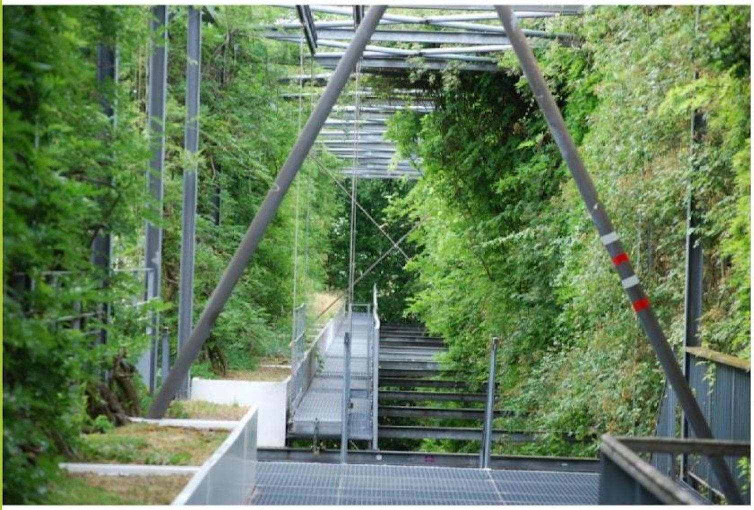

Benefits of Green Buildings (Green Roofs, Green Walls and Vertical Indoor Greenery)

A compilation of numbers, data and facts from different Investigations 2025

GREENER CITIES IN EUROPE

EFB

EUROPEAN FEDERATION GREEN ROOFS & WALLS

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A compilation of numbers, data and facts from different investigations 2025

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1. Preface

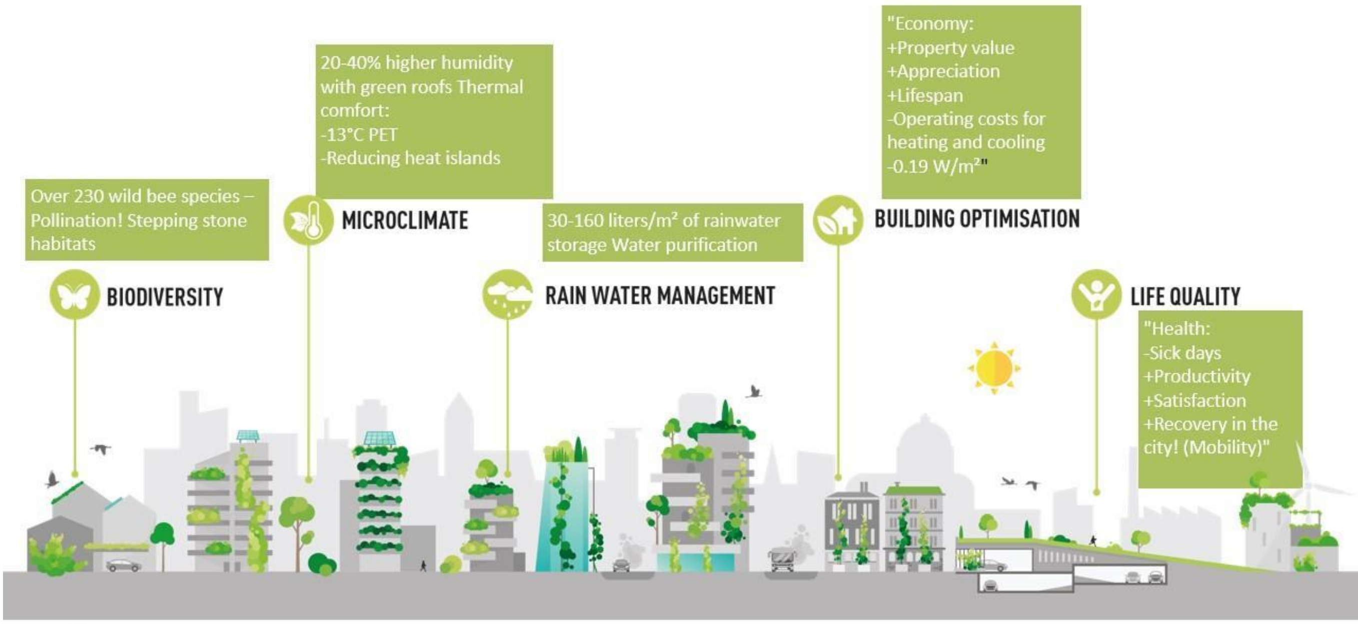
Greening of buildings (roofs, walls and interiors) is innovative, future-oriented and trendy. Their range of effects has been intensively researched, examined and verified. Nowadays there is broad scientific backing for these findings on a worldwide scope, as green roofs and walls have been implemented already in ancient times and have industrialized in the 1980s in central Europe. Green infrastructures and nature-based solutions on buildings can be used to solve a wide variety of challenges in building optimisation and urban development.

The range of services of building greening covers the areas of climate adaptation and mitigation, water, microclimate, energy, quality of life, Health and wellbeing, ecology, environment and (circular) economy, jobs, food safety and urban soils. Greening serves as an important rainwater management tool, with the plants acting as a natural air conditioning system for outdoors, achieving cooling effects in overheated urban centres. Greened buildings help maintain cooler and warmer temperatures inside buildings, as well as save energy costs. The improved quality of life and the creation of valuable recreation spaces is directly tangible for city dwellers and is becoming increasingly important. The same applies to urban wildlife and biodiversity.

From experience, we also know that it is of utmost importance, to provide the right technological approach for the targeted greening objective and respect the buildings properties- may it be a new or a refurbishment project in order to maximize the targeted effects for the “client” (public, investor, user, nature, etc.) under local site conditions across different climate zones.

In this prescribing information "**Benefits of Green Buildings**" a compilation of the most important arguments in favour of roof, façade, and interior greening are presented, underpinned with selected test results and references – without claiming completeness. This also means that this list can be supplemented and modified.

The European Federation of Green Roof and Wall Associations explicitly thanks their national members from Germany (BUGG) and Austria (GRÜNSTATTGRAU) for the opportunity to present this work on a European scope and contribute to enrichment by integrating references from other national members. It is intended to be a first step towards a simple reference work for builders, planners, scientists and consultants. We all wish for many implemented “buzzing” green buildings that are a true nature-positive enrichment.



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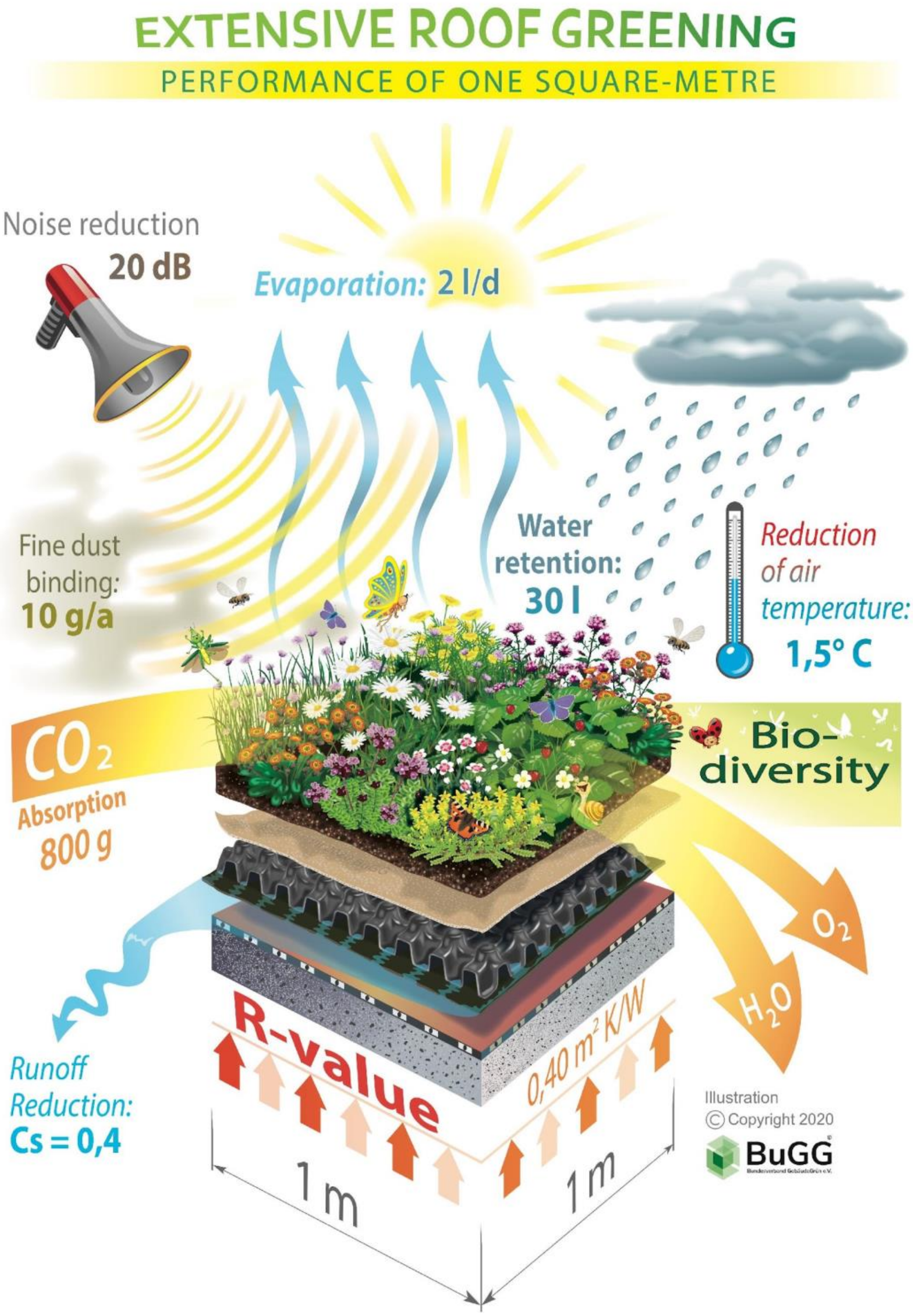
2. Benefits of Green Roofs

Extensive and intensive green roofs are widely known to provide a wide range of ecosystem service benefits. These have been researched by the scientific community around the world since the early 1990s. They have been assessed from different angles, especially from both the building performance and ecosystem services perspectives.



2.1. Surface Temperature Reduction

The surface temperature of façades and roofs influences both the energy performance of the building itself and its effect on the surrounding outdoor space and related microclimatic conditions. Most references compare green roofs with conventional flat roof forms, such as tin roof, black roof and gravel roofs and reflect the performance during summer heatwaves or the balance throughout the year.

- Significant reduction of heat transfer into the building when comparing green roof build-ups with gravel, black, and tin roofs. (1)
- Day to night temperature amplitude of 50 K for bitumen roof compared to 10 K for green roof. (2)
- 30-60% reduction of heat transfer on a radiation-intensive summer day under an extensive green roof with a 10-15 cm substrate layer in comparison to a gravel roof. (3)
- Compared to bitumen and gravel roofs, surface temperature reduction up to 25°C on green roofs. (2) (4)
- In a specific project, the annual temperature amplitude from -5°C in winter and +70°C in summer was changed by implementing a retention wetland roof to 10°C in winter and +30°C in summer. (5)
- The surface temperature of a green roof in August 2012 was up to 17°C less than the grey reference roof. (6)
- Through additional irrigation, the surface temperature could be significantly reduced - by up to 10 K at the surface and by up to 4 K on average at the roof waterproofing layer. (7)
- In dry summers, irrigated extensive green roofs can reduce the temperature of the waterproof membrane between the building and the green roof by up to 5 K, and the temperature of the vegetation layer by up to 10 K, compared to a non-irrigated green roof. (7)
- Other international studies report larger temperature differences comparing green roofs to reference roofs, with a maximum of 33°C. (18) (19) (20)
- Heat flow through the building roofs in summer can be reduced by approximately 70-90% via green roofs. (136)
- The temperature difference between conventional and green roofs in summer is about 12 °C, whereas it is 4 °C in winter. (137)
- The results of the analysis showed how the traditional roof in June reached a peak of 74.3 °C with a daily excursion of 51.5 °C whereas green roofs were able to produce a surface temperature from 0.57 to 0.63 times lower. (138)
- Teemusk and Mander (2009) analysed the temperatures under a green roof (10cm deep) and under a gras roof (15cm deep) in comparison to conventional roofs with bitumen and metal coverings. The temperature profile was similar: unwanted higher temperatures on the surfaces of the green roofs did not lead to a significant increase in temperatures under the substrate layers. The difference between the temperature amplitude under the substrate layers of the green roofs and the surfaces of the conventional roofs was 20 °C on average. In autumn and spring, the soil layer of the gras roof had higher temperatures and a lower amplitude than the substrate layer of the green roof, which cooled down more. In winter, the temperatures under the substrate layers of the planted roofs were higher than the surfaces of the conventional roofs; the average amplitude was 1 °C and 7-8 °C. (91)

- Solcerova et al. (2017) found that irrigated green roofs were cooler at night and a little warmer during the day compared to white gravel roofs. It follows that green roofs help lower temperatures at night when the heat island effect is the strongest. (92)

- Baryla et al. (2019) studied Sedum green roofs and compared the surface temperature with conventional roofs (June-December 2016). The largest temperature differences were observed in June and July, with a maximum difference between the temporary surface temperature of a green roof and a conventional roof of up to 24 °C. In summer, the surface temperature during the day was 5 °C higher than the air temperature. Atmospheric precipitation reduced the temperature gradient in the soil as well as the temperature fluctuations during the day due to the increase in humidity after precipitation. The daily range of surface temperature fluctuations was greater than that of the air temperature. (93)

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2.2 Reduction of Urban Heat Island Effect

The Urban heat island effect leads to higher air temperatures, particularly in the centre of cities, compared to the surrounding rural areas. The urban heat island is expected to increase with the growing of the cities and climate change impacts. It makes heat waves much more severe than would otherwise be the case, and this threatens human wellbeing. One reason for the heat island effect is the thermal behaviour of sealed surfaces which is determined by its absorption coefficient, by its density, heat capacity and thermal conductivity that results in thermal storage and sensible heat. As soon as vegetation and soils are involved, the energy from solar radiation is transferred to evaporative cooling and transpiration linked to a plant's photosynthesis. The following performance indicators have their origin in the continental climate of central Europe, if not referenced specifically.

- The difference in temperature due to vegetation cooling effects results in 2.5-10 K in relation to the dimension. (13)

- In one study, a temperature reduction of up to 3°C was generated for Chicago due to green roofs. (14)

- Modelling results for scenarios covering a large area with extensive green roof installations have resulted in air temperature reduction of 0.2°C to 0.9°C. (15) (16) (17)

- In one city quarter study, a moderate greening scenario of roofs and walls and other green infrastructure elements resulted in a reduction of 2.2°C in air temperature but up to 22.3°C PET reduction, significantly improving thermal comfort. (Note: the physical equivalent temperature PET is a more realistic performance indicator than air temperature because it measures individual thermal comfort of humans derived from a set of parameters in a given situation). (88)

- Test by Heusinger 2012: Lower air temperature of an average of 0.2°C at 50 cm distance above roof level, maximum reduction reached during the day, with an average of 0.6°C and a maximum of 1.5°C at 2 PM. (6)

- Beradi (2016) found out that an increase in the amount of leaf area on a green roof leads to a reduction in temperature of 0.4 °C at the pavement level during the day, with a greater reduction in temperature occurring at the roof level. In addition, the green roof has a cooling effect on the floor underneath the green roof. (97)

- Dong et al. (2020) analyzed Landsat 8 data for the city of Xiamen in China. Between 2015 and 2019, approximately 540,000 m^2 of green roofs were installed in this city. With the relatively coarse pixel grid, it was determined with an accuracy of about 1,000 m^2 that a temperature reduction between 0.4 °C and 0.9 °C resulted from green roofs based on the satellite images. (90)

- Richter (2022) did a research about the climate change adaptation benefits of green roofs through "a systematic review process and an in-depth investigation and statistical analysis of a total of 123 scientific studies." Green roofs were found to lead to significant reductions in temperatures around buildings or in entire neighborhoods in terms of their urban climate potential. Average temperatures were lowered by 0.6 °C on average (max. 1.8 °C), and the maximum cooling potential reached up to 3.8 °C. Key factors for this were the available water supply and the large-scale implementation of green roofs. (94)

- If green roofs are deployed widely, the average air temperature of the related area can be reduced by 0.3–3.0 °C. (140)

- The results demonstrated the ability of a vegetated roof to notably contribute to the mitigation of UHI in summer without penalizing the thermal performances of the roof in winter. (138)

- Extensive Green roofs, when implemented on a city scale, can reduce average ambient temperatures by 0.3 to 3 K, as shown in simulation studies. (140)

2.3. Latent Heat

The term describes a measure for urban cooling. If part of the incident radiant energy from the sun is transformed into latent heat rather than sensible heat, this results in the air temperature remaining lower over soils from which water evaporates. Green roofs are able to produce latent heat from their substrates.

- 62-67% of the global radiation is transferred into latent heat by a green roof; therefore, this energy does not go into higher air temperature. (8)
- Pisello et al. combined the benefits of a green and cool roof by optimizing plant selection (preferably light or white foliage; foliage even in winter) to achieve maximum reflection of shortwave radiation. As a result, the number of overheating hours in the interior of a 16th-century multi-family house in central Italy was reduced by 98.2%. (95)

2.4. Evaporative Cooling

- Evaporating 1 m³ of water generates 680 kWh of evaporative cooling energy. (2)
- 60-75% of the annual precipitation load of an extensive green roof is evaporated. (2)
- 41-48% of the annual precipitation is evaporated. (8)
- Transformation of radiation balance to evaporative cooling of 58% in an extensive green roof during summer. (9)
- Evaporation of partially covered intensive green roofs (utilising large scale plantainers) of 200 l/m² during one vegetation period. (10)
- Test by Christen & Vogt (11):
    - Utilising a 90-100% green space coverage, 80% of the available energy originating from the sun (global radiation) is transformed into evaporation on the earth's surface.
    - With green space coverage from 0-30%, only 20% of the energy transforms into evaporation (therefore cooling).
- Test by Heusinger 2017: Evaporation of an extensive green roof of 3.3 mm/m²/day (6), ratio from sensible to latent heat (Bowen ratio) after precipitation <1; Result: Green roofs generate cooling effects (if the volume-soil moisture is larger than 0.1). (12)
- Test by Köhler and Kaiser 2018: Evapotranspiration during summer is 2-2.5 mm/day linked to green roofs with a 16 cm substrate depth. Evaporation is 1.5-2 l/m²/day on a green roof with a 10 cm substrate depth and 4.5 l/m²/day on a green roof with a 16 cm substrate depth. (7)

- Gößner et al. (2021) measured the evapotranspiration of four different green roof configurations with different drainage plates and substrate thicknesses from April to September 2021 (96):

  - The configuration with a 6 cm drainage plate, 15 cm substrate, and grass vegetation evaporated 526 mm.

  - The configuration with a 2.5 cm drainage plate, 6 cm substrate, and Sedum vegetation evaporated 370 mm.

  - The configuration with an 8.5 cm retention box, 10 cm substrate, and mixed vegetation evaporated 488 mm.

- Depending on water availability, green roofs evaporate more than 400 l/m² annually (135). This cooling performance leads to an average reduction in the ambient air temperature of 1.34 °C for green roofs. (89)
- Evapotranspiration is composed of evaporation and transpiration, removing heat through convection and evaporation, accounting for 51.5% of heat dissipation in green roofs. (139)
- Roofs equipped with a storage and capillary irrigation system showed a remarkably large evaporation rate for Sedum species behaving as C3 plants during hot, dry periods. (135)

2.5. Air Humidity

Humidity influences evaporation through the human skin and therefore has a direct effect on thermal comfort for people outdoors (summer) and indoors (winter). Vegetation contributes to, and benefits from higher humidity.

- During summer, up to 20% (4) or 40% (21) higher air moisture compared to unvegetated areas.

2.6. Water Storage and Greywater Use

On the one hand, climate change is causing more intense and longer periods of drought leading to water scarcity, and on the other, an increase in extreme rainfall events, which must be held back on site in order to relieve the burden on the municipal sewer system and budget. The utilisation of rainwater on site to relieve pressure on the sewer systems, as well as the purification performance of wastewater through green roofs are major issues nowadays. It is not only important to retain water, but also to return it to the evaporation cycle on site and avoid unnecessary artificial irrigation. The principles of the sponge city, which is designed to capture and use rainfall as much as possible, are applied.

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- In extensive green roof substrates, on a yearly average, 75-90% of the total precipitation is retained. (22) (23)
- In extensive green roof substrates, water storage depends on thickness, components and nature of the substrates, and the intensity of precipitation on a yearly average. Therefore, it varies between 0 (for rainfall > 40 mm h-1) and 100% (for rainfall < 10 mm h-1), with average delay of 3 to 5 hours. (153)

- 65-70% of the yearly precipitation is retained by extensive green roofs with a substrate depth of 10 cm, while a gravel roof retains 18%. (7)
- During the vegetation period, 80-90% of the precipitation is retained by extensive green roofs (with a substrate build-up of 10 cm), while a gravel roof retains 29%. (7)
- Additional water buffer layers of 53 l/m² can be added. (5)
- Intensive green roofs retain between 60-99% of the total precipitation, depending on their build-up, with a storage capacity of 30-160 l/m². (24)
- Investigations on the runoff behaviour of green roofs with a compound build-up show (25):
    - 8 cm substrate depth: 2.5-4 l/m² runoff, in relation to the duration of the rain event.
    - Substrate depth influences the retention capacity of the green roof significantly.
    - The longer the duration of the rain, the smaller the influence of the substrate depth.
    - Runoff coefficient (FLL method) increases during prolonged rainfall events.
    - After the substrate has been fully saturated, no more water is retained.
    - An increase in slope between 2% and 6% has a negligible effect on water retention.
- Investigation of runoff behaviour of slope less roofs with 8 cm substrate structures (26):
    - In multi-layer construction methods, the water drains out almost completely within 3 hours (approximately 98-99%).
    - With single-layer construction, about 98% after 23 hours.
- Around 80% of the plant species studied were found to be tolerant to the use of greywater. (50)
- Extensive green roofs result in an average reduction of stormwater runoff by 58%, while intensive green roofs reduce it by 79%. The peak runoff is also reduced by an average of 71% with extensive green roofs. (89)
- Richter (2022) investigated the climate change adaptation benefits of green roofs through "a systematic review process and an in-depth investigation and statistical analysis of a total of 123 scientific studies." The results showed that all studies found that green roofs provide a certain level of stormwater retention and delay the onset of runoff and peak runoff. On average, different types of green roofs retained about 40% of stormwater during the winter months and up to 73% during the summer months. For individual events, values of 60% stormwater retention, peak runoff coefficients of 0.37, and delays in the onset of runoff and the runoff maximum of 235 and 250 minutes, respectively, were achieved. Parameters such as substrate thickness, pre-moisture, the age of the roof, slope, amount of rainfall and rain intensity, season, latitude, plant species, and substrate composition can influence effectiveness. The comparison of regulations for the hydrological design of green roofs showed wide ranges in the calculation of effectiveness. In nearly all comparative calculations, the currently relevant methods in German planning practice showed increased flood protection due to underestimating the retention capacity of green roofs, while also highlighting the potential for systematic over dimensioning of downstream drainage systems. (94)
- Around 80% of the studied plant species were found to be tolerant when using greywater. (50)

- Walker et al. Found out that grey water from bathrooms and washing machines is suitable for watering extensive green roofs. The quality requirements for irrigation water were largely met. The evaporation rate was 10-20% lower when using grey water than when using tap water. Nevertheless, the ecologically far more sensible use of grey water can be recommended. (121)
- Runoff coefficients, relating the amount of runoff to the amount of irrigation received, ranged from 0.26 to 0.43 in green roofs with native plant species, in combinations of vascular plants and mosses. (143)
- The average rainfall retention for 76 observations in green roofs under Mediterranean climate was 62% and the rainfall peak attenuation was 75%. (145)
- There are wide variations between roofs in terms of their water retention capacity: 6 L/sq.m. for the least absorbent roof compared with 532 L/sq.m. for the most absorbent. (146)
- Roofs made up of “agricultural” and “mixed” substrates can store more water than roofs with “mineral” substrates (Classification according to RMQS- French database of soil quality). (146)
- These roofs with agricultural substrates almost 30 cm deep showed ability to regulate 10-year rainfall events. (146)

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2.7. Biodiversity and Urban Nature

Over time, green roofs increasingly accumulate soil organisms and other users of this ecosystem, such as spiders and beetles. Biodiverse and intensive green roofs in particular serve as a valuable urban stepping stone biotope for pollinators and their food chains, such as birds and bats. The animals use green roofs as a corridor and connection to other green spaces, as a source of food and, for some species, as a nesting site. Biodiverse green roofs are specialized habitats that as well support a wide range of plant species, like mosses, herbs and grasses Research on over 100 year old green roofs have shown that even rare species (e.g. orchids) besides a selection of over 140 other species can be found on semi-intensive roofs.

Many bird species, such as house sparrows, blackbirds, tits, linnets, robins, black redstarts, wagtails, mallards, gulls, oystercatchers, little ringed plover and lapwing benefit from green roofs for resting, foraging and even nesting. In some cities green roofs are part of the species protection programme for targeted species, e.g. the crested lark in Vienna.

- Extensive green roofs: main flower visitors are capable of flying (bees, butterflies, hoverflies, etc.), beetles, ants, bugs (Hemiptera), and larvae of Diptera and ladybirds. (5)
- Three-roofs comparison: 2 x extensive & 1 x intensive green roof (28):
  - Extensive green roof 1: beetle 78 individuals; wild bees 10 species.
  - Extensive greening 2: beetle 183 individuals; wild bees 13 species.
  - Intensive greening: beetle 358 individuals; wild bees 18 species.
  - Finding that only at a substrate height of 15 cm minimum do drought and frost-sensitive species survive, and nutrient cycles and food relationships can form.
- Discovery of 51 wild bee species on 5 roofs examined. (29)

- Discoveries from Switzerland (30):
  - Dry grass habitat green roof: approximately 80 beetle species.
  - Sedum roof: approximately 5-10 beetle species.
  - A total of over 300 beetle species have been found, 30 of them on the Red List.
  - Discovery of over 175 plant species (including 9 species of orchids) on a 100-year-old roof.
- Considering vascular plants (147):
  - 300 vascular plants were inventoried on 30 green roofs in Switzerland, i.e. 21 % of the regional flora, including 33 species threatened, i.e. 11 %, at regional level and 8 at national level, i.e. 3 %;
  - on average, 36 species are found on an extensive roof and 43 on an intensive roof, 50% of these taxa had a spontaneous origin;
  - the most frequently inventoried families are Poaceae, Asteraceae, Caryophyllaceae, Fabaceae & Lamiaceae.
- Considering Bryophytes (147):
  - 38 vascular plants were inventoried on 20 extensive green roofs in Switzerland, i.e. 10 % of the regional bryoflora, including 5 species threatened, i.e. 13 %, at regional level and 1 at national level, i.e. 3 %;
  - on average, 9 species are found on an extensive roof and 2 on an intensive roof.
- Study by Bingen University of Applied Sciences 2016 on simple extensive greening (31):
  - Significantly higher species occurrence than on gravel roofs.
  - Approximately 8 bumblebees per 100 m^2.
  - Approximately 2 honeybees per 100 m^2.
  - Approximately 1 wild bee per 100 m^2.
  - Approximately 20 wasps per 100 m^2.
  - Approximately 32 hoverflies per 100 m^2.
  - Approximately 10 flies per 100 m^2.
  - Other insects approximately 38 per 100 m^2.
- 236 wild bee species have been detected on green roofs so far; used as a food source and nesting opportunity. (32)
- 28 species of wild bees and 13 species of wasps on 10 extensive green roofs. (33)
- 90 different wild bee species on 9 green roofs (extensive to intensive) in Vienna. Wild bee diversity and abundance was strongly positively affected by increasing forage availability and fine substrates. Furthermore, the installations of areas with finer and deeper substrates showed the benefit for ground nesting and eusocial wild bees. (113)
- Conventional substrates (such as pozzolan) are less suitable than natural brown soil or underlayer for the nesting of terricultural bees. (148)
- Catalano et al (2017) analysed several times simple intensive green roofs. From the results, it can be deduced that the species number initially increases over the years, then stabilize and stagnates in diversity over a long period of time. (98)
- Köhler und Ksiazek-Mikenas (2018) discovered that an adapted, targeted maintenance leads to lasting success and the preservation of biodiversity over longer periods of time.(99)

- Vanstockem et al. (2019) statistically analyzed the factors of 129 extensive greened roofs in Belgium regarding their floristic biodiversity. The green roofs were between 1 and 19 years old and had substrate depths ranging from 2 to 15 cm. Results from this study show: the vegetation is constantly changing, and the environment is less important for the diversity than the substrate height. (100)
- Filazzola et al. (2019) did a meta-study on the faunistic biodiversity of green infrastructure. One focus of the authors was on green roofs and green facades. From their overview of over 1800 publications, 33 studies ultimately met their strict criteria for quantitative analysis. Through statistical analysis, with the aim of comparing greened variants with typical non-greened ones, they concluded from the research on the analyzed animal groups -birds, arthropods, and nematodes - that roof and facade greening significantly contribute to habitat enrichment. (101)
- Ksiazek-Mikenas (2017) compared several green roofs in Germany (Neubrandenburg, Berlin) with the diversity of extensive green roofs in Chicago/USA. It was confirmed that the initial structural diversity is one of the essential factors for biodiversity, which can still be detected years later. (102)
- Heller 2020: Study on locust surveys on green roofs in Basel, Zurich and Aarau (103):
  - 20 different roofs were examined, among other things to shed light on the influence of solar green roofs on species abundance
  - 21 locust species and the European praying mantis were found.
- Green roofs can harbor over 100 different species. (104)
- A larger food supply in the form of flowering plants leads to a higher number of species and abundance of bees. (105)
- The species diversity tends to be higher on intensive green roofs compared to extensive green roofs. (106)
- The crested lark (Galerida cristata), whose populations are shrinking worldwide, is observed regularly on a long-term study as main bird species that benefits from biodiverse green roofs in Vienna. (122)
- Native plants that grow spontaneously in urban areas, in old roofs and walls, can be considered a suitable option in implementing green roofs. (142)
- The native plant species Antirrhinum linkianum under an irrigation level of 60% of the reference evapotranspiration produced flowers, seeds, and adequate green coverage. (142)
- For a group of selected plant species, commonly found in old roofs and walls of buildings, there are no evident differences between irrigation levels of 60% and 100% of reference grass evapotranspiration. (142)
- The use of two different irrigation levels (100% and 60% of reference grass evapotranspiration) did not induce noticeable differences in the aesthetic value of different combinations of native vascular plants and mosses, indicating the possibility of substantial water savings in the irrigation of green roofs under Mediterranean conditions. (144)

- From a group of 37 native plant species (planted, sowed or spontaneous, during a 6-year period), ca. 40% were able to thrive in extensive green roofs under Mediterranean conditions. (170)
- Five wild edible plants were found suitable, regarding physiology traits and gastronomic aptitude, for enhanced sustainable production solutions for urban farming in green roofs under Mediterranean conditions. (149)
- A number of 43 tolerant to extreme conditions moss species (ca. 3% of total species within the countries of the Mediterranean Basin) could potentially be selected, based on ecological preferences, for use on green roofs in the Mediterranean. (152)
- It is possible to accelerate the growth of moss artificially, producing species suitable for the use in green roofs in 5-8 weeks. (151)
- The abundance of pollinators on intensive and semi-intensive roofs is comparable to that observed in other urban green spaces. (146)
- Soils on green roofs have a comparably high level of microbial biomass (129.4 µg DNA/g soil), about twice the average level measured with the RMQS benchmark (59.2 µg DNA/g soil). (146)

2.8. Air Quality and Pollutants Binding

Urban vegetation and soils bind and absorb fine dust and other respirable particles, which are emitted by various sources like the industry, buildings and vehicles. These particles are harmful to human health. Their filter function is important here, as are the degree of deposition, infiltration and the proportion of evergreen vegetation.

- 7.3 $g/m^2/year$ nitrogen and sulphur oxides binding. (38)
- 10-20% higher filter effect in comparison to non-vegetated roofs. (39)
- Extensive green roofs fine particulate binding maximum 10 $g/m^2/year$. (39)
- If all roofs are fully covered with green roofs, up to 1.6 tonnes of particulate matter can be absorbed per year in a district. (27)
- Degradation of carbon monoxide, hydrocarbon (butane) and benzene from diesel and petrol exhaust gases was up to 90% compared to the baseline state for extensive greening. (40)
- Dettmar (2020) found that a green roof can bind particulate matter from up to 100 meters in the surrounding area if it is implemented correctly. (108)
- Brunnetti et al (2021) investigated the ability of green roofs to convert nitrogen-rich water. As a result, 94% of the nitrogen introduced was washed out on a non-greened green roof (substrate only) and 67% of the nitrogen introduced on a green roof with vegetation. This means that up to 32% of the nitrogen introduced could be converted. The amount could be increased by selecting suitable plants and avoiding periods of water stress. (109)

- Kuronuma et al. (2018) calculated the payback period of green roofs based on their CO_2 storage capacity. The CO_2 emissions generated during their production were also considered. The results showed that the payback period for extensive greened roofs ranged from 5.8 to 15.9 years. Therefore, they contribute to CO_2 reduction over their lifespan. (110)
- Sedum plants can filter about 10-30% of fine particles in the size range of 0.3–5 µ from the air. (39)

2.9. Carbon Storage

Green roofs bind and store carbon over time, the effect depends on their design (extensive to intensive) and also on the composition of materials used and maintenance processes.

- After three years, a carbon absorption of 0.8 - 0.9 kg/m² (800 kg for a 1000 m² greenroof area). (35)
- Mosses can absorb 2.2 kg/m² of carbon in one year (the same value as intensive grassland). (36)
- Unirrigated extensive green roofs carbon absorption of 0.313 kg/m²/year (313 kg for 1000 m² green roof). (12)
- CO2 absorption of 0.375 kg/m²/year. (37)
- Extensive green roofs absorb approximately 0.5 kg of CO_2 per m² per year. (37) (112)
- Out of 28 roofs analysed in Switzerland, the rate of organic matter varies from 0,7 to 12,7 %. (153)

2.10. Noise Reduction

Cities are becoming increasingly noisy and all of this background noise has a negative impact on human health and wellbeing. Green roofs are able to reduce noise entering the building.

Noise from above:

- If substrate is dry, then 8 dB; if substrate is moist, then 18 dB. (5)
- Extensive green roof (7 cm); at 1400 Hz = 5 dB; at 750 Hz = 20 dB. (41)
- 15 cm substrate depth at 50-2000 Hz 5-13 dB; at more than 2000 Hz = 2-8 dB. (43)

Noise from side:

- Extensive greened flat roof, sound source neighbouring street maximum noise reduction at 1000 Hz = 6 dB. (42)
-

Other:

- Comparative measurement of green roofs with different properties to the absorption coefficient Range from 0.2 – 0.63. (5)
- Even extensive green roofs with a thin substrate layer can reduce noise in the indoor spaces below. The reduction in sound ranges from 5 to 20 dB. (89)
- Measurements from an indoor-to-outdoor sound transmission lab and field evaluations of vegetated roofs of varied substrate depths, water content, and plant species showed that the sound transmission loss of vegetated roofs is greater than that of non-vegetated reference roofs by up to 10 and 20 dB in the low and mid frequency ranges, respectively. (154)

2.11. Biomass

The strategic use of biomass generated by urban greenery, e.g. as part of maintenance work, is a relatively new but promising topic. Opportunities are growing through new projects that are orientated towards the production of useful plants.

Comparisons available (44):

- Extensive green roof (comparison with dry nutrient-poor grassland) calorific value approx. 13 MWh/ha a (corresponds to 1.3 kWh/m²a).
- Semi-intensive green roof with shrubs (compared to green waste in parks) has a calorific value of 4 - 16 MWh/ha a (corresponds to 0.4 to 1.6 kWh/m²a), depending on the biomass volume.
- Intensive greening with lawns (comparison with grass clippings in parks) Calorific value approx. 23 MWh/ha a (corresponds to 2.3 kWh/m²a).

2.12. Insulation

Most cities are currently experiencing a sharp increase in hot days and tropical nights. Growing investments in conventional cooling technology lead to further increases energy demand and additional heat load. In winter, however, thermal insulation is beneficiary to improve the heat preservation of the building and reduce heating costs. Globally, there is a trend reversal from heating to cooling. Green roofs can have a positive influence on thermal insulation, both in winter and in summer. The following studies have been conducted in a continental climate.

- Winter insulation effect of the roof structure of 2-10%. (2)
- With 10 cm substrate depth, an extensive green roof achieves an additional R-value (heat transfer resistance) of 0.14 to 0.40 m²K/W under maximum water saturation, depending on the type of substrate. This corresponds to approx. 6 mm to 16 mm of conventional insulation of the thermal conductivity group (WLG) 040. (3)

- 3-10% less heat loss in winter with a green roof (installation depth 10-15 cm) compared to a gravel roof. (1)
- Zhao et al. (2015) studied the impact on heat flow through a green roof and a conventional roof in winter. The heat transfer on the green roof was reduced by 23% compared to the conventional roof, and by 5% with a snow cover on top. (115)
- Penalvo-Lopez et al (2020) measured the cooling energy consumed by a green roof compared to a conventional roof on the Mediterranean coast of Spain. On a standard summer day, 30% of the cooling energy could be saved, and on a winter day 15% of the heating energy could be saved. (116)
- In winter, extensive green roofs lead to energy savings of up to 8% on already insulated roofs, while intensive green roofs save up max. to 10%. In summer, however, green roofs can save up to 84% of energy. The thicker the substrate layer, the greater the insulation performance. (117)
- The reductions of heat loss from roofs in winter are about 10–30%, and in summer, heat flow is reduced by 70–90%. (136)
- The vegetated roof could significantly reduce the daily temperature excursion compared to the reference membrane, indicating a reduction of the heat losses of the indoor spaces toward the external environment. (138)

2.13. Prolonged Building Life Span, material protection against hazards

In general, green roofs act as a protective buffer system when it comes to temperature differences and radiance, that shorten the lifetime of the buildings waterproofing and impact on the lifecycle. They as well serve as hail protection, which is becoming more severe and which directly affects the insurance costs of buildings. Taking into account recent discussions about a shift to prolonged use and more resilient buildings and the need to raise the global refurbishment quota, green roofs are an effective measure to impact on sustainability of all kinds of buildings.

- Depending on the type of green roof, 40-80 % of the sun's radiation is reflected and absorbed in the foliage (50 % absorption, 30 % reflection). (45)
- Extension of the service life of the roof waterproofing by 10-20 years (service life usually 20- 30 years); with a service life extension to 40 years, the service life of an extensive green roof is achieved, which means that replacement cycles coincide. (46)
- The hail resistance of green roof structures and the underlying roof waterproofing have shown that green roofs with a substrate layer thickness ≥ 80mm have a high resistance. In compliance with the minimum requirements of ÖNORM B3691 and L1131, the roof waterproofing does not suffer any damage. Thus, the green roof structure is an effective and sustainable protective layer to prevent hail damage to the roof waterproofing and thus prevent water ingress into the interior of the building. (89)

- BuGG - Bundesverband GebäudeGrün (2021) found in a survey conducted together with the ZVDH - Zentralverband des Deutschen Dachdeckerhandwerks among roofers that the majority of respondents stated that the life span of a roof sealing until the first major repair was over 20 years, both under a green roof and under a solar green roof. The life span of a conventional roof sealing until the first major repair was mostly stated as 16-20 years, the life span of a non-green roof seal with a PV system was only stated as 11-15 years. (118)
- The green roofs also reduced the maximum roof membrane temperature in the summer by more than 20°C and daily temperature fluctuations experienced by the roof membranes by about 30°C. These reductions will lower the ageing and thermal stresses associated with temperature fluctuations, thus contributing positively to membrane durability. Preliminary observations and membrane temperatures recorded also suggest that green roofs could likely improve membrane durability by reducing heat aging, thermal stresses, ultra-violet radiation and physical damages. (136)

2.14. Rentability

Every investor and building owner and facility manager is keen to shorten their return on investment and ensure the effective and transparent maintenance cost of a building. Studies show that the investment cost for greenery is marginal compared to the overall investment. Green roofs reduce energy bills and add to the purchase price of units. Green roofs are therefore considered a bankable investment.

- The construction costs of a (green) roof amount to about 1.3% of the total construction costs of buildings. (47)
- In multi-storey residential buildings, the cost share of the green roof can even be as low as 0.4% of the construction costs. (47)
- 5000 m² roof with multifunctional green roof can save up to €6,000 in electricity costs per year with rainwater harvesting and the cooling effect. (13) (48)
- Teotonio et al. investigated citizens' willingness to pay for green roofs. The results show a higher willingness to pay for accessible green roofs. About this, knowledge of the benefits and accessibility have a major influence on willingness to pay. The recreational benefit is the top priority for the individual, even before aesthetics. (119)
- The green roofs are reported to consume less energy in the range of 2.2–16.7% than traditional roofs during summertime. (155)

2.15. Biosolar

Space is a scarce resource in densely built cities, the competition for this space is growing. The development pressure on cities to fulfil EU and state level action targets is high. Targeting the shift away from fossil fuels and making efficient use of urban spaces available for a holistic transition, a spotlight must be placed on innovative solutions such as green roofs with integrated solar PV and/or solar thermal systems. The combination of technologies on the same roof area produces positive synergies benefiting the building and the city. Some of these positive synergies:

Benefits for Plants and Wildlife

Integrated fire protection

Space availability for human health&wellbeing

PV/Solar Module cooling

Increased reflectance of solar irradiance

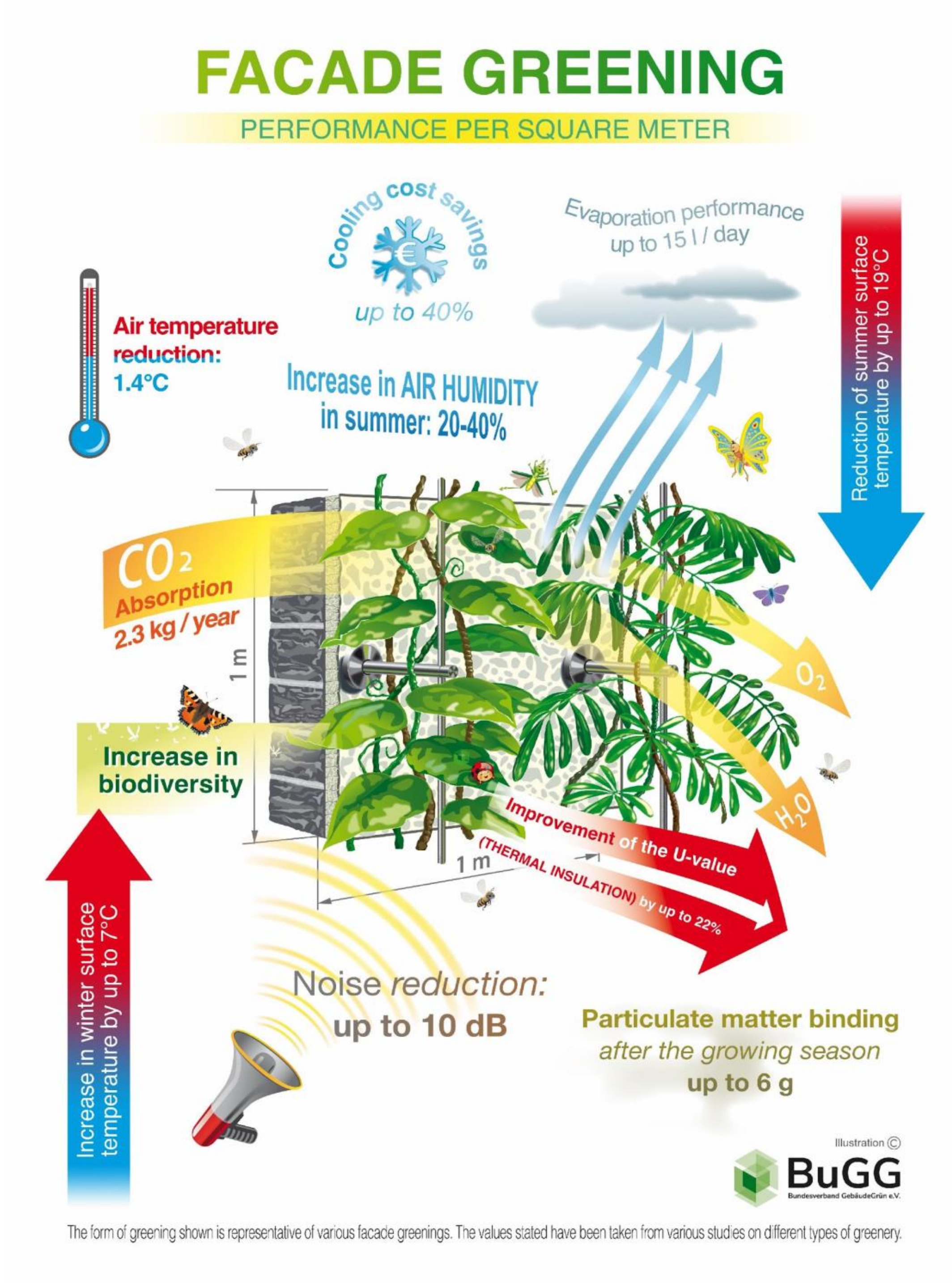
Ballasting and Durability

- New habitat niches for animals are created under photovoltaic modules. (107)
- 18 different wild bee species found on four solar green roofs in Vienna area. (156)
- The efficiency of the PV was improved by 6,5% on an extensive green roof compared to a bitumen roof. (157)
- Evaporative cooling of plants can reduce the heating of PV modules and thus increase energy yield by about 2.6%. (89)
- The efficiency of the PV was improved by 8,3% on an extensive green roof compared to a bitumen roof. (158)
- Green roof can increase energy generation of a PV panel up to 1.3 ± 0.4% compared to a concrete roof. (159)
- With a temperature coefficient of 0.5%/°K (e.g., crystalline), a solar module installed over a green roof can achieve 4-5% higher performance (0.5%/K * 8K = 4%) compared to a bitumen roof. (49)
- According to Henke (2017), the level of additional efficiency of the PV modules in combination with a green roof can be narrowed down to a range of 0.8-8%. (161)

- Gupta et al. (2017) investigated the performance improvement of PV modules on green roofs compared to a concrete roof in Singapore. The experimental results showed that the power output of a PV green roof system can be about 8.60% higher than that of a reference PV system on a bare concrete roof, while the maximum improvement in efficiency can be up to 3%. Evaporation was found to play an important role in reducing cell temperature and improving performance on days with clear skies and relatively high and constant solar irradiance. However, the evaporation rate may fluctuate on days with low irradiance, which may make the improvement in efficiency and performance of PV green roof systems minimal compared to PV systems on bare concrete roofs. (120)
- Comparison of bifacial modules between silver-leaved and green plants: 17% higher yield with silver-leaved plants and light-coloured substrate (Albedo) compared to the standard green roof. (162)
- The presence of an 8 cm vegetated substrate under a photovoltaic system reduced the average monthly temperature of the roof surface by 4.5°C in summer (in August 2021) compared to a photovoltaic system without substrate. (163)

3. Benefits of Green Walls

Green walls and green facades with climbing plants are different forms of vertical greenery. Their performance is directly related to their constructed and integrated components and layers. Most green walls, also known as living walls, are back-ventilated systems, some forms also integrate insulation layers. The performance of climbing plants also varies from species to species, for example evergreens have a different performance to deciduous plants.



3.1. Surface Temperature

The surface temperature of façades and roofs influences both the energy performance of the building itself and its effect on the surrounding outdoor space and related microclimatic conditions. Most references compare green roofs with conventional flat roof forms, such as tin roof, black roof and gravel roofs and reflect the performance during summer heatwaves or the balance throughout the year.

- Temperature difference between 2 and >10.K. (51)
- Surface temperature reduction between 8 and 19 °C. (51)
- Lower surface temperatures of up to to 11.6 °C compared to non-greened walls. (52)
- Comparative measurement - smallest temperature differences on the outside of the façade. (53)
- Mazzali et al. (2013) measured temperature differences on the facade and compared green and non-green facades. On sunny days, the temperature differences between the bare and green wall ranged from a minimum of 12 °C to a maximum of 20 °C. On cloudy days, the temperature differences decreased to 1 °C to 2 °C. (124)
- Hoelscher et al. (2016) investigated transpiration rates (sap flow) and surface temperatures of green and ungreened walls, as well as plant leaf temperatures (temperature probes) of three climbing plants: Parthenocissus tricuspidata, Hedera helix, and Fallopia baldschuanica. Additionally, air temperature, relative humidity and incoming radiant heat were measured, with no cooling effect observed for the street canyon. The surface temperatures of the greened outdoor walls were up to 15.5°C lower than those of the ungreened walls, while for the interior wall the difference was up to 1.7°C (measured during the night). The cooling effect mainly depended on shading, while a smaller portion was attributable to transpiration. The insulation of the direct greening reduced radiation during the night. They concluded that greening can be an effective strategy for reducing heat stress in indoor spaces, as long as the plants are sufficiently watered with up to 2.5 l/m² per day per wall area. (126)
- The temperature difference between living walls and bare walls is in the range of 1–31.9 °C depending on the built-up and climate, indicates a comparative master study. (164)
- Already a partially developed green facade showed the high capacity to intercept the direct solar radiation, reducing the external surface wall temperatures up to 10.1°C on the South orientation, and indoor temperature up to around 2.5°C. (165)
- Developed green facade was able to intercept the large impact of the solar radiation in the early hours of the day with a reduction of 15-16.4°C on the building surface temperature, dependent on the orientation. (165)
- From this quantitative research, it has been shown that there is an important potential of lowering urban temperatures when the building envelope (walls and roofs) is covered with vegetation. Air temperature decreases at roof level can reach up to 26.0 °C maximum and 12.8 °C day-time average (Riyadh), while inside the street canyon decreases reach up to 11.3 °C maximum and 9.1 °C daytime average. (166)

3.2. Urban Heat Island Effect

The Urban heat island effect leads to higher air temperatures, particularly in the centre of cities, compared to the surrounding rural areas. The urban heat island is expected to increase with the growing of the cities and climate change impacts. It makes heat waves much more severe than would otherwise be the case, and this threatens human wellbeing. One reason for the heat island effect is the thermal behaviour of sealed surfaces which is determined by its absorption coefficient, by its density, heat capacity and thermal conductivity that results in thermal storage and sensible heat. As soon as vegetation and soils are involved, the energy from solar radiation is transferred to evaporative cooling and transpiration linked to a plant's photosynthesis. The following performance indicators have their origin in the continental climate of central Europe, if not referenced specifically.

- Living Wall (back ventilated) System Temperature reduction compared to ambient temperature from 1.3 - 3.5 K (on warm August day). (54)
- Temperature reduction of 1.3 °C to a non-greened reference wall at 60 cm Distance to System. (52)
- Soil-bound Climber´s wall reduction of 0.8°C. (52)
- Cooling by up to 5 °C on a hot day possible. (55)
- Green façades and living walls can contribute in average to an urban temperature decrease of 1,37°C. (89)
- Simulations show that green facades can reduce the perceived temperature in their surroundings by up to 13 °C. (123)

3.3. Evaporation, Water Retention and Air Humidity

Humidity influences evaporation through the human skin and therefore has a direct effect on thermal comfort for people outdoors (summer) and indoors (winter). Vegetation contributes to, and benefits from higher humidity.

- 10 to 15 l/m²/day evaporation (façade height: 20m) with climbing plants; Evaporative cooling of 280 kWh per façade and day. (2)
- 20-40 % higher relative humidity in summer and 2-8 % in winter. (45)
- Expanded cork panels may retain 0.4 mm of water after a rainfall, contributing to the water supply of ivy-based green facades, a contribution of up to 40% of the daily irrigation requirements. (167)

3.4. Biomass

The strategic use of biomass generated by urban greenery, e.g. as part of maintenance work, is a relatively new but promising topic. Opportunities are growing through new projects that are orientated towards the production of useful plants.

- Comparisons available (44):
  - Soil-bound climbing plants (comparison with maintenance of pruning fruit trees) have related to the variety of biomass a calorific value of 5 to 9 MWh/ha a.
  - Living wall systems (comparison with dry nutrient-poor grassland) calorific value approx. 13 MWh/ha a.
  - Leaf fall on soil-bound climbers (Calculation example based on an average green facade) Calorific value approx. 23 MWh/ha a.

3.5. Carbon, Air Purification and Pollutants Binding

Urban vegetation and soils bind and absorb fine dust and other respirable particles, which are emitted by various sources like the industry, buildings and vehicles. These particles are harmful to human health. Their filter function is important here, as are the degree of deposition, infiltration and the proportion of evergreen vegetation. Green walls bind and store carbon over time, the effect depends on their design and also on the composition of materials used and maintenance processes.

- 1,000 m^2 large and 20 cm deep climbers greening (Hedera helix 'Wörner' - south side) a carbon sequestration of approx. 2.3 kg CO_2/m^2a named as well as an O_2 production of 1.7 kg O_2/m^2a (2 t CO_2 per year). (56)

- NO_2 (nitrogen dioxide): Filter capacity 20-30 %. (57)

- Detection of dust quantities after a Vegetation period of 4 g/m^2 (Parthenocissus) or 6 g/m^2 (Hedera) show a reduction of 71 % respirable substances and thus supply Air Relief. (58)

- Sternberg et al. (2010) used scanning electron microscopy to study ivy leaves collected from roads. The research question was whether ivy (Hedera helix L) can absorb dust and pollutants that trigger decay processes on stone walls and can affect human health in urban environments. The results showed that ivy acts as a “particle sink” especially in heavily trafficked areas and absorbs fine dust. It was able to absorb fine (< 2.5 µm) and ultrafine (<1 µm) particles with a density of up to 2.9×1010 per m^2. The results suggest that by absorbing pollutant particles, ivy can delay biological destruction processes on historic walls and reduce respiratory problems in humans caused by vehicle pollutants. (128)

- Fine dust smaller than 10 µm is reduced by approximately 42–60% by facade greening. (129) (130)

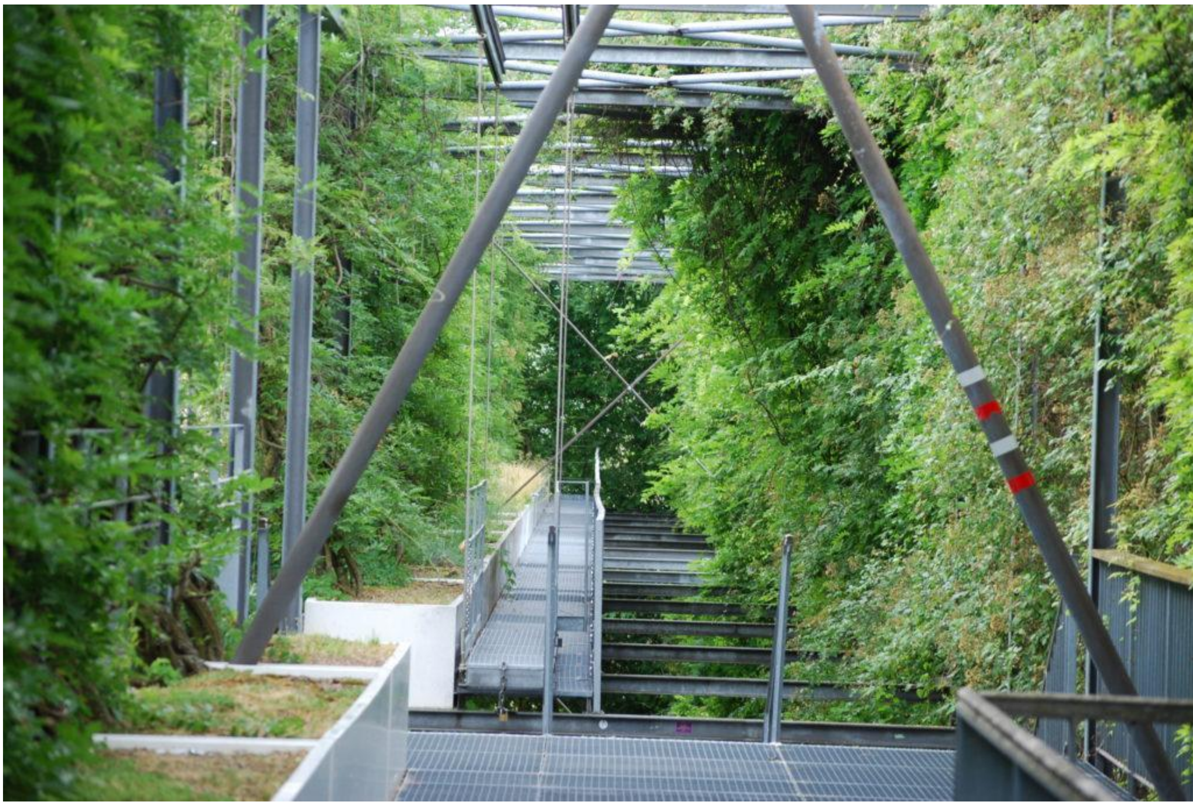
- Nitrogen oxides are reduced by 29% through green roofs and by 11.7-40% through facade greening. (89)

- The annual average accumulation of CO_2 reaches the level of 13.41–97.03 kg carbon/m^2 for 98 m^2 of vertical greenery system. (168)

3.6. Thermal Insulation

Most cities are currently experiencing a sharp increase in hot days and tropical nights. Growing investments in conventional cooling technology lead to further increases energy demand and additional heat load. In winter, however, thermal insulation is beneficiary to improve the heat preservation of the building and reduce heating costs. Globally, there is a trend reversal from heating to cooling. Green roofs can have a positive influence on thermal insulation, both in winter and in summer. The following studies have been conducted in a continental climate.

- Vegetation layers on walls serve as thermal insulation material, reducing energy demand during cooling and heating seasons. (164)
- The green walls installed on the west façade decrease the inner temperature of the facade up to 10°C during daytime. (169)
- The experimental green wall lowered the operative temperature inside the scaled-down building block up to 5°C. (169)
- Regarding winter thermal insulation, a soil-bound climbers wall vegetated with ivy (Hedera helix) showed a temperature difference between Exterior leaves and wall surface of 3 °C. (58)



- In the case of living walls (wall-bounded) the measurement study of a public building in Vienna in winter showed a temperature up to 7 °C higher behind the wall. (59)

- In the case of an uninsulated façade of the previously mentioned building, the heat flux was reduced half (50%). (1)

- The U-value can be improved by approximately 22% for wall-bounded facade greening systems. (131)

- Cameron et al (2015) measured the energy consumption of a brick building element that was filled with water and kept at a constant temperature of 16°C. The elements were surrounded by brickwork - some bare and some covered with ivy. The ivy cover led to a 21% reduction in energy consumption in the first winter compared to the bare bricks. In the second winter, when the planting was more established, an average saving of 37% was achieved. The ivy cover increased the brick temperature significantly in winter. The greatest energy savings from the greening occurred in extreme weather conditions such as cold, strong wind or rain. (125)

- Perez et al. (2022) studied the effects of the Leaf Area Index (LAI, also known as leaf cover) on the energy balance using the example of a double-wall facade with Boston Ivy growth. The LAI changed seasonally over five periods, with a corresponding differentiated energy balance: Early summer (LAI of 4.8; 54% savings in cooling), late summer (LAI of 4.4; 30% savings in cooling), autumn (LAI of 1.7; 5.4% increase in heating), winter (LAI of 0.9; 5.4% increase in heating), and spring (LAI of 3.6; 11.9% increase in heating). The increase in energy consumption during the colder months is attributed to the loss of leaves in the greenery. Additionally, two effects were identified and characterized: the influence of facade exposition and a slight insulation effect at night, with the green canopy acting as a thermal barrier. (127)

3.7. Noise Protection

Cities are becoming increasingly noisy and all of this background noise has a negative impact on human health and wellbeing. Green roofs are able to reduce noise entering the building.

- Sound absorption through ivy (Hedera helix) with a growth of 20 cm thickness was 5 dB. (60)

- Boston ivy (Parthenocissus tricuspidata) soil-bound 1.7 dB, Living wall 2.7 dB (at 500-1000 Hz). (61)

- Boston ivy soil-bound (Parthenocissus tricucpidata) 4 dB (at 500-1000 Hz) (62) and 5 dB at over 5000 Hertz. (61)

- Living Wall, depending on Hz, build-up and substrate depth performs 4-9.9 dB (63) and 5 dB. (51)

- Noise in the surrounding urban area is reduced by green roofs and green facades by up to 10 dB (depending on frequency). (89)

3.8. Sun Protection and Shading

Many investors, building owners and facility managers are keen to shorten their return on investment and ensure the effective and transparent maintenance cost of a building. Studies show that the investment cost for greenery is marginal compared to the overall investment. Green walls reduce energy bills and add to the purchase price of units. They can as well substitute technical shading investments.

- 40 - 80 % of the sun's radiation is absorbed or reflected by the Foliage (climbing plant). (45)
- Shading rate of 70 - 95 % due to deciduous greening with climbers. (2)
- In the case of vegetated sun protection systems, cooling cost savings of approx. 43 %. (64)
- Mitigation factors (sun protection) of Scaffolding climbing plants according to DIN 4108, Part 2 from 0.62 to 0.3. (65)
- Savings of 26% in primary energy (heating & cooling) in comparison with conventional Sun protection on south facades. (66)
- Savings of 49% in primary energy (heating & cooling) compared to no sun protection on south facades. (66)
- Green facades reduce solar radiation on the building envelope by approximately 85 – 100% and thus counteract heating. (51)
- Double-skin facade can provide comparable shadow factor values for all orientations, to those provided by the artificial barriers proposed in building regulations such as facade setbacks, cantilevers, awnings, slats, and others. (165)

3.9. Rentability and Energy Savings

- Tests under controlled temperatures showed the high potential of the double-skin green facade as a passive system in comparison to the reference one, obtaining accumulated electrical energy savings up to 34% for cooling periods with a leaf area index of 3.5–4 during the summer period, under Mediterranean continental climate. (165)
- If applied to the whole city scale, the combination of both green roofs and green walls could mitigate raised urban temperatures, and, especially for hot climates, bring temperatures down to more ''human-friendly'' levels and achieve energy saving for cooling buildings from 32% to 100%. In cases where little cooling load is needed, cooling demand can be reduced to zero by covering building surfaces with vegetation. In other cases, energy savings can also be significant, varying from 90% to 35%. (166)
- Green walls and roofs create thermally comfortable indoor and outdoor conditions, enhancing the liveability of urban environments and reducing reliance on active cooling systems. (141) (150) (164)

3.10. Biodiversity and Nature

Biodiversity on wall level is an emerging topic. Specific system providers of green walls have started to offer design elements that support the capacities for animals, there are cities that promote facade-integrated nesting opportunities for certain target species. The ecologic value of evergreen climbing plats as a habitat are evident.

- Used by bat species; various bird and insect species use Ivy (Hedera helix) as a habitat (67) (68):

  - 6 types of tensioners

  - 2 butterflies

  - Hoverflies

  - Bee species and wasp species that eat nectar

  - Pollen is used by ivy silk spider, honeybees, wild bees and wasp species

  - Fruit of the ivy food for Robins, Garden- and Redstart, Blackbirds, Thrushes and Starlings

  - Nesting site for Blackbirds, Yellow Warblers, Girlitz, Greenfinch, Gray Flycatcher, Honeysuckle, Wren, Rattlecap and Song Thrush

- Wild bees on 14 vertical green walls (ground-based with climbers to living walls) in Vienna: 32 different species from 12 different genus. The hotspot was Nepeta faassenii and Sedum sp. (132)

3.11. Acceptance

In comparison to green roofs, green walls are often implemented in street canyons (open, public space) or in inner yards of buildings. They are therefore accessible green space in direct interaction with citizens, they are more visible. Especially in retrofit projects on buildings with a mixed ownership, getting permission for any measure can be a challenge. The acceptance is therefore of utmost importance.

- Result: 84 % of the inhabitants of green buildings and 68% of the inhabitants of non- greened buildings have a positive opinion about green walls. (69)

- Positive response and great approval by survey. (70)

- In densely built-up urban areas, where nature qualities are largely lacking, green walls are received as a "piece of nature memory" with a particularly high symbolic value. (71)

- Green facades provide a connection to the otherwise rather excluded city Nature. They promote an awareness of nature through the visibility of the seasons and the observation of ecological relationships. (72)

- Green facades offer a visually soothing variety in the often uniform cityscape. That strengthens the distinctiveness of a residential area, which strengthened the "local identity". (73)

3.12 Fire Resistance

In divergence to green roofs, that are known for their classifications as "hard roofs" (broof-t1) in several countries, to increase the mainstreaming aspect and implementation readiness of green walls in cities, that have been longing for a deep policy and regulation implementation, it had proven necessary to apply rigorous fire testing scenarios.

- In the case of vital, well-maintained plants, the horizontal effect of fire is very limited. Furthermore, vital green facades are self-extinguishing after the primary fire. (111) (114)
- Inflammation of the woody shoots and the leaf mass of the greenery can be expected at temperatures of approximately 500°C. (171)
- Avoiding the mentioned 500°C in the greenery was always successful in the conducted experiments when a sufficiently projecting fire barrier made of steel sheet, with a thickness of 1.0 to 2.0 mm, was mounted horizontally above the fire chamber—regardless of whether ivy was directly attached to the test stand or a greened trough system was present above it. (171)

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4. Indoor Vertical Greenery

Studies by the Federal Environment Agency show that adults in Germany, aged 25 to 69, spend an average of around 20 hours per day indoors - 14 of which are spent in their own homes. Plants have a positive impact on people; the closer they are to our daily lives, the greater their influence on wellbeing and indoor comfort.

4.1. Improving Health

A green environment positively affects overall health. This benefit extends not only to workplaces and homes but also to recovery from serious illnesses and surgeries.

Health improvements (before-and-after comparison studies):

- Reduction in reported symptoms by 21-25% (74)
- Overall symptom reduction (75)
- Cough: 37-38% (74)
- Fatigue: 30-32% (74)
- Dry skin: 11-23% (74)
- Headache: 18-45% (74)
- Shortened recovery time after surgery (76)

4.2. Stress Reduction

Stress has a fundamentally negative impact on both mental and physical wellbeing, in both the short and long term.

- Comparative measurement: 47% feel more relaxed in the room with plants. (77)

4.3. Higher Wellbeing

Wellbeing has various levels - physical, emotional and economical. The following study references are concerned with determining physical wellbeing, which is a subjective perception. Improved wellbeing reduces ill-being and helps mitigate negative symptoms.

- 93% of respondents felt more comfortable in green office and preferred it as a working environment. (77)

- Employees who worked in offices that had plants reported higher overall quality-of-life scores. Research participants in green conditions felt more physically and psychologically comfortable and reported higher job satisfaction than participants in other conditions. (78) (79) (80)

- 29% increase in perceived comfort due to improved humidity levels from vertical indoor greenery, compared to a room without greenery. (81)

4.4. Noise Reduction

Noise impacts wellbeing and overall quality of life. Prolonged exposure can cause temporary or permanent hearing damage and negatively affect health. It stimulates the autonomic nervous system and the hormonal system, influencing physical, mental, and social wellbeing.

- Greening, as a high-quality porous absorber, reduces (regardless of design) the reverberation time and leads to higher speech intelligibility. (86)
- Reverberation time 0.2 seconds lower. (77)
- Higher equivalent sound absorption area relative to room volume (0.53 compared to 0.43 or 0.33). (77)
- Façade greening achieves an interior sound reduction index of 22 dB. (133)

4.5. Increase in Productivity

Productivity is the amount of work a person can complete in a given period of time. There are a number of complex factors involved. A productive person works efficiently, manages their time well, achieves better results in less time, and remains highly motivated.

- Productivity increases by 15% in offices with plants. (82)
- Plants in the extended surroundings of the workplace positively impact performance and productivity. (83) (134)
- Motivation increases by 29% in greened workplaces. (77)

4.6. Increase in Concentration

Attention is the allocation of conscious resources to the contents of consciousness. This can be, for example, perceptions of the environment or one's own behaviour and actions, but also thoughts and feelings. Concentration is a measure of the intensity and duration of attention and is often mentioned in the context of learning environments.

- 16% reduction in concentration problems was observed in offices and classrooms with plants. (74)
- Reaction time in the presence of plants was 12% faster than in the absence of plants. (84)

4.7. Reduced Germ Load

Since the COVID-19 crisis at the latest, germ contamination in indoor spaces, especially in kindergartens, schools, hospitals and at doctors' offices, has become a major concern.

- In plant-filled room the airborne bacterial load was on average 65-72% lower than in similar room without plants. (34)
- Households with more indoor plants are characterized by lower proportion of human-sourced bacteria in house dust. (160)

4.8. Evaporation

The evaporation of indoor greenery plays a dual role, on the one hand with regard to the targeted control of humidity indoors along the seasons (especially winter dryness due to the heating season is as well a factor for sicknesses/homestays) and on the other hand for achieving a hygrothermally comfortable indoor climates for building users.

- Investigation as part of a research project (85):
    - Evaporation from vertical greenery: 50 g/m²/h
    - 20% higher humidity in a closed, greened office space compared to a non-greened reference area
    - 8–14% higher humidity when the door is open
- Increase in humidity by approximately 15–20% was observed in the green office. (77)
- During the heating season, the period in which indoor conditions are considered hygrothermally comfortable is extended by 60% in greened areas compared to non-greened areas. (87)

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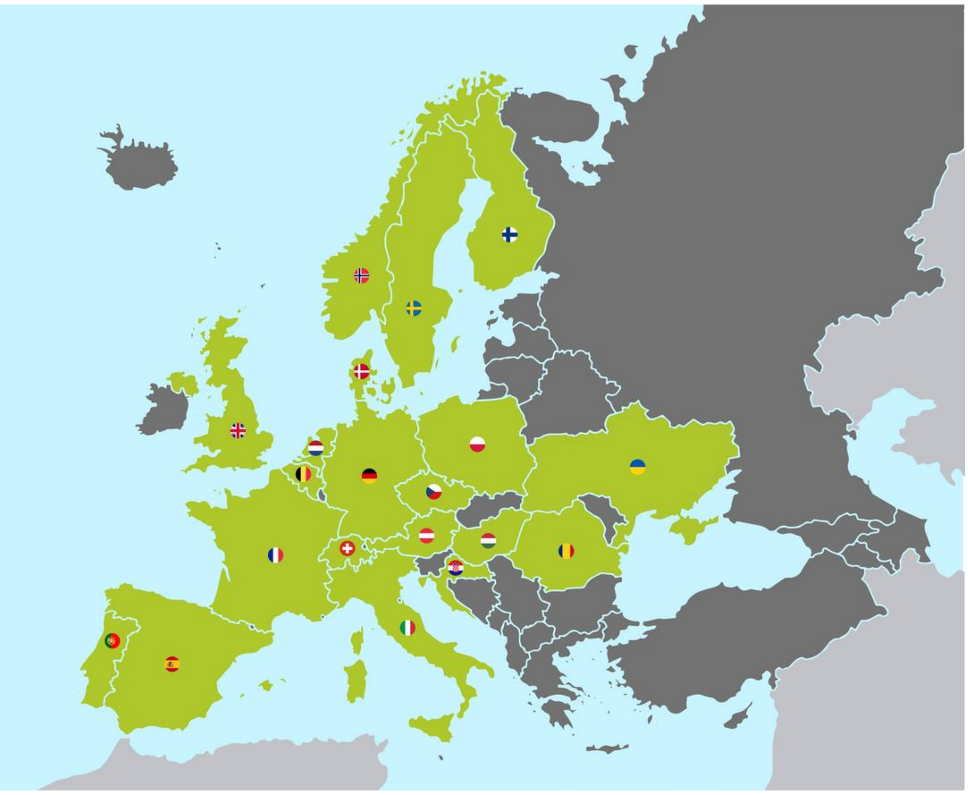
6. About the EFB - European Federation of Green Roof and Wall Associations

The European Federation of Green Roof and Living Wall Associations (EFB) is a non-profit organisation, established in 1997 as the European Umbrella Organisation for national Green Infrastructure associations, ensuring the active representation of international interests on a European level.

EFB provides home to a friendly network for its current 18 national members, reaching out to over 1600 small to medium enterprises, universities, research institutes, city governments, public decision-makers, and various entities related to planning and architecture, engaged in manufacturing, supplying, and constructing green roofs and walls. The members are active in different fields with conferences and knowledge events, guidelines, standards, research and implementation projects.

Key areas of EFB work:

- Umbrella network of the national green roof and living wall associations (NPO sector) in Europe
- Open to public Communication, dissemination through social media platforms, interviews, events, etc.
- Open knowledge and best practice sharing over Seminars, webinars, meet-ups, and other events
- Expertise in business, market-related questions, and CSR in nature-based solutions (NBS) on buildings
- Sharing Vegetation technology expertise for greening building systems across climatic zones
- Providing Expertise in NBS-related EU to national policies, building plan regulations and standards
- Linking towards the European Commission and involvement in various working groups and platforms
- Deploying Joint actions with the green branch Europe: SoGreen, ELCA, IFLA, EILO, ENA, WUP, WGIN, ECTP, etc.



7. National Green Roof and Green Wall Associations in Europe

Austria: Verband für Bauwerksbegrünung (VfB)

The mission of the Austrian Green Roof and Living Wall Association (VfB), founded in 1991, is to promote public awareness of the benefits, to work with and further develop technical quality standards and to inform interested parties about various aspects. Since 2017, the Austrian association is 100% owner of the Austrian competence centre and central coordination unit GRÜNSTATTGRAU with over 380 partners.

Belgium: Belgische Federatie voor DAK en GEVELgroen (BFDG)

Since the founding in 2021 the mission of the BFDG is to increase the quality and awareness of green roofs and green walls in the construction market and improve the quality and reputation of green roofs and green facades in the construction market. To achieve this, various specialised committees focus on determining the qualifications of the various layers and the relationship between them based on European guidelines and scientific expertise.

Croatia: National Association for Greening Roofs and Facades (GRoF)

Established in July 2024, GRoF is a voluntary professional association promoting the integration of green roofs and facades into urban planning. In response to fragmented practices, it aims to define clear standards and strengthen the role of building greenery in construction policy. Since 2025, GRoF is part of the EFB network.

Czech Republic: Svaz zakládání a údržby zeleně, z.s.(SZÚZ.) - Asociace zelených střech a fasád (AZSF)

The Czech Green Roof and Living Wall Association (AZSF) was founded in 2013 under the Czech Landscape Gardening Association (SZÚZ). It comprises natural and legal persons which actively engage in business activities in areas of landscaping and greenery on buildings, particularly green roofs and facades. It provides seminars, publishes expert guidelines, green market reports and organizes the national "Green Roof of the Year" competition.

France: Association de la végétalisation de l'îlot bâti et des infrastructures vertes (ADIVET)

Founded in 2002, ADIVET has expanded its focus beyond its original mission of greening buildings to include infrastructure, as greening of these areas addresses the same issues, often involves the same actors and provides similar ecosystem services. The association is active in communication, training, and international collaboration, contributing to the sustainable development of urban greening. It brings together all the players in the value chain of greening buildings and urban infrastructure in France.

Germany: Bundesverband GebäudeGrün e. V. (BuGG)

Bundesverband GebäudeGrün e. V. (BuGG), formed from the merger of the two previously independently acting well-established associations Deutscher Dachgärtner Verband e.V. (DDV) and Fachvereinigung Bauwerksbegrünung e.V.(FBB), represents over 560 members from various sectors of green roofs, walls, and interior greening. It promotes building greening through advocacy, technical expertise, networking, and public outreach. BuGG offers company-neutral resources like guidelines, fact sheets, and market reports, hosts symposia and awards, and collaborates with policymakers and trade associations to advance greening practices across Germany.

Hungary: Magyar Kertépítők Országos Szövetsége (MAKEOSZ) Zöldtető- és Zöldfal Építők Országos Szövetsége (ZEOSZ)

MAKEOSZ (Association of Landscape Contractors of Hungary) represents landscape contractors dedicated to high-quality professional work. A specialized division (ZEOSZ) focuses on green roofs and walls, reflecting the significant role of these in many members’ portfolios. MAKEOSZ promotes green building through guidelines, education, and collaboration.

Italy: Associazione Italiana Verde Pensile (AIVEP)

AIVEP is a non-governmental, non-profit organization, founded in 1997, that promotes all national activities of green roofs, green facades and other technology with greenery-related functions in architecture. It aggregates all those who work professionally and scientifically in the field of green roofs or are interested in the topic of green roofs to combine resources and energies.

Netherlands: Vereniging Bouwwerk Begroeners (VBB)

The VBB is the Dutch Association for Building Greeners, founded in 2008. It acts as a knowledge platform for multifunctional and green roofs, green facades and indoor greening. As the license holder of the Dutch VBB-FLL quality standard, the VBB’s mission is to share knowledge, provide consulting services and to maintain a high-quality standard in the greening sector.

Poland: Polskie Stowarzyszenie „Dachy Zielone" (PSDZ)

The Polish Green Roof Association unit members, including researchers, architects, consultants, and government officials, focusing on green roofs and living walls since 2009. The association promotes green infrastructure, and it's benefits through trainings and conferences. The aim is the cooperation with municipal offices, contributing to creation of local and national policy concerning importance of green infrastructure to cities. It works on creating national guidelines and policies to encourage the use of green roofs and walls.

Portugal: Associação Nacional de Coberturas Verdes (ANCV)

ANCV is a non-profit organization, founded in 2015, which aims to promote green infrastructure in cities, especially those that can be installed on buildings such as green roofs, highlighting importance, and the numerous contributions they can give to the possibility to create healthy, sustainable, biodiverse and resilient urban territories.

Romania: Asociația Constructorilor de Acoperișuri, Pereți și Fațade Verzi – (Converde)

Converde emerged after a prolonged period during which the founders individually endeavoured to contribute to the development of Romania's green roof and facade market. Their collective realization led to the establishment in 2023 of a young and professional entity. It collaborates with architects, developers, and municipalities to integrate green infrastructure into urban planning while advocating for supportive legislation and standards.

Scandinavia: Scandinavian Green Infrastructure Association (SGIA)

SGIA is a non-profit organisation with members from academia, municipal departments, green roof entrepreneurs, architects, developers and other organisations with an interest in green roofs and urban green infrastructure. The association build the bridge between Scandinavian actors of green infrastructure by creating a platform for sharing knowledge, gaining inspiration and creating collaboration between actors dedicated to the development of resilient green infrastructure. SGIA work actively to guide the development of Scandinavian cities towards liveable cities through the process of re-naturing urban areas and in this way accomplishing benefits for both nature, people and the economy.

Switzerland: Schweizerische Fachvereinigung Gebäudebegrünung (SFG)

SCHWEIZERISCHE FACHVEREINIGUNG GEBÄUDEBEGRÜNUNG
ASSOCIATION SUISSE DES SPECIALISTES DU VERDISSEMENT DES EDIFICES

Founded in 1996, SFG unites professionals, planners, and companies to promote green roofs, facades, and interiors in Switzerland. Known for its commitment to sustainable quality and professional execution, it publishes recognized QA-standards and guidelines. Today, it is recognized as a nationally leading specialist institution for the areas of green roofs, facade greening and indoor greening with the focus on biodiversity and solar green roofs.

Spain: Asociación Española de Cubiertas Verdes y Ajardinamientos Verticales (ASESCUVE)

ASESCUVE

Founded in 2010, ASESCUVE is the meeting point for professionals developing green roofs and vertical landscaping in Spain. Its mission is to promote green roofs and facades, advocate for regulations and technical standards, and enhance urban sustainability by means of Nature based Solutions which have made a positive impact in the urban environment. It provides technical training, represents the sector in public institutions and collaborates on national and European projects to advance green infrastructure.

Spain: PRONATUR Naturación y Agricultura Urbana (PRONATUR)

PRONATUR is the Spanish Society for the Promotion of Nature in Urban and Rural Areas and was founded in 1992. It promotes and coordinates activities between University, Administration and firms for improvement of nature in urban environment with socioeconomic dimensions. Some of the priority areas are total health, the environment, climate change, sustainable urban agriculture, conservation of natural resources, biodiversity, circular economy, water management, landscaping and recreation, all applicable to the development of research projects, organization of events, publication of books and articles in collaboration with public and private institutions, both international and national and local.

United Kingdom: The Green Roof Organisation (GRO)

GRO is an independent not-for-profit Trade Association that has been established to support and develop the UK Green Roofing industry. Established in 2008, GRO represents manufacturers, contractors, suppliers, and various stakeholders like NGOs, academia and architects. The organization developed the GRO Green Roof Code of Best Practice, first published in 2011 and updated in 2014 and 2021, to provide industry standards and guidance. The code has been widely adopted across the UK construction sector.

Ukraine: Ukrainian Association of Green Infrastructure (UAGI)

The UAGI is a non-governmental organisation that brings together landscape industry experts, scientists and enthusiasts working to create sustainable cities through greening urban areas. Founded in 2023 to combine the international experience of partners with the practical skills of Ukrainian landscape industry professionals and scientists. Its goals include post-war reconstruction, sharing global best practices, organizing events, and bridging science with practice to create greener, modern cities.

8. List of Research Facilities Focused on Green Building Research

Austria

University / Research institution	Faculty / Institute / Department	Contact Person	Link
University of Life Sciences Vienna, BOKU	Institute of Soil-Bioengineering, Landscape construction and Vegetation Engineering IBLB	Stangl R., Pitha U., Scharf B.	https://boku.ac.at/en/baunat/iblb
University of Life Sciences Vienna, BOKU	Institute of Landscape planning (ILAP)	Reinwald, F.; Schneider, G.	https://boku.ac.at/en/rali/ilap
University of Life Sciences Vienna, BOKU	Institute of Landscape Development, Recreation and Conservation Planning ILEN	Brandenburg C.	https://boku.ac.at/en/rali/ilen
University of Life Sciences Vienna, BOKU	Institute of Sanitary Engineering and Water pollution control SIG	Langergraber G.	https://boku.ac.at/en/wau/sig
Technical University Vienna	Research Unit for ecological Buildings technologies	Korjenic A.	https://www.tuwien.at/en/cee/mbb/obt
Technical University Vienna	Research unit landscape architecture	Hauck T.	https://ar.tuwien.ac.at/en/faculty/Institutes/Institute-of-Urban-Design-and-Landscape-Architecture/landscape-architecture-and-landscape-planning
Medical University of Vienna	Center for public health	Haluza, D.	https://www.meduniwien.ac.at/web/en/about-us/organisation/medical-science-divisions/center-for-public-health/
Joanneum Research	Institute for Climate, Energy Systems and Society	Kaltenegger I., Schwaiger H.	https://www.joanneum.at/life/en/
Austrian Institute of Technology	Climate Resilient urban pathways	Tötzer T.	https://www.ait.ac.at/en/research-topics/climate-resilient-urban-pathways
Institute of Building Ecology IBO - Research Association and GmbH		Figl G.	https://www.ibo.at/en/
GRÜNSTATTGRAU Research- and Development GmbH		Formanek S.	https://gruenstattgrau.at/en/partner/database/
Alchemia Nova- Institute for circular economy & nature based solutions			https://www.alchemia-nova.net/
Vertical Farm Institute Research GmbH		Podmirseg D.	https://verticalfarminstitute.com/
Green4Cities GmbH		Schnepf D., Scharf B.	https://www.green4cities.com/en/
GreenPass GmbH		Kraus F., Scharf B.	https://greenpass.io/
AEE Intec - Institute for sustainable Technologies			https://www.aee-intec.at/index.php?params=&lang=en

Czech Republic

University / Research institution	Faculty / Institute / Department	Contact person	Link
University Centre for Energy Efficient Buildings of CTU (UCEEB)	Urban Ecohydrology Research Team (thermal performance, fire, retention)	Sněhota M.	https://www.uceeb.cz/en/home/
Brno University of Technology (BUT)	Faculty of Civil Engineering - Advanced Materials, Structures and Technologies (AdMaS) (retention, energy balance)		https://admas.eu/en/
Jan Evangelista Purkyně University in Ústí nad Labem (UJEP)	Institute for Economic and Environmental Policy (IEEP) (environmental economics)	Hekrle M.	https://www.ieep.cz/en/
Výzkumný ústav pro krajinu (VUKOZ) (Landscape Research Institute)	(substrate testing)	Dubský M.	https://www.vukoz.cz/

Czech University of Life Sciences (ČZU)	Faculty of Environmental Sciences (FŽP) - Department of Ecology - Insect ecology (insect biodiversity)	Knapp M.	https://www.fzp.czu.cz/cs/r-6894-o-fakulte/r-6895-katedry-a-soucasti/r-7298-katedry/r-7299-katedra-ekologie/r-13227-vyzkumne-skupiny/r-13220-ekologie-hmyzu/r-13221-aktuality
University of South Bohemia (JČU)	Faculty of Science - Department of Botany - Restoration Ecology Group (botanical biodiversity)	Řehounková K.	https://www.restoration-ecology.eu/

France

University / Research institution	Faculty / Institute / Department	Contact person	Link
Scientific and Technical Centre for Building (CSTB)			https://www.cstb.fr/
Centre for Studies on Risks, the Environment, Mobility and Urban Planning (Cerema)			https://www.cerema.fr/en/cerema
National Museum of Natural History (MNHN)			https://www.mnhn.fr/en
Institute of Ecology and Environmental Sciences of Paris (iEES Paris)			https://iees-paris.fr/en/
Water, Environment and Urban Systems Lab (Leesu)			https://www.leesu.fr/?lang=en

Germany

University/Research Institution	Faculty / Institute / Department	Contact person	Link
Nürtingen-Geislingen University (HfWU)	Faculty of Landscape Architecture, Environment and Urban Planning	Pfoser N.	https://www.hfwu.de/
Technical University of Munich (TUM)	Faculty of Architecture	Ludwig F.	https://www.arc.ed.tum.de/en/gtla/professorship/
Hochschule Geisenheim University (HGU)	Institute of Landscaping and Vegetation Technology	Birgelen A. Stollberg M.	https://www.hs-geisenheim.de/forschung/institute/landschaftsbau-und-vegetationstechnik/ueberblick-institut-fuer-landschaftsbau-und-vegetationstechnik
Dresden University of Applied Sciences (HTW)	Faculty of Agriculture/ Environment/Chemistry	Günther H.	https://www.htw-dresden.de/en/luc
Neubrandenburg University of Applied Sciences (HSNB)	Department of Landscape Sciences and Geomatics		https://www.hs-nb.de/fachbereich-landschaftswissenschaften-und-geomatik/
Weihenstephan-Triesdorf University of Applied Sciences (HSWT)	Institute of Horticulture	Bucher, A.	https://www.hswt.de/en/research/research-profile/research-institutions/institute-of-horticulture
Technical University of Berlin (TUB)	Institute of Landscape Architecture and Environmental Planning	Richter S. Schmidt M.	https://www.tu.berlin/en/ilaup
Berlin University of Applied Sciences and Technology (BHT)	Department of Life Sciences and Technology	Grade S.	https://www.bht-berlin.de/v
University of Kassel	Department of Architecture, Urban Planning and Landscape Planning	-	https://www.uni-kassel.de/fb06/en/
Osnabrück University of Applied Sciences	Faculty of Agricultural Sciences and Landscape Architecture	Kiehl K.	https://www.hs-osnabrueck.de/wir/fakultaeten/aul/
HafenCity University Hamburg (HCU)	Department of sustainable urban and infrastructure planning (USIP)	Dickhaut W. Richter M.	https://www.hcu-hamburg.de/master/reap
Leibniz University Hannover (LUH)	Institute of Landscape Architecture	-	https://www.ila.uni-hannover.de/en/

Bavarian State Institute for Viticulture and Horticulture (LWG) Veitshöchheim	Institute of Urban Green Spaces and Landscaping	Eppel J.	https://www.lwg.bayern.de/landespflege/index.php
Bavarian Center for Applied Energy Research (ZAE Bayern) Würzburg	Energy efficiency	Ebert H.P.	https://en.zae-bayern.de/
Institute for Agricultural and Urban Ecological Projects (IASP) at the Humboldt University of Berlin	Biogenic raw materials department	Herfort S.	https://www.iasp-berlin.de/forschung/biogene-rohstoffe
Institute for Sustainable Landscape Architecture (INLA) at the HfWU		Knoll S.	http://www.hfwu-inla.de/
Competence Centre for Building Greening and Urban Climate e.V. Nürtingen		Pekrun C.	https://www.kgs-nt.de/en-gb/home
Helmholtz Centre for Environmental Research (UFZ)	Department of Systemic Environmental Biotechnology (SUBT)	Moeller L.	https://www.ufz.de/index.php?en=34238
Botanical Garden Frankfurt am Main		Alberternst B. Nawrath S.	https://www.botanischergarten-frankfurt.de/projekte/lebendige-daecher-zusammen-mit-der-kfw-stiftung
Center for Applied Energy Research (CAE)	Institution for energy research	Ebert H. Reim M.	https://www.cae-zerocarbon.de
Federal Institute of Materials Research and Testing (BAM)	Department of construction material	Von Werder J.	https://www.bam.de/Navigation/EN/Home/home.html
Fraunhofer Institution for Building Physics	-	Hofbauer W.	https://www.ibp.fraunhofer.de
German institution for Textile+ Fiber Research (DITF)	Smart Living Textiles Technology Center	Riethmüller C.	https://www.ditf.de
Independent Institute for Environmental Issues (UfU Berlin)	Department of Climate Protection & Transformative Education	Rosenwinkel S.	https://www.ufu.de
Institute for Acoustics and Building Physics at the University of Stuttgart		Wochner M.	https://www.iabp.uni-stuttgart.de
Institute of Ecological Urban and Regional Development (IÖR)		Janssen G.	https://www.ioer.de
Institute for Ecological Economy Research (IÖW)	Climate and Energy	Kegel J.	https://www.ioew.de
Institute of Statics and Construction TU Darmstadt	Field of Energy efficiency in construction	Bishara N.	http://www.ismd.tu-darmstadt.de
Inter 3 Berlin	Institute for resource management	Kondra M.	https://www.inter3.de
Rhine-Westphalian Technical University (RWTH)	Institute of Urban Planning and Transportation	Witte A. Heine S.	https://www.rwth-aachen.de/go/id/a
Training and Research Institute for Horticulture (LVG)		Scharsich K.	https://lvg-heidelberg.info/
Technical University Cologne	Faculty of Plant, Energy and Mechanical Systems	Kloster N.	http://www.th-koeln.de
Technical University Nürnberg	Construction and Engineering, Technology and Building Envelope Department	Krippner R.	https://www.th-nuernberg.de
Technical University Bingen	Life Sciences and Engineering	Hietel E.	https://www.th-bingen.de
Technical University Braunschweig	Institute for Geoecology	Weber S.	https://www.tu-braunschweig.de

Technical University Dortmund	Faculty of resources and energy systems	Kaiser M.	https://www.tu-dortmund.de
Technical University Dresden	Institute for landscaping	Lohaus I.	https://tu-dresden.de
Training and Research Institute for Horticulture and Arboriculture (LVAG)	-	Kaiser D. Schulz H.	https://www.lvga-bb.de
University of Cologne	Institute of Biology Education	Edelmann H.	https://biologiedidaktik.uni-koeln.de
HAWK University for applied science and arts	Faculty of Management, Social Work and Building	Käsmaier M.	https://www.hawk.de/en
Zittau/Görlitz University of Applied Sciences	Faculty of Mechanical Engineering	Scholz S.	https://www.hszg.de
FH Münster University of Applied Sciences	Faculty of civil engineering	Uhl M.	https://www.fh-muenster.de

Hungary

University / Research institution	Faculty / Institute / Department	Contact person	Link
Budapest University of Technology and Economics (BME)	Department of Building Construction	Horvath S.	https://www.epszerk.bme.hu/en/
Hungarian University of Agriculture and Life Sciences (MATE)	Institute of Landscape Architecture, Department of Urban Planning and Municipal Green Infrastructure	Báthoryne Nagy I. R.	https://tajepiteszet.uni-mate.hu/telep%C3%BCl%C3%A9s%C3%A9p%C3%ADt%C3%A9szeti-%C3%A9s-telep%C3%BCl%C3%A9si-z%C3%B6ldinfrastrukt%C3%BAra-tansz%C3%A9k

Portugal

University / Research institution	Faculty / Institute / Department	Contact person	Link
University of Lisbon	Higher Institute of Agronomy (ISA) - Linking Landscape, Environment, Agriculture and Food (LEAF)	Afonso do Paço T.	https://www.isa.ulisboa.pt/en/leaf/presentation
University of Lisbon	Higher Institute of Agronomy (ISA) - Department of Sciences and Engineering of Biosystems (DCEB)		https://www.isa.ulisboa.pt/dceb/apresentacao

Spain

University / Research institution	Faculty / Institute / Department	Contact person	Link
University of Seville	Research group AGR-268 - Urban Greening and Biosystems Engineering (NATURIB)	Fernandez Cañero R.	https://grupo.us.es/naturib/
University of Lleida	Innovative Technologies for Sustainability Research Group	Pérez G.	https://it4s.cat/
Technical University of Cartagena	Faculty of Agronomy - Research Unit for Landscape and Urban Horticulture	Ochoa J.	https://personas.upct.es/perfil/jesus.ochoa

Sweden

University / Research institution	Faculty / Institute / Department	Contact person	Link
Swedish University of Agricultural Sciences (SLU)	Department of landscape architecture, planning and management	Emilsson T.	https://www.slu.se/en/departments/department-of-landscape-architecture-planning-management/
Lund university	Division of water resources engineering	Sörensen J.	http://www.tvrl.lth.se/english

IVL Swedish Environmental Research Institute	Nature-based solutions in an urban environment	Hansson K.	https://www.ivl.se/english/ivl/our-offer/our-services/nature-based-solutions-in-an-urban-environment.html
RISE research institute	Built environments, Climate adaptation, Urban development	Schade J.	https://www.ri.se/en/expertise-areas/projects/environmental-investment-of-green-roofs-tools-and-comparisons-with-lca

Switzerland

University / Research institution	Faculty / Institute / Department	Contact person	Link
University of Applied Sciences Western Switzerland	Institute Land Nature Landscape (inTNP) - Green roofs laboratory	Prunier P.	https://www.hesge.ch/hepia/en/laboratoire/green-roofs-laboratory
ZHAW School of Life Sciences and Facility Management	Institute of Natural Resource Sciences - Research Unit Greenspace development Institute of Environment and Natural Resources (IUNR) Wädenswil	Brenneisen S. Baumann N. Trachsel Geissmann E.	https://www.zhaw.ch/en/lsfm/institutes-centres/iunr https://www.zhaw.ch/en/lsfm/institutes-centres/iunr/urban-ecosystems
Hochschule Luzern Technik & Architektur	Institut für Gebäudetechnik und Energie IGE Institut für Bauingenieurwesen IBI Forschungsgruppe Fassaden und Metallbau	Settembrini G. Arnold K.	https://www.hslu.ch/de-ch/technik-architektur/ueber-uns/organisation/kompetenzzentren-und-forschungsgruppen/bau/gebaeudetechnik-und-energie/ https://www.hslu.ch/de-ch/technik-architektur/ueber-uns/organisation/kompetenzzentren-und-forschungsgruppen/bau/kompetenzzentrum-gebaeudehuelle-und-ingenieurbau/gebaeudehuelle/bauteile-und-systeme/

United Kingdom

University / Research institution	Faculty / Institute / Department	Contact person	Link
The Open University	School of Environment, Earth & Ecosystem Sciences	Maseyk K.	https://www5.open.ac.uk/stem/environment-earth-ecosystem-sciences/
University of West England	School of Architecture and the Built Environment	Rumble H.	https://www.uwe.ac.uk/about/colleges-and-schools/arts-technology-and-environment/architecture-and-environment
Swansea University	Faculty of Humanities and Social Sciences	Bohata K.	
Sheffield University	Green Roof Centre	Dunett N.	https://www.sheffield.ac.uk/architecture-landscape/research/landscape/ecology/green-roof
Bartlett School of Architecture - University College London	Faculty of the Built Environment	Cameron B.	https://www.ucl.ac.uk/bartlett/
Salford University	School of Science, Engineering & Environment	Elkadi H.	https://hub.salford.ac.uk/ignition-living-lab

Ukraine

University / Research institution	Faculty / Institute / Department	Contact person	Link
Kyiv National University of Construction and Architecture	Department of Occupational Health and Environmental Protection	Tkachenko T.	https://eng.knuba.edu.ua/