Fostering the deployment of green roofs

In a nutshell

SUMMARY
It is best practice to develop appropriate policy schemes that support the construction of green roofs in new and existing buildings, both public and private. Green roofs can also host renewable energy systems, such as photovoltaic panels (see best practice for more information on renewable energy generation in public buildings and social housing). Policy schemes that support the deployment of green roofs can incorporate economic incentives, reduced bureaucracy, and specific technical support for inclusion of green roofs in the construction or renovation of buildings.
Target group
Public administrations responsible for the management of green urban areas.
Applicability
This best practice is applicable to all local authorities responsible for land use planning.
Environmental performance indicators
• Percentage of surface covered with green roofs out of the total surface of the urban area (m^2green roof/m^2urban area) • Percentage or number of buildings with green roofs in a given urban area (%) or number of buildings with green roofs in a given urban area (%)
Benchmarks of excellence
N/A

Description

Cities are characterised by the extent of impervious surfaces within them. The buildings occupy a large proportion of urban areas, which results in a biodiversity loss as well as a lack of green spaces. It is best practice to develop appropriate policy schemes that support the construction of green roofs in new and existing buildings, both public and private. Green roofs can also host renewable energy systems, such as photovoltaic panels (for more information see best practice on renewable energy generation in public buildings and social housing). Policy schemes that support the deployment of green roofs can incorporate economic incentives, reduced bureaucracy, and specific technical support for inclusion of green roofs in the construction or renovation of buildings.

The structure of this best practice deals initially with the description and the technical characteristics of the green roofs and secondly deals with the installation and positioning of the PV on the rooftop.

Green roofs

A green roof is a common roof (or a deck) of an existing building onto vegetation (or habitat in general), which is intentionally grown for wildlife, is established. According to the water storage capacity, energy saving potential of the building, kind of habitat that is achieved/established etc. different types of green roofs can be constructed (Green roof guide, 2012).

In principle, the selected vegetation is a key element for the construction of the green roof. Basically the green roofs are classified into the following categories according to the vegetation used: extensive, semi-extensive[1] and intensive. The extensive green roofs are ideal for the growth of drought-tolerant plants, e.g. sedum. Those plants need very little maintenance, whereas irrigation is not required. Because of the little maintenance they are often the choice for building owners who are looking to reduce costs and improve the environment as well. For the semi-extensive type of green roofs, plants like shrubs, perennials, herbs or grasses can be used (in general plants which do not have large irrigation need or depends upon the local weather conditions. Also, due to the fact that those roofs are open to the public, hard paved areas can be constructed. The intensive green roofs the growing media is usually fairly deep and can support trees growth. A roof top garden or a patio is a typical example of an intensive roof. Figure 1 depicts pictures from the three aforementioned types of green roofs (Getter & Rowe, 2006; Green roof guide, 2012).

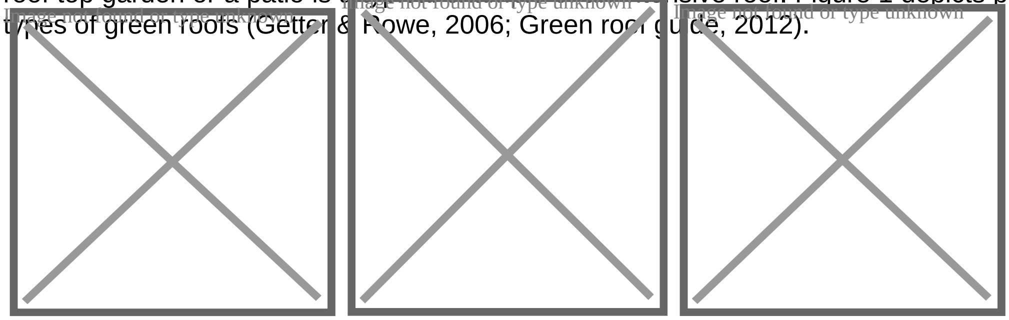

Figure 1: Types of green roofs; the order from the left is intensive, semi-extensive, extensive

The extensive green roofs are further classified into the sedum[2] (or substrate-based planted or mats), which is constructed when aesthetic or visual impacts are important, and into biodiverse when a number of local plants and trees with locally sourced growing mediums are chosen. For the first case (sedum) the thickness of the growing medium is approximately 50 mm and is visually consistent throughout the year. In the second case (biodiverse roof) the visual impact may change during winter. Also this kind of extensive roof may result in a better habitat that attracts and sustains local birds, insects and invertebrates. Moreover locally sourced materials to form the base e.g. soil or other similar construction materials are used, which improves the biodiversity potential of the roof. As a general remark, the extensive green roofs provide better habitat than intensive roofs and usually plants that can survive on the shallow low-nutrient substrates that form their growing medium are used. Also, extensive green roofs provide good storm-water attenuation as well as improve runoff quality. Indeed, when green roofs are designed in order to maximise storm-water capture they usually use fertile soils and intensive plant cover, usually Sedum, whose use is not optimal for biodiversity (Bates et al., 2006). This kind of green roof can be also found in the literature as brown roof. Summarising, the main technical characteristics of green roofs are presented in Table 1.

Table 1: Technical characteristics of a green roof linked to the vegetation (Green roof Centre, 2007; Green roof guide, 2012)

	Extensive	**Semi-extensive**	**Intensive**
Overall depth (cm)	8-13	13-18	18-60+
Saturated weight (kg/m^2)	60-170	-	200-500+
Plants	Mosses, sedums, succulents, herbs and few grasses	Selected perennials, sedums, ornamental grasses, herbs and little shrubs	Perennials, lawn, putting green, shrubs and trees, rooftop farming
Irrigation	No (not recommended)	Partially (according to local weather conditions)	Yes
Maintenance	low	medium	High
Costs	low	medium	high

A typical engineering design of a green roof is illustrated in Figure 6-8 where the required layers are also presented. The size of each layer (thickness) depends upon the vegetation on the rooftop (i.e. needs for irrigation etc.) and/or the heating/cooling targets of the building that have to be achieved (i.e. with the green roof the heating and cooling loads of the building decrease). In particular, the different layers from the top of the building roof (or from the bottom of the green roof structure) are listed below (Figure 2):

1. Roof resistant barrier
2. Protection layer
3. Drainage layer, which allows water to flow
4. Filter layer, usually filter fabric, which prevents clogging
5. Growing medium, a substrate, which is composed of organic matter and inorganic material
6. Vegetation

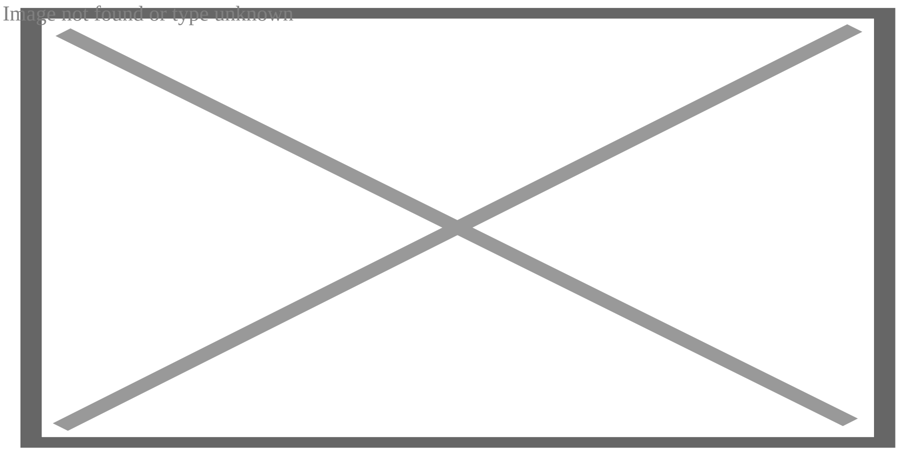

Figure 2. Green roof layers; a typical engineering design (Green roof guide, 2012)

Also, the rainfall recovery is an important aspect that has to be addressed by the project developers. In particular, there are technical solutions, which recommend the coupling of green roofs with other systems which collect the rainfall accumulations (Ascione et al., 2014).

An important element that must be taken into account before the construction of a green roof is the estimation of the maximum load that the building can support. Certain parts of a roof are stronger because they are supported either by a load-bearing wall or by pillars. In addition, the roof can be checked for water-tightness. As a general remark, the building must be in perfect condition because any repairs to the roof will be more costly to carry out once the green roof has been installed.

Furthermore, the installation of the growing medium and all the necessary layers is also a rather important construction element. In case the roof is not flat then the pitch must be calculated. As a general rule, the growing medium remains stable on a pitch of up to 25^{o}. But when the slope is greater, one may need to fix metal, wood or plastic support construction base to the roof membrane to hold everything in place and to avoid any erosion by heavy rain. Moreover, it is important to ensure roof access. The roof must be accessible both during construction and for periodic maintenance.

The sun exposure and the direction and the speed of the winds are also a key element for the construction of the green roof. Those two elements determine the type of the plants to be used as well as their position[3].

Combination of green roofs and photovoltaic panels or solar panels

This technological combination contributes significantly to the development of an ecosystem approach as well as generating electricity from renewables[4]. In general, the efficiency of the PV panels is highly influenced (negatively) by the high temperature. On the other hand, the evapotranspiration from the plants on a green roof affects positively the energy efficiency of the PV panels. From a technical perspective, the temperature in the black and grey surface (parts) of the PV panels is increased during the summer, especially when the sun is at its peak (in terms of energy generation). Moreover, the high surface temperature of a convenient building roof can also affect the ambient temperature (increase) of the air (environment) around the PV panels thus reducing their efficiency (Green roof guide, 2012).

A green roof maintains a lower surface temperature as compared with a convenient building roof because the plants on the roof transpire. Therefore, this transpiration contributes to the maintenance of the temperature of the ambient air around a PV panel approximately between 20 to 28^{o}C. Given this concept, the green roof contributes positively to the efficiency of the PV panels. Regarding positioning, the PV panels should be properly installed followed the standard angles range from 25^{o} to 45^{o}. For the installation of the PV panels, the structure of the green roof provides the necessary load for preventing wind suction with the installed array of panels (Green roof guide, 2012). Therefore complicated technical solutions for efficient panels mounting are not required (Figure 3).

Concerning the equipment used, the aforementioned concept can be also built by installing solar thermal panels for the production of hot water instead of PV panels for electricity generation. The positioning and orientation technical aspects (limitations) are the same with the PV, which discussed later.

Figure 3 illustrates the combination of green roofs and PV (or solar thermal) panels.

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Figure 3: Combination of green roofs and PV panels; on the right picture a solar thermal panel is presented

Summarising, it is best for the public administration to develop appropriate policy schemes that support the construction of green roofs in existing and retrofitting buildings. In particular, such schemes can incorporate all the technical aforementioned aspects concerning their implementation in existing buildings for a given urban area/city. The second step is the establishment of local incentives in order to subsidise the technical projects. However, the formulation of such plans should be done very carefully and local parameters should be taken into consideration. Regarding the local parameters, an indicative example of the measures of such a plan is listed below:

1. For warm climates, it is important to identify the districts where the temperature is higher and exceeds 30^{o}C. Afterwards it is important to identify the large areas (large surfaces of the buildings[5]) in order to suggest to construct a green roof.
2. For climates with high rainfall, extra priority should be given in the application of sustainable drainage measures.
3. In order to provide a significant level of evaporative cooling and rainfall attenuation, green roofs should consist of an adequate depth of substrate covering a significant area of a roof. A minimum suggested target is 80mm substrate depth over 80% of the roof area (Maurer, 2009).
4. Generate green electricity from renewables (i.e. electricity through PV panels and/or hot water from solar panels).

[1] In the literature can be also found as semi-intensive

[2] Sedum is one of the principal vegetation systems that can be used; is very drought and wind tolerant, form a dense covering, is visually attractive and they can form either into a blanket/mat system or a substrate-based planted or hydro seeded system.

[3] For instance, tall plants need to be protected from winds if they are not to be uprooted.

[4] The generated electricity can either be distributed in the existing grid network or be used for building purposes.

[5] For instance, in Greater Manchester authorities it is recommended that buildings with a roof larger than 1,000 m^2 should install a green roof.

Environmental benefits

Green roofs provide a series of environmental benefits which are listed below:

- *Storm-water attenuation*: Green roofs help reverse the effects of impermeable surfaces on storm-water management, by reducing runoff and peak flows (volume). Rainwater is captured by the roof and either evaporates and transpires or is released at much slower rates once the surface becomes saturated, depending on the type of green roof and the intensity of rainfall. It has been reported that green roofs can reduce runoff by 60 to 100% (Getter and Rowe, 2006).
- *Water savings*: If storm-water is captured from green roofs, it can be reused for a number of non-potable applications such as toilet flushing or garden watering, thereby reducing the quantity of water that needs to be abstracted and treated to drinking water standard.
- *Energy savings:* Green roofs provide shading by reducing solar energy gain and also insulate buildings, reducing fuel and electricity use for both cooling and heating. Given the large percentage of urban energy use from buildings, green roofs can have a significant impact on urban energy consumption, with associated greenhouse gas emission reductions as well as cost savings. At the same time, green roofs can also reduce the need for heating in winter and for cooling in summer, and are therefore suitable for cold and warm climates, as well as for continental climates which are subject to strong seasonal temperature variations. Moreover, green roofs also improve the efficiency of air conditioning systems by reducing the temperature of the intake air.
- *Reduced urban heat island effect:* Urban surfaces have a low sunlight reflected fraction and therefore absorb much solar energy. This, in addition to the lack of evapotranspiration from impermeable urban surfaces, helps create the urban heat island effect, where urban temperatures are higher than those of the surrounding countryside. Green roofs contribute to the reduction of the related impacts due to the higher sunlight reflected fraction and also allow evapotranspiration.
- *Air pollution reduction and CO_2 absorption:* Green roofs help reduce airborne contaminants and particulate matter, improving the health of urban residents, and their plants also absorb carbon dioxide emissions. Air quality is also improved due to the increased humidity and oxygen levels.
- *Habitat provision:* Green roofs provide habitat for insects, birds and microorganisms.

On the other hand, the installation of PV panels can contribute to the creation of extreme shading underneath the panels. On one hand the shade may affect the growth of the vegetation on the green roof but on the other hand it may provide a unique shady habitat. Another element is the water run off form the surface of the panels. This amount of moisture can be concentrated at the bottom of the PV panels (or underneath of them) establishing/creating a greater diversity of vegetation than would be expected on a fully exposed green roof. Table 2 reflects the aforementioned findings and they are data coming from a German example in Ufa-Fabrik in Berlin Tempelhof (Köhler et al., 2007).

Table 2: Vegetation dynamics under the PV installation (Köhler, et al., 2007)

	Before panel installation **1992-1999**	Northern roof of the roof without PV panels **2001**	Northern roof of the roof without PV panels **2006**	Southern part of the roof, vegetation under the PV panels **2001**	Southern part of the roof, vegetation under the PV panels **2006**
Average number of plant species	41	41	51	43	63
Average cover of all vascular plants plant species (%)	89	85	95	97	90

	Before panel installation **1992-1999**	Northern roof of the roof without PV panels **2001**	Northern roof of the roof without PV panels **2006**	Southern part of the roof,vegetation underthe PV panels **2001**	Southern part of the roof, vegetation under the PV panels **2006**
Average height of all plant species (cm)	65	110	70	118	90
Average cover of the genus Sedum typical for extensive green roofs (%)	22	48	46	27	25
Number of plants benefited by the shade of PV panels				7	17

As a general remark, the environmental performance of each of the discussed roof types in this best practice is presented in Table 3.

Table 3: Environmental performance of the different green roof types (Green roof guide, 2012)

	Water attenuation	**Water runoff**	**Energy reduction**	**Biodiversity**	**Maintenance**
Sedum mat	x	x	x	x	Medium
Sedum	xx	xx	x-xx	x-xx	Medium
Extensive	xxx	xxx	xxx	xxx	Very low
Biodiverse	xxx	xxx	xxx	xxxx	Very low
Intensive	xxxx	xxx	xxx	xxx	Very high

x: poor, xxxx: very good

Side effects

Green roof benefits are sometimes mutually exclusive, and the following trade-offs should be taken into consideration (Philip, 2011):

- Green roofs designed with the main objective of reducing storm-water runoff require high vegetation cover supported by a fertile soil. This can lead to nitrate leaching which compromises water quality in the runoff that flows from the roof. In addition the plant species that are good for attenuation (such as Sedum) reduce the potential for biodiversity development.
- Depending on climatic conditions, green roofs may restrict the collection and reuse of rainwater from the roof surface, particularly where the objective is to attenuate storm-water in soils and plants. Designs can however be

chosen that optimise reuse opportunities by providing natural treatment of rainwater through soil filtration, although such designs are unlikely to offer the same biodiversity and aesthetic benefits.

Applicability

This best practice is applicable to all local authorities responsible for land use planning.

Moreover, the green roofs are in general applicable to all the existing and retrofitted buildings. Below some special aspects/technical considerations/limitations are listed. However, as it was mentioned in the Description section, and especially for the retrofitted buildings, the ability of the building to hold the load from the installed green roof (and the PV/solar panels if exist) should be carefully assessed in prior to the construction phase.

- The intensive green roof requires a deeper layer of growing medium and thus generates significant costs as well as weight, which needs to be supported by the construction of the building. They also require more maintenance.
- The intensive green roofs can be (usually) constructed in flat roofs and made accessible to the public. They are designed to house plants and shrubs that require regular maintenance and generally need a thicker layer of substrate on which to grow (thicker growing medium).
- The extensive green roofs are lighter and they can be installed on large surfaces such as those of industrial buildings or sporting facilities (Getter and Rowe, 2006).
- The extensive green roofs is not made accessible to the public, whereas can be constructed either on flat or sloped roofs, and are designed to require little or no maintenance. The substrate layer on extensive green roofs is thinner and they therefore house moss, herbs, grass or succulents (Getter and Rowe, 2006).
- Often blanket systems are the only type that can be used on existing buildings due to load restrictions. On new buildings, however, where additional structural loading can be taken into account during the design and construction process, substrate systems (which can comprise recycled materials) are preferred because of the greater environmental benefits they bring.

Economics

It is rather difficult to quantify the capital costs of a green roof. Several parameters may influence those costs from the type of the roof to be constructed, the vegetation to be used or in general from the objectives of each project. However, the capital costs for an intensive green roof is relatively high as compared with the extensive type (Berardi et al., 2014).

For instance, parameters like the height of the building, thicknesses of the layers used, vegetation used and other supplementary systems (e.g. irrigation if needed) in parallel with many other factors influence strongly the installation cost. An indicative cost of 140 £/m^2 (about 190€/m^2) has been estimated by the Green Roof Guide included waterproofing and insulation. The same organisation also calculated an indicative installation cost for semi-extensive green roof, which ranges from 80 to 120 £/m^2 (110-165€/m^2).

For the construction of green roofs, there are also some economic benefits and barriers, which are summarised in Table 4 (Berardi et al., 2014). It should be noted that it is also difficult to quantify them because of the certain specificities and local parameters e.g. value of the buildings, labour costs etc.

Table 4: Economic benefits and barriers of green roofs (Berardi et al., 2014)

Economic benefits	Economic barriers
Reduce energy consumption	High construction cost
Increase thermal insulation in retrofitting	High maintenance cost especially with intensive green roofs or hen irrigation is needed

Reduce maintenance costs of roof due to lengthening life	Complexity of construction
Reduce costs of water rain off and urban infrastructure	Risks of failure
Improve market and price of the buildings	Expensive integration in existing buildings if adjustments to the structure are needed
Increase usable surface of the building	

Additionally, in some European countries local policy instruments that promote the construction of the green roofs are already in place. For instance, in Copenhagen, Denmark all new roofs with a roof pitch under 30^o have to be landscaped, providing there is no structural engineering reason preventing it. Likewise, in Munich, Germany, there is an obligation to landscape all suitable flat roofs with a surface area more than 100 m^2; in Esslingen, Germany, 50% of the cost of green roofs is paid back, whereas in Darmstadt, Germany, owners receive up to 5,000 € for planting a green roof (Berardi et al., 2014).

As it was previously mentioned in the environmental benefits, the green roofs contribute to the reduction of the energy loads of a building. In particular, in cold climates, green roofs were slightly more cost-effective than the traditional roofs. For instance, EC (2013) and Ascione et al., (2013) reported that the annual energy costs for a building with a traditional roof in Oslo were estimated at 11,529 €, which were 551 € more than a green roof. However, for the green roofs where plants require irrigation (see Description section), it has been reported that the cost of watering in warm climates outweighed the benefits gained from reduced energy demands. For example, annual energy and watering cost for a traditional roof in Seville were estimated at 14,314 €, which are 32 € more than for the most suitable vegetation of a green roof. The payback period time was estimated rather long and in Southern Europe the installation cost was never repaid (Ascione et al., 2013; EC, 2013).

Although the installation of a green roof is more expensive than that of a normal roof, green roofs do generate important direct cost savings in terms of energy consumption and storm-water management and less direct savings for society as a whole (health, amenity, aesthetics etc.) Green roofs, by attenuating storm-water, can help defer or replace expenditure linked to traditional storm-water infrastructure. For instance, according to Peck (2005) and Getter and Rowe, (2006) converting 6% of Toronto's roof surfaces to green roofs would be equivalent in terms of storm-water retention to building a storage tunnel worth over 40 million €. The life cycle costs of green roofs can be lower than those of normal roofs, particularly so in countries such as Germany where the widespread uptake of this technology has allowed for economies of scale (Bates et al., 2006). Table 5 compares the costs and benefits associated with a conventional gravel roof and an extensive green roof over a 40-year period.

Table 5: Cost-benefit analysis for green roof versus gravel roof (Adapted from Giesel, 2003)

Gravel-covered roof		**Extensive green roof**	
Costs		Costs	
Gravel cover 5 cm (5 €/m^2)	5,000	Precautionary measures (10 €/m^2)	10,000
		Green roof (20 €/m^2)	20,000
Repair	4,000	Repair	0
Partial renewal after 20 years	27,500	Partial renewal after 20 years	0
		Regular maintenance (0.50 €/m^2 for 40 years)	20,000
Benefits		Benefits	
Reduction of sewage disposal costs	0	Reduction of sewage disposal costs (0.60 €/m^2/year)	-24,000

Gravel-covered roof		Extensive green roof	
Improved thermal insulation	0	Improved thermal insulation (0.06 €/m^2/year)	-2,400
Costs minus benefits	**36,500**	**Costs minus benefits**	**23,600**
Overall savings versus the green roof after 40 years	**0**	**Overall savings versus the green roof after 40 years**	**12,900**

Driving forces for implementation

All the already listed environmental benefits (under the Achieved Environmental benefits) act as the main driving forces for implementation. Apart from them, there are also other positive impacts such as:

- *Cost savings:* By protecting the roofing membranes from damage linked to solar radiation and temperature fluctuations, green roofs help extend the life span of roofs – sometimes doubling it. Moreover, green roofs can increase property values because of their aesthetic value. Finally, the energy savings mentioned previously also help reduce costs.
- *Aesthetic value:* Green roofs are attractive to look at and provide health benefits linked to contact with green spaces.
- *Employment creation:* By requiring substrate, plants, installation and maintenance, green roofs can help boost local landscaping businesses.
- *Use of waste material:* Green roofs, and brown roofs in particular, can reuse waste material as a substrate, for example from construction sites. This reduces the pressure on landfills, the costs of transporting this material, and can lead to financial savings. Best practice within London requires the sourcing of construction material from local and sustainable sources, so that green roofs with the deepest substrate are considered more optimal.

Reference organisations

There are several organisations, associations, clusters of public administration etc., which have already in place suitable local policy schemes for the construction of green roofs. An indicative list (not exhaustive) is presented below:

- Greater London Authority. (2008a). Living roofs and walls – technical report: supporting London plan policy. London, United Kingdom: Greater London Authority.
- Greater London Authority. (2011). The London plan – Spatial development strategy for Greater London. London, United Kingdom: Greater London Authority.
- Greater London Authority (GLA). (2010). The draft climate change adaptation strategy for London – Public Consultation Draft. London: GLA
- The Green Roof Centre, Sheffield University. www.thegreenroofcentre.co.uk
- Living Roofs, the independent UK website to promote Green Roofs. www.livingroofs.org
- The number of green roofs varies a lot across Europe, mainly as a consequence of the presence or lack of incentives and policies to encourage them. Germany is the world leader in green roof construction, with many cities having incentives in place to encourage their installation. These incentives enable the cities to achieve cost savings in comparison with traditional large-scale stormwater management options. “For example, the city of Esslingen in Germany will pay up to 50% of the cost of installing a new green roof, and the city of Darmstadt will pay up to 5000 Euros toward a new green roof” (Getter and Rowe, 2006). Switzerland is another green roof leader, with similar city-

level incentives: in Basel for example “homeowners can claim 20% of green roof investment costs for converting unused rooftops to vegetative rooftops. This policy was so successful that in 18 months an area the size of seven football fields was greened. Now, there is a new law in that city that all new flat roofs must be greened” (Brenneisen, 2004 as cited in Getter & Rowe, 2006).

- Scandinavia is yet another leading region in the installation of green roofs. For example, the environmentally-friendly Augustenborg neighborhood of Malmö, Sweden, is home to several green roofs, including one of over 10000 m^2 called the “Augustenborg Botanical Roof Garden”. The green roof attenuates storm-water, insulates the buildings but also encourages local biodiversity. The green roofs of the neighborhood are part of a wider sustainable storm-water management strategy which aims to attenuate and collect storm-water in order to reduce local flooding. The roof garden is open to the public and is accessible, increasing the learning opportunities that can be derived from it. Augustenborg has made the most of this green roof, promoting it through brochures, and the botanical roof garden building is also home to the Scandinavian Green Roof Association. The Institute disseminates lessons learned and provides training but also undertakes research into simple and cost-effective green roof solutions.
- Green roofs have been used in many countries with widely varying climates and therefore have an important replication potential (Bates et al., 2006), but these differing conditions should be taken into account in project design. Plant selection is important: indeed, climatic conditions such as temperature and precipitation can affect the survival of different plant species, as can very localised microclimatic factors such as air vents. Drought tolerance is the most important variable to factor in when choosing plant species; succulents are often chosen.
- Green roofs are not suitable for all roofs, as they entail substantial additional weight, particularly for the heavier intensive green roofs. New buildings can be designed to accommodate this weight, but existing buildings need to be checked for compatibility prior to installation. Green roofs can help buildings meet guidelines for green buildings such as BREEAM in the UK or LEED in the USA. Brown roofs in particular can play a role in city Local Biodiversity Action Plans, by helping to create habitat for target species. For example, the black redstart is one of the target species within Birmingham’s LBAP.
- In France it is mandatory for all the new commercial buildings to feature roofs that are at least partially covered in either PV and/or solar panels or plants.

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