Harnessing nature's capital

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The Role of Green Walls and Green Roofs in Carbon Sequestration

Moray Council

Prepared by: Collective Architecture

Collective Architecture
4th Floor, Albert Chambers
13 Bath Street, Glasgow G2 1HY

info@collectivearchitecture.co.uk
www.collectivearchitecture.co.uk

Client: Moray Council

Council Offices High St,
Elgin IV30 1BX

Project Team: Architect: Collective Architecture
Project Manager: Currie & Brown
Environmental Consultant: LUC
Planning Consultant: JLL

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Introduction

The sustainable practice known as green roofs and walls have become widely used to reduce the effects of climate change and enhance the liveability of urban areas. The green roof is known as a living system and is able to store carbon in the long term. A green roof's vegetation and soil medium is also able to capture and store air pollutants from the surrounding environment, making the practice popular in urban areas. The 'long term green roof effect' is an indirect impact of green roofs in which less energy is used to power buildings leading to a reduction in fossil fuel consumption.

01 Green Roof Viability in Scotland

The following chapter gives a brief outlook on policies in Europe and the UK

1.1 Context Policy in Europe

Source of Information: Living Roofs and Walls from policy to practice 10 years of urban greening in London and beyond

1. SCOTLAND:
Has no mandatory policy for Green roof infrastructure and current planning guidelines place little weight of 'expectation' on developers to integrate green roofs into development. How is this achieved in the rest of the UK and Europe...

2. LONDON:
No mandatory policy, but successfully increasing green roof infrastructure through the land-use Planning System for the past 10 years, notably through The London Plan.

3. PARIS:
Has an ambitious target of installing 100 hectares of green roof and walls by 2020, through the Paris Culteurs. France is the only country in the world to have a law that encourages green roofs, requiring all new commercial developments across france to integrate green roofs or solar panels. Installed 1million m2 of green roof in 2017.

4. ROTTERDAM AND AMSTERDAM:
Incentives since 2008. Target of achieving 600,000m2 of Green Roof Infrastructure by 2025.

5. COLOGNE, MUNSTER, MUNICH, STUTTGART AND BERLIN:
All have reductions in storm water fees if Green roofs are installed or retrofitted.

6. STUTTGART:
Requirements for all new developments to have Green Roofs. Stuttgart, Hamburg and Frankfurt have had funding programmes for green roofs and walls, paying 50% of costs up to a value of 10,000 Euros. These have now been phased out.

7. BERLIN:
Many German cities have mandatory targets for achieving green space. Berlin use the Biotope Area Factor.

8. BASEL:
Since 1996 under the Building and Construction Law, the city requires green roofs on all new developments with flat roofs. After 2002, Green roofs have to be designed to maximize biodiversity. There are also financial incentives.

9. COPENHAGEN:
Mandatory green roof policy for all new buildings with pitches less than 30 degrees.

10. MALMO:
Using the Green Space Factor and Green Points systems, to promote Green Infrastructure.

11. STOCKHOLM:
Green Space Factor is used as a Planning tool. This is a requirement for all property developers building on land owned by the city.

SUMMARY:

Most central European Cities have mandatory policies and incentive programmes to promote green roof infrastructure. These cities have been able to significantly increase their green roof per capita (m2/ inhabitant) as demonstrated in Table A below.

London on the other hand has created a successful mechanism for change without a mandatory system or incentive programmes. By placing Green Infrastructure at the heart of a Spatial Development Strategy, this has creating an environment where there is an expectation that green infrastructure will be provided with new developments.

	Population	Total area of green roofs (m²)	Green roofs per capita (m²/inhabitant)
Basel	175,131	1,000,000	5.71
Stuttgart	590,000	2,000,000	3.38
Linz	193,814	500,000	2.57
Munich	1,450,381	3,148,043	2.17
Vienna	1,714,000	2,560,000	1.49
Malmö	303,000	400,000	1.32
Hanover	522,686	638,500	1.22
London's CAZ	**230,000**	**205,000**	**1.21**
Düsseldorf	588,169	698,000	1.19
Berlin	3,600,000	4,000,000	1.11
Washington D.C.	681,170	254,470	0.37
Rotterdam	634,661	235,000	0.37
Amsterdam	813,562	300,000	0.36
Melbourne City	148,000	54,000	0.36
Portland	570,000	157,989	0.27
Chicago	2,700,000	508,130	0.19
Tokyo	13,184,161	1,345,250	0.10
Toronto	2,615,060	250,000	0.09
Singapore	5,100,000	468,000	0.09
Copenhagen	510,000	40,000	0.07

The figures have been collated from various cities and organisations and from work as yet unpublished by Humboldt University. Data collection methods vary. It should be noted that figures for London relate only to the Central Activity Zone as data for the Greater London area for 2015 are not available.

1.2 Policy and Development in London

London has a relatively short history of implementing Green Roof Infrastructure and does so primarily through the land use planning system. Since 2008 the London plan has provided the strategic planning policy framework which influences policy development in local boroughs.

2008: Introduction of London Living Roofs and Walls Policy

2011: Update to The London Plan to include Chapter 5 ' Urban green Policy'

2016: London Plan updated to include policy 2.18 'Green Infrastructure', capturing both the urban greening and green roof policies

Since 2010 the total amount of green roof has doubled and the London market accounts for over 40% of the UK's Green Roof Industry.

1.3 Scotland

Scotland's major cities have growing populations and with that comes a greater pressure on our cities infrastructure. Increased density puts a greater strain on the following:

- Surface water management
- Urban cooling
- Biodiversity
- Air quality
- Health and well being
- C02level
- Noise pollution

Green roof infrastructure helps to address all of these things. However, the use of Green Roof Infrastructure is not commonplace. This may be due to a number of factors - economic, lack of awareness of their benefits but the major one is a lack of policies to drive uptake.

Codes of Practice:

There are no British Standards to guide specifiers and contractors as to the best methods. The most widely accepted Code of Practice amongst leading suppliers in the UK is the German FLL. There is also the GRO code. The GRO is a partnership of industry and stakeholders collaborating to develop guidance for specification, design, manufacturing, installation and maintenance.

Scotland is broadly striving for greener cities in line with zero carbon targets but what mechanisms could be improved to increase and promote the use of Green roof Infrastructure in Scotland:

- **Are there mandatory policies that can be introduced?**

- **Are there incentives for developers for both new development and existing structures that could be introduced?**

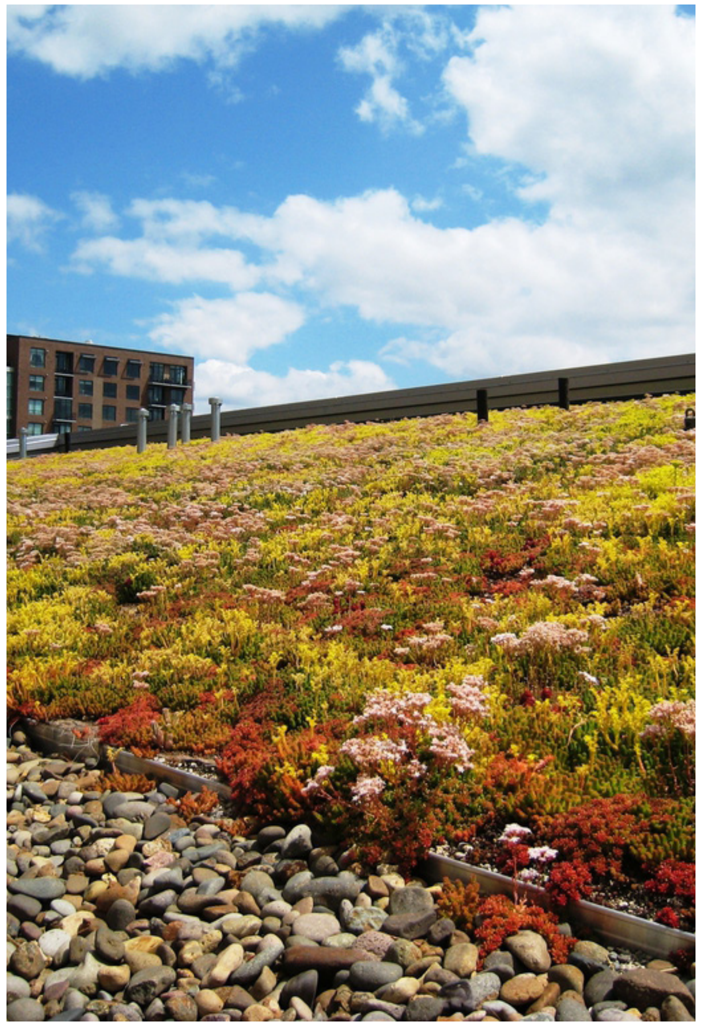
- **Are there changes to national and local strategy policy that could be developed to embed green roofs to ensure that this is a consideration for all future developments**

02 Green Roofs

Following is an introduction to green roofs, an outline of their benefits along with a description of the different green roof systems available.

COLLECTIVE ARCHITECTURE

2.0 Green Roofs



Examples of Green Roofs

Benefits of installing a green roof:

- Adding mass, thermal resistance and absorbing less heat than regular roofs, so you reduce the carbon footprint and the urban heat island effect

- Creating a habitat for animals and insects. As well as directly providing an environment and food supply, planted roofs also cool and humidify the surrounding air, creating a beneficial microclimate

- The vegetation in green roofs can filter out carbon dioxide, nitrates and other harmful materials. This also helps improve local air quality, which can benefit both humans and animals. (you can expect to hear much more on the subject of air quality and over-heating throughout 2021)

- Depending on the green roof design, the immediate water run-off can be reduced considerably – by as much as 90 per cent, reducing stress on drainage systems and in turn helping to mitigate localised flooding

- Plants are also effective at reducing noise, as they provide natural sound insulation; they can reduce reflected sound by up to 8dB.

2.1 Carbon Sequestration and Wider Benefits of Green Roofs

Carbon Sequestration:

Green roofs help reduce carbon dioxide in the environment in two ways:

1. Green vegetation directly decreases CO2 in the air through photosynthesis, storing the carbon in plants and roots
2. Urban vegetation can reduce the amount of heat absorbed by the buildings, reducing the building's cooling demand.

Vegetation takes in carbon dioxide from the air and stores it as carbon in the tissues of the plants as it grows. This carbon is deposited in the roots, leaves, and stems of plants as they develop. Some of this carbon will be deposited or left in the soil or substrate during the life of the plant, where it will decompose and turn into humus, or soil, offering a longer-term carbon store. This carbon storage in the soil or substrate will keep growing as the plants develop over many years, resulting in a net sequestration of carbon. However, it is important to note that soils also naturally release carbon through the respiration of the microbial and fungi species that inhabits it.

As with all construction, the materials used to construct the green roof have a carbon cost. A green roof can only be called a net carbon sequester once it has stored the same amount of carbon as it took to build it. As a result, it is critical to evaluate the various components of a green roof and, if feasible, reduce their carbon footprint. The following are key components of a green roof system that significantly contribute to its carbon footprint:

- Substrate (artificial lightweight aggregate, transport to site)
- Drainage and filter layers (plastic materials)
- Maintenance (petrol driven tools, irrigation systems, water, pumps)
- Plants (resources to produce pre-grown vegetation or seed)

Wildlife and Biodiversity:

Green roofs can be thought of as green'stepping stones' for wildlife, and, if well planned, they can support a variety of flora and fauna unattainable on traditional roofs. However, green roofs do not directly replace ground-based habitats, and they are not a part of a ground-level "green corridor." Different habitats and species will be supported by various types of green roofs, substrates, and plants. It is possible to create biodiverse roofs that resemble distinct environments. They can be particularly useful as a means of reviving the pioneer (wasteland) villages that are occasionally lost during redevelopment. The most biodiverse places are frequently abandoned brownfield lands found in urban settings. The best designs frequently support a variety of substrates, microhabitats, and substrate depths to support a variety of wildlife habitats. To achieve the goals of local Biodiversity Action Plans, green roof designs should vary across the UK. Additionally, certain endangered species' habitats can be recreated using green roofs.

Wellbeing:

Green roofs, especially dense and easily accessible rooftops, provide extra health benefits. In order to boost welfare and offer a sanctuary from the stresses of city life, additional accessible green spaces can be created in dense urban buildings, such as podium deck gardens and resident roof terraces.

Urban Cooling:

Water within the planting areas can help contribute to reducing the Urban Heat Island Effect (UHIE). As buildings heat up and the UHIE increases, so does the need for cooling. Green roofs can help with this as the plants and soil evaporate moisture. This process of evapotranspiration cools the air around the building. In doing so reducing the need for cooling and helping reduce the UHIE.

2.2 Green Roof Systems

When constructing a green roof there are some fundamental considerations that determine the system required to support the planting scheme. The key decisions are about access and what the roof is to be used for, is it for nature conservation and biodiversity or aesthetics? How will the area be used and how much maintenance will be possible.

Green roofs are classified in two main categories: extensive and intensive.

1. **Extensive green roof:** has a growth medium depth of 3 to 6 inches.
2. **Intensive green roof:** any green roof with a soil, or growth medium, depth greater than 6 inches.

1. Extensive

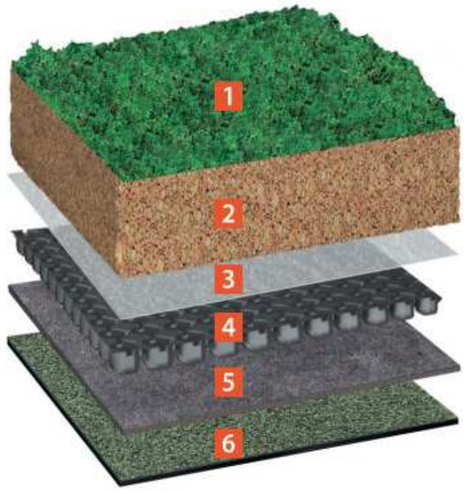
USE: For ecological benefits
MAINTENANCE AND COST: Low
SUBSTRATE/VEGETATION: Sedum or wildflower

- Extensive green roofs are most commonly used as they are lightweight and relatively low maintenance
- Generally, public access is not expected to be provided on this type of green roof, nevertheless, they remain a popular choice, as they are lightweight.

1A. Extensive Sedum

USE: Lightweight roofs and ecological benefits
MAINTENANCE AND COST: Low
SUBSTRATE/VEGETATION: Sedums

- Extensive green roofs are most commonly used as they are lightweight and relatively low maintenance.
- Generally, public access is not expected to be provided on this type of green roof, nevertheless, they remain a popular choice, primarily for ecological benefits they are lightweight
- One of the most appealing benefits of this green roof type is that it can be installed on new developments or on an existing one (weight permitting).
- Sedum are drought and wind tolerant and therefore should remain green all year round, though they do need irrigation in extended drought events.
- Sedum mats - these mats have base layer of polyester with a growing medium placed on top. The sedum seeds are then dispersed on top of this layer. The mat should be laid on at least 60mm of substrate.



1. Sedum blanket
2. Substrate (Typically 60-80mm)
3. Filter Fleece
4. Water Retention and drainage
5. Protection layer
6. Waterproofing system

Source: Bauder

1A. Extensive Wildflower Biodiverse

USE: Ecological benefits with a particular focus on biodiversity
MAINTENANCE AND COST: Low
SUBSTRATE/VEGETATION: Blended substrate/native wildflowers/grasses/succulents

- A biodiverse roof is used for its ecological benefits. They consist of a blended substrate planted/seeded with wildflowers/grasses and succulents or wildflower turf.
- Due to increased depth of substrate, biodiverse green roofs increase the ecological benefit (stormwater, acoustics and thermal properties etc) whilst also providing important habitat for wildlife.
- Maintenance is low for this type of green roof, after two years they are relatively self-maintaining
- They contribute to achieving additional BREEAM points by improving air quality and assisting in controlling rainwater run off of this layer.

1. Vegetation: Native seeds and plug mixes in combination with other habitat features.
2. Biodiverse substrate
3. Filter fleece
4. Water retention and drainage
5. Protection layer
6. Waterproofing system

Source: Bauder

2. Intensive

USE: Roof gardens
MAINTENANCE AND COST: High
SUBSTRATE/VEGETATION: Herbs, flowering plants, taller grasses, larger shrubs, trees etc

- Intensive green roof require the deepest soil and it has the greatest impact on the structure beneath it.
- Effectively, all planting types are accommodated for this type of green roof. In a design in which you expect users to interact with the roof, this is the most suitable choice, as you can create a park-like setting.
- Garden and park roofs are capable of storing vast amounts of rain water, therefore they create good Sustainable Urban Drainage Systems (SUDS). This provides an effective thermal barrier too.
- Depending on the type of vegetation planted, this green roof type can be extremely effective for biodiversity.
- Maintenance is high because they must constantly be watered or trimmed etc, in order to maintain an enjoyable environment. They essentially require the same amount of maintenance as parks.
- The degree of maintenance depends heavily on the type of vegetation planted.

1. Intensive planting
2. Intensive substrate (typically 200-250mm)
3. Filtration later
4. Drainage board
5. Protection Later
6. Separation and slip layer
7. Waterproofing

Source: Bauder

2A. Semi-Intensive

USE: In visible areas
MAINTENANCE AND COST: Periodic/ Medium
SUBSTRATE/VEGETATION: Herbs, flowering plants, taller grasses and small shrubs.

- Semi-intensive green roofs are heavier than extensive green roofs. As such, they are used less commonly.
- They require a deeper substrate. Periodic maintenance. However, the benefit of this is that a more diverse range of planting can be utilised; particularly ones that need more nutrients than those that can be used in extensive green roofs.
- Because they have an aesthetic appeal, semi-intensive green roofs are used in projects where the roof is visible.
- Maintenance for this green roof system more frequent than extensive systems, however, it does not exceed maintenance of regular planters

1. Intensive planting
2. Intensive substrate (typically 200-250mm)
3. Filtration later
4. Drainage board
5. Protection Later
6. Separation and slip layer
7. Waterproofing

Source: Bauder

3. Solar Green and Biosolar

USE: Providing solar energy for buildings
MAINTENANCE AND COST: Low
SUBSTRATE/VEGETATION Extensive and intensive green roofs can be integrated

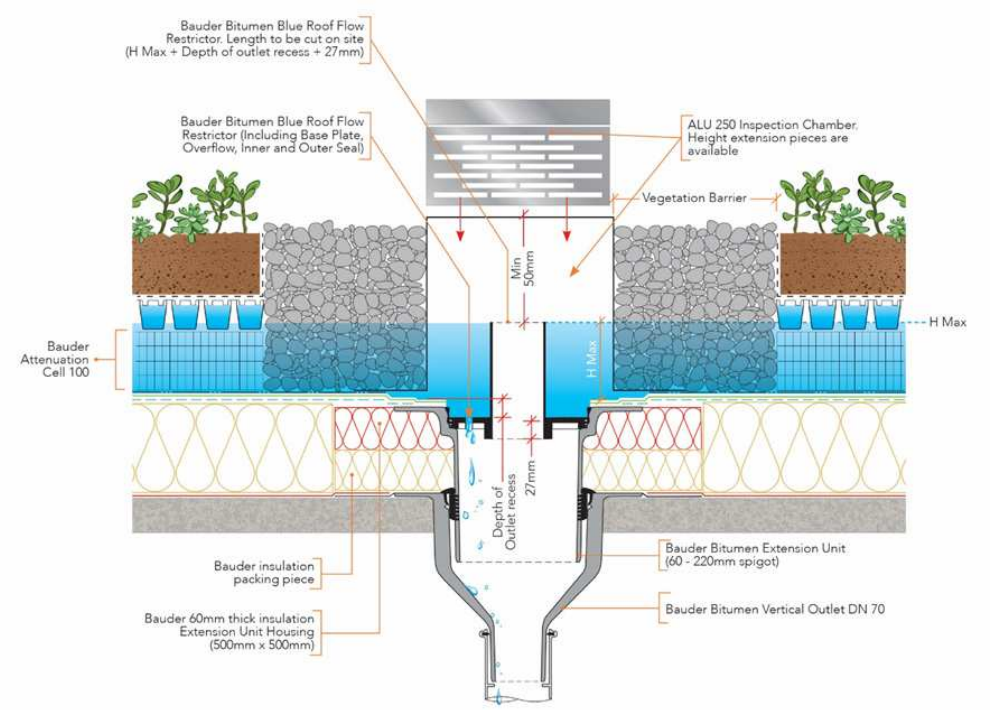
- This is a system where green roof and solar technologies are integrated. Most commonly used on extensive green roofs, biodiversity is maximised and solar gain is boosted.
- Sometimes the solar element of the green roof takes precedence and this is when it is unsuccessful. The success of this system lies in the integration of solar mounts within the engineered layers of the green roof itself.
- Light and rain can penetrate beneath the solar panels. Solar arrays create different micro-climates, increasing biodiversity potentials.
- Extensive roofs are most suited to the installation of solar panels, however, they are being increasingly installed on intensive green roofs too, providing shade on rooftop gardens.
- Water run-off provides irrigation for vegetation planted beneath.

Note: Solar green roofs (as opposed to biosolar green roofs) are where the solar mounting system is not integrated into the green roof system. Generally this will mean that the solar-panel system is separate to the green roof system. Biosolar roofs are where the solar mounting system is integrated into the green roofs system. There currently three integrated systems in the UK market supplied by Bauder Optigreen and Zinco.

4. Blue Green Roof

USE: Retaining and reusing rain water
MAINTENANCE AND COST: Low
SUBSTRATE/VEGETATION: Extensive and intensive green roofs can be integrated

- Blue roofs combine blue and green roof technologies. Whilst standard green roofs use conventional drainage layers, blue roofs aim to increase water volume and control water released.
- A blue roof retains¬¬ rain fall within the roof structure before discharging it in a controlled manner.
- Blue roofs are designed for water retention above the waterproofing part of the roof. This is different from conventional roofs, where water is drained rather than stored.
- It is a form of Sustainable Urban Drainage Systems (SUDS) to help alleviate urban flooding caused by run-off.
- Unlike other forms of SUDS, blue roofs make use of spaces that may otherwise be redundant without extending beyond building footprints.



Source: Bauder

2.3 Green Roofs for Retrofit

Green roofs are often associated with newly constructed buildings; however, in some cases, green roofs can be installed on existing buildings. Many older structures were overdesigned/engineered and have spare structural capacity, allowing green roofs to be installed without additional construction. In contrast, many recent buildings and industrial units are built to near-capacity.

¬Before planning a green roof, in all circumstances, the load-bearing capacity of a building must be determined, and the guidance of a structural engineer is crucial. When retrofitting a green roof, it is critical to determine whether the installation will exceed the building's existing structural capability and the extent to which this will need to be altered to sustain the installation. Once the general loading capacity of the structure is determined, as well as any strong or weak loading places, the green roof can be designed to suit, or the building's capacity can be modified. In some cases, it is possible to strengthen an existing roof in critical locations (rather than the entire roof) in order to obtain the desired outcome and also minimise costs.

If the present waterproofing appears to be in good condition, the water tightness should be evaluated. If the waterproofing layer is in poor condition, it should be changed or covered with a new waterproof coating. The protection provided by the green roof will help the waterproofing beneath remain in good condition for many years after installation. If the existing in-situ waterproofing is to be used, it must be root resistant, or a separate root resistant membrane can be installed before the other green roof parts are laid.

When designing a green roof, a level of water retention within the layers and substrate will be anticipated. It is critical to the roof's performance that any excess water be drained from the roof as quickly as possible. This will keep the roof from ponding or becoming overloaded.

Because most existing structures have weight restrictions, extensive green roofs are better suitable for retrofits. Intensive green roofs offer more planting options but often weigh significantly more than extensive roofs.

03 Green Walls

Following is an introduction to green walls, an outline of their benefits along with a description of the different green wall systems available.

3.1 Green Walls

A green wall is a vertical structure which is covered with vegetation by design. It uses a similar medium as the green roofs described previously with a sedum substrate which is applied vertically.

Benefits of installing green walls:

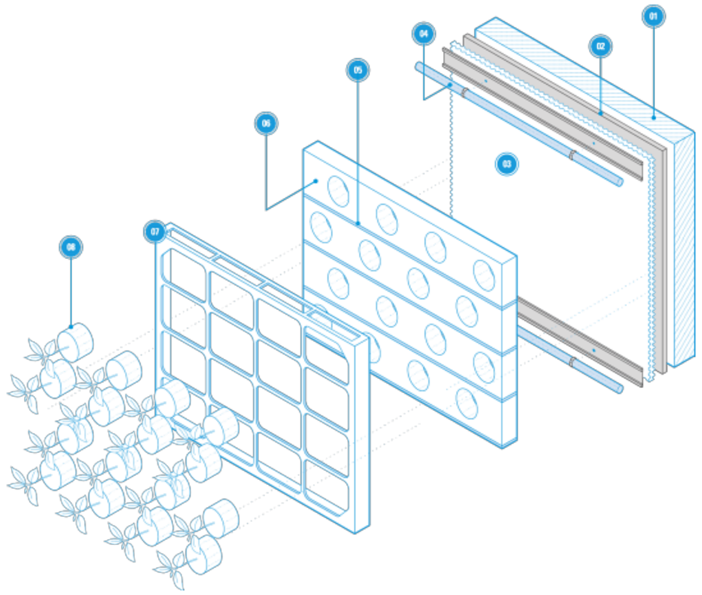
- Remove air pollutants.
- Reduce urban temperatures.
- Thermal benefits to buildings.
- Improve biodiversity.
- Attenuate Rain water.
- Reduce noise.
- Increase productivity & creativity.
- Improve sense of well-being.

3.2 Green Wall Systems

There are three types of common systems: panel/modular systems, tray systems and freestanding walls

A. Panel/modular systems:
Plants are pre-grown into panels that can be used inside or outside, and in any type of climate. This is the most common type of system used for external building facades.

1. Support system
2. Waterproof backing board
3. Rear drainage layer
4. Aluminium rails and dripline
5. Capillary breaks
6. Growing medium
7. Panel box
8. Plants



Based on Bioticture's living wall system

B. Tray systems:
Plants are pre-grown off-site and inserted into the wall, which allows for a great degree of design flexibility, especially since trays can be easily removed and replaced. Typically cheaper than panel systems, tray systems are most commonly used in interior settings.

C. Freestanding walls:
Freestanding walls are smaller, movable living walls that can be placed in indoor or outdoor settings. They can be placed against a wall or in the middle of a room, and are ideal for temporary spaces or floor plans that change over time. They can also be used as partitions or room dividers.

04 Cost Estimates

The following is a high level estimate cost study for the maintenance of green roofs and living walls using standard industry estimating rates.

4.1 Cost Estimates

The information below provides an outline estimate of the likely annual maintenance costs associated with green roofs and living walls. Location/design and other variating factors will ultimately have an effect on the overall cost.

Green Roof

The outline estimate assumes an extensive, low maintenance / biodiverse green roof design.
A total per m2 rate has been developed from annual costs for the following maintenance operations:

- Visual inspection twice per annum
- Weed twice per annum
- Annual cut back of vegetation
- Clear gullies / drainage
- Allowance for irrigation in extreme weather to avoid plant losses (likely not required each year)
- Allowance for periodic replacement / infill planting (infrequent - not required each year)
- The following has also been added to the total costs for the operations above:
- Allowance for access constraints (+20%)
- Allowance for preliminary costs (+15%)

Following the application of the rates above the outline annual per m2 cost for ongoing maintenance is an estimated £10.07 per m2.

£7.30	Sub total
£8.76	Allowance for access constraints (+20%)
£10.07	Allowance for preliminary costs (+15%)
£10.07	**Total estimated annual maintenance (1m2)**

It should be noted that access constraints, design of roof, health and safety measures, location and other factors will all have an impact on ongoing maintenance costs which cannot all be accounted for as part of a high-level estimate. No allowance has been made for inflation. No allowance has been made for any ongoing surveys, engineers surveys, repair / replacement of sub-structure / drainage features, or replacement of substrates. Estimates of how this rate would apply to different roof sizes is set out below.

Rates have been sourced from Spon's External Works and Landscape Price Book (2023).

Green Roofs

Example Maintenance Area	Annual Maintenance Cost Estimate (rounded)
10-30sqm	£300.0
30-70sqm	£700.0
70-100sqm	£1,000.0
100-150sqm	£1,500.0
150sqm +	£2,000.0

Living Wall

Spon's External Works Landscape Price Book (2023) provides estimated total annual costs for living wall maintenance. Estimated costs allow for regular visits to maintain planting and systems; inclusive of feeding; pest control and calibration of irrigation systems.

Example Maintenance Area	Annual Maintenance Cost Estimate (rounded)
10-30sqm	£300.0
30-70sqm	£700.0
70-100sqm	£1,000.0
100-150sqm	£1,500.0
150sqm +	£2,000.0

05 Case Studies

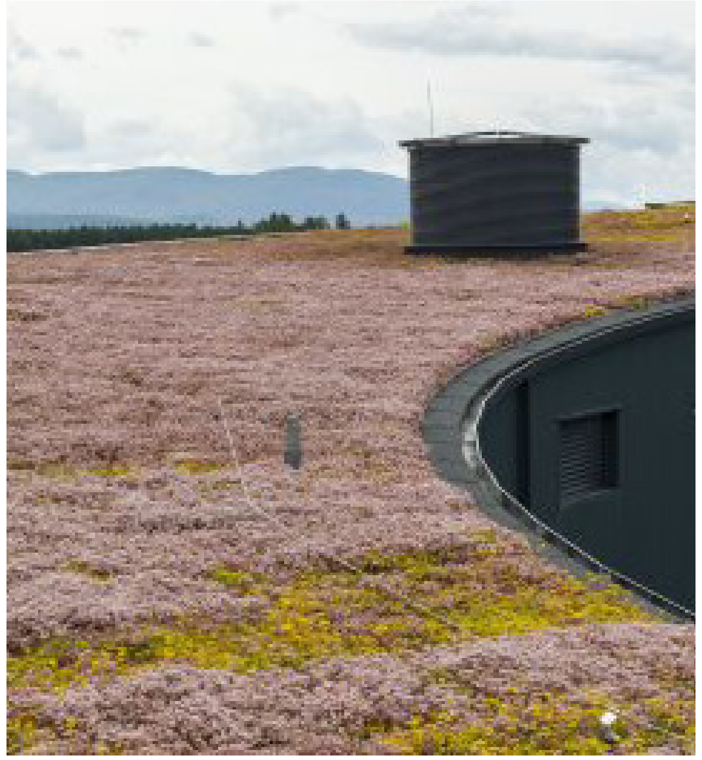
The following is a series of case studies of green roofs being used in Scotland across a range of buildings from industrial to small scale residential.

5.1 Cairns Distillery

Case Study: Cairns Distillery
Location: Grantown on Spey, Cairngorms

The new distillery in Grantown on Spey opened its doors in 2022. It is owned by Gordon & MacPhail, and the vision for the building was to reflect its surroundings.

The sedum green roof is one of the largest installed in the Cairngorms National Park and is approximately 900 square metres. The roof, being located on the banks of the River Spey has become a haven for bees.



Photographs of the Cairns Distillery and its green roof

5.2 Macallan Distillery

Case Study: Macallan Distillery in Craigellachie
Location: Aberlour, Moray

The Macallan Distillery, designed by Rogers Stirk Harbour + Partners is located in Speyside which is a designated area of great landscape value, therefore the distillery was designed to be as sensitive as possible to its context. The wildflower green roof was designed to be an extension of the surrounding landscape.

Photographs of the Macallan Distillery and its green roof

5.3 Gallie Craig Coffee House

Case Study: Gallie Craig Coffee House
Location: Stanraer, Dumfries & Galloway

The building is positioned at the most southerly point of Scotland close to vertical cliffs. Due to its exposed location and its position in a nature reserve, the building aimed to be as environmentally sensitive as possible.

The green roof used a similar grass which grew in the surrounding landscape to blend the building into its surrounding.

Photographs of the Gallie Craig Coffee House and its green roof

5.4 Findhorn Eco Village

Case Study: Findhorn Eco Village
Location: Findhorn, Moray

The eco village is a residential community in Findhorn, Moray Scotland. The aim of the community's architecture is to be as ecologically sustainable as possible and maintain a low carbon footprint. Their buildings are built from sustainable and where possible locally sourced materials. Some of the roofs in the village are roofed in sedum green roofs with native plants.

Photographs of a residence in the eco village

5.3 Domestic Green Roof

Location: St. Andrews, Fife,

The installation of a sedum roof to a residential extension in St Andrews was initially received with scepticism from the Planning Authority due to the non-traditional nature of the proposals, however, permission was granted and the roof installed in Spring 2013. Subsequently, the owner has planted bulbs and alpine flowers to increase the biodiversity value of the roof.

Photographs by Muir Dorrans, Architect

Conclusion

Typically, over the course of their lifetime, green roofs and walls become net carbon sequesters. The length of time it takes, however, is determined on the construction of the green roof how it develops, and where it is located. Additionally, it is crucial to keep in mind that not all advantages of green roofs/walls must be directly related to carbon. For instance, green roofs offer a variety of ecosystem services, such as the reduction of air pollution and the improvement of recreational space, all of which still significantly benefit urban areas and make them more liveable and are therefore equally important to consider.

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