have regard when preparing the SDS. Most relevant to a living roofs policy is 'the achievement of sustainable development in the United Kingdom' as required by section 41 of the Greater London Authority Act 1999.

Para. 2.9
Section 41 of the 1999 Act also requires the Mayor to ensure that the SDS is consistent with national policies.

Para. 2.11
The 1999 Act requires that 'the SDS must deal only with matters that are of strategic importance to Greater London', being matters of more than local importance. It will thus be important to make a strategic justification for including a living roofs policy in the London Plan.

Part 3 of GOL Circular 1/2000 identifies the key issues that the SDS should address. These include the following matters of relevance in the current context:

Para. 3.3
The effect that the SDS would have on the achievement of sustainable development in the UK.

Para. 3.16
The need for housing policies that make the best use of previously developed land.

Para. 3.19
The protection and enhancement of the quality of London's built environment, and the promotion of urban renaissance through good urban design and improvements to the public realm.

Para 3.23
The protection and enhancement of London's 'natural and open environment', including the promotion of 'green chains and ecological corridors of strategic importance'.

Para. 3.26
The SDS 'should be consistent with the London Biodiversity Action Plan' and should 'provide guidance on how UDPs should contribute to the Mayor's strategic environmental priorities'.

This review of GOL Circular 1/2000 (op.cit) confirms that the inclusion of the living roofs policy in the London Plan can be justified because it:

i) assists in the determination of the acceptability of development proposals;
ii) contributes to the achievement of sustainable development;

iii) supports efforts to make best use of previously-developed land;
iv) promotes the enhancement of the built environment and the public realm;
v) promotes the enhancement of the natural environment, including the formation of ecological corridors;
vi) is consistent with the London Biodiversity Action Plan.

The living roofs policy also promotes the objectives of other London Plan policies including:

- policies addressing climate change adaptation (policies 4A.15, 4A.5iii);
- overheating and the urban heat island effect (policy 4A.5iv);
- biodiversity (policy 3D.12);
- sustainable design and construction (policy 4A.2i);
- sustainable drainage (policy 4A.5vii);
- urban intensification and the design principles for a compact city (policies 2A.3 and 4B.1);
- the promotion of world-class architecture and design (policy 4B.2);
- the retro-fitting of buildings to reduce environmental impacts (policy 4.B.4i).

It is concluded that a suitably drafted living roofs policy would support several statutory Mayoral objectives and be consistent with a range of established London Plan policies.

5.4 Conclusion/Recommendation

The living roofs policy and reasoned justification for its incorporation in the London Plan is set out at the end of this chapter. The following points should be noted.

- The policy and justification has been kept brief, focusing on the main benefits of living roofs. Detail about intensive and extensive roofs and their various subsets will be considered in the revised supplementary planning guidance document (SPG.) to the London Plan on sustainable design and construction.

- The text and policy do not major on green walls given their greater technical challenge. Reference is limited to a brief acknowledgement in the supporting text.

- In framing the policy, regard was given to the success of the London Borough of Merton's ten per cent renewables policy, which sought similarly to impose requirements upon developers without there being an explicit planning policy basis for so doing at the time. Merton justified its policy by reference to (then) PPG22: Renewable Energy (now replaced by PPS 22: renewable energy Ref: 6.4) and the national target of providing ten per cent of electricity from renewables by 2010. In the current instance, we have sought to root the living roofs policy through explicit reference to a range of other London Plan policies.

- Early drafts of the policy sought to list the types of building to which the policy should apply. However, this became a long list. Instead, a simpler approach has been taken of applying the policy to all developments above a given floor space threshold, 'where feasible'. The onus of demonstrating non-feasibility would fall upon the developer.

- The policy applies to all schemes referable to the Mayor. More explicit requirements with respect to relevant development types, floor space thresholds and general requirements for living roof provision can be set out in Local development Frameworks (LDF) and Supplementary Planning Documents (SPDs) in line with the policy adopted in the London Plan. The policy relates to the 'application of potential strategic importance'/'large scale development' thresholds set out in the T&CP (Mayor of London) Order. The supporting text requires a developer's proposed means of policy compliance to be specified in the design and access statement that would accompany a planning application.

The policy is as follows.

Policy 4A.11 Living Roofs and Walls

The Mayor will and boroughs should expect major developments to incorporate living roofs and walls where feasible and reflect this principle in LDF policies. It is expected that this will include roof and wall planting that delivers as many of these objectives as possible:

- *accessible roof space*
- *adapting to and mitigating climate change*
- *sustainable urban drainage*
- *enhancing biodiversity*
- *improved appearance.*

Boroughs should also encourage the use of living roofs in smaller developments and extensions where the opportunity arises.

Living roofs can take many forms in order to maximise their benefits in a given location. Vegetated roofs, including terraces and gardens, can improve the thermal performance of the building, reduce the urban heat island effect, absorb rainfall to reduce flash flooding, enhance biodiversity, provide amenity for residents who may not have access to private gardens and improve appearance.

High quality designs for 'green walls' incorporating vegetation over a majority of a building's vertical surfaces will also be considered favourably where living roofs are difficult to achieve. The revised Sustainable Design and Construction SPG will contain further guidance on the appropriate roof type in order to maximise benefits.

The new London Plan policy now expects major developments to incorporate living roofs and walls where feasible. It is clear that living roofs and walls can bring significant environmental benefit, however, the precise degree of benefit achieved largely depends on the technical specification of the roof or wall, although other factors, such as location, aspect and effectiveness of any management, may also play a part. In taking the policy forward and promoting its implementation it is important that guidance is provided regarding how the various environmental benefits can be achieved.

In response to this, standards are proposed for living roofs below, and these should be included in the Mayor's supplementary planning guidance (SPG) on Sustainable Design and Construction as it is revised. These proposed standards seek to achieve an overall maximum environmental benefit. Specific standards on living walls are not included as opportunities for incorporating these are more unique.

5.5 Further Guidance Towards a Preferred Standard
In order to provide the greatest overall environmental benefit from living roofs. It will be essential to develop a preferred standard for designers and developers to adhere to. These can be either intensive, extensive or a recreation roof. The following provides a proposed essential standard for inclusion in the forthcoming revision of the SPG to the London Plan on Sustainable Design and Construction.

Living Roofs – Essential Standard (Draft)
The provision of either intensive, extensive or recreational roof space (or a combination of these) should be provided on all new development.

Further to the above standard the following proposes a Mayor's preferred standard to provide further guidance in the SPG towards the development of an essential standard.

Mayor's Preferred Standard (Draft)

- *A minimum of 70 per cent of the roof space should be vegetated to provide maximum benefit for SUDS, building energy performance and biodiversity.*
- *At least 25 per cent of the total roof space in any one development should be accessible to residents and/or workers.*
- *A roof with an average depth of 100mm substrate with 80 per cent of the substrate having an average holding capacity of approximate 2 litres/10mm/m^2 equivalent providing a potential minimum capacity 20 litres/m^2.*

Depending on the development in question the following guidance may be instructive when trying to achieve particular benefits:

- where some contribution to an overall SUDS scheme is considered to be of importance the minimum holding capacity of the roof should be at least 12 litre/m^2
- where some contribution to the thermal efficiency or cooling of a building is required, an average depth of 100mm to provide maximum thermal mass and evapotranspiration for roofs must be achieved.
- where some contribution to visual aesthetics is required, an intensive/semi intensive roof treatment with a minimum substrate depth 150mm should be used
- where some contribution to the Biodiversity value of the building is required a mosaic of different substrate depths; varying between 75mm and 150mm, seeded and planted with native wildflower species that includes other materials to vary the micro-habitat/ typography characteristic of the locality in which the roof is situated must be provided
- for a recreation roof, some form of ball court or other playing surface should be provided. Adequate health and safety measures for the playing of games and sports on the roof both to protect the players and to prevent equipment and balls falling on people below.

Other factors that will need to be addressed will include:

- location/orientation
- health and safety of users/maintenance crews
- over-shadowing
- requirements for plant and other equipment.

For all options, whether retro-fit or new build, the structural capability of the building will need to be carefully considered before determining a specification.

Appendix 1

Policy Approaches in Other Cities

1 Introduction
This appendix reviews policy approaches adopted in other cities for the purpose of encouraging or enforcing the use of living roofs and green walls. The evidence has been gathered through a literature review undertaken by the consultant team, and includes policies for the following cities:

City	Green Roof Measures
Basel:	building regulations
Beijing:	policy targets
Berlin:	financial incentives and mandatory policy requirements
Chicago:	building regulations and financial incentives
Cologne:	financial incentives
Linz:	planning policy and financial incentives
Munster:	financial incentives
Portland, Oregon:	financial incentives
Seattle:	mandatory policy requirements
Tokyo:	planning policy and financial incentives
Toronto:	financial incentives
Vancouver:	planning policy and building bylaws

For simplicity, living roofs and green walls will be referred to generically as 'green roofs'.

2 Examples

Basel: Building Regulations
In 2002, the city of Basel introduced requirements for green roofs into its building regulations. These specify factors such as the use of native soils and flora, the depth of the growing medium, the inclusion of mounds to encourage insect life, and also include a requirement to consult the city's resident expert on the design of green roofs of 1,000m^2 or more.

Source: Canada Mortgage and Housing Corporation (2006) Green roofs: a resource manual for municipal policy makers.

Beijing: Policy Targets
With the city's Olympic games in 2008 motivating efforts to improve air quality, Beijing has set a policy target of greening 30 per cent of high-rise buildings and 60 per cent of low rise buildings (i.e. less than 12 storeys) by 2008.

Source: Gary Grant (2006) Green roofs and facades.

Berlin: Financial Incentives and Mandatory Policy Requirements
Berlin is one of three German municipalities combining the functions of city and state government in one. The city has pioneered the 'biotope area factor' (BAF), which expresses the ratio between 'ecologically effective surfaces' (e.g. gardens, green roofs, etc) and the total area of a site. BAF target values are set for different forms of development, with new housing attracting a BAF of 0.6 and commercial development 0.3. Different forms of ecologically effective surface then receive a weighting for the purpose of calculating whether the development complies with the BAF target or not. Thus, a conventional sealed roof surface scores 0, and a surface with vegetation with more than 80cm of soil covering (i.e. an intensive green roof) scores 0.7.

These targets are mandatory in 13 zones specified in a legally binding Berlin Landscape Plan, and are applied on a voluntary basis in other areas of the city.

Green roofs result in a reduction of drainage charges of 50 per cent irrespective of whether they are connected to the storm drains or not.

Source: Goya Ngan (2004) Green roof policies: tools for encouraging sustainable design.

Chicago: Building Regulations and Financial Incentives
In response to the city's pronounced heat island effect, the city employs an energy conservation code that requires roofs to achieve a minimum solar reflection or 'albedo' of 25 per cent. Although the city's policy does not state as such, it is accepted that green roofs are a practical means of meeting this requirement.

Chicago also encourages developers by allowing them to develop at higher density than policy would otherwise allow if at least 50 per cent or more less than 160m^2 of a roof surface area – whichever is greater – is covered by vegetation.

Chicago also operates a modest grants scheme and storm water retention credits.

Sources: Gary Grant (2006) Green roofs and facades; and Canada Mortgage and Housing Corporation (2006) Green roofs: a resource manual for municipal policy makers.

Cologne: Financial Incentives
Cologne offers developers reductions in storm water drainage connection charges if their buildings incorporate green roofs meeting specified performance standards.

Source: Goya Ngan (2004) Green roof policies: tools for encouraging sustainable design.

Linz: Planning Policy and Financial Incentives
The motivation for encouraging green roofs in Linz has been the lack of urban green space. The city has a general Green Space Plan (2001) that provides standard policies for inclusion in area development plans. These policies are mandatory. An example is as follows:

New and proposed buildings with an area of over 100m^2 and a slope of up to 20 degrees, excluding shed roofs, are to be greened. The uppermost layer of the green roof construction shall as growing medium have a thickness of at least 12cm and the coverage of living plant material shall be at least 80 per cent.

Linz also offers financial subsidies for construction costs from the roof deck up, with up to 30 per cent of eligible costs reimbursable. These subsidies are available regardless of whether the green roof is mandatory or voluntary, and for both extensive and intensive roofs. To encourage implementation, 50 per cent of the subsidy is paid out after construction and the other 50 per cent once the vegetation has established.

Source: Goya Ngan (2004) Green roof policies: tools for encouraging sustainable design.

Munster: Financial Incentives
The city offers an 80 per cent reduction in storm water drainage charges if a green roof is installed.

Source: Gary Grant (2006) Green roofs and facades.

Portland, Oregon: Financial Incentives
City-owned buildings are required to have a green roof covering at least 70 per cent of the roof. Remaining roof surfaces must be covered with energy-efficient roofing materials.

Other incentives offered by the city include 'floor area bonuses' – understood to be a preferential property tax – and a 35 per cent reduction in storm water management charges.

The city's Ecoroof initiative is intended to raise awareness of the benefits of green roofs.

Source: Review of green roof policy approaches by the Planning Inclusive Communities Agency of Canada, 2006.

Seattle Green Factor: Mandatory Policy Requirements
The Seattle Green Factor is a menu of landscape strategies applying to all new development in neighbourhood business districts comprising more than four dwellings, more than 370m^2 or with more than 20 parking spaces. It is intended to increase the amount and quality of landscape in dense urban areas.

The Seattle Green Factor came into effect in January 2007 and is essentially similar to that employed in Berlin. A city ordnance requires the equivalent of 30 per cent of a site to be vegetated, with bonus weightings awarded for grey water recycling.

Source: Seattle.gov

Tokyo: Planning Policy and Financial Incentives
The city has a target of creating 30km^2 of green roofs. To this end, it applies a policy that compels developers of new private buildings with a footprint larger than 1,000m^2, and new public buildings with a footprint greater than 250m^2, to green 20 per cent of their roof areas or face an annual fine. The policy is effective, stimulating the construction of c. 50,000m^2 of green roofs annually. The Japanese government is now applying Tokyo's policy nationally.

Source: Gary Grant (2006) Green roofs and facades.

Toronto: Financial Incentives
Toronto's strategy for encouraging the use of green roofs includes:
- commitments by the city authority to install green roofs;
- pilot programmes with financial incentives to encourage green roofs in private development;
- awareness-raising programmes.

The city is in the course of pursuing a policy-making process for green roofs that embraces a review of the benefits, focus group workshops, round table meetings and, in April 2008, the adoption of a green roof strategy by the city council. Toronto has a green roofs task force to promote demonstration projects.

Source: Review of green roof policy approaches by the Planning Inclusive Communities Agency of Canada, 2006.

Vancouver: Planning Policy and Building Bylaws
As a pilot programme, the city has published a development plan for the Southeast False Creek neighbourhood – a 25 hectare mixed use development – that requires all buildings to have at least 50 per cent green roof coverage. Steps are also being taken to adjust the city's building bylaws to establish a 'green baseline' for development, including green roofs.

Source: Canada Mortgage and Housing Corporation (2006) Green roofs: a resource manual for municipal policy makers.

Other Cities
The literature review found that many other cities are currently reviewing the potential of green roof policies or promoting demonstration projects.

3 Conclusions

The principal means by which the fifteen cities surveyed encourage or require green roof developments can be summarised as follows:

i) direct financial incentives – grants and subsidies;
ii) indirect financial incentives – reduced drainage charges or larger development allowances;
iii) ecological compensation – the green factor approach;
iv) building regulations and planning policy.

In addition, many of the cities are sponsoring demonstration projects and the provision of information to developers.

Of the twelve cities reviewed in this paper, eight are using planning policy and building control mechanisms. Two – Berlin and Seattle – are promoting the 'green factor' method.

A degree of caution needs to be applied in considering the applicability of these measures in London. The statutory powers available to the city authorities included in this review vary widely. Some, such as Berlin, combine city and regional functions. North American cities often enjoy more autonomy to set building codes, and there is a wide variation in the distinction between planning and building control functions.

In summary, encouragement can be taken from green roof initiatives taken in other cities around the world, but the legal and regulatory context in London is different and will demand a bespoke policy formulation if it is to withstand challenge and meet its objectives. For current purposes, it is obviously essential that any green roof policy in the London Plan is robust and reflects the Government Office for London's guidance on the content of the Mayor's spatial strategy.

Appendix 2

Case Study Matrix

Site Name/ Project Title	Location	Type of Building	Reason for Installation	Benefit a	b	cc	s	Accessibility	Build Up Details	Comments
Intensive										
Royal Arsenal	Woolwich	R/UC?	Amenity Space/ Planning condition [?}	Y	Y	Y	Y	Y	Yes	At grade level on a podium deck
Jubilee Park	LB Tower Hamlets	Tube station	Amenity Space	Y	Y	Y	Y	Y	?	At grade level with water features. Water feature possibly adds to cooling effect
Jacobs Island	LB Southwark	R/UC	Private amenity space	Y	Y	Y	Y	Y	?	Water feature adds to cooling effect possibly. At grade level
1 Poultry	City of London	C	Private amenity space	Y	Y	Y	Y	Y	?	At roof level
Cannon St Station	City of London	C	Private amenity space	Y	Y	Y	Y	Y	?	At roof level
New Providence Wharf	LB Tower Hamlets	R /UC	Private amenity space Possible planning condition	Y	Y	Y	Y	Y	Yes	At grade level
Tower of London History & Gallery shop	City of London	C	Remedial work and visual masking	?	Y	Y	Y	?	Yes	Roof is very close to the White Tower and forms part of the original Keep mound
Bishops Square	City of London	C	Amenity Space for office workers	Y	Y	Y	Y	Y	Yes	On 2/3 levels. Completed in 2006
Hackney Community College	LB Hackney	PB	Lawn covered podium with hard landscaping	Y	Y	Y	Y	Y	Yes	Ground level
Bedzed	LB Sutton	R	Sustainability, Amenity	Y	Y	Y	Y	Y	Yes	Private gardens for residents

Key to Type of Building

R Residential
C Commercial
PB Public Building (community centre/local authority building/community organisation)
UC Above a car park on a podium deck

Key to Benefits

a Amenity
b Biodiversity
cc Climate change adaptation
s SUDS

Site Name/ Project Title	Location	Type of Building	Reason for Installation	Benefit a	b	cc	s	Accessibility	Build Up Details	Comments
Semi Intensive										
Inn the Park	RB Westminster	C	Visual masking, Biodiversity Planning condition re biodiversity	Y	Y	Y	Y	Y	Yes	Ground level up to single storey
Shaws Cottage	LB Lewisham	R	Biodiversity sustainability	Y	Y	Y	Y	Y	Yes	Simple design. Built in early 1990s
North Haringay Primary School	LB Haringey	School	Educational	Y	Y	Y	Y	Y	Yes	
Clayond Gardens and Community Centre	LB Hounslow	PB	Cooling, possible planning constraint	Y	Y	Y	Y	Y	Yes	Thermal mass adds to cooling of the building
Extensive										
9 Stock Orchard St	LB Islington	R	Sustainability						Yes	Sarah Wrigglesworth Practice
1A Hungerford Rd	LB Islington	R	To facilitate planning sustainability, visual amenity						Yes	Private house. The green roof was a desired but it was also felt it would facilitate planning permission
Laban Dance Centre	LB Lewisham	School	Biodiversity, Planning condition						Yes	Use of rubble from site
New Providence Wharf	LB Tower Hamlets	R	Planning condition re biodiversity	N	Y	Y	Y	N	Yes	New Providence Wharf has a variety of different green roof solutions. Good case study as it points the way to how different systems can be integrated
New Providence Wharf	LB Tower Hamlets	R	Planning condition re biodiversity	N	Y	Y	Y	N	Yes	

Please Note
ACCESSIBILITY refers to workers/residents having access to the roof for enjoyment. Most roofs have to be accessible for Facilities Managers and other professionals.

Site Name/ Project Title	Location	Type of Building	Reason for Installation	Benefit a	b	cc	s	Accessibility	Build Up Details	Comments
Extensive										
New Providence Wharf	LB Tower Hamlets	R	Planning condition re biodiversity, Also visual amenity	Y	Y	Y	Y	N	Yes	This roof is the 'best' from an ecological point of view and is interesting in that there was a need to balance visual with bio'
Canary Wharf Estate	LB Tower Hamlets	C	Visual amenity	Y	Y	Y	Y	N	Yes	6 roofs in all covering about 5,000m^2
Container City	LB Tower Hamlets	C/R	Sustainability	N	Y	Y	Y	N	Yes	Containers converted to office and accommodation space
Ethelred Estate	LB Lambeth	R	Sustainability	N	Y	Y	Y	N	Yes	Refurbished local authority residential during re waterproofing
Stephen Lawrence Centre	LB Lambeth	PB	Biodiversity, Planning condition	N	Y	Y	Y	N	Yes	Part of LB Lewisham's drive for green roofs for biodiversity. An interesting success story as away from the rivers and therefore no pressure from EA
Haberdashers-Hatcham college	LB Lewisham	School	Biodiversity, Planning condition	N	Y	Y	Y	N	Yes	
King Alfred School story	LB Barnett	School	Sustainability	N	Y	Y	Y	N	Yes	Single storey
Goldsmith Place	LB Camden	R	Sustainability see comment	N	Y	Y	Y	N	Yes	Interesting roof, use of mats and substrate with non-sedum plugs and seeds. To solve issue of extensive ponding on waterproof membrane. Retrofit
Tesco	LB Sutton	C	Biodiversity, Planning condition	N	Y	Y	Y	N	Yes	Very interesting design on a big span building. Mats and rubble used where loading possible
Barclays HQ	LB Tower Hamlets	C	Biodiversity	N	Y	Y	Y	N	Yes	

Site Name/ Project Title	Location	Type of Building	Reason for Installation	Benefit a	b	cc	s	Accessibility	Build Up Details	Comments
Extensive										
Parliament Hill School	LB Camden	School	Sustainability	N	Y	Y	Y	N	Yes	Good example of sedum plug system
Roots and Shoots	LB Lambeth	PB	Sustainability, biodiversity	N	Y	Y	Y	N	Yes	Combination of sedum plug/'brown' roof/ Balcony greenery
Gold Lane	LB Barnett	R	Sustainability, possible planning condition	N	Y	Y	Y	N	Yes	Good example of green roofs on social housing
BBC Wood Lane	LB Hammer-smith and Fulham	C	?	N	Y	Y	Y	N	Yes	
Calthorpe Project	LB Islington	PB	Sustainability	N	Y	Y	Y	N	Yes	Completed in early 1990s. Good example of simple successful green roof that has stood the test of time
Bedzed	LB Sutton	R	Sustainability	N	Y	Y	Y	N	Yes	Well-known project, though probably providing no energy gain
Highgate Northern Line Control Centre 1845m^2	LB Haringay	C	Visual and Biodiversity, Planning	N	Y	Y	Y	N	Yes	
Royal Holloway	Egham	PB	Sustainability	N	Y	Y	Y	N	Yes	Large area
New North Community Centre	LB Islington	PB	Sustainability/ Education	?	Y	Y	Y	N	Yes	
Stakesfield Primary School	LB Enfield	School	Sustainability/ Education	N	Y	Y	Y	N	Yes	Large area
New St SQ	City of London	C	Sustainability biodiversity possible planning condition	N	Y	Y	Y	N	Yes	
Young Vic	LB Lambeth	PB	Memorial planting for loss of life WW2	N	Y	Y	Y	N	Yes	

Appendix 3

Whole-life Costing

There are a number of common ways to calculate Whole Life Costing (WLC) that include:

- **Discounted Cash Flow, or DCF**. This is the sum of all future inflows and outflows of cash discounted using a Discount Rate to estimate the future value of the cashflows. The answer can be positive or negative
- **Net Present Value, or NPV**. This is also the sum of all future inflows and outflows of cash discounted using a Discount Rate to estimate the future value of the cashflows. The answer is usually positive, however, negative NPV is entering common usage. NPV is one type of DCF, however, it is the description most used for a DCF calculation today
- **Total Whole Life Cost, or TWLC**. This is the sum of all future inflows and outflows of cash, but it is not discounted
- **Annualised Whole Life Cost, or AWLC**. This is the non-discounted sum of cashflows divided by the number of years in the study period.

All these methods produce a number – not £'s that can be ever seen or are tangible – and that number is unique to the calculation and the time of calculation. The complication is that NPV is often reported with a £ sign which rather confuses matters.

The value of WLC is to compare and select between options, and simply, the option with the largest positive number provides the highest financial returns.

So if the NPV of 200mm of insulation is 1000, and the NPV of 250mm of insulation is 1500, then we should select the 250mm option, as it offers a better return on the initial investment over the life of the asset.

As with all assessments, the more complex the method becomes, the more difficult it is to be accurate. One particular problem with WLC is that many elements cannot be financially assessed through lack of information.

For example, the manufacturers can give very good estimates of the additional U value of the deeper insulation that means energy savings can be calculated. However, even here the use profile may not be known at all. The energy savings will be much greater for a seven-day operation, such as a call centre, than a traditional nine to five office.

In other cases, the savings can be calculated, but the cost of the calculation is too high to justify the exercise. However, there are ways that this can be worked with, because as the WLC answer is a comparator, any unknowns can be factored in as an estimate.

Also, with WLC, any common costs can be ignored since they will be the same for all options. So, in the insulation example, the waterproof covering can be ignored, as it's the same for both options.

The Structure of the Analysis

The types of Green Roof that were analysed for this study were;

- extensive roofs
  o insulation under the waterproofing
  o insulation over the waterproofing and for both;
  o mat based installations
  o substrate based installations
- semi-extensive roofs
  o substrate based installations
- intensive roofs
  o substrate based installations.

The green roofs were modelled on the basis of a common underlying structure to ensure that the impact of this component on the NPV calculations and comparisons was the same for each roof type. The assumed structure is a reinforced concrete frame, and that the drainage is the same across all roofs.

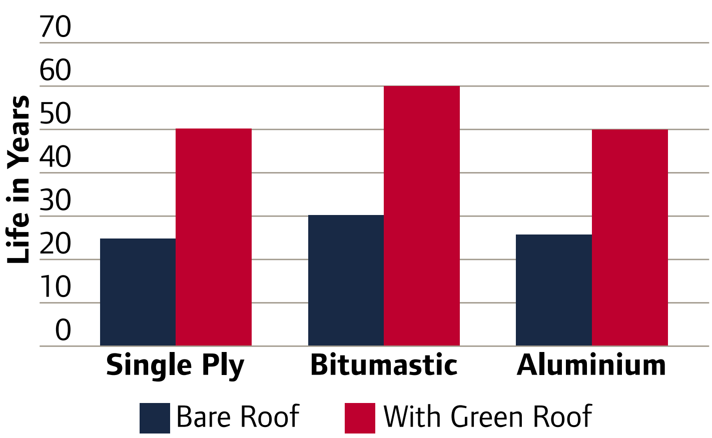
There are potentially a number of benefits of green roof many of which are dealt with elsewhere in this report. However, in the following calculations only energy reduction and the extended life of the roof covering have been taken into account as cost in use impacts; all other savings have been ignored due to site specific cost impacts or insufficient data.

It is generally accepted by the European roofing industry that the protection provided by a green roof extends the life of the roof's waterproofing. The following asset lives were adopted for this study.

Table A3.1: Service Life of Waterproof Layer

	Single Ply	Bitumastic	Aluminium
Bare Roof	25	30-35	25
With Green Roof	50	60-70	50

Figure A3.1: Comparisons of Service Life



Selection of Discount Rate is very important in any analysis, as five and ten per cent Discount Rates for the same conditions give very different results see Table 7.

Table A3.2: How Discount Rate Affects Value of NPV

Discount Rate	NPV
5 per cent	24188
7 per cent	19307
8 per cent	17350
10 per cent	14154

While Net Present Value is a very robust approach to analysis with very few areas open to manipulation, it should be acknowledged that a skilled practitioner in NPV can influence the result by selecting an inappropriate Discount Rate.

The choice of Discount Rate has a high impact on Green Roof projects, as they typically involve significant costs of construction in the present day (i.e. 100 per cent non discounted costs), and benefits that accrue over the life of the roof. This means that higher discount rates make these projects look less attractive than cases with identical costs and benefits, but lower discount rates. (For more information on Discount Rates see http://www.wlcf.org.uk/ChoiceOfDiscountRates.htm).

The Discount Rate used in this report is eight per cent, which is a good "average" rate when the actual rate for a specific business cannot be calculated.

The NPV model used for this study assumed a 33-year life simply for the sake of convenience. Modelling over a longer period would have changed the numbers but not the comparative result.

In the case study illustrated in Section 5.5, it has been assumed that the building is owner occupied, and that the cost in use savings can be realised by the developer.

If the developer intends to sell the investment after the tenant is found, the benefits will translate into a better yield and shorter letting voids.

See 'A Developers Guide to Green Roofs', The Green Roof Centre, Sheffield University www.thegreenroofcentre.co.uk and section 15.5 for further explanation.

Appendix 4

Research Management Structure and Wider Stakeholder Involvement.

Research Steering Group

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Eli Konvitz	Arup / FALP Climate Change Research
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Chinese
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Punjabi
ਜੇ ਤੁਹਾਨੂੰ ਇਸ ਦਸਤਾਵੇਜ਼ ਦੀ ਕਾਪੀ ਤੁਹਾਡੀ ਆਪਣੀ ਭਾਸ਼ਾ
ਵਿਚ ਚਾਹੀਦੀ ਹੈ, ਤਾਂ ਹੇਠ ਲਿਖੇ ਨੰਬਰ 'ਤੇ ਫ਼ੋਨ ਕਰੋ ਜਾਂ ਹੇਠ
ਲਿਖੇ ਪਤੇ 'ਤੇ ਰਾਬਤਾ ਕਰੋ:

Vietnamese
Nếu bạn muốn có văn bản tài liệu
này bằng ngôn ngữ của mình, hãy
liên hệ theo số điện thoại hoặc địa
chỉ dưới đây.

Hindi
यदि आप इस दस्तावेज की प्रति अपनी
भाषा में चाहते हैं, तो कृपया निम्नलिखित
नंबर पर फोन करें अथवा नीचे दिये गये

Greek
Αν θέλετε να αποκτήσετε αντίγραφο του παρόντ
εγγράφου στη δική σας γλώσσα, παρακαλείστε ν
επικοινωνήσετε τηλεφωνικά στον αριθμό αυτό ή
δρομικά στην παρακάτω διεύθυνση.

Bengali
আপনি যদি আপনার ভাষায় এই দলিলের প্রতিলিপি
(কপি) চান, তা হলে নীচের ফোন্ নম্বরে
বা ঠিকানায় অনুগ্রহ করে যোগাযোগ করুন।

Turkish
Bu belgenin kendi dilinizde
hazırlanmış bir nüshasını
edinmek için, lütfen aşağıdaki
telefon numarasını arayınız

Urdu
اگر آپ اِس دستاویز کی نقل اپنی زبان میں
چاھتے ھیں، تو براہ کرم نیچے دئے گئے نمبر
پر فون کریں یا دیئے گئے پتے پر رابطہ کریں

Arabic
إذا أردت نسخة من هذه الوثيقة بلغتك، يرجى
الاتصال برقم الهاتف أو مراسلة العنوان
أدناه

Gujarati
જો તમને આ દસ્તાવેજની નકલ તમારી ભાષામાં
જોઈતી હોય તો, કૃપા કરી આપેલ નંબર ઉપર
ફોન કરો અથવા નીચેના સરનામે સંપર્ક સાધો.

Design for London

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MAYOR OF LONDON