



## Rainwater Management Concepts

Greening buildings, cooling buildings

Planning, Construction, Operation and Maintenance Guidelines





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## Foreword



People all over the world are increasingly focussed on the topics of environmental pollution and climate change.

Conserving the environment and resources, securing healthy living and working conditions for the long term and implementing the highest standards of environmental and social sustainability – these are some of the goals that pose new challenges for the actors involved in ecological building.

New processes and technologies have been developed, trialed and evaluated in selected projects in Berlin as part of the city's "Urban Ecology Model Projects" programme. In recent years, new technical systems have been developed out of findings from these model projects and has found its way into current standards and regulations. These findings are being incorporated into my department's guidelines and decision-making aids, making current knowledge available for future projects.

This publication is a guideline for rainwater management concepts and focuses on greening and cooling buildings. It is aimed equally at experts and interested citizens and contains details on planning, building, operating and maintaining related systems and equipment.

Public building projects serve a role-model function in implementing ecological, economic and innovative standards, and as case studies for how ecological standards in terms of environmental protection and the reduction of environmental pollution can be taken into account. The development of standard specifications for public and publicly funded construction projects is also aimed at reducing planning and construction costs and minimising future operating costs.

Dividing general ecological concepts for typical urban construction projects into individual modules – energy, water, greenery, building materials, waste – has proven to be a vital approach, and the right one. Exemplary greening concepts that include information on managing precipitation water also need to be developed for building plots and buildings.

Berlin's Senate Department for Urban Development offers a platform for networking individual areas of ecological construction on its homepage, where information and other tools and aids on various topics of ecological planning and building are also available.

The future of our cities and landscapes depends on the extent to which climate change and its environmental effects can be managed through suitable measures at a national and municipal level. "These changes require new infrastructure projects to anticipate the effects of climate change in the design of water, sanitation, rainwater and other urban infrastructure." Berlin also endorsed these demands at the fifth World Water Forum in 2009 in Istanbul, as part of the Istanbul Water Consensus for Local and Regional Authorities. Only when many people also take responsibility for implementing these demands will there be noticeable results worldwide.

This publication is one 'building block' in achieving this. I am pleased that we, the Senate Department for Urban Development, are contributing to solving this global problem.

**Ingeborg Junge-Reyer**  
Senator for Urban Development





## Introduction

The recommendations provided here are based mainly on findings from the monitoring of a new building project for the Institute of Physics at the Humboldt University Berlin's Adlershof campus, a project in which innovative rainwater management and facade-greening approaches were planned and implemented and that has since attracted international attention.

Expert scientific project monitoring and evaluation was commissioned by the Berlin Senate Department for Urban Development, Department VI, and carried out by a working group from the Technical University Berlin, the Humboldt University (HU) Berlin and the University of Applied Sciences Neubrandenburg.

An accompanying monitoring and evaluation programme began in the final phase of planning and continued during the construction and operation of the installation after the property was transferred to the HU Berlin. The goal was and is to develop recommendations for optimising and economically operating such installations in individual project phases, thereby minimising operating costs. A further focus of the project was to develop practically relevant and application-oriented findings as tools and guidelines for the planning, construction, operation and maintenance of future projects.

Other relevant topics such as the overall energy efficiency of buildings, the choice of building materials and the optimisation of waste flows etc. were not followed up in this project, but were, where necessary, integrated into corresponding project recommendations or networked with other projects where possible. The evaluation of the project was carried out in cooperation with other departments of Berlin's state government, such as the Senate Department for Health, the Environment and Consumer Protection (Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz), the Plant Protection Office (Pflanzenschutzamt) and the State Office of Health and Social Affairs (Landesamt für Gesundheit und Soziales).

The recommendations for future building projects in these guidelines focus on the area of rainwater management and greening facades and are complemented by information on roof greening. These recommendations result from previous monitoring and experiences and the analysis and evaluation of other model urban ecology projects.

However, these are recommendations based on a few years of operation. It has been shown that the early and appropriate involvement of competent specialist firms and expert staff, and not just to carry out rainwater management and building greening, is a mandatory prerequisite for the implementation of innovative technologies, for the reduction of operating costs, and for improving both the visual quality of a building and its amenity qualities for users.

Projects, buildings and installations should be subjected to precise examination and evaluation for about two years after completion. This requires the installation and evaluation of relevant measuring systems so that the installation can be promptly optimised as required. Any higher costs resulting from the monitoring can be compensated for by reduced operating costs.

## Summary

For **planning** today, not only approved technical regulations are necessary, but an **optimisation** in terms of diverse, partly competing goals is also required.

Networked **planning**, appropriate, professional execution of **construction work**, and the secured and optimised **operation** of installations all have key functions in minimising operating costs and successfully implementing innovative technical systems and installations.

Projects, buildings and installations should be subjected to a precise **examination** and **evaluation** for at least two years after completion. This requires the installation and evaluation of relevant measuring systems so that the installation can be promptly optimised as required. Any higher costs resulting from the monitoring can be compensated for by reduced operating costs.

The trialing of new processes and technologies in **model projects** has proved its worth. In recent years, new technical systems have been developed out of findings from model projects. They found their way into current standards and regulations, and are now of importance in presenting innovative environmental technologies to the public.

Dividing **general ecological plans** for typical urban building projects into individual modules – energy, water, greenery, building materials, waste and their networking – has proven to be a vital approach, and the right one.

**Greening concepts** must be developed for building plots and buildings and should include information on **managing water from precipitation**.

In inner urban areas in particular, options for **building greenings** and facade and roof greenings should be examined in order to improve the urban climate. Greening should usually be planned for flat, slightly sloping and visible roofs.

**Building greening measures** (roof/facade) and increasing the proportion of green space on properties enhance the quality of amenity for users, improve the microclimate, reduce temperature extremes, improve the exchange of air and are an integral component of species protection.

Because of the evaporative cooling produced, the associated reduction of temperatures in the building's immediate surroundings, and the reduction in energy consumption for air-conditioning the building, greening is a major element in **optimizing a building's energy balance**.

Building greening is a major **element of rainwater management** and its potential for retaining water in the forms of evaporation and of delaying and reducing runoff must be taken into account in the planning process.

**Links with other forms of rainwater management**, such as water evaporation in ponds, waste water use and rainwater infiltration, must be examined at an early planning stage and considered in a networked way in overall ecological concepts.

A further significant advantage of greening buildings lies in the **retention** of nutrients and pollutants introduced with precipitation. This positive urban ecological effect is increasingly important. Large quantities of herbicides (weed killer) are added to building materials, e.g. in root penetration-proof roof sheeting and paints. The washing out of these chemicals in rainwater and the resulting consequences for the various rainwater management measures and plant growth must be noted.

In **choosing plants**, local conditions (light requirements, orientation), maintenance requirements (pruning, fertilising, pest control/plant protection, removal of unwanted growth) and the use of suitable growing media and watering systems must all be considered.



Growing media, non-woven materials and drainage layers allowing for a capillary uptake of water must be used for **plants in planters** that are watered using soak irrigation.

In **choosing materials**, the composition of growing media and plant fertiliser must reflect the intended use of the runoff water. In extensive roof greening, for example, the growing media and sealing systems used must be adapted to the subsequent use of the water as waste water in the building, for bodies of water in the design of open areas, or for infiltration and addition to ground water.

Plantings in planters must be provided with **insulation**. A comparison of these with non-insulated planters has shown that insulation provides a considerable benefit to the growth of climbing plants in every location.

Special roof greening systems are classified as additional insulation and **combining photovoltaic installations** with roof greening results in further synergies for both systems.

The **planning, construction, operation and maintenance** of installations must be carried out by **specialist firms** with the relevant references.

**Care and maintenance recommendations** must be taken into account and described in detail in the planning and tendering phase and care and operating guidelines must be drawn up before a property is handed over to future users.

**Adiabatic exhaust air cooling** has proven to be an extremely effective alternative to conventional air conditioning. Evaporative cooling of 680 kWh is produced from the evaporation of one cubic metre of water. The evaporation of water in the exhaust air and the use of a plate heat exchanger cool incoming air by up to 10 degrees compared with outside air. Completely separating incoming and outgoing air avoids hygienic risks and does not increase humidity inside the building. The use of rainwater instead of drinking water also provides additional considerable savings, because there is no need for softening or desalination and no effluent is produced.

In order to reduce the effect of urban heat islands, **cooling via water evaporation** must be more frequently considered while developing urban spaces in future.



Measuring sensors on the roof of the Institute of Physics building





## Decentralised rainwater management

The management of water from precipitation is a major step towards a sustainable use of resources and a vital prerequisite in complying with the standards of the Federal Water Act (Wasserhaushaltsgesetz) and Water Framework Directive.

The principle of diverting precipitation into sewage systems (combined and separate sewage systems), introduced over 100 years ago, has had a considerable negative impact on water quality and the microclimate. For this reason, a paradigm shift in urban development and water management is now necessary, one that takes the natural water cycle of precipitation, evaporation and condensation into account<sup>5</sup>.

§1 of the Federal Water Act (Wasserhaushaltsgesetz – WHG) defines bodies of water as “an integral part of the natural environment and as a habitat for animals and plants, waters must be protected. They shall be managed in such a way that they serve the public interest and that avoidable impacts to their ecological functions and to the terrestrial ecosystems and wetlands shall not occur and hence that overall sustainable development is ensured. ...

Everyone shall be required to exercise all due caution under the circumstances in order to prevent pollution of the water or any other detrimental change in its properties in order to ensure that water is used economically as is required in the interests of natural water resources in order to preserve the vitality of natural water resources and to prevent the increase and acceleration of water run-off.” [Act on the regulation of matters pertaining to water – Federal Water Act (WHG-Wasserhaushaltsgesetz of 19.08.2002 ... )].

The introduction or discharge of substances into surface waters and groundwater must also be avoided where this may “cause permanent or considerable harmful changes to the physical, chemical or biological properties of the water ... Waste water shall be disposed of in such a manner that the public interest is not affected. The disposal of domestic waste water in decentralised installations may also be in the public interest.” (§3 and §18 of the WHG).

Directive 2000/60/EC of the European Parliament and the Council of the 23rd of October 2000 established a framework for community action in the field of water policy – the EC Water Framework Directive (EC WFD) is a framework for the future protection of waters in the EU and accession countries. It represents a general European legal framework for the protection of all bodies of water (surface water and groundwater). The application and implementation of the EC WFD is regulated at various levels.

“Berlin’s main water management goal is the permanent securing of drinking water quality through the recovery of water from the city’s urban area. To achieve this, groundwater quality must be maintained and surface water purity improved ... All public water supply funding guidelines must be applied in a balanced and coordinated manner, taking into account their compatibility with housing and the protection of nature, the environment and the economy ...

The goal of extensively reducing the input of materials from the sewage network into Berlin’s waters shall also be pursued”.<sup>11</sup>

Rainwater management concepts must be developed and evaluated in accordance with local conditions. Precipitation water should be retained where it falls as far as possible and be evaporated, used, and/or infiltrated through the active soil zone. In addition to using rainwater as process water, other environmentally friendly alternative forms of rainwater management, such as infiltrating precipitation water runoff from roofs and reinforced surfaces as well as building greening options should be examined [Rundschreiben SenStadt VI C No. 1/2003].

The operation and management of systems must be established in advance and must be contractually regulated if it cannot be performed by appropriately trained in-house staff.

Decentralised rainwater management is granted central importance, particularly in discussions on climate change. The evaporation of natural precipitation is one of the most important global energy components<sup>9</sup>. An average of 75% of precipitation water evaporates from the Earth’s land areas. The lack of evaporation in urban areas is one of the main causes of ‘urban heat islands’. In terms of interventions in the ecosystem from a water management point of view, the evaporation of water from precipitation is the highest priority.



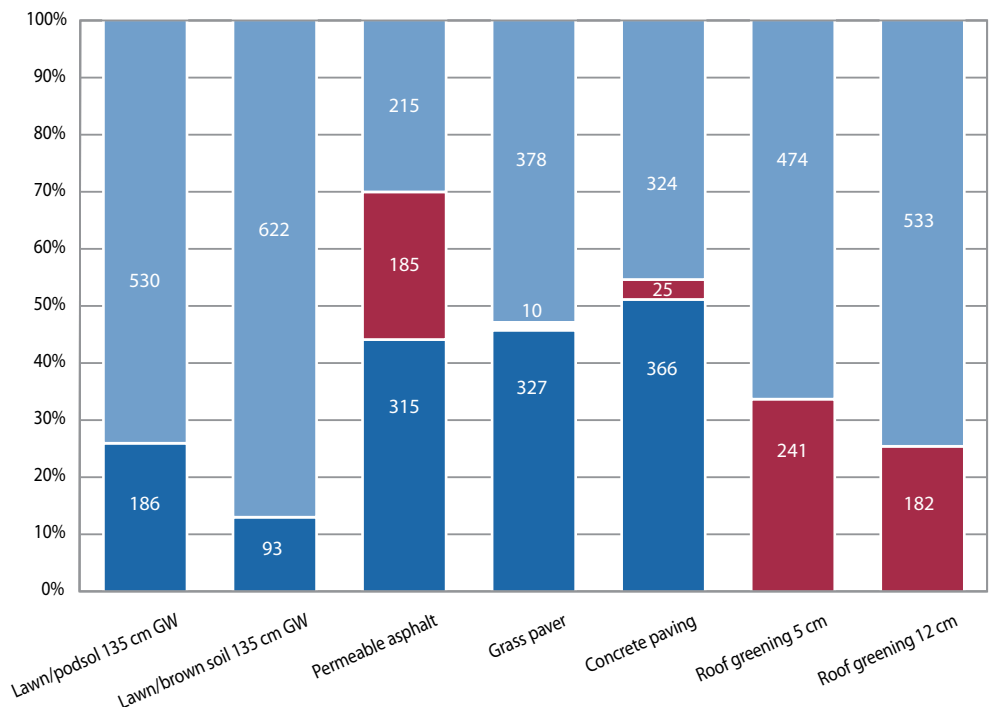
In the catchment area of the Spree and Havel rivers in the Berlin/Brandenburg area, 80% of precipitation evaporates, with only 20% going into ground water and into runoff. In the diagram below, the first two columns represent the annual balance of a lawn area with various soil types and a simulated ground water level of 1.35 m. Of 715 mm of precipitation, 85 to 90% evaporates annually on average, with 10 to 15% going to form new ground water. Urban areas are characterised by completely sealed surfaces such as streets and buildings, but also by partly permeable areas with little or no vegetation. These surfaces have a rate of new groundwater formation that is three to four times higher than with naturally overgrown forested or agricultural land, so they over-compensate for the lack of infiltration from completely sealed surfaces. The diagram below shows three different partly permeable surfaces in terms of their water balance.

Research has shown that infiltration rates in cities are not fundamentally reduced. The missing component in the water cycle is evaporation. If sealed surfaces are to be balanced or compensated for, the environmental priority must be the evaporation of precipitation water. Roof greenings with 5 to 12 cm of growing media evaporate 65 to 75% of annual precipitation (see diagram below). Greened roofs offer considerable potential for balancing the effects of sealed surfaces, with about 25 to 35% of precipitation from them going into runoff, mainly in winter. Used in combination with infiltration installations, this can result in an almost balanced water supply.

**Water balance of variously-used surfaces in millimetres**  
01.01.2001 – 31.12.2004 TU Wilmersdorf, Berlin

Water balance of variously-used surfaces as an annual average total in millimetres; 01.01.2001–31.12.2004 Lysimeter station compared with extensively greened roofs at the TU Berlin in Wilmersdorf

- Evaporation
- (surface) Runoff
- Groundwater regeneration
- GW ground water level





Lysimeter station at the TU Berlin in Wilmersdorf, Berlin, measuring of precipitation, infiltration and evaporation, lawn on podsol and brown earth soil types, simulated ground water levels of 1.35 and 2.10 m (s. Fig. S. 12)



Lysimeter station – scales from below



Lysimeter station at the same site for measuring the water balance of partly sealed surface reinforcements, incl. permeable asphalt, grass pavers, pre-stressed concrete pavers (s. Fig. p. 12)



Measurement of evaporation and runoff from different types of extensively greened roofs (5 cm and 12 cm of growing media, s. Fig. p. 12)



Rainwater management at the new building of the Technical Vocational College (Oberstufenzentrum Bautechnik II/Holztechnikconstruction) in Pankow, Berlin

The productivity and functional capability of ecosystems must be secured in the long term so as to protect, care for and develop nature and landscapes. "The protection and improvement of the climate, including the local climate, should be worked towards through nature protection and landscape maintenance measures" [§1, §2 Federal Nature Conservation Act (Bundesnaturschutzgesetz)]. This also means that the various rainwater management options must be taken into account with the following priorities:

### Evaporation

The impairment of the natural water cycle through the sealing of surfaces and construction results mainly in a reduction in evaporation. Compared with natural and cultivated landscapes, urban areas primarily lack vegetation. Building and courtyard greening measures can compensate for or balance this intervention in the ecosystem. Artificial bodies of water and using waste water for cooling buildings and watering can also contribute to compensating for the lack of evaporation.

### Usage

Rainwater usage is regulated in DIN 1989-1 on "Rainwater harvesting systems – Part 1: Planning, installation, operation and maintenance"<sup>30</sup>. It applies to domestic applications (watering, cleaning, toilet flushing and laundry) and commercial and industrial uses (e.g. cooling, washing and cleaning systems). The data sheet on "Innovative water concepts – service water utilisation in buildings"<sup>1</sup>, which documents details on planning, constructing, operating and maintaining installations, should also serve as a reference.

### Infiltration

Infiltration installations are classified into the two different kinds of infiltration, namely through vegetated soil zones (trench, pond and surface infiltration) and through pipe, trough and pit infiltration directly into the subsoil. Measurements and definitions can be found in the DWA (German Association for Water, Wastewater and Waste) advisory leaflet A 138, "Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water"<sup>2</sup> and DWA data brochure M 153 "Recommended Actions for Dealing with Stormwater"<sup>3</sup>. Infiltration of precipitation water that is not dangerously contaminated in the state of Berlin is regulated in the Precipitate Water Exemption Ordinance (Niederschlagswasserfreistellungsverordnung)<sup>4</sup>.

The networking and the integrated approach of various rainwater management measures into the decentralised retention of precipitation water must be incorporated into the development of an overall ecological concept that includes unsealing and greening surfaces to promote evaporation, building greening (extensive and intensive roof greening, facade greening), waste water usage, and various infiltration options.

Informing and coordinating with building clients and users on planned measures, the limiting of sealed surfaces as well as measures to unseal surfaces are all fundamental planning prerequisites. In evaluating profitability, the consideration of investment and operating costs, bearing in mind current fees (e.g. the rainwater fee), and a non-monetary assessment of measures, such as the effects on ground water, surface water and the building, must be taken into account. Non-monetary project goals for further economic feasibility studies must be defined in the first phase of project planning or during the competition phase. The various project goals must be weighted and this weighting must be justified and documented accordingly.



Potsdamer Platz – an urban body of water. In case of torrential rains, this expanse of water can be dammed up to 30 cm above the minimum water table.



**Non-monetary project goals:**

- Retention of rainwater on the property
- Improving the climate through evaporation
- Conservative handling of water resources
- Soil conservation/reducing land consumption
- Increasing urban biodiversity
- Retention of contaminants and of water quality
- Social sustainability
- Visualisation, pedagogic sustainability

Managing rainwater and recirculating it in the natural water cycle is of central importance in climate protection. Only the proportion of rainwater that is recirculated through evaporation creates precipitation. This so-called 'small water cycle' on the land's surface makes up the larger proportion of local precipitation. Precipitation evaporating from the world's oceans and transported to land makes up only a small proportion of local precipitation on average. The greater proportion results from previously evaporated moisture on land<sup>5</sup>.

Increasing urbanisation and the accompanying reduction in vegetation and natural soils reduces not only local evaporation, but also the precipitation from this water deficit regionally and nationwide in consequence. This results in a "chain reaction" of reduced precipitation, which in turn is not available for evaporation (see diagram below). These changes to the natural small water cycle lead to an increase in temperatures locally and regionally. About 1.15 million m<sup>2</sup> are currently being "urbanised" daily across Germany<sup>43</sup>. The resulting heat and thermal radiation cause the phenomenon of urban heat islands and influence global warming.

The diagram below provides an insight into the connection between the small and large water cycles. The small water cycle of precipitation and evaporation is being increasingly reduced by urbanisation and deforestation. About 350 km<sup>2</sup> of forest are being lost daily worldwide<sup>45</sup>. The chain reaction resulting from this reduction in the small water cycle impacts varying locations differently: in Europe precipitation is reduced three to four fold, in the Amazon there is an eight-fold reduction, so for every cubic metre of water less that evaporates there due to deforestation, precipitation in the catchment area is reduced by 8m<sup>3</sup>.

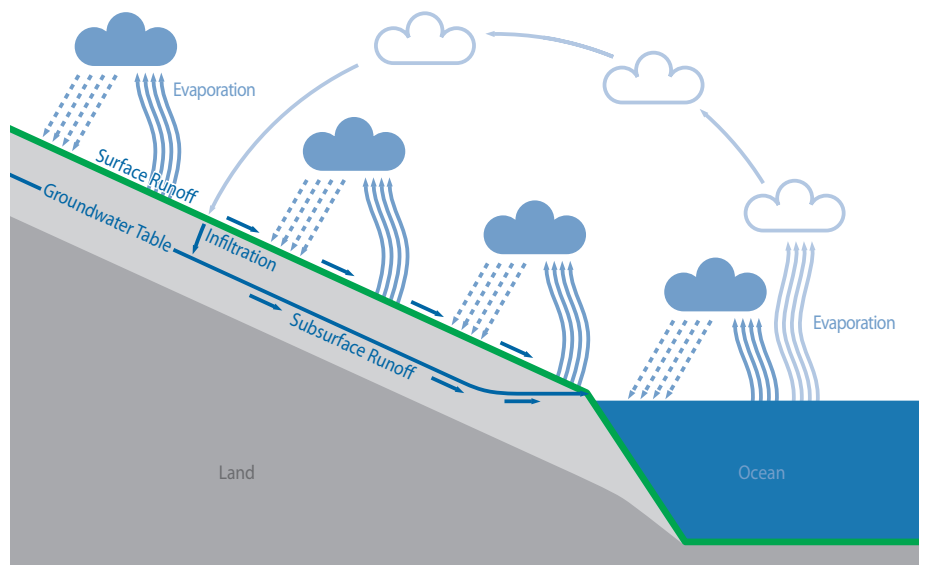


Urban areas (above) in contrast to natural landscape (below) change the natural distribution of water and the climate.

**Changes to the small water cycle**

Reduction of evaporation on land leads to a decrease in precipitation

Changes to the small water cycle, reduction of evaporation on land leads to a decrease in precipitation<sup>5</sup>



Sealed surfaces like roofs and streets modify the microclimate by altering the radiation and energy balance. One consequence is the increasing of temperatures in buildings' immediate surroundings, an uncomfortable indoor climate and an increase in the energy required to cool buildings. One solution is to create evaporative cooling by greening buildings.

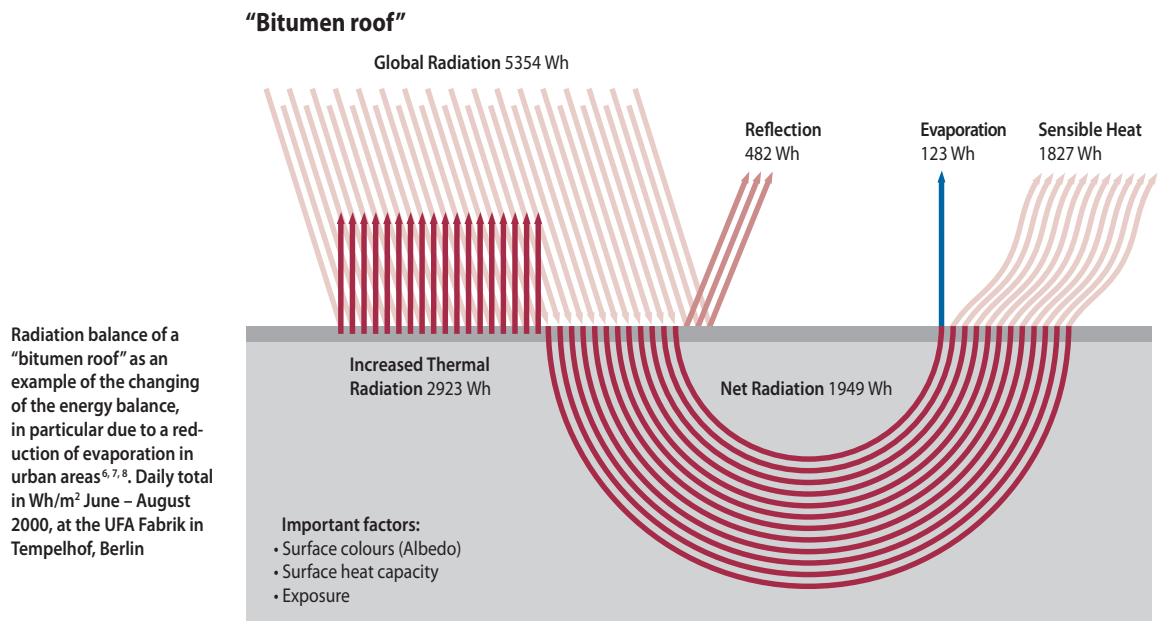
Ungreened roofs convert about 95% of the radiation balance into heat. The proportion of long-wave thermal radiation from the higher surface temperatures of ungreened surfaces is also much greater (see diagram, below left). In contrast, extensively greened roofs transform 58% of the radiation balance into water evaporation in the summer months (see figure, below right). Measurements made on two neighbouring roofs in Berlin were supplemented by measurements of green facades made during monitoring at the Institute for Physics. Greened facades are closely

related to a building's energy balance, especially due to shading and evaporative cooling in areas around windows. This results in many goals overlapping – saving energy, improving the microclimate and protecting water resources.

Given this effect and the problem of global climate change, rainwater management measures must be weighted using the priorities shown in Table 1. Unsealing surfaces and developing vegetation has highest priority, and infiltration directly in the subsoil through pits and trenches has lowest priority. To prevent nutrients and contaminants being introduced into ground water, the qualitative aspects of water protection as shown in Table 1 must also be taken into account. Rainwater usage is given a higher priority here than rainwater infiltration. The goal of management measures is to completely dispense with the discharge of rainwater through the sewage system. Depending on local conditions, various rainwater management measures should be combined.

Should connection to the sewage network be required, designers of individual rainwater management measures must determine whether the water will be discharged into a storm water sewer or go into a combined sewage system. If the former is the case, the quality of rainwater runoff is important, because it usually flows directly into surface water. In the case of discharge into a combined sewage system, however, measures must be optimised in order to achieve the greatest temporary retention of torrential rain so as to avoid overflow in the drainage capability.

### Energy balance in a mean daily comparison of a non-green and a green roof



Decentralised rainwater management in Germany has hitherto focused on infiltration. Despite the considerable advantages of decentralised infiltration compared with conventional discharge, this approach does not adequately take into account the natural water cycle. The problem of urban areas lies not in reduced infiltration rates, but in a lack of evaporation<sup>44</sup> due to the displacement of vegetation and a lack of open soil with vegetation cover. To achieve a balance or replace sealed surfaces, the environmental priority must be on various measures that support the natural water cycle of precipitation, evaporation and condensation, which means developing vegetation structures, establishing greening, creating open bodies of water and using rainwater to air-condition buildings through evaporative cooling (Table 1).

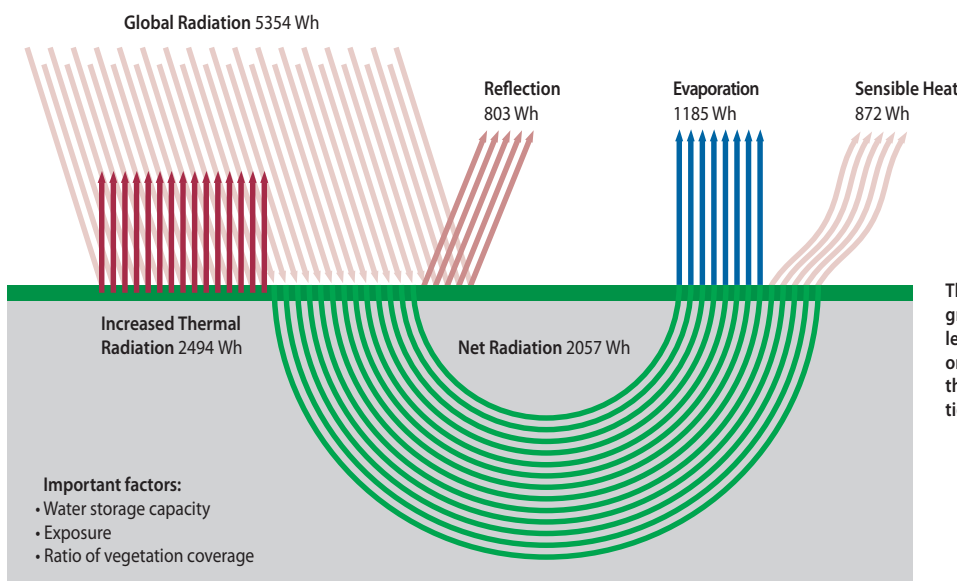
Priority	Evaluation	Measures
1	●●● 1.0	Unsealing sealed surfaces (parks, gardens, courtyard greening) roadside trees
2	●●○ 0.78	Facade and roof greening
3	●● 0.67	Artificial urban bodies of water, open water surfaces
4	●○○ 0.56	Using rainwater for cooling buildings and watering
5	●○ 0.44	Trench infiltration in connection with vegetation structures (trees, bushes), grass pavers
6	● 0.33	Using rainwater for toilet flushing and other waste water usages
7	○○ 0.22	Trench infiltration, partly permeable surface reinforcements
8	○ 0.11	Pit and trough infiltration

Tab. 1  
List of priorities for decentralised rainwater management measures while taking into account the natural water cycle of precipitation, evaporation and the formation of new ground water<sup>9</sup>



Trench infiltration without vegetation (Priority 7)

### Extensive roof greening



The radiation balance of a greened roof as an example of rainwater evaporation positively influencing the urban climate. Reduction in the proportion of heat by about 70% and of thermal radiation<sup>6,7,8</sup> Daily total in Wh/m<sup>2</sup> June – August 2000, in the UFA Fabrik in Tempelhof, Berlin

Several decentralised rainwater management projects focusing on evaporation have been carried out in Berlin in cooperation with the TU Berlin's "Watergy" research group. Each project combines several measures from Table 1 to increase overall efficiency. These projects include those on the SEB site (formerly DaimlerChrysler) on Potsdamer Platz, at the UFA Fabrik in Tempelhof, at the Institute for Physics building in Adlershof and the Watergy building at the TU Berlin in Dahlem. "Watergy" investigated the extremely high heat transfer in the evaporation/condensation and absorption process. With 680 kWh/m<sup>3</sup> of water (at 30°C), no other element latently transfers as much energy as does the medium of water. This effect is not only of global importance (the evaporation of water is the most important energy component, even more important than long-wave radiation and the "greenhouse effect", often mentioned in relation to it). Latent heat transfer in the evaporation/absorption process can also be used inside

buildings or greenhouses for the seasonal storage of summer heat for winter or for cooling buildings.

The applications of waste water are many and varied, e. g. for toilet flushing, for air-conditioning buildings, in washing and cleaning systems and in systems for watering green spaces. The prerequisites for the acceptance of waste water use and for the secure operation of installations in the long term are professional planning, sizing and construction, regular maintenance, a responsible operator, and compliance with relevant regulations. A new installation technology has been developed in recent years to use waste water in domestic, commercial and industrial areas. Furthermore, planning, construction, operation and maintenance criteria are available as decision-making aids in the "Innovative water concepts – service water utilisation in buildings" brochure<sup>1</sup>.

In constructing new public buildings or converting existing ones and in publicly funded construction projects for applications in which drinking water quality is not imperative, the possibilities of using waste water and installing a second distribution network must be investigated. [Rundschreiben SenStadt VIC No. 1/2003].



Roof greening, rainwater usage und urban bodies of water at Potsdamer Platz Berlin (Priorities 2, 6 and 3 in combination)



The dimensions of decentralised rainwater management measures must be specified in planning through long-term simulation based on the ATV DVWK advisory leaflet 138. A combination of various decentralised rainwater management measures can be measured and evaluated for this purpose and there are various software programmes available for creating long-term simulations. Precipitation data, which can be obtained for specific regions from the German National Meteorological Service (Deutscher Wetterdienst – DWD), should be used as mass input data. For reasons of cost, it may be reasonable to use simulated precipitation data, which take into account specific local rainfall yield factors and daily and annual values.

The results of these calculations provide information on the functional reliability of rainwater management systems in torrential rains and on the proportion of useable rainwater in systems using waste water over the calculation period. These two qualities are independent from each other but their goals are partly

complementary. From the point of view of using as much rainwater as possible, rainwater volumes should be stored in cisterns for as long as possible. In contrast, for managing torrential rains cisterns should be kept as empty as possible.

The combination of roof greening and other decentralised rainwater management measures such as waste water use and/or infiltration has so far not yet been satisfactorily implemented in software programmes. There is a lack of input data incorporating practical measurements of evaporation in parallel to comprehensive precipitation data. Roof greening significantly influences the useful proportion of precipitation, as does the temporary retention of torrential rain, which greatly depends on the saturation level of the growing media<sup>10</sup>. The proportion of evaporation on greened roofs is an annual mean of about 70% and is thus usually underestimated (see table on page 12).



Brochure “Innovative water concepts – service water utilisation in buildings”



The view from the roof of the Institute for Physics in Berlin Adlershof to the ponds in the inner courtyard, which also serve for evaporation and as a filtration system in case of torrential rain.

Sensors for measuring the radiation balance of a greened facade compared with an ungreened facade (below)





## Building greening (roof/facade)

In individual cases building greening can be designated as binding under the terms of §9 (1) No. 25 of the **Federal Building Code** (Baugesetzbuch – BauGB) or as a compensation measure under §31 (2) of the Code. §1 (5) of the Code states that land-use plans should safeguard “sustainable urban development that reconciles the social, economic and environmental protection requirements of current and future generations ...”.

Greened roofs are permissible under §32 of the Berlin **Building Ordinance**, where it states that “if there is no fear of fire starting outside due to flying sparks or radiant heat or if measures are taken to prevent this”.

“**Special ecological requirements**” were defined as early as 1990 in Berlin’s publicly funded social housing construction guidelines by the **Wissenschafts Forum Berlin 1990**, and were to be implemented in housing planning in order to save resources and achieve environmentally friendly construction. In doing so, Berlin set standards that became a national benchmark for housing construction and for modernisation and maintenance measures as part of urban renewal. Vegetation concepts for facade and roof greening, consultation on professional planning and implementation and first instructions for use of the ecological building measures and installations could all receive funding and support.

A **courtyard greening programme** was started in Berlin (West) in 1983. Its main goal was to reduce the deficit in green spaces in inner-urban areas by funding courtyard greening, facade greening and extensive roof greening measures. In former East Berlin too, there was a courtyard greening programme in the 1980s.

From 1990, the programme developed in 1983 was implemented for the whole of Berlin’s inner city and professional advice was obtained on maintaining and caring for projects.

During the programme period, from 1983 until end of 1995, 1,643 projects were approved and 740,000 m<sup>2</sup> of courtyard and facade and 65,000 m<sup>2</sup> of roof surfaces were greened<sup>12,13,15</sup>.

“**Ecological Criteria for Building Projects/ Competitions**” were defined for Berlin for the first time and then updated in 2001. These state that “particularly in residential inner-city areas of high density, it is necessary to show adequate measures of compensation such as open spaces planted with greenery and the greening of facades and roofs. Roof greening should preferably occur in the form of extensive roofs and the substratum should be at least 10 cm thick to ensure effective water retention”<sup>14</sup>.

In the inner city, the “**Biotope Area Factor**” (BAF) (Biotopflächenfaktor – BFF) is a special form for securing “green qualities”, balancing deficits in terms of open space, and reducing environmental pollutants. The BAF stipulates the proportion of a property that is to be planted and set aside for ecosystem functions. The BAF may be designated as binding in a landscape plan for selected, similarly structured urban areas. ([www.stadtentwicklung.berlin.de/Natur+Grün/Landschaftsplanung](http://www.stadtentwicklung.berlin.de/Natur+Grün/Landschaftsplanung)).



The Biotope Area Factor has proven valuable as an ecological value in landscape planning that specifies the proportion of area affecting the natural environment in relation to property size.

One goal in the early phase of project planning is to develop and evaluate rainwater management concepts in accordance with local conditions.

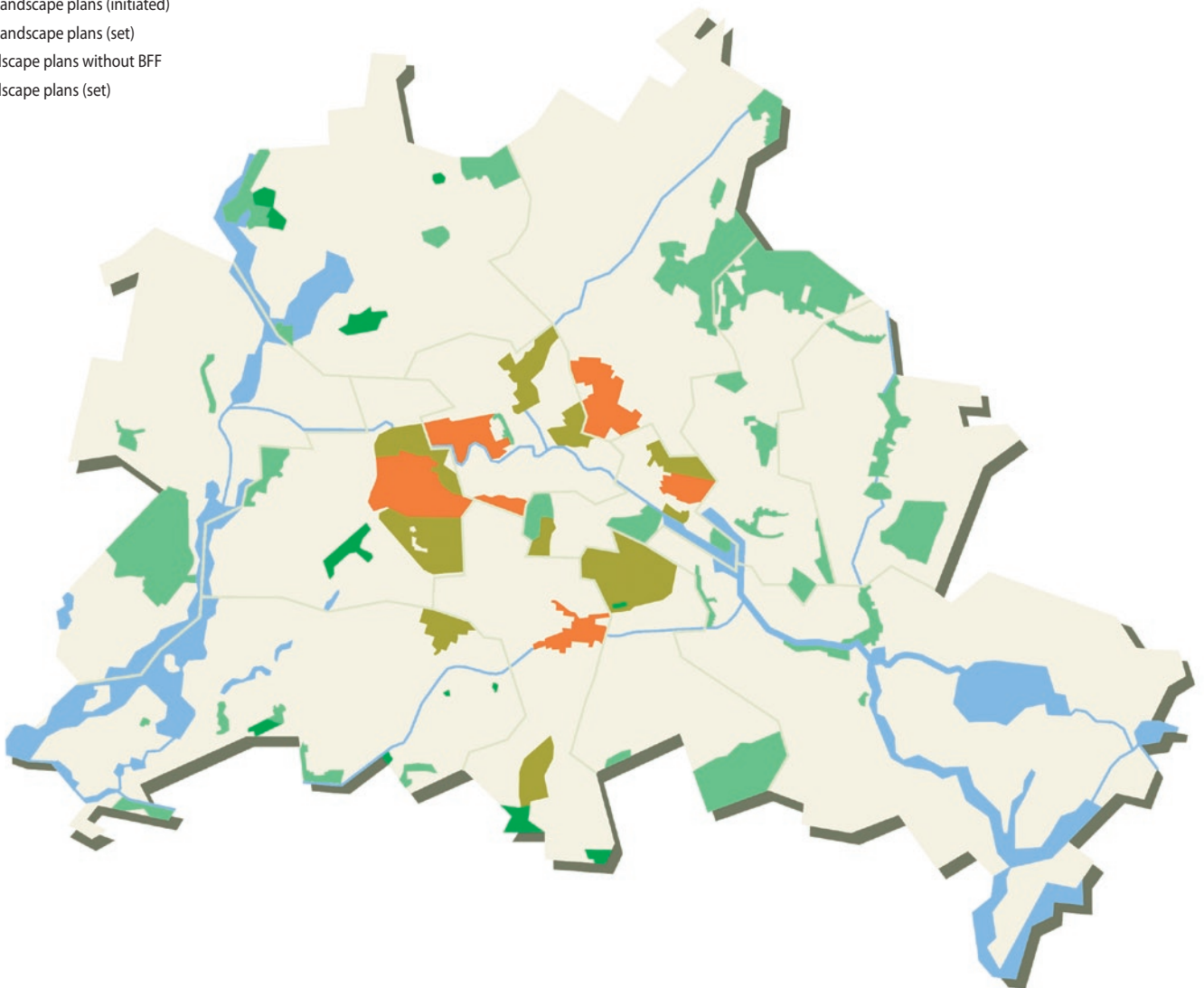
In Berlin a **rainwater fee** (Niederschlagswasserentgelt) is charged and is currently €1.84/m<sup>2</sup>/year (per m<sup>2</sup> of surface from which water flows into the sewage system per year).

The rainwater fee is assessed according to the sealed surface from which the precipitation water flows into the public waste water system. In identifying built and reinforced surfaces, it is taken into account that surfaces that have little or no influence on the runoff of precipitation water are not or are only partly included in calculations to assess the rainwater discharge fee.

All concreted, asphalted, paved or other surfaces covered with materials impervious to water are classified as sealed surfaces.

#### Berlin's BFF landscape plans

- BFF landscape plans (initiated)
- BFF landscape plans (set)
- Landscape plans without BFF
- Landscape plans (set)

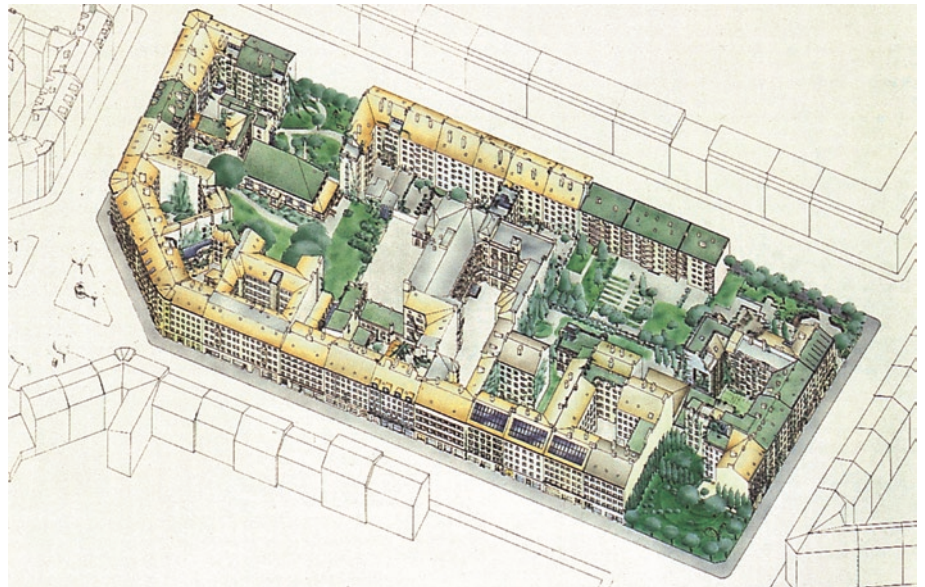




50% of the surface of a green roof is included in the calculation to assess the fee ([www.bwb.de](http://www.bwb.de)).

The first model project to investigate the topics of rainwater management and building greening was part of the **Experimental Housing and Urban Development (EXWOST)** programme, in the field of ecology and environmental construction research. This model project was supported with federal and state funds and scientifically monitored and evaluated.

Projects such as Block 103, Block 6 and the ecological houses in Corneliusstrasse are still regarded as urban ecology “pioneers”<sup>15</sup>.



Block 103 in Berlin Kreuzberg (above)

Ecological House in Tiergarten, Berlin (left)



Block 6 after optimisation/redesign 2006/2007





## Green roofs

Green roofs offer a whole range of advantages, which can be divided into private benefits for owners and residents, and those that extend to the wider world.

Benefits include an enhanced overall visual quality and improved insulation and rainfall retention, which usually result in a reduced rainwater fee. These advantages become noticeable in the annual ancillary costs bill for the building. Advantages for the wider world include the reduction of urban heat islands, reduced rainwater runoff and a decrease in the burden on the sewage system. The effects on "urban nature" are another major aspect here. Green roofs provide habitats for specialised types of plants and animals. This aspect of "increasing urban biodiversity" is vital but cannot be expressed in monetary terms<sup>16</sup>.

A 'greener' city is regarded positively by most inhabitants, but the financial value of this effect is hard to estimate. However, for a relatively small additional sum, greening results in a wide range of various benefits.

The construction of roof gardens is a special case and is not possible for all buildings. The higher construction costs involved in creating them can be directly added to rent at a rate of a quarter of the roof garden's surface. A roof terrace or roof garden significantly increases the value of the property beneath it.

### Planning

A wide range of green roofs has been created in Germany and increasingly built across the country since about 1970. In recent years about 10 million m<sup>2</sup> of new green roofs have been created annually. Most of these, about 80%, are extensive roof greenings. The remaining 20% are roof gardens or intensive roof greenings. The intensive forms are gardens created on top of buildings with plantings typical of gardens in growing media between 0.5 and 1.0 m thick. Roof gardens are maintained by gardeners while plants also found in ground-level gardens are used. One difference, however, is that mainly low and slow-growing plants are preferred so that they present as even a surface as possible over the long term.

In contrast, extensive green roofs usually have to manage with about 0.1 m of substratum. Extensive means "low maintenance" but extending over a large area on buildings. The choice of plants is limited to vegetation that can survive dry periods, but the vegetation should also be able to accept intermittent soakings. These site conditions restrict the choices available, but on the other hand they provide extreme habitats for a series of special types of plants which would not have much chance at ground level.

The diagrams below illustrate the main different types of green roofs. From relatively light-weight but robust constructions of about 40 kg/m<sup>2</sup>, through the typical extensive roof with a growing media around 0.1 m thick (which, with an appropriate sub-structure, can also be created as an artificially designed natural landscape), up to intensive green roofs, there is a wide range of design and technical possibilities. Depending on the structural conditions, almost every kind of landscape can be reproduced on a roof. "Publicly accessible roofs" are a special form. These are load-bearing roofs over underground garages or other structures where a storage area with potential for retaining rainwater can be planned as a drainage layer.

The structural requirements range from 50 to 170 kg for extensive greening. These values have no upper limit for roof gardens, although 200 to 300 kg/m<sup>2</sup> is an average value. Precipitation water stored in the growing media is a major factor in the weight of green roofs.

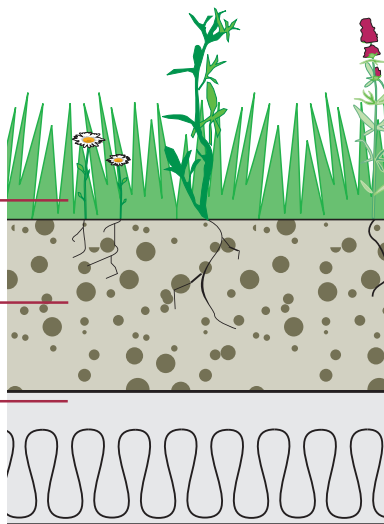
A root penetration-proof layer must be laid over the roof construction. One drainage per 200 to 300 m<sup>2</sup> should be planned. A watering system is necessary for intensive greening/roof gardens. A watering system is also helpful for extensive green roofs if visible roof surfaces are to be watered either for visual reasons or to improve the microclimate in the summer months.



Hydroseeding  
(Alternative:  
Dry seeding)

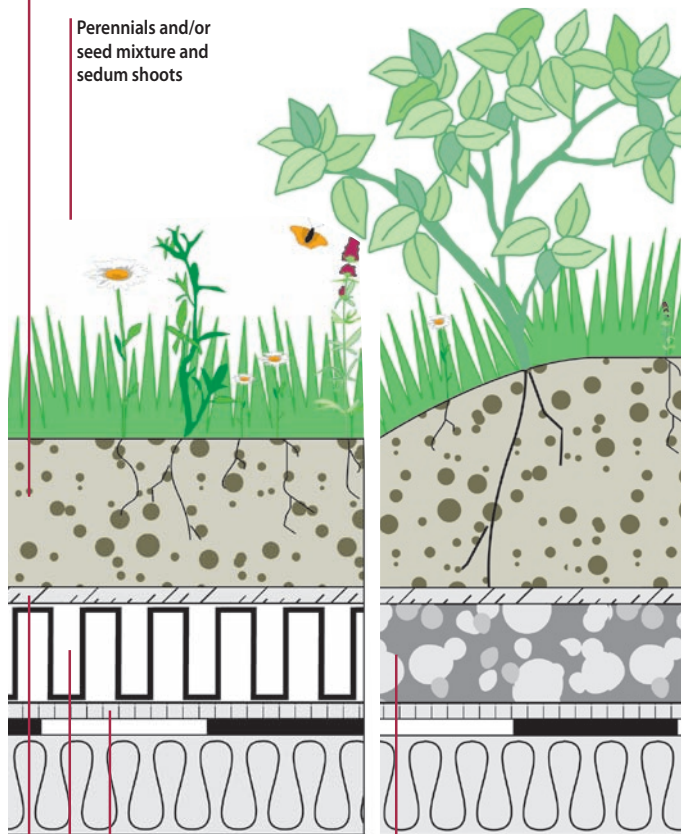
Extensive single-  
layer substratum

Protective and  
storage fleece



Extensive substratum  
On extensive multi-layer growing media  
compatible substratum with high  
water-storage capacity and good air  
pore volume. Ridging as required.

Perennials and/or  
seed mixture and  
sedum shoots



Drainage-layer bulk material

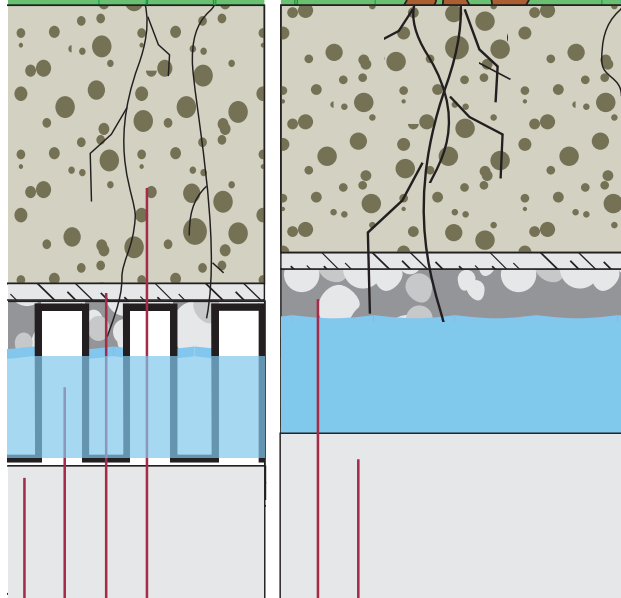
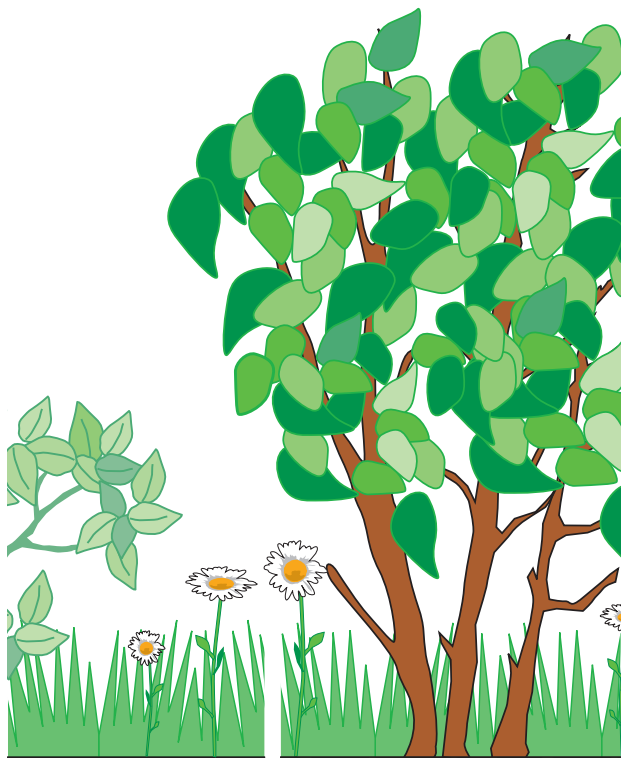
Protective and storage fleece

Solids drainage

Filter fleece

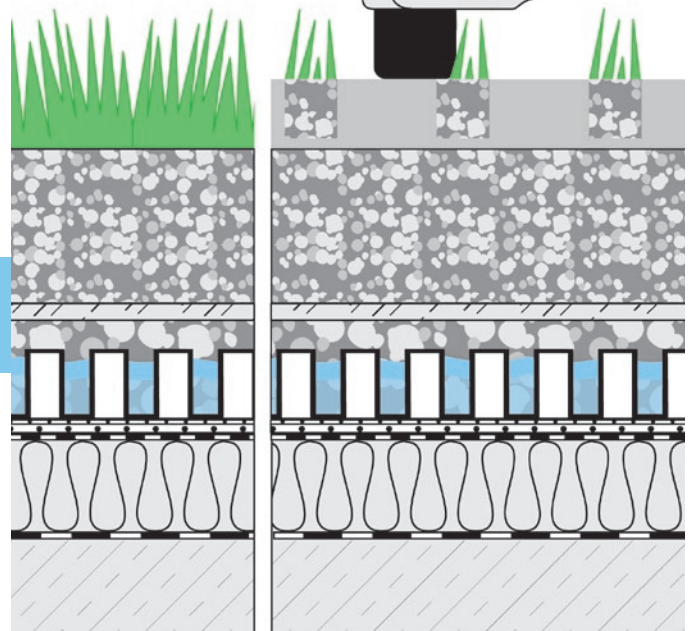
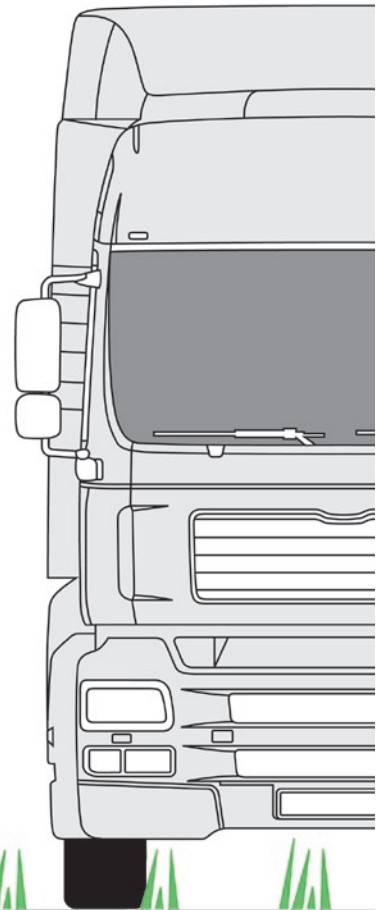
Variations of an extensive  
single-layer greening<sup>17</sup>

The "flower meadows";  
different drainages can be  
used with various depths  
of growing media<sup>17</sup>.



Root-protection channel as accumulation trough  
 Drainage-layer bulk material  
 Intensive substratum  
 Alternative: Lawn substratum  
 Filter fleece  
 Solids drainage  
 Protective and storage fleece

Depending on the depth of the growing media, a typical garden or "landscape-like" design is possible on roofs if the structure is sufficient to hold it<sup>17</sup>.



HDPE foil  
 Solids drainage  
 Gravel-turf base course  
 Filter fleece  
 Gravel-turf substratum

The highest assumed loads on publicly accessible building roofs open up almost unlimited design possibilities. Drainage elements and gravelled lawn

layers are storage media that are relevant for residential water management, which must be included in a property-based calculation of water runoff<sup>17</sup>.

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**Roof pitch**

Green roofs are normally flat roofs, but these can include slight inclines of a few percent towards the drainage.

Extensive green roofs with 20 to 30% inclines are no problem. Guard rails must be built on steeper roofs. Complete coverage with vegetation should also always be planned to coincide with the beginning of a project.

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**Fire protection**

Green roofs are classified as “rigid roofing” due to their low fire load. Research into this was carried out with defined fire loads in early 1980. In future discussions on reducing fire insurance costs, this issue can again be taken up with the consideration that watered roofs and/or roof plantings of succulents may be regarded as especially “fire resistant”.

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**Choosing the growing media**

The growing media of intensive green roofs are like those of gardens: rich in humus, loose and usually well-watered.

Extensive growing media are coarsely porous, poor in humus, and based on volcanic raw materials or recycled products. Extensive green roofs are not usually artificially watered. The exact demands of roof growing media are regulated in the FLL (2008), which is also regarded as a benchmark outside Germany<sup>18</sup>.

In networking various forms of rainwater management, particular attention must be paid to the selection/composition of growing media and building materials. Growing media that are low in humus or humus-free must be used to avoid mineralising roof runoff and causing turbidity.

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**Protection against falling**

Extensive green roofs must be inspected from time to time, so sufficient numbers of special belay points must be installed on roofs so that this work can be carried out safely. Stable guard rails should be included in planning calculations. Building users like to frequent extensive green roofs, although this is, in fact, prohibited. It may be difficult to subsequently attach a guard rail. This is usually just a small additional expenditure in the construction phase, but one that can significantly improve safety for years.

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**Wind suction**

Roofs are very exposed to wind and fine earth can easily blow off, especially if a substratum is not yet extensively laid. Building elements can be raised at the edges and technical solutions, such as a stone or brick border on the roof perimeter, can counteract updrafts.





Differentiated planting areas as an example of successful intensive roof greening at Leipziger Platz

### Building cooling and insulation

Green roofs are much cooler than ungreened roofs in the midday hours of summer. This is illustrated in the following diagram of a green roof at the UFA Fabrik in Tempelhof in Berlin, which compares the green roof with a neighbouring "bitumen roof". In this case, the green roof's maximum surface temperature, measured using infrared sensors, is about 30°C; that of the "bitumen roof" is 55°C.

Green roofs do not cool down as much overnight as do conventional "bitumen roofs"; they have a generally balanced temperature amplitude. This effect contributes to making roof cladding durable for longer. In this case, the bitumen surface of a conventional roof has a day-night temperature amplitude of 50 degrees; the sealing of a green roof is only 10 degrees.

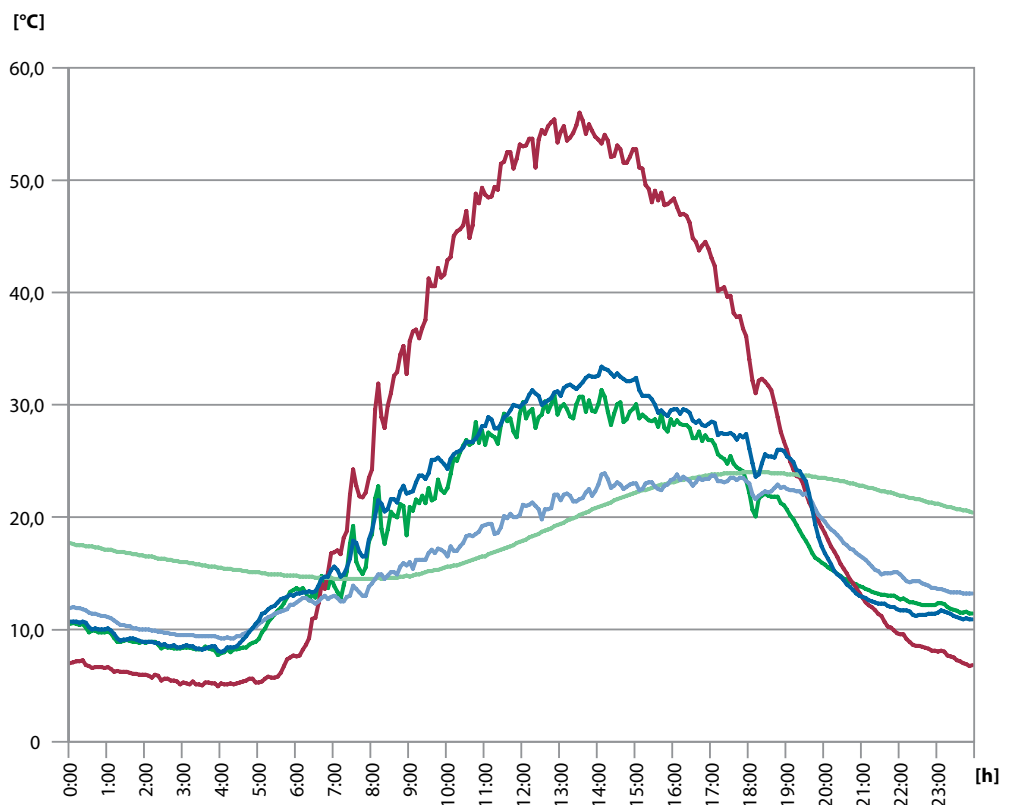
However, temperatures alone are not the only concern in considering the heat and energy effects of green roofs. The different moisture levels of growing media and the variable vegetation upon them result in different heat transition coefficients, so green roofs have so far not been taken into account during heat insulation considerations. The recommendation remains to install heat insulation in the layers under vegetation. For this reason, various manufacturers recommend so-called 'thermo roofs', which use typical materials to make a demonstrable contribution to insulation<sup>19</sup>.

A working group from the University of Applied Sciences Neubrandenburg investigated the heat transition coefficients of a typical extensive green roof substratum, including typical vegetation<sup>20</sup>, and studied the heat transition effects of a year in different climatic situations.

Temperature range on 20.06.2001 at the UFA Fabrik in Tempelhof, Berlin

Surface temperatures on the 20th of June, 2001, measured as infrared temperatures of a greened roof compared with a "bitumen roof" at the UFA Fabrik in Tempelhof. The ungreened roof showed a temperature amplitude of 50 degrees compared with the 20 degrees of the green roof and 10 degrees of the sealing of the green roof.

- "Bitumen roof" surface
- Green roof surface
- Green roof sealing
- Air 1 m above green roof
- Air at green roof surface





There is a positive winter insulating effect of about 2 to 10%. Since about 22% of heat is lost through roofs, this is an extra insulating effect, which, depending on the condition of a building's outer shell, yields further, hitherto unexpected savings, roughly corresponding with an additional layer of one-centimetre thick insulation material.

There is also a summer effect, with significant temperature reductions preventing strong heat input into buildings. In tropical climates, such as Singapore, this cooling effect in summer is the decisive argument for extensive green roofs. The effect reduces the summer heat load of a typical building by 60%<sup>21</sup>. There is a potential future effect here for buildings with high inner heat loads, in particular in calculating air-conditioning systems.

### Green roofs and solar energy installations

Electricity production with solar cells is partly a temperature-dependent variable<sup>22</sup>. The cooling of photovoltaic cells is one variant in the wide range of possibilities of individually adjusting photovoltaic installations at a site. The increase in heat at midday in summer is a side effect of solar radiation and reduces electricity production. If a photovoltaic installation can be cleverly positioned on a green roof, cooling could provide an increased yield, although there is so far no scientific proof that the combination of photovoltaics and greening does increase yields.

Counterbalancing this potential increased yield is the fact that plants will only grow successfully if rainwater is conveyed on a small scale from the modules to the vegetation and if they get sufficient sun. Semi-transparent solar modules would be appropriate here. Photovoltaic modules act as sunshades, so plants under the cells would change from types that prefer sites exposed to full sun to more "standard" species. The number of

species on photovoltaic roofs would increase proportionally with the variability of the sites. Maintenance would also be required to promptly remove plants that grow too high, such as sage bush, so that the modules are not overshadowed.

Combining green roofs and photovoltaic installations offers many possibilities, but they must be well coordinated. There are already various good commercial examples of photovoltaic installations on green roofs<sup>23</sup>. A green roof extending across a flat surface, for example, offers the possibility of anchoring the panels' frames on the roof so that they will be storm-resistant and penetration-free.



Photovoltaic installation on an extensive green roof – a successful synergy

Photovoltaic modules on the green roof of the UFA Fabrik in Tempelhof in Berlin ([www.ufafabrik.de](http://www.ufafabrik.de))



## Building green roofs

For the construction of green roofs, one should observe the relevant regulations in the **FLL's green roof guidelines**<sup>18</sup> as well as the recommendations on planning and building traffic areas on buildings<sup>24</sup> and the related standards stipulated therein.

The **separation** of roof sealing and roof greening is a major point over which potential conflict can arise. An appropriate inspection of the substructure's impermeability must be carried out to prevent disputes in the event that damage occurs. Installing a leak-detection system that can be activated in case of damage may be a reasonable and manageable additional investment in large projects.

During **construction supervision**, extra care must be taken to ensure that the roof's seal is not damaged through carelessness in subsequent work. Roofs are often used by other construction workers to cut materials or as storage. The fragility of the roof sealing is not always clear to all tradespersons and it is often hard to determine who damaged a roof's sealing after the fact.

A green roof consists of a range of layers of materials with very different requirements. Seams that must be bonded or heat-sealed are typical areas where errors can occur, so regular inspection during installation is essential. Corners and edge seals on chimneys, air vents and all forms of projecting building components are potential problem areas.

Delivery notes showing declarations/compositions and representative samples of all delivered **roofing materials** should be retained for subsequent checks. This also applies to insulation material, where the better, usually more expensive materials can often only be distinguished from other products by carefully examining the differences. The same applies to plant growing media and vegetation.

Standards are defined by the FLL, but cannot be assessed through visual inspection. If a standard has been noted in the tender documents, it should be tested using samples.

If, contrary to expectations, plant growth on the **roof substratum** is inadequate, it may be due either to the wrong substratum, the wrong or too weak plants, or incorrect initial care, such as insufficient watering during the first year. Many roof-sealing materials contain pesticides; thus, the exact specifications made in tendering and what was in fact delivered should be carefully checked.

The laying of growing media and planting should be supervised with particular care. An appropriate quality of individual plants, lawn mats and plant slips is essential for planting. In addition to **good-quality primary materials**, sound initial care carried out over subsequent weeks must also be ensured, which above all means adequate watering during the summer months. Too short a hose is all too often the reason that not all areas of a roof are watered equally or to a sufficient depth.

Loss of plants in the early growth phase may have many causes and must be clearly and comprehensibly explained as part of site supervision. The FLL speaks of "**developmental care**", which should lead to 90% plant coverage within a period of two years. This criterion is easy to check and if this value is not reached, the reasons why must be investigated. Qualified expert staff, who can recognise emerging damage to green roofs early on, should carry out annual inspections of the roof and document the results.



Potsdamer Platz – laying of the growing media



Roof greening as "potential open space"



Intensive roof garden



## Operation and maintenance

Following successful early growth care, a **care and maintenance contract** for subsequent years should be concluded with a specialist firm. The contract must specify in detail the work to be carried out.

Like ground-level gardens, roof gardens must be carefully maintained. Activities range from minimal care such as regular watering, fertilising, pruning, replanting and other work up to time-consuming activities such as plant protection. There are so far no reliable figures on the time and money that this care entails. The FLL's roof greening guidelines<sup>18</sup> speak of four to eight maintenance operations a year. Lawns on intensively greened roof gardens should be mowed from two to twelve times a year.

Contrary to popular opinion, extensive green roofs are not completely maintenance-free and do require a minimum of care. This will depend on the visual requirements of the extensive green roof. Minimum care includes an annual visual inspection. Gardening work should be carried out in two to four maintenance operations, depending on the overall look desired. Removing spontaneously established "problem plants" is one variety of this basic work. These plants should be completely removed as soon as possible, together with their root systems, and include all forms of 'pioneering species', willows and birches as well as maple and cherry seedlings. Among the herbaceous plants, only sweet clover is really known as a problem plant, because it can comprehensively crowd out other vegetation. Among the grasses, wood small-reed can spread very quickly, especially on growing media deeper than 12 cm.

Plant loss and replantings must be assessed during regular maintenance. Some species, such as those requiring large amounts of water or with very aggressive roots, should not be planted on roofs. This includes all fern varieties, which are popular but need special safeguards.

Although for some years it has been thought that extensive green roofs can survive largely unfertilised, fertilising with slow-release agents should be considered in certain regions. Like golf courses, extensive green roofs are designed not for plant mass, but for complete coverage by vegetation, which means regular, light fertilising. Complete plant coverage is also important for the shade provision and evaporation effects expected from green roofs.

If a green roof is combined with other decentralised rainwater management measures, the consequences of **fertilisation** for the water quality of artificial bodies of water, for example, must be clearly established in advance!

Problems such as areas of erosion must be recognised early on during **annual inspections**. The replanting of defective areas, the rectification of erosion and the clearing of safety strips may constitute the main maintenance measures, which, when regularly carried out, take only a little time but ensure the green roof's functionality for years to come.

Green roofs are designed for the long term and should usually have the same 'lifespan' as buildings. They can last longer than the guaranteed warranty periods, as shown by the few still existing 100-year-old green roofs.







## Facade greening

Expertly created and maintained greened facades are not only a delightful sight in inner urban areas while mediating between buildings and open landscape, they also improve the urban climate by increasing evaporation and reducing the intensity of reflection onto neighbouring buildings. They balance out extremes of temperature, especially in areas with high levels of sealed surfaces. Greening can protect facades against adverse weather, functioning as heat insulation in summer and protecting against the cold in winter.

Climbing plants can be specifically used to provide a building with shade and serve as natural sunshades. Planted in front of glass facades, they prevent solar radiation from entering in summer and buildings from overheating. In winter, however, short-wave solar radiation is desired and can save energy used for heating. At this point most plants have shed their leaves. Some evergreen species such as honeysuckle (*Lonicera Henry*) are therefore not suitable for this application.

Evaporative cooling from plants also cools buildings by reducing incoming long-wave radiation. This develops due to high surface temperatures on exterior sunshades, for example. Conventional sunshades reduce incoming short-wave radiation in the building, but transform solar radiation into heat and long-wave radiation. Only water evaporation properly dissipates heat and transports the latent energy into upper layers of the atmosphere.

Exact measurements on the evaporation rates of climbing plants were made at the Institute for Physics, where various species were tested for water demand and potential use to cool buildings. The results on water consumption were astounding. At the beginning of the project it could not have been estimated how high the real evaporation rate of a 20 m climbing plant would be when supplied by a relatively small root zone in a facade greened with plants in planters. Average daily evaporation was in fact 10 to 15 l/m<sup>2</sup> of the planter surface (see diagram, page 36). In this case, the evaporative cooling corresponded to 280 kWh per facade per day.

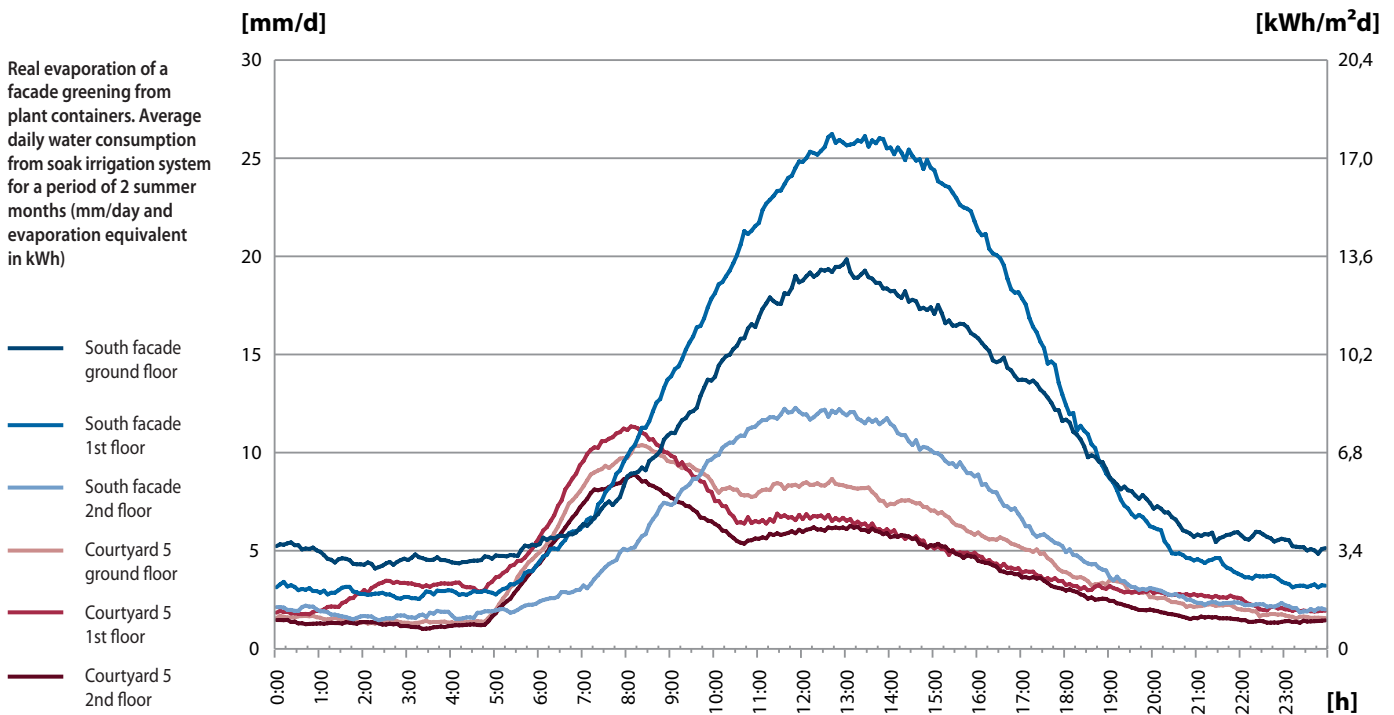
One litre of water consumption produces evaporative cooling of 0.68 kWh, which is equivalent to one millimetre of water evaporating from 1 m<sup>2</sup>. As with green roofs, evaporation takes place outside the building, yet there are advantages for the air conditioning of buildings as compared with conventional sunshades. In summer, heat and long-wave radiation enters a building, whether through "wrong" behaviour by users, such as opening windows despite high outside temperatures, or through heat bridges and conventional panes of glass without solar protective glazing. The advantage of conventional sunshades compared with plantings in front of a glass facade is that they can be controlled according to need on cloudy or sunny days. However, discussions with users at the Institute for Physics have shown that this advantage is secondary compared with the aesthetic qualities of plantings in front of the window. In principle, users were more satisfied with plantings in front of their window than with conventional sunshades.



The costs of watering also become much less of a factor when compared with energy savings. The evaporative cooling, especially on days when cooling is needed, has a much greater value relative to water costs. However, it is difficult to precisely quantify costs and savings compared with conventional sunshades, since measurements were not made within the building envelope.

The following recommendations for planning, building and maintaining facade greenings are based on the results of monitoring by the Institute for Physics at the Humboldt University Berlin campus in Adlershof with the aid of the relevant literature, the FLL guidelines and DIN standards and regulations. They are designed to serve as orientation aids. The literature provides detailed information on plants suitable for the respective sites in particular and on the appropriate climbing supports (see literature list, page 60).

**Average evaporation of facade greening**  
Adlershof Physics building, 15.07 to 14.09.2005





## Planning

In planning green facades it is necessary to coordinate technical and architectural issues with other planners involved in the process as early as possible.

It must first be decided whether, to what extent, and with what goal green facades are to be planned for the building. The possibilities are much better for new than for existing buildings. Facades are a signature of a building that everyone can see and greening them can contribute to their identity and uniqueness. Facade panels greened with moss are the distinctive identifying feature of Japan's 'Mos Burger' chain. The greening of surfaces in buildings in the style of Hundertwasser is also a major element in making those buildings so recognisable. Facade greening installations by Patrick Blanc<sup>25</sup> have also become a trademark that is increasingly in demand all over the world.

It has been a long development from the first wave of greening in the 1980s, which worked mainly with self-clinging climbing plants such as Virginia creeper, up to Patrick Blanc's installations at the Galeries Lafayette department store in Berlin's Friedrichstrasse.

However, this range reveals the potential that greening offers. Whereas the direct greening of courtyards carried out in the 1980s was more or less complete with the purchase of suitable plants, complex wall installations require regular and costly professional maintenance. Although a few years ago the focus was still on the urban ecology aspects of greening, the aspect of inimitable design is now becoming increasingly important. The costs of a green display are relatively high. They are a special form of modern garden art. Because they are not very prevalent, they make only a slight contribution to the cooling of cities in summer, but they do make people aware of the topic of "greenery" on buildings. Surveys in Japan have shown that passers-by view green facades very positively<sup>29</sup>. These visual enhancements of a city reflect positively on the image of the specific property's owner or inhabitants and on the city that establishes such installations, which are partly supported by funding programmes.

Test installation for ten different facade greening methods in Singapore. The test was carried out from October 2007 to November 2008. As well as greenings with plants in planters, flat systems in particular, described as "Living Walls", were installed and scientifically monitored<sup>26</sup>.



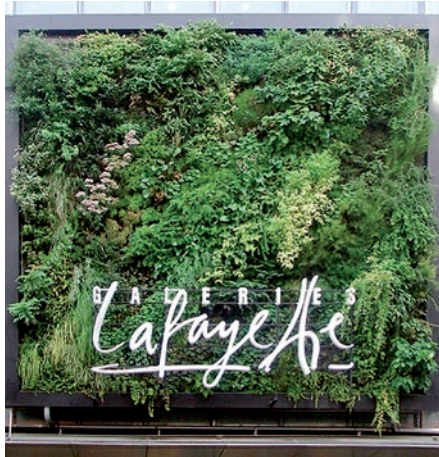
Good examples, such as the Physics building at the Humboldt University Berlin campus in Adlershof, contribute to spreading the idea of building greening. Feasible examples, as well as the possibility to exchange information and ideas with experts on detailed questions concerning such a sensitive part of the building as the widely visible facade, are of great importance to architects. Design is one facet, but functionality and maintenance costs are aspects of this topic that must also be taken into account.

Experience with green facades shows that the FLL's rules and standards on planning, creating and maintaining facade greenings<sup>27</sup> provide good guidance for those considering such installations. Plant growth varies over the years, following a typical course from small and inconspicuous coverage, through luxuriant and up to fully-grown surface coverage. In contrast, technical materials begin in

good condition and deteriorate over the years until they must be replaced. These "material-specific" trajectories are a further challenge in the necessary maintenance of green facades. The first national German facade seminar held by the FBB in October 2008 in Remscheid took up the topic of proven facade greening, and it was clear that these new installations, such as those in planters at the Physics building in Adlershof, or the installations of Patrick Blanc and others are leading to a renewed discussion on the benefits of green facades<sup>28</sup>.

Compiled using criteria from the FLL guidelines on greening facades, a brief catalogue will now be presented covering the issues to take into account while planning such an installation.

A Patrick Blanc installation at a department store in Berlin.  
Left: View on 29.07.2008;  
Right: View of the dormant winter phase on 06.03.2009



**Questions to be resolved in planning a green facade. These will lead to choosing the right greening methods:**

**Size of the surface to be greened**

**Are there windows in the surface?**

**The facade's surface material**

- solid wall (brick or plaster facade)
- curtain wall facade with air space

**Why is greening being carried out?**

- distinctive facade design
- ecological contribution
- to provide shade for the surface
- the green facade as an element of rainwater management
- evaporation of precipitation, building cooling

**Is it possible to ensure regular maintenance?**

- How accessible are all the greening systems?
- Are special measures required to prevent falls?
- Is the infrastructure easy to reach for watering and fertilising etc.?

**Should climbing plants be used?**

- Should climbing plants that grow at ground level be exclusively used?
- Can plant containers be integrated into the facade?
- Should vertical greening elements (no climbing plants) be used?

**Is there a specific principle/design that should be taken into account in the greening?**

- For example: plantings in geometric structures
- plantings in organic forms
- Are certain effects to be created using the surface textures of different types of plants?
- Are specific flowering aspects desired?
- Presentation in different seasons

**Once established, should the green facade be largely self-maintaining, requiring only minimal care?**

**Should the planting be seasonally adapted to specific times or events?**



Test installation of a green facade



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### Legal aspects

In planning green facades, primary consideration must be given to legal aspects that contain relevant statements on facade greening or to those that prescribe or could prohibit the greening. Of particular importance are:

- The Federal Building Code (Baugesetzbuch)
- Land use plans
- Plans for construction and green spaces
- Project and infrastructure plans
- Historic monuments preservation, design regulations etc.
- Laws concerning neighbours

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### Economic aspects

In addition to the planning and construction costs, the running costs of operation and maintenance must also be budgeted for. Depending on the purpose of the greening, savings (e.g. on energy costs due to the air conditioning of buildings with the help of greened facades and roofs, using rainwater for watering etc.) must be taken into consideration and offset.

The following costs must be incorporated into the planning at an early stage:

- Planning costs of the greening and its technical, design and ecological prerequisites
- Construction costs of the greening and its structural, design and ecological prerequisites
- Operating costs (e.g. automatic watering and fertilisation etc.) and maintenance costs (e.g. plant care, maintenance of equipment)
- Maintenance requirements: duration and frequency of operation and maintenance must be realistically estimated
- Establishing of responsibilities
- Provision of qualified expert staff
- Monitoring and optimisation of operation and maintenance

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### Structural prerequisites

For new and existing buildings, the suitability of facades for greening must be checked. In particular, the following aspects must be taken into account:

- Materials
- Construction
- Condition

The FLL's rules and standards<sup>27</sup> provide an overview of the greening of facades for various constructions and building materials. From these prerequisites it can be determined whether the facade is suitable for self-climbing or trellis-climbing plants.

As a further technical prerequisite, the automation of maintenance should be planned to ensure a continuous and adequate supply of water and nutrients:

- Fertiliser metering device
- Automatic watering system

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### Ecological prerequisites

To ensure good, successful growth, sites must be examined and optimised in terms of the following aspects:

#### • Soil quality

The building must be protected from waterlogging. Soil around the building in particular may have been changed, compacted and/or mixed with building rubble. The porous sand and gravel used to fill the building pit results in bad conditions for growth and low water-retention capacity. Large-scale soil replacement or improvement may be necessary. Growing media and soils should be checked in advance for toxic substances and growth inhibitors.

#### • Water supply

To ensure a continuous water supply during the growth period, an automatic watering system should be installed, especially for large plantings. If a waste water system is used for watering, the watering system for the plantings should be separated from other waste water systems to enable central fertilising. Using rainwater may be a good

solution, but toxic substances that negatively impact plant growth must be excluded. Water quality monitoring is particularly necessary if the water may have come into contact with possibly toxic building materials. Rainwater for watering that is collected from streets or “bitumen roofs” etc. must be checked for growth inhibiting factors (phytotoxicity). “Bitumen roofs” often have the herbicide Mecoprop mixed into them as ‘root-penetration protection’. It is introduced through roof runoff into the waste water system or directly into surface water<sup>46, 47</sup> and can lead to considerable problems with the plants’ growth performance.

• **Nutrient supply**

The fertilising of plantings should be connected to the automated watering system to ensure a continuous supply of nutrients. If rainwater is used, a high-nitrate liquid fertiliser containing micronutrients should be employed, at a proportion of 8/8/6 mg/litre of NPK, for example. Using a high-nitrate fertiliser instead of an ammonium-based nitrate fertiliser is important because ammonium acidifies low-ion rainwater. The fertiliser must also contain all the necessary micronutrients.

For greenings in planters that use soak irrigation, it must be noted that this is a closed system, which does not allow for any discharge if overdosing occurs. It is also not possible to add fertiliser on the surface of the planter because soak irrigation reverses the water’s usual direction, absorbing it from lower levels up to the surface. Solid slow-release fertiliser is therefore not an option for planters watered by a soak irrigation system.

A dosage device that controls the necessary addition of fertiliser relative to water volumes is required for precise fertilisation. This can be done using an electronic water meter connected with a programmable controller. It is essential to separate waste water pipes from watering and other uses!

• **Light**

Sites with northern exposure or those subject to continuous shade from high building densities or trees are unfavourable and can only be planted with the few species that can cope with shade.

• **Temperatures/wind conditions**

Facades are very exposed to wind, especially at their edges, but also where there is high building density over large areas of their surface. It must be determined whether a facade is suitable for greening in terms of its height and the prevailing wind direction. Wind can also cause drying, frost and mechanical damage. Facades or parts of buildings that get very hot or reflect strong sun in summer may also be unfavourable for greening.

Plantings in planters are especially at risk from frost and extreme temperature fluctuations in the summer months. Should plantings be in planters, the containers must be big enough and insulated with durable materials. Earth-bound sites are preferable.

• **Sources of emissions**

Airborne pollutants from the surrounding area (e.g. in industrial areas) can also damage plants, as can warm exhaust air from ventilators close to the plants.



An example of planter insulation at the Physics building in Adlershof: exterior: fibre-cement concrete; several centimetres of insulation and a plastic inner planter for the planting

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## Design aspects

The design aspects of a green facade must be incorporated into planning at an early stage and the goals of the greening, in terms of site, height, form, colour, foliage etc., must be established so that the building to be greened fits in visually with the surrounding buildings or landscape. Greening (plants, trellises, planters) should fit in with the building's architecture and emphasise its style, but only ecological planning can ensure that site conditions are optimal for the desired species and that the goals of the greening can be achieved.

The following design aspects must be taken into account:

- The building's architecture
- Surface, structure, and material of the facade
- The building's use
- Size and proportions of the facade (height, division due to windows, balconies, sills etc.)
- The goals of the greening (site size, height, width, colour aspects, shading, air conditioning of the building)
- The surrounding architecture and landscape into which the building to be greened is to be integrated or from which it is to stand out.

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## Selecting climbing supports

Climbing supports must be durable, capable of bearing weight, stable, low-maintenance and fit in with the goals of the greening.

The following criteria must be taken into account in choosing climbing supports:

- The materials' compatibility with plants and the substances used to treat them
- Durability of materials
- Suitability for the type of plant desired (different needs of twiners, climbers and scramblers and of individual species)
- Suitability for the desired goals of the greening (e.g. networked climbing supports for flat greening)
- Design aspects
- Maintenance required
- Costs

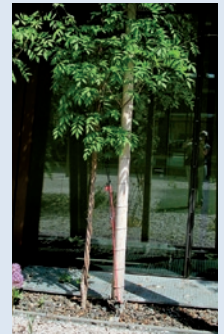
Different climbing forms of plants make special demands on the construction of climbing supports:

- Twiners and creepers prefer stable, vertical structures. These can be spaced 30 to 80 cm apart. Round profiles with a diameter of 0.4 to 5 cm are especially suitable. Depending on the species, fasteners placed at intervals of 0.5 to 2 m may be advisable.
- Stem tendrill climbers and leaf tendrill climbers prefer latticed constructions with a lattice width of 10 to 20 cm and a diameter of 0.4 to 3 cm.
- Scramblers prefer horizontal structures spaced at intervals of 0.4m or latticed constructions spaced at intervals of 0.3 to 0.5 m.

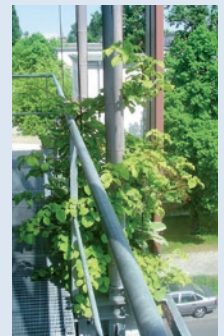
In constructing climbing supports, the following criteria must be taken into consideration:

- Vertical loads from the weight of climbing supports and plants
- Horizontal load from wind
- Material-related tensions caused by changes in temperature or humidity
- Tensions caused by plants, e.g. wisteria's twining and secondary diameter growth. This requires a way to loosen climbing supports (e.g. ropes that can be loosened at their upper ends).
- Dimensions of fasteners, anchors and dowels.

More details on materials, constructions, structural and fastening can be found in the FLL guidelines for planning, creating and maintaining green facades with climbing plants<sup>27</sup>.



Wisteria (*Wisteria sinensis*) adapts well to climbing ropes. It must be noted that this plant, a fast-growing twiner, will quickly twist ropes. Regular loosening of ropes above the plant is necessary.



The climbing hydrangea (*Hydrangea petiolaris*) is a root climber. It will climb supports, but must be tied to them.



## Selecting climbing plants

Most climbing plants come from tropical areas. They live in forests where they can use other plants to climb up into the crown area and the light with minimum effort. These sites provide plants with a balanced climate with only slight fluctuations in temperature while the dense leaf canopy protects them from rain and wind. The shading of root areas by treetops protects roots from drying out.

Such an ideal site is not usually available to plants growing on inner-city green facades, where they are exposed to wind and sun. Plants and soil dry out quickly and wind and torrential rains can also cause mechanical damage to plants. The special site conditions of a facade, as well as its related microclimate, causes each facade to be unique.

The choice of climbing plants should be oriented towards the goals of the greening, the light conditions, and the type of climbing support used. If the goal is to provide a long-lasting, extensive green space, plants should be chosen whose growth habits create a good cross-networking on suitable climbing supports.

Plants must be chosen carefully if the goals of the greening are to be achieved. If greening is incorporated into the planning of new buildings at an early stage, the facades to be greened can be adapted to meet plants' needs. It must first be decided whether the facade is to be greened with self-climbers or trellis-climbing plants.

Self-climbing plants are subdivided into:

- Root climbers
- Adhesive-pad climbers

Trellis-climbing plants are divided into:

- Twiners, winders
- Climbers (Leaf tendrill climbers, stem tendrill climbers and creepers)
- Scramblers

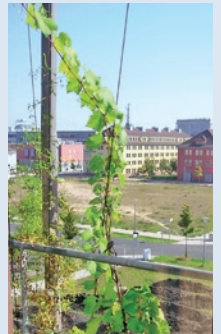
Maintenance requirements can vary greatly according to the type of climbing plant. For example, scramblers must be tied down. The following aspects must be taken into account in choosing climbing plants for the greening of new and existing buildings:

- A plant's light and warmth needs must fit in with the orientation of the facade to be greened and the related climatic conditions (light, wind, precipitation, daily temperature ranges, frost).
- The climbing forms of plants must fit in with the climbing support used
- Maintenance requirements of the species
- Height reached
- Vigour
- Growth form, density of the greening
- Diameter of stems and shoots in relation to the distance of the climbing support from the facade
- Aspects of the plant's appearance (flowers, fruits, leaf form, colours, evergreens)
- Ecological significance

The FLL rules and standards on green facades<sup>27</sup> and books by other authors<sup>32, 33, 34</sup> provide more details on types of climbing plants and the suitability of individual species. A mix of several types should be sought if there are uncertainties about the suitability of species for a site. There is always a wide range of plants that is better suited to the site conditions in individual cases. In mixing species, it must be ensured that they are complementary in their growth forms and do not impede each other.



BU: Dutchman's pipe (*Aristolochia macrophylla*) is a twiner. Its stems will wind around climbing ropes and climb high. However, bamboo rods and metal struts are too thick for the plant to twine around.



The grape vine (*Vitis vinifera*) is a climber. It forms small tendrils on the stem that can twine around ropes. It cannot cling to metal struts or railings but grows well on ropes.

### Construction

Once a green facade has been decided on, the following variants are available:

- Climbing plants (ground-level, without climbing supports – use of self-climbers)
- Climbing plants (ground-level, with climbing supports)
- Climbing plants as greening in planters (with climbing supports)
- Green facade with vegetation/no climbing plants

Construction planning should involve an appropriate specialist company to ensure compliance with the relevant standards and regulations<sup>27, 35, 36, 37</sup>. Only if this is done can the appropriate warranties be provided.

Installing planters: The better the planters are integrated into the facade construction, the less likely it is that structural problems will occur. Solutions integrated into buildings are in all cases preferable to subsequently mounted planters.

Left: An example of a durable, stable climbing support made of stainless steel



Right: Climbing plants make it possible to create green spaces – inside and out



The filling of plant troughs



Tab. 2  
Recommendations  
for facade greening  
in planters

Area	Selection
Suitable plant types	Preferably trellis-climbers that won't grow too big.
Minimum planter	As large as possible, about 1m <sup>3</sup> of growing media is ideal for woody climbing plants. In Singapore, a breadth and depth of 0.5m is prescribed; previously this was not regarded as greening in planters. The FLL has not specified any minimum size so far. Plantings in planters must be provided with planter insulation.
Substratum	Growing media of extensive green roofs as specified in FLL <sup>18</sup> with a low proportion of organic substance. If soak irrigation is used, a high-capillarity substratum and filter fleece are important additional requirements.
Watering	Automated soak irrigation with regular functional inspections and automatic consumption measuring. Drip-feed watering tends to get blocked and clogged, pipes laid in growing media are hard to manage. Water requirements will vary according to orientation, plant height and species. Individual management of individual planter groups where possible.
Fertilising	Small amounts (NPK = Nitrogen, Phosphorus, Potassium and micronutrients) added regularly to the water supply, with liquid fertiliser preferable to solid. If rainwater is used, nitrates should be added as a nitrogen source in preference to ammonium, because ammonium acidifies rainwater. A nitrogen-reduced fertiliser should be used in preference to one based on phosphorus or potassium, because rainwater already contains nitrates.
Plant protection	Prompt inspections, healthy plants are less susceptible, although a planter is always an extreme site for a plant and is thus susceptible to pests. Select substances in accordance with valid workplace safety regulations, because substances can easily enter a building through the windows and building users must not be exposed to them. The use of beneficial organisms should be prioritized over chemical methods.

The first planting of greening is part of construction. The climbing plants listed in the table below are among the best-known kinds and species. A brief appraisal of growth sites and maintenance requirements is provided in the following table. Ivy is the best-known

climbing plant. A self-climber with shoots that grow away from the light, it was used at the Adlershof Physics building project only on the concrete surface of a free-standing ventilation duct.



Tab. 3  
Overview of frequently  
used and suitable climbing  
plants

Species	Picture	Climbing mode/ Suitability	Site, Recommendations	Maintenance requirements
Ivy <i>Hedera helix</i>		Root climber	Shade to semi-shade. Only recommended for solid, large facades.	High, pruning recommended 2–3 times annually. Can also sprawl on a flat area in front of a building.
Wisteria <i>Wisteria sinensis</i>		Twiner	Sunny to semi-shade. Solid climbing support required, (e.g. stainless steel profile).	Requires hard pruning 2–3 times annually.
Trumpet vine <i>Campsis radican</i>		Root climber, scrambler	Sunny, warm, protected, no water-logging. Climbing support required, decorative frame for southern doorways	Moderate pruning
Virginia creeper <i>Parthenocissus Tricuspidata</i>		Adhesive-pad climber	Solid walls, large buildings	Needs very little care
Grape vine <i>Vitis var. varieties</i>		Tendrill climber	Sunny, warm, protected. Decorative on espaliers, less suitable for extensive and flat green roofs	Pruning required 2–3 times annually

Species	Picture Suitability	Climbing mode/ Recommendations	Site, requirements	Maintenance
Honeysuckle <i>Lonicera div.</i>		Twiner	Slight shade to semi-shade, high humidity, lime-free soil, does not tolerate heat or dryness. Decorative yellow or red flowers, on pergolas.	Requires pruning.
Climbing hydrangea <i>Hydrangea petiolaris</i> or <i>H. anomala</i> <i>ssp. Petiolaris</i>		Root climber, Scrambler	Cool, damp site, semi-shade, acidic soil. Slow-growing, decorative composite flowers.	Shoots grow away from the light, susceptible to weevil infestation. Shoots do not climb well, so must be trained.
Clematis <i>Clematis spec.</i>		Leaf tendril climber	Sunny, likes warmth, tolerates dryness, partially wind-protected site required.	Loses leaves fast in low sites.
Dutchman's pipe <i>Aristolochia macrophylla</i>		Twiner	Sunny to semi-shade, protected from wind, nutrient-rich soil. Grows to medium height.	Requires moist soil, can become luxuriant, growth must be trained.

### Planting

For advice on woody climbing plants, consult the FLL's "Gütebestimmungen für Baumschulpflanzen" (guidelines for nursery plants)<sup>38</sup> and the FLL's "Gütebestimmungen für Stauden" (guidelines for shrubs and bushes)<sup>39</sup> for bushy climbing plants. DIN 18916 "Vegetation technology in landscaping - plants"<sup>36</sup> also contains useful information.

The shoots and stems of climbing plants must be disentangled and trained in fan form along the surfaces to be greened or the climbing supports must be tied in a manner appropriate to the species. As required, ties must be regularly inspected and removed, loosened or renewed to prevent shoots from either being cut or falling off.

Open plantings should be mulched or under-planted. In the case of under-planting, it should be noted that it can lead to competition for water and nutrients. An example of under-planting with hosta (*Hosta spec.*) is shown in the photo on the left.



Hosta (*Hosta spec.*) providing a luxuriant under-planting for facade greening in a planter.

### Soil

DIN 18915 "Vegetation technology in landscaping – soils"<sup>35</sup> on soils and plants should be consulted. Unsuitable soils on ground-level sites must be replaced or improved. Plant holes must be large enough (at least 0.5 m<sup>2</sup> in size and 0.5 m deep, with root space of at least 1 m<sup>3</sup>). They should be designed as planting strips, which contain several plants and must be permanently permeable to air and water. Sealed surfaces should be kept to a minimum and surfaces around plantings should always be permeable to air and water.

### Operation and maintenance

Regular inspection of technical components of green facades is necessary to maintain functional conditions in the long term and should cover the fastening components of planters, climbing supports and watering and fertilising equipment.

Drainage must be checked for blockages. Plant protection measures should only be carried out after inspection and as targeted measures in order to keep expended resources at the absolute minimum required.

The FLL guidelines<sup>27</sup> have so far not made any generalised statements on maintenance and there are no guidelines for green facades. The Adlershof Physics building project has been helpful in this context. Initial approximate values for the maintenance of plantings in planters have been established here. It has also been shown that three of four maintenance operations during the growth period are necessary and sufficient. Estimates of required time expenditure had to be regularly adjusted upwards, because accessibility is problematic on all facades, even in this project that was deliberately built to accommodate a green facade.

The number of maintenance operations required by 'living wall' systems depends on the type of planting and is comparable with those of complex shrub and summer flower plantings. Weekly checks are necessary. Further maintenance work will depend on the design requirements of the greening.

### Maintenance

All maintenance must be carried out by competent staff from a specialist firm. DIN 18919 "Vegetation technology in landscaping – care of vegetation during developing and maintenance in green areas"<sup>37</sup> should be consulted. The pruning and tying of plantings onto climbing supports must fulfil the plant's specific requirements. Expert staff, who are familiar with the basic rules of the greening of buildings and have verifiable experience, must be deployed to maintain high-quality plantings such as plantings in planters<sup>40</sup>.



### Watering

Watering, especially of larger plantings and container plantings, should be automatic and checked regularly. It is recommended that watering be combined with a continuous monitoring of water consumption by the control system. The water requirements of individual sections of watered areas must also be inspected and checked for faulty controls.

### Fertilising

Fertilising must be done automatically, especially for larger and container plantings, and be regularly checked to ensure that it is functioning correctly. The plants' requirements, quality of the growing media or soil on site, and water quality must be taken into consideration in choosing fertiliser. If a soak irrigation system is used, fertiliser must be added to the water. Adding fertiliser onto the substratum from above would not be effective here due to the reversed movement of the water through the soil. Commercially available liquid compound fertiliser (NPK = Nitrogen, Phosphorus, Potassium and micro-nutrients), added through a dosing system, is a safe and labour-saving solution. If rainwater, which is alkaline but contains nitrates, is used for watering, a nitrogen-reduced fertiliser on a nitrate basis is recommended. Using ammonium as a source of nitrate will acidify the low-ion water. Fertiliser should be withheld from the end of July because it would impair both the hardening of the plants' shoots and their resistance to frost.



Well-developed facade greening in planters, the Physics Building project in Adlershof in 2006

A "living wall" test installation in Australia



Hydrangea (*Hydrangea*) (climbing hydrangea, left) as scramblers need horizontal structures. It must be fastened to ropes. Honeysuckle (*Lonicera*, right) a twiner, grows well

on ropes. The distances between the ropes here are however too great, so the plants have to be trained onto them occasionally.

### Training and fastening of plants

At least twice a year the permanent fastenings must be inspected and renewed as necessary. The inspection of fastenings can easily be integrated into regular maintenance operations. Any relevant measures should be carried out as required. Temporary fastenings, the training of new shoots on climbing supports and the removal of fastenings that are no longer needed should be carried out two or three times a year or as required (e.g. in May, June, August and October).

### Pruning

Pruning is essential for plants close to technical equipment (downpipes, awnings, roller blind housings, lightning protection devices, antenna cables, water pipes etc.) and windows, eaves and ventilation openings.

Pruning done to maintain plants should be carried out at a time, frequency and in a manner adapted to the goals of the greening and to the plant varieties involved. Detailed information on individual varieties is available in the relevant literature<sup>27, 32, 33, 50, 51</sup>.

### Plant protection

Plantings that are not optimally adapted to their site and not provided with sufficient water and nutrients are susceptible to pests such as black vine weevils and their larvae, which live in soil, as well as to aphids, mites, leaf-miner flies, thrips and cicadas and fungal diseases, e.g. mildew. Two or three annual inspections by plant protection experts are necessary to detect infestation by animal or fungal pests and to carry out the technically correct measures to combat them. Continuous qualification of maintenance staff is recommended<sup>40</sup>.

Measures to combat pests should be only be carried out as necessary. The use of pesticides should be avoided where possible, for example, if pests can be defeated by beneficial organisms (e.g. phytoseid mites to combat spider mites, insect-pathogenic nematodes against black vine weevil larvae).

Information on the right time for such inspections and on plant protection measures can be obtained from the Berlin Plant Protection Office (Pflanzenschutzamt).

### “Weed” removal

Unwanted weeds, shrubs and saplings should be removed four times a year, in May, June, August and October. This must be done by skilled professionals with expertise in recognising plant types. It is of utmost importance that weeds be removed before they develop seeds.

Weeds compete directly with facade plants and should be removed. They also promote the uncontrolled development of pests, which can then infest plantings<sup>40</sup>.

An individual work plan must be developed for each project. The table below gives an outline of the timing and extent of maintenance activities at the Physics building in Adlershof. This can be regarded as a model for similar projects, because comparable information is lacking in the literature. The work consumes a total of 152 hours a year for 300 climbing plants in 150 planters and 75 earthbound plants.



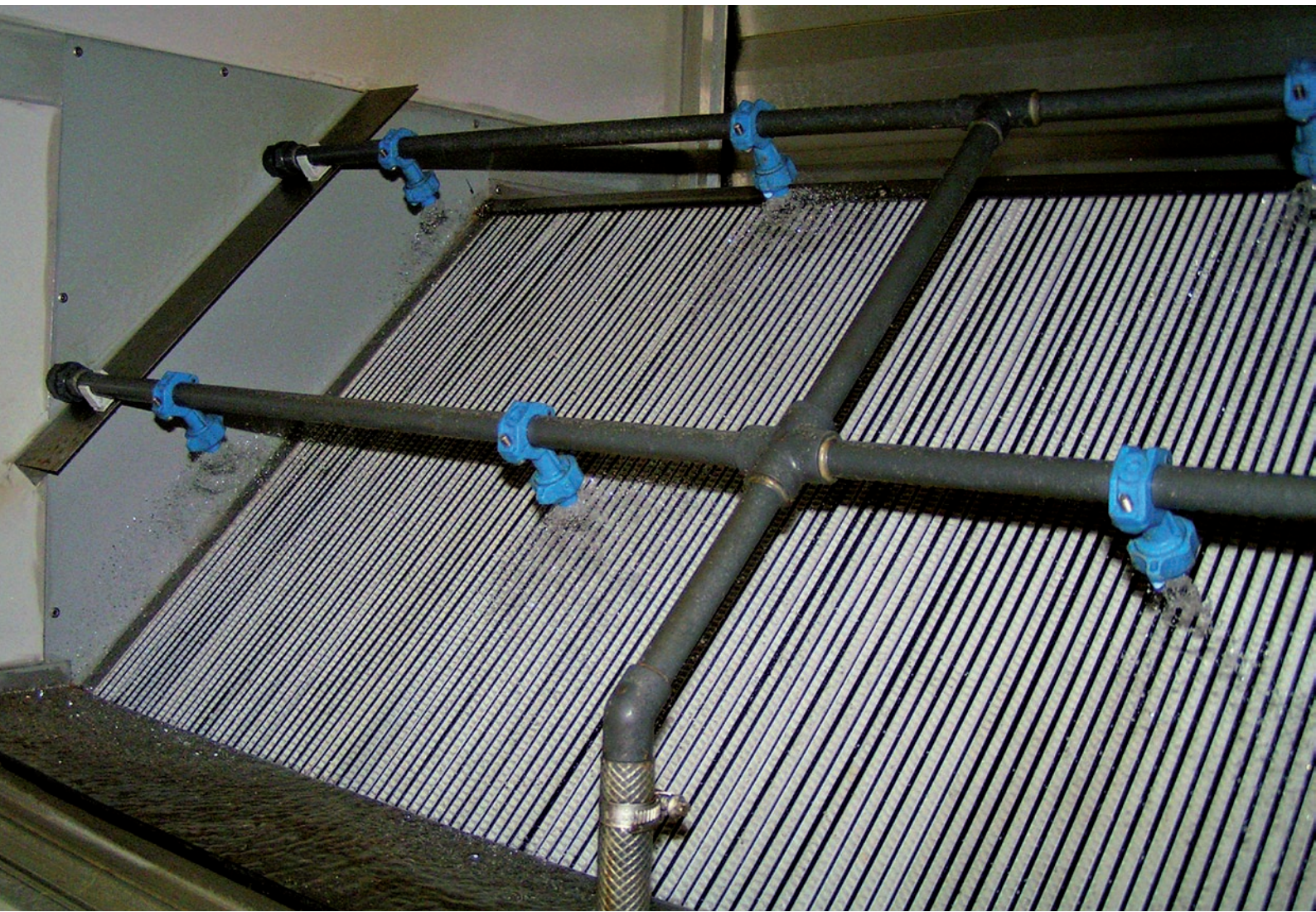
Weeds have become established in these rather inaccessible planters and are competing strongly with climbing plants and

under-planting in the relatively small planters.

Tab. 4  
Annual extent of maintenance work using the example of the Physics building in Berlin-Adlershof

	April/May	June/July	September	November	Time required
1. General stock control and system checks of watering system	Start-up watering	Check that all planters are properly supplied, plant vitality	Check that all planters are properly supplied, plant vitality	Emptying of watering system	2 h every 2nd and 3rd visit; 8 h every 1st and 4th visit  <b>20 h</b>
2. Maintenance/repairs (Magnetic valves, float switch, watertightness)	Eliminate leaks, exchange magnetic valves		Clean float switch		4 h maintenance, 12 h repair  <b>16 h</b>
3. Nutrient supply	Continuous, with watering				System checks  <b>4 h</b>
4. Trimming 4.1 Pruning 4.2 Thinning out		Prune Wisteria		Winter pruning for vitis, removal of dead outgrowths, 2nd pruning of wisteria	4 – 8 h per visit  <b>12 h</b>
5. Check fastenings, loosen ropes		X Loosen ropes for wisteria		X Loosen ropes for wisteria	<b>8 h</b>
6. Replanting			X		<b>10 h</b>
7. Plant protection	Continuous				<b>40 h</b>
8. Removal of weeds/rubbish	X	X	X		14 h per visit  <b>42 h</b>





## Using rainwater to cool buildings

According to an EU study, there will be a twelve-fold increase in air-conditioned space in Germany from 1990 to 2020<sup>41</sup>, resulting in a forecast increase of 225% in energy consumption for this period. The specific energy consumption for electricity, heat and cooling for office buildings across Germany is about 500 kWh/m<sup>2</sup> per year. "... Values of up to 1000 kWh/m<sup>2</sup>a are not infrequent."<sup>42</sup> Air conditioning plays a key role for buildings with high levels of technical equipment and thus requires high power consumption. Furthermore, the summer sun protection requirements of building envelopes are often only inadequately met or not met at all. Frequent causes of high energy consumption in summer are, for example, large glass facades that are insufficiently equipped with exterior sunshades and a lack of cooling at night. This results from inadequate ventilation at night, a lack of storage capacity inside the building envelope, suspended ceilings as well as the absence of heat storage capacity of glass facades.

While in the winter months incoming solar radiation and heat recovered from technical building equipment can be used, directly reducing the energy required for heating, this heat must be dissipated into the atmosphere in the summer months with as little expenditure of primary energy as possible. The most common way to achieve this by using electrically powered compression cooling.

Another concept is to use solar energy cooling ("solar cooling") or CHP waste heat (district heating or decentralised CHP plants) through absorption refrigerators. Although it may initially seem reasonable to generate cooling in summer from unusable CHP waste heat or solar heat, it can lead to extremely high operating costs.

The reasons for this are:

- An equipment efficiency (production of cooling in proportion to the heat required) between 40 and 70%
- Loss of circulation within a building (up to 70%) due to large pipe diameters with small temperature ranges
- Costs of water, waste water and salt in recooling
- Maintenance and repair costs
- Electricity costs for the necessary operating energy for equipment, recooling and circulation



### The significance of water evaporation

Water evaporation is the only form of real cooling, with 680 kWh/m<sup>3</sup> of energy consumed. This value corresponds to evaporation at 30°C. At 100°C it is 630 kWh/m<sup>3</sup>. Therefore, from a global point of view evaporation is the biggest energy component in the conversion of solar radiation. Where evaporation is lacking, as it is in urban spaces, solar radiation is converted into heat and long-wave radiation instead of being used to evaporate water. Buildings in cities are impacted by the urban heat island effect as inner heat loads are not adequately dissipated in the summer months. The solution is usually air conditioning, which produces cooling, usually in a technical manner using electricity. In the overall energy balance, however, the result is not cooling in the true sense, but rather a transfer of energy. Heat is withdrawn via a heat pump from one side and transferred to another medium. Since electricity is used to do this, more heat is produced than cooling. The efficiency of this process depends on the efficiency of the equipment and is usually between 1.8 and 4.0. Using electricity to cool buildings merely exacerbates the problem of urban heat islands.

The only solution that properly dissipates heat is water evaporation, in which energy is latently bound, transported and then released where steam condenses, usually in the atmosphere during cloud formation. There the energy goes into space as long-wave radiation or returns to the Earth's surface as long-wave radiation as part of atmospheric counter-radiation. The so-called 'greenhouse effect' is a fictive popular-science explanation of a phenomenon that in reality consists of a complex interaction of long-wave, short-wave and latent energy transport processes between the Earth's surface, the atmosphere and space.

Land use has by far the greatest influence on the local climate, with urban areas in particular representing the greatest "intervention" through the sealing of surfaces and lack of vegetation.

Rainwater runoff from roofs and other sealed surfaces in cities can be collected and used to cool buildings. And by using indirect evaporative cooling, this effect can be achieved without increasing humidity inside the building or running the hygienic risks involved in evaporation into the ambient air. This involves water being sprayed not into the air supply to the building, but into exhaust air before it leaves the building, which can cool the exhaust air from 26°C to 16°C, for example. Using a heat exchanger (air-to-air, usually a plate heat exchanger) the air supply is pre-cooled with the exhaust air without the two having direct contact (photo, right). The heat exchanger is usually the same one used to recover heat in winter. This kind of air conditioning is called "adiabatic cooling".

Adiabatic air conditioner using rainwater.



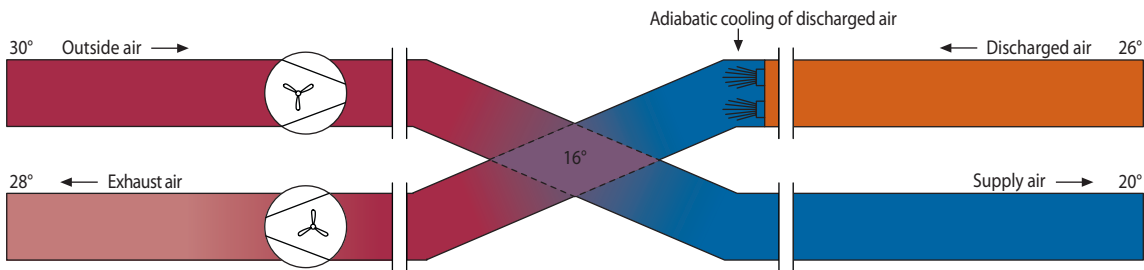


## The fundamentals of adiabatic cooling

### Functional principle

The basis of adiabatic cooling is a heating and ventilation system with heat recovery. At its core is an air-to-air heat exchanger, e.g. a plate heat exchanger, which separates the exhaust air from supply air that transfers heat or cooling. Plate heat exchangers are needed in winter to recover the heat from exhaust air. The same heat exchanger can be used for cooling in summer. All the main components of adiabatic cooling are thus provided, the only additional component being the humidification of exhaust air in a waste water system before the exhaust air passes through the heat exchanger. Rainwater can be used as a waste water resource.

Evaporating water is a low-cost, effective way of providing air conditioning for buildings. With outside temperatures of up to 30°C, the incoming air supply can be cooled to 20 – 22°C, without having to resort to technically produced cooling. Even with higher outside temperatures, considerable amounts of energy can be saved. With outside temperatures of 38°C, one system investigated produced an energy saving of about 70% compared with conventional systems. Conventional cooling can thus be dispensed with completely if building planning includes a combination of adiabatic cooling and passive cooling measures, such as green facades and roofs and a nightly cooling concept.

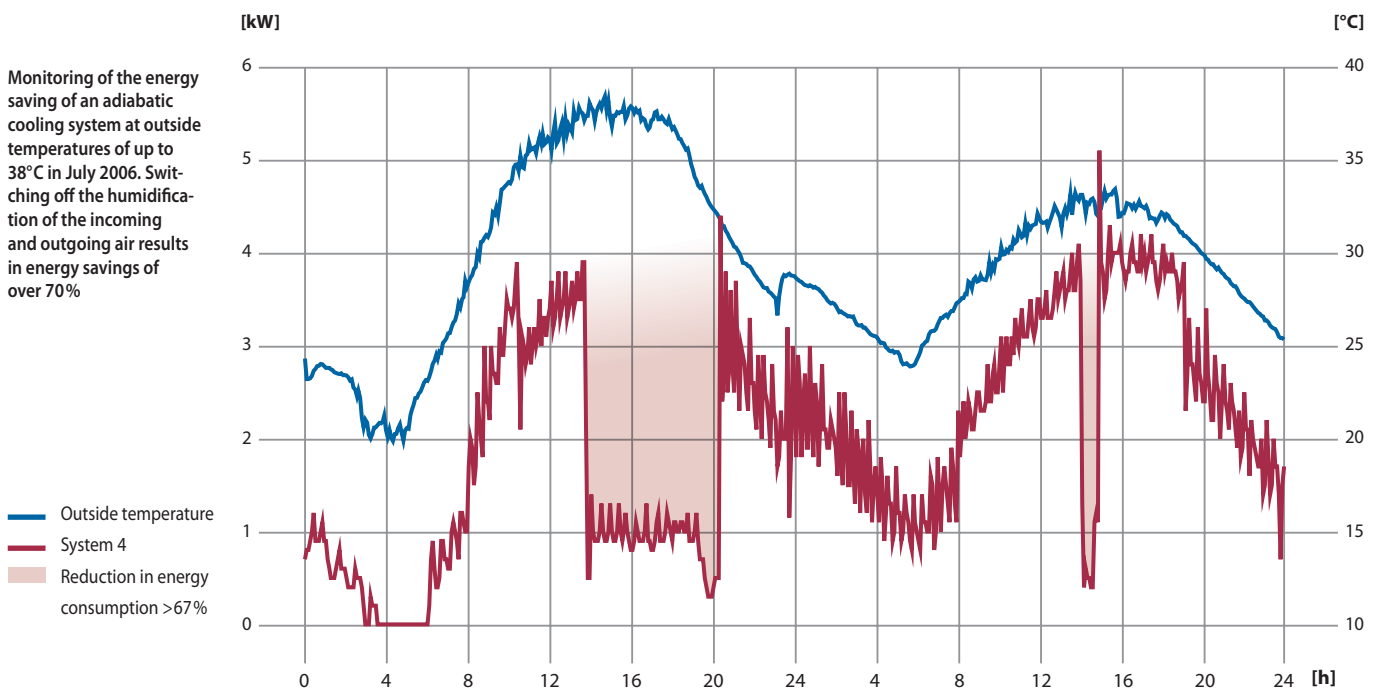


The principle of adiabatic cooling in air conditioning. The temperatures shown represent examples of the cooling process and are just one variant among various possible operating conditions.

The graph below shows the energy savings resulting from adiabatic cooling on the hottest days of the years from 2005 to 2008. To ensure functionality, the heating and ventilation systems in the test project investigated were also equipped with a conventional heater and cooler. In this case, cold water was provided by two absorption refrigerator machines using district heating. Adiabatic cooling also saves the operating costs associated with a conventional cooling concept (district heating, water, waste water, salt). The efficiency of adiabatic cooling can be tested by switching the humidification, which automatically keeps incoming air at a constant temperature, on and off.

Using rainwater as a resource for adiabatic cooling achieves further synergies, because rainwater contains low levels of salt/calcium carbonate. Using rainwater instead of drinking water in air conditioning saves both water and waste water while rainwater is returned to the natural water cycle of precipitation/evaporation. This has significant positive effects on the local microclimate and reduces global warming by initiating evaporation and condensation processes. While using electricity to produce conventional cooling is inefficient and exacerbates the problem of urban heat islands, adiabatic cooling improves the microclimate around the building. So-called "solar cooling", compared with adiabatic cooling, also entails considerably

Energy consumption with and without adiabatic cooling



higher investment, operating and maintenance costs; the water consumption and desalination for recooling within the process costs about eight times as much as adiabatic cooling. Conventional cooling production also suffers considerable circulation losses, accounting for more than 50% of the cooling provided in the systems investigated so far. This is due to the low temperature ranges between the supply and return flows of the cooling, e.g. 4/8°C or 6/12°C, and the associated larger pipe diameters and greater flow amounts, compared with hot water circulation. There are no circulation losses with adiabatic cooling, because the cooling is produced directly in the heating and ventilation system.

Especially high levels of efficiency can be achieved by re-humidifying exhaust air within the heat exchanger, so that the evaporation process is continuously carried out using the exhaust air. Ideally the exhaust air should leave the heat exchanger at the same temperature as the outside air and a humidity of 100%.

#### **Use of rainwater for adiabatic cooling**

Adiabatic cooling has already proven to be a very good alternative to conventional building cooling, especially when combined with the use of rainwater. The background to these considerable operating costs savings is as follows:

1. Rainwater has very low electrical conductivity as an indicator of a very low proportion of salt. Compared with systems using drinking water, rainwater systems require only half the amount of water to produce evaporative cooling and no waste water is produced.
2. Water evaporation is extremely positive from an energy consumption point of view. The evaporation of one cubic metre produces about 680 kWh of evaporative cooling. Compared with the use of electricity or district heating to cool buildings, there is a potential energy saving of 70 to 90% per year. The potential energy savings depend primarily on the interior space to be cooled, the humidity of the exhaust air and the technical characteristics of the system.

If drinking water is used for adiabatic cooling, regular desalination is necessary to avoid the calcification of heat exchangers and nozzles. The resulting waste water can be used in other waste water cycles, e.g. in toilets. It makes good sense to integrate other waste water uses in parallel to adiabatic cooling, because the system is only used temporarily in summer.

As part of intelligent management, exhaust air cooling should be given priority in waste water usage over other uses. Toilet flushing or watering of green spaces, for example, could be temporarily switched to drinking water use so as to make rainwater available for exhaust air cooling for a longer period. Separating uses requires two separate waste water systems with independent pressure booster systems.

#### **Planning and construction**

##### **State of technology, rules and standards**

In planning this kind of heating and cooling system for buildings, DIN EN 13779 "Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems"<sup>48</sup> should be consulted. There are currently no detailed technical specifications for adiabatic cooling. Compared with the conventional building cooling by air conditioning, adiabatic cooling systems do not dehumidify incoming air. This is due to the slight difference in temperature between the pre-cooled incoming supply air and the outgoing exhaust air as compared with a chiller, which operates with a flow temperature of 4°C. This is lower than the incoming supply air's dew point so the air (using energy also for latent heat) is dried. If air needs to be dried for reasons of comfort, one energy-optimised variant is dehumidification using saline solutions. The saline solution can be dried out in the sun. Lithium chloride is the saline solution usually used.

The "Watergy" system, which provides high potential energy savings by using latent heat energy as seasonal storage of heat generated in summer for heating purposes in winter, is a further development of dehumidification using saline solutions. In this application, magnesium chloride, which is available at a relatively low price, is used as a heat transfer medium. An adiabatic cooling system using a saline solution can thus be used in summer and then used in turn to heat the building in winter ([www.watergy.de](http://www.watergy.de)).





UV waste water disinfection

### Hygiene requirements

There are no legally formulated quality or monitoring standards regulating the use of waste water in buildings. The values published in the brochure on "Innovative water concepts - service water utilisation in buildings" (pub. Senate Department for Urban Development (Senatsverwaltung für Stadtentwicklung) Berlin 2003)<sup>1</sup> are recommended as a guide to the qualitative goals of waste water use in adiabatic cooling.

- Low-load, smooth roof surfaces are suitable for systems that use untreated rainwater.
- Problem roofs (e.g. those heavily frequented by birds) should not be connected to systems using rainwater or should only be connected if appropriate treatment is provided.
- The composition of construction materials used for surfaces onto which rainwater falls and is collected must be taken into account. Uncoated metal roofs and some "bitumen roofs" may increase the introduction of heavy metals or problematic organic compounds into rainwater and are therefore not recommended.
- Green roofs result in much less precipitation water being available for other uses. Selecting suitable growing media and plantings of roof surfaces will prevent appreciable quantities of impurities or mineralised organic compounds from getting into the cisterns.

To secure the hygiene of the adiabatic cooling system, it should be ensured that there is no contact with waste water or of outgoing exhaust air with incoming supply air. This involves several measures:

- To prevent any leaks in the heat exchanger and in the transfer of outgoing exhaust air to the incoming supply air, a **reverse pressure mechanism** within the installation is **recommended**. This means mounting thrust fans in front of the equipment for the incoming supply air so that the incoming supply air is under higher pressure than the outgoing exhaust air.
- **Waste water should be emptied** (once daily or weekly) as soon as the adiabatic cooling ceases operating.
- **Incoming supply air and outgoing exhaust air/exiting air must be kept as separate** as possible from each other outside the building, so that the exiting air cannot be transferred into the incoming supply air.
- A plate heat exchanger can be substituted by a **heat transfer medium** (e.g. water) in completely separating outgoing exhaust air and incoming supply air. However, this may affect the efficiency of the cooling transfer and re-humidification process within the heat exchanger.

In addition to the measures described above to ensure the separation of incoming and outgoing air, it is highly recommended that UV waste water disinfection be carried out using a system inspected/certified by the DVGW (German Technical and Scientific Association for Gas and Water). Further UV disinfection of the water during its circulation through the system is also recommended to exclude possible bacterial recontamination. Facilities for taking samples to test waste water quality (a short spigot with a ball valve) must be built into adiabatic cooling systems. These sampling points can also be used to manually empty the system.

### Operation and maintenance

To identify malfunctions and test systems' functional capabilities, it is recommended that water and energy meters be built into adiabatic cooling systems. Meters should be connected to the building's central control systems where possible, so as to promptly record and assess high-resolution functionalities. The waste water feed and stroke/blowdown must be recorded. To check the efficiency of exhaust air humidification, combined air temperature/air humidity sensors should be integrated into the ventilation system in accordance with the following table.

In particular, the timing of the waste water feed and resulting waste water must be checked to test the efficiency and correct functioning of the systems. Regular checks of the energy meters in the air conditioner's cooler and heater will also provide information on the system's functional efficiency, and thus on the overall energy savings.

In order to reduce the sewage water fee (Schmutzwasserentgelt), the amount of rainwater used as waste water in exhaust air cooling must be recorded. A reduction of the rainwater fee (Niederschlagswasserentgelt) resulting from the use of waste water must be determined in accordance with local conditions and must also be applied for.

Further information on planning, construction, operation and maintenance of ventilation and air conditioning systems and on hygienic standards for these systems can be obtained from the German Association of Engineers (VDI) Guidelines 3803 and 6022.

Size	Parameter	Unit
Outside air	Temperature	°C
Incoming supply air	Temperature, humidity	°C, %
Outgoing exhaust air	Temperature, (humidity)	°C, (%)
Exiting air	Temperature, humidity	°C, %
Waste water feed	Amount	m <sup>3</sup>
Waste water volume	Amount	m <sup>3</sup>
Conductivity of waste water	el. conductivity	µS

Tab. 5  
Installation of metering, measuring and control equipment for an adiabatic cooling system



Waste water trough over which adiabatic cooling circulates, feeding valve with mechanical floater in the foreground, conductivity gauge in the pressure line in the background

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## Glossary

**Absorption** Uptake and dissolution of mainly gaseous substances (air, polluting gases etc.) in other substances (e.g. water, filter).

**Absorption refrigerator** A refrigerator that, in contrast to compression refrigeration machines, achieves compression through the temperature-responsive solution of the refrigerant. These are also described as thermal compressors. The refrigerant is absorbed into a second substance in a solvent circuit at a low temperature and desorbed at higher temperatures. This process uses the temperature dependency of the physical solubility of two substances. The prerequisite for the process is that both substances be soluble in each other in any proportion within the temperature range used.

**Active soil zone** Microorganisms in this soil zone use organic and inorganic substances for their own metabolisms, thereby transforming or breaking down these substances.

**Adiabatic (state) change** A thermodynamic process in which a system changes from one state to another without exchanging thermal energy with its environment.

**Adiabatic cooling** A process used in air conditioning systems to air-condition buildings using evaporative cooling. The process is applied indirectly: one air flow is humidified as the other air flow is cooled. Evaporative cooling is a renewable energy, because only air and water are used for cooling. The principle of this process is the same as that of sweating, in which water evaporates through transpiration. The heat required for the evaporation is drawn from the environment, which cools human skin.

**Adsorption** Accumulation of substances consisting of gases or liquids on the surface of a solid body, or more generally on the boundary surface between two phases. Adsorption is distinguished from absorption, in which the substance permeates the interior of a solid body or liquid.

**Adsorption refrigerator** Accumulation on a solid substance is described as adsorption in process engineering and desorption accordingly as dissolution from a solid substance. In an adsorption refrigerator the refrigerant is selected so that a change in the aggregate state accompanies the adsorption or desorption. Since the adsorption of the refrigerant involves condensation, it is facilitated by low temperature and high pressure, which reduces the volume of the refrigerant and releases energy in the form of heat.

**Albedo** Unit of measurement measuring the reflectivity of diffusely reflecting, not self-luminous surfaces. Quotient of reflected to incident light quantities.

**Best Available Technology (BAT)** BAT (best available technique – BAT) is an English legal term used to describe “newest state of the art” technology that is available to users under “economically reasonable conditions”. The EU Commission has sought to use this term to replace “state of the art (Stand der Technik)”, which is used in the Federal Immission Control Act (Bundesimmissionsschutzgesetz – BImSchG).

**Biocide** The term “biocide” covers all chemicals used to combat harmful organisms in chemical/biological ways, e.g. disinfectants, wood preservation products and all pesticides.

**Biotope Area Factor (BAF)** Instrument for securing “green qualities” in Berlin’s inner city. It can be stipulated in Berlin as a statutory ordinance in a landscape plan. It contributes to the standardisation and concretisation of environmental quality goals, specifies the proportion of the area of a property to serve as a planted area and takes on other ecosystem functions.

**Climbing supports** Technical constructions that enable climbing plants to grow up vertical facades. The difficulty involved is that there are various kinds of climbing mechanisms. In our case, “leaf tendril climbers”, whose young shoots can twine around a rope, are preferred. Profiles that are too wide will not be effective. Other species are scramblers, whose tough tendrils can hook onto existing structures.

**Co-generation heating and power station (CHP)** A co-generation heating and power station consists of motors or gas turbines that use the heat produced in electricity generation as district heating to heat buildings and provide hot water. Facilities with an output of >5 or 10 MW are no longer referred to as ‘co-generation heating and power stations’, but as ‘micro-combined heat and power facilities’.

**Demonstration projects** As part of pilot projects, large-scale demonstration projects are supported and funded to demonstrate, for the first time, the way in which forward-looking methods of avoiding or reducing environmental pollution can be implemented.

**Drinking water** is the most important nutrient and is also used for other domestic purposes. 99% of the German population obtains it from the public water supply, which complies with the high-quality standards of the German Drinking Water Ordinance (Trinkwasserverordnung). In Germany the supply of drinking water makes up approx. 4% of total water consumption. Each German consumes 130 litres daily on average, so water consumption in Germany is at a low level in comparison with consumption levels in other European countries.

**Ecology** The study of the relationship of living beings to their biological environment (from the Greek oikos “home” and logos “study”). The term was coined by Ernst Haeckel, who defined it as “The whole science of the relationships of organisms to their surrounding world”. Ecology (a sub-discipline of biology) was initially defined as the study of the natural environment. It is now more broadly understood as the science of the interactive relationships between organisms and environmental factors.

**Element input into nature** Element inputs are solid and gaseous pollutants that are released during the extraction, processing and use of raw materials and energy and that can pollute natural cycles (incl. people).

**Energy** is the ability of a body to do work. It is measured in the same unit as work, in joules (1 KJ = a thousand joules, 1 MJ = 1 million joules). Another unit of energy in use is the kWh (kilowatt hour). Units of energy are often also specified in units of primary energy (1 kg or tonne of coal equivalent TCE = 29,308 KJ = 8.14 kWh; 1 kg or tonne of oil equivalent TOE = 41,868 KJ = 11.63 kWh; 1 m<sup>3</sup>, natural gas = 31,736 KJ = 8.82 kWh). 1 joule is equivalent to one watt second (Ws).

**Environment** This term is defined in various ways. In its most comprehensive definition ‘environment’ means the totality of factors (incl. physical, mental, technical, economic and social relationships and conditions) that predetermine existence. It is defined here as the entirety of natural conditions that define human living space.

**Eutrophication** (over-fertilization) is the over-fertilization of bodies of water, resulting in the accelerated growth of water plants but also of algae. Waters then become contaminated because the oxygen demand increases, causing an oxygen deficit in the water. At an advanced stage, the dieback of water plants leads to their rotting and the formation of poisonous substances such as ammonia and hydrogen sulphides. Eutrophication arises out of a surplus of nutrients (mainly nitrate and phosphate) from agricultural fertilizers and effluents. The result is a decline in fish stocks and the death of large numbers of fish. Rainwater runoff from sealed surfaces causes a continuous inflow of nutrients into surface water in areas with separate sewers for rainwater and effluents, while torrential rains contaminate the water in areas with combined sewers.

**Extensive roof greening** Cost-effective greening, especially suitable for low-load roofs with no designated usage. Low levels of annual maintenance; watering is usually only required in the early stages. Its mineral nutrient-poor, coarsely porous growing media should be 5 to 12 cm deep.



**FBB** The Fachvereinigung Bauwerksbegrünung e.V. is a consortium of scientists, planners, builders, producers and municipalities involved in the field of roof greening, who have made it their goal to promote roof greening, ensuring the implementation of practicable quality criteria and a comprehensive and objective information policy in the interests of consumer protection.

**FLL** – Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. The FLL publishes various guidelines on greening buildings, which the FBB promotes and supports. Important connections involving a range of trades and disciplines are presented in these guidelines. The FLL series of publications includes diverse rules and standards as well as publications on planning, creating, developing and maintaining installations, which are updated in accordance with current technological developments

**Ground water** is the water underground. This invisible resource is a major element of the water cycle and fulfils vital ecological functions. It is also the main source of drinking water. Ground water must be protected from contamination, so it is extremely important to consistently apply precautionary principles in handling it.

#### **Growing media**

Engineered substratum produced for green roof and green facade technology purposes. It includes well defined values for retention rates and low components of fertilizer. These artificial materials can be combined with recycling materials, crushed roof tiles, volcanic components like lava, pumes or expanded slate.

**Intensive roof greening** A synonym for roof gardens. Garden-type areas of vegetation are planned and maintained, usually by professional gardeners on non-earthbound surfaces. The ecological aspects of intensive roof gardens can be optimised by using rainwater management, where appropriate drainage and storage layers are laid under plantings and terraces.

**Lysimeter** Open, overgrown ground cylinders for measuring precipitation, infiltration and evaporation, which are set into the ground, flush with their surroundings. Lysimeters are usually placed on a scale so as to promptly and exactly determine the water balance. The filtrated water can thus be qualitatively and quantitatively analysed.

**Micro-combined heat and power facilities** take the heat produced in electricity generation and use it for heating and hot water. This can increase the efficiency of the primary energy used from 30 to 40% to 60 to 90%. In summer this heat can be converted into cooling using absorption or adsorption refrigeration machines.

**Monitoring** systematic recording, observation or surveillance of a procedure or process using technical devices or other observation systems. The function of monitoring is to enable intervention in a monitored operation or process if it is not taking the desired course or specific threshold values fall short or are exceeded. Monitoring is thus a special type of recording.

**Natural Resources** Natural resources are all elements of nature useful to humanity. These include non-renewable resources (raw materials, forms of primary energy, soil and land, genetic resources), renewable resources (plants, animals, water, air and wind) and quasi-inexhaustible resources (for a human timescale) such as the sun's radiation energy. To this are added their countless functions that are essential to human life (sink functions, i.e. the absorption of emissions and wastes), habitat functions and the maintenance of natural systems (materials and life cycles).

**PLC – Programmable Logic Controller;** flexible control modules that carry out all kinds of control tasks depending on digital and analogue input. They can be used to control waste water systems, rainwater management systems and for watering.

**Precipitation water** Water derived from precipitation (rain, snow, hail etc.), flowing off and collected from built or sealed surfaces, mainly rainwater.

**Primary energy** Forms of primary energy are substances or energy fields, the energy content of primary energy media and of energy streams that have not yet undergone technical conversion and from which secondary energy can be obtained directly or through one or more conversion processes (e.g. black coal, brown coal, crude oil, biomass, wind power, solar radiation and geothermal energy).

**Rainwater** Defined in DIN 1989 as water from natural precipitation that has not been contaminated by usage.

**Retention** The prevention and delay of runoff.

**Roof runoff water** Precipitation water that flows off roofs and changes in quality due to reactions with the roofing material and with accumulations on the roof.

**Soil** is the uppermost (usually only 20 to 40 cm thick) built-on and not built-on layer of the Earth's solid crust, including water flowing or standing under the ground, where this can be influenced by human activity. Soil takes on a wide range of irreplaceable natural functions for people, serving to produce food, providing surface for settlement and traffic, absorbing wastes and emissions, as well as countless regulatory and habitat functions.

**'State of the art'** Term used in legal norms to describe the development status of progressive processes and systems for limiting environmental pollution.

**Sustainable development (SD)**, also referred to as long-term environmentally friendly development, is the new development guideline established in 1992 in Rio as part of Agenda 21. It is defined here as development that aspires to achieve high ecological, economic and socio-cultural standards within the boundaries of the environment for all people alive today and for future generations, development that reconciles economic productivity and social security with the long-term conservation of natural livelihoods.

**Types of environmental pollution** Environmental pollution can be divided into the following categories: (1) Solid, liquid and gaseous contaminants. Environmental chemicals and substances damaging to health and the environment in products and foods may be regarded as a sub-category. (2) Noise, shaking and environmentally-polluting heat and radiation. (3) Destruction of natural life cycles due to changes to landscapes, building and erosion. (4) Over-use of natural resources beyond their ability to regenerate (e.g. over-fishing, deforestation). In a broader definition, this term also describes the wasting of non-renewable resources and primary energy.

**UV equipment** Ultraviolet radiation (UV) is used to disinfect waste water in systems using rainwater. "Ultraviolet radiation is used to treat water, air and surfaces. UV radiation reliably reduces pathogens and the bacteria count in water being treated to become drinking water. The addition of chemicals is not required.

**Water Framework Directive (WFD)** The European Community's Water Framework Directive became law on 22.12.2000, giving the starting signal for a water protection policy in Europe that will coordinate the management of waters in river catchment areas beyond national and state borders.

**Water protection** The goal of water protection in Germany is to maintain and restore the good ecological quality of all bodies of water. Bodies of water and their banks and immediate environments are to be maintained or restored so that the symbiotic communities typical of the respective natural areas can develop there.

**Waste heat** Incidental heat energy generated in chemical, physical or technical processes as a (often unwanted) by-product (co-product).

**Waste water** As defined in DIN 4046: water serving commercial, industrial, agricultural or similar purposes with various qualities, which can also include drinking water quality. As defined in DIN 1989: water for domestic and commercial applications that do not require drinking water quality. Here: treated rainwater for purposes in which drinking water quality is not required. It can be used for toilet flushing, cooling, washing and cleaning systems or for watering green spaces.

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**Senatsverwaltung  
für Stadtentwicklung**

**Publisher**

Berlin Senate for Urban Development  
Communications  
[www.stadtentwicklung.berlin.de](http://www.stadtentwicklung.berlin.de)

In cooperation with



Technical University Berlin



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We would like to thank our colleagues from the Humboldt University Berlin, the Plant Protection Office (Pflanzenschutzamt) Berlin, and the Office of Health and Social Affairs Berlin for their expert professional support.  
We also thank Steve Moddemeyer and Lee S. Roberts, Collins Woerman, Seattle, USA for editing.

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**Layout**

Adler & Schmidt Kommunikations Design, Berlin

**Berlin, Juli 2010**







»The future lies not in  
whether we believe in it or not,  
but in whether  
we are prepared for it.« *(Erich Fried)*