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Green Roofs: their existing status and potential for conserving biodiversity in urban areas

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Green Roofs: their existing status and potential for conserving biodiversity in urban areas

EcoSchemes Ltd
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StudioEngleback

Environmental Impacts Team

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Summary

This report assesses the potential for green roofs to benefit the conservation of biodiversity in urban areas. It takes forward an earlier report (*Roof gardens – a review*) published by English Nature's predecessor, the Nature Conservancy Council, in 1990, and reflects a renewed groundswell of interest in green roofs in recent years. The introduction considers the huge untapped potential of roofs and the advances being made in roof greening in Germany, where 13.5 million square metres of green roof were installed in 2001.

A brief history provides examples of roof gardens from ancient times, through the Italian Renaissance, on to the garden city movement of the late 19th century and the modernist movement of the 20th century. Classic roof gardens of the 1930s are described and the post-war growth in the green roof industry in Europe.

The three categories of green roof are explained: intensive (equivalent to parks or gardens); simple intensive (with well maintained lawns or ground cover); and extensive (low maintenance and normally low growing turf, moss or sedum mats)

The various benefits of green roofs are discussed - these include:

- attenuation of storm water run-off;
- absorption of air pollutants and dust;
- reduction in the 'urban heat island' effect;
- provision of wildlife habitat;
- attractive open space;
- health benefits;
- protecting the building fabric from sunlight and temperature fluctuations;
- reducing costs, including drainage, heating, air conditioning.

The policy background for roof greening in the UK is examined. Although policies on urban renewal, the construction industry, open space, green networks, biodiversity conservation, sustainable urban drainage and urban design are all relevant, in the UK policy makers have largely ignored green roofs.

In the chapter on ecology and biodiversity it is suggested that almost any habitat that can be re-created could in theory be created on a roof. However, in practice technical and financial constraints mean that grasslands, sedum mats, mosses and arrested pioneer communities will tend to predominate. In the UK, there is currently interest in using green roofs as mitigation for habitats lost during urban regeneration, especially on brownfield sites. Studies of natural colonisation on neglected roofs provide useful guidance for those who may be designing green roofs for ecological mitigation purposes. There is little information relating to the fauna of green roofs, however a study of several roofs in Basel, Switzerland, has shown that they support many invertebrates including Red Data Book species, and have a significant positive effect on several bird species (including black redstart - which makes this work of special interest for urban biodiversity conservation in England). A review of UK

Biodiversity Action Plans identifies several species which might benefit from green roofs, including bats, several birds, beetles, flies, bees, wasps and spiders.

Various issues to be considered by those planning green roofs include urban design; building structure; waterproofing of the building; protection of the waterproofing layer; insulation; growing medium; drainage; irrigation; fire prevention; access; maintenance and cost. These issues are considered in turn in the chapter on construction and design.

The report concludes by reiterating that green roofs can provide many general environmental and associated aesthetic and health benefits. Although individual green roofs offer local environmental benefits, any significant contribution to wider environmental quality is only likely to become apparent once a more substantial area of town and city roof space has been greened. Such a programme will require political commitment and concerted action underpinned by science, technical expertise and good design. In order to refine the design of green roofs for biodiversity conservation, some further research and experimentation is required. Suggestions include studies of patterns of colonisation and succession on green roofs of different types over a number of years and experimentation with different designs.

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1. Introduction

For centuries there have been some city dwellers who have considered their environment to be unnecessarily barren and have sought to improve life by making space for nature in the form of parks and gardens. More recently, with cities continuing to grow in size and complexity, the search for potential greenspace has led people to look more closely at the buildings themselves. Most of the unused space in towns and cities is on the rooftops - for example, buildings (and therefore roofs) cover 24,000 hectares or 16% of Greater London (GLA 2001[a]), which is equivalent to an area 28 times the size of Richmond Park. An estimated 20,000 hectares (200 million m^2) of existing urban roofs in the UK could be vegetated with little or no structural modification (Corus 2001). In Germany, the country which leads the world in roof greening, 1 million m^2 of green roofs were installed during 1989 (Thompson & Sorvig 2000). In 1997 the figure had climbed to 11 million m^2 and in 2001, 13.5 million m^2 of green roofs, costing an estimated €250 million (£153 million) were installed (Haemmerle 2002). However, in the UK green roofs still appear to be a novelty and those that have been established are largely for showcase buildings or environmental centres, perhaps giving the impression that they are not appropriate for mainstream buildings. The winter floods of 2000/2001 reminded us of the need to reduce surface water run-off in our towns and cities; this could be achieved, in part at least, through the provision of vegetated drainage systems. The development of brownfield sites through the urban renewal process means that some existing urban green spaces will be lost. There is the potential for green roofs and other building integrated habitat to help solve some of these apparently intractable problems.

The broader environmental benefits of green roofs are well-tested and becoming better known. Green roofs make buildings more thermally efficient, prolong the life of a roof, ameliorate the extremes of temperature and humidity, moderate surface water run-off, help to reduce air pollution and noise and provide greenspace for people and wildlife. In addition, the vegetation that green roofs provide within an otherwise grey urban setting may have psychological benefits for people who overlook them. All this suggests that green roofs have the potential to play a significant part in improving the quality of urban life.

Green roofs, vegetated facades, nest boxes, voids and various other features) can support a range of plants and animals. Indeed, building-integrated habitat may come to play an important role in the conservation of urban biodiversity. In towns and cities, where open land is particularly scarce, and where market forces and policies favour re-development, maintaining and creating the natural green space on which wildlife depends is particularly challenging. In the modern cityscape, brownfield sites are of special note for they are often of significant biodiversity interest. As the majority of vacant urban sites will be subject to re-development pressure, the task of meeting biodiversity conservation objectives in towns and cities becomes ever more difficult. It will increasingly require new approaches and innovative techniques.

Multi-functional environmental design can ensure that elements on, in and around buildings serve several purposes. A roof or external wall can be more than just a weather-proof surface or structural element - it can be part of a living, cooling, cleansing skin. Recent experience with a wide range of projects shows that what would normally be a relatively sterile feature on a conventional structure can become a valuable wildlife habitat. This report reviews existing green roof practice and focuses on its value for biodiversity, particularly in the urban context.

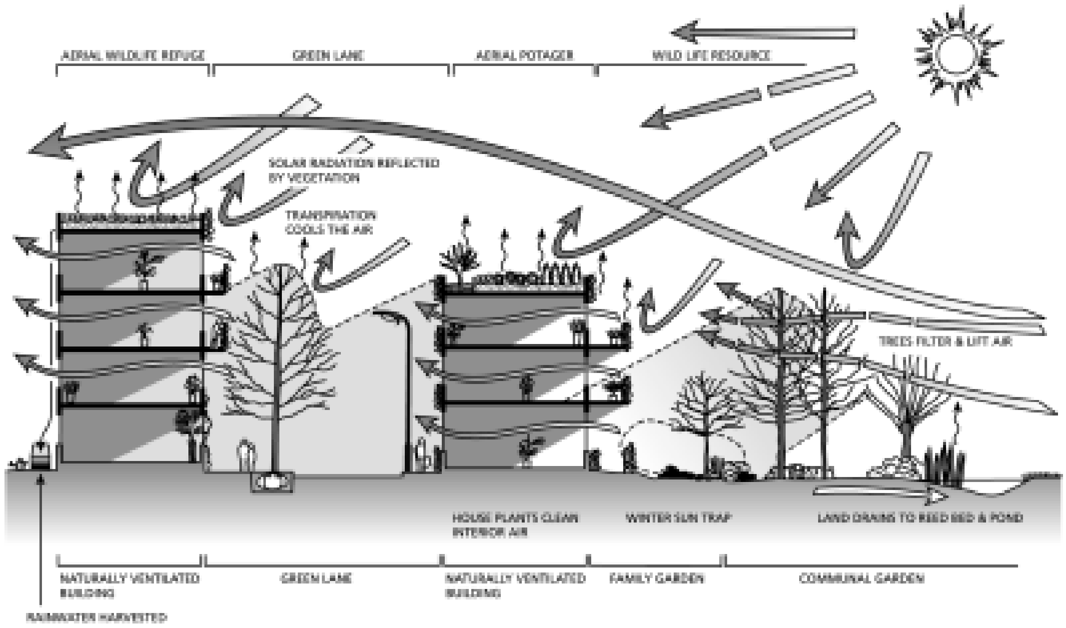

Figure 1 Multifunctional Urban Design

Graphic: Studio Engleback

2. Overview

2.1 Definitions

The term ***green roof*** is used here to describe both intensive ornamental roof gardens and extensive roofs with more naturalistic plantings or self-established vegetation. Brownlie (1990) has defined a ***roof garden*** as an area of usually ornamental planting with a substrate isolated from the natural ground by a man-made structure of at least one storey. We extend that definition to roofs that have been initially planted and/or sown, as well as those that have been allowed to colonise and develop naturally. They do not necessarily have to be ornamental in function. ***Eco roof*** is a term usually used to describe a naturalistic extensive green roof (see 'Categories of Green Roof' below for explanation of extensive and intensive). The term ***spontaneous green roof*** is used to describe a roof covered with self-established vegetation.

When the exterior walls (facades) of buildings are vegetated they are known as ***green facades***. Masonry may become colonised by lichens, mosses, grasses and flowering plants that in nature grow on cliffs and rocky outcrops. Climbing plants may grow directly against the building fabric or may climb trellis work. Geotextile blankets may be attached to walls and seeded with moss or *Sedum*. It is even possible to grow reedbeds in fabric pockets attached to walls.

Earth-sheltered structures are set into the ground, with a continuous earth cover replacing at least part of what would be the walls and roof of a conventional building. Such buildings are usually well vegetated and blend well with the landscape and are usually associated with rural locations. Earth-sheltering is outside of the scope of this report.

Where vegetation is deliberately planted, seeded or encouraged to establish itself on buildings, whether it be on the roof or on the exterior walls, we suggest the use of the term ***building-integrated vegetation***.

Building-integrated habitat is a term we suggest to describe any deliberately established habitat on buildings, including substrates, vegetation, perches, artificial roost and nesting containers, boxes and voids.

On ***brown roofs*** the intention is to allow ruderal vegetation (vegetation associated with disturbed sites) to colonise low fertility substrates like those found in the rubble of demolished buildings.

Wildlife overpasses are modified, often vegetated, bridges designed to allow wildlife to cross major road or rail corridors (Jackson 1996). These structures illustrate the potential for establishing vegetation on buildings. Examples include highway overpasses planted with native woodland for use as bear and wolf crossings in the Canadian Rockies (Leeson 1996), crossings for small mammals and deer in the Netherlands, deer crossings in Hungary and shrub-planted dormouse bridges over the Channel Tunnel Rail Link in Kent.

The term green roof is extended by some to include roofs which are green in the environmental sense, for example energy efficient roofs such as those with extra insulation or photo-voltaic (PV) cells or those made of sustainably-produced or recycled materials. Our definition of green roofs excludes these, although we recognise the contribution such features can make to conserving biodiversity in a more global context. Advice on PVs is contained in an annex to PPG22 Renewable Energy.

Example

BedZed, Beddington, London Borough of Sutton.

Designed by a team led by architect Bill Dunster, BedZED (Beddington Zero Energy Development) is a mixed housing and work space scheme which aims to embrace all aspects of sustainable development. There are 82 homes and 1600m^2 of workspace with the first units occupied in 2001. Every part of the roofscape is used for passive solar, PVs, roof gardens or extensive *Sedum* coir mats. South facing roofs and facades have been utilised for collecting solar energy (either passive solar or PVs). Flat roofs have been used to provide private gardens where 300mm of soil has been covered with turf (but owners or tenants will be free to grow whatever they wish). This has meant that extensive green roof has been limited to the remaining (mainly north facing) areas. This scheme illustrates how the adoption of solar technology can limit the area available for building-integrated vegetation. However it was possible to provide sufficient capacity to collect solar energy for the needs of the buildings whilst leaving space for vegetation. One limitation of this kind of scheme is that flora and fauna which requires a sunny aspect is not provided for.

2.2 Categories of green roof

The German Landscape Development Research Society (FLL) has identified three categories of green roof on the basis of use, construction method and maintenance requirements (FLL

1995). These classifications may not always be clear cut - intermediate or mixed types of green roof are possible.

The three types are:

- intensive;
- simple intensive;
- extensive.

Intensive green roofs are usually referred to as roof gardens. They are equivalent to gardens or parks at ground level. They may include lawns, beds, shrubs and tree plantings - even water features. They are usually constructed over reinforced concrete decks and are normally accessible. They require frequent maintenance including irrigation, fertilising and weeding. With deep soil layers, planters and other installations, this type of green roof has the highest demands on building structure and is the most expensive to build and maintain - although it will usually form a very small part of the overall cost of the (usually substantial) development that it is associated with.

Simple intensive green roofs are vegetated with lawns or ground covering plants. This vegetation requires regular maintenance, including irrigation, feeding and cutting. Demands on building structure are moderate and this type of roof is less expensive to build than intensive green roofs but more expensive and complex than extensive green roofs. They are occasionally accessible, though more often designed to be overlooked.

Extensive green roofs require minimal maintenance and are not irrigated (except in some cases during establishment). Vegetation normally consists of mosses, succulents, herbs or grasses and is intended to be self-sustaining. There is often an emphasis on the use of native species and ecological objectives. This type of roof is not normally designed to be accessible, except for maintenance, and may be flat or sloping. If a typically thin substrate is used it is the least demanding in terms of building structure and the least costly to build and maintain. Extensive roof systems would usually represent an increase in the initial cost of roofing for small-scale developments. However they would not normally form a significant part of the overall cost of a large commercial or industrial development. Although there are currently no examples on buildings, extensive green roofs could include woodlands if sufficient depths of soil were provided.

2.3 A brief history of green roofs

Green roofs and roof gardens are not new – their history began in ancient times. Although the exact details of their location and appearance are not recorded, it is believed that the Hanging Gardens of Babylon, which were built sometime between the eighth and sixth centuries BC in Mesopotamia, were raised terraces, irrigated and planted with groves of trees.

Roof gardens have been identified in the ruins of Roman Herculaneum, buried during the eruption of Mount Vesuvius in AD 79. Mediterranean rooftops had boasted gardens long before and have ever since (Whalley 1978).

In Ireland and the Scottish Islands the remains of earth-sheltered huts dating from the Viking period have been found. Scandinavians have continued to use sod (or turf) to cover pitched roofs and the practice continues to the present day (Brownlie 1990). Settlers in the American mid-west in the early 19th century constructed entire houses from turf. Although the walls were usually scraped clean, the turf roof was left to grow.

There are examples of roof gardens from the middle Ages, including the monastery at Mont Saint Michel in Normandy, which was rebuilt in the 13^{th} century. The cloisters of each level are the roofs of the accommodation below them. Planting includes lawns, herbaceous borders, vegetable patches and hedges.

The Palazzo Piccolomini at Pienza in Italy is one of the first of the Renaissance roof gardens, built for Pope Pius II in the 15^{th} century. Possibly the highest roof garden of that era was constructed in Lucca at the top of the 40 metre Benettoni Tower, supporting four large oak trees. The exact date of construction is not known but it appears in an engraving of 1660. Other roof gardens were constructed for the Medici family in Tuscany and the Gonzaga family in Mantua.

Notable examples of roof gardens in imperial Russia were those created at the Kremlin, Moscow and the Hermitage, St Petersburg (founded 1764).

Sennett (1905) was a proponent of garden cities. The roof gardens of Berlin, which had become a well-known feature of the city by the end of the nineteenth century, were his inspiration for a call for the widespread use of roof gardens in Britain. Bardswell (1923) however, noted that roof gardens in London were 'few and rare' but describes examples such as the roof garden of the Home for Working Boys in Bishopsgate Street in the City of London, which had trees up to twenty feet high including, sycamores, limes, 'nut', cedar, chestnut, holly, fir and plane. In the early twentieth century leading modernist architects including Frank Lloyd Wright, Le Corbusier (Le Corbusier 1924) and Roberto Burle Marx continued to advocate the use of roof gardens. Two celebrated pre-war roof gardens still exist - the roof gardens to the Rockerfeller Center in New York, and the Derry and Toms garden in Kensington, London. Both date from the 1930s.

In the 1960s a few office complexes in Switzerland (e.g. Grosse Schanze Park, Bern and Ciba Geigy Building, Basel) included roof gardens. Advances in flat-roof waterproofing technology gave more architects the confidence to specify roof gardens during the 1970s, when they became more common in Scandinavia, Germany, Switzerland and the United States (Whalley 1978). There were a few examples in the UK, the best known being the Willis, Faber and Dumas building in Ipswich, which was recently listed by English Heritage (built 1971) and Gateway House, Basingstoke (built 1976).

Although specialist green roof companies were established in Switzerland and Germany as early as the late 1950s, it was not until the 1970s that extensive low maintenance grass or *Sedum* roofs became commonplace. The industry continued to expand rapidly during the 1980s and 1990s with interest beginning to spread throughout the rest of Europe and North America.

2.4 Benefits

The various benefits of green roofs have been discussed by Brownlie (1990), Johnston (1995), Johnston & Newton (1993), Osmundson (1999) and Wells (2001). They may be summarised as follows:

Environment
- attenuation of stormwater run-off
- run-off attenuation reduces sewer overflows
- option of cleaning and recycling grey water
- absorption of air pollutants and dust
- reduction in the 'urban heat island' effect
- increased humidity
- absorption of noise
- absorption of electromagnetic radiation
- helping to absorb greenhouse gases (particularly CO_2) and giving off oxygen
- use of recycled materials

Ecology & Biodiversity
- provision of new wildlife habitat
- replacement of habitat lost through development
- provision of quiet refuges
- providing links or stepping stones in greenspace networks
- often only available green space in inner urban core

Amenity
- more options for designers
- hides grey and uniform roofing materials
- screens equipment
- attractive views of vegetation
- extension of park system
- provides gardens - more people space

Health
- psychological benefits of contact with nature
- improved air quality – helps to reduce lung disease
- improved water quality

Building Fabric
- Protecting the roof from ultra violet radiation
- Protecting the roof from mechanical damage
- reducing diurnal/seasonal temperature changes in roof
- may improve thermal insulation

Economic

- extend roof life
- attract buyers/tenants
- may reduce water/sewer charges
- reduce heating and air conditioning costs
- use of recycled materials from site reduces costs

Education

- Green roofs can provide outdoor classrooms in inner city areas

These benefits are discussed in more detail in the chapters on construction, environment and ecology.

3. Policy background

In the UK there are currently no public policies that relate directly to green roofs, however policies on urban renewal, construction, open space, nature conservation and drainage do have some relevance and these are considered in turn as follows:

3.1 Urban renaissance

The Government continues to highlight the need to tackle the many problems facing England's towns and cities: Following the Urban Task Force's report *Towards the Urban Renaissance* (1999) and the 17th Report of the House of Commons Select Committee on Environment, Transport and Regional Affairs (Anon 1999) the Government published its Urban White Paper (DETR 2000). Although the Urban White Paper promotes the recycling of brownfield sites and the need to protect the wider countryside from inappropriate development, it also emphasises the importance of quality urban design and the value of open green spaces in cities. It is recognised that a past obsession with zoning for different land uses and a slavish adherence to planning guidelines and standards has led to urban decay and ugly low-density, land-hungry suburban development. It has been suggested that future emphasis in urban redevelopment should be on innovative, sustainable, well-designed, higher density, multi-functional schemes. It seems likely that building-integrated habitat, including green roofs, will play an increasingly prominent and useful role in this demanding new policy environment.

3.2 Building and design

English Nature has sought to understand and address the impacts of key economic sectors on the delivery of nature conservation objectives through its sector analysis programme. English Nature's Construction Sector Analysis (Sisman 2001) identifies the obvious wide ranging and often significant negative impacts associated with that industry. However it also recognises that there are opportunities for the enhancement and creation of new wildlife habitat. The construction industry itself is currently undergoing change. The Deputy Prime Minister's Construction Task Force identified a series of key performance indicators for a modernised construction sector (Egan 1998). Part of the follow up to that report was a Sustainability Working Group which identified biodiversity as one of its key performance indicators. The emphasis in these policy documents is on the avoidance of damage to existing sites of conservation value, especially SSSIs, and the appropriate management of land. However, the potential contribution the construction industry could make to benefit biodiversity through the widespread use of green roofs, particularly those with self-established vegetation or plantings in naturally occurring combinations has been overlooked.

Architects are increasingly aware of the need for environmentally responsible design (e.g. Melet 1991, Roaf et al 2001, Schmitz & Gunther 1998, Van der Ryn 1996, Wines 2000, Yeang 1995, Zeiher 1996) and there is recent evidence of a growing interest in green roofs (Harman 2002). Construction industry initiatives like the Building Research Establishment Environmental Assessment Method (BREEAM) for assessing the environmental performance of new buildings have some versions that include consideration of nature conservation aspects, which can encourage the creation of building-integrated habitat.

The Construction Industry Research and Information Service (CIRIA) promotes best environmental practice in the industry and manages the Construction Industry Environment Forum (CIEF). It has produced research that proposes the adoption of environmental indicators that encourage habitat creation (CIRIA 2000[a]) which by implication would include green roofs.

Recent official guidance on urban design in the UK (see DETR/CABE 2000, DTLR 2001, Llewellyn-Davies 2000) has overlooked the role and value of green roofs. Building-integrated vegetation needs to be recognised as a distinct landscape type with a useful role in an urban design context. It is hoped that the Commission on Architecture and the Built Environment (CABE), the Government's adviser on urban design and a champion of beauty and innovation, will turn its attention to the issue.

3.3 Open space

As England's towns and cities have grown, so local communities have made an effort to ensure that sufficient open space is provided for outdoor recreation and visual relief from the built environment. For example, local plans often aspire towards the National Playing Field Association's standard of 6 acres (2.43 hectares) per 1000 people for playing fields and more modest targets for other types of park. Normally, insufficient open space exists in inner city areas to meet guidelines for open space provision. This has led to the adoption of strategies of hierarchical provision of open space, whereby the objective is to ensure that open space of various type and size is provided within easy access of everyone. Now added to policy demands for open space for sport, relaxation and informal play are new demands for more natural areas that provide wildlife habitat. PPG 17 Planning for Open Space, Sport and Recreation (ODPM 2002) recognises these natural green spaces within the typology of open spaces. The World Health Organisation encourages local authorities to recognise and act upon the links between open space provision and health (WHO 1997). Open spaces encourage people to exercise and interact and the vegetation filters out pollutants, cools the city, provides wildlife habitat and can help reduce noise.

3.4 Green networks

Green networks are interlinked natural or vegetated open spaces in otherwise built up or intensively exploited areas. Green networks are promoted through various policies at European and national level. In England, official policy (PPG9 Nature Conservation and PPG 17 Open Space, Sport and Recreation) emphasises the importance of corridors and linkages. Dense development in urban areas interrupts green corridors or links and there will normally be limited opportunities to create substantial new areas of greenspace. Roof greening is a promising method of addressing this problem.

English Nature has promoted the concept of multi-functional green networks (Barker 1997). Added to the early ideas of open spaces being important for recreation and beauty are the additional functions of biodiversity conservation, sustainable drainage, pollution abatement, local transport corridors, climate amelioration and outdoor classrooms (Countryside Commission *et al* 1991, Forman 1991). Green networks have their origins in linear parks which link urban parks to rural areas, an approach spearheaded in the US and then adopted in Europe (Little 1990). In the UK green networks have been promoted through the concept of green chains and wildlife corridors as pioneered in the new towns of Telford and Milton Keynes. Green chains figure in a number of UDPs and are recommended in strategic planning guidance for London. Green chain policies seek to link accessible open spaces. Green roofs could be used to improve the more urban sections of chains.

Although the ability of habitat corridors to act as conduits for wildlife in fragmented landscapes is unproven (Dawson 1994, Hill *et al* 2001), they may still be attractive open spaces for people and can be valuable habitats in their own right. Barker (1997) suggests that in the disturbed environment of lowland England 'a close mosaic of stepping stone habitat patches may be as effective as a continuous strip in allowing [many species] to permeate the whole area'. This suggests that green roofs, being part of a building, and therefore not normally a key part of a wildlife corridor, could become valuable components of a mosaic of stepping-stone habitats in urban neighbourhoods.

Inspired by the idea that people require contact with nature as part of everyday life (Rohde and Kendle 1994), English Nature has adopted its own standards for the provision of easily accessible natural greenspace in urban areas (English Nature 1996). The recommendations include one that 'urban dwellers should have an accessible natural greenspace within 300 metres from home'. Green roofs could help such an objective to be met in densely developed neighbourhoods.

Even open spaces which are inaccessible to people are important, constituting secondary elements in a green network (e.g. in providing visual benefits) and providing refuges for wildlife which may colonise or visit adjacent, publicly accessible open spaces. In this way inaccessible green roofs could provide a valuable role providing additional habitat and species diversity in urban areas.

3.5 Biodiversity Action Plans

The Rio Declaration of the United Nations Conference on Environment in 1992 – the Earth Summit - led to the formulation and adoption of strategies for sustainable development and biodiversity conservation in 150 countries. In 1994 the UK Government published *Biodiversity: The UK Action Plan* and established the UK Biodiversity Action Plan Steering Group which started to publish countrywide targets and action plans in 1995. However action for priority habitats and species has rarely been focused within towns and cities. Local Biodiversity Action Plans (LBAPs) have subsequently been developed through many local authority-facilitated partnerships to translate national targets for species and habitats into effective action at the local level. They also identify conservation priorities which reflect the local character of an area. LBAPs which target buildings or the built environment include Newcastle (2001) and Westminster (2000). A number of species and habitat action plans have been published which can be directly linked to green roofs and built structures, such as black redstart (Birmingham & The Black Country, London), peregrine falcon (London) and a long-tongued bumblebee (London).

3.6 Nature conservation strategies

Local planning authority nature conservation strategies (which mostly date from the late 1980s and nowadays are seen as underlining an authority's commitment to a LBAP) recommend the protection of sites of conservation interest. As well as SSSIs, planning authorities normally identify sites of county or local value, where development would not normally be permitted. However it is recognised that local sites may be developed if there is an over-riding need. In such cases the authorities may require that equivalent areas be created nearby so that the overall area of wildlife sites is maintained. Such approaches aim to maintain an area's 'natural capital'. Where sites of recognised value are developed and the site lost consists of habitats that are re-creatable, green roofs could play a role in ensuring that the overall stock of greenspace is maintained or increased.

3.7 Protected species

Various species receive special protection under legislation such as the Wildlife and Countryside Act 1981 (as amended) or the European Union Habitats Directive 1992. Some of these are associated with derelict buildings, brownfield or other urban areas deemed suitable for redevelopment. Examples include birds such as the black redstart, which in England shows a marked tendency to breed and forage on urban derelict sites and which is listed in Annex I of the European Habitats Directive and included on Schedule 1 of Wildlife & Countryside Act 1981. Green roofs may provide the necessary habitat for this and other 'wasteland' species as redevelopment proceeds (Bertrand 2002, Frith et al 1999, Frith & Gedge 2000, Wells 2001).

3.8 Sustainable urban drainage systems

PPG 25 Development and Flood Risk reminds us that development reduces surface permeability by replacing vegetated ground with roofs and paved areas. It recommends the use of sustainable urban drainage systems (SUDS) as a way of reducing problems associated with rapid run-off and higher peak flows in urban areas (see also SEPA 1997, 2000, CIRIA 2000). Although green roofs can form a valuable component of SUDS, -their potential is not yet recognised in official UK advice.

3.9 Swiss and German policy examples

The impressive advances in roof greening in Switzerland and Germany have been attributed to the policy environment. In Switzerland, federal law requires all federal agencies to apply the 'Swiss Landscape Concept' when commissioning or rehabilitating federal buildings and installations. This means that facilities must be compatible with natural settings and landscape (SAEFL 1998). Laws also require that 25% of all new commercial developments are 'greened' in an attempt to maintain microclimates.

In Germany 43% of cities offer financial incentives for roof greening (DDV 2001). Osmundson (1999) has reviewed German policy on roof greening: of the 193 large cities in Germany, 29 (including, Berlin, Boblingen, Frankfurt, Karlsruhe, Kassel, Leonberg and

Stuttgart) give direct financial support to roof greening ranging from €5 - €50 (£3 -£30) /m^2, or between 25 – 100% of the installation cost. The League of Cities in Germany supports the idea, citing the significant saving in heating and air conditioning costs. Indirect aid for green roofs is provided in other ways, for example 17% of German cities offer reduced sewage disposal charges for developments with green roofs. The Federal Nature Conservation Act requires mitigation for the ecological impact of building construction. This means that green roofs are often required by conditions attached to construction permits.

4. Environmental benefits

4.1 Energy conservation

An unprotected and poorly insulated roof can lead to overheating of rooms directly below it as surface temperatures soar in strong sunlight. Planting on and above a roof can reduce air conditioning costs by providing summer shade. The use of deciduous plants will allow winter sun to enter windows or heat up exposed walls or roofs. Planting can also act as a windbreak, thereby reducing wind chill.

In winter the extra insulation that some types of green roof provide helps to keep warmth in, thereby reducing heating demands. Some green roof systems include air gaps and other insulating layers between the main structure and growth medium which can improve insulation. Savings in fuel heating costs have been estimated at 2 litres of fuel oil/m^2/year for a typical green roof in Germany (ZinCo 2000).

4.2 Air quality

Cities continue to have air quality that does not meet minimum standards thought to be necessary for good health. In the UK an estimated 24,000 people die prematurely each year from the effects of air pollution (GLA 2001[b]). Large scale planting programmes can help to alleviate urban air quality problems. Space is usually a limiting factor, however in most cities there is a vast underused area on roofs. If this space could be harnessed on a large enough scale to develop green roofs and other building-integrated vegetation, real improvements in air quality might be achieved.

Vegetation has been shown to reduce atmospheric pollution by:

- filtering particulates;
- absorbing gaseous pollutants.

The ability of vegetation to filter and absorb pollutants depends on weather conditions, the type and concentration of the pollutants, the local topography, the location of the planting and the nature of the vegetation. Vegetation provides a large surface area for filtering particulates, which include dust, soot, heavy metals and pathogenic microbes. Species with a high surface to volume ratio - with hairs on leaves for example – are the most efficient. For example, Lablokoff (1953) measured dust deposited on the leaves of trees in Paris over a two week period and found elm performed best by trapping 2.735 g of dust per 100g of leaf compared with lime, the worst performing tree tested, with 0.936g of dust per 100g of leaf.

Many airborne pollutants, including nitrates and volatile organic chemicals, may be absorbed through the leaf stomata and subsequently metabolised by plants (Wolverton *et al* 1985, Wolverton & Wolverton 1993).

A major component of photochemical smog is ozone, which is formed when nitrous oxides (NO_x) and volatile organic compounds (VOCs) react on hot sunny days. High temperatures, which may be increased by the heat island effect, exacerbate the problem. Traditional dark coloured roofs absorb sunlight and re-radiate heat contributing towards urban heat islands (see discussion on urban climate below). Stratospheric ozone filters out dangerous ultraviolet radiation, but near the ground ozone is toxic – it can aggravate breathing difficulties in humans and damage plants even in low concentrations (<40 parts per billion). Even rural areas down wind from cities have increasingly high concentrations of ozone, which are believed to cause crop damage estimated at $ 500 million (£ 333 million) per annum in the US (USEPA 1997).

4.3 Urban microclimate

Urban climates differ from those of rural areas in a number of respects. In general they are dirtier, less humid and warmer than the surrounding countryside. Average wind speeds are usually lower due to the sheltering effect of buildings, but conversely the air is more turbulent owing to the increased surface roughness and 'canyoning' effects of the buildings and streets. There are usually more frost-free days in urban areas and the growing season is longer. There is less direct sunlight but more artificial light. In winter heat emanating from buildings may elevate soil temperatures by more than 5˚C, which can lead to dehydration and subsequent damage to vegetation during dormancy (Scrivens 1982). City centres are up to 7˚C higher than the surrounding countryside due to the heat island effect (USEPA 1992) The larger the city the more intense the heat island effect. It has been found that the greatest temperature difference occurs on the hottest summer days (Oke 1982). Increased urban temperatures are part of the cause of photochemical smog. Data from the US suggests that for every 3˚C increase in temperature there is a 10% increase in polluted days (Akbari *et al* 1992).

The urban heat island effect is caused by a variety of factors including:

- anthropogenic heat released from fuel combustion and people;
- less evaporative cooling from vegetation;
- less wind cooling in streets;
- the configuration of streets traps radiation rather than losing it to the sky;
- solar heat stored in the urban fabric.

Cities have large areas of asphalt and other dark materials which have low albedo, or reflectivity, so absorbing radiant heat from the sun and re-radiating at night. Flat gravel covered roofs may be up to 21˚C hotter than vegetated roofs (Kaiser 1981).

Table 1 Albedo of roofs and vegetation

(after Littlefair *et al.* 2000)

Surface	Albedo[1]
Roofs	
Smooth asphalt (weathered)	0.07
Asphalt	0.10 – 0.15
Tar & Gravel	0.08 – 0.18
Tile	0.10 – 0.35
Slate	0.10
Corrugated iron	0.10 – 0.16
Highly Reflective roof after weathering	0.60 – 0.70
Vegetation	
Deciduous plants	0.20 – 0.30
Dry grass	0.30
Deciduous woodland	0.15 – 0.20
Coniferous woodland	0.10 – 0.15

In summer, air conditioners transfer hot air into the streets. A federal programme in the United States encourages building owners to tackle this problem by making roofs more reflective through the application of white pigments or by using vegetation. Vegetation shades buildings and has a higher albedo than most building materials and in addition provides cooling through evapo-transpiration. Studies by Sacramento and Phoenix have indicated that increasing tree cover by 25% can reduce afternoon air temperatures by between 6 – 10˚C, and simulations of a 30% vegetation cover produced a midday 'oasis' effect, reducing temperatures by as much as 6˚C (Taha 1988). Gao (1993) has shown that vegetation in streets can reduce temperatures by 2˚C.

Transpiration adds humidity to what is frequently uncomfortably dry city air. Vegetated roofs may also cause a reduction in local wind velocities by increasing the surface roughness of buildings.

[1] The albedo is the ratio of radiation reflected from a surface to the incoming radiation onto the surface.

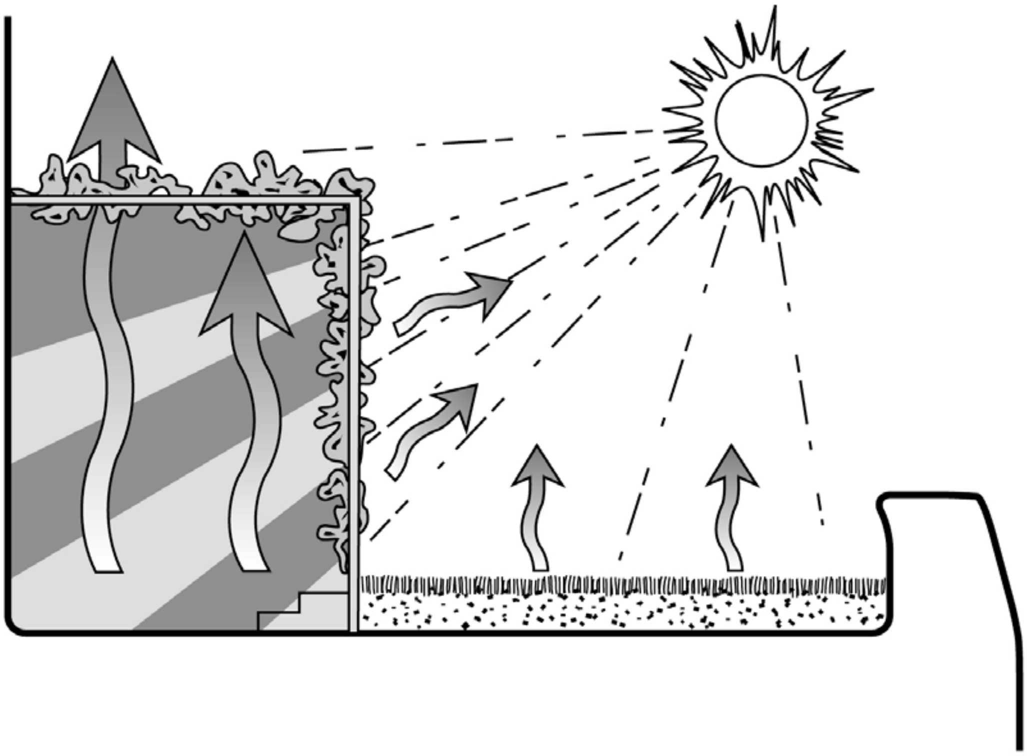

Figure 2 Vegetation shades the building, has higher albedo than most building materials and cools through evapo-transpiration.

Graphic: Studio Engleback

4.4 Precipitation & surface water runoff

The predominance of sealed surfaces in the urban environment causes rapid run-off and higher peak flows, which carry nutrients, silts, hydrocarbons, chlorinated organics and heavy metals from surfaces of buildings and streets into watercourses. The first flush, that is the initial washing of surfaces after rainfall, contains the highest pollution levels (USEPA 1974). Urban peak flows can overload and damage drains, cause flooding downstream and may cause foul sewers to overflow. Global warming is leading to climate change that is predicted to cause an increase in the frequency and intensity of rainfall (Atkins *et al* 1999, DOE 1996, UKCIP 2001).

Sustainable urban drainage systems (SUDS) are now being promoted as a way of reducing these effects (SEPA/EA 1997, SEPA *et al* 2000, CIRIA 2000[b]). SUDS use permeable surfaces – soil and vegetation - to filter, absorb and moderate the flows of run-off.

75% of rain falling on extensive green roofs can be retained in the short term and as much as 15-20% of this can be retained for up to 2 months. A 25mm deep moss and sedum layer over a 50mm deep gravel bed retains about 58% of rainfall and a 100mm turf layer retains about 71%. Where a rainstorm delivers 50 litres of water per m^2 on to 60mm thick extensive green roof, 25 litres of water per m^2, or 50% would be retained (Scholz-Barth 2001). Immediately following a 10mm rainstorm where 200 litres of water fell onto a $18m^2$ extensive roof only 15 litres of runoff reached the ground (Thompson & Sorvig 2000). Green roofs often form an integral component of SUDS in Germany where attenuation of run-off is considered to be one of the most important benefits of green roofs.

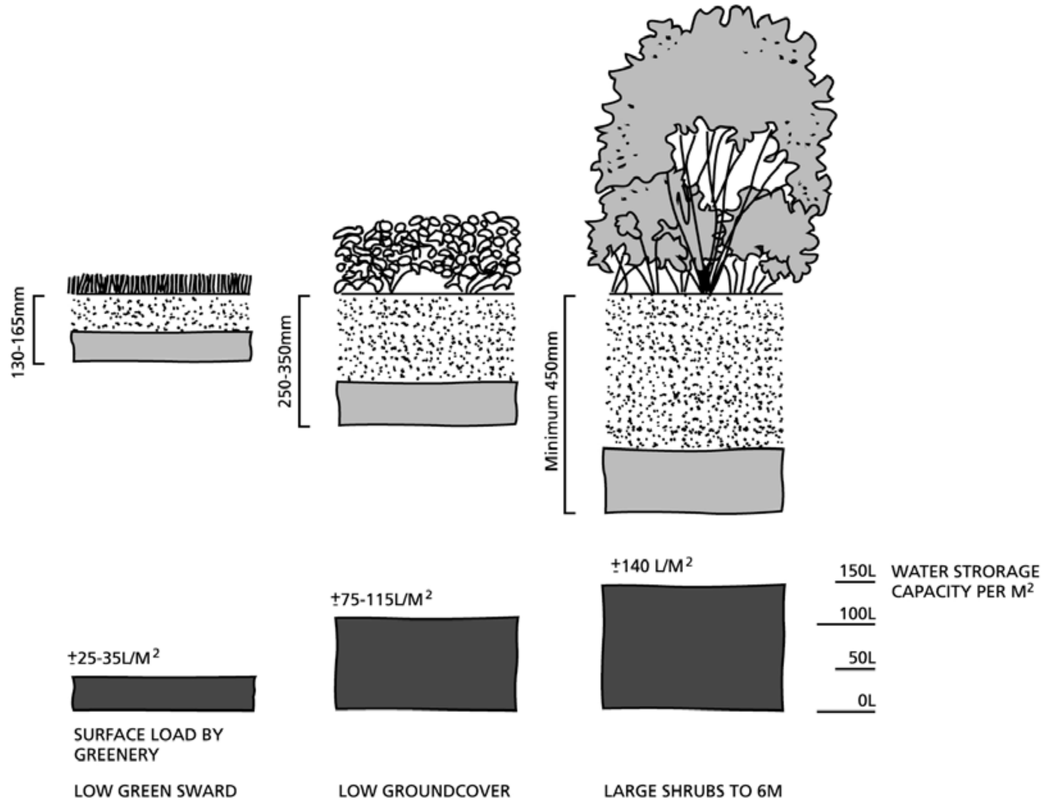

Figure 3 Green roofs reduce run-off.

Graphic: Studio Engleback

4.5 Water conservation

Approximately one third of potable mains water in the UK is used for flushing toilets. This huge waste could be reduced by recycling grey water through constructed wetlands to be re-used for flushing or irrigation.

Constructed wetlands (most often reed beds) are now commonly used to treat effluent. The cleansing occurs in the root zone of the plants where microbes break down impurities (Cooper 1990). Constructed wetlands of this kind can also be installed on walls or roofs. An experimental vertical reed bed was established on a residential block in Berlin some years ago (Johnston & Newton 1993). In London, The Metropolitan Water Company is promoting a constructed wetland water cleansing system designed to operate on the roofs of buildings (C. Shirley-Smith, pers. comm.) A test roof has been established at Middlesex University which is essentially a convoluted channel which allows grey water to flow through a sward of low growing native plants. The target is to produce pathogen-free water with <10 mg/litre suspended solids and BOD and <5mg/litre ammonia. The proponents suggest that establishment costs can be recouped through savings in water and sewage costs over the long term.

4.6 Noise

It has been estimated that up to 20% of the population of the European Union (80 million people) are subjected to noise levels which health experts consider to be above acceptable limits (European Commission 1996). Noise barriers are usually made from solid materials like concrete or earth. Narrow belts of vegetation are not an effective barrier to noise, however the soil of roof gardens is useful as a sound barrier. In a standard test an unvegetated Kalzip roof reduced sound by 33dB. A Kalzip Nature Roof reduced sound by 41dB when dry and 51dB when wet (T. Mills, Corus, pers. comm.) This compares with a typical reduction of 43dB for a 100mm concrete wall. These figures suggest that a green roof can reduce sound within a building by 8dB or more when compared with a conventional roof.

4.7 Electromagnetic fields and radio-frequency/ microwave electromagnetic radiation

Although a subject of debate, there is increasing concern over the possible negative effects of electromagnetic fields associated with power supplies and radio and microwave transmissions. Vegetation is known to absorb radiation and therefore has the potential to be part of future strategies for reducing exposure to electromagnetic radiation.

4.8 Use of recycled materials

Many of the materials used in green roof construction, for example, membranes and drainage mats, are manufactured from recycled plastics. Growing media often include recycled building materials (e.g. crushed brick and concrete). By using such materials developers can avoid charges incurred through disposal at landfills. Growing media could contain composts made from recycled household, agricultural and horticultural waste.

4.9 Increase in open space

Most roof surfaces are unused by people. By adding green roofs to buildings, the area available for leisure, recreation or wildlife can be increased. Buildings (and therefore roofs) in London are estimated to cover 16% of the surface area of the capital, which is equivalent to about 24,000 hectares (GLA 2001[a]). Through the process of redevelopment and refurbishment, a significant part of this area could be realised for recreation and wildlife habitat whilst retaining development density and urban amenity at street level.

5. Ecology & biodiversity

Potential biodiversity benefits of building-integrated habitats include:

- helping to remedy areas of deficiency i.e. providing new habitat in areas which are currently lacking 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 theory, any habitat that can be created in a particular place, can be created on a roof in the same area, although there may be constraints associated with the limited areas available on typical roofs, construction issues, extremes in microclimate and differences in hydrology. These constraints mean that certain types of habitat, predominately grassland, tall herb, succulents, moss mats, bare ground or other arrested succession communities are more likely to be created on roofs. For example, there has been recent interest in the use of green roofs as mitigation for habitats lost during urban regeneration, especially on brownfield sites (Bertrand 2002, Frith & Gedge 2000, Wells 2001). Although edaphic conditions on a roof will differ from the original and the area of a roof will usually be smaller than that of the habitat it is replacing, it may be possible to maintain some of the essential ecological functions of a site through this approach. Some of the difficulties with re-establishing an existing habitat onto the roof of the building that replaces it include:

- It may be impossible to re-create or maintain the correct soil, hydrological and micro-climatic conditions on a roof.
- The habitat may be too heavy for the proposed building (e.g. woodland on lightweight structure).
- The habitat may not be re-creatable within acceptable timescales.
- Elevation may cause the habitat to become isolated, making it inaccessible to some species which cannot fly, be dispersed by the wind or climb. There may be a loss of connectivity with adjacent habitats.

5.1 Approaches

Although the use of green roofs has become relatively commonplace, those designed specifically for biodiversity conservation are still uncommon. In practice, most habitat creation on roofs has been limited to low growing, open or sparsely vegetated areas where vegetation succession is slow or arrested because of thin soils. Where trees and shrubs have been planted on buildings, for example in conventional roof gardens, they are normally isolated or in small groups and ornamental species. The ability of such plantings to provide ecological functions associated with true woodlands or scrub is severely limited. Other possibilities include wetlands (ponds have been created on roofs) and heath (some earth-sheltered structures feature heather). The following are the most common approaches to creating habitats on roofs:

5.1.1 Natural colonisation

Providing a substrate and leaving it to colonise naturally has to date usually happened by default rather than design, but it is an approach which is receiving increasing attention from those interested in the biodiversity potential of roofs.

Conventional roofs will become vegetated if left undisturbed for long enough. Pioneer soil-forming plants like algae and lichens eventually create suitable conditions for other plants to colonise. More than 600 species of lichens have been recorded from the built environment and many of these grow on roofs. Some are nationally scarce (Meech 2001). New concrete is usually too alkaline (~ pH 11) for most organisms to survive on it (Dobson 1996) but as it weathers and is neutralised it may be colonised by a range of algae, mosses and lichens. Most roof materials have a much lower, more benign pH. The rougher the surface, the easier it is for plants to colonise. Drip and drainage lines, areas beneath bird perches and places where leaves and other materials collect are colonised first. Lichens and mosses can be encouraged by using polyvinyl acetate adhesive and spreading urine, diluted dung, skimmed milk, thin porridge, beer, yoghurt or rice water (Dobson 1996). Moss cushions frequently become dislodged from steep roofs, so that the process of succession is constantly being pushed back. Sinker *et al* (1985) remarked that birds constantly searching for insect food on a vegetated roof 'destroyed the fragile community each year setting back the succession to an earlier stage.'

Payne (2000) has surveyed the self-established flora of 639 roofs and wartime pillboxes in East Anglia over an eight-year period and found a total of 135 species of higher plant. The most frequently encountered species are shown in table 2.

Table 2 Ten most common species found on roofs

(after Payne 2000)

Species	% of roofs surveyed	Remarks
Sedum acre	34	Native perennial of dry habitats.
Saxifraga tridactylites	21	Occurs in vast numbers on asbestos roofs in a few locations, lifting its position in this table. Mainly occurs in limestone areas
Poa annua	15	Common annual grass. Most common plant of gutters – less common on roofs proper.
Senecio vulgaris	13	Common annual weed
Stellaria media	10	Common annual weed
Sedum album	5	Possibly introduced perennial of walls, rocks and roofs.
Cardamine hirsuta	5	Native annual of dry habitats, including rocks and walls.
Acer pseudoplatanus	4	Seedlings common in gutters, usually quickly die off
Cymbalaria muralis	4	Introduced. Common on old walls.
Sedum reflexum	4	Introduced perennial. Naturalised on old walls, rocks and roofs in southern England

Of the 30 most commonly encountered species, 24 are considered to be dispersed by wind, 8 are dispersed by both wind and birds, and 3 by birds alone. Other studies reviewed by Payne (2000) suggest that most roof plants are dispersed by the wind. Wind dispersed plants include moss and lichen spores and species with plumed seeds such as many composites and willowherbs. Bird sown plants include berry-bearing species in the Rosaceae and other families. Ant dispersal may be another important mechanism. Plants such as snapdragon, wallflower, ivy-leaved toadflax, herb Robert, annual mercury and white dead nettle are all examples of ant-dispersed species which occur on walls (Gilbert 1992) and which could also occur on roofs. Ants have been known to carry seeds distances of up to 60 metres.

Example

Deptford Creek

When planners and developers instigated the regeneration of Deptford Creek, a Thames-side area of derelict factories and wharfs in S.E. London, local environmentalists were concerned about potential impacts on valuable brownfield habitats and species, including rare invertebrates and the black redstart (Bertrand 2002). Brownfield sites provide virtually the only useful terrestrial habitat in Deptford.

Already two development schemes at Deptford Creek have incorporated green roofs. The first, the new Laban Dance Centre has a green roof is in two sections totalling an area $600m^2$. The largest part is constructed of crushed brick and concrete of varying depth. This has been designed on principles developed in Switzerland to increase the biodiversity of green roofs. Sown with an annual wild flower mix to give an immediate impact and it is subsequently being allowed to colonise naturally. The second part consists of volcanic pellets designed to be covered by mosses and lichens. This roof is visible through glass panels.

Greenwich Reach 2000 is a retail and housing complex for which planning consent has been approved. The roof will include about $200m^2$ of crushed brick and concrete to be colonised naturally plus about $300m^2$ of a more conventional sedum mat.

There are now four other major schemes in the Deptford Creek which include plans for green roofs totalling about $2500m^2$. All of them will have at least 65% of their roof area greened. One particular scheme which is yet to receive planning permission includes over $1000m^2$ of green roof space (95% of the total roof area) and will include boulders and pieces of old timber for both visual effect and to provide a varied micro-topography to boost biodiversity. The roofs will also include nesting structures for several species of birds, including black redstarts, sand martin and kingfisher.

It is hoped that this planned cluster of green roofs around Deptford Creek, which is probably unique in the UK, will demonstrate the cumulative benefits of roof greening in the urban core.

5.1.2 Turf

A number of green roofs have been covered with turf, sometimes fairly species-rich. A diverse sward may persist for many years, although where management has been lacking there is anecdotal evidence that suggests that the build up of thatch and humus leads to the sward becoming rank and species diversity to decline. Some roofs have been seeded with wild-flower and grassland seed mixtures (see Shaw's Cottages example). Advice on seeding grassland and diversifying existing dull grasslands is provided by Gilbert & Anderson (1998).

Example

Shaw's Cottages, London Borough of Lewisham.

A two storey timber-framed house built using the Segal method, designed and occupied by architect John Broome, this project is now eight years old and provides a good example of how green roofs 'mature.'

The roof was originally designed to provide a variety of substrates and aspects, with areas of gravel/soil mix on flat areas, and chalk rubble and garden soil on the pitched sections. Part of it was turfed with regular lawn grass and part left to colonise naturally. The gravel areas were subsequently inoculated with *Sedum acre* and *Sedum reflexum* in an attempt to speed up the greening process.

When examined in the summer of 2001, it was remarkable how much the areas which had been left to colonise naturally had converged, despite their differing soil chemistry and position on the roof. Vegetation cover on both substrates was completely closed. Bryophytes and Sedums were prominent in both and a very similar range of species were present, including several ruderals. The main difference was in the contribution of *Geranium molle* to the vegetation (see table).

The turfed area supported a dense tussocky grassland sward comprising species such as *Agrostis stolonifera, Dactylis glomerata* and *Phleum bertolonii*, with herbs including *Cerastium fontanum, Trifolium repens, Plantago lanceolata, Rumex obtusifolius, Malva sylvestris* and, in disturbed areas, *Medicago lupulina* and *Euphorbia peplus*.

Table 3 Vegetation composition eight years after construction

Gravel/soil mix

Species	% cover
Tortula muralis	70
Sedum reflexum	40
Chenopodium album	15
Brachythecium rutabulum	5
Sonchus oleraceus	5
Festuca rubra	5
Geranium molle	2
Veronica sp.	2
Taraxacum officinale agg.	2
Lactuca serriola	2
Senecio vulgaris	1
Trifolium dubium	1

Chalk rubble

Species	% cover
Geranium molle	70
Tortula muralis	40
Chenopodium album	10
Sedum acre	5
Sedum reflexum	5
Senecio vulgaris	2
Capsella bursa-pastoris	2
Festuca rubra	2
Sonchus oleraceus	1

A shady drip zone on a flat part of the roof below an overhanging section of turfed pitched roof had developed a spontaneous cover of *Geranium robertianum* and *Plantago lanceolata.*

In terms of wildlife interest Jon Broome reports that a fox regularly lies up on the roof and wasps have nested in the turfed areas. Apple trees overhang the roof, and fallen apples on the flat sections attract blackbirds and other birds.

5.1.3 Sedum mats

Most extensive green roofs installed in Europe are seeded with low growing succulents, usually stonecrops *Sedum* spp. These plants are hardy and drought tolerant. In winter the foliage may turn red in some species. They require minimal maintenance (which is a major benefit) and have attractive flowers, which are known to attract nectar-feeding insects like bees and butterflies. *Sedum* blankets have a predictable appearance, which gives confidence to those specifying this type of roof.

5.1.4 Fauna associated with green roofs

Even intensively managed green roofs will attract some wildlife. The use of native species and provision of quiet areas, nest and roost boxes and voids can help to attract wildlife to even relatively formal landscapes including roof gardens. Johnston and Newton (1993) and Meech (2001) have reviewed the techniques available for attracting birds and bats to nest or roost on buildings. Nesting sites have been provided on buildings using open-fronted and hole-entrance boxes, ledges, platforms, gaps and voids and purpose made bricks. Animals which are encouraged in this way include flycatchers, robin, wagtails, blackbird, tits, house martin, swallow, swift, kestrel, kittiwake and bats. Other bird species associated with buildings are barn owl, little owl, peregrine, house sparrow and feral pigeon.

There is a paucity of information relating to the fauna of green roofs and much of what is available is anecdotal. One of the few studies is by Brenneisen (2001), who studied the birds, beetles and spiders associated with green roofs in the Basel area, Switzerland. A sample of 11 roofs were found to support a total of 172 species of beetle with 10% listed in the Swiss red data book. Older roofs had more species, whilst roofs with the greatest structural diversity had the highest number of species and density of beetles. The study showed that the ability of the roof to retain water was a key factor in attracting beetles.

Some 60 species of spider were found on the same 11 roofs. Of these 70% were from a common group that are known to disperse well. 40% of the 60 species are registered as 'faunistically interesting' (meaning that they are comparable to Red Data Book species - there being no Red Data Book for spiders in Switzerland). Older roofs again had a higher diversity of spider species and roofs with the highest structural diversity had the highest number of species.

Birds were studied on 16 roofs. There were a total of 1844 sightings, of which 1304 involved a specific activity. Activities noted included (listed in order of frequency): searching for insects, preening, searching for seeds, searching for nesting material, roosting and singing. The height of the roof had no apparent effect on bird use. The 25 bird species which were recorded using green roofs in Basel were categorised according to frequency of use (relative to the number of breeding pairs in the locality) - see table 2. It was suggested that green roofs had a significant positive benefit on the first group (feral pigeon, black redstart, white wagtail and house sparrow).

Table 4 Use of green roofs by various bird species in Basel, Switzerland

Group	Frequency of use
Feral pigeon, black redstart, white wagtail, house sparrow	High
Collared dove, carrion crow, magpie, goldfinch, tree sparrow,	Medium
Grey wagtail, wheatear, whinchat	Low
Mallard, swift, house martin, swallow, spotted flycatcher, blackcap, blackbird, starling, blue tit, great tit, greenfinch, chaffinch, serin	Minimal

Brenneisen also reported that wheatear, skylark, crested lark, lapwing, common tern and mallard have been recorded as breeding on green roofs in Switzerland and Germany.

The use of green roofs by black redstart - a rare and protected species in Britain - is of particular note. A significant proportion of the UK breeding population of this species occurs in urban areas and it is particularly associated with brownfield sites. The use of green roofs has therefore been suggested as a possible means of providing replacement habitat for black redstarts when their breeding and foraging habitat is developed (Bertrand 2002, Frith *et al* 1999, Frith & Gedge 2000, Wells 2001).

House sparrow is another species which is of increasing conservation concern due to the continuing decline in populations. The species now features in the London and Birmingham Local Biodiversity Action Plans. Although the causes of the decline are not fully understood, the availability of invertebrates for feeding the young has been put forward as a major factor (Summer-Smith 1999). The use of green roofs in urban areas could potentially provide alternative foraging areas for house sparrows, whilst nesting sites can be designed into new buildings or retro-fitted to existing ones.

Mallin (1980) reported frequent use of a twenty-third floor roof garden by bees. Any small, wind-dispersed or flying arthropod could theoretically reach a green roof, but the number of species which establish is likely to be constrained by the limited availability of different habitats and the general aridity of the environment. Scarce or notable invertebrates that might benefit from green roofs include various species associated with open, dry and sunny habitats containing sparsely vegetated and bare ground. Examples include *Ponera coarctata* the indolent ant (a nationally scarce species), the RDB3 bee *Ceratina cyanea*, which is known to nest in dead bramble stems in open unmanaged or sporadically disturbed grasslands and waste ground, and the nationally scarce stem nesting bees *Hylaeus cornutus* and *H. signatus*, which are especially associated with *Reseda* and *Daucus* in open grassland and waste ground. A number of bees and wasps usually associated with dune habitats are found in open sandy waste ground habitats, such as the nationally scarce bees *Dasypoda altercator* and *Megachile leachella* and the sphecid wasps *Astata pinguis*, *Gorytes tumidis* and its nationally scarce cleptoparasite *Nysson dimidiatus*. All could potentially utilise green roofs.

Spider-hunting wasps, or pompilids, include various species that might benefit from green roofs, especially where these include sandy substrate and open sporadically managed vegetation. Many scarce beetles associated with open dry grasslands and waste ground occur in some urban areas, including a number of Red Data Book tumbling flower beetles *Mordellistena spp.* that develop inside the herbaceous stems of plants such as wormwood *Artemesia.* Scarce spiders such as the ant eating *Zodarion italicum* and the nationally scarce jumping spider *Bianor aurocinctus* are widespread in open dry grasslands and waste ground in parts of the south-east.

In general, green roofs are likely to be especially valuable for invertebrates if they can provide friable (e.g. sandy) substrates with a varied micro-topography and micro-hydrology (e.g. hollows, clifflets) plenty of scattered rocks, rubble and dead wood and logs, and with an open and diverse vegetation cover and plenty of bare ground. If necessary friable or sandy material for burrowing invertebrates can be provided as a series of veins crossing another substrate type.

Plants that provide nectar and pollen resources are especially important, and in many cases plant species support specific invertebrate species. Unmanaged or sporadically managed vegetation provides continuity and large resource of dead herbaceous stems, fruit heads and seed heads for stem nesters and seed-feeding invertebrates. Plants stressed by mineral deficiency and high water deficit appear to provide an especially valuable resource.

Example

Kantonspital Klinikum II and Rosetti-Bau in Basel, Switzerland

These two roofs have been studied by Stephan Brenneisen of the University of Basel. Klinikum II roof was constructed in 1980 and was one of the first to be built in the Canton. Rosseti-Bau was built in 1998. Interestingly both of these roofs have been assessed using the ‘Karlsruhe’ test , which is used in Germany and Switzerland to assess the ‘productivity of biota’, thermal and water retention properties of roofs. Using data from his study of green roofs in Basel, Brenneisen has extended the Karlsruhe test to include a biodiversity quotient.

Klinikum II

The hospital lies in the heart of Basel. The roof at $4000m^2$ is one of the largest in the city. As one of the first to be built, the *raison d'etre* for this roof was as an attractive view for patients recuperating in the buildings above. This is of interest as most green roofs have been constructed for water retention and thermal insulation. It is also different from other roofs in the city as it is constructed of a mixture of soil, gravel and peat. The roof was originally seeded and has also been colonised by several alpine species which are relatively rare in the Basel region.

This roof scores very high on the biodiversity part of the Karlsruhe test primarily because of its age and has, for this same reason, the greatest species list of any roof in Basel.

The fauna is very similar to that of extensive managed grasslands and the lack of relief features means that it does not retain moisture in periods of drought. Therefore invertebrates tend to be ones that can tolerate dry conditions. Bird activity on this roof is one of the highest in Basel with black redstart, house sparrow and goldfinch frequent visitors.

Rosetti-Bau

Although this roof is only a few years old and is comparatively small in size ($1500m^2$) it is one of the first built according to new guidelines provided by the Urban Ecology Unit of the Institute of Geography, Basel University. The substrate is of varied depth and topography to encourage colonisation by invertebrates which favour higher levels of soil moisture. The substrate mix differs from Klinikum II. It consists of river gravels and alluvial soil obtained within the Basel region as stipulated by the local government (for ecological reasons and because the alluvial plain in the Basel region is being lost to industry). The species list is relatively small, probably due to its young age. At present it has been colonised by many common aerial dispersers. However several species, which are not present on older roofs have colonised. The increased soil depth and varied topography has allowed beetles and spiders less tolerant of drought to survive through the summer. The species diversity of this roof should continue to increase to a level in excess of that of the much older and larger Klinikum II.

5.1.5 Potential Relevance to BAPs

The UK, London, and Birmingham Biodiversity Action Plans and the Biodiversity Audits for London and East Anglia were examined in order to identify species of conservation concern which could benefit from green roofs. The results are shown table. Plant lists are not presented here because there are relatively few species of special conservation concern for which roofs are considered important. However, a huge number of plant species do occur on roofs (see Payne 2000) and there is the potential to deliberately introduce and encourage particular species of conservation concern, where this is locally appropriate. Animal species which might benefit include bats, several birds, beetles, flies, bees, wasps and spiders. Several of the birds have been shown to utilise green roofs in Switzerland (Brenneisen *op. cit.*).

An example of a rare plant which is associated with roofs is thatch moss *Leptodontium gemmascens*. It is listed as Vulnerable in the British Red Data Book on Mosses and Liverworts and Rare in Europe (Church *et al* 2001) and is the subject of a Biodiversity

Action Plan. Its natural habitat is decaying vegetation, such as the bases of grass and rush tussocks in acid grassland and heathland, but it is better known as a plant of thatched roofs which are in the early stages of decay. It used to be fairly widely distributed across southern England but with the decline of thatch it has become rare, with only 8 post-1970 records in the UK, of which four were on thatch, including a recent one (1994) from Thomas Hardy's Cottage in Dorset. A variety of other more common mosses also occur on thatched roofs e.g *Ceratodon purpureus* and *Syntrichia (Tortula) ruralis*). Even where thatched roofs still occur, they are often unsuitable for this species since these days the thatch tends to be renewed before it reaches a suitable stage of decay (Urban Wildlife News 1999).

The Newcastle BAP is of note because it specifically identifies man-made structures as being important for some species. Species mentioned include starling, which roosts on old buildings; kittiwake, which nests on bridges; kestrel, which nests on the roofs of blocks of flats; and black-headed gull which uses a factory roof in internationally important numbers. The draft Hull LBAP (Hull Biodiversity Partnership 2002) includes a built environment habitat action plan. Whilst it does not specifically mention roofs, it does recognise the importance of buildings for lichens, wall-fern, bats and hirundines.

Table 5 A checklist of species which might benefit from green roofs

taken from National, London and Birmingham Biodiversity Action Plans, and Biodiversity Audits for London and East Anglia

Species	How green roofs could help	UK BAP	London BAP	Birmingham & Black Country BAP	Biodiversity Audit for East Anglia
Pipistrelle and other bats	Improved foraging and artificial roost sites	+	+	+	+
Kestrel	Foraging and artificial nesting sites	+		+	+
Song thrush	Foraging	+		+	+
Goldfinch	Foraging	+			+
Greenfinch	Foraging	+			
House martin	Improved foraging and artificial nesting sites	+	+		
Swallow	Improved foraging and artificial nesting sites	+			+
Pied wagtail	Foraging	+			
Black redstart	Foraging and artificial nesting sites	+	+	+	
House sparrow	Foraging and artificial nesting sites		+	+	
Wall butterfly	Breeding and foraging habitat			+	
Buttoned snout moth *Hypena rostralis*	Could utilise green roofs or walls planted with hop *Humulus lupus*	+			+
Brown-banded carder bee or 'humble bumble' *Bombus humilis*[2]	Foraging (and possibly nesting) habitat	+	+		+

[2] long-tongued bumblebees in English Nature's Species Recovery Program. Both bumblebee species require abundant forage plants especially Fabaceae, Scrophulariaceae, and to a much lesser extent Asteraceae, Lamiaceae. Workers particularly favour plants such as *Lotus, Odontites, Ballota, Trifolium pratense* and queens will use species such as Fodder vetch *Vicia villosa* and Broad-leaved Everlasting pea *Lathyrus latifolius*, which could be seeded or planted on green roofs.

Species	How green roofs could help	UK BAP	London BAP	Birmingham & Black Country BAP	Biodiversity Audit for East Anglia
Shrill carder bee *Bombus sylvarum*[1]	Foraging (and possibly nesting) habitat	+			+
Cerceris quinquefasciata, Cerceris quadricincta[3]	Foraging and nesting on green roofs with sandy substrate	+			+
An otitid fly *Dorycera graminum*[4]	Foraging and breeding habitat				+
A mining bee *Andrena florea*[5]	Foraging and nesting on sandy substrate		+		
A tachinid fly *Gymnosoma nitens*[6]	Foraging and breeding				+
A mining bee *Lasioglossum pauperatum*[7]	Foraging and nesting habitat on sandy substrate				+
A cleptoparasitic bee *Nomada fulvicornis*[8]	Foraging and breeding habitat on sandy substrate				+
A noctuid moth Small Ranunculus *Hecatera dysodea*[9]	Foraging and breeding habitat				+
Bombardier beetle *Brachinus crepitans*[10]	Foraging and breeding habitat		+		
Bloody-nosed beetle *Timarcha tenebricosa*[11]	Foraging and breeding habitat		+		
Stripe-winged grasshopper *Stenobothrus lineatus*[12]	Foraging and breeding habitat		+		
The spider *Zelotes latreillei*[13]	Foraging and breeding habitat		+		

[3] RDB1 and RDB3 solitary wasps, both included in English Nature's Species Recovery Program, excavate their nests in hot sandy conditions and provision them with common weevil species. They are typically associated with open unmanaged or sporadically disturbed flower-rich grasslands, waste ground and heath edge.

[4] RDB3 fly, which is on English Nature's Species Recovery Program. Many recent records are from waste ground and open unmanaged or sporadically disturbed grasslands.

[5] RDB3 mining bee requires White Bryony *Bryonia dioica* as a pollen resource and nests in sandy ground.

[6] RDB1 tachinid fly which is parasitic on *Sciocoris cursitans*, a nationally scarce shieldbug of dry sandy and calcareous places. Most records of *G. nitens* are recent, from waste ground and open unmanaged or sporadically disturbed grasslands.

[7] solitary bee which nests in sandy ground and forages on yellow composites. There are modern records from open unmanaged or sporadically disturbed grasslands and waste ground, where the bee may be frequent.

[8] cleptoparasite on the nationally scarce ground nesting mining bees *Andrena bimaculata, A. spectabilis* and *A. tibialis.* On open unmanaged or sporadically disturbed grasslands and waste ground *A. spectabilis* may be widespread, foraging on a range of plants including yellow crucifers and bramble.

[9] was considered extinct in Britain, but has re-established in the East Thames region in waste ground habitats feeding on *Lactuca* spp.

[10] lives under stones and leaf rosettes in short, dry grassland, larvae are ectoparasitic on the pupae of other beetles. Quite a few recent records from waste ground and open grasslands.

[11] mainly on calcareous or sandy grassland,

[12] in dry habitats, with a few from waste ground

[13] open grassland and sparsely vegetated ground, perhaps feeding on ants.

6. Design and construction

Brownlie (1990), Osmundson (1999) and Scrivens (1980[a], 1982) have discussed the various issues to be considered by those planning green roofs. They include:

- urban design and aesthetics
- building structure
- waterproofing of the building
- protection of the waterproofing layer
- insulation
- growing medium
- drainage
- irrigation
- fire prevention
- access
- maintenance
- cost

6.1 Urban design and aesthetics

Many people consider natural green spaces, particularly in an urban context, to be incongruous and inappropriate and some may actually fear it (Rohde and Kendle 1994, Barker 1997). It seems likely that some people who might tolerate or even welcome vegetation close to buildings would object to it growing on the building fabric. Some of these objections may stem from conservatism and ignorance about the benefits which greening might have, which could be overcome through familiarity and education. However, there are always likely to be some people who will object to green roofs because they do not like their appearance. Someone who enjoys a neat rooftop lawn might dislike the relatively untidy appearance of an overgrown extensive roof (dead vegetation during winter may be seen as a sign of neglect if not removed). Millward & Mostyn (1989) have shown, though, that once people become used to natural open space they do not want it to evolve into a conventional park. This sentiment is also likely to apply to extensive green roofs.

In practice, green roofs in a city centre are not obvious to most passers by, although they may be overlooked by people on high floors, who might otherwise be overlooking typical rooftop eyesores of litter-strewn decks and building services plant. In a more suburban residential or industrial setting, where more roofs are pitched, people are more likely to notice roofs that have been vegetated. Most people would probably welcome roof greening in industrial situations, where there is usually relatively little consideration given to appearance. The use of green roofs in a suburban setting is likely to be more controversial than either very urban or rural situations. Where extensive green roofs have been proposed for new houses in southern England, planners have occasionally expressed concerns over appearance, but there have been no reported complaints once projects have been completed (Jon Broome, pers. comm.)

6.2 Building structure

When designing a new building with a green roof or modifying an existing building to support a green roof, architects and engineers take account of the dead load of wet soil, plants and other materials and the potential live load of people or moving machinery which must be safely supported. Intensive green roofs with trees may have more than 600mm depth of soil and planters, with a wet weight of >1 tonne/m^2, which combined with crowds can lead to total loading of >10kN/m^2 (Tandy 1973, Scrivens 1980[a]). In practice, this kind of roof garden needs to be supported by a heavy steel or reinforced concrete structure. Although these structures are expensive, they are usually several storeys in height and little, if any, extra strength would need to be added to support a green roof. Scrivens (1980[b]) has suggested that the roof garden at the Willis, Faber and Dumas building added nothing to the overall capital cost of the building.

In the case of a low-rise lightweight structure an intensive green roof would require substantial additional structural support. This would normally make intensive green roofs too expensive an option for the developers of these kinds of buildings.

Extensive or simple intensive green roofs require thinner soil layers, typically 150-200mm in depth for lawns or turf (loading >5.0kN/m^2) but as thin as 50mm or less for *Sedum* or moss mats (loading c. 0.7kN/m^2). Wet weight of vegetation and substrate on a green roof with substrate depth of 180mm is reported to be 220kg/m^2 by ZinCo (2000). Wet weight of a turf roof at the Findhorn eco-village with 150mm of soil was 510kg/m^2 (Talbott 1997). Turf roofs with 100mm of soil at the Centre for Alternative Technology in Powys, weigh around 500kg/m^2 when wet, requiring rafters double the standard thickness of 100mm (Kingsbury 2001). These figures compare with an ordinary tiled roof designed to support approximately 150kg/m^2. Extensive green roofs with very thin substrate layers (<50mm) may not require strengthening (Kaiser 1981). Erisco Bauder (2000) produce geotextile blankets 25mm thick. One sown with *Sedum* and mosses has a saturated weight of 30kg/m^2 and a coir fibre fleece sown with herbs, grasses, Sedums and mosses has a saturated weight of 42 kg/m^2.

6.3 Waterproofing

A wide range of materials are available for waterproofing green roofs, including bituminous fabrics, butyl rubber and plastics. These materials, usually referred to as membranes, may be laid on concrete, timber, metal, plastic or composite decks. Care must be taken when choosing and installing membranes for green roofs to ensure reliability, as with most construction methods, repairs may be difficult once a green roof is installed. It is recommended that membranes are flood tested before the covering green roof components are installed.

6.4 Protecting the building fabric

Exposed roof materials are subjected to large annual and diurnal fluctuations in temperature which can lead to expansion and contraction and eventual failure. Ultraviolet light causes roofing materials to degrade, so that they may lose their strength and may leak. Soil and vegetation protects roof membranes from these threats - the waterproofing of the Derry and Toms roof garden was found to be in excellent order after 60 years (Osmundson 1999). However roof membranes covered with soil and vegetation may still be vulnerable to root penetration and mechanical damage. It is therefore important that membranes are protected by dedicated mats or multipurpose layers that meet this requirement. Some waterproof materials are root resistant and may only require protection from temperature changes or mechanical damage. Protective mats do add to the cost of the roof, although it is not considered to be significant, especially when weighed against benefits associated with increases in longevity of the waterproofing layer. Unit construction systems, e.g. KalZip Natureroof (Corus 2001) may isolate the green roof from the building structure helping to protect it from damage and allowing for easier maintenance.

There is a widespread belief that vegetation threatens building structure. Although some species of plant that become rooted in mortar can damage masonry over a long period of time, most plants have little or no negative impact on buildings and actually protect the building fabric from the weather. The National Trust has adopted the helpful policy that 'wildlife is innocent until proven guilty' (Meech 2001). In any case, purpose built green roofs include features that protect the building fabric from vegetation and fauna.

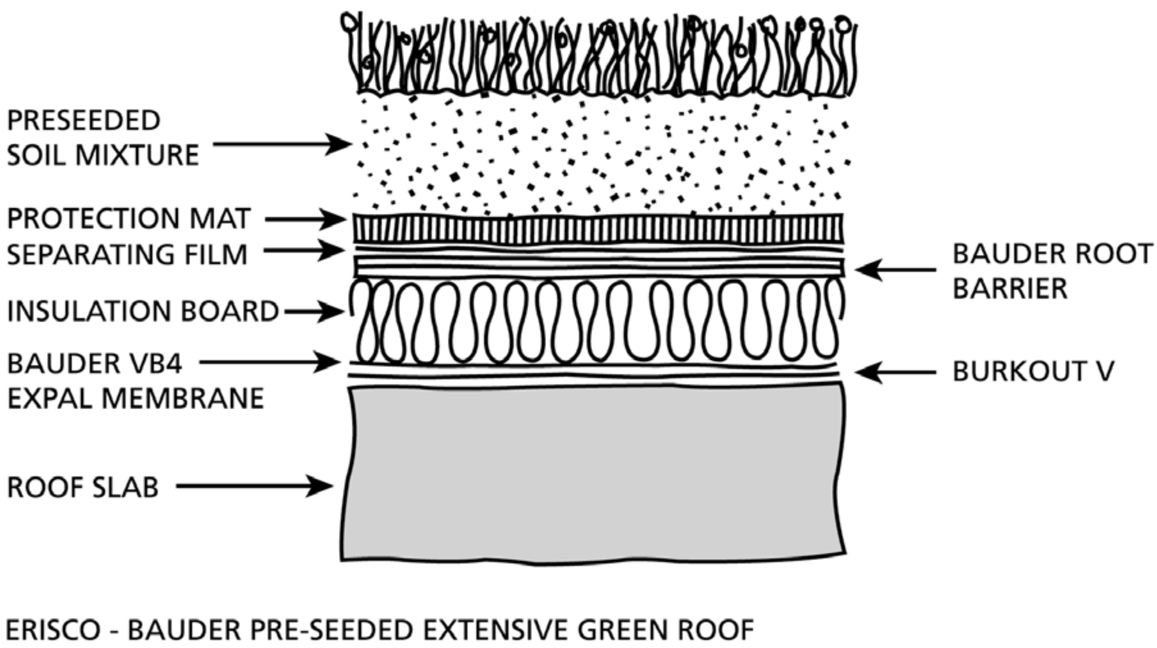

Figure 4 Roof membrane and insulation layer protected by mat and root barrier

Graphic: Studio Engleback

6.5 Growing medium

The choice of substrate or growing medium depends on the type of vegetation that is desired. Soil depths of green roofs range from <10mm to 2000mm. In general, extensive green roofs, supporting mosses, succulents, grasses and wild flowers normally require shallow soils of 200mm or less. On roofs that slope at an angle of more than 22 degrees, soil without supporting baffles will slump. On steep roofs, thin (25mm) mats of synthetic or coir fibres may be used to support the growth of herbs, grasses, *Sedum* and mosses (Erisco Bauder 2000).

Shrubs and small trees typically require a soil depth of 500 - 600 mm and larger trees 800 - 1300 mm of soil. The 30-year-old roof top garden in the diplomatic area of Geneva supports large birch and beech trees growing in just 600mm of soil. These species are shallow rooting and are appropriate for a more exposed setting. In other instances, trees provided with greater depth of soil may fail to do well, as much of the soil is not utilised. A wide range of growing media are used on green roofs. General purpose topsoil mixtures are usually provided by roof manufacturers for intensive or simple extensive roof types where trees, shrubs or lawns are grown. Traditionally the emphasis has been on growing healthy plants and tests would normally be made to ensure that sufficient nitrogen, potassium, phosphorous and trace elements are present in the soil. Substrates are chosen for their water retention, permeability to water, air retention, suitability for root growth and plant anchoring properties. Soils that suffer from excessive organic decay and shrinkage would normally be avoided. German fire regulations require that the organic content of the medium may not exceed 20% (FLL 1995). The deeper the substrate, the less vulnerable it will be to drying out. These soils are usually a neutral loam mixture of sterilised compost and sand, sometimes mixed with materials like crushed brick. Some manufacturers use light expanded clay aggregate (LECA) which is well drained, lightweight and silt-free - it is recommended that soils with high silt content are avoided because silt tends to block drainage layers and drains. Sand, gravel, peat and peat substitutes (bark, leaf mould, coir) have also been used on green roofs.

Where a specific habitat type is desired on an extensive green roof, an appropriate substrate must be used. For example, Gedge (2000) specified a crushed concrete and brick mixture for a proposed rooftop re-creation of a London wasteland habitat. Where a diverse mixture of plants is desired, the emphasis will be on a nutrient-poor substrate, low in phosphorous, nitrogen and potassium (Gilbert & Anderson 1998). Self-established vegetation will build up its own humus layer over time. With some extensive roofs, disturbance of spoil during installation may lead to the rapid release of nitrogen which can favour the growth of ruderals (plants associated with disturbed sites). If this effect is unwanted it has been recommended that turf containing the desired species is used (Scrivens 1982). The requirement for growing medium leads to added expense in installation over conventional roofs and if specific habitats are to be created specialist advice on soil/substrate and species selection will be required.

6.6 Roof drainage

Although green roofs absorb some of the rainfall that they receive, there is still the need to discharge excess water to the building's drainage system. Most green roof designs include a drainage layer, which consists of a purpose-made fibrous plastic mat, often corrugated or moulded. Some extensive green roofs designs, with thin soil layers supporting moss or succulents may dispense with a drainage layer (Trillitzsch 1979). Similarly on some pitched green roofs, particularly turf roofs, a drainage layer may be absent. Drains serving green roofs are vulnerable to blockages caused by silt deposition.

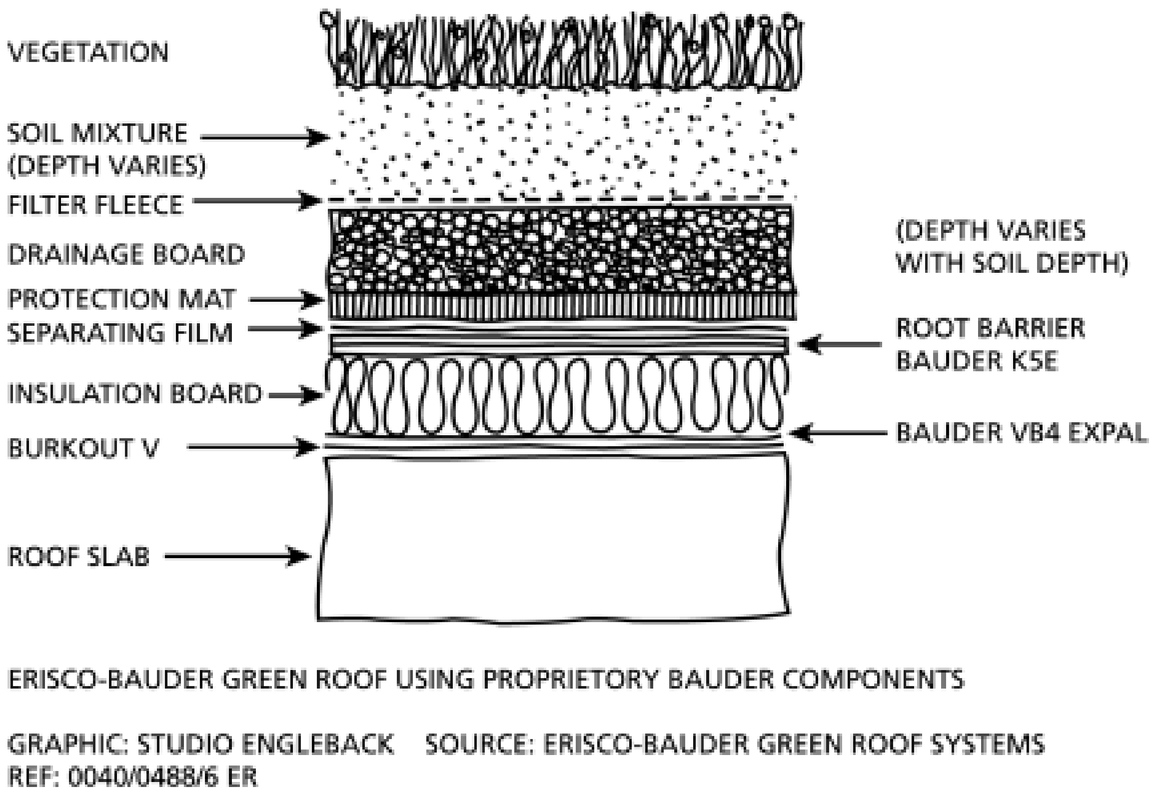

Figure 5 Filter fleece prevents silt entering drainage system

Graphic: Studio Engleback

6.7 Irrigation

Green roofs are generally exposed to higher wind speeds and to greater insolation levels than sites at ground level and the soil layer on them is usually thinner than that at ground level. These factors combine to cause high evapo-transpirative losses. The problems of water deficit are exacerbated because the roof is cut-off from natural groundwater. Therefore intensive roof gardens are usually irrigated during dry weather. Irrigation systems used in intensive green roofs include the roof dam (where the drainage layer is deliberated flooded), buried porous pipes and sprinklers. Irrigation systems may be automated or computer controlled.

Extensive roofs are often designed to be planted with species that inhabit arid habitats in the wild, particularly *Sedum* and other succulents which are found on rocky outcrops and in other dry situations. The fleshy nature of the leaves and the plants ability to withstand drought removes the need for irrigation.

In most European climates grass roofs, especially the simple-intensive lawn style of grass roof, require regular watering in summer to avoid turning brown. The browning of vegetation is tolerated on most extensive grass roofs, where irrigation is not normally used.

6.8 Wind

High winds can lift membranes or lightweight decks, especially on flat roofs. Edges and corners are particularly vulnerable. Slabs or substrate may be used to assist in holding down roofs, with thicker, heavier layers used in vulnerable areas (FLL 1995). Green roofs are no more vulnerable to this threat than conventional roofs of a similar design. Where trees are planted on roofs they may require shielding from the wind or in unavoidably exposed situations, may need to be anchored. On tall buildings higher wind speeds may exacerbate water loss or damage plants through windburn, and may prove to be constraints to the effective long-term survival of plant and invertebrate communities. Barriers (e.g. parapet walls) may be required to mitigate these effects.

6.9 Insulation

No additional insulation is required for the successful establishment of a green roof, although designers usually use a green roof as an opportunity to improve the thermal efficiency of the building. Green roofs may be 'cold', whereby an air gap separates the membrane from the insulation beneath, or 'warm' or 'inverted' whereby insulation covers the waterproof layer.

6.10 Fire prevention

There are no special fire risks associated with green roofs with low vegetation, however German authorities only consider extensive roofs to be fire resistant if the substrate/soil is at least 30mm deep; if the substrate/soil contains less than 20% organic matter; if there is a 1m wide gravel or slab fire break every 40m; and if gravel strips are provided around all structures penetrating the roof (FLL 1995).

6.11 Access

Stairways, perimeter barriers, safe paths and in some cases lighting and lifts, all built to the relevant standards, are required if a green roof is to be used by people.

6.12 Maintenance

Intensive green roofs require regular maintenance. Simple intensive green roofs, like lawns, might require mowing and weeding on a weekly or fortnightly basis during the growing season. Extensive green roofs would normally only require annual visits to remove rubbish, check fire breaks and drains and in some cases remove unwanted colonising plants. The first three years of roof maintenance are usually the responsibility of the green roof manufacturer. Some 'wildflower meadows' on extensive green roofs may require annual mowing with cuttings removed.

6.13 Costs

Costs for extensive green roofs in the U.S. currently range from \$150 (£100) to \$200 (£133) /m^2 including everything from waterproof membrane to plants. These costs stem mainly from the additional materials comprising a green roof. While green roof construction is similar to that of a conventional flat roof, the soil substrate and plants are expensive and need to be lifted onto the roof with a crane. Planting can also be expensive. It is expected that costs for extensive green roofs in the US will be reduced to between \$80 (£53) and \$150 (£100) /m^2 as the industry matures (Scholz-Barth 2001).

In Germany the growth in the market for green roofs and improvements in manufacturing and installation techniques have led to reductions in establishment costs. Compressed air is used to move dry soil substrate onto roofs, and pre-grown vegetation mats, are rolled out over the soil. The cost of a typical extensive green roof system in Germany inclusive of lining sheet, insulation, filter mat, drainage mat, substratum, and pre-seeded mat but excluding labour would be of the order of 20-40 €/m^2. Materials for intensive roof garden systems with a deep substrate layer capable of supporting trees and shrubs can cost more than 200 €/m^2 (ZinCo 2001), Unit labour costs vary considerably depending on the size of the project.

In the UK the typical cost for the supply and installation of an extensive roof system (Kalzip Nature Roof) inclusive of lining sheet, insulation, filter mat, drainage mat, substratum, and plug plants or pre-seeded mat is £98/m^2 for a 600m^2 roof. Prices may rise to £130/m^2 for a small roof (150m^2) and fall to £85/m^2 for a larger roof (2500m^2). (pers. comm. T. Mills, Corus Building Systems, January 2002).

7. Recommendations and conclusions

There is sufficient evidence to demonstrate that green roofs can provide many general environmental and associated aesthetic and health benefits. It is generally assumed that green roofs can benefit wildlife and existing studies indicate that a wide range of plant, bird and invertebrate species do occur on roofs. In addition there are a number of species of conservation concern in the UK that might potentially find additional or alternative habitat on green roofs. However, further work is needed to reveal the significance of roofs in supporting wildlife populations. Proposals are currently being progressed in a number of locations to design and create building-integrated habitat specifically for biodiversity conservation (e.g. the 'brown' roofs at Deptford Creek, S.E. London). These are hopefully in the vanguard of a movement to create similar features throughout the nation's cities.

A critical issue, in terms of conservation, is size. A few widely spaced installations, no matter how well-designed for particular species are unlikely to make a significant impact. Only when a certain threshold of a total number or area of green roofs is reached are conservation and other environmental benefits likely to become apparent. A programme to achieve this will, of course, require political commitment and concerted action, underpinned by scientific research, technical expertise and good design.

UK policy on urban planning, design, environment, drainage, ecology and biodiversity largely ignores green roofs. This is regrettable because, as has been shown in Switzerland and Germany, there is huge potential for roof greening. Government guidance and encouragement is urgently needed. English Nature intends to continue its work on green roofs, helping to refine our understanding of the role they can play in the conservation of biodiversity in towns and cities.

In order to do this some fundamental research and experimentation is required. This should include:

- further case studies of existing green roofs, to determine what species utilise what types of roof;

- studies of patterns of colonisation and succession on green roofs of different types over a number of years and, coupled with this, the effects of different management strategies;
- experimentation with different designs, orientations, substrate type and depth and micro-topographical detailing;
- examination of whether connectivity to the ground is important, for example through climber covered walls, vegetated buttresses or ramps.

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Selected green roofs

The following is a selection of projects, illustrating a range from single dwellings to factory complexes, intensive and extensive, in Europe, North America, Asia and Australasia. It only represents a fraction of green roofs built, especially extensive roofs in Germany and intensive (podium level) roofs in the Far East and plazas over car parks in US cities.

Project	Designer/Builder	Remarks
United Kingdom		
Intensive		
Arundel Great Court, London	-	1970s. Roof garden. 300mm soil/grass and 450mm soil for shrubs, 1400mm soil for trees.
BedZed, Beddington, L.B. Sutton	Dunster	2001. Green development of dwellings/workspace. Solar panels. Roof gardens with 300mm soil. Also some extensive Sedum coir matting.
Birmingham Children's Hospital, Birmingham	Lever/ Erisco Bauder	Lawn
Bloomingdales Garden Centre, Laleham-on-Thames	Cole Thompson/ Erisco Bauder	Lawn
British Gas Building, Reading, Berkshire	Foster/ Erisco Bauder	Lawn
Castle Mall, Norwich, Norfolk	-	Park on roof of car park.
De La Warr Pavilion, Bexhill, East Sussex	Chermayeff/ Mendlessohn	1935. Simple intensive (lawn) on art deco pavilion
Derry and Toms, Kensington, London	George/ Hancock	1938. 6th floor roof garden. 600-1000mm^2 of heavy silt loam soil. Slugs, snails, aphids, bees, wasps, butterflies. Plants leaf and flower 3 weeks ahead of those at ground level.
Earth Centre, Doncaster, Yorkshire	Niall Phillips/ Erisco Bauder	1999. Lawn
Ebley Mill, Stroud, Gloucs	Niall Phillips/ Erisco Bauder	Lawn
Gateway House, Basingstoke, Hants	Arup	197-1982. 2nd to 6th floor. Topsoil 225-900mm. Heavy planting. Irrigated. Pools. Nesting birds.
Harvey's Store, Guildford, Surrey	-	1957. 6th floor. Roof garden with soil 75-100mm deep with 450mm deep planters for trees. Includes pools 100-300mm deep. Intensive.
Hester Mallin Apartment, London	-	1971. 23rd floor. 7.2m^2. Container garden behind parapet walls. Bees reported.
Jacobs Island, London	Scrivens/ ZinCo	1997. 6000m^2 Roof gardens with pond over garages.
Kingston Hospital, Kingston upon Thames, London		1970.100mm - 800mm soil depth. Roof garden for staff.
Langdon Cliffs, Dover, Kent	Van Heningen & Hayward/ Niall Phillips/ Erisco Bauder	Lawn
Longmans, Harlow, Essex	C D Partnership	Roof garden with low shrubs
National Theatre, London	Euroroof/ ZinCo	1996. Intensive planted beds on terrace.
Plantation House, London	Arup/ Erisco Bauder	Shrubs and perennial borders
RMC HQ, Runnymede, Berkshire	Cullinan/ Lovejoy	1990. 4500m^2 simple intensive roof garden.
Royal Northern College of Music, Manchester		1974. 2nd floor courtyard roof garden, irrigated.

Project	Designer/Builder	Remarks
Sainsbury Centre, Phase 2, UEA, Norwich, Norfolk	Foster	Lawn
Sir Joseph Banks Centre, RBG Kew, London	Broadway Malyan	1986. LECA substrate, irrigated.
Wesleyan Assurance, Birmingham	Hing and Jones/ Erisco Bauder	Low flowering shrubs in roof garden.
West Suffolk Hospital, Bury St. Edmonds, Suffolk	-	1978. 100mm compost on sloping 1st. floor roof secured by netlon. Irrigated.
Willis, Faber & Dumas, Ipswich, Suffolk	Foster	1971. Irrigated lawn on 225mm of loam.
Extensive		
Almeida, Kings Cross, London	Clarke/Erisco Bauder	Sedum blankets on steeply pitched roofs.
BBC House of the Future	Jestico and Whiles/Kalzip	Sedum
Birchdene Drive (12 houses), Thamesmead, London	Architype	Turf
Bix Barn, near Henley, Oxon	Simmonds Mills	1993. Chalk turf on barn at BBOWT Warburg Nature Reserve.
Bix Hide, near Henley, Oxon	Simmonds Mills	1992. Turf on bird watching hide at BBOWT Warburg Nature Reserve
Calthorpe Project, Kings Cross, London	Architype	Turf
Cambridge University Sports Centre, Cambridge	ARUP	10,000m^2 of earth-sheltering.
Canoe Lake Toilets, Portsmouth, Hants	Erisco Bauder	Sedum
Castell Henlys Iron Age Centre, Pembrokeshire	Niall Phillips	Turf
Centre for Alternative Technology (CAT), Powys	Various	Turf roofs on several exhibition buildings.
Centre for Understanding the Environment, Horniman Museum. Forest Hill, London	Architype	Turf
Chisholm House, Ditchling, East Sussex	Jon Broome	Turf
Crowe Hall, Bath, Avon	Hadfield Associates/ Erisco Bauder	Sedum
Cumbria Visitor Centre, Penrith	Quarmby	1990. Extensive roof
Diggers (10 houses), Brighton, East Sussez	Architype/ EcoSchemes	1994. Self-build scheme. Turf roofs. DOE/RIBA/NHBC Housing Design Award for 1997.
Dobbs Cross, Saddleworth Moor, Yorkshire	Corus	2000. Kalzip Nature Roof (Sedum). Trial site on stable block.
Earth Centre (Conference and Arrivals Centre), Doncaster, Yorkshire	Dunster/ Erisco Bauder	Sedum
EcoTech Building, Swaffham, Norfolk	Alumsac	Sedum
Environment Agency Offices, Bodmin, Cornwall	Form Design Group/ Erisco-Bauder	Sedum
Findhorn Village,	Talbott	1991. Turf on second round of eco-homes and youth centre.
Garden Retreat, Cadmore End, Bucks	Neil May/Simmonds Mills	1995. Turf stabilised by split chestnut and rope ‘ladders’ laid over chalk rubble.
Great Notley Primary School, Essex	AHMM/ Erisco Bauder	Sedum
Hedgehog (10 houses), Brighton, East Sussex	Architype/ EcoSchemes	Self build scheme, turf.

Project	Designer/Builder	Remarks
Hooke Park, Dorset	Simmonds Gough Mills	Turf on bark mulch on butyl membrane, student project (now demolished)
House of the Future, Museum of Welsh Life, Cardiff	Jestico & Whiles/ Corus	2000. Kalzip Nature Roof (Sedum)
Ilfracombe Pavilion, Devon	Ronalds/ Erisco Bauder	Extensive roof
Integer House, BRE, Watford, Herts	Cole Thompson/ Erisco Bauder	35 degrees pre-cultivated 'Xeroflor' XF300 vegetation blanket with a hydroscopic mineral wool mat rootzone
Interpretation Centre, Wessex Water, Weston-super-Mare, Somerset	Erisco Bauder	Large Sedum roof
Laban Dance Centre, Deptford Creek, Deptford, London	Creekside Environment Project	Brownfield roof – first of several planned for the Deptford Creek area
Little House, Laindon, Essex	Jon Broome	Turf
London Wildlife Garden Centre, Peckham, London	Architype / EcoSchemes	1990. Turf. Extensive. Times/RIBA award for community architecture.
Liss Junior School, Hants	HCC architects/ Erisco Bauder	Sedum
Making Place, North Kensington, London	Architype	Turf
Matzdorf House, Islington, London	Jon Broome	Turf
Millennium Seed Bank, Wakehurst (RBG Kew)	Alumasc	Sedum
Moorside Road (14 houses), Lewisham, London	Architype	Turf
National Federation of City Farms, Bristol	Architype	Turf
National Wildflower Centre, Liverpool	Hodder	?
Nottingham University Campus, Notts	Hopkins/ Erisco Bauder	Sedum
Opera House Extension, Winchester, Hants	Corus	2002. Kalzip Nature Roof
Paignton Zoo, Paignton, Devon	Elliot	Sedum
Pizza Hut/ Asda, Swindon, Wilts	Corus	2002. 485 m^2 Sedum species on Kalzip Nature Roof
Pizza Restaurant, Jersey	Riva/ MEPK/ Corus	2000. Kalzip Nature Roof (Sedum)
Raleigh Gardens, London	Penoyre and Prasad/ Erisco Bauder	Sedum
St David's Information Centre, Pembrokeshire	Smith Robert/ Erisco Bauder	Extensive grass
St Paul's Bus Station Walsall	Allford, Hall, Monaghan, Morris	Turf on concrete shell
Scottish Widows, Edinburgh	Sylvia Crowe	1976. Roof of multi-storey car park 100-500mm of silt loam with peat planted with low shrubs/heather.
Shaw's Cottages, Lewisham, London	Jon Broome/ EcoSchemes	1993. Turf roof on a new house in Lewisham. (see case study)
Skirmet Shed, Bucks	Simmonds Mills	1994. 25m^2 100mm thick turf roof
Surrey Docks City Farm, London	Architype	Turf
Sutton Courtenay Environmental Education Centre, Didcot, Oxon	Simmonds Mills	2002. Plants from site planted into nutrient poor soil over geotextiles.
Underhill, Yorkshire	Quarmby	Part lawn, part extensive grass, part shrubs and heathers.
Westonbirt Arboretum	Simmonds Mills	1994. Turf on 80m^2 roof of shelter.

Project	Designer/Builder	Remarks
Ireland		
Skellig Interpretative Centre	Peter and Mary Doyle	Extensive grass.
France		
Intensive		
Cite Scolaire Internationale de Lyon	Jourda & Perraudin	1992. Huge lawn roof.
Couli Vert, Paris	-	Linear park on viaduct linking Bastille area to Peripherique.
Jardin Atlantique, Gare Montparnasse, Paris	-	3 hectare park on roof.
Louvre Extension, Paris	Pei/ Barcel	Uses Barcel roof garden system.
Nombre d'Or. Montpelier	Bofill/ Soprema	Massive roof garden uses Elastophene system by Soprema.
Palais des Sports, Paris	-	Lawn roof.
Palais Omnisports, Bercy, Paris	-	Lawn roof.
Belgium		
ECOVER factory, Oostmalle, Belgium	-	1992. Extensive. 5,000 m^2 roof of meadow grasses and sedum.
Netherlands		
AZL HQ, Heerlen	Arets	Extensive. Turf roof.
Romolenpolder, Haarlem	-	1990. Green housing scheme with extensive grass roofs.
Schiphol International Airport, The Netherlands	Strodhoff & Behrens/ Begruennungs	Extensive. Pre-vegetated moss and sedum mats of coir fibre.
Germany		
Intensive		
Allianz Building, Stuttgart	Luz/ Optima	Densely planted raised beds on stepped terraces.
Bank in Cologne	Caltes/ ZinCo	1985. Intensive roof garden. Pond and water feature.
Bernau Sud Housing, Berlin	Franke/ ZinCo	1996. Intensive, park over garages.
Business Centre, Ostfildern	Gailinger/ Zinco	1990. Intensive informal.
Dentists Association, Munster	Skribbe/ ZinCo	1984. Intensive over garages.
Diakonissen Hospital, Karlsruhe	Sade, Zimmerman, Fritz/ ZinCo	1985. Intensive. 600m^2 hospital garden for patients.
Galling Roof Garden, Bielefeld	Galling/ ZinCo	1996. Intensive with pond.
Gate Tower Park, Reutlingen	Eppinger and Schmid	Formal park over car park.
Farmers Insurance, Hannover	Adam/ Optima	Formal office roof garden.
Wiese Housing Estate, Ettlingen	Langensteiner/ ZinCo	1995. Intensive over car park.
Golf Course, Birkenwerder, Berlin	Giese/ ZinCo	1996. Intensive. Small golf course c/w trees, shrubs and greens.
Hotel Ibis, Berlin	Wetter/ ZinCo	1997. Mainly intensive with mature trees but also small extensive (Sedum) area.
Industrie-Kredit Bank Conference Centre,	Dorn	Trees, shrubs and lawn above car park.
Investment Bank, Potsdam	Ahner+Brehm/ ZinCo	1996. Intensive, park-like roof.
Lauer Building,	Grau & Hild/ ZinCo	1993. Richly planted roof garden.
Orthotech Laboratory, Leipzig	Borman/ ZinCo	1994. City centre roof planted with flowering perennials and succulents.
Newton Street Housing, Friederichshafen	Szabo/ ZinCo	1996. Intensive park over garages.

Project	Designer/Builder	Remarks
Private Residence, Wendlingen	Morgenthaker/ ZinCo	1984. Roof with pond and vegetable garden.
Regional Bank Service Centre, Göppingen	Eich/ ZinCo	1993. Intensive. A series of terraces.
Social and Recreation Building, Hannover	Droge/ Optima	Informally planted terraces.
Unisys Building, Frankfurt	Meid and Romeick/ Dorn	Formal office roof garden.
Extensive		
Bauder HQ	Erisco Bauder	Large Sedum roof.
Concert Hall, Ludwigsburg	Erisco Bauder	Sedum roof.
Fire Station, Ludwigsburg	Erisco Bauder	Sedum roof.
Furniture Centre, Boblingen	IN-Bau/ ZinCo	1989. Intensive/Extensive. Drought resistant shrubs and grasses.
Green House, Rheine	Elbehausen	Earth sheltered house with extensive roof.
Housing at Herzogenrath	Windkunst	Extensive grass roof.
Lunette Building of Ranstatt Fortress	Hansjorg Muller/ ZinCo	1996. Extensive. 100-year-old grass roof replaced with Floratec FS 50 system.
Nature Lovers House, Dortmund	Pangert	Sedum with grasses
Penthouse, Steinenbronn	Metall & Dachtecnik/ ZinCo	1988. Extensive. Richly planted terrace and meadow.
Service Centre, Goppingen	ZinCo	1993. Sedum mixed with various other plants.
Service Centre Ostkreuz, Berlin	ZinCo	8500m^2 on industrial office buildings using ZinCo International's Floratec FS 50 system.
Show home at Documenta Urbana, Kassel	-	Extensive green roof plus green facades.
VHV Corporate Headquarters, Hanover	Uwe Isterling/ Optima	1992. Various grasses, sedums and herbs set into 6 cm substrate.
Switzerland		
9 Houses at Dietkon	Vetsch	1993. Lawn roofs.
Ciba Geigy Building, Basel	-	1966. 150mm soil. Extensive.
De Bude Park, Geneva	-	400mm soil. Roof garden on 9th floor. Intensive.
Grosse Schanze Park, Berne	-	1970. Intensive. Covers complex of car park, offices and station. 1100m^2. Soil 200mm-1200mm. Grass, shrubs and trees. Irrigated.
Kantonspital, Basel	Optima (part)	1979. Complex of roofs. Simple intensive and extensive. (see case study)
St Martin, Lausanne	-	Intensive. 400-1200mm soil. Irrigated.
Swiss Ban Union, Basel	Burckhardt/ ZinCo	1990. Intensive. Planted beds.
Uetlihof, Zurich	Optima	1980. Extensive.150mm LECA. Turfed with natural vegetation.
Austria		
EFA Radio Satellite Station, Aflenz	Peichl	1976-1979. Earth sheltered complex with meadow roof.
Pit Project, Breitenbrunn	Noever	1971. Underground house complex covered by meadow.
Hundert Wasser Haus, Vienna	-	Roof garden with trees.
University of Vienna	Saiko	Roof gardens on buildings over railway terminus.
Czech Republic		
Hotel Intercontinental Prague	-	Roof garden above car park with trees, shrubs, lawn.

Project	Designer/Builder	Remarks
Italy		
Hotel Excelsior, Venice	Sasaki	1991. Intensive. Formal garden with Moorish theme, pools in central courtyard.
Pesaro	Abram/ ZinCo	1994. Intensive, sloping, flowers.
Radaelli Roof Terrace, Omate, Milan	Radaelli/ Zinco	1994. Intensive, includes lawn, borders.
Spain		
Housing project, Madrid	Martinez/ Medina/ ZinCo	1992. Intensive. Includes tree avenues and pools.
Norway		
Fanafjell, Bergen	-	Traditional houses with turf roofs.
Folk Museum, Oslo	-	Traditional houses and barns with turf roofs.
Office building, Lillehammer	-	Roof terrace with planters.
Sweden		
Austenborg Botanical Roof Garden, Malmo	Public works depts. and universities.	2001. World's first botanical roof garden. Various demonstration moss/sedum extensive roof treatments.
GreenZone Ford Dealership, Umea Sweden, 2000	Veg Tech	Extensive greenroof of pre-vegetated sedum and moss tile mats on three buildings.
Hotel at Dalarno	-	Turf on traditional Scandinavian timber building.
Russia		
Kresty Prison, St Petersburg	-	Rooftop vegetable garden.
United States		
Intensive		
555 Market Building, San Francisco	Osmundson	1965. Formal roof garden includes trees and shrubs.
Bunker Hill, Los Angeles	-	Formal gardens at podium level accessed by large staircase.
Champion Paper Co., Stamford, Conneticut	-	Trees in planters with picnic tables on roof.
Chicago City Hall Greenroof, Chicago Illinois	William McDonough / Roofscapes	Uses Sarnafil roof. Monitored for urban heat island effect.
Constitution Plaza, Hartford, Conneticut	Sasaki	1964. Formal gardens at podium level.
Crocker Terrace, San Francisco	Skidmore, Owings, Merrill	Formal garden on roof of bank.
Embarcadero Center, San Francisco	-	Formal gardens at podium level.
Enid A Haupt Garden, Smithsonian, Washington DC	Sasaki	1987. Formal garden with many trees over museum.
Federal Reserve Bank, Boston	Stubbins/ Fager	1970s. Formal gardens with trees, shrubs at podium level.
Harvey's Resort, Lake Tahoe, Nevada	-	Multi-storey car park with roof garden/terraces.
Hilton Palazzo del Rio, San Antonio, Texas	-	1984. Formal roof garden above porte cochere for residents.
Kaiser Center, Oakland, California	Beckett/ Osmundson	1960. Roof garden at podium level includes pond.
Nathan Marsh Pusey Library, Harvard	Stubbins/ Fager	1976. Trees, shrubs, lawn on roof.

Project	Designer/Builder	Remarks
New England Merchants National Bank, Boston	-	1970. 1000m^2 on 39th floor. Highest roof garden in the world? Intensive.
Persching Square, Los Angeles	Hanna Olin	Pond, waterfall, trees over car park.
Rockerfeller Center, New York		1930s. Formal gardens at podium level.
Utah State Capitol	Hansen	Formal gardens above car park.
Westin St. Francis Hotel, San Francisco	Osmundson	1972. Formal roof garden on single storey annexe.
Woolf House, San Francisco	-	Vegetable gardens above apartments.
Extensive		
Arizona Sonora Desert Museum	Line and Space	*Opuntia* (prickly pear)
Brewster House, Massachusetts	Wells	1980. Extensive grass.
Brunsell Residence, Sea Ranch, California	Bowman	1987. Rooftop meadow with same species as adjacent headland.
Filucy Bay Residence, Longbranch, Washington State	Olson & Sunberg	1968. Meadow roof in forest setting.
Ford Motor Company, Rouge River Plant, Dearborn Michigan	William McDonough/ Roofscapes	45,000m^2 of assembly plant roofing covered with sedum and other plants.
Grizzly Creek Rest Area, Glenwood Canyon, Colorado	Davis and Brandeberry/ Flores	Native shrubs used to help building blend with natural slope
Moore Residence, Conneticut	DeVido	Grass roof on building in woodland glade.
Underground Gallery, Cape Cod	Wells	Extensive grass.
Canada		
Bonaventure Hilton, Montreal	Sasaki	Formal garden on exhibition hall includes 'stream', trees and shrubs.
Boyne School, Shelburne, Ontario	Pollard/ Allen	?
Environmental Sciences Building, Trent University, Peterborough, Ontario	Heriques/ Oberlander	?
Fishermans Cottage, Farm of Louisburg, Cape Breton, Nova Scotia	-	Sod roof.
Former George Brown College, Kensington Market, Toronto	Spiegel	Irrigated, simple intensive.
Kaiser Resources, Vancouver	Osmundson	Formal terrace garden on upper storey.
Legislative Building, North West Territories	Matzuzaki Wright/ Oberlander	?
Mary Lambert Swale Housing Project, Toronto	Reloh and Petch/ Kuhn	Intensive roof garden in planters.
Toronto City Hall podium	Green Roofs for Healthy Cities Coalition	8 trial plots, intensive and extensive.
Vancouver Public Library	Safdie/ Oberlander	Extensive
Wilson House Solar Project, Hockley Valley. Toronto	Martin Liefhebber/ American Hydrotech	?
YMCA Facility, Kitchener, Waterloo, Ontario	McKinnon/ Hensel	?
Mexico		
Four Seasons Hotel, Mexico City	Aleman, Garel/ Gonzales	1994. Formal courtyard garden above car park.
Japan		
ACROS Building, Fukuoka	Ambasz	1989-95. Stepped terrace roof gardens.
Arakjawa Natural Park, Tokyo	Ogata	Public park includes large pond with marginal aquatic planting above sewage treatment plant
Big Sight International Exhibition Centre, Tokyo	Tajima Roofing/ ZinCo	1996. Simple intensive (lawns)

Project	**Designer/Builder**	**Remarks**
International Congress Centre, Tokyo	Vinoly/ ZinCo	1996. Park like elevated 'courtyard' with mature trees.
Kitakyushu Hotel, Kitakyushu	-	Traditional Japanese garden at 2^{nd} storey level
New Otani Hotel, Tokyo	Iwaki	Hotel roof garden includes waterfall and pond said to be most spectacular roof garden in the world.
Rhiga Royal Hotel, Tokyo	Araki	Includes informal planting around waterfall above hotel storerooms.
Shinjuku Mitsui Building, Tokyo	Toyo	Formal plaza roof garden with mature trees.
Shinjuku N S Building, Tokyo	Araki	Formal gardens above shops
Soft and Hairy House, Tsukuba City	Ushida-Findlay	1994. Mixture of shrubs, extensive grass and intensive vegetables/herbs.
Sunshine 60 Building, Tokyo	Araki	Roof gardens in podium level of Japan's tallest building includes informal planting of many mature trees and waterfall.
Taisho Marine and Fire Insurance Co	Araki	Densely planted beds at podium levcel of formal plaza.
Hong Kong		
Ap Lei Chau Estate, Aberdeen	Belt Collins	1990s. Intensive. Trees and shrubs in planters on roof of commercial centre and car parks
Wonderland Villas, Tsuen Wan	-	1980s. Intensive. Park on multi-storey car park.
Australia		
Central Park, Perth	Forbes and Fitzharding/ Landscan	Lawns, trees and shrubs over car park
Transperth Bus Depot, Perth	Cameron, Chisholm and Nichol/ TRACT	Lawns, trees and shrubs over bus garage.
St. Georges Square, Perth	Collier/ Adams	Formal gardens above car park

Selection of green roof websites

Website	Remarks
www.alumasc.co.uk	UK supplier of ZinCo systems
www.app.hu	APP – German supplier of green roof systems
www.archut.de	Hawitt – Gruppe - German supplier of green roof systems
www.bacqube.bayareacouncil.org/901.	New corporate HQ in San Francisco with wildflower meadow on roof
www.bott-gruen.de	Peter Bott – green roof designer
www.casp.it	Green roofs from the Cooperativa Agricola Sviluppo Piemonte, in association with Optigrun
www.cityfarmer.org/rooftop	Promotes rooftop vegetable gardens
www.cityfarmer.org/russiastp.html	Article about rooftop vegetable gardens in Russia
www.cityofchicago.org/Environment/html/RooftopGarden.html	City of Chicago City Hall rooftop garden monitored as part of urban heat island initiative.
www.cmhc-schl.gc.ca/	Article promoting green roofs in Canada
www.cnn.com/2001/NATURE/01/01/rooftop.gardens.enn/index.html	Article on how green roofs cool air
www.dachgaertnerverband.de	German roof gardening association – lists German cities with green roofs incentives.
www.ecoschemes.com	Includes article on building-integrated vegetation
www.ecover.com	ECOVER factory in Belgium includes information on green roof.
www.ehlert-wirtz.de	German supplier of green roof drainage systems.
www.erisco-bauder.co.uk	Erisco-Bauder - supplier of green roof systems
http://fesweb.ntu.ac.uk/staffwebs/greenroofs/aboutGRandESB.htm	Paul Collins, School of Property and Construction, The Nottingham Trent University. Green roof website
www.fytodak.com/AlgemeenGB.html	Dutch supplier of green roof systems
www.greenroof.co.uk	Blackdown Horticultural Consultants –plants for Kalzip Nature Roof/ Corus.
www.greenroof.com	International Green Roof Insitute/ Augustenborg Botanical Roof Garden, Malmo
www.greenroofs.com	Linda S. Velazquez, Landscape Architect, University of Georgia
www.green-roof-systems.co.uk/green-roof-systems/index.html	RAM-RGC green roof consultancy
www.greenscape.eu.com/ pages/roof1.html	UK suppliers of Fytodak green roof systems
www.gruendachtechnik.de	Gruendachtechnik – German supplier of green roof systems
www.greennetwork.de	Greennetwork – German affiliate of Optigrun.
www.gruenesdach.de	Grunes Dach – German supplier of green roof systems
www.haemmerle-gruendach.de	Fritz Haemmerle – German green roof proponent
www.hydrotechusa.com	American Hydrotech garden roofs system (Zinco design)
www.indiana-architecture.com/ Introduction.html	US 'grass-step' sod roof
www.interlog.com/~rooftop/greening.html	Rooftop Gardens Resource Group Canada - Article from Eco-Architecture 2 (1996) by Monica Kuhn
www.isatis.de	ISATIS Montana - German supplier of plants for green roofs
www.kalzip.co.uk	Corus Building Systems - UK based, supplier of Kalzip Nature Roof
www.kenilworth.com/Construction/C_01_01/C_01_01_Feature2.htm	Article promoting roof gardens in Toronto, Canada
www.mcdonough.com.	William McDonough & Partners' - US architects with green roof experience
www.optigruen.de	Optigrun – German supplier of green roof systems
www.optima-dachbegruener.de	Aktual Bauteile u. Umweltschultzsysteme / Optima Zentrale – German supplier of green roof systems
www.peck.ca/grhcc	Coalition of Canadian firms promoting green roofs
www.re-natur.de	ReNatur – German supplier of green roof systems
www.roofmeadow.com	Roofscapes - US green roof supplier affiliated to Optigrun.
www.sarnafilus.com	US partner for Optigrun and Roofscapes Inc.
www.segalselfbuild.co.uk/articles/creatingagreenro.html	How to install a turf roof (Architype Ltd. Architects)

Website	Remarks
www.sfg-gruen.ch	Swiss green builders association – includes articles on green roofs (in French and German)
www.sierraclub.org/sierra/200105/hearth.	Article from Sierra Magazine by Wendy Holtcamp on green roofs, conserving energy and cooling the air.
www.zinco.de	ZinCo - German supplier of green roof systems
www.zwirner.de	Zwirner - German supplier of green roof systems

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Top left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Middle left: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888
Bottom left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Main: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792

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